Investigating Shifts in Engineering Manufacturing Development (EMD) Factors for Department of Defense Assets through Decadal Analysis

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Analysts and estimators often use cost factors to estimate future costs throughout several phases of a weapon system's development. Factors can be used as a primary methodology early in development when few programmatic or technical details are known, or as a secondary crosscheck throughout later development to assess other estimating methods. This research focuses on factor development for the Engineering and Manufacturing Development phase and uniquely investigates Level 2 Work Breakdown Structure elements to assess any changes or trends over time. Using standardized cost reports (DD 1921) as a basis, we analyzed seven decades and eight WBS elements by commodity type, contract and contractor type, and service branch. After completing several statistical tests, we determined which factors were stable, increasing, decreasing, or unpredictable over time. Our research empirically substantiates the need to evaluate data points (i.e. programs) carefully prior to inclusion for factor development rather than relying on simpler rules of thumb, such as use the 'latest data' or include 'all available data.'

Introduction

"It is a capital mistake to theorize before you have all of the evidence. It biases the judgement."
– Sherlock Holmes, A Study in Scarlet (Doyle, 1930)

For the cost estimator, perhaps one could replace 'theorize' and 'evidence' with 'estimate' and 'data', and have an equally appropriate statement. Holmes' second line provides the reason and importance of the statement; indeed, perhaps some well-intentioned rules of thumb (e.g., 'use the latest data' or 'use all of the data') about what data to include can bias estimates as well. Our research provides an empirical analysis of data commonly used to develop a factor estimate and detects whether a different approach may be recommended.

Many methods exist for a cost analyst to create accurate and robust cost estimates. Four standard methods are analogy, parametric, engineering build-up, and expert opinion. As part of the second methodology, parametric, factors can often provide a relatively quick and trusted estimate for weapon systems. Most commonly, factors provide a relationship between the prime mission product (PMP) and other elements within the system, which allows estimating at differing levels of the system. For this analysis, we developed parametric factors for the Level II Common Element in the standard Work Breakdown Structure (WBS).

Cost organizations sometimes develop standard factors to use as primary or secondary estimating methodologies when completing estimates. These factors often require regular updates to the underlying data, which implies '*time period'* may play a role in factor accuracy. Our research uses decadal analysis to identify possible trends within categories of data and the most applicable data based on similarity. Understanding the time-driven aspect of these factors may help analysts create more defendable and accurate estimates.

Literature Review

Much literature exists about acquisitions, cost estimating, methodologies, and parametric factors. While not exhaustive, some of these studies certainly bear mentioning. At a high level, one impetus for defendable acquisitions programs derives from the DoD Directive 5000.01 "Defense Acquisitions System." This directive outlines the need for a disciplined approach to acquisitions to deliver "products and services that satisfy user needs … at a fair and reasonable price" (Department of Defense, 2020). Congress relies on the Government Accountability Office (GAO) to encourage these objectives by establishing the guidelines and best practices for cost estimates. The GAO publishes the Cost Estimating and Assessment Guide as a reference from which the DoD acquisitions community can obtain procedures to create trusted and verifiable estimates (Government Accountability Office, 2020). The DoD and each military service have several regulations and instructions governing the topic as well. However, it is up to the cost estimator to tailor an estimate, in a timely manner, utilizing the best data available. Just as every program is part new and part heritage, estimates must be unique to the program and built from the knowledge of previous programs.

One outcome of a cost estimate is the point estimate. The point estimate is the culmination of data results in a reasonable estimate of a program or asset's costs. The point estimate is the best prediction of future costs. An analyst establishes a point estimate by collecting data within each element of the program. Methodologies are the process of collecting and applying this data to a new program. A cost estimator may choose a combination of the following methodologies to construct an accurate point estimate: Expert Opinion, Engineering Build-Up, Analogy, and Parametric. Which methodologies are appropriate depends on data availability, which stage in the acquisitions process the program is in, and how much data the estimator can collect in the time available (Department of the Air Force, 2007).

The parametric method relies on historical costs from comparable systems and utilizes the statistical relationship between many systems to determine the historical relationship between elements of the systems. The analyst develops a parametric estimate by collecting data on several similar programs and analyzing the cost drivers to determine if a statistically significant relationship exists between them. This method assumes the same relationship that drove costs in the past will continue to drive costs in the future (Government Accountability Office, 2020).

Since the parametric methodology is based on statistically verified factors, it remains valid when the system characteristics change. However, the system characteristic must remain within the relevant range of the dataset. The parametric method may prove inadequate when a new system does not significantly match the program or parameters of the historical program(s), when not enough data exists to create a factor, or when complexity hinders understanding of the baseline relationships (Government Accountability Office, 2020).

More specifically, cost factors can be derived via parametric methods. Cost factors can be used to estimate a wide range of system costs and several prior investigations demonstrate their significance. Blair (1998) developed and published factors from avionics programs at the Engineering and Manufacturing Development (EMD) stage to estimate future programs. Wren expanded the Blair factors using the data available in 1998. By averaging data from the Blair study and the more recent programs, he developed composite factors for each support element (Wren, 1998). Further updates came in 2015 when Otte expanded the research from just Air Force aeronautical programs. His factors provided updates to existing factors and created factors for new WBS elements such as System Test & Evaluation and common support equipment, among others. It also included data not only from the Air Force but also from the Navy, Army, and Foreign Military Sales (FMS) systems (Otte, 2015). Over the years, many departments have maintained cost factor handbooks that track common factors within an organization. They include the Marine Corps Cost Factors Manual, the Army Cost Analysis Handbook, the Air Force Cost and Planning Factors, and the Historical Air Force Construction Cost Handbook. Analysts utilize these handbooks within and between branches, and often, departments will develop internal Cost Factor handbooks for specific program types (Mislick & Nussbaum, 2015). In 2019, Markman et al. generated 443 factors from 102 development phase programs in categories of commodity, development type, contract type, and

service branch (Markman et al., 2021). Edwards expanded this effort by extending factors into the production phase and created 3,462 unique factors from 145 programs (Edwards et al., 2021).

