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Developing Standard EMD Cost Factors For Major Defense Acquisition Program (MDAP) Platforms

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THESIS

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Abstract

This research involves the creation of standard factors that more accurately reflect observed outcomes in the development stages of major programs. Traditionally, estimation techniques such as analogy, parametric, engineering build-up, and factors are utilized to develop budgets and serve as the baseline for measuring project progress. This effort accomplishes the development and creation of 443 new standard cost factors that are delineated by five categories: commodity type, contract type, contractor type, development type, and service. The factors are developed for those elements that are "common" in a wide array of projects such as program management, systems engineering, data, training or site activation. This research conducts statistical analysis of factor values at the Work Breakdown Structure (WBS) element level, as well as the subcategories of the five identified categories. Statistical differences between subcategories were identified only 34.38% of the time, likely due to the high Coefficient of Variation (CV) values across the dataset. In refined subsets of the dataset, the CV generally decreased, indicating that the average percent estimating error improved when more detailed information was available. Thus, the outcome of this research is that cost estimators must employ both statistical and practical analysis in the creation of cost estimates. Furthermore, analysts will have a reference tool made up of 443 unique factors from which to begin analysis for creating estimates and conducting the iterative process of refining cost estimates.

Dedication

This thesis is dedicated to my wife, children, and all of my family who have supported me throughout the course of my educational career. I owe my accomplishments to your steadfast encouragement.

Acknowledgments

I would like to express my sincere appreciation to my research advisor, Dr. Daniel Ritschel, for his guidance and support throughout the course of this thesis effort. I appreciate the structure he provided, as well as the freedom he allowed me to explore the areas of research I felt were most compelling. I would also like to thank Dr. Edward White for providing a level of detailed feedback that allowed me to deliver a high-quality research effort. Finally, I would like to thank my sponsor, Mr. Shawn Valentine, from Air Force Lifecycle Management Center for accommodating my many questions and educating me on a myriad of cost estimating topics throughout the course of this research.

Matthew R. Markman

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DEVELOPING STANDARD EMD COST FACTORS FOR MAJOR DEFENSE ACQUISITION PROGRAM (MDAP) PLATFORMS

I. Introduction

Background

The Air Force Cost Analysis Handbook (AFCAH) lists four cost estimating techniques as the main methods utilized by cost estimators: analogy and factor, parametric, build-up (engineering), and expert opinion (subject matter expert) (AFCAH, 2007). The use of standard factors not only appears in the AFCAH but is a widely accepted and common practice in the field (Government Accountability Office, 2009). The elements of the level II Work Breakdown Structure (WBS) defined in MIL-STD-881-D offer the opportunity for detailed examination in order to establish estimates for Major Defense Acquisition Program (MDAP) platforms (Department of Defense, 2018).

Currently, the research division of the Air Force Life Cycle Management Center (AFLCMC) periodically publishes standard factor tables for aircraft Engineering and Manufacturing Development (EMD) that capture prime contractor data for a selection of clean-sheet design aircraft programs. Despite the utility of the AFLCMC published tables, additional data exists that can assist in refining these factors, as well as developing new factors. The inclusion of data from five additional commodity categories (electronic/automated software, missiles, ordnance, space, and Unmanned Aerial Vehicles (UAVs)) allows the tables to capture a greater range of program types. In addition, modification programs are not currently captured in the AFLCMC tables. Similarly, analysis at the subcontractor level has not yet been accomplished; this breakdown allows for the establishment of more specific factors. Each additional category of data provides estimators the ability to accomplish more in-depth analysis based on the type of program in question. Thus, the refining of factors for EMD programs will provide estimators with a more robust tool set upon which to draw from, ultimately leading to more precise estimates going forward.

Problem Statement

The intent of the EMD factors table AFLCMC publishes is to employ standard factors for crosschecking initial estimates with analogous historical programs. A great deal of research was accomplished in recent decades regarding factors, starting with Blair (1988) and Wren (1998). Following these initial studies, periodic updates took place, accomplished by Blair herself, as well as several other cost analysts, not all of which achieved publication or mass distribution. Unfortunately, the current factor tables' limitation to prime contractor data of clean-sheet design aircraft programs represents a shortfall when it comes to the operational application of level II WBS factors for EMD programs. This effort represents a comprehensive update to several previously accomplished factor studies. It includes a level of data (e.g. modification programs and subcontractor data) not yet fully accounted for in previous published research or AFLCMC published tables. By including additional categories of data, the utility and applicability of the factors table increases significantly.

Research Objectives

In order to establish the most applicable factors for EMD programs, publish them for operational use, and rely on them for data analysis and estimate crosschecks, several key questions must be examined. Furthermore, the conclusions drawn from these questions will help determine where future efforts should be focused towards gathering new data and/or refining existing factors.

1. What are the standard factors for clean-sheet design programs with respect to the level II WBS elements?
2. What are the standard factors for modification programs with respect to the level II WBS elements?
3. What is the statistical difference in standard factors between different commodity types with respect to the level II WBS elements?
4. What differences are found in the standard factors when comparing prime and subcontractor data?
5. What statistical differences exist between the types of contracts utilized for MDAPs?
6. What statistical differences exist in factors between each service?
7. What statistical differences exist between each development type?

Methodology

Data is collected from the Cost Assessment Data Enterprise (CADE) system. Specifically, Cost Data Summary Reports (CDSR), commonly referred to as 1921s, are the primary data source. Data is collected by commodity type, contractor category, contract type, and program type (clean-sheet design and modification programs). In order to analyze the data for each of these categories, as well as the relationship(s) between them, several statistical techniques come into play. The process begins with descriptive statistics to develop the standard factors for each required element.

Establishing the mean, median, and standard deviation for each of the elements provides a starting point to identify trends in the data. Also, the identification of interquartile ranges amongst the individual elements allows for analysis of variance at multiple levels. These descriptive statistics provide the overarching basis from which the more detailed analysis and testing occurs.

Once the factors are derived, the data is tested for normality with the Shapiro-Wilk test. Due to the non-normality findings, non-parametric testing is employed to provide insight as to how the categories relate to one another. The statistical tests utilized to accomplish this are the Kruskal-Wallis test along with the Steel-Dwass test which are used to compare differences between two or more independent groups. The non-parametric tests' results ultimately dictate the data's applicability to future cost estimating practices in MDAPs.

Scope and Limitations

Data collection relies upon the information contained in submitted DD Form 1921s from CADE. The 1921 represents the satisfaction of Contractor Cost Data Reporting (CCDR) requirements as defined by the Defense Cost Resource Center (DCRC) for all Acquisition Category I and IA programs (Department of Defense, 2007). The CADE database is the official Office of the Secretary of Defense data source and an efficient tool to gather the data required to establish and analyze standard factors; furthermore, this aligns with AFLCMC's data gathering approach for their published tables. CADE contains comprehensive data dating back to 1961 and as recent as 2017. The data gathered from 1921s provides a common format and follows the established

WBS defined in MIL-STD-881D, normalizing information from programs spanning a period of 56 years (Department of Defense, 2018). The level II WBS elements that pertain to this analysis include Systems Engineering/Program Management (SE/PM), System Test and Evaluation (ST&E), Training, Data, Peculiar Support Equipment (PSE), Common Support Equipment (CSE), Site Activation, Other, and Spares (Department of Defense, 2018). By including five additional commodity types (electronic/automated software, missiles, ordnance, space, and UAV) in this research, the body of knowledge is expanded beyond the current focus on clean-sheet design aircraft programs. In addition, this research introduces modification and subcontractor data for EMD programs as well. The research provides the cost community with a streamlined ability to analyze characteristics of MDAP platforms in a quick, logical manner which previously existed only in a limited capacity.

In order for the factors established in this research to prove accurate and reliable, the data gathered must satisfy several key qualifiers. Initial 1921s provide no utility for this study, making final 1921 reports the optimal source document. However, a small portion of the data comes from interim 1921s. In these instances, the data contained on the interim 1921s was equal to or greater than the final contract price. Within the CADE database, limitations exist that contribute to the exclusion of certain programs entirely, such as a lack of available data, inconsistency in reporting by the contractor, and even errors in reporting. These issues lie mainly in older programs, but several instances do occur in more recent programs, and as a result are not included in the final dataset.

Thesis Overview

The establishment and advancement of analysis of MDAP platforms over the course of the past several decades represents a large step forward in the Department of Defense's (DoD) ability to accurately estimate the cost of new weapon systems. However, the ability to improve upon this analysis is achievable based upon the data and tools available. Compiling data from 1921s in CADE into a central database and then normalizing cost figures enables comparisons of an array of programs across a variety of platforms. Only then can accurate, reliable factors be established and applied for the purpose of cost estimating in the DoD.

The remainder of this thesis details the process of attaining these factors, beginning with a literature review of relevant studies and data pertaining to the use and application of standard factors in the field of cost estimating. A detailed account of the data gathering methodology follows the literature review. The methodology chapter describes the application of descriptive statistics and statistical tests to the data gathered. With the framework of data gathering and the statistical techniques laid out in detail, the results and analysis chapter follows. Within this section lies the determinations made from the entire dataset, as well as individual conclusions drawn from isolated sections of the database; these isolated sections include commodity type, contractor level, program type, and several others. Each section of results and analysis provides an understanding of both the significance of the given factors, as well as insight into how they can be further analyzed or applied to more detailed levels of the WBS. Finally, the conclusion answers each of the stated research questions and applies the findings to the role of standard factors in DoD cost estimating and their place in the future of the field.

II. Literature Review

Chapter Overview

We will have to provide the services and products our warfighters need and protect the taxpayers' interest by obtaining as much value as we possibly can for every dollar entrusted to us.

-The Honorable Frank Kendall

The toolkit of a cost analyst consists of four primary estimating methods, as well as secondary techniques, but the use of standard factors represents a commonly utilized practice that is both defined in the Air Force Cost Analysis Handbook (AFCAH) and applied to a large extent in many current program offices (Government Accountability Office, 2009). With billions in taxpayer dollars at stake each year within the Department of Defense's (DoD) acquisition budget it is imperative that program offices, and specifically cost analysts can understand their program, draw conclusions from past programs, and leverage technology to arrive at estimates in which the American public can place their confidence and trust (Government Accountability Office, 2009). Because of this responsibility, this research aims to expand the breadth of analytical tools available, specifically with respect to the utilization of standard factors in Major Defense Acquisition Programs (MDAP).

To fully grasp the concept and application of standard factors in cost estimating, a basic foundation of knowledge must exist regarding the different cost estimating methodologies, elements of the Work Breakdown Structure (WBS), previous research on factors, and the utility of factors in the practice of cost estimating. Therefore, this chapter focuses on a review of associated literature and past research with the intent of highlighting the efficacy of factors as a cost estimating technique, as well as several shortfalls this research intends to remedy.

Cost Estimating Methodologies

Several key documents designate and define the cost estimating methodologies utilized within the DoD, including the Air Force Cost Analysis Handbook (AFCAH) and the Government Accountability Office Cost Estimating and Assessment Guide. These publications assist in setting a baseline for program offices and cost analysts to craft credible and consistent cost estimates, as well as an overarching legal requirement for the DoD to have policies in place to safeguard the billions of taxpayer dollars afforded to MDAPs each year (Government Accountability Office, 2009). While the documents define the acceptable estimating methodologies, they do not represent an all-encompassing guide book, as every MDAP presents its own unique challenges. The four techniques outlined in the AFCAH include: analogy and factor, parametric, build-up (engineering), and expert opinion (subject matter expert) (Department of the Air Force, 2007). While each technique represents a different approach to cost estimating and has benefits and drawbacks, the merit of utilizing multiple strategies to achieve greater confidence in an estimate cannot be understated. The introduction of more than one estimating technique provides cost analysts with the ability to triangulate a point estimate that considers levels of detail not fully captured by individual techniques or estimates. Furthermore, this approach serves as a crosscheck to ensure estimates do not fall too far outside the bounds of reasonableness for the given program.

Parametric

The parametric estimating technique represents an approach based upon a statistical relationship drawn between historical costs and certain characteristics (program, physical, and performance), also referred to as cost drivers (Government Accountability Office, 2009). This type of estimate follows a distinct process to arrive at a cost estimating relationship (CER), beginning with the collection of data, typically by way of extensive input from engineering and other functional area program personnel (Department of the Air Force, 2007). Following data collection, cost drivers must be identified to move forward with establishing the actual CERs for analysis. Upon completing these steps, the actual parametric model can be utilized; though it must be noted that the actual parametric equations utilized to formulate the estimate require extensive time and effort in the data collection phase, whereas if the equations already exist from previously established CERs, this method lends itself to rapid completion (Department of the Air Force, 2007).

The parametric technique offers several key benefits that prompt cost analysts to utilize it for estimating, most notably its versatility, which is often a factor given the changes a program undergoes in its maturation and development (Government Accountability Office, 2009). The utility of an estimating tool that is easily modified in response to changes, as well as objectively based, provides the program office with the ability to adapt and overcome changes rather than spending a great deal of time determining how those changes could or should affect the estimate and the program. However, the technique also brings with it some disadvantages, such as the requirement to maintain and update the currency of the data utilized to derive the CERs. Furthermore, because some parametric estimates contain extremely complex CERs, the ability to thoroughly understand how variables relate to one another may not fully materialize without the creator of the original CERs and model (Government Accountability Office, 2009). With these characteristics in mind, it becomes possible to categorize what type of programs and scenarios warrant the use of the parametric approach. Because this estimating methodology provides the analyst with objective and repeatable models and is based on actual historical program costs, it proves especially useful in cost/performance trade-off studies and the early stages of a program when the program requirements lack complete clarity (Department of the Air Force, 2007).

Build-Up (Engineering)

The build-up method of cost estimating consists of an exhaustive collection of lower level program element estimates followed by a roll-up of each estimate to arrive at the total program cost (Department of the Air Force, 2007). Often referred to as the engineering approach, this technique is based largely on in-depth engineering data and requires a great deal of labor and material cost information to reach a reliable estimate. A key component of this approach is the underlying assumption that historical cost data can be leveraged to predict future costs; in this case the historical data is most often gathered from the production phase of the program which affords the analyst the level of detail required to formulate the estimate (Government Accountability Office, 2009). While the different names of this method (build-up, engineering, bottom-up, grass-roots estimating) do not dictate a difference in methodology, it is important to note that in some instances the term “build-up” may reference an estimate that compiled lower level estimates which may have been created from other methods and do not use the direct application of engineering and functional costs (Department of the Air Force, 2007).

The engineering method offers a level of utility and accuracy not captured by some other methods and provides cost analysts with the ability to utilize recent and relevant data that is often readily available. Because this approach requires such a high level of detail, it lends itself to easy auditing and can be adjusted in real time as things like labor rates fluctuate (Government Accountability Office, 2009). Despite these benefits, this technique presents several shortfalls that ultimately make it unusable for some programs and situations. The vast amount of time, manpower, and details required to adequately construct an estimate with this method presents a challenge in and of itself, especially given the already constrained resources of most DoD programs. Furthermore, the potential for omissions of sub-categories of WBS elements creates a risk of double counting of costs (Department of the Air Force, 2007). Because of the sheer amount of data and information required, this estimating approach is best applied to software development and production estimating (Government Accountability Office, 2009).

Expert Opinion (Subject Matter Expert)

The expert opinion approach to cost estimating relies on information gathered directly from subject matter experts (SME) in each area of the program, most often in instances of early concept design or development where data is scarce (Department of the Air Force, 2007). Because this technique carries a great deal of subjectivity, it has a limited application and is seldom utilized as anything more than a starting point for further investigation and estimation (Government Accountability Office, 2009). The way the cost analyst gathers the data required can have a large effect on the final estimate;

thus, the following methods are often presented as the most effective and efficient: the Delphi technique, round-table discussions, and one-on-one interviews with individual SMEs (Department of the Air Force, 2007).

Expert opinion provides a good starting point for cost analysts, especially in instances where requirements lack clarity or data is virtually unavailable. It also serves to fill gaps in other methods and crosscheck more detailed estimates based on the inclusion of legitimate information gathered from an appropriate number of experts in each relevant area (Government Accountability Office, 2009). The primary disadvantages of utilizing SMEs to develop an estimate are bias and credibility, reinforcing the fact that if possible, this approach should take a backseat to other techniques that can account for greater detail and/or include data.

Analogy and Factor

The analogy method of cost estimating takes historical data from existing similar programs or systems and applies a scaling factor (or range of factors) to account for differences in the new system and arrive at a feasible estimate (Mislick & Nussbaum, 2015). The scaling factor(s) represent disparities between the old and new programs in the context of size, performance, technology, complexity, and many others, and sets an initial estimate given the early stage of the program's life cycle (Government Accountability Office, 2009). The goal of these scaling factors is to establish them with the assistance of expert opinion in a quantitative, defensible manner that results in a credible estimate. The analogy method can be performed at the system, subsystem, or component level, as well as in sub-levels of the WBS to build up to higher level estimates (Department of the Air Force, 2007).

The analogy and factor approach to cost estimating gives the cost analyst the ability to leverage historical information that is already well-defined and available to arrive at an estimate that typically exceeds the defined variables of their current program. Ultimately, this represents a low-cost, minimally time-consuming estimate that allows for cost and budget discussions that are defensible and easily understood (Government Accountability Office, 2009). However, this technique can lend itself to excessive subjectivity when it comes to the adjustment factors utilized, because they represent individual historical data points as the basis of the estimate (Mislick & Nussbaum, 2015). Given its pros and cons, this approach most often gets used in programs that lack detailed requirements but will in some way mirror an existing system for which data is readily available (Department of the Air Force, 2007). The AFCAH provides a simple illustration shown in Figure 1 that depicts how the various estimating methodologies are typically applied depending upon the program’s life cycle, as well as the level of detail required.

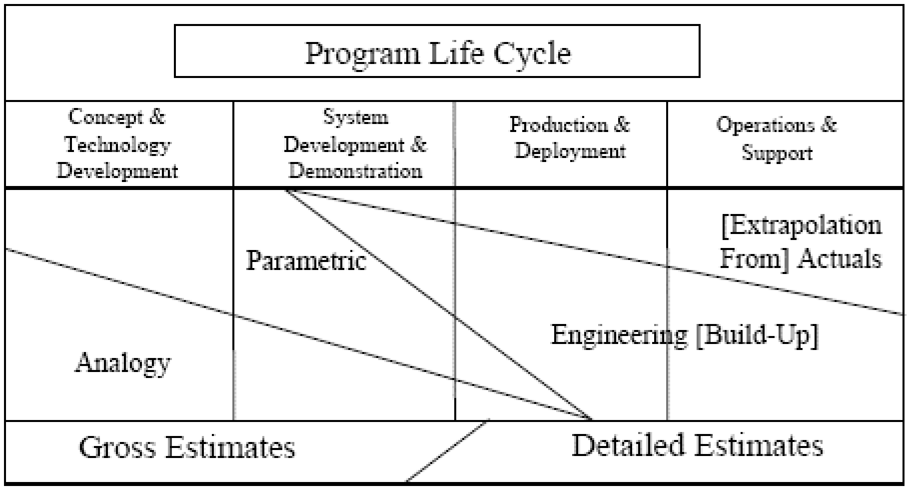


Figure 1. Selection of Methods, (AFCAH, 2007)

Elements of the Work Breakdown Structure (WBS)

The Work Breakdown Structure (WBS) as a concept is one of the few aspects of Major Defense Acquisition Programs (MDAP) that has remained constant over the course of the past several decades (Department of Defense, 2005). It represents a decomposition of a project into smaller, more manageable components and is sometimes referred to as the management blueprint for the project (Mislick & Nussbaum, 2015). The WBS is mandated and governed by MIL-STD-881D, ultimately fulfilling broader requirements set forth in Department of Defense (DoD) Instruction 5000.2; this DoD publication aims to maintain uniformity in definition and consistency of approach for programs developing a WBS (Department of Defense, 2018). For the sake of consistency, the DoD has revised and updated guidance regarding the WBS only when major technological advances or changes in the acquisition process warranted such action (Department of Defense, 2005).

The WBS can be broken down further at a variety of levels; the first sub-categorization of the WBS lies in two interrelated sub-structures: the contract WBS and the program WBS. The contract WBS exists primarily as a reporting mechanism for the contractor to the government and relates directly back to the contract Statement of Work (SOW). Whereas the contract WBS focuses on contractor requirements, the program WBS serves as an extension of the contract WBS by encompassing the entire program at a summary level (Mislick & Nussbaum, 2015). Within the program WBS, three distinct levels display and define the actual program outputs and relate the elements of work to one another, as well as the end product (Mislick & Nussbaum, 2015). Each represents a medium by which work progress is recorded and communicated from every level to posture program leadership and the contractor to identify, coordinate, and implement changes as needed (Department of Defense 2011).

The WBS consists of three primary hierarchical levels, with a fourth and fifth sometimes included in expanded forms; for this research only the top three levels are addressed. Level one represents the entire system or material item such as an aircraft, ship, space, or surface vehicle system (Mislick & Nussbaum, 2015). The second level captures major elements subordinate to the system identified by level one and consists of prime mission products, including all hardware and software elements. Level two also includes combinations of system level services applicable to the program including the following elements common to most programs: integration and assembly, system test and evaluation (ST&E), systems engineering/program management (SE/PM), common support equipment (CSE), peculiar support equipment (PSE), training, data, operational/site activation, and initial spares and repair parts (Department of Defense, 2018). These system level combinations are then further deconstructed into the level three elements which consist of more detailed components of the level two major elements of the program, including hardware, software, and services (Department of Defense, 2005). Figure 2 displays a generic version of the WBS with varying amounts of detail as viewed from left to right, as published in MIL-STD-881D.