Typical parametric factors are the averages of many factors across a vast time period. For example, if calculating the factors for a new bomber program, an analyst may draw from data on the B-52 Stratofortress and the B-1 Lancer, among others. There is a several decade gap between the developments of those aircraft. It may not be prudent to assume the relationships between their cost elements have not diverged, as many aspects of DoD acquisitions have evolved and developed over time. Even more recent reforms such as the Nunn-McCurdy Act of 1982, the Packard Commission of 1986, the Defense Acquisition Workforce Improvement Act (DAWIA) of 1990, the Federal Acquisitions Streamlining Act (FASA) of 1994, and the Weapon Systems Acquisition Reform Act (WSARA) of 2009 have led to changes not only in reporting, but also in the development of acquisitions programs. In addition, revisions to acquisition handbooks and standards, such as Military Standard Work Breakdown Structure for Defense Materiel Items (MIL-STD-881F), may create differences in the definitions of certain WBS elements. These changes ultimately can affect how managers develop and track systems, which could, in turn, effect the calculation of standard factors.

Category	Number	Remaining
Development Programs in Database		620
Prototype/Experimental Programs	30	590
Unavailable Milestone B Date	11	579
Non-Final or Late Interim Data	168	411
No WBS Cost Values	2	409
Ground Vehicle	1	408
Final Dataset for Analysis		408

Table 1: Data Exclusion

Database

Cost Data Summary Reports (CDSR), officially the DD Form 1921 or simply 1921s, contain the necessary cost data to develop and analyze factors. Contractors must submit these reports on contracts valued at $50 million or more on Acquisition Category I programs (DoD, 2007). DoD and contractors follow the guidance of MIL-STD 881F which provides a standardized reporting structure at Level 2 of the WBS.

The Office of Cost Assessment and Program Evaluation (CAPE) developed the Cost Assessment Data Enterprise (CADE) which stores a wide range of official cost data, including 1921s. The Air Force Life Cycle Management Center cost staff (AFLCMC/FZC) collects and summarizes these reports in an available database. Our research used a dataset that consists of 1921s spanning from 1951 until 2019, representing an extensive range of programs within the Engineering, Manufacturing, and Development (EMD) life-cycle phase.

The AFLCMC/FZC cost database contains 620 1921s in the EMD life-cycle, though we only included 408 1921s that fit the criteria for this research. We list the programs associated with these 408 1921s in Appendix A. The final dataset was selected following previous factor research criteria (e.g., Markman et al, 2021). Table 1 details the exclusion criteria and the number of programs utilized for this research.

While we excluded initial 1921 data, we included some interim 1921s based on input from AFLCMC/FZC. Any interim 1921s included in this dataset were practically complete from a cost perspective, but the 1921 does not administratively list them as such. We excluded prototype and experimental programs as their costs may not reflect traditional programs. There were 11 programs where Milestone B dates could not be determined and classified into decades. Finally, we excluded systems within CADE which had no EMD data or were in a non-readable format.

We classified the data into four categories: commodity, contract type, contractor type, and service. Within these categories, subcategories form the basis for our comparisons. For example, the category of contract type contains the subcategories Cost Plus and Fixed. Table 2 lists the subcategories and the number of 1921s associated with each. We then categorized the data by decade, which resulted in multiple factors for most programs. Categories and decades with fewer than five data points did not contain enough data to test. Table 2 gives an overview of the data categorizations for this research.

Table 3 shows the number of data points by decade and Level II WBS element. Amounts shown in very light gray were not analyzed due to lack of data points (i.e., <5). We will not include these decades in the Kruskal-Wallis or Wilcoxon tests, but we have included them for reference.

AFLCMC/FZC collected the 1921 data and extracted the relevant information into a central database, normalizing the data to fiscal year 2021 dollars using Office of the Secretary of Defense (OSD) inflation indexes and each report's "report as of" date. For decadal analysis, we have further categorized the data points by Milestone B date and rounded them down to the decade. For example, the 1990s decade includes all data with a Milestone B year from 1990 through 1999. We selected Milestone B as this is when a program leaves the Technology Maturation & Risk Reduction phase and enters the Engineering & Manufacturing Development phase.

Category	**Total**	**% of Data**
1921s	408	100.00%
Commodity Type		
Aircraft	142	34.80%
Electronic/Automated Software	96	23.50%
Engine	14	3.40%
Missile	10	2.50%
Rotary Wing	87	21.30%
Space	24	5.90%
UAV	13	3.20%
Contract Type		
Cost Plus	212	52.00%
Fixed	110	27.00%
Contractor Type		
Prime	247	60.50%
Subcontractor	139	34.10%
Service		
Army	68	16.70%
Navy (including Marine Corps)	158	38.70%
Air Force (including Space Force)	150	36.80%
Joint	10	2.50%

Table 2: Data Categories

WBS

The Work Breakdown Structure (WBS) is the framework for detailing the system requirements of a program. Organized in an hierarchical structure where each level specifies an aspect of the level above it, its purpose is to describe a system in enough detail to understand and manage the system. Creating standard WBS formats throughout DoD acquisitions ensures consistency between programs.

The design of the common WBS expresses which elements of a system are essential to understanding the cost and schedule of the program. The first level (Level 1) is the entire system or project. Every other element will eventually connect to the Level 1 WBS element, and so too will all costs. The next level (Level 2) consists of the major elements of the system. The Prime Mission Equipment (PME) is one of the Level 2 elements and consists of the direct deliverable of the system, such as the aircraft or software itself. Systems Engineering/Program Management (SE/PM) is the engineering, technical control, and business management of the system. System Test

Decade	**1950**	**1960**	**1970**	**1980**	**1990**	**2000**	**2010**	**Total**
WBS								
SEPM	1	5	24	46	51	220	38	385
ST&E	8	6	22	46	48	174	28	332
Training	6	4	13	29	30	90	8	180
Data	6	5	23	44	35	129	21	263
Site Activation			2	15	6	31	4	58
Support Equipment	7	4	12	29	27	61	10	150
Spares	7	3	2	11	11	36	6	76
G&A		8	21	35	46	216	39	365
Grand Total	35	35	119	255	254	957	154	1809

Table 3: Dataset Characteristics by Decade

and Evaluation (ST&E) consists of the design and production of models, prototypes, and hardware necessary to validate the system during the development stage. Training includes all deliverable training services, devices, equipment, and parts used to instruct personnel on the use and maintenance of the system. The Data element includes the production, acquisition, transformation, and storage of data used within the program. Site Activation includes real estate, construction, utilities, and equipment needed to house, service, and launch the PMP. Support Equipment includes Common Support Equipment and Peculiar Support Equipment. Common Support Equipment (CSE) is the design, development, and production of equipment necessary to support and maintain the system when not directly engaged in its mission. Peculiar Support Equipment (PSE) is the design, development, and production of equipment necessary to support and maintain the system when it is not directly engaged in its mission but is not CSE efforts. We have combined PSE and CSE into Support Equipment for our analysis as their definitions may overlap from program to program. Spares consist of spare components, assemblies, and subassemblies for the initial replacement of the PMP (Department of Defense, 2018). Figure 1 depicts the general structure of a DoD WBS.