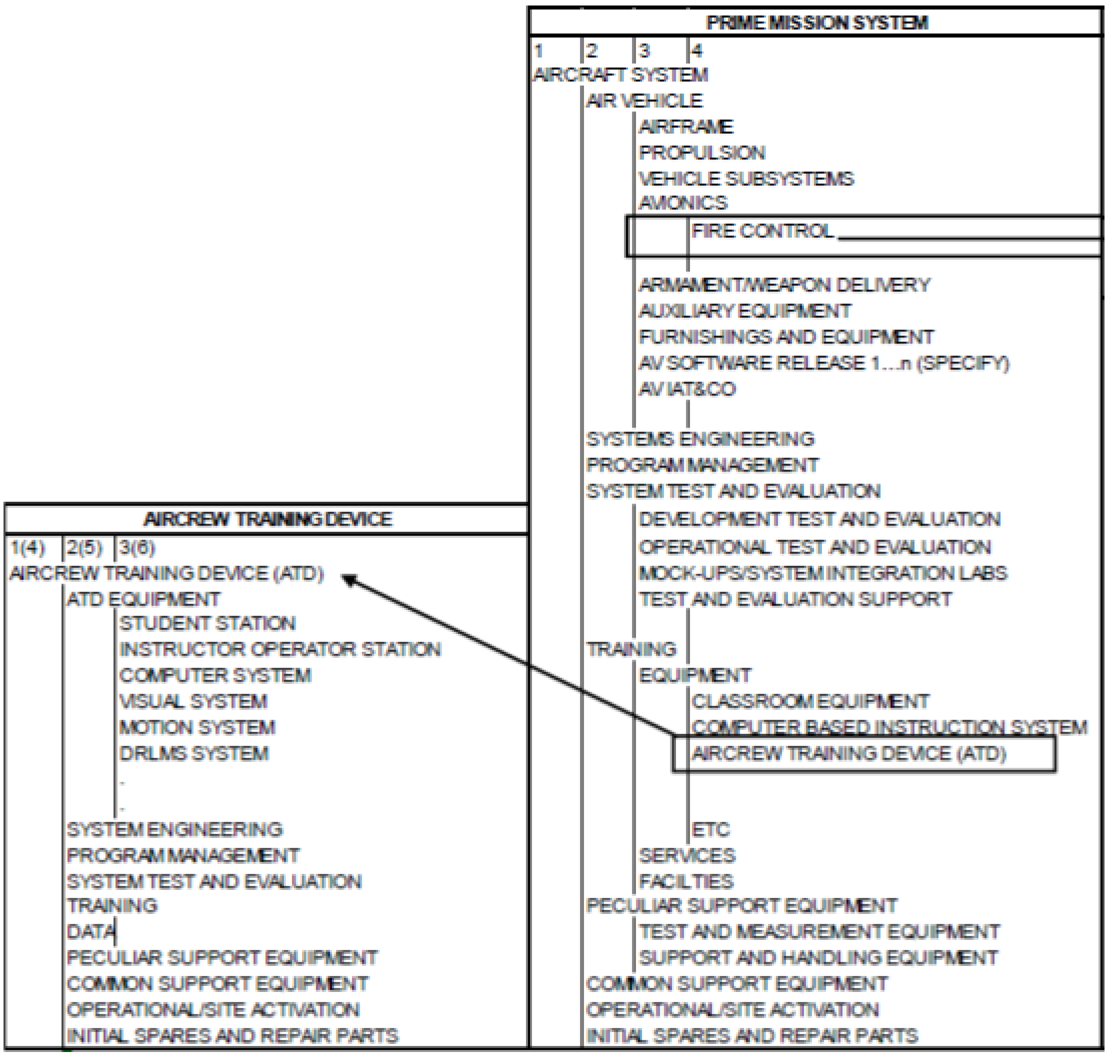


Figure 2. Work Breakdown Structure Matrix (Contract WBS) (MIL-STD-881D, 2018)

The WBS offers several key benefits that extend across the entirety of a program's life cycle. The common structure mandated by MIL-STD-881D allows for the normalization of data and information across a variety of commodity types and DoD agencies. The WBS also aids in tracking technical efforts, risks, resource allocations, expenditures, and the status of cost, schedule, and technical performance (Department of Defense, 2005). The utility of the WBS provides personnel at all levels the ability to reference past and current MDAPs to better understand and forecast their own costs, schedules, and overall program. This is accomplished through subcomponents of the WBS like the Earned Value Management System (EVMS) and the Integrated Master Schedule (IMS) (Department of Defense, 2005). Constructing an effective WBS often requires immense effort, but the value of a single, common benchmark to reference and track major factors like cost and schedule cannot be understated, especially given the scrutiny these subjects receive from senior leaders and the public.

Previous Research on Factors in Cost Estimating

Extensive research on factors in cost estimating does not exist to the extent necessary to fully and efficiently utilize the technique. Limited scope studies within the Air Force began in the 1980's and were followed up sporadically with similarly limited updates and publication, creating a gap in cost analysts' ability to employ the technique effectively. The first major USAF aircraft factor study, often referred to as the "Blair Study" was conducted by Ms. Joan Blair in 1988 and established cost element factors for programs in the Engineering and Manufacturing Development (EMD) phase of the acquisition life cycle (Wren, 1998). The Blair Study consisted of 24 programs and encompassed data for aircraft avionics support systems only, which proved useful for specific purposes at the Aeronautical Systems Center (ASC) at Wright Patterson Air Force Base (WPAFB) for a period of approximately ten years, but ultimately became outdated and questionable for use in current programs (Wren, 1998).

A 1998 study performed by Mr. Don Wren utilized the Blair Study as a starting point and included an additional 20 programs, but again only in the realm of aircraft avionics and for the primary purpose of utilization by the ASC at WPAFB (Wren, 1998). The efforts of Blair and Wren represent a sizable stepping stone towards an exhaustive reference table of factors for DoD analysts, but lack the breadth required to make the studies applicable to more than a specific set of programs based at WPAFB. Wren acknowledged in the findings of his 1998 study that he was unable to update the factors from the Blair Study due to unavailability of data and substantial program adjustments over the course of a decade (Wren, 1998). This acknowledgement reinforced the need for a more exhaustive study, as well as periodic updates to maintain the credibility of the factors. In 2015, almost 20 years after Wren's study, Mr. Jim Otte conducted a factor study aimed at updating and expanding the outdated factors utilized by many AFLCMC personnel. His work reflects another step towards a more substantial set of factors for analysts across the DoD, and even includes previously unacknowledged WBS elements (Otte, 2015). Despite the substantial increase in utility of Otte's findings versus Blair and Wren's, a multitude of shortfalls remain, including the lack of additional commodity types besides aircraft, modification programs, subcontractor data, and even contract type.

The utility of factors in cost estimating extends beyond just acquisition programs, reaching across various government agencies and functions to support more efficient budgeting and execution of taxpayer dollars (Mislick & Nussbaum, 2015). With such widespread utilization of the factor method, a variety of different research exists, especially within the DoD. The Naval Center for Cost Analysis (NCCA) engages in continuous research on cost estimation and publishes periodic findings to guide and strengthen cost analysis within the Navy (NCCA, 2018). In addition to this research, the NCCA conducts economic and business case analyses for a variety of issues within the Department of the Navy, creating benchmarks from which factors can be created for cost estimates (NCCA, 2018). While all military branches are governed by general DoD guidance, service-specific directives illustrate some differences in the application of certain requirements, such as cost estimation. The Air Force's use and research of the factor method extends beyond the acquisition world and is detailed even in lower level directives like functional area Air Force Instructions (AFI) to better predict costs in logistics, personnel, programming, and flying hour operations (Department of the Air Force, 2018). Additionally, the Air Force publishes dozens of factor tables for personnel to utilize for estimates specific to their respective functions; these tables are updated regularly and serve as a benchmark for cost estimation within the Air Force. Another illustration of cost factors' place in the DoD comes from the publishing of Area Cost Factors (ACF) each year to assist in preparation and review of military construction, Army and Army Family Housing projects, and a variety of other facility related projects (PAX, 2018). These factors are the reflection of a selection of characteristics to accomplish broad levels of analysis and estimation and serve as benchmarks for estimators to then add their own individual details to modify the factors and arrive at a credible estimate (PAX, 2018).

Utility of Factors in Cost Estimating

The analogy and factor method of cost estimating presents numerous strengths for DoD analysts constructing estimates for MDAPs, but this approach also serves the private and public sectors in formulating cost estimates for large projects. In the case of public works projects, specifically transportation infrastructure, there is sometimes a lack of credible estimates available due to the financial interests of potential contractors and the agenda that accompanies large contract awards (Flyvbjerg, Holm, Buhl, 2002). There are claims of this type of problem existing even within government contract awards; however, the issue can be at least partially relieved by the establishment of standard factors for analogous projects to protect entities (state and local governments in many cases) in need of these major services from being misled with regard to cost estimates. One issue, however, with this remedy lies in the lack of exhaustive analogy and factor studies in existence and/or available to those in need of the data (Flyvbjerg, Holm, Buhl, 2002). While it can be argued that MDAPs pose entirely different challenges compared to large infrastructure projects, the common theme lies in the vast complexity and likelihood of changes that each type of project contains. Infrastructure projects do not represent the sole area in need of improved estimation; numerous international studies have found construction projects in general exhibit cost overruns and inefficiencies that can be traced to poor estimating practices (Baloi & Price, 2003; Elfaki, Alatawi, & Abushandi, 2014). Such widespread occurrence of inaccurate estimating necessitates a focus on the establishment of improvements in the resources available to estimators, with historical standard factors being one of those resources.

In some instances, an estimate is created quickly and without proper data to meet the demands of decision makers who simply desire a figure to reference; this results in estimates that lack the necessary methodological and computational aspects, creating an estimating environment that places greater focus on the point estimates rather than the data from which they were formulated (Akintoye & Fitzgerald, 2000; Settani et al, 2015). While the practice of cost estimating exists in different capacities around the world, the common theme remains the intent to arrive at an estimate that aids in the decision-making process of the project (Greves & Joumier, 2003). The shortcomings of the use and structure of historical data and information are illustrated by large projects' consistent cost overruns (Riquelme & Serpell, 2012). The myriad of issues identified in projects around the world reinforces the need for additional data that will provide analysts the ability to effectively leverage historical information to arrive at a credible cost estimate. The data required to perform the necessary analysis for cost estimating requires scrutinization to ensure accuracy and applicability, but the time invested in this pursuit yields more effective estimates (Ali Abbas et al., 2012). The analogy and factor technique represents just one of many cost estimating methodologies, but when properly utilized in any field or environment it aids in achieving an estimate that embodies completeness, reasonableness, and analytic defensibility (Mislick & Nussbaum, 2015).

The creation and utilization of standard factors makes it possible to conduct more effective and extensive analysis at a variety of levels to construct credible cost estimates, especially in programs early in their lifecycle or with limited information regarding the central task (Mislick & Nussbaum, 2015). Several of the primary areas in which additional analysis is beneficial for program offices include commodity type, contractor designation (prime or sub), and contract type. These characteristics of a program serve as a starting point for data normalization, as well as more in-depth scrutinization within the structure of the WBS. The use of qualitative context factors like those dictated by the WBS format assist in the effective interpretation and use of historical information, which further strengthens the legitimacy of cost estimates that employ the standard factor approach (Riquelme & Serpell, 2012). Using the level two WBS elements as a guide, analysts have virtually every historical MDAP with relevant data at their fingertips to create factors to then extrapolate upon for their specific program. The value of a central database that encompasses all commodity types, contractor designations, and contract types lies in the ability to conduct analysis at each of these respective levels and manipulate the data to create factors for each level two element of the WBS. Through the creation of factors, cost analysts throughout the DoD can target specific analytical levels and more effectively formulate credible, defensible estimates for MDAPs.

Chapter Summary

Accurately predicting the costs of complex, multi-million-dollar systems proves challenging even for programs with defined, stringent requirements; thus, the added challenges of constrained fiscal resources and ever-evolving warfighter needs highlight the importance of effective cost estimating within the DoD. To achieve what can be deemed "effective" cost estimating, analysts must be able to draw upon historical information, employ proven techniques, and understand the entire content of the estimate they produce. This chapter explored the primary cost estimating methodologies and briefly stated the primary use, benefits, and shortfalls of each with an emphasis on DoD program characteristics. The analogy and factor approach to cost estimating requires the understanding of the WBS; this chapter offered a detailed explanation of its structure, along with examples of its utility across a variety of different program types. A primary goal of this research lies in the expansion and refinement of previously accomplished factor studies. Therefore, the most closely related studies were reviewed to establish a basis of understanding of existing data; in addition, the general practice of utilizing standard factors throughout DoD cost and budget functions provided insight into the broad application and potential for the methodology. Finally, the utility of factors in the field of cost estimating was addressed to highlight the various levels of analysis possible; specifically, the areas most applicable to MDAPs were referenced to reiterate the gap in current research that exists and how that gap can be rectified. The following chapter of this thesis delves into the specific statistical methodology utilized to perform the analysis necessary to complete this research.

III. Methodology

Chapter Overview

This chapter offers an in-depth explanation regarding the data and methodology used to analyze the data. The data source, data collection process, and criteria for inclusion and exclusion in the data set will be discussed. Then, the steps required for normalization and factor calculation will be represented before moving on to the topics of comparison analysis and statistical tests. These topics will be discussed at length to facilitate greater understanding of the data and initial findings. Finally, the chapter will summarize the key points of the methodological components of the research.

Data

The data gathered in this research is from the Defense Automated Cost Information Management System (DACIMS), which exists within the Cost Assessment Data Enterprise (CADE) system. DACIMS contains Cost Data Summary Reports (CDSR), often referred to as 1921s, which contain the necessary cost data to establish factors for the Major Defense Acquisition Programs (MDAP) targeted for this research. Appendix B exhibits a sample submission of a DD Form 1921 by a contractor to the government. Engineering, manufacturing, and development (EMD) data was chosen as the only life-cycle phase to be analyzed based on a gap in this area identified by the literature review for this research, as well as a lack of data in the existing Air Force Lifecycle Management Center Research Office's (AFLCMC) factor database for MDAPs. The dataset consists of 102 programs spanning from 1961 to 2017, representing a broad range of programs across numerous commodity types and services.

While 189 programs are available within CADE, only 102 of those programs fit the criteria for inclusion in the final dataset. These 102 programs are listed in Appendix A by commodity type. Several qualifiers were established prior to data collection to ensure as much uniformity as possible; this was done in accordance with the AFLCMC's previous research, as well as relevant research regarding estimating the final cost of a Department of Defense (DoD) acquisition contract. Table 1 depicts the exclusion criteria and accompanying number of programs not utilized for this research.

Table 1. Dataset Exclusions

Category	Number Removed	Remaining Programs
Available Programs in CADE		189
Ships	17	172
Surface Vehicle	16	156
System of Systems	2	154
No EMD Data	25	129
1921 File Format Not .XLS	27	102
Final Dataset for Analysis		102

Programs containing initial 1921 data only were excluded. A small portion of the data came from interim 1921s. In these instances, the data contained on the interim 1921s was equal to or greater than the final contract price. There were 27 programs that contained data but lacked accessible files within CADE, resulting in the entire program's exclusion from the dataset. These were primarily older programs with manually transcribed data from the 1980's or earlier and in many instances contained illegible data. There were 23 programs that contained inaccessible files for only certain contracts or components, but the contracts or components that did contain accessible files were included in the dataset, thus leaving the final number of programs in the dataset unaffected at 102. Ship, system of systems, and surface vehicle data was also excluded from this research to focus efforts on the programs most relevant to the Air Force.

Differentiation between contractor type, as well as unique aspects of programs (blocks, phases, etc.) resulted in multiple factors for most programs, each with their own level II WBS elements. Table 2 provides an overview of the major characteristics of the final dataset for this research, which consisted of 443 unique factors.

Table 2. Dataset Characteristics

Category	Total
Total Programs Included	102
Unique Factors Created	443
Commodity Type	
Aircraft	245
Electronic/Automated Software	118
Missile	22
Ordnance	12
Space	36
UAV	10
Contract Type	
CPAF	74
CPFF	39
CPIF	66
Cost-Other	135
FFP	27
FPI	20
FPIF	19
Fixed-Other	6
Unknown	57
Development Type	
Commercial Derivative	4
Modification	135
New Design	150
Prototype	9
Subsystem	105
New MDS Designator	40
Contractor Type	
Prime	308
Subcontractor	135
Service	
Air Force	196
Army	94
Multiple	24
Navy (includes Marine Corps)	129

Each category and accompanying subcategory represented in Table 2 corresponds to information from the CADE database utilized for data collection except the development type subcategories (new design, modification, prototype, new Mission Design Series (MDS) designator, commercial derivative, and subsystem). This category contained a level of subjectivity due to a lack of explicit definitions within current governing DoD acquisition publications. Defining each subcategory of development type was accomplished through consultation with active cost estimators and alignment with generally accepted descriptions utilized in the field. New Design programs were those whose capabilities were new to the DoD, while Modifications were defined as programs undergoing a major change to core capabilities or performance. Prototypes were MDAPs whose intent was to test an emerging capability for future utilization within the DoD. New MDS Designator captured primarily aircraft MDAPs with minor changes, such as the F-16B which accommodates two pilots instead of one for training purposes. Commercial Derivatives were defined as programs whose capability hinged upon a capability present in the commercial market that was adapted for military use. The Subsystem designation was also primarily for aircraft MDAPs and was assigned to those programs whose efforts were accomplished independent of the airframe, such as an engine upgrade.

Data Collection

Gathering data required the manual process of copying 1921 data from individual files accessed within CADE into a central database file. Several major designators were established for the data to facilitate analysis, including development type, service, commodity type, contractor level (prime or subcontractor), and contract type. The most crucial aspect of the data collection process was normalizing the dataset to analyze programs that occurred across a span of over 6 decades. To accomplish this step, the "report as of" date on the 1921 was recorded and then cross referenced with the period of performance (PoP) timeframe to establish the escalation year as the midpoint of the PoP, which facilitated calculations for each program's cost figures. However, not every 1921 contained the PoP timeframe, resulting in a standard deduction of two years from the report as of date for use as the escalation year. The deduction of two years was based upon an AFLCMC conducted study of 294 programs that revealed an average time of five years for an MDAP to progress from Milestone B to Initial Operating Capability. The midpoint value of that time span was then rounded down to two years. The escalation tables used to accomplish normalization calculations were the AFLCMC published tables for 2018 (Valentine, 2018).

Factor Calculation

The cost element factors contained in this research are the ratio (percentage) of the individual level II Work Breakdown Structure (WBS) elements to a base cost. The base cost is represented by a program's Prime Mission Equipment (PME) value, which does not include the contractor's fee or miscellaneous expenses (general and administrative (G&A), undistributed budget, management reserve, facilities capital cost of money (FCCM)). An example of this ratio is the dollar value or cost of System Engineering/Program Management (SE/PM) divided by the program's PME value. Table 3 depicts an example of this calculation.

Table 3. Example Cost Factor Calculation

Prime Mission Equipment (PME) Value	$456.2K
System Engineering/Program Management (SE/PM)	$148.2K
Cost Factor = 148.2÷456.2=0.325 or 32.5%	

After establishing cost factors for the level II WBS elements it is possible to develop composite factors for a myriad of unique categories. Specific level II WBS elements can be examined in groupings to establish aggregate values that represent an average or percentage that can be used in formulating estimates. These groupings allow for analysis at innumerable levels, such as fixed wing aircraft, rotary wing aircraft, a specified contractor for radar modifications, a specified contractor's role in a program (prime vs. sub), a specified period for a certain commodity type, and many more. Table 4 illustrates how this averaged cost factor represents a more accurate factor as it guards against the skewness that can result from calculations based on single data points.

Table 4. Example Composite Cost Factor Calculation

		PME	SE/PM	Percentage
Program 1		250K	60K	0.24
Program 2		370K	41K	0.11
Program 3		450K	80K	0.18
Program 4		155K	30K	0.19
	TOTAL	1,225K	211K	0.72

Cost Factor = 0.72 ÷ 4 = 0.18 or 18%

Comparison Analysis

Once the factors were established for each program, the mean, median, and standard deviation values for the various program groupings were calculated. In addition, interquartile ranges were calculated to examine variability among factors. This allowed for descriptive analysis prior to beginning statistical testing and analysis. This also provided a basis from which the programs were grouped and analyzed to compare differences in total cost. Similar to the innumerable amount of potential composite cost factors, there are many comparisons that can be performed using this dataset. This research highlights five major comparisons: service, commodity type, contractor designation, contract type, and development type. Table 5 lists the categories and respective sub-categories compared in this research.

Table 5. Categories for Comparison Analysis

Categories				
Service	**Commodity Type**	**Contractor Designation**	**Contract Type**	**Development Type**
Army	Aircraft	Prime	CPAF (Cost Plus Award Fee)	Modification
Navy (includes Marine Corps)	Electronic/Automated Software	Sub	CPFF (Cost Plus Fixed Fee)	New Design
Air Force	Missile		CPIF (Cost Plus Incentive Fee)	Prototype
Multiple	Ordnance		Cost-Other (Other than CPAF, CPFF, CPIF)	Subsystem
	Space		FFP (Firm Fixed Price)	New MDS Designator
	UAV		FPI (Fixed Price Incentive)	Commercial Derivative
			FPIF (Fixed Price Incentive Firm Target)	
			Unknown	

For each of the categorical comparisons, the same hypothesis test will be utilized, as shown in Equation 1:

$$H_o: \Delta_x = \Delta_y$$
$$H_a: \Delta_x \neq \Delta_y$$

Equation 1

In the hypothesis tests X and Y represent different sub-categories of one of the categories for each comparison. For instance, when comparing commodity type, X and Y are defined as Aircraft and Electronic/Automated Software, Electronic/Automated Software and Missile, Aircraft and Missile, etc. for each individual test. If there is a failure to reject the null, no difference exists between the medians of the sub-categories. If the null is rejected, then a difference between the medians exists.

Statistical Tests

To perform hypothesis testing, several statistical tests were utilized, including the Shapiro-Wilk test and the Kruskal-Wallis test. The Steel-Dwass test was performed as a multiple comparison test. The Shapiro-Wilk test determined non-normality within each of the categories examined, leading to the rejection of the null hypothesis that normality existed within the respective category populations. Due to the non-normality findings revealed in the Shapiro-Wilk test, non-parametric testing was employed to indicate how the sub-categories related to one another by using the Kruskal-Wallis test. The Kruskal-Wallis test is a rank based nonparametric test utilized to determine whether statistically significant differences exist between two or more groups of an independent variable on a continuous dependent variable. Finally, the Steel-Dwass multiple comparison test identified which rank orders of the tested groups were statistically different for each instance of subcategory comparison.