Utilizing a standardized WBS makes estimation more consistent across programs and departments. For our purposes, it enables comparisons that make factor development and analysis possible. These elements are typical of most major acquisitions programs and will be of particular interest in our research.

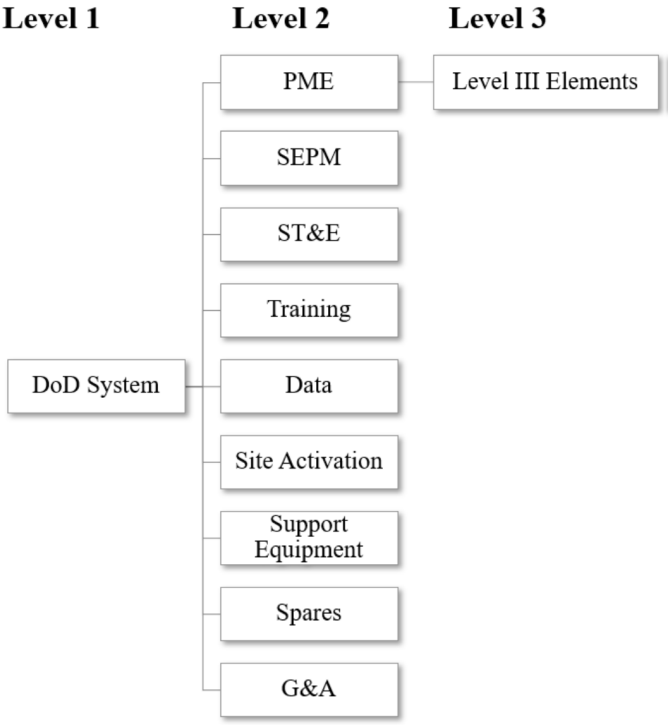

Figure 1: Example of WBS structure

Methods

Factor Calculation

The parametric WBS element factors used in this analysis are the mean (average) of the analogy factors for all programs contained within each WBS element, subcategory, and decade. The analogy factors are the ratio, expressed as a percentage, of the WBS Level II elements to the Prime Mission Equipment (PME) values. The PME values do not include contractor fees, miscellaneous expenses (general and administrative (G&A), undistributed budget, management reserve, or facilities capital cost of money (FCCM)). Table 4 depicts an example of an analogous factor calculation created by dividing System Engineering/Program Management (SEPM) by the program's PME value.

We have categorized these Level II WBS factors and averaged them to develop parametric factors in each decade. Table 5 gives an example of how four programs in the same WBS element and decade calculate a single parametric factor.

Prime Mission Equipment	$ 718.3K
System Engineering/Program Management (SEPM)	$ 120.1K
Analogy Factor = 120.1/718.3 = 0.167 or 16.7%	

Table 4: Example of Analogy Factor Calculation

	PME	SEPM	Ratio
Program 1	$400K	$60K	0.150
Program 2	$280K	$20K	0.071
Program 3	$600K	$220K	0.367
Program 4	$180K	$52K	0.289
Total	$1,460K	$352K	0.877
Parametric Factor = 0.877 / 4 = 0.219 or 21.9%			

Table 5: Example of Parametric Factor Calculation

Statistical Tests

We utilize several statistical analyses to perform the hypothesis tests. These include descriptive statistics and the Kruskal-Wallis test. The Wilcoxon Rank Sum test serves as a multiple comparison test. We evaluated normality with Descriptive Statistics as any WBS categories found to be non-normally distributed needed non-parametric testing. This non-parametric testing indicates how each decade within a subcategory related to each other. A Kruskal-Wallis test this by comparing the distributions of the responses by decade (Kruskal & Wallis, 1952). The final test was the Wilcoxon test between each decade and all data points not within the decade to identify which decades were statistically different from the overall subcategory. This research compares decadal factors to traditionally calculated factors and illustrates any difference between the decade and the remaining data comprising a traditional factor.

Descriptive analysis determines if the data came from normal distributions. Normality is a necessary condition in parametric tests, as parametric tests assume the population from which we draw the samples is normally distributed. Data that fails the normality test must use non-parametric tests. Visually inspecting the data distribution and comparing the mean, median, and standard deviation determined that none of the data categories appeared normally distributed. To avoid the violation of normality in our testing, we used non-parametric tests for the remainder of our analysis.

We compare each category using the hypothesis test shown in Equation 1, where x represents the different decades in each subcategory for each comparison and y represents a parametric factor for the entire subcategory for comparison. For example, when comparing the decades for aircraft within SEPM, x is defined as the 1970s, and y would be the aircraft SEPM overall factor. Failure to reject the null hypothesis, $H0$, signifies that there is no difference between the medians of the WBS element and each decade. If we reject $H0$, then a difference does exist.

$$H0: \Delta x = \Delta y$$

$$Ha: \Delta x \neq \Delta y$$

Equation 1

Analysts use Kruskal-Wallis tests to determine whether several datasets come from the same distributions and have the same median values. We use it to determine if the data from one decade matches the distribution of the other decades' data.

We use the Wilcoxon Rank Sum test when comparing only two datasets. It is similar to a Student's t-test but without the assumption of normality. A Wilcoxon test compares the locations of the data points of two samples to determine if they are from the same distribution. To test each decade, we created a dummy variable to categorize the decade in question in one group and every other decade in the other. Given distributions of the same shape, the Null Hypothesis of a Wilcoxon test is that the medians of the two samples are equal and rejecting this Null Hypothesis would indicate which decades are not of the same distribution as the rest of the subcategory. Analyzing medians is less prone to the impacts of outliers; and as our data is skewed, we tend to see many possible outliers. Our tests compare the medians of the distributions, and the analysis identified trends and changes in the medians between decades.

Results

"How often have I said to you that when you have eliminated the impossible, whatever remains, however improbable, must be the truth?"
— Sherlock Holmes, The Sign Of Four (1890)

We conducted the aforementioned statistical tests across all categories for each of the WBS elements to identify the distributional fit between decades, which allows us to recommend data for certain decades. However, we limit reporting and commenting to an example case and a few of the more interesting findings.

Example of Analysis using SEPM

The Systems Engineering and Program Management (SEPM) WBS element is a prominent factor in the analysis. It contains the most 1921s of the available programs with 386, representing 94.6% of the programs. SEPM factors ranged from 0.0117% to 911.4% of PME. At the high end of the range, the 911.4% factor may indicate reporting anomalies and/or extreme issues in the upper value—as such, we trimmed it from the data set and kept the next maximum value of 382.3%. Figure 2 shows the distribution of SEPM values and provides descriptive statistics used in further analysis. The distribution is still skewed, but the standard deviation is much smaller at 49.5%, and the mean and median are closer to each other at 44.3% and 29.5%, respectively. The distribution is skewed right and far from normally distributed.

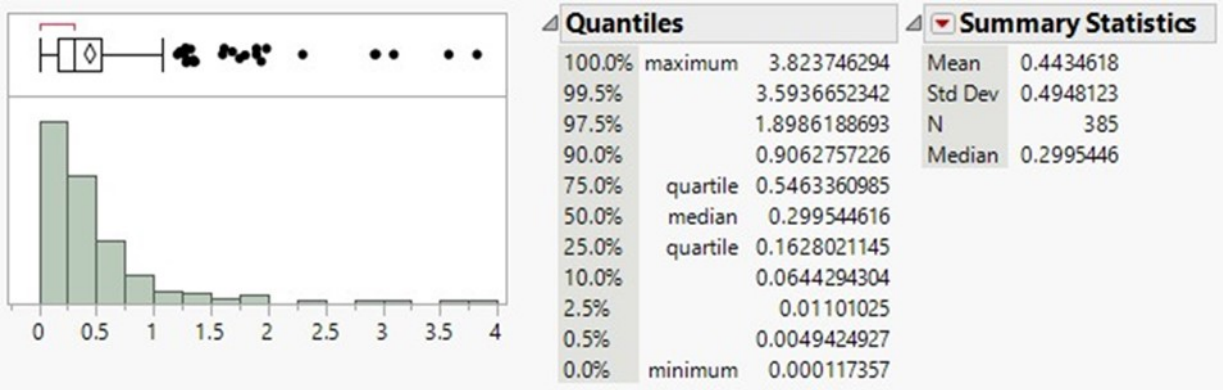

Figure 2: SEPM Descriptive Statistics

Table 6 displays individual descriptive statistics for SEPM broken out by decade. As previously mentioned, excluded from the analysis are decades with less than 5 data points (e.g., 1950 in Table XX), but are included here for comparison to other decades (Howell, 2010).

SEPM Summary Table by Decade							
Decade	1950	1960	1970	1980	1990	2000	2010
Mean	0.26	0.11842	0.18893	0.34387	0.40447	0.47302	0.65357
Std Dev		0.08643	0.17072	0.29198	0.61088	0.49159	0.60133
N	1	5	24	46	51	220	38
Max	0.26	0.25175	0.65209	1.26801	3.82375	3.57635	3.09701
0.75	0.26	0.20532	0.26091	0.47241	0.44964	0.57181	0.83865
Median	0.26	0.0762	0.14311	0.27827	0.23298	0.34771	0.50689
0.25	0.26	0.05263	0.06816	0.11313	0.15362	0.19623	0.29008
Min	0.26	0.04866	0.0293	0.00597	0.00012	0.00531	0.01251

Table 6: SEPM Summary by Decade

The SEPM factor appears to be growing from 1960 through 2010. The mean, median, and quartiles have, for the most part, consistently increased. The mean has grown from 11.8% to 65.3%, and the median has grown from 7.6% to 50.7%. The mean is consistently within the third quartile, confirming the right skew of the distribution. Due to this type of skew, the median may be a better measure of the distribution as the median is less affected by outliers and highly skewed distributions.

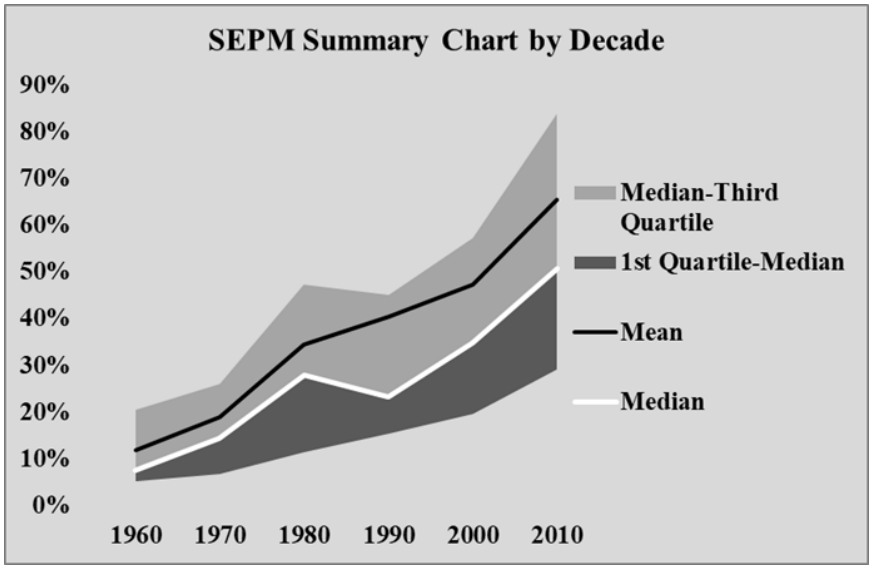

Figure 3: SEPM Summary by Decade

Figure 3 illustrates how the SEPM factor over time has changed quite dramatically, which indicates a rule of thumb such as 'use all of the data' is likely not the best method for a new weapon system. Additionally, note that SEPM appears to have an increasing trend over time, which indicates this cost category generally contains much more of a weapon system's cost now than five decades earlier.