Chapter Summary

This chapter reviewed the methodological approach to the establishment of factors for MDAPs within the DoD. The discussion of data and data collection offers insight into how and why the dataset used for this research provided an effective basis for factor development. Furthermore, the specific categories and sub-categories for comparison were highlighted to capture the intent of the research. To accomplish meaningful comparisons, several steps to create the individual and composite factors were taken, which are detailed in this chapter. Next, a description of the comparative analysis process introduced several statistical tests employed to identify trends and analyze the factors. The following chapter will provide a detailed look at the results and analysis of the factors derived from this dataset.

IV. Results and Analysis

Chapter Overview

This chapter presents the results from applying the methodology outlined in Chapter III and is broken down into four sections. The first section provides an overview of the dataset from which the subsequent statistical analysis is conducted. The second section calculates the descriptive statistics by Work Breakdowns Structure (WBS) element and establishes values for mean, median, interquartile range (IQR), and standard deviation. Section three presents a more detailed set of results through statistical difference tests performed for each level II element of the WBS by category and an explanation of their respective findings, as well as contractor comparisons and timeframe specific analysis. The final section examines the results from several subsets of the dataset by filtering the data using varying criteria, to include commodity type, contract type, development type, contractor designation, and service.

Dataset Characteristics

All data utilized in the statistical analysis conducted in this research was gathered from the Cost Assessment Data Enterprise (CADE) system from individual Cost Data Summary Reports (CDRS). Of the 189 programs listed in CADE, 102 contained usable Engineering, Manufacturing, and Development (EMD) data that was delineated by contractor and also denoted by contractor type (prime or subcontractor). These 102 programs are listed in Appendix A. Table 6 displays the number of programs that were not included in the final dataset due to commodity type, availability of data, or improper file format.

Table 6. Dataset Exclusions

Category	Number Removed	Remaining Programs
Available Programs in CADE		189
Ships	17	172
Surface Vehicle	16	156
System of Systems	2	154
No EMD Data	25	129
1921 File Format Not .XLS	27	102
Final Dataset for Analysis		102

After finalizing the 102 programs for analysis, further differentiation between contractor type, as well as unique aspects of programs (blocks, phases, etc.) resulted in multiple factors for most programs, each with their own level II WBS elements. The total number of unique factors created was 443 and is detailed by category in Table 7.

Table 7. Dataset Characteristics

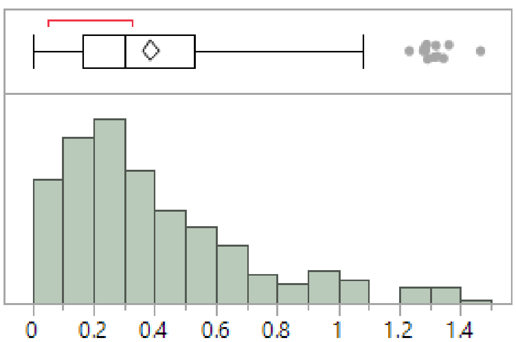
Category	Total
Unique Factors Created	443
Commodity Type	
Aircraft	245
Electronic/Automated Software	118
Missile	22
Ordnance	12
Space	36
UAV	10
Contract Type	
CPAF	74
CPFF	39
CPIF	66
Cost-Other	135
FFP	27
FPI	20
FPIF	19
Fixed-Other	6
Unknown	57
Development Type	
Commercial Derivative	4
Modification	135
New Design	150
Prototype	9
Subsystem	105
New MDS Designator	40
Contractor Type	
Prime	308
Subcontractor	135
Service	
Air Force	196
Army	94
Multiple	24
Navy (includes Marine Corps)	129

Descriptive Statistics

The cost element factors contained in this research are the ratio (percentage) of the individual level II Work Breakdown Structure (WBS) elements to a base cost. The base cost is represented by a program's Prime Mission Equipment (PME) value, which excludes the contractor's fee or miscellaneous expenses (general and administrative (G&A), undistributed budget, management reserve, facilities capital cost of money (FCCM)). An example of this ratio is the dollar value or cost of System Engineering/Program Management (SE/PM) divided by the program's PME value. After establishing cost factors for the level II WBS elements it is possible to develop composite factors for a myriad of unique categories. Specific level II WBS elements can be examined in groupings to establish aggregate values that represent an average or percentage that can be used in formulating estimates. These groupings allow for analysis at innumerable levels, such as fixed wing aircraft, rotary wing aircraft, a specified contractor for radar modifications, a specified contractor's role in a program (prime vs. sub), a specified period for a certain commodity type, and many more. This averaged cost factor represents a more accurate factor as it guards against the skewness that can result from calculations based on single data points.

SEPM

The Systems Engineering and Program Management (SEPM) element of the WBS represents one of the more prominent factors in this analysis in several ways. First, SEPM had the fewest amount of blank values of any WBS element, with only 19 blanks, or 4.29%. SEPM values ranged from 0.43% to 4768% of Prime Mission Equipment (PME), indicating potential reporting anomalies and/or additional issues in the extreme upper values. To establish meaningful exclusion criteria, the distribution of all SEPM values was computed using JMP software. Analysis of the distribution resulted in values above 150% of PME being removed from the dataset for all remaining SEPM analysis. These excluded values represented only 4.06% of the dataset, were more than three standard deviations from the mean, and in most cases were part of a Major Defense Acquisition Program (MDAP) with a total PME of less than ten million dollars. Figure 3 shows the distribution of SEPM values after exclusions were made and provides descriptive statistics utilized in further analysis.



Quantiles

100%	maximum	1.465552958
75%	quartile	0.5319708958
50%	median	0.3038569765
25%	quartile	0.1643247848
0%	minimum	0.00432192

Summary Statistics

Mean	0.3884475
Std Dev	0.3015703
N	406

Figure 3. SEPM Descriptive Statistics

The resulting distribution for the SEPM WBS element is characterized by many data points, as well as a high standard deviation value. The distribution's central points lie between 0.25 and 0.4, which is reinforced by the mean and median values of 0.38 and 0.30, respectively.

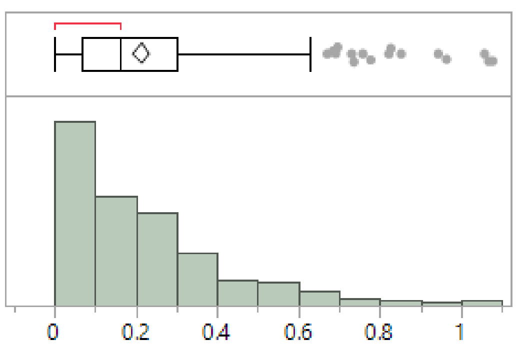
The individual distributions and descriptive statistics for each level II WBS element are broken out by commodity type, contract type, development type, contractor designation, and service and will be discussed in the next section of this chapter. Table 8 displays an example of the individual distributions and descriptive statistics broken out by category for the SEPM WBS element. The detailed analysis displayed in Table 8 for subsequent WBS elements in Chapter IV (ST&E, Training, Data, PSE, CSE, Site Activation, Other, and Spares) can be found in Appendix C.

Table 8. SEPM Summary Table

	Mean	Std Dev	N	Max	75%	Median	25%	Min
Service								
Air Force	0.3685	0.2755	177	1.324	0.4894	0.2972	0.159	0.0043
Army	0.508	0.3372	91	1.3453	0.6989	0.4426	0.2514	0.0098
Navy	0.3393	0.3039	115	1.4655	0.465	0.2551	0.1421	0.0105
Multiple	0.3142	0.2053	23	1.0007	0.4047	0.2699	0.1626	0.0903
Development Type								
Modification	0.3484	0.2555	124	1.3191	0.4954	0.2845	0.1539	0.0043
New Design	0.4738	0.3472	131	1.4655	0.6582	0.3759	0.219	0.0053
Prototype	0.1906	0.1472	8	0.39	0.3417	0.1783	0.0627	0.0126
Subsystem	0.373	0.2816	101	1.324	0.5343	0.2793	0.161	0.0105
New MDS Designator	0.3249	0.2924	39	1.3619	0.3887	0.2517	0.1154	0.0445
Commercial Derivative	0.184	0.1011	3	0.2676	0.2676	0.2128	0.0716	0.0716
Contractor Type								
Prime	0.3849	0.3068	284	1.3619	0.4896	0.2947	0.1609	0.012
Subcontractor	0.3966	0.2898	122	1.4655	0.5613	0.3336	0.1724	0.0043
Commodity Type								
Aircraft	0.3025	0.2385	227	1.3619	0.4115	0.2292	0.1421	0.0105
Electronic/Automated Software	0.5463	0.3511	107	1.4655	0.7816	0.4875	0.2568	0.0098
Missile	0.5014	0.3297	20	1.2822	0.7695	0.3897	0.2682	0.0576
Ordnance	0.3426	0.1737	11	0.6117	0.5007	0.285	0.2439	0.0811
Space	0.3825	0.3093	31	1.3191	0.4972	0.3109	0.1488	0.0043
UAV	0.4913	0.3217	10	1.324	0.5435	0.3655	0.303	0.2617
Contract Type								
CPAF	0.4128	0.2641	66	1.2792	0.5792	0.3649	0.2206	0.0337
CPFF	0.5189	0.3896	37	1.3453	0.7022	0.4233	0.2387	0.0053
CPIF	0.3905	0.2987	61	1.2924	0.522	0.2729	0.18	0.0276
Cost-Other	0.4082	0.3103	126	1.4655	0.5874	0.3175	0.1767	0.0043
FFP	0.2457	0.2531	25	1.0786	0.3494	0.156	0.0871	0.0105
FPI	0.2118	0.2232	17	1.0081	0.2349	0.1694	0.0729	0.0484
FPIF	0.4203	0.2811	19	1.2822	0.5578	0.3931	0.2218	0.0675
Fixed-Other	0.572	0.2327	4	0.8384	0.8026	0.5427	0.3707	0.3643
Unknown	0.3131	0.2573	51	1.3144	0.4426	0.243	0.1275	0.0385

ST&E

System Test & Evaluation (ST&E) contained the second largest amount of datapoints for analysis. Only 57 rows, or 12.87%, of the total factors were blank values for ST&E which left a sizable dataset from which to draw conclusions. Values for ST&E ranged from below 0.1% to as high as 1485% of PME, indicating potential reporting anomalies in the upper extreme values. ST&E values below 0.1% of PME were excluded as they represented trivial dollar amounts (less than $16K in most cases). On the high end of the distribution, ST&E values above 150% of PME were excluded, and in all five instances the PME dollar amount for the MDAP was less than ten million dollars. The upper and lower exclusions of ST&E values make up only 2.71% of the dataset. Figure 4 depicts the ST&E distribution as well as its accompanying descriptive statistics. The individual descriptive statistics for ST&E broken out by commodity type, contract type, development type, contractor designation, and service are found in Appendix C.



Quantiles

100%	maximum	1.077668426
75%	quartile	0.2999260488
50%	median	0.1611484545
25%	quartile	0.0658709168
0%	minimum	0.001281157

Summary Statistics

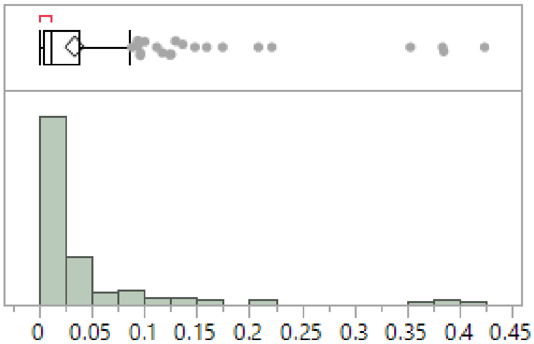
Mean	0.21441
Std Dev	0.2027471
N	374

Figure 4. ST&E Descriptive Statistics

Despite the high value for standard deviation displayed by the ST&E WBS element, the resulting mean and median values lie within close proximity to one another in the distribution. ST&E also exhibited a large number of available data points, with only 15.5% of the entire dataset excluded for analysis.

Training

The Training WBS element showed a sharp decline in reported data, with more than half of the dataset containing no value for Training. Despite 235 (53.05%) of the rows being blank, this element still contains ample data for analysis. The vast majority (85.4%) of the Training data comes from the aircraft and electronic/automated software commodity types. Distributional analysis resulted in the threshold for inclusion in the analysis of this element being set at values above 0.05% of PME. This resulted in the exclusion of 14 (3.16%) data points, the majority of which were less than $100K amounts in multi-million-dollar MDAPs. Also, two Training values above 80% were excluded, which amounted to less than 0.5% of the total dataset. These extreme upper values of 82% and 2275% represented a commercial derivative program and a likely reporting anomaly, respectively. Figure 5 shows the distribution and descriptive statistics for the 192 values analyzed for the Training WBS element. The individual descriptive statistics for Training broken out by commodity type, contract type, development type, contractor designation, and service are found in Appendix C.



Quantiles

100%	maximum	0.423777764
75%	quartile	0.0370268538
50%	median	0.0101459635
25%	quartile	0.0031587488
0%	minimum	0.000621284

Summary Statistics

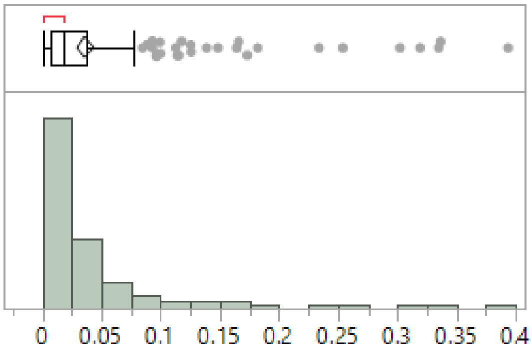
Mean	0.0342243
Std Dev	0.0648891
N	192

Figure 5. Training Descriptive Statistics

The Training WBS element contained data for less than half of the entire dataset. Its standard deviation value was high in relation to the calculated mean value, due in part to several data points in one tail of the distribution. The Training data resided largely between the values of 0.01 and 0.04.

Data

The Data WBS element lacked 176 values, or 39.73% of the total dataset. Data is similar to Training with respect to its concentration of information within the aircraft and electronic/automated software commodity groups. It surpasses the characteristics of Training, with 87.3% of the dataset for the Data WBS element coming from these two commodities. Data represented the lone element with no additional exclusions beyond blank values, as the distribution was much more concentrated than other elements. Figure 6 provides a look at the descriptive statistics for the Data WBS element. The individual descriptive statistics for Data broken out by commodity type, contract type, development type, contractor designation, and service are found in Appendix C.



Quantiles

100%	maximum	0.39350792
75%	quartile	0.036726503
50%	median	0.01867793
25%	quartile	0.007443493
0%	minimum	5.75642e-6

Summary Statistics

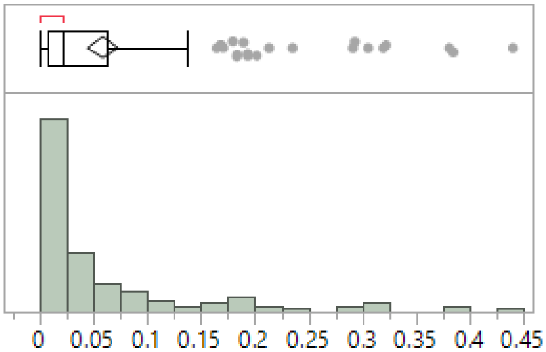
Mean	0.0364283
Std Dev	0.0568872
N	267

Figure 6. Data Descriptive Statistics

While the Data WBS element offered values for over 60% of the entire dataset, its distribution is characterized by a high standard deviation value and numerous values well beyond three standard deviations from the mean of 0.03.

PSE

Peculiar Support Equipment (PSE) contained only 149 values of Data. Blank PSE values make up 64.56% of the entire dataset. Upper and lower exclusions add another 1.8% to the amount excluded. The upper exclusions made were only two values, one of which was nearly 300% of PME, indicating likely reporting anomalies, and the other well above three standard deviations and part of a multinational development effort. The concentration by commodity type is similar to the Training and Data WBS elements, with 65.8% of the dataset coming solely from the aircraft commodity type. Figure 7 shows the descriptive statistics for PSE. The individual descriptive statistics for PSE broken out by commodity type, contract type, development type, contractor designation, and service are found in Appendix C.



Quantiles

100%	maximum	0.440001636
75%	quartile	0.062978593
50%	median	0.021701256
25%	quartile	0.0074884715
0%	minimum	0.000117023

Summary Statistics

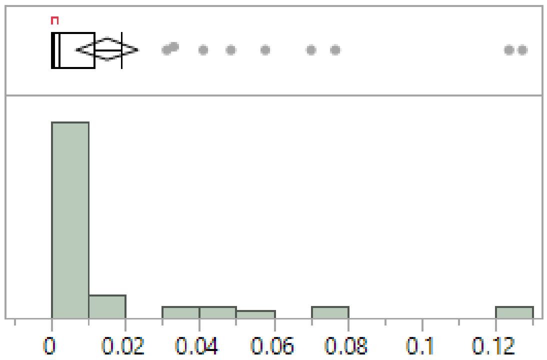
Mean	0.0584986
Std Dev	0.0867449
N	149

Figure 7. PSE Descriptive Statistics

The PSE WBS element displays a concentration of data points between the values of 0.01 and 0.05. Beyond that concentration, the data is spread as far as five standard deviations from the mean. The 149 data points for PSE account for only 33.6% of the entire dataset.

CSE

Common Support Equipment (CSE) represented a sharp decline of available data, resulting in only 50 values for analysis. The CSE WBS element is also made up primarily by the aircraft commodity type (62%), and then evenly distributed between each of the remaining types. Only two values (0.45%) were excluded from the CSE analysis, both of which were beyond three standard deviations and indicative of reporting anomalies based on their extremely high values. The descriptive statistics for the CSE WBS element are shown in Figure 8. The individual descriptive statistics for CSE broken out by commodity type, contract type, development type, contractor designation, and service are found in Appendix C.



Quantiles

100%	maximum	0.127285037
75%	quartile	0.011501404
50%	median	0.0019863765
25%	quartile	0.0006335303
0%	minimum	2.5209e-7

Summary Statistics

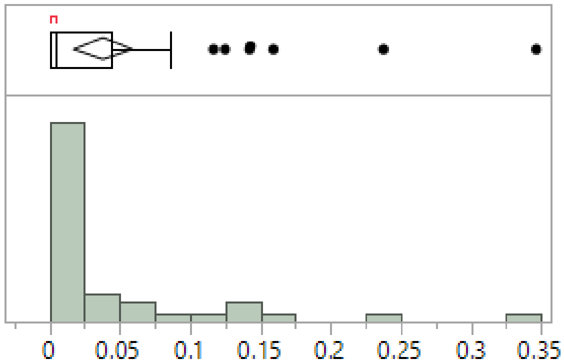
Mean	0.0151615
Std Dev	0.0291964
N	50

Figure 8. CSE Descriptive Statistics

Just over ten percent of the dataset is represented by the CSE WBS element, which yielded only 50 values for analysis. Its distribution lacks any major shape with data points spread several standard deviations from the mean value of 0.015.

Site Activation

Site Activation mirrored the limited availability quality of CSE, offering only 47 data points, or 11.29% of the total factors, for analysis. The 47 data points exclude three upper extreme values beyond three standard deviations. The majority of the values (78.7%) for the Site Activation WBS element are comprised of the aircraft and electronic/automated software commodity types. The Site Activation descriptive statistics are summarized in Figure 9. The individual descriptive statistics for Site Activation broken out by commodity type, contract type, development type, contractor designation, and service are found in Appendix C.



Quantiles		
100%	maximum	0.346422893
75%	quartile	0.043293824
50%	median	0.004073782
25%	quartile	0.000564161
0%	minimum	9.29461e-6

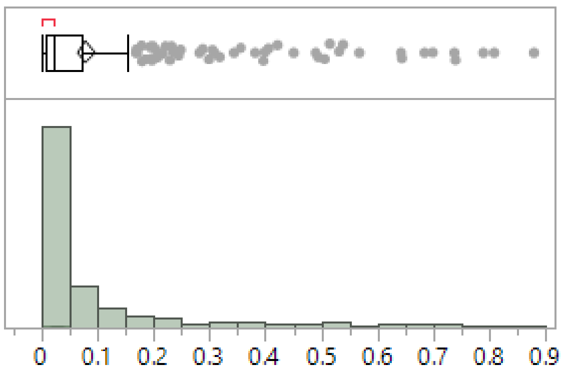
Summary Statistics	
Mean	0.0386819
Std Dev	0.0706161
N	47

Figure 9. Site Activation Descriptive Statistics

Almost 90% of the dataset was excluded from the Site Activation WBS element's analysis, and such a small sample size yielded a distribution devoid of a dominant shape. The standard deviation value was nearly double the value of the mean and data points encompassed a range that exceeded four standard deviations.

Other

The Other WBS element is not included in Mil-Std-881D as a formal WBS element. It was utilized for the descriptive statistical analysis only to capture several areas not included within a formal WBS element and is not included in subsequent sections of this analysis. These areas included such costs as industrial facilities, undistributed budget, management reserve, and facilities capital cost of money (FCCM). The Other WBS element had robust data. Only 57 blank values existed for this element, and nine additional values were negative and therefore not included in this analysis. In addition, six values over 100% and above three standard deviations were excluded, bringing the total exclusion percent to 3.38% (not including blank values). Almost identical to Site Activation, the Other WBS element's concentration of aircraft and electronic/automated software commodity types was 79%. Figure 10 displays the descriptive statistics and distribution for the Other WBS element. The individual descriptive statistics for Other broken out by commodity type, contract type, development type, contractor designation, and service are found in Appendix C.



Quantiles

100%	maximum	0.879620467
75%	quartile	0.071182549
50%	median	0.022807094
25%	quartile	0.008520869
0%	minimum	0.0000446195

Summary Statistics

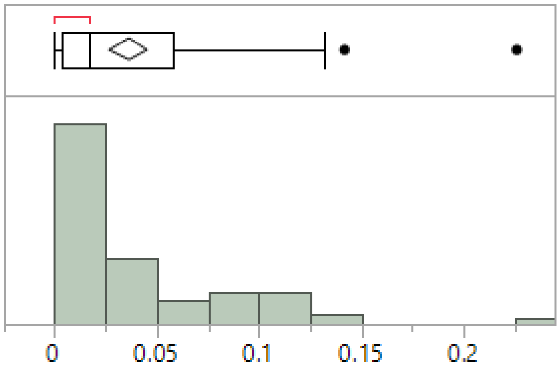
Mean	0.07967
Std Dev	0.145694
N	371

Figure 10. Other Descriptive Statistics

The Other WBS element represented the third largest sample of data for analysis with 371 data points. Its distribution displayed a high concentration of values less than 0.1 and only a small amount of data beyond 0.2 This WBS element was characterized by a high standard deviation value relative to the mean.