ST&E

The ST&E factors have been slightly decreasing, in contrast to the SEPM factors. There is also more variability in the ST&E factors through the decades, but overall, there has been a shift from higher to lower factors. The mean has changed from 33.3% to 21.9%, and the median has shifted from 32.0% to 10.2%. Again, the mean resides within the third quartile, except for the 1970s, where the mean and median are very close.

ST&E Summary Table by Decade							
Decade	1950	1960	1970	1980	1990	2000	2010
Mean	0.33320	0.38307	0.42179	0.28501	0.17351	0.15181	0.21870
Std Dev	0.15924	0.26609	0.26592	0.27351	0.15695	0.18037	0.32311
N	8	6	22	46	48	174	28
Max	0.59372	0.83931	1.06772	1.07767	0.60513	1.05752	1.49831
0.75	0.47241	0.62385	0.60037	0.43902	0.26537	0.21052	0.32363
Median	0.32009	0.29513	0.40791	0.19222	0.12392	0.09505	0.10234
0.25	0.18537	0.16597	0.19156	0.07796	0.06399	0.03424	0.00345
Min	0.12973	0.14332	0.02533	0.00405	0.00050	0.00011	0.00000

Table 7: ST&E Summary by Decade

While not as consistent or large as the trend in SEPM, ST&E data contains a decreasing trend between the 1970 and 2000 decades. As a result, factors for ST&E tend to vary noticeably by decade, with recent decades tending to be quite a bit lower than earlier decades.

'Categories'

Other WBS elements contain less significant or stable patterns, but often vary as well. As such, we include charts for completeness, but do not directly address each of them. These are available for review in Appendix B.

Based on the data, clear differences often exist between decades. Depending on the WBS element, cost factors may increase, decrease, or remain somewhat stable, but significant shifts and changes appear fairly routine.

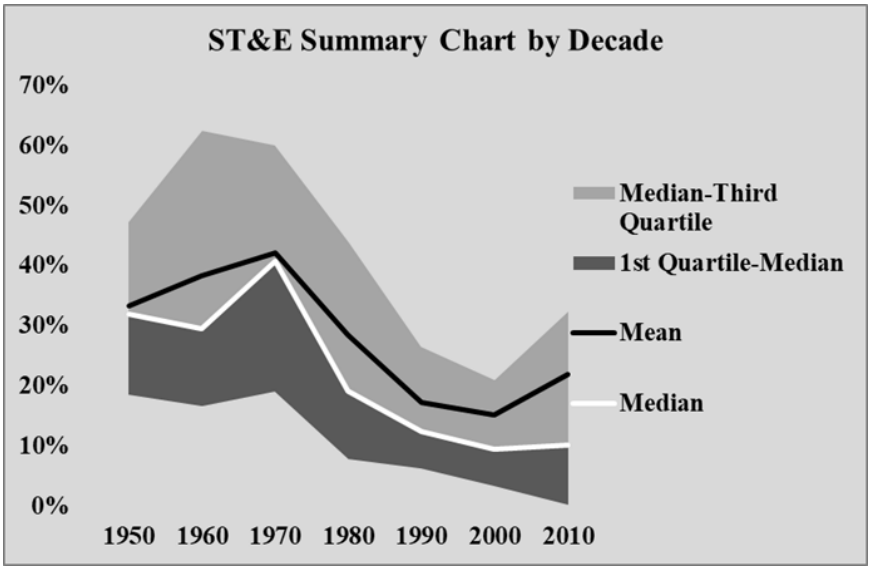

Figure 4: ST&E Summary by Decade

WBS	Mean	Median	Mean	Median	Mean	Median	Mean	Median
Decade	1950		1960		1970		1980	
SEPM			11.8%*	7.6%*	18.9%***	14.3%***	**34.40%**	**27.80%**
ST&E	33.3%*	32.0%*	38.3%*	29.5%*	42.2%***	40.8%***	28.5%*	19.2%*
Training	**2.00%**	**2.00%**			**1.70%**	**0.40%**	**2.40%**	**0.40%**
Data	**2.10%**	**1.50%**	**2.50%**	**2.80%**	**5.80%**	**2.70%**	**4.60%**	**1.90%**
Site Activation							1.8%**	0.2%**
Support Equipment	5.40%	3.50%			16.3%*	5.9%*	**6.30%**	**3.20%**
Spares	8.9%***	10.1%***					**5.40%**	**1.50%**
G&A			10.3%***	10.0%***	22.30%	21.60%	17.0%**	17.9%**

WBS	Mean	Median	Mean	Median	Mean	Median
Decade	1990		2000		2010	
SEPM	**40.40%**	**23.30%**	**47.3%***	**34.8%***	**65.4%*****	**50.7%*****
ST&E	**17.40%**	**12.40%**	**15.2%*****	**9.5%*****	**21.90%**	**10.20%**
Training	**2.50%**	**0.30%**	**3.60%**	**0.60%**	**4.20%**	**0.30%**
Data	**2.90%**	**1.80%**	**3.10%**	**1.80%**	**2.20%**	**1.20%**
Site Activation	**4.10%**	**1.40%**	**6.3%****	**4.0%****		
Support Equipment	**2.7%***	**0.8%***	**10.30%**	**1.90%**	**1.4%****	**0.3%****
Spares	**6.30%**	**2.40%**	**6.30%**	**1.70%**	**1.50%**	**1.00%**
G&A	**25.70%**	**18.30%**	**26.10%**	**23.20%**	**35.90%**	**25.90%**

Table 8: WBS Summary Table and Significance Results

Statistical Tests & Results

Our research addresses the creation and statistical significance of factors between decades within several categories in each WBS element. We sought to examine the statistical differences between decades in Level II WBS factors for various DoD commodities, contract types, contractor types, and service branches. We found clear trends with statistically significant decadal differences in several subcategories within SEPM and ST&E. There are also several large spikes across decades.