Spares

The Spares WBS element exhibited a low number of data points. Only 84 values were analyzed after removing the 358 blanks and one upper extreme value that was above 100% of PME. The concentration by commodity type for the Spares WBS element is similar to the Training, Site Activation, and Other WBS elements with 86.9% of the data points coming from aircraft and electronic/automated software. The descriptive statistics and distribution for Spares is shown in Figure 11. The individual descriptive statistics for Spares broken out by commodity type, contract type, development type, contractor designation, and service are found in Appendix C.



Quantiles

100%	maximum	0.226030455
75%	quartile	0.057498319
50%	median	0.0174865055
25%	quartile	0.003555311
0%	minimum	0.000025983

Summary Statistics

Mean	0.0362014
Std Dev	0.0436054
N	84

Figure 11. Spares Descriptive Statistics

Less than 20% of the dataset was available for analysis for the Spares WBS element. Its values were not characterized by large disparities like several other WBS elements' values, with a standard deviation just slightly higher than the mean. Its data points were concentrated between 0.01 and 0.05.

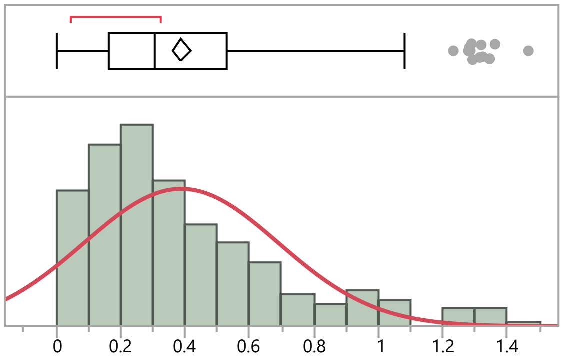
Results by Category

This section first presents the findings for each WBS element by category from the Shapiro-Wilk test. The null hypothesis for the Shapiro-Wilk test assumes normality for each dataset. The results of the nonparametric testing conducted after determining non-normality for each WBS element are then detailed. The null hypothesis for the Kruskal-Wallis test asserts that all group medians being tested are equal. An alpha value of 0.05 was utilized for all statistical testing in this analysis. The five categories examined were commodity type, contract type, development type, contractor type, and service.

Shapiro-Wilk Test Results

Conducting the Shapiro-Wilk test for normality revealed findings of non-normality for each WBS element. Figure 12 illustrates the low p-value returned for

SEPM, which prompted the rejection of the null hypothesis and conclusion that the data for each WBS element was non-normal.



Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.885540	<.0001*

Figure 12. SEPM Shapiro-Wilk Test

The Shapiro-Wilk test results for SEPM are consistent with the remaining eight WBS elements, which necessitated the non-parametric testing conducted for each WBS element for the five categories detailed in the remainder of this section. Given the consistent skewed right distribution of each WBS element, the locations of the distributions are referred to as the median values in the remainder of this analysis. The Shapiro-Wilk test results for each WBS element can be found in Appendix C.

Commodity Type

The Kruskal-Wallis test revealed that statistical differences exist between WBS element median values within the commodity type category. For SEPM, ST&E, and Site Activation, statistical differences between group medians were identified, prompting the rejection of the null hypothesis as shown in Table 9.

Table 9. Kruskal-Wallis for Commodity Type

WBS Element	Alpha	Chi-Square	P-value	Null Hypothesis Test Result	N
SEPM	0.05	49.2441	<0.0001	Reject	406
ST&E	0.05	32.3203	<0.0001	Reject	374
Training	0.05	6.9636	0.2234	Do Not Reject	192
Data	0.05	6.1052	0.2961	Do Not Reject	267
PSE	0.05	2.2603	0.8121	Do Not Reject	149
CSE	0.05	1.0203	0.9609	Do Not Reject	50
Site Activation	0.05	14.4899	0.0059	Reject	47
Spares	0.05	3.7434	0.2905	Do Not Reject	84

After determining statistical differences existed, the Steel-Dwass multiple comparison test was utilized to identify which commodity types exhibited differences. Table 10 summarizes the significant differences that occurred for each WBS element by commodity type. The aircraft commodity type displayed the most statistical differences, while ordnance displayed no statistical differences. SEPM and ST&E contained the greatest amount of statistical differences of the WBS elements, making up 85.7% of all differences.

Table 10. Commodity Differences Summary

	Aircraft	Electronic/Automated Software	Missile	Ordnance	Space	UAV
SEPM	2	1	1	0	0	0
ST&E	2	1	1	0	3	1
Training	0	0	0	0	0	0
Data	0	0	0	0	0	0
PSE	0	0	0	0	0	0
CSE	0	0	0	0	0	0
Site Activation	1	1	0	0	0	0
Spares	0	0	0	0	0	0

The SEPM and ST&E WBS elements display the majority of differences, making the case that estimates in these areas be carefully constructed, especially given the high factor values that each represents with respect to PME. Based on the number of differences that occurred across commodity types, analysts must be aware of what commodities are included in any dataset utilized for analysis or estimate formulation. The detailed results of the Steel-Dwass test for each pairwise comparison is detailed in Appendix E.

Contract Type

Applying the Kruskal-Wallis test to each WBS element for the contract type category revealed several more statistical differences than the commodity type category. For the WBS elements of SEPM, ST&E, Data, and PSE the calculated p-value was less than the alpha value, which led to a rejection of the null hypothesis as illustrated by Table 11.

Table 11. Kruskal-Wallis for Contract Type

WBS Element	Alpha	Chi-Square	P-value	Null Hypothesis Test Result	N
SEPM	0.05	32.8151	<0.0001	Reject	406
ST&E	0.05	34.4853	<0.0001	Reject	374
Training	0.05	5.6801	0.683	Do Not Reject	192
Data	0.05	19.4757	0.0125	Reject	267
PSE	0.05	18.7037	0.0165	Reject	149
CSE	0.05	6.8419	0.4455	Do Not Reject	50
Site Activation	0.05	9.8514	0.1972	Do Not Reject	47
Spares	0.05	9.4857	0.2196	Do Not Reject	84

Conducting the Steel-Dwass multiple comparison test across all contract types revealed significant differences across all but one contract type. These differences are broken down by contract type for each WBS element in Table 12. SEPM and ST&E register the most interactions with 90.9% of total differences. Fixed Priced Incentive (FPI) contracts displayed the most statistical difference of any contract type with 36.36% of the total differences.

Table 12. Contract Type Differences Summary

	CPAF	CPFF	CPIF	Cost-Other	FFP	FPI	FPIF	Unknown
SEPM	2	2	0	1	2	3	0	0
ST&E	1	1	0	1	1	5	0	1
Training	0	0	0	0	0	0	0	0
Data	0	0	1	0	0	0	0	1
PSE	0	0	0	0	0	0	0	0
CSE	0	0	0	0	0	0	0	0
Site Activation	0	0	0	0	0	0	0	0
Spares	0	0	0	0	0	0	0	0

The concentration of differences in the SEPM and ST&E WBS elements provides compelling statistical justification for affording extra time and research for estimates in these areas. Furthermore, any MDAP expecting a FPI contract should place increased scrutiny on the programs that contribute to their factor calculation and what type of contracts were utilized. The PSE WBS element displayed statistical differences according to the Kruskal-Wallis test, but no individual pair differences were found using the Steel-Dwass test due to extremely low n values for several subcategories. The detailed results of the Steel-Dwass test for each pairwise comparison is detailed in Appendix E.

The contract type category warranted further analysis based on the large number of subcategories, as well as low n values for several of those subcategories. The contract type analysis was revised to represent only two subcategories, fixed price and cost plus. The 57 contracts designated “unknown” were excluded from the revised subcategories. Table 13 represents the Kruskal-Wallis test results for each WBS element after generalizing the contract type category. Table 13 also illustrates a comparison between the original contract type analysis containing eight subcategories and the revised contract type analysis containing only two subcategories.

Table 13. Kruskal-Wallis for Contract Type Comparison

	Original Analysis (8 Contract Types)			Fixed Price vs Cost Plus Analysis		
WBS Element	**Alpha**	**P-value**	**Null Hypothesis Test Result**	**Alpha**	**P-value**	**Null Hypothesis Test Result**
SEPM	0.05	<0.0001	Reject	0.05	0.0003	Reject
ST&E	0.05	<0.0001	Reject	0.05	0.0004	Reject
Training	0.05	0.683	Do Not Reject	0.05	0.8676	Do Not Reject
Data	0.05	0.0125	Reject	0.05	0.174	Do Not Reject
PSE	0.05	0.0165	Reject	0.05	0.854	Do Not Reject
CSE	0.05	0.4455	Do Not Reject	0.05	0.4578	Do Not Reject
Site Activation	0.05	0.1972	Do Not Reject	0.05	0.0021	Reject
Other	0.05	0.0089	Reject	0.05	0.03	Reject
Spares	0.05	0.2196	Do Not Reject	0.05	0.7913	Do Not Reject

As depicted by the gray highlighted WBS elements of Data, PSE, and Site Activation, the results of the Kruskal-Wallis test were different in several instances when approaching contract type analysis with the more generic subcategories. For the Data and PSE WBS elements, statistical differences were not found in the fixed price versus cost plus analysis but were identified in the original analysis with more subcategories. For the Data WBS element, the only difference in the original analysis occurred between a fixed price contract and an unknown contract type. Because unknown contract types were excluded from the revised analysis, this difference was no longer present. For the PSE WBS element, the low n values of several subcategories disallowed the identification of any individual pair differences in the original analysis, thus trivializing the results and comparison of the Kruskal-Wallis test for the revised analysis. The Site Activation WBS element represented one of the smallest samples of any WBS element, thus the small n values for its subcategories may have played a part in no statistical differences being identified in the original analysis. In the generalized analysis, more uniform and meaningful n values existed for the two subcategories, which likely led to the identification of statistical differences.

Development Type

The Kruskal-Wallis test results for development type were very similar to the results for contract type, with statistical differences identified in SEPM, ST&E, Data, PSE, and Spares as shown in Table 14. For these five WBS elements, the null hypothesis was rejected, prompting further analysis by way of the Steel-Dwass multiple comparison test.

Table 14. Kruskal-Wallis for Development Type

WBS Element	Alpha	Chi-Square	P-value	Null Hypothesis Test Result	N
SEPM	0.05	18.3391	0.0026	Reject	406
ST&E	0.05	15.3905	0.0088	Reject	374
Training	0.05	6.7041	0.2436	Do Not Reject	192
Data	0.05	13.8759	0.0164	Reject	267
PSE	0.05	11.4644	0.0429	Reject	149
CSE	0.05	6.3575	0.273	Do Not Reject	50
Site Activation	0.05	8.5601	0.128	Do Not Reject	47
Spares	0.05	13.0157	0.0232	Reject	84

The Steel-Dwass test results identified where statistical differences existed between the median values for each development type category, as shown in Table 15. Differences existed between specific categories of development types within the SEPM, ST&E, Data, PSE, and Spares WBS elements. Each category of development types had a single significant difference except for commercial derivative, which was the smallest category and made up less than 1% of the dataset.

Table 15. Development Type Differences Summary

	Modification	New Design	Prototype	Subsystem	New MDS Designator	Commercial Derivative
SEPM	1	2	0	0	1	0
ST&E	0	0	0	1	1	0
Training	0	0	0	0	0	0
Data	0	0	1	0	1	0
PSE	1	0	0	0	1	0
CSE	0	0	0	0	0	0
Site Activation	0	0	0	0	0	0
Spares	1	1	0	0	0	0

The development type displayed few statistical differences when examining the entire dataset but was not devoid of differences entirely. This raises the question for analysts as to whether or not this trend would remain true when examining a more specific sample of data. Less than half of the WBS elements exhibited differences, which points to the conclusion that broad datasets can be utilized for estimates spanning multiple development types. The detailed results of the Steel-Dwass test for each pairwise comparison is detailed in Appendix E.

Contractor Type

The application of the Kruskal-Wallis test by contractor type displayed the fewest amount of differences thus far in the analysis. Only the WBS elements of ST&E and PSE returned p-values less than the alpha of 0.05 and led to a rejection of the null hypothesis. Table 16 provides a summary of the Kruskal-Wallis test results, which dictate the WBS elements that required further analysis through the application of the Steel-Dwass test.

Table 16. Kruskal-Wallis for Contractor Type

WBS Element	Alpha	Chi-Square	P-value	Null Hypothesis Test Result	N
SEPM	0.05	0.7777	0.3778	Do Not Reject	406
ST&E	0.05	12.064	0.0005	Reject	374
Training	0.05	0.0811	0.7759	Do Not Reject	192
Data	0.05	2.66	0.1029	Do Not Reject	267
PSE	0.05	5.3186	0.0211	Reject	149
CSE	0.05	1.6912	0.1934	Do Not Reject	50
Site Activation	0.05	0.0571	0.8111	Do Not Reject	47
Spares	0.05	0.087	0.768	Do Not Reject	84

Because the null hypothesis was rejected for only two of the WBS elements, only two statistical differences registered for each contractor type category because the only two designations for this category were “prime” and “subcontractor”. Table 17 shows the resulting significant interactions found by the Steel-Dwass multiple comparison test by contractor type.

Table 17. Contractor Type Differences Summary

	Prime	Subcontractor
SEPM	0	0
ST&E	1	1
Training	0	0
Data	0	0
PSE	1	1
CSE	0	0
Site Activation	0	0
Spares	0	0

Only the ST&E and PSE WBS elements displayed statistical differences, meaning estimates based on both prime and subcontractor data for the remaining WBS elements can encompass a large dataset and remain relatively accurate. For ST&E and PSE, analysts must separate the contractor type in order to avoid basing estimates on factor values that are statistically different. The detailed results of the Steel-Dwass test for each pairwise comparison is detailed in Appendix E.

Service

Similar to the Kruskal-Wallis test results for contractor type, the Service category revealed only two instances of statistically different median values for WBS elements. SEPM and ST&E were identified as the two areas where differences existed. Table 18 depicts the p-values and hypothesis test results for each WBS element.

Table 18. Kruskal-Wallis for Service

WBS Element	Alpha	Chi-Square	P-value	Null Hypothesis Test Result	N
SEPM	0.05	20.1146	0.0002	Reject	406
ST&E	0.05	9.1187	0.0278	Reject	374
Training	0.05	3.7819	0.286	Do Not Reject	192
Data	0.05	1.6337	0.6518	Do Not Reject	267
PSE	0.05	2.666	0.446	Do Not Reject	149
CSE	0.05	2.1053	0.5508	Do Not Reject	50
Site Activation	0.05	1.222	0.7477	Do Not Reject	47
Spares	0.05	1.0621	0.588	Do Not Reject	84

Despite only two WBS elements containing statistical differences in median values, the Steel-Dwass multiple comparison test was able to identify a total of 12 significant interactions. Table 19 provides the detailed breakdown of how many interactions each service registered by WBS element. Programs for the Army and for multiple services made up 66.7% of the total interactions and each WBS element contained an equal amount of interactions.

Table 19. Service Differences Summary

	Air Force	Army	Navy	Multiple
SEPM	1	3	1	1
ST&E	1	1	1	3
Training	0	0	0	0
Data	0	0	0	0
PSE	0	0	0	0
CSE	0	0	0	0
Site Activation	0	0	0	0
Spares	0	0	0	0

MDAPs for the Army and for multiple services warrant more in-depth analysis with respect to factor-based estimates, as these areas displayed the highest concentration of statistical differences. The differences occurred in the SEPM and ST&E WBS elements across all services. The detailed results of the Steel-Dwass test for each pairwise comparison is detailed in Appendix E.

Contractor Comparison

The Kruskal-Wallis test was conducted for each WBS element to determine if statistical differences existed between individual contractors. The five contractors utilized for this analysis were identified based on the number of factors each represented across the entire dataset of 443 factors. These five contractors represented 201 of the 443 total factors (45.37%). A lower bound timeframe of 1998 was established based on relevant mergers between major contractors. Table 20 illustrates the Kruskal-Wallis test results for this subset of data across all commodity types.

Table 20. Kruskal-Wallis for Top 5 Contractors by Commodity Type

WBS Element	# Remaining	% of Original Dataset	Alpha	P-Value
SEPM	184	41.53%	0.05	0.1293
ST&E	175	39.50%	0.05	0.9093
Training	94	21.22%	0.05	0.2025
Data	112	25.28%	0.05	0.4682
PSE	44	9.93%	0.05	0.3215
CSE	24	5.42%	0.05	0.7137
Site Activation	22	4.97%	0.05	0.2299
Other	189	42.66%	0.05	0.9272
Spares	34	7.67%	0.05	0.5622

No statistical differences were identified between contractors, which prompted further analysis examining only the aircraft and electronic/automated software commodity types, as shown in Table 21.

Table 21. Kruskal-Wallis for Top 5 Contractors by Commodity Type (Aircraft & Electronic/Automated Software Only)

WBS Element	# Remaining	% of Original Dataset	Aircraft	Electronic/Automated Software	Alpha	P-Value
SEPM	134	30.25%	82	52	0.05	0.2263
ST&E	129	29.12%	82	47	0.05	0.6958
Training	69	15.58%	38	31	0.05	0.3003
Data	92	20.77%	58	34	0.05	0.3268
PSE	33	7.45%	27	6	0.05	0.5397
CSE	14	3.16%	11	3	0.05	0.2534
Site Activation	15	3.39%	6	9	0.05	0.0953
Other	135	30.47%	78	57	0.05	0.3582
Spares	26	5.87%	13	13	0.05	0.6239

The revised dataset of only aircraft and electronic/automated software yielded the same results as the dataset that included all commodity types, with no statistical differences identified for any WBS element. Based on the lack of statistical differences, estimators can largely disregard which contractor(s) will be involved in a program when it comes to utilizing factors for estimate creation.

Timeframe Specific Analysis

To determine the significance of the 27 programs that were excluded due to inaccessible files or illegible data entries (largely programs from the 1980's or prior), a subset of the data spanning the past two decades was accomplished. By establishing a lower bound timeframe of 1998, 92 factors (20.77%) were excluded. Table 22 displays the descriptive statistics for the SEPM WBS element for the original dataset, as well as the revised dataset spanning the most recent 20 years.

Table 22. SEPM Descriptive Statistics Comparison

Commodity	Original Mean	1998-Pres Mean	Original Median	1998-Pres Median	Original CV	1998-Pres CV
Aircraft	0.3025	0.3433	0.2292	0.2727	78.84	71.78
Electronic/Automated Software	0.5463	0.5479	0.4875	0.4875	64.27	66.76
Missile	0.5014	0.5014	0.3897	0.3897	65.77	65.77
Ordnance	0.3426	0.3484	0.285	0.3409	50.7	52.22
Space	0.3825	0.4059	0.3109	0.3109	80.86	83.38
UAV	0.4913	0.5154	0.3655	0.3887	65.49	64.32

The descriptive statistics of the subset of data for SEPM are similar in most cases, and identical in some, to the original dataset. To ensure the SEPM WBS element was not an anomaly, the ST&E WBS element was also examined. Table 23 illustrates the findings for ST&E.

Table 23. ST&E Descriptive Statistics Comparison

Commodity	Original Mean	1998-Pres Mean	Original Median	1998-Pres Median	Original CV	1998-Pres CV
Aircraft	0.2498	0.242	0.2036	0.1912	85.61	88.02
Electronic/Automated Software	0.1702	0.1772	0.1038	0.1072	113.04	114.47
Missile	0.2041	0.2041	0.1842	0.1842	86.79	86.79
Ordnance	0.1513	0.1595	0.0961	0.1016	65.98	63.5
Space	0.0778	0.0749	0.0448	0.0448	112.99	121.18
UAV	0.2068	0.187	0.1893	0.1631	61.54	64.31

The descriptive statistics for the subset of data for ST&E follow a similar trend as SEPM in that they closely resemble, or even mirror, the descriptive statistics for the original ST&E dataset. The consistency displayed for each of these WBS elements between the subset and original dataset leads to the conclusion that the 27 programs excluded due to inaccessible files or illegible entries would likely not affect the descriptive statistics or statistical analysis conducted in this research.

The collective results of each level of categorical analysis lead to a general conclusion that only the SEPM and ST&E WBS elements contain statistical differences significant enough to consider when establishing an estimate. However, every other element besides Training and CSE displayed statistical differences in at least one category. This means that analysts should always be as specific as possible when establishing estimates for the SEPM and ST&E WBS elements. However, for the remaining WBS elements, analysts can include a broader dataset to arrive at an estimate, at least until greater levels of detail are available. The fact that little or no statistical difference exist in some WBS elements does not negate the fact that each program has a specific purpose, and as that purpose is refined and finalized analysts should refine the data shaping their estimate accordingly.

Purpose Specific Analysis

The results of the Kruskal-Wallis tests by WBS element for each of the five examined categories, as well as the number of significant interactions found by the Steel-Dwass multiple comparison tests would lead to the conclusion that as a general rule, factor values have a low level of statistical difference across commodity type, contract type, development type, contractor type, and service. However, the distributions and descriptive statistics of the values for each WBS element reveal large Coefficient of Variation (CV) values (standard deviations divided by mean) in each category. Table 24 shows the CV means for each WBS element.

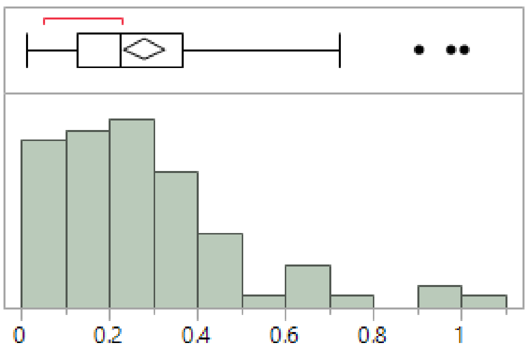
Table 24. Coefficient of Variation Summary

WBS Element	Collective Mean	Collective Std Dev	CV
SEPM	0.3802	0.2732	71.86%
ST&E	0.2117	0.1822	86.07%
Training	0.0295	0.0503	170.51%
Data	0.0331	0.0477	144.11%
PSE	0.0538	0.0749	139.22%
CSE	0.0149	0.0268	179.87%
Site Activation	0.0307	0.0526	171.34%
Spares	0.0787	0.1375	174.71%

Because the standard deviations are so large for this dataset, the statistical analysis did not identify differences in certain instances where a cost analyst may identify differences through practical analysis. The remainder of this section will present the results for three scenarios in which the data was filtered down to a lower level in support of a hypothetical initial cost estimate.

Scenario 1

The first scenario examined the SEPM WBS element by contract type after filtering down to aircraft MDAPs for the Air Force using only prime contractor data. The descriptive statistics for this focused analysis are displayed in Figure 13 and offer similar characteristics as the analysis conducted using the entire dataset, specifically with respect to the standard deviation.



Quantiles

100%	maximum	1.008198833
75%	quartile	0.364259187
50%	median	0.222932693
25%	quartile	0.123784755
0%	minimum	0.012620638

Summary Statistics

Mean	0.278698
Std Dev	0.2111317
N	80

Figure 13. Scenario 1 Descriptive Statistics

Despite examining only 80 of the 406 available factors for SEPM, the CV was three percent higher than the entire SEPM dataset. The results of non-parametric testing disallowed a rejection of the null hypothesis that the median values were statistically different.

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

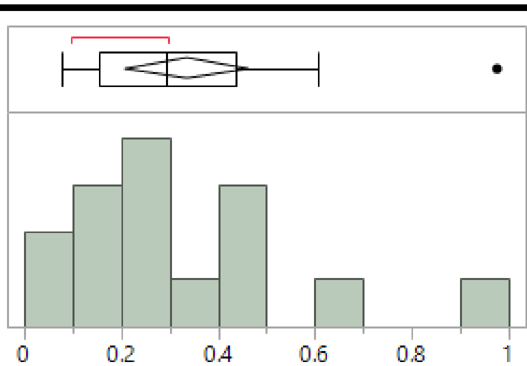
Level	Count
Cost-Other	16
CPAF	9
CPFF	11
CPIF	8
FFP	4
Fixed-Other	1
FPI	10
FPIF	5
Unknown	16

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
6.2440	8	0.6199

Figure 14. Scenario 1 Kruskal-Wallis Test

The resulting p-value of 0.6199 is indicative of broad similarities in the medians of each of the eight contract types (excluding "Unknown"). For the sake of due diligence, an analyst's objective becomes understanding why the p-value returned by the Kruskal-Wallis test is so high and if it remains high if the data is refined based on additional information. Therefore, the sample of data was refined further by removing fighter platform factors and analyzing remaining factors with Cost-Other or CPFF contracts. Figure 15 illustrates the distribution for this more specific sample of data.



Quantiles

100%	maximum	0.977628321
75%	quartile	0.436560629
50%	median	0.294511723
25%	quartile	0.153617205
0%	minimum	0.076198799

Summary Statistics

Mean	0.3349916
Std Dev	0.2334968
N	15

Figure 15. Scenario 1a Descriptive Statistics

The CV remained high despite the small sample, but further testing using both the Kruskal-Wallis test and Steel-Dwass multiple comparison test revealed significant differences between the two types of contracts. The results of these statistical tests are displayed in Figure 16.

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count
Cost-Other	7
CPFF	8

2-Sample Test, Normal Approximation

S	Z	Prob>|Z|
37	-2.14096	0.0323*

1-Way Test, ChiSquare Approximation

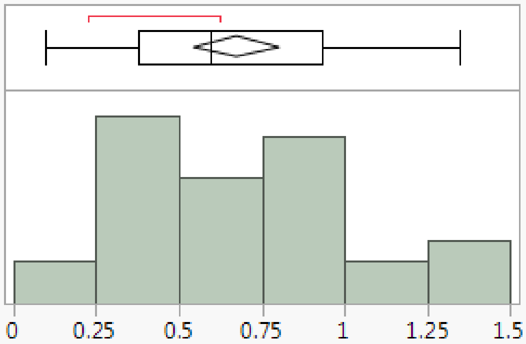
ChiSquare	DF	Prob>ChiSq
4.8348	1	0.0279*

Figure 16. Scenario 1a Kruskal-Wallis and Steel-Dwass Tests

Establishing that statistical differences existed at this level of data was only possible with additional details that led to the exclusion of inapplicable data points. Therefore, the more detail that can be acquired for the creation of a composite factor, the more likely that factor will be helpful in establishing an accurate estimate. In this instance, the CPFF contract displays statistical differences with Cost-Other contracts.

Scenario 2

The second scenario pared the dataset down to only prime contractor data for Army MDAPs in the electronic/automated software commodity type and examined development type, looking only at the SEPM WBS element. Figure 17 shows the descriptive statistics for this scenario, which contained a similar number of data points as the first scenario.



Quantiles

100%	maximum	1.345342466
75%	quartile	0.9319295673
50%	median	0.596985006
25%	quartile	0.3752669638
0%	minimum	0.093962336

Summary Statistics

Mean	0.6737858
Std Dev	0.345058
N	30

Figure 17. Scenario 2 Descriptive Statistics

The standard deviation as a percent of the mean for this sample was nearly 20% lower than the entire dataset for SEPM. The Kruskal-Wallis test still revealed the same results as the initial test in scenario 1 and the null hypothesis could not be rejected based on a lack of statistical differences between the three categories' median values. Figure 18 displays the number of values tested for each category of development type, as well as the resulting p-value for the test.

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count
Modification	5
New Design	21
Subsystem	4

1-Way Test, ChiSquare Approximation

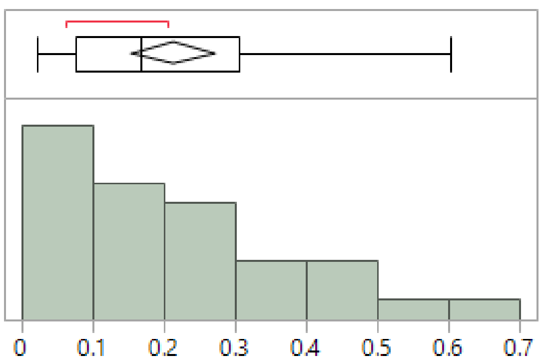
ChiSquare	DF	Prob>ChiSq
2.8684	2	0.2383

Figure 18. Scenario 2 Kruskal-Wallis Test

The null hypothesis for the Kruskal-Wallis test in this scenario could not be rejected based on the p-value of 0.2383 and the alpha value of 0.05. The small sample sizes for the modification and subsystem categories may have had an impact on the high p-value, but the takeaway from the analysis of this sample of data is that no statistical difference exists between development types.

Scenario 3

The third scenario looked at only Navy Aircraft MDAPs with cost type contracts and excluded new designs and commercial derivatives. The data was compared by development type for the ST&E WBS element. This scenario yielded the greatest amount of data compared to the first two scenarios with 31 factors for analysis. The descriptive statistics are displayed in Figure 19.



Quantiles

100%	maximum	0.602345042
75%	quartile	0.306232179
50%	median	0.166076413
25%	quartile	0.074293492
0%	minimum	0.021080446

Summary Statistics

Mean	0.2140754
Std Dev	0.1619641
N	31

Figure 19. Scenario 3 Descriptive Statistics

Despite the small sample of data in this scenario, this CV was higher than the entire dataset for ST&E's CV value. However, this large value did not affect the ability to reject the null hypothesis that median values were statistically different between development types. Figure 20 shows the p-value for the Kruskal-Wallis test, as well as the number of each development type in this sample of data. It also displays the resulting p-values and significant differences by commodity type, revealing that subsystems are the most statistically different.

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count
Modification	13
Subsystem	8
Variant	10

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
7.6110	2	0.0222*

Nonparametric Comparisons for Each Pair Using Wilcoxon Method

Alpha
0.05

Level	- Level	p-Value
Variant	Subsystem	0.0145*
Variant	Modification	0.3364
Subsystem	Modification	0.0326*

Figure 20. Scenario 3 Kruskal-Wallis & Steel-Dwass Tests

The analysis conducted in this scenario revealed statistical differences between development types, the most significant of which occurs between the new MDS designator and subsystem subcategories. The conclusion of this scenario highlights the fact that more details allow for analysis that accounts for the data which most closely represents the area of interest, rather than a broad dataset that may mask key differences.

Chapter Summary

This chapter detailed the statistical analysis conducted for this research and prepares the reader for the results to be discussed in chapter V. A brief overview of the dataset was provided to revisit the key points of data collection and methodology. Next, the descriptive statistics for each WBS element were presented, with additional statistics by commodity type, contract type, development type, contractor designation, and service provided in Appendix C. The results of two non-parametric tests were provided to examine statistical differences in median values, followed by a brief discussion of purpose specific analysis and the introduction of statistical versus practical analysis. Chapter V will address these results as they apply to the field of cost estimation and the use of these factors for future estimating purposes.

V. Conclusions

Chapter Overview

This chapter addresses the major conclusions drawn from the research and analysis conducted in the preceding four chapters. The findings for each research question are presented and then discussed in the context of relevance and significance to the cost analysis and acquisition community. The topics of limitations and future research are addressed in this chapter as well.

Research Questions Answered

Factor Development

The first two research questions address the creation of factors for each WBS element for two different types of development: New Design and Modification. Following the completion of data collection, four additional types of development were delineated to accomplish more detailed analysis. The six development types, as well as their accompanying factor values separated by WBS element are displayed in Table 25.

Table 25. Factors by Development Type

	Modification	New Design	Prototype	Subsystem	New MDS Designator	Commercial Derivative
SEPM	0.3484	0.4738	0.1906	0.373	0.3249	0.184
ST&E	0.2155	0.2143	0.2673	0.1744	0.2934	0.1804
Training	0.0245	0.0395	0.0029	0.0277	0.0543	0.0134
Data	0.0448	0.0297	0.006	0.0333	0.0441	0.024
PSE	0.0477	0.0573	0.0118	0.0485	0.0978	0.0039
CSE	0.0129	0.0148	0.0001	0.0378	0.0108	0.0018
Site Activation	0.0495	0.05	0.004	0.0046	0.0276	0.0001
Other	0.0874	0.0812	0.0328	0.0726	0.0459	0.2406
Spares	0.0222	0.0438	0.0279	0.0283	0.0504	0.0054

For each WBS element, two to three development types registered factor values that were similar enough to one another to fail to reject the null hypothesis that the median values for each group were equal. These development types require more informational qualifiers to determine whether statistical differences could exist at a lower level of analysis. The range of values across development types for each WBS element varies, but it is clear that some differences do exist. However, due to the large coefficient of variation (CV) values, differences do not always register when conducting statistical analysis. The delineation between statistical and practical analysis then becomes an important discussion for analysts to understand before constructing an estimate. The following section of this chapter will examine this topic in greater detail.

Results of Statistical Analysis

The final four research questions address the topic of statistical differences between the subcategories of five primary categories: commodity type, contract type, development type, contractor type, and service. For each of these research questions, a summary table displays the results of the statistical tests performed on the data of the respective categories. WBS elements with values greater than zero in the accompanying row displayed statistical differences between subcategories. The values displayed in the table represent the number of differences each subcategory registered based on the Steel-Dwass multiple comparison test.

Commodity Type

The differences revealed by the Kruskal-Wallis and Steel-Dwass tests are summarized in Table 26 by commodity type.

Table 26. Commodity Differences Summary

	Aircraft	Electronic/Automated Software	Missile	Ordnance	Space	UAV
SEPM	2	1	1	0	0	0
ST&E	2	1	1	0	3	1
Training	0	0	0	0	0	0
Data	0	0	0	0	0	0
PSE	0	0	0	0	0	0
CSE	0	0	0	0	0	0
Site Activation	1	1	0	0	0	0
Spares	0	0	0	0	0	0

The SEPM and ST&E WBS elements display the majority of differences, making the case that estimates in these areas be carefully constructed, especially given the high factor values that each represents with respect to PME.

Contract Type

The differences revealed by the Kruskal-Wallis and Steel-Dwass tests are summarized in Table 27 by contract type.

Table 27. Contract Type Differences Summary

	CPAF	CPFF	CPIF	Cost-Other	FFP	FPI	FPIF	Unknown
SEPM	2	2	0	1	2	3	0	0
ST&E	1	1	0	1	1	5	0	1
Training	0	0	0	0	0	0	0	0
Data	0	0	1	0	0	0	0	1
PSE	0	0	0	0	0	0	0	0
CSE	0	0	0	0	0	0	0	0
Site Activation	0	0	0	0	0	0	0	0
Spares	0	0	0	0	0	0	0	0

The concentration of differences in the SEPM and ST&E WBS elements provides compelling statistical justification for affording extra time and research for estimates in these areas. Furthermore, any MDAP expecting a FPI contract should place increased scrutiny on the programs that contribute to their factor calculation and what type of contracts were utilized.

Development Type

The differences revealed by the Kruskal-Wallis and Steel-Dwass tests are summarized in Table 28 by development type.

Table 28. Development Type Differences Summary

	Modification	New Design	Prototype	Subsystem	New MDS Designator	Commercial Derivative
SEPM	1	2	0	0	1	0
ST&E	0	0	0	1	1	0
Training	0	0	0	0	0	0
Data	0	0	1	0	1	0
PSE	1	0	0	0	1	0
CSE	0	0	0	0	0	0
Site Activation	0	0	0	0	0	0
Spares	1	1	0	0	0	0

The development type displayed few statistical differences when examining the entire dataset but was not devoid of differences entirely. This raises the question for analysts as to whether or not this trend would remain true when examining a more specific sample of data. Less than half of the WBS elements exhibited differences, which points to the conclusion that broad datasets can be utilized for estimates spanning multiple development types.

Contractor Type

The differences revealed by the Kruskal-Wallis and Steel-Dwass tests are summarized in Table 29 by contractor type.

Table 29. Contractor Type Differences Summary

	Prime	Subcontractor
SEPM	0	0
ST&E	1	1
Training	0	0
Data	0	0
PSE	1	1
CSE	0	0
Site Activation	0	0
Spares	0	0

Only the ST&E and PSE WBS elements displayed statistical differences, meaning estimates based on both prime and subcontractor data for the remaining WBS elements can encompass a large dataset and remain relatively accurate. For ST&E and PSE, analysts must separate the contractor type in order to avoid basing estimates on factor values that are statistically different.

Service

The differences revealed by the Kruskal-Wallis and Steel-Dwass tests are summarized in Table 30 by service.

Table 30. Service Differences Summary

	Air Force	Army	Navy	Multiple
SEPM	1	3	1	1
ST&E	1	1	1	3
Training	0	0	0	0
Data	0	0	0	0
PSE	0	0	0	0
CSE	0	0	0	0
Site Activation	0	0	0	0
Spares	0	0	0	0

MDAPs for the Army and for multiple services warrant more in-depth analysis with respect to factor-based estimates, as these areas displayed the highest concentration of statistical differences. The differences occurred in the SEPM and ST&E WBS elements across all Services.

Statistical differences between subcategories were identified only 34.38% of the time. To better understand why this value was relatively low, the descriptive statistics were examined for each category, as well as each WBS element. This revealed large standard deviation values and large CV values, pointing to the conclusion that each Major Defense Acquisition Program (MDAP) presents unique characteristics that must be explored and understood to make the inclusion of its data truly meaningful in the context of constructing a cost estimate. The practicality of achieving an in-depth understanding of each program utilized for a factor and analogy cost estimate is not realistic in most cases. Thus, the "preliminary" nature of many factor and analogy estimates. These generic composite factors represent a starting point for analysts in instances where MDAP characteristics may be unrefined (i.e. broad capability deliverable(s) with undefined processes). Given the fluid nature of estimates at this stage of developing requirements, a robust dataset remains appropriate. Once a program's requirements have been solidified and the manner in which they will be accomplished is well-defined, analysts can begin to refine their dataset to MDAPs with direct application to their program. The intent of this research is to make the dataset utilized for analysis available to DoD analysts to enable an approach to factor creation that can be tailored to the needs of the individual.

Statistical and practical analysis each provide a valuable approach to understanding the data utilized for an estimate. In the context of factor cost estimating, practical analysis offers the ability for estimators to examine a dataset and determine logically which data points to include or exclude. The practical analysis can be in addition to or in place of statistical analysis, depending on the situation. An analyst constructing an estimate for a new cargo aircraft engine for the Air Force may find no statistical difference between SEPM values for a dataset of 100 factors. However, if the analyst learns the program will likely award some type of fixed contract, the dataset can be refined to exclude inapplicable MDAP factors. The dataset becomes smaller but more precise and the potential for statistical differences between the smaller set of subcategories must be examined. The ability to establish both general and specific estimate values strengthens the defensibility of the estimate by displaying a range of values and explicit reasoning for the merits of each one.

Significance of Results

This research represents one of the largest Department of Defense (DoD) factor studies for MDAPs conducted to date. Previous efforts within the Air Force Lifecycle

Management Center (AFLCMC) (Blair, 1988, Wren, 1998, Otte, 2015) established factor values for specific purposes and System Program Offices (SPO), whereas this effort is intended for wider-access distribution accessible to analysts across the DoD to accomplish individualized analysis. The compilation of Engineering, Manufacturing, and Development (EMD) data contained in 443 separate Cost Data Summary Reports (CDSR) into a single location provides DoD analysts the ability to streamline estimate formulation while also increasing the breadth of data from which estimates are based. The descriptive statistics for each WBS element and accompanying summary tables provide analysts the ability to create an initial estimate almost instantaneously. With this estimate as a placeholder, the analyst can then incorporate statistical and/or practical analysis to arrive at a more accurate estimate. These steps can be performed as an iterative process as more details emerge, further refining the estimate.

As the iterative process of refining the dataset was carried out in the hypothetical scenarios discussed in chapter IV, it was evident that one characteristic to consider was that of the value of the coefficient of variation (CV). The CV can be defined in the context of cost estimating as “the ‘average’ percent estimating error when predicting subsequent observations within the representative population” (Mislick & Nussbaum, 2015). Table 31 shows the CV values for SEPM and ST&E for the entire dataset, as well as each of the hypothetical scenarios.

	SEPM	ST&E
All Data	71.86	86.07
Scenario 1	75.75	-
Scenario 1a	69.70	-
Scenario 2	51.21	-
Scenario 3	-	71.63

Table 31. CV Summary

The improvement in CV value that occurs when the data is refined is best illustrated by scenario 1a and scenario two. The differences for these hypothetical scenarios span a range of 3.9% higher to 28.8% lower than the entire dataset CV values, making the CV a characteristic to examine but not rely on as a sole indicator of accuracy.

Limitations

The primary limitations in this research are based on the data source for CDSRs. The Cost Assessment Data Enterprise (CADE) system was utilized for all data collection which presented several challenges. While the purposeful exclusion of the Ship, Surface Vehicle, and System of System commodity groups reduced the potential number of programs from 189 to 154, the unavailability of EMD data eliminated another 25 MDAPs from the dataset. These 25 MDAPs contained Production and/or Sustainment data, which was also excluded from this research. Another 27 MDAPs were primarily older programs with manually transcribed data from the 1980's or earlier and in many instances contained illegible data. These exclusions resulted in a total of 87 programs not examined or analyzed. The legacy Contractor Cost Data Report (CCDR) library contains an additional 247 programs that were not included in this research. These files represent programs initiated primarily in the 1970s and 1980s, and as a result the CCDRs are not in .XLS format. The CADE system contains only Acquisition Category I (ACAT) programs, therefore ACAT II and III programs were also excluded from this effort. An additional limitation of this research lies in the compilation of subcontractor costs by prime contractors. Often times the entirety of the subcontractor's (or multiple subcontractors') costs are included in the Prime Mission Equipment (PME) costs of the prime contractor. This results in lower factor values for prime contractors for each WBS element than if the subcontractor costs were broken out by WBS element throughout the entire reporting process.

Future Research

The ability to expand upon this research is vast. The inclusion of the Ship, Surface Vehicle, and System of Systems commodity types, as well as non-.XLS CDSR files represents a potential addition to this EMD factor effort. The establishment of Production factors could be accomplished utilizing the same methodology as this research. Also, non-MDAP Science and Technology (S&T) program factors could be created to better serve cost analysts supporting efforts not contained within a SPO. The approach to this type of factor development would hinge upon cost data reporting requirements and availability of data.

Summary

This research utilized available data from the CADE system to centralize CDSRs for 102 MDAPs and create 443 unique factor values across numerous commodity types, development types, contract types, and services for each WBS element. The factor approach to cost estimating hinges upon the availability of meaningful data, and the centralization of over 50 years of MDAP data allows cost estimators in the DoD to efficiently access and refine a broad dataset to create estimates for their respective programs. Furthermore, the dataset provides a starting point to perform the iterative process of refining the data and applying statistical and/or practical analysis to arrive at a defensible estimate. The importance of efficient and effective cost estimating in the acquisition workforce within the DoD is evident based on budgetary restrictions, political climate, and many other factors. Thus, the importance of this research lies in the analyst's ability to expand their estimating toolset by quickly and efficiently accessing a compilation of hundreds of relevant data points that previously existed in hundreds of distinct locations.