For decades and subgroups with five or more data points, we display the mean and median. However, our analysis and discussion will focus on the medians of the distributions due to the manner of our tests and the skew of our distributions. In addition, we chose the median versus mean as a point of comparison as the median is less affected by extreme values. We exclude all subgroups with less than two decades, as we would not be able to compare them.

We indicate the results of the Wilcoxon tests on these numbers with asterisks. The p-values under 0.05 are moderately significant and have a single asterisk next to the mean and median values. P-values below 0.01 are significant and have two asterisks. P-values below 0.005 are highly significant have three asterisks. We have also marked those decades we would recommend using for future factor creation using bold format. Table 8 illustrates these significance levels. We will explore graphs of the medians by decade within some of the WBS sections to highlight changes to factor composition.

KEY	Significance	Recommended
Not Significant ($p>0.05$)	x.xx%	**x.xx%**
Moderately Significant ($0.05\geq p>0.01$)	x.xx%*	**x.xx%***
Significant ($0.01\geq p>0.005$)	x.xx%**	**x.xx%****
Highly Significant ($p\leq 0.005$)	x.xx%***	**x.xx%*****

Table 9: Wilcoxon Results Significance Levels Key

SEPM factors appear to increase from the 1960s to the 2010s, with highly significant factors in the 1970s and 2010s. Having significant factors early and late in the decades corresponds with an upward or downward trend. ST&E shows an opposite trend, decreasing in the median from a high in the 1970s to a low in the 2010s. ST&E has highly significant factors in the 1970s and 2000s. G&A factors increased from the 1960s to the 2010s but were only significant in the early decades. Table 9 illustrates the shifts in the median for these WBS elements. The relationship between an increase or decrease in the factors marked with significant decades will appear in these same WBS elements when discussing them at the subcategory level. Site Activation saw an increase between the 1980s and the 2000s, with the 2000s being significant. Support Equipment saw a decline with significant factors in the 2010s. Spares had highly significant factors in the 1960s, where the median was much higher than the other decades.

Since Training and Data had no significant decades, all the data appears to be from the same distribution. Future analysts could use all decades' data to develop factors as none of the decades contain data that differ greatly from the distribution.

For significant decades with visible trends such as SEPM, ST&E, and G&A, an analyst should consider using the most recent decades as the older decades might not reflect newer programs. In WBS elements like Spares, where one decade is significant, and the median is dissimilar from the remaining decades, we recommend excluding data from that decade and using the remaining decades to develop an estimate. Figures 5, 6, and 7 provide visualization of the median data from Table 9. Note that in some lines may not connect due to lack of data in intervening decades.

In general, our recommendations are to exclude early decades if they have significant Wilcoxon results, or later decades if they appear to represent an anomaly, such as with Spares. We recommend all decades when no decades are significant. These recommendations apply in the remaining analysis by subcategories unless we specifically outline decades in the analysis.

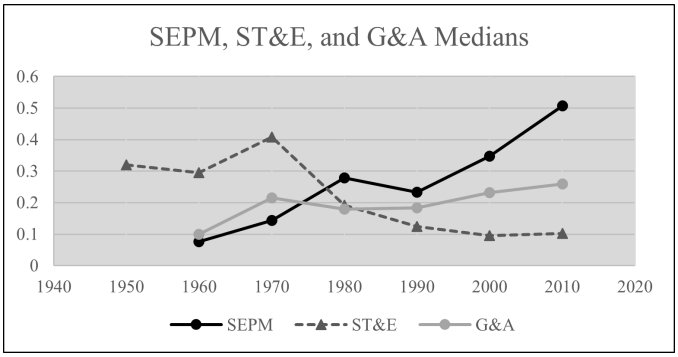

Figure 5: SEPM, ST&E, and G&A Medians by Decade

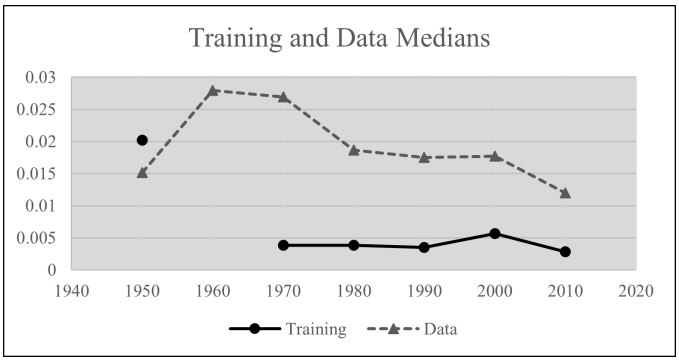

Figure 6: Training and Data Medians by Decade

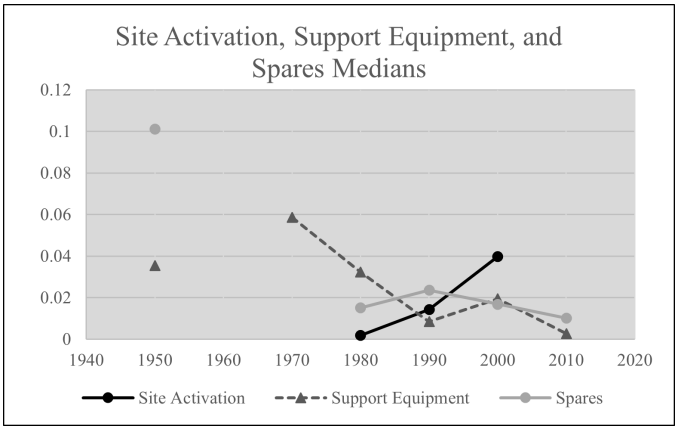

Figure 7: SA, SE, and Spares Medians by Decade

Significance of Research

We can interpret the findings of this research in many ways. First, analysts should avoid grouping the decades with significant differences with the other decades in that subcategory without justification. With several of the WBS elements, clear time trends were present in the data, and the significant results were indicative of the extreme ends of those trends. Where trends exist, using older data for a modern system may not be appropriate as the relationships those factors represented may no longer be most representative. Second, decades that have no significant differences are more likely to fully represent the subcategory in question, and a factor using all available decades may be appropriate.