Appendix A – List of Programs

Aircraft
A-6A Full Scale Development
A-6E Full Scale Development
AH-64E Apache (Formerly AB3)
ARH - Armed Reconnaissance Helicopter
B-1 CMUP - B-1 LANCER Penetrating Bomber Conventional Mission Upgrade Program
B-1B Integrated Battle Station (IBS)
B-2 DMS: Defensive Management System
B-2 EHF SATCOM AND COMPUTER INCREMENT I – B-2 Advanced Extremely High Frequency SatCom Capability
B-2 RMP - B-2 Radar Modernization Program
B-52 Combat Network Communications Technology (CONECT)
B-58A Full Scale Development
BLACK HAWK UPGRADE (UH-60M) - Utility Helicopter Upgrade Program
C-130 AMP - C-130 Aircraft Avionics Modernization Program
C-130J - HERCULES Cargo Aircraft Program
C-17A - GLOBEMASTER III Advanced Cargo Aircraft Program
C-5 AMP - C-5 Aircraft Avionics Modernization Program
C-5 RERP - C-5 Aircraft Reliability Enhancement and Re-engining Program
CH-47F - Cargo Helicopter. CH-47D Helicopter Upgrade Program
CH-53K - Heavy Lift Replacement Program
Comanche - Reconnaissance Attack Helicopter (RAH-66)
CRH - Combat Rescue Helicopter
E-10 – Multi-Sensor Command and Control Aircraft Program
E-2D AHE - E-2D Advanced Hawkeye
F/A-18E/F - SUPER HORNET Naval Strike Fighter
F-22 - RAPTOR Advanced Tactical Fighter
F-22A Increment 3.2B
F-117A Full Scale Development
F-35 - Lightning II Joint Strike Fighter (JSF) Program
H-1 UPGRADES (4BW/4BN) - United States Marine Corps Mid-life Upgrade to AH-1W Attack Helicopter and UH-1N Utility Helicopter
JSTARS - Joint Surveillance Target Attack Radar System
KC-135A Full Scale Development
MH-60R - Multi-Mission Helicopter Upgrade
MH-60S - Multi-Mission Combat Support Helicopter
P-8A - Poseidon Program

RQ-4A/B Full Scale Development
V-22 - OSPREY Joint Advanced Vertical Lift Aircraft
VH 71 - Presidential Helicopter Fleet Replacement Program
VH-92A Presidential Helicopter
YA-10 Development
Electronic/Automated Software
3DELRR - Three-Dimensional Expeditionary Long-Range Radar
ADS (AN/WQR-3) – Advanced Deployable System
AMDR - Air & Missile Defense Radar
AMF JTRS – Joint Tactical Radio System Airborne & Maritime/Fixed Station
AOC-WS – Air and Space Operations Center-Weapon System
CAC2S - Common Aviation Command and Control System
CANES - Consolidated Afloat Network Enterprise Services
CEC – Cooperative Engagement Capability
CIRCM - Common Infrared Countermeasures
DCGS ARMY - Distributed Common Ground System Army
F-15 EPAWSS - Eagle Passive Active Warning Survivability System
FAB-T – Family of Beyond Line-of-Sight Terminals
FBCB2 - Force XXI Battle Command Brigade and Below Program
G/ATOR - Ground/Air Task Oriented Radar
GCSS ARMY - Global Combat Support System Army
GSE - Ground Soldier Ensemble
IAMD - Integrated Air & Missile Defense
ITEP - Improved Turbine Engine Program
JATAS (Joint and Allied Threat Awareness System)
JLENS – Joint Land Attack Cruise Missile Defense Elevated Netted Sensor System
JPALS - Joint Precision Approach and Landing System
JTRS GMR – Joint Tactical Radio System Ground Mobile Radio
JTRS NED - Joint Tactical Radio System Network Enterprise Domain
Land Warrior - Integrated soldier fighting system for the Infantryman
LMP - Logistics Modernization Program
MIDS – Multi-Functional Information Distribution System (Includes Low Volume Terminal and JTRS)
MP RTIP - Multi-Platform Radar Technology Insertion Program
MPS – Mission Planning System
NGJ - Next Generation Jammer
NMT - Navy Multiband Terminal
Space Fence Inc 1 - Space Fence Ground-Based Radar System Increment 1

WIN-T – Warfighter Information Network-Tactical
Missile
Advanced Precision Kill Weapon System (APKWS)
AGM-88E AARGM - AGM-88E Advanced Anti-Radiation Guided Missile (AARGM) Program
AIM-9X - Air-to-Air Missile Upgrade
GMLRS/GMLRS AW - Guided Multiple Launch Rocket System/Guided Multiple Launch Rocket System Alternative Warhead
ICBM - Fuze Modernization Program
JAGM – Joint Air-to-Ground Missile
JASSM (JASSM/JASSM-ER) – Joint Air-to-Surface Standoff Missile
JCM - AGM-169 Joint Common Missile
Offensive Anti-Surface Warfare Increment 1 (Long Range Anti-Ship Missile)
Patriot PAC-3 - Patriot Advanced Capability 3
SM-6 – Standard Missile-6
Ordnance
B61 Mod 12 Life Extension Program Tailkit Assembly
ERM - Extended Range Munition
EXCALIBUR - Family of Precision, 155mm Projectiles
SDB I – Small Diameter Bomb Increment I
SDB II – Small Diameter Bomb, Increment II
Space
AEHF – Advanced Extremely High Frequency (AEHF) Satellite Program
EPS - Enhanced Polar System
GPS OCX – Global Positioning Satellite Next Generation Control Segment
GPS-IIIA – Global Positioning Satellite III
MUOS – Mobile User Objective System
NAVSTAR GPS – Global Positioning System
NPOESS - National Polar-Orbiting Operational Environmental Satellite System
SBIRS HIGH - Space-Based Infrared System Program, High Component
TSAT – Transformational Satellite Communications System
UAV
GLOBAL HAWK (RQ-4A/B) - High Altitude Endurance Unmanned Aircraft System
MQ-1C Gray Eagle
MQ-4C Triton (Formerly BAMS)
NAVY UCAS – Navy Unmanned Combat Air System
REAPER (MQ-9 UAS) - Unmanned Aircraft System
VTUAV - Vertical Takeoff and Land Tactical Unmanned Air Vehicle (Fire Scout)

Appendix B – Sample DD Form 1921

COST DATA SUMMARY REPORT

Form Approved OMB No. 0704-0188

The public reporting burden for this collection of information is estimated to average 8 hours per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Executive Services Directorate (0704-0188). Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.
PLEASE DO NOT RETURN YOUR COMPLETED FORM TO THE ABOVE ORGANIZATION.

1. PROGRAM
a. MDAP:
b. PHASE:

2. PRIME MISSION PRODUCT

3. CONTRACTOR TYPE (X one)
[ ] PRIME / ASSOCIATE
[X] DIRECT-REPORTING SUBCONTRACTOR

4. NAME/ADDRESS (Include ZIP Code)

5. APPROVED PLAN NUMBER

6. CUSTOMER (DIRECT-REPORTING SUBCONTRACTOR USE ONLY)

7. CONTRACT TYPE: FFP

8. CONTRACT PRICE: $33,599.5

9. CONTRACT CEILING: $33,599.5

10. TYPE ACTION
a. CONTRACT NO.:
b. LATEST MODIFICATION:
c. SOLICITATION NO.: N/A
d. NAME: N/A

11. PERIOD OF PERFORMANCE
a. START DATE *(YYYYMMDD)*:
b. END DATE *(YYYYMMDD)*:

12. APPROPRIATION
[X] RDT&E
[ ] PROCUREMENT
[ ] O&M

13. REPORT CYCLE
[ ] INITIAL
[ ] INTERIM
[X] FINAL

14. SUBMISSION NUMBER: 6

15. RESUBMISSION NUMBER: 0

16. REPORT AS OF *(YYYYMMDD)*: 20110403

17. NAME (Last, First, Middle Initial)

18. DEPARTMENT: Project Planning & Analysis

19. TELEPHONE NUMBER (Include Area Code)

20. EMAIL ADDRESS

21. DATE PREPARED *(YYYYMMDD)*: 20110525

WBS ELEMENT CODE	WBS REPORTING ELEMENTS	NUMBER OF UNITS TO DATE	COSTS INCURRED TO DATE			NUMBER OF UNITS AT COMPLETION	COSTS INCURRED AT COMPLETION		
			NONRECURRING	RECURRING	TOTAL		NONRECURRING	RECURRING	TOTAL
A	B	C	D	E	F	G	H	I	J
1	Electronic/Automated Software System	0.0	$47,522.2	$0.0	$47,522.2	0.0	$47,522.2	$0.0	$47,522.2
1.1	Prime Mission Product (PMP)	0.0	$34,963.8	$0.0	$34,963.8	0.0	$34,963.8	$0.0	$34,963.8
1.1.1	Flight Management System	0.0	$21,511.2	$0.0	$21,511.2	0.0	$21,511.2	$0.0	$21,511.2
1.1.2	PMP Applications Software	0.0	$0.0	$0.0	$0.0	0.0	$0.0	$0.0	$0.0
1.1.3	PMP System Software	0.0	$7,535.0	$0.0	$7,535.0	0.0	$7,535.0	$0.0	$7,535.0
1.1.4	Integration, Assembly, Test and Checkout	0.0	$5,917.6	$0.0	$5,917.6	0.0	$5,917.6	$0.0	$5,917.6
1.2	Platform Integration	0.0	$0.0	$0.0	$0.0	0.0	$0.0	$0.0	$0.0
1.3	System Engineering/Program Management	0.0	$7,876.8	$0.0	$7,876.8	0.0	$7,876.8	$0.0	$7,876.8
1.3.1	System Engineering	0.0	$5,046.5	$0.0	$5,046.5	0.0	$5,046.5	$0.0	$5,046.5
1.3.2	Program Management	0.0	$2,830.3	$0.0	$2,830.3	0.0	$2,830.3	$0.0	$2,830.3
1.4	System Test and Evaluation	0.0	$3,686.1	$0.0	$3,686.1	0.0	$3,686.1	$0.0	$3,686.1
1.4.1	Development Test and Evaluation	0.0	$1,201.5	$0.0	$1,201.5	0.0	$1,201.5	$0.0	$1,201.5
1.4.2	Operational Test and Evaluation	0.0	$0.0	$0.0	$0.0	0.0	$0.0	$0.0	$0.0
1.4.3	Mock-ups / System Integration Labs (SILs)	0.0	$1,699.5	$0.0	$1,699.5	0.0	$1,699.5	$0.0	$1,699.5
1.4.4	Test and Evaluation Support	0.0	$785.1	$0.0	$785.1	0.0	$785.1	$0.0	$785.1
1.4.5	Test Facilities	0.0	$0.0	$0.0	$0.0	0.0	$0.0	$0.0	$0.0
1.5	Training	0.0	$0.0	$0.0	$0.0	0.0	$0.0	$0.0	$0.0
1.5.1	Equipment	0.0	$0.0	$0.0	$0.0	0.0	$0.0	$0.0	$0.0
1.5.2	Services	0.0	$0.0	$0.0	$0.0	0.0	$0.0	$0.0	$0.0
1.5.3	Facilities	0.0	$0.0	$0.0	$0.0	0.0	$0.0	$0.0	$0.0
1.6	Data	0.0	$995.5	$0.0	$995.5	0.0	$995.5	$0.0	$995.5
1.6.1	Technical Publications	0.0	$995.5	$0.0	$995.5	0.0	$995.5	$0.0	$995.5
1.6.2	Engineering Data	0.0	$0.0	$0.0	$0.0	0.0	$0.0	$0.0	$0.0
1.6.3	Management Data	0.0	$0.0	$0.0	$0.0	0.0	$0.0	$0.0	$0.0
1.6.4	Support Data	0.0	$0.0	$0.0	$0.0	0.0	$0.0	$0.0	$0.0
1.6.5	Data Depository	0.0	$0.0	$0.0	$0.0	0.0	$0.0	$0.0	$0.0
1.7	Peculiar Support Equipment	0.0	$0.0	$0.0	$0.0	0.0	$0.0	$0.0	$0.0
1.7.1	Test and Measurement Equipment	0.0	$0.0	$0.0	$0.0	0.0	$0.0	$0.0	$0.0
1.7.2	Support and Handling Equipment	0.0	$0.0	$0.0	$0.0	0.0	$0.0	$0.0	$0.0
1.8	Common Support Equipment	0.0	$0.0	$0.0	$0.0	0.0	$0.0	$0.0	$0.0
1.8.1	Test and Measurement Equipment	0.0	$0.0	$0.0	$0.0	0.0	$0.0	$0.0	$0.0
1.8.2	Support and Handling Equipment	0.0	$0.0	$0.0	$0.0	0.0	$0.0	$0.0	$0.0
1.9	Operational/Site Activation	0.0	$0.0	$0.0	$0.0	0.0	$0.0	$0.0	$0.0
1.9.1	System Assembly, Installation and Checkout on Site	0.0	$0.0	$0.0	$0.0	0.0	$0.0	$0.0	$0.0
1.9.2	Contractor Technical Support	0.0	$0.0	$0.0	$0.0	0.0	$0.0	$0.0	$0.0
1.9.3	Site Construction	0.0	$0.0	$0.0	$0.0	0.0	$0.0	$0.0	$0.0
1.9.4	Site/Ship/Vehicle Conversion	0.0	$0.0	$0.0	$0.0	0.0	$0.0	$0.0	$0.0
1.10	Industrial Facilities	0.0	$0.0	$0.0	$0.0	0.0	$0.0	$0.0	$0.0
1.10.1	Construction/Conversion/Expansion	0.0	$0.0	$0.0	$0.0	0.0	$0.0	$0.0	$0.0
1.10.2	Equipment Acquisition or Modernization	0.0	$0.0	$0.0	$0.0	0.0	$0.0	$0.0	$0.0
1.10.3	Maintenance (Industrial Facilities)	0.0	$0.0	$0.0	$0.0	0.0	$0.0	$0.0	$0.0
1.11	Initial Spares and Repair Parts	0.0	$0.0	$0.0	$0.0	0.0	$0.0	$0.0	$0.0
	Subtotal Cost				$47,522.2				$47,522.2
	Reporting Contractor G&A				$6,320.5				$6,320.5
	Reporting Contractor Undistributed Budget								$0.0
	Reporting Contractor Management Reserve								$0.0
	Reporting Contractor FCCM				$190.1				$190.1
	Total Cost				$54,032.8				$54,032.8
	Reporting Contractor Profit/Loss or Fee				-$20,433.3				-$20,433.3
	Total Price				$33,599.5				$33,599.5

22. REMARKS

DD FORM 1921, 20070416 PREVIOUS EDITION IS OBSOLETE. SECURITY CLASSIFICATION **Unclassified**

Appendix C – Descriptive Statistics by WBS Element

SEPM Summary Table								
	Mean	Std Dev	N	Max	75%	Median	25%	Min
Service								
Air Force	0.3685	0.2755	177	1.324	0.4894	0.2972	0.159	0.0043
Army	0.508	0.3372	91	1.3453	0.6989	0.4426	0.2514	0.0098
Navy	0.3393	0.3039	115	1.4655	0.465	0.2551	0.1421	0.0105
Multiple	0.3142	0.2053	23	1.0007	0.4047	0.2699	0.1626	0.0903
Development Type								
Modification	0.3484	0.2555	124	1.3191	0.4954	0.2845	0.1539	0.0043
New Design	0.4738	0.3472	131	1.4655	0.6582	0.3759	0.219	0.0053
Prototype	0.1906	0.1472	8	0.39	0.3417	0.1783	0.0627	0.0126
Subsystem	0.373	0.2816	101	1.324	0.5343	0.2793	0.161	0.0105
New MDS Designator	0.3249	0.2924	39	1.3619	0.3887	0.2517	0.1154	0.0445
Commercial Derivative	0.184	0.1011	3	0.2676	0.2676	0.2128	0.0716	0.0716
Contractor Type								
Prime	0.3849	0.3068	284	1.3619	0.4896	0.2947	0.1609	0.012
Subcontractor	0.3966	0.2898	122	1.4655	0.5613	0.3336	0.1724	0.0043
Commodity Type								
Aircraft	0.3025	0.2385	227	1.3619	0.4115	0.2292	0.1421	0.0105
Electronic/Automated Software	0.5463	0.3511	107	1.4655	0.7816	0.4875	0.2568	0.0098
Missile	0.5014	0.3297	20	1.2822	0.7695	0.3897	0.2682	0.0576
Ordnance	0.3426	0.1737	11	0.6117	0.5007	0.285	0.2439	0.0811
Space	0.3825	0.3093	31	1.3191	0.4972	0.3109	0.1488	0.0043
UAV	0.4913	0.3217	10	1.324	0.5435	0.3655	0.303	0.2617
Contract Type								
CPAF	0.4128	0.2641	66	1.2792	0.5792	0.3649	0.2206	0.0337
CPFF	0.5189	0.3896	37	1.3453	0.7022	0.4233	0.2387	0.0053
CPIF	0.3905	0.2987	61	1.2924	0.522	0.2729	0.18	0.0276
Cost-Other	0.4082	0.3103	126	1.4655	0.5874	0.3175	0.1767	0.0043
FFP	0.2457	0.2531	25	1.0786	0.3494	0.156	0.0871	0.0105
FPI	0.2118	0.2232	17	1.0081	0.2349	0.1694	0.0729	0.0484
FPIF	0.4203	0.2811	19	1.2822	0.5578	0.3931	0.2218	0.0675
Fixed-Other	0.572	0.2327	4	0.8384	0.8026	0.5427	0.3707	0.3643
Unknown	0.3131	0.2573	51	1.3144	0.4426	0.243	0.1275	0.0385

ST&E Summary Table								
	Mean	**Std Dev**	**N**	**Max**	**75%**	**Median**	**25%**	**Min**
Service								
Air Force	0.2251	0.2074	166	0.9641	0.328	0.1672	0.0668	0.0013
Army	0.2157	0.1915	80	1.0575	0.2784	0.1992	0.0793	0.0012
Navy	0.2201	0.215	105	1.0776	0.3083	0.1582	0.0697	0.0032
Multiple	0.1059	0.1027	23	0.3312	0.1821	0.0642	0.0207	0.0021
Development Type								
Modification	0.2155	0.2193	119	1.0776	0.2986	0.1396	0.0623	0.0013
New Design	0.2143	0.188	114	1.0575	0.304	0.1817	0.0611	0.0016
Prototype	0.2673	0.1028	9	0.4561	0.325	0.282	0.1792	0.1177
Subsystem	0.1744	0.1883	89	0.8523	0.2378	0.1038	0.0428	0.0012
New MDS Designator	0.2934	0.2281	39	0.9436	0.4288	0.2456	0.0987	0.0083
Commercial Derivative	0.1804	0.1432	4	0.3659	0.328	0.1585	0.0548	0.0388
Contractor Type								
Prime	0.2294	0.2019	274	1.0776	0.3089	0.1838	0.0754	0.0012
Subcontractor	0.1733	0.2001	100	1.0575	0.2396	0.0999	0.0305	0.0016
Commodity Type								
Aircraft	0.2498	0.2139	225	1.0776	0.3515	0.2036	0.021	0.0013
Electronic/Automated Software	0.1702	0.1924	88	1.0575	0.2199	0.1038	0.0348	0.0012
Missile	0.2041	0.1772	18	0.7363	0.2615	0.1842	0.0619	0.0243
Ordnance	0.1513	0.0998	11	0.3389	0.2468	0.0961	0.0704	0.0596
Space	0.0778	0.0879	23	0.3797	0.1157	0.0448	0.021	0.003
UAV	0.2068	0.1273	9	0.3924	0.3266	0.1893	0.0887	0.0444
Contract Type								
CPAF	0.1802	0.1964	63	1.0575	0.2761	0.1072	0.038	0.0025
CPFF	0.1671	0.2095	31	0.8523	0.2213	0.0791	0.0253	0.0016
CPIF	0.2586	0.22	55	1.0677	0.3796	0.1997	0.0829	0.0021
Cost-Other	0.1824	0.1748	113	0.9641	0.2618	0.1277	0.0474	0.0012
FFP	0.1777	0.1503	20	0.4561	0.3426	0.13	0.0588	0.0118
FPI	0.3907	0.1991	20	0.9436	0.5222	0.3267	0.2803	0.1276
FPIF	0.2876	0.2168	17	0.7307	0.3371	0.2167	0.1233	0.0226
Fixed-Other	0.2714	0.2483	4	0.6104	0.5283	0.2227	0.0632	0.0298
Unknown	0.2248	0.2163	51	1.0776	0.2416	0.1608	0.0968	0.0044

Training Summary Table								
	Mean	**Std Dev**	**N**	**Max**	**75%**	**Median**	**25%**	**Min**
Service								
Air Force	0.0319	0.0643	95	0.3849	0.0297	0.0093	0.0034	0.0006
Army	0.0398	0.0673	45	0.5237	0.0482	0.0148	0.004	0.0006
Navy	0.0329	0.0653	50	0.3837	0.0274	0.0071	0.0021	0.0006
Multiple	0.0482	0.0647	2	0.094	0.094	0.0482	0.0024	0.0024
Development Type								
Modification	0.0245	0.0406	64	0.1746	0.028	0.0051	0.0026	0.0006
New Design	0.0395	0.0772	76	0.4237	0.0384	0.0166	0.0038	0.0008
Prototype	0.0029	0.0019	2	0.0042	0.0042	0.0029	0.0015	0.0015
Subsystem	0.0277	0.0475	23	0.2214	0.0376	0.0063	0.0021	0.0006
New MDS Designator	0.0543	0.0886	24	0.3837	0.0897	0.0166	0.0023	0.0006
Commercial Derivative	0.0134	0.0118	3	0.0253	0.0253	0.0133	0.0016	0.0016
Contractor Type								
Prime	0.0344	0.0674	163	4237	0.0318	0.01	0.0031	0.0006
Subcontractor	0.0329	0.0486	29	0.2214	0.0471	0.0109	0.0031	0.0006
Commodity Type								
Aircraft	0.0307	0.0544	111	0.3837	0.0298	0.0055	0.0022	0.0006
Electronic/Automated Software	0.0527	0.0922	53	0.4237	0.0503	0.0254	0.005	0.0006
Missile	0.0117	0.0122	7	0.0388	0.0109	0.0079	0.0042	0.0032
Ordnance	0.0081	0.0039	6	0.0148	0.0121	0.0062	0.0051	0.0051
Space	0.0142	0.0119	9	0.0344	0.0233	0.0146	0.0029	0.001
UAV	0.0176	0.018	6	0.0486	0.0335	0.0123	0.0019	0.0015
Contract Type								
CPAF	0.0468	0.0785	30	0.3849	0.0515	0.0275	0.004	0.0006
CPFF	0.0491	0.0981	18	0.4237	0.049	0.0167	0.0039	0.0013
CPIF	0.0371	0.0736	27	0.3532	0.0396	0.0079	0.0028	0.0006
Cost-Other	0.0313	0.0608	59	0.3837	0.0285	0.0065	0.0023	0.0006
FFP	0.0526	0.064	8	0.1594	0.1171	0.0178	0.002	0.0008
FPI	0.0142	0.0124	15	0.0424	0.0244	0.0159	0.0022	0.0006
FPIF	0.0266	0.0554	13	0.2086	0.0155	0.0102	0.005	0.0034
Fixed-Other	0.0016	-	1	0.0016	0.0016	0.0016	0.0016	0.0016
Unknown	0.021	0.0271	21	0.0962	0.0354	0.0047	0.0017	0.0006

Data Summary Table								
	Mean	**Std Dev**	**N**	**Max**	**75%**	**Median**	**25%**	**Min**
Service								
Air Force	0.0385	0.0608	126	0.3935	0.0404	0.0217	0.0097	<0.0001
Army	0.0405	0.0646	50	0.3191	0.0514	0.018	0.0048	0.0001
Navy	0.0319	0.0473	85	0.254	0.0342	0.0148	0.0063	0.0003
Multiple	0.0194	0.0103	6	0.0322	0.0282	0.0189	0.0137	0.002
Development Type								
Modification	0.0448	0.0664	84	0.3365	0.0479	0.0243	0.0079	<0.0001
New Design	0.0297	0.0457	85	0.3022	0.0364	0.0134	0.0074	0.0001
Prototype	0.006	0.0065	6	0.0154	0.013	0.0042	0.0003	<0.0001
Subsystem	0.0333	0.0616	54	0.3935	0.03381	0.018	0.0044	<0.0001
New MDS Designator	0.0441	0.0543	34	0.254	0.0527	0.0269	0.0126	0.0016
Commercial Derivative	0.024	0.0187	4	0.0522	0.0431	0.0152	0.0139	0.0137
Contractor Type								
Prime	0.0384	0.0572	206	0.3365	0.0442	0.0205	0.0085	<0.0001
Subcontractor	0.0296	0.0555	61	0.3935	0.031	0.0175	0.0056	0.0001
Commodity Type								
Aircraft	0.0355	0.0498	174	0.3365	0.04	0.0206	0.0083	<0.0001
Electronic/Automated Software	0.0407	0.0736	59	0.3935	0.0306	0.0164	0.0077	<0.0001
Missile	0.0418	0.0861	12	0.3022	0.0212	0.0107	0.0069	0.0007
Ordnance	0.01	0.0109	4	0.0256	0.0212	0.0071	0.0017	0.0003
Space	0.024	0.0291	10	0.076	0.0564	0.0076	0.0031	<0.0001
UAV	0.0449	0.0534	8	0.1642	0.0667	0.028	0.0126	<0.0001
Contract Type								
CPAF	0.0376	0.0635	39	0.3935	0.0403	0.0217	0.0095	0.0003
CPFF	0.0362	0.0401	19	0.1389	0.0529	0.0246	0.0015	<0.0001
CPIF	0.0243	0.0409	43	0.2338	0.0269	0.0092	0.0032	<0.0001
Cost-Other	0.0351	0.0571	74	0.3348	0.032	0.0206	0.0065	<0.0001
FFP	0.0262	0.0396	18	0.1482	0.0274	0.0133	0.0032	<0.0001
FPI	0.0358	0.0251	19	0.0964	0.0598	0.0333	0.0134	0.0067
FPIF	0.0691	0.1041	16	0.3365	0.09	0.0167	0.008	0.0007
Fixed-Other	0.006	0.004	4	0.0113	0.0102	0.0049	0.0028	0.0027
Unknown	0.0468	0.0631	35	0.3191	0.0458	0.0294	0.0121	0.0024

PSE Summary Table								
	Mean	Std Dev	N	Max	75%	Median	25%	Min
Service								
Air Force	0.0646	0.0922	79	0.44	0.0775	0.0282	0.0112	0.0003
Army	0.0399	0.0626	28	0.2929	0.0535	0.0115	0.0071	0.0023
Navy	0.0592	0.0917	40	0.3846	0.0636	0.0177	0.0057	0.0001
Multiple	0.0593	0.0565	2	0.0993	0.0993	0.0593	0.0194	0.0194
Development Type								
Modification	0.0477	0.088	60	0.44	0.0465	0.0177	0.0035	0.0001
New Design	0.0573	0.077	46	0.3054	0.0626	0.0286	0.0084	0.0001
Prototype	0.0118	0.0049	3	0.0175	0.0175	0.009	0.0088	0.0088
Subsystem	0.0485	0.0609	13	0.1836	0.1025	0.0194	0.0047	0.0005
New MDS Designator	0.0978	0.107	26	0.3846	0.1906	0.0481	0.0167	0.0026
Commercial Derivative	0.0039	-	1	0.0039	0.0039	0.0039	0.0039	0.0039
Contractor Type								
Prime	0.0497	0.0778	120	0.3846	0.0513	0.0186	0.007	0.0001
Subcontractor	0.0945	0.111	29	0.44	0.1502	0.0545	0.0134	0.0006
Commodity Type								
Aircraft	0.0549	0.0789	98	0.3846	0.0618	0.0216	0.0076	0.0001
Electronic/Automated Software	0.0468	0.0565	12	0.1644	0.0948	0.0094	0.0038	0.0004
Missile	0.0716	0.0993	11	0.2929	0.1707	0.0085	0.007	0.0001
Ordnance	0.0235	0.0193	9	0.0624	0.0373	0.0182	0.0081	0.0023
Space	0.1247	0.1673	11	0.44	0.3195	0.0477	0.0079	0.0003
UAV	0.0496	0.0632	8	0.1934	0.0693	0.0213	0.0094	0.0063
Contract Type								
CPAF	0.054	0.0637	14	0.1934	0.069	0.0347	0.0111	0.0006
CPFF	0.0203	0.0279	13	0.0973	0.0265	0.0092	0.0009	0.0003
CPIF	0.0398	0.0542	28	0.2351	0.0412	0.0214	0.0065	0.0001
Cost-Other	0.0699	0.1099	44	0.44	0.0636	0.0186	0.0094	0.0004
FFP	0.0238	0.0249	11	0.0775	0.0414	0.0175	0.0026	0.0006
FPI	0.1098	0.1167	14	0.3846	0.1906	0.0619	0.0199	0.0018
FPIF	0.0338	0.0686	9	0.2133	0.0341	0.0042	0.0034	0.0004
Fixed-Other	0.0041	-	1	0.0041	0.0041	0.0041	0.0041	0.0041
Unknown	0.0929	0.0925	15	0.3221	0.1686	0.0798	0.0194	0.0001

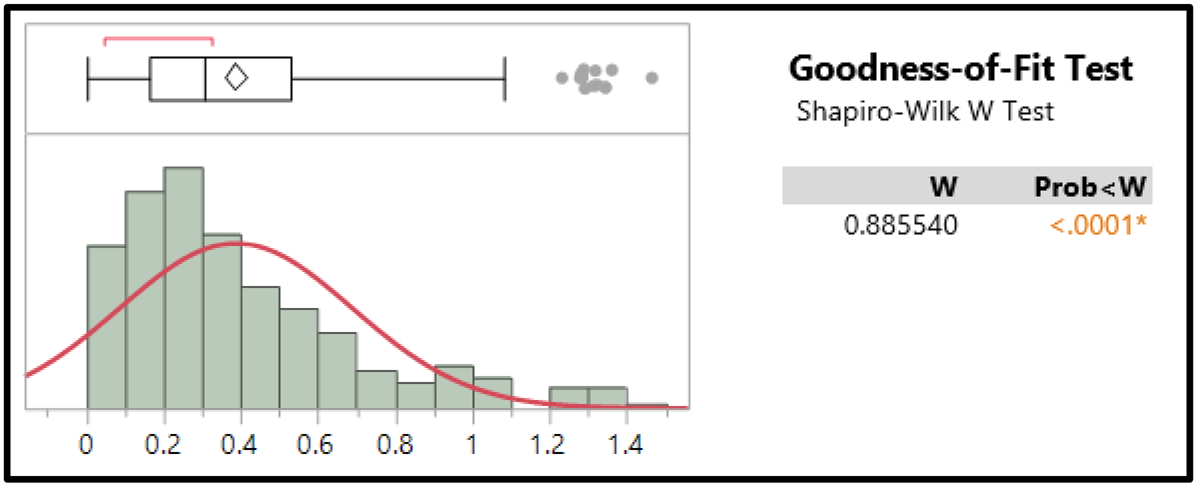
CSE Summary Table								
	Mean	**Std Dev**	**N**	**Max**	**75%**	**Median**	**25%**	**Min**
Service								
Air Force	0.0136	0.0313	22	0.1272	0.0043	0.0014	0.0008	<0.0001
Army	0.0211	0.0331	14	0.1237	0.0317	0.0088	0.0009	<0.0001
Navy	0.01186	0.0224	13	0.0767	0.0096	0.0011	0.0006	0.0002
Multiple	0.0063	-	1	0.0063	0.0063	0.0063	0.0063	0.0063
Development Type								
Modification	0.0129	0.0319	19	0.1272	0.0049	0.0013	0.0008	<0.0001
New Design	0.0148	0.0206	18	0.0767	0.0218	0.0067	0.0013	<0.0001
Prototype	0.0001	0.0001	2	0.0002	0.0002	0.0001	0.0001	0.0001
Subsystem	0.0378	0.0537	5	0.1237	0.0908	0.0063	0.0006	0.0006
New MDS Designator	0.0108	0.0171	5	0.0411	0.0242	0.0038	0.0008	0.0006
Commercial Derivative	0.0018	-	1	0.0018	0.0018	0.0018	0.0018	0.0018
Contractor Type								
Prime	0.0133	0.0268	41	0.1272	0.0082	0.0015	0.0006	<0.0001
Subcontractor	0.0235	0.039	9	0.1237	0.0259	0.0095	0.0008	0.0005
Commodity Type								
Aircraft	0.0125	0.0309	31	0.1272	0.0081	0.0018	0.0008	<0.0001
Electronic/Automated Software	0.0149	0.028	7	0.0767	0.0186	0.0015	0.0006	<0.0001
Missile	0.0218	0.0212	6	0.0486	0.0429	0.0202	0.0005	0.0004
Ordnance	0.0353	0.0493	2	0.0702	0.0702	0.0353	0.0004	0.0004
Space	0.0013	-	1	0.0013	0.0013	0.0013	0.0013	0.0013
UAV	0.0209	0.0327	3	0.0578	0.0578	0.0021	0.0002	0.0002
Contract Type								
CPAF	0.0069	0.0103	10	0.0332	0.0089	0.0024	0.0009	0.0005
CPFF	0.0365	0.0301	2	0.0578	0.0578	0.0365	0.0152	0.0152
CPIF	0.0215	0.0404	9	0.1237	0.0253	0.0081	0.0005	<0.0001
Cost-Other	0.0103	0.0193	14	0.0702	0.0102	0.0017	0.0008	<0.0001
FFP	0.0004	0.0002	3	0.0006	0.0006	0.0006	0.0001	0.0001
FPI	0.0028	-	1	0.0028	0.0028	0.0028	0.0028	0.0028
FPIF	0.029	0.0459	9	0.1272	0.0627	0.0018	0.0005	0.0004
Fixed-Other	-	-	-	-	-	-	-	-
Unknown	0.0057	0.0064	2	0.0102	0.0102	0.0057	0.0011	0.0011

Site Activation Summary Table								
	Mean	Std Dev	N	Max	75%	Median	25%	Min
Service								
Air Force	0.049	0.0798	23	0.3464	0.0654	0.0235	0.0004	<0.0001
Army	0.0299	0.0319	4	0.0687	0.0623	0.025	0.0024	0.0009
Navy	0.0309	0.0686	18	0.2378	0.0057	0.002	0.0005	0.0001
Multiple	0.0065	0.0049	2	0.01	0.01	0.0065	0.003	0.003
Development Type								
Modification	0.0495	0.0968	12	0.3464	0.059	0.0141	0.001	<0.0001
New Design	0.05	0.059	19	0.1595	0.1168	0.0241	0.0009	0.0001
Prototype	0.004	-	1	0.004	0.004	0.004	0.004	0.004
Subsystem	0.0046	0.004	4	0.01	0.0088	0.041	0.0011	0.0005
New MDS Designator	0.0276	0.0788	9	0.2378	0.0032	0.0013	0.0003	0.0001
Commercial Derivative	0.0001	<0.0001	2	0.0001	0.0001	0.0001	0.0001	0.0001
Contractor Type								
Prime	0.0405	0.0737	40	0.3464	0.059	0.0042	0.0005	<0.0001
Subcontractor	0.0277	0.0519	7	0.1424	0.0345	0.003	0.0009	0.0005
Commodity Type								
Aircraft	0.0168	0.0476	26	2378	0.0088	0.0015	0.0004	<0.0001
Electronic/Automated Software	0.0917	0.1018	11	0.3464	0.143	0.0687	0.0069	0.0005
Missile	0.0009	-	1	0.0009	0.0009	0.0009	0.0009	0.0009
Ordnance	-	-	-	-	-	-	-	-
Space	0.0602	0.0591	6	0.1424	0.1232	0.0494	0.0023	0.0005
UAV	0.0024	0.0017	3	0.004	0.004	0.0028	0.0005	0.0005
Contract Type								
CPAF	0.0498	0.0511	5	0.1168	0.1014	0.0426	0.0017	0.0005
CPFF	0.0277	0.0316	6	0.0687	0.0662	0.0152	0.0013	<0.0001
CPIF	0.0723	0.0777	6	0.1595	0.1471	0.0649	0.0008	0.0005
Cost-Other	0.0355	0.0675	15	0.2378	0.0345	0.004	0.0013	0.0005
FFP	0.0008	0.0009	3	0.0018	0.0018	0.0005	0.0001	0.0001
FPI	0.0023	0.004	4	0.0084	0.0064	0.0004	0.0002	0.0001
FPIF	0.009	0.0152	3	0.0267	0.0267	0.0002	0.0001	0.0001
Fixed-Other	-	-	-	-	-	-	-	-
Unknown	0.079	0.1505	5	0.3464	0.1948	0.0044	0.0006	0.0001

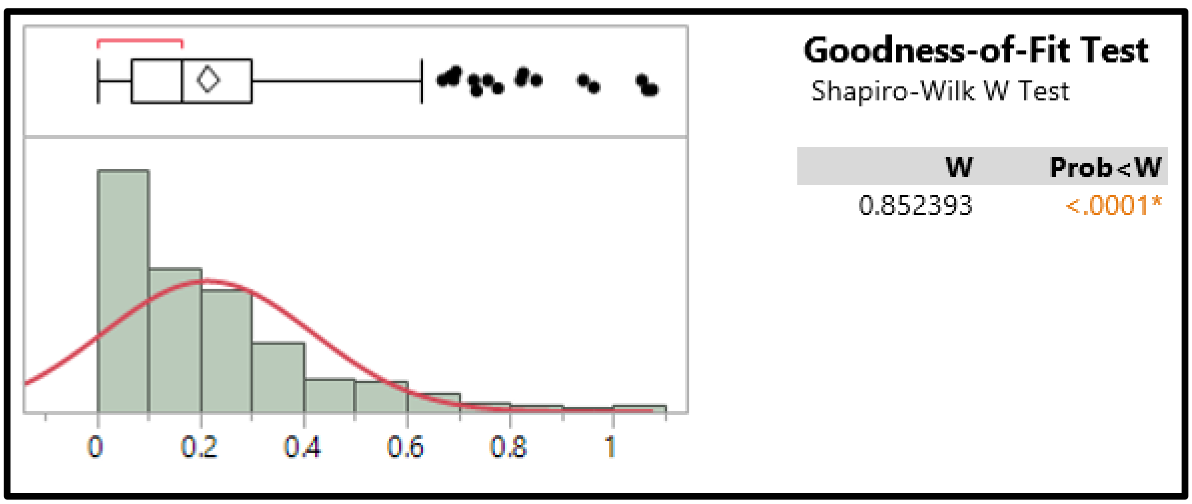
Other Summary Table								
	Mean	**Std Dev**	**N**	**Max**	**75%**	**Median**	**25%**	**Min**
Service								
Air Force	0.072	0.133	160	0.6989	0.062	0.022	0.0079	<0.0001
Army	0.0928	0.1386	86	0.7394	0.1189	0.0374	0.0094	<0.0001
Navy	0.0714	0.1567	105	0.8796	0.0544	0.014	0.0068	0.0001
Multiple	0.1268	0.202	20	0.7897	0.1535	0.0526	0.0182	0.0032
Development Type								
Modification	0.0874	0.1569	117	0.8089	0.0868	0.0241	0.009	<0.0001
New Design	0.0812	0.1384	132	0.7394	0.0813	0.0269	0.01	0.0002
Prototype	0.0328	0.0373	6	0.0993	0.0634	0.0214	0.0018	0.001
Subsystem	0.0726	0.1365	86	0.6989	0.063	0.0199	0.0062	0.0002
New MDS Designator	0.0459	0.087	26	0.4216	0.0502	0.0113	0.0084	0.0001
Commercial Derivative	0.2406	0.4264	4	0.8796	0.673	0.0408	0.0081	0.0013
Contractor Type								
Prime	0.0864	0.1544	245	0.8796	0.0807	0.0241	0.0085	<0.0001
Subcontractor	0.0665	0.1264	126	8089	0.0627	0.0187	0.0078	<0.0001
Commodity Type								
Aircraft	0.0762	0.1415	186	0.8796	0.0689	0.0239	0.0086	<0.0001
Electronic/Automated Software	0.0727	0.1365	107	0.7394	0.0766	0.0157	0.0065	0.0004
Missile	0.1434	0.2227	21	0.7897	0.1941	0.0449	0.0107	0.0002
Ordnance	0.0779	0.1823	12	0.6425	0.0871	0.0086	0.0032	<0.0001
Space	0.0962	0.14	35	0.5061	0.1198	0.0343	0.0119	0.003
UAV	0.0274	0.0418	10	0.1401	0.0266	0.0103	0.0086	0.0056
Contract Type								
CPAF	0.0963	0.1627	66	0.8796	.09.9	0.0387	0.0126	0.0015
CPFF	0.0625	0.127	36	0.5154	0.0487	0.0124	0.0049	<0.0001
CPIF	0.083	0.1402	58	0.8089	0.0969	0.0256	0.0093	0.0005
Cost-Other	0.0919	0.1688	125	0.7897	0.0868	0.0215	0.009	<0.0001
FFP	0.044	0.0853	22	0.2991	0.0304	0.0062	0.0022	0.0002
FPI	0.0245	0.017	7	0.0483	0.0451	0.022	0.0056	0.0054
FPIF	0.0747	0.1294	18	0.5318	0.0782	0.0287	0.0087	0.0005
Fixed-Other	0.0176	0.0229	6	0.0504	0.0452	0.0043	0.0018	0.001
Unknown	0.0617	0.1025	33	0.5677	0.0679	0.0338	0.0113	0.0002

Spares Summary Table								
	Mean	Std Dev	N	Max	75%	Median	25%	Min
Service								
Air Force	0.043	0.0558	33	0.226	0.0846	0.0113	0.0018	<0.0001
Army	0.0221	0.0259	10	0.0644	0.0538	0.0107	0.0016	0.0006
Navy	0.0341	0.0347	41	0.1134	0.0434	0.0225	0.0047	<0.0001
Multiple	-	-	-	-	-	-	-	-
Development Type								
Modification	0.0222	0.0479	25	0.226	0.0177	0.0046	0.0014	<0.0001
New Design	0.0438	0.0394	34	0.1319	0.0779	0.0332	0.0091	0.0001
Prototype	0.0279	-	1	0.0279	0.0279	0.0279	0.0279	0.0279
Subsystem	0.0283	0.0288	7	0.0884	0.0368	0.0225	0.0101	0.0004
New MDS Designator	0.0504	0.0493	15	0.1418	0.1117	0.0303	0.0069	0.0008
Commercial Derivative	0.0054	0.0069	2	0.0103	0.0103	0.0054	0.0005	0.0005
Contractor Type								
Prime	0.0372	0.0468	62	0.226	0.0536	0.0174	0.0034	<0.0001
Subcontractor	0.0331	0.0336	22	0.1073	0.0623	0.0195	0.0046	0.0004
Commodity Type								
Aircraft	0.0397	0.0498	52	0.226	0.0781	0.0168	0.0035	<0.0001
Electronic/Automated Software	0.0239	0.0284	21	0.1073	0.0434	0.0152	0.0015	0.0001
Missile	-	-	-	-	-	-	-	-
Ordnance	-	-	-	-	-	-	-	-
Space	0.0356	0.0304	6	0.0757	0.0703	0.025	0.0098	0.0091
UAV	0.0519	0.0353	5	0.092	0.0905	0.0302	0.0242	0.0205
Contract Type								
CPAF	0.0255	0.0298	17	0.0943	0.036	0.0113	0.0034	0.0012
CPFF	0.0045	0.0074	4	0.0156	0.0121	0.0012	0.0002	0.0001
CPIF	0.0255	0.0192	11	0.0516	0.0449	0.0275	0.0048	0.0001
Cost-Other	0.0439	0.0438	18	0.1167	0.0897	0.0226	0.0065	0.0002
FFP	0.041	0.0824	7	0.226	0.034	0.0047	0.0014	<0.0001
FPI	0.0593	0.0545	10	0.1418	0.1168	0.0432	0.0127	<0.0001
FPIF	0.0152	0.0195	4	0.0419	0.0359	0.0092	0.0006	0.0005
Fixed-Other	-	-	-	-	-	-	-	-
Unknown	0.044	0.0428	13	0.1134	0.0927	0.0236	0.0072	0.0006