We discovered an interesting relationship while analyzing these trends. The SEPM and ST&E decadal factors appear to change by decade in opposite directions. These two WBS elements are often the most significant cost drivers outside of PME. It is not apparent that these trends will continue, but it is interesting that as SEPM has become a larger cost driver, ST&E has become smaller. In such instances, analysts should likely use only the most recent or relevant programs to develop parametric factors. Not doing so could result in older or less relevant data points incorrectly influencing the factors when used for new programs.

For an estimator without the necessary time or tools to conduct a detailed analysis, we offer two tables with recommend decadal periods for data selection. Table 10 and Table 11 display an overview of the recommended decades for each WBS element and subcategory. An "X" in a decade indicates the decade within a subcategory that is most representative of future factors. Blank decades are either not recommended for use due to not being representative or were not evaluated due to lack of data points.

	SEPM							ST&E							Training							Data						
Decade	1950	1960	1970	1980	1990	2000	2010	1950	1960	1970	1980	1990	2000	2010	1950	1960	1970	1980	1990	2000	2010	1950	1960	1970	1980	1990	2000	2010
Commodity Type																												
Aircraft					X	X	X	X				X	X	X	X	X		X	X	X	X		X	X	X	X	X	X	X
Electronic/Automated Software						X	X	X					X	X	X						X	X						X	X
Rotary Wing					X	X	X						X	X						X	X						X	X	
Contract Type																												
Cost Plus					X	X	X	X				X	X	X	X				X		X	X					X	X	
Fixed							X	X				X		X	X						X							X	X
Contractor Type																												
Prime					X	X	X	X				X	X	X	X	X		X	X	X		X	X	X	X	X	X	X	X
Sub						X	X	X					X	X	X					X	X						X	X	
Service																												
Air Force					X	X	X	X					X	X	X	X		X	X	X	X		X		X	X	X	X	X
Navy					X	X	X	X				X	X	X	X				X	X	X				X	X	X	X	X
Army						X	X	X					X	X	X					X	X	X					X	X	X

Table 10: Recommended Decades Part 1

	Site Activation							Support Equipment							Spares							G&A						
Decade	1950	1960	1970	1980	1990	2000	2010	1950	1960	1970	1980	1990	2000	2010	1950	1960	1970	1980	1990	2000	2010	1950	1960	1970	1980	1990	2000	2010
Commodity Type																												
Aircraft					X		X					X	X	X		X			X	X	X					X	X	X	X
Electronic/Automated Software														X													X	X	X
Rotary Wing																										X	X	X	
Contract Type																												
Cost Plus						X	X						X	X						X	X					X	X	X	X
Fixed							X					X		X					X		X					X	X	X	X
Contractor Type																												
Prime					X	X	X						X	X	X					X	X	X						X	X	X
Sub													X	X														X	X	X
Service																												
Air Force							X						X	X	X					X	X					X	X	X	X
Navy							X					X	X	X							X	X	X				X	X	X
Army																											X	X	X

Table 11: Recommended Decades Part 2

Conclusion

This research utilized data from the AFLCMC/FZC database derived from CADE to develop and analyze decadal factors in eight WBS elements and across several commodities, contract types, contractor types, and service branches. The creation of robust factors requires utilizing the most extensive database available to the analyst. However, understanding changes in factor composition over time can assist in the creation of more defensible estimates in the future. The factors tested in this research highlight decadal differences between programs within categories. Analysts should consider these differences when creating parametric factors for cost estimates.

While we do not claim that some of these findings have not been observed by other estimators, the study does provide a wide-ranging historical and empirical analysis to test common rules of thumb. As we have demonstrated, some WBS element factors have increased, decreased, or had spikes, indicating that not all decades and time periods represent the overall WBS element or subcategory. Tables 10 and 11 can help estimators focus data collection and investigative efforts on the time periods most likely to benefit their specific analysis and estimate. Our research provides a framework for creating and improving parametric factors for cost estimates. Efficient and effective cost estimating relies on the most relevant and useful data. The importance of this research is informing cost estimators to take into consideration the decade, or time period in general terms, from which they calculate factors.

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Appendix A

Aircraft	F-15E	G/ATOR	AH-1Z & UH-1Y
A-10A	F-16A	GCSS-A	AH-64D
A-6A	F-16A/B	GSE	AH-64E
A-6E	F-16C/D	IAMD	ARH-70A
A-6F	F-22A	ITEP	CH-47D
AC-130U	F-35A/B/C	JATAS	CH-47F
ASIP	F-4A	JLENS	CH-53K
AV-8B	F-4C	JMPS	CV-22
B-1A	F-5E	JPALS	H-1/AH-1Z
B-1B	F-5F	JTRS	H-1/UH-1Y
B-2A	KC-135A	JTRS GMR	HH-60A
B-52H	KC-135R	JTRS MIDS	MH-60R
B-58A	KC-46A	JTRS NED - MUOS Waveform	MH-60S
C-130 AMP	LVT MIDS	LMP	OH-58D
C-130J	P-8A	LVT MIDS	RAH-66A
C-17A	RQ-4/E-10	MUOS	SH-60B
C-5A	S-3A	N/A	SH-60F
C-5A/B	S-3B	WIN-T	UH-1N
C-5M	T-45TS	**Engine**	UH-60M
E-2C	T-46A	A-10A	V-22
E-2D	VC-25A	A-4A	V-22/CV-22
E-3 FMS	**Electronic/Automated Software**	A-6F	**Space**
E-3A	3DELRR	A-7A	AEHF
E-6A	AMDR	B-1B	EPS
E-7A	AMF JTRS	CH-53K	GPS - OCX
E-8A	AN/TSC-154	F/A-18A	GPS-IIIA
E-8C	AN/TVQ-2	F/A-18E/F	GT - EPS
EA-18G	B-1B	F-111F	NAVSTAR GPS - Block IIR
EA-6B	CAC2S	F-14A	NAVSTAR GPS - MUE
F/A-18A	CANES	F-15A	NAVSTAR GPS - OCS
F/A-18A/B/C	CIRCM	F-16A/B	NAVSTAR GPS Blk IIF
F/A-18C/D/E/F	CNS/ATM	F-22A	NPOESS
F/A-18D	Cobra Judy	F-35A/B/C	SBIRS HIGH
F/A-18E/F	DCGS	F-5E	TSAT
F-101A	Distributed Battle Command System	V-22	**UAV**
F-102A	EA-18G	**Missile**	MQ-1C
F-104A	F-15E	AGM-129A	MQ-4C
F-105A	F-16 Blk 30	AIM-9X	MQ-9A
F-106A	F-16 Blk30	ER	RQ-1A
F-14A	F-16 Blk40/50	JAGM	RQ-4A/B
F-14D	F-22A	MALD-J	RQ-5A
F-14D, F/A18C/D	FAB-T	N/A	RQ-7A
F-15A	FBCB2	**Rotary Wing**	RQ-8A