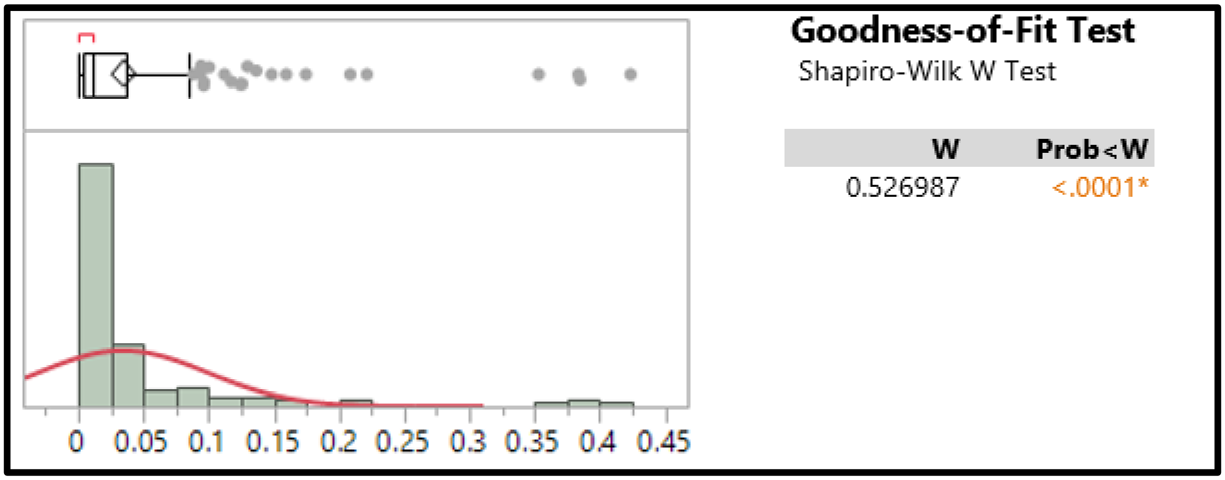
Appendix D – Shapiro-Wilk Test Results by WBS Element



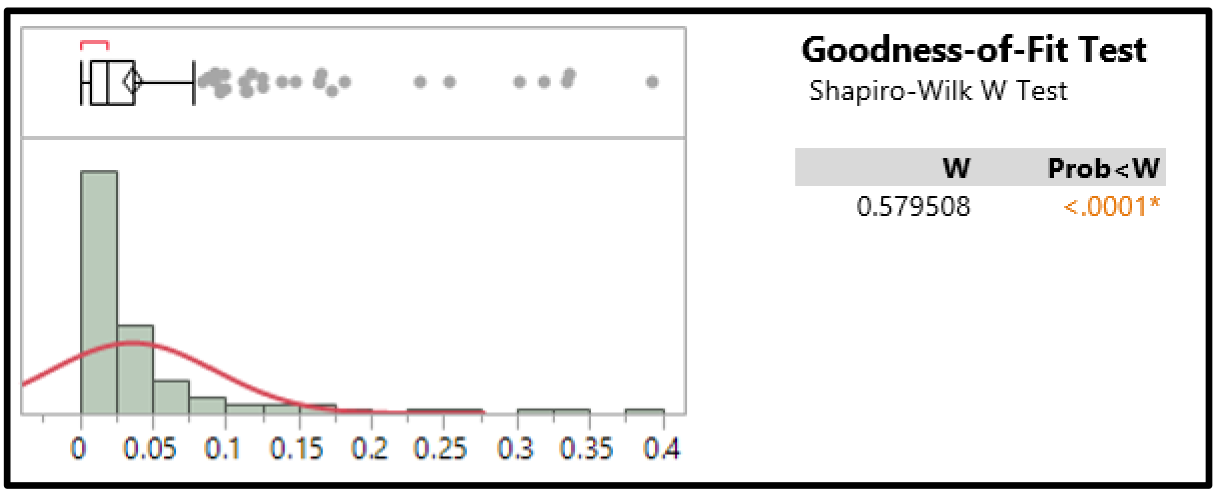
SEPM Shapiro-Wilk Test



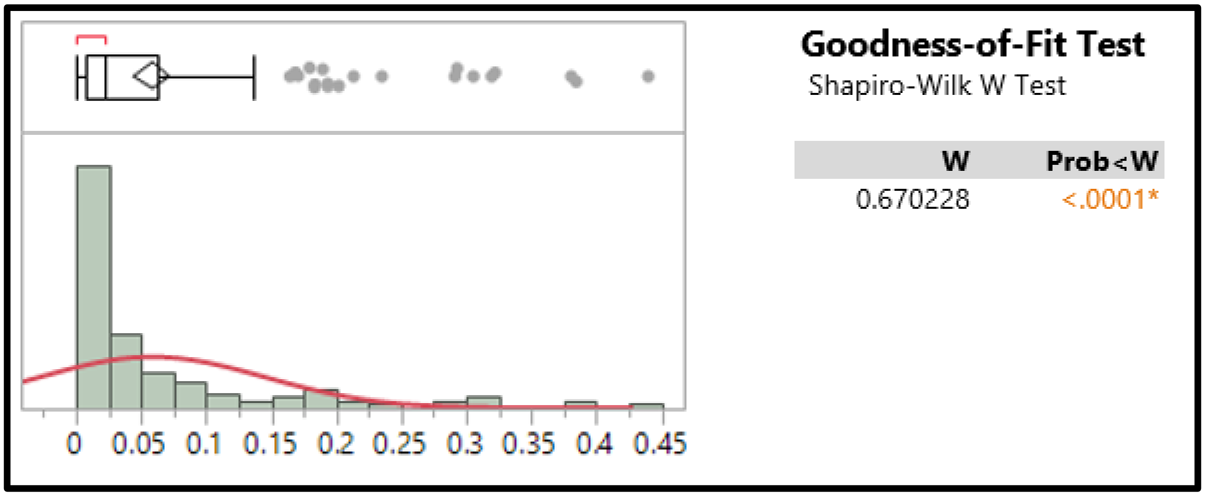
ST&E Shapiro-Wilk Test



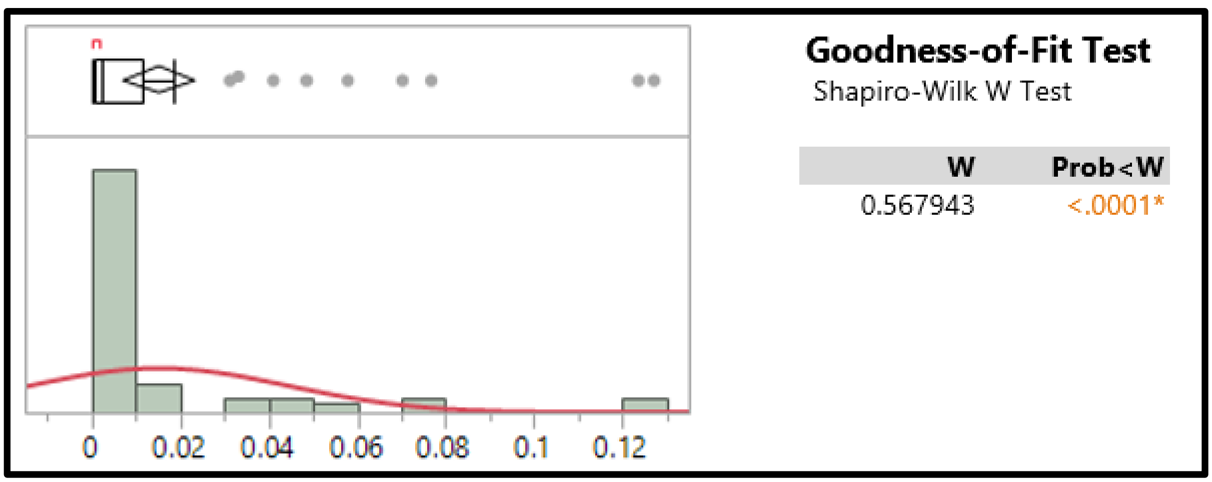
Training Shapiro-Wilk Test



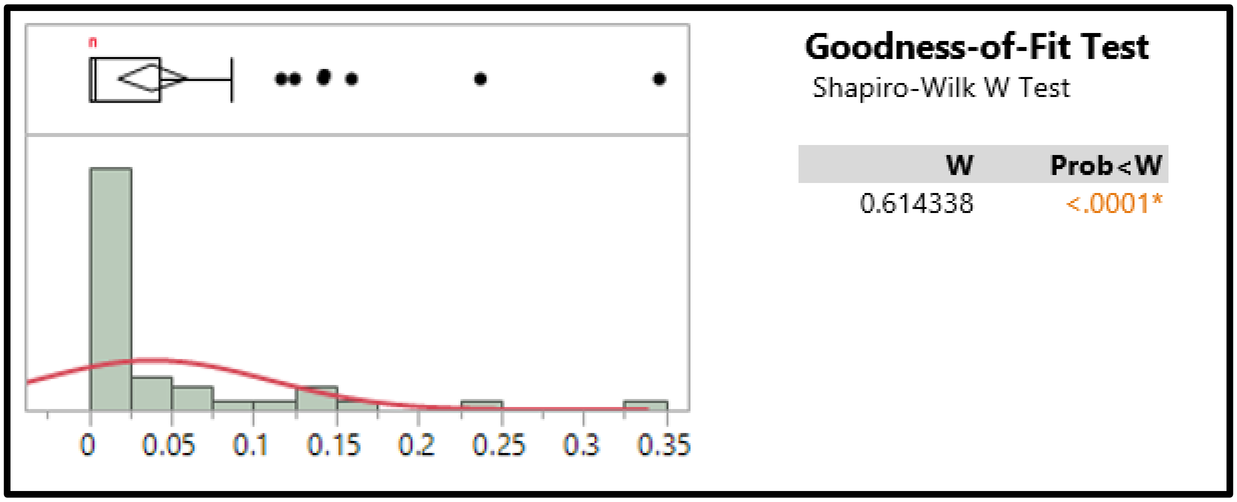
Data Shapiro-Wilk Test



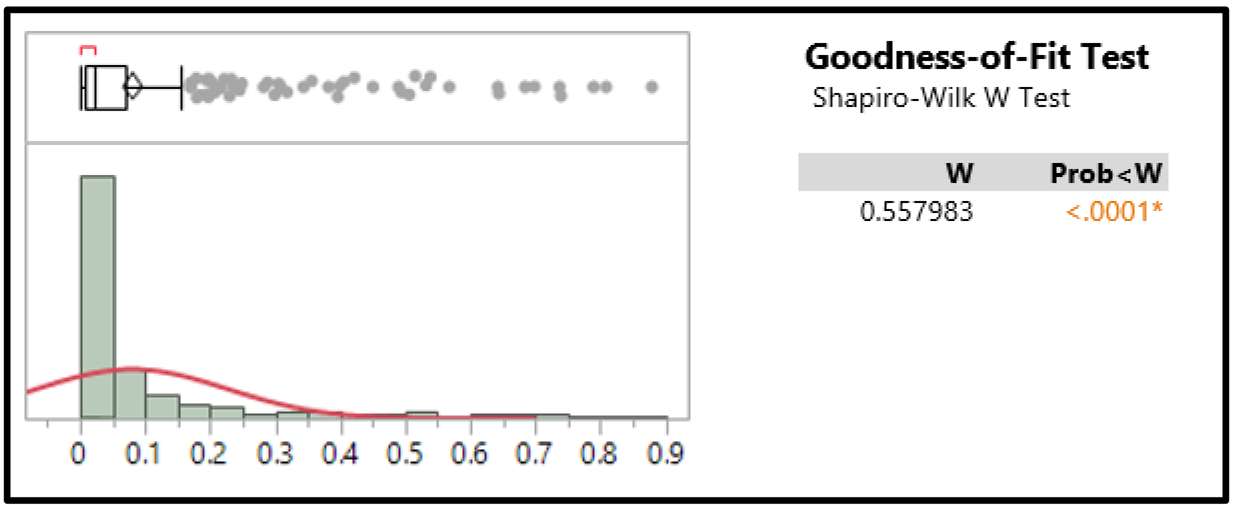
CSE Shapiro-Wilk Test



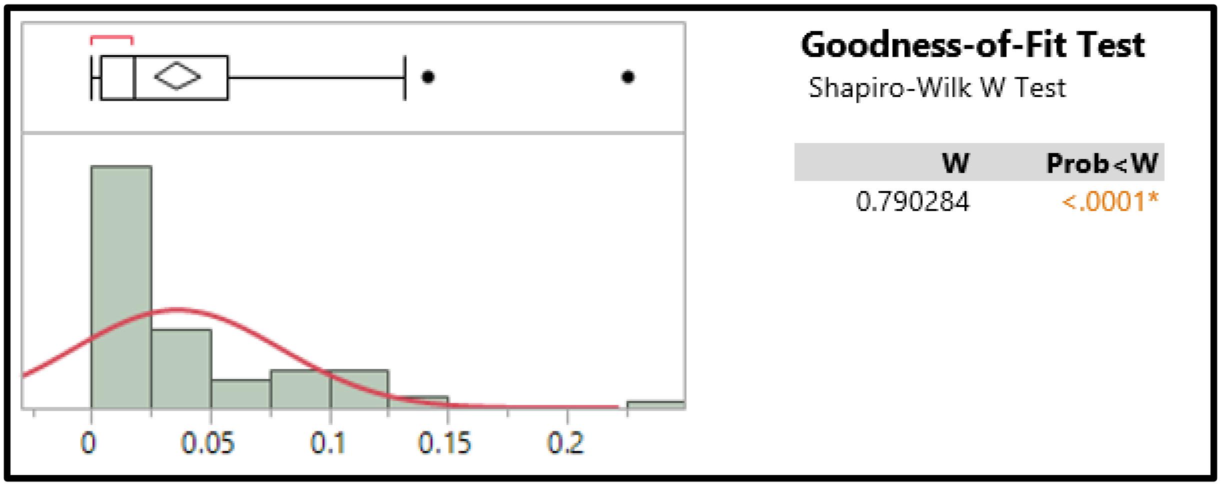
PSE Shapiro-Wilk Test



Site Activation Shapiro-Wilk Test



Other Shapiro-Wilk Test



Spares Shapiro-Wilk Test

Appendix E – Steel-Dwass Results

Steel-Dwass Results for Commodity Type		
Level	**Level**	**WBS Element**
Electronic/Automated Software	Aircraft	SEPM, ST&E, Site Activation
UAV	Aircraft	
Missile	Aircraft	SEPM
Ordnance	Aircraft	
Space	Aircraft	ST&E
UAV	Space	ST&E
UAV	Ordnance	
UAV	Missile	
Space	Ordnance	
Ordnance	Missile	
Missile	Electronic/Automated Software	
UAV	Electronic/Automated Software	
Space	Missile	ST&E
Ordnance	Electronic/Automated Software	
Space	Electronic/Automated Software	

Steel-Dwass Results for Contract Type		
Level	**Level**	**WBS Element**
Fixed-Other	Cost-Other	
Fixed-Other	CPIF	
Fixed-Other	CPAF	
CPFF	Cost-Other	
Unknown	FPI	ST&E
FPIF	FPI	
Fixed-Other	FFP	
FPIF	FFP	
Unknown	FFP	
CPFF	CPAF	
CPAF	Cost-Other	
FPIF	CPIF	
FPIF	Cost-Other	
Fixed-Other	CPFF	
FPIF	CPAF	
FPI	FFP	ST&E
FPIF	CPFF	
CPIF	Cost-Other	
FPIF	Fixed-Other	
CPIF	CPAF	
Unknown	CPIF	Data
FPI	Fixed-Other	
CPIF	CPFF	
Unknown	FPIF	
FFP	CPFF	SEPM
Unknown	CPFF	
FPI	CPFF	SEPM, ST&E
Unknown	CPAF	
FFP	CPIF	
Unknown	Cost-Other	
FPI	CPIF	
Unknown	Fixed-Other	
FFP	CPAF	SEPM, Other
FPI	CPAF	SEPM, ST&E
FFP	Cost-Other	
FPI	Cost-Other	SEPM, ST&E

Steel-Dwass Results for Development Type		
Level	Level	WBS Element
Prototype	Modification	
New MDS Designator	Subsystem	ST&E
New MDS Designator	Modification	PSE
Prototype	New Design	
New MDS Designator	New Design	SEPM
New MDS Designator	Commercial Derivative	
New Design	Modification	SEPM, Spares
Prototype	Commercial Derivative	
New Design	Commercial Derivative	
Modification	Commercial Derivative	
New MDS Designator	Prototype	Data
Subsystem	Commercial Derivative	
Subsystem	Modification	
Subsystem	New Design	
Subsystem	Prototype	

Steel-Dwass Results for Contractor Type		
Level	Level	WBS Element
Subcontractor	Prime	ST&E, PSE

Steel-Dwass Results for Service		
Level	Level	WBS Element
Army	Air Force	SEPM
Navy	Multiple	ST&E
Multiple	Air Force	ST&E
Navy	Air Force	
Multiple	Army	SEPM, ST&E
Navy	Army	SEPM

Bibliography

Air Force Cost Analysis Agency (2007). *Cost Risk and Uncertainty Analysis Handbook*. Washington DC: AFCAA.

Akintoye, A., & Fitzgerald, E. (2000). Survey of current cost estimating practices in the UK. *Construction Management and Economics, 18(2)*, 161-172.

Ali Abbas, S., Liao, X., Ur Rehman, A., Azam, A., & Abdullah, M. (2012). Cost Estimation: A Survey of Well-known Historic Cost Estimation Techniques. *Journal of Emerging Trends in Computing and Information Sciences, 3(4)*, 612-636. Retrieved July 31, 2018, from https://pdfs.semanticscholar.org/67a1/2c3aeafe6e58703d4b04e4963a575c6317c9.pdf.

Baloi, D., & Price, A. D. F. (2003). Modelling global risk factors affecting construction cost performance. *International Journal of Project Management, 21(4)*, 261-269.

Department of Defense (2011). *Work Breakdown Structures for Defense Materiel Items.* MIL-STD-881C. Washington: DoD.

Department of Defense (2007). *Cost and Software Data Reporting (CSDR) Manual*. DoD 5000.04–M–1. Washington: DoD.

Department of Defense (2005). *Work Breakdown Structures for Defense Materiel Items.* MIL-HDBK-881A. Washington: DoD.

Department of the Air Force. *Financial Management: US Air Force Cost and Planning Factors.* AFI 65-503. Washington: HQ USAF, 13 July 2018.

Department of the Air Force. (2007). *Air Force Cost Analysis Handbook*. Washington: U.S. Department of the Air Force.

Elfaki, A. O., Alatawi, S., & Abushandi, E. (2014). Using Intelligent Techniques in Construction Project Cost Estimation: 10-Year Survey. *Advances in Civil Engineering, 2014, 107926th ser., 1-11*. Retrieved July 31, 2018.

Flyvbjerg, B., Holm, M.S., Buhl, S. (2002). Cost Underestimation in Public Works Projects: Error or Lie? *Journal of the American Planning Association, 68(3)*, 279-295.

Government Accountability Office. (2009). *Cost estimating and assessment guide* (Report No. GAO-09-3SP). Washington, DC: U.S. Government Printing Office.

Greves, David & Joumier, Herve. (2003). Cost engineering for cost-effective space programmes. Esa Bulletin-european Space Agency - ESA BULL-EUR SPACE AGENCY. 115. 71-75.

Kendall, F., Hon. (2017). Getting Defense Acquisition Right. https://www.defense.gov/Portals/1/Documents/pubs/Getting-Acquisition-Right-Jan2017.pdf

Mislick, G. K., & Nussbaum, D. A. (2015). *Cost Estimation: Methods and Tools.* Hoboken, NJ: John Wiley & Sons.

Naval Center for Cost Analysis. (2018). NCCA. Retrieved July 19, 2018, from https://www.ncca.navy.mil/references.cfm

Otte, Jim. (2015). *Factor Study September 2015*. Air Force Lifecycle Management Center Research Group, Wright Patterson Air Force Base, OH.

PAX. (2018, April 24). DoD Area Cost Factors (ACF). Programming Administration and Execution System Newsletter (PAX), 3.2.1, 1-19.

Riquelme, P., & Serpell, A. (2013). Adding Qualitative Context Factors to Analogy Estimating of Construction Projects. Procedia - Social and Behavioral Sciences, (74). Retrieved July 21, 2018, from https://ac.els-cdn.com/S1877042813004667/1-s2.0-S1877042813004667-main.pdf?_tid=ab4ccb38-10d8-4a26-8874-5d00d10fc6a1&acdnat=1531852501_491c91b1a45e3da1f9fc5d5141441d48

Settani, E. ... et al, 2015. To cost an elephant: an exploratory survey on cost estimating practice in the light of product-service-systems. *Journal of Cost Analysis and Parametrics, 8 (1),* 1-22.

Tracy, S.P., & White, E.D. (2011). Estimating the Final Cost of a DoD Acquisition Contract, *Journal of Public Procurement, 11(2)*, 190-205.

Valentine, S. (2018). [AFLCMC Producer Price Indices PPI3364]. Unpublished raw data.

Wren, Don. (1998). *Avionics Support Cost Element Factors*. Aeronautical Systems Center, Wright Patterson Air Force Base, OH.

Vita

Captain Matthew R. Markman graduated from Amarillo High School in Amarillo, Texas. He entered undergraduate studies at the United States Air Force Academy, Colorado where he graduated with a Bachelor of Science degree in Business Management. Following the completion of his undergraduate degree, he was commissioned as an Officer in the United States Air Force.

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

This research involves the creation of standard factors that more accurately reflect observed outcomes in the development stages of major programs. Traditionally, estimation techniques such as analogy, parametric, engineering build-up, and factors are utilized to develop budgets and serve as the baseline for measuring project progress. This effort accomplishes the development and creation of 443 new standard cost factors that are delineated by five categories: commodity type, contract type, contractor type, development type, and service. The factors are developed for those elements that are "common" in a wide array of projects such as program management, systems engineering, data, training or site activation. This research conducts statistical analysis of factor values at the Work Breakdown Structure (WBS) element level, as well as the subcategories of the five identified categories. Statistical differences between subcategories were identified only 34.38% of the time, likely due to the high Coefficient of Variation (CV) values across the dataset. In refined subsets of the dataset, the CV generally decreased, indicating that the average percent estimating error improved when more detailed information was available. Thus, the outcome of this research is that cost estimators must employ both statistical and practical analysis in the creation of cost estimates. Furthermore, analysts will have a reference tool made up of 443 unique factors from which to begin analysis for creating estimates and conducting the iterative process of refining cost estimates.

15. SUBJECT TERMS

Factors, Work Breakdown Structure, Cost Estimating, Major Defense Acquisition Program (MDAP)

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