Appendix B

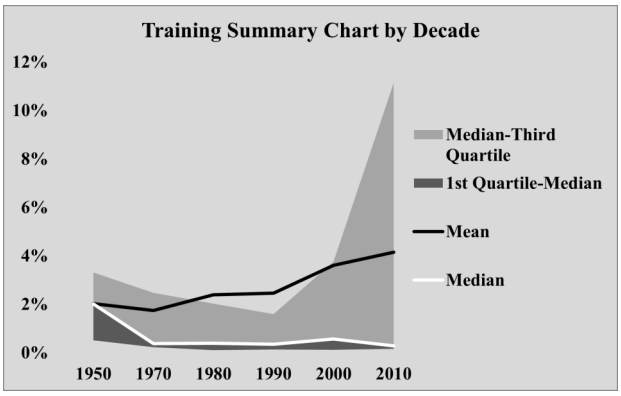

Figure 8: Training Summary by Decade

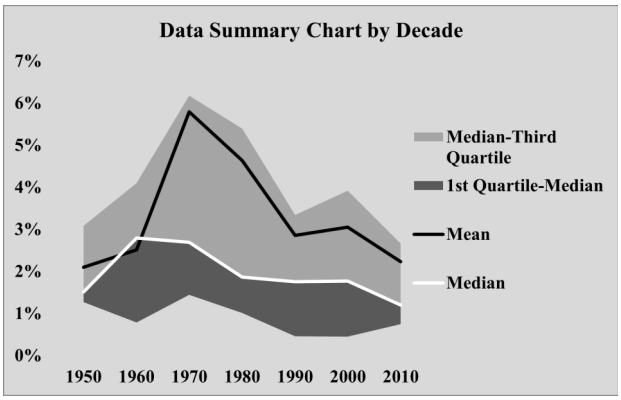

Figure 9: Data Summary by Decade

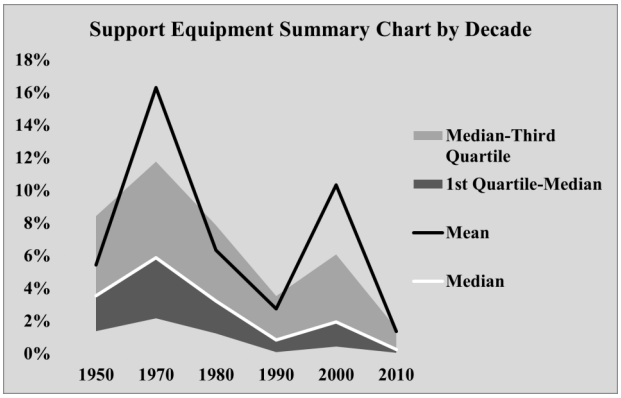

Figure 10: Support Equipment Summary by Decade

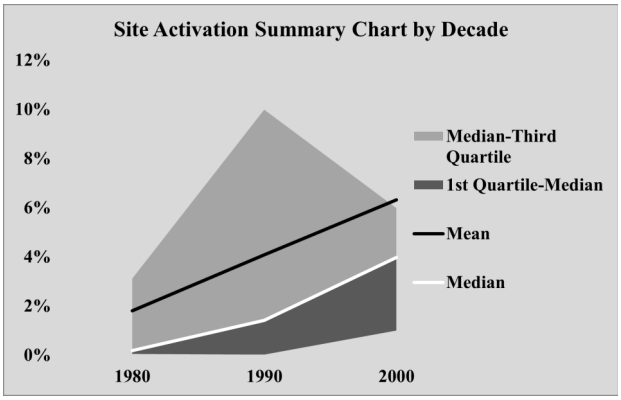

Figure 11: Site Activation Summary by Decade

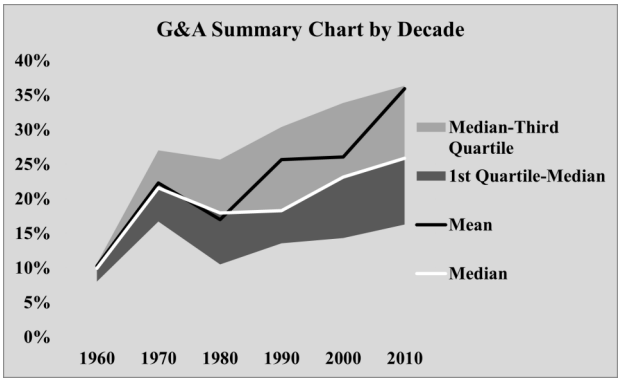

Figure 12: G&A Summary by Decade

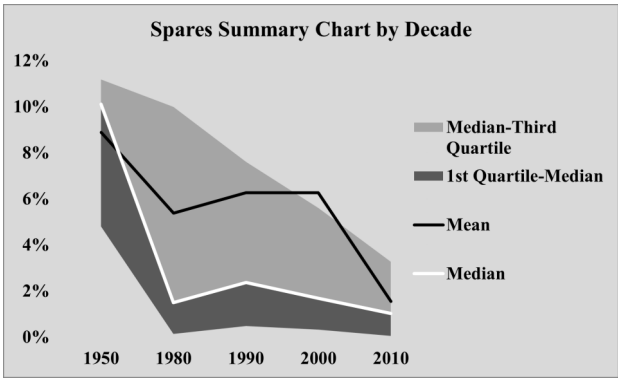

Figure 13: Spares Summary by Decade

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