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

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Abstract

This paper creates standard cost factors that more accurately reflect observed outcomes in the development stages of major programs. Specifically, this effort creates 443 new 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, or training. This paper establishes factor values at the Work Breakdown Structure (WBS) element level for each subcategory of the five identified categories. Coefficient of Variation (CV) values were found to be high (71.86% to 179.87%) in each subcategory. In a refined subset of the dataset, the CV decreased, indicating that the average percent estimating error improved when more detailed information was available. The outcome of this research is that cost estimators will have a reference tool of 443 unique factors for creating estimates and conducting the iterative process of refining cost estimates.

Introduction

Background

Cost analysts have a range of models and techniques that are utilized in a variety of ways on Major Defense Acquisition Program (MDAP) estimates. One of these tools is the application of standard cost factors. Factors are utilized as primary and as cross-check methodologies when estimating "common" cost elements such as program management, systems engineering, training, site activation, and spare costs.

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 limited 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 to include Army, Navy, and Joint programs. Other identified gaps in currently published EMD factors include neglected *commodity categories* (e.g., electronic/automated software, missiles, ordnance, space, and Unmanned Aerial Vehicles [UAVs]), *development types* (e.g., modification programs), and *subcontractor* data. 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 expansion and 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.

Research Objectives

The purpose of this paper is to investigate the current state of EMD cost factors, refine existing standards where available, and develop and publish new cost factors for operational use by cost analysts in an array of project types. Furthermore, the conclusions from this paper help determine where future efforts should be focused towards gathering new data and/or refining existing factors. The specific objectives are to

1. Develop a suite of standard cost factors for incorporation into the current cost estimator toolkit.
2. Create a software tool for tailoring cost factors by unique characteristics such as commodity type, contract structure, or program features.

Literature Review

Cost Estimating Methodologies

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 (GAO, 2009). With billions in taxpayer dollars at stake each year within the Department of Defense (DoD) acquisition budget, it is imperative that program offices, and specifically cost analysts, 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 (GAO, 2009). Because of this responsibility, this paper aims to expand the breadth of analytical tools available, specifically with respect to the utilization of standard factors in MDAPs.

Several key documents designate and define the cost estimating methodologies utilized within the DoD, including the *Air Force Cost Analysis Handbook* (AFCAH) and the GAO *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 (GAO, 2009). 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). 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.

Figure 1 from the AFCAH details the four cost estimating methods and shows the progression over the program life cycle.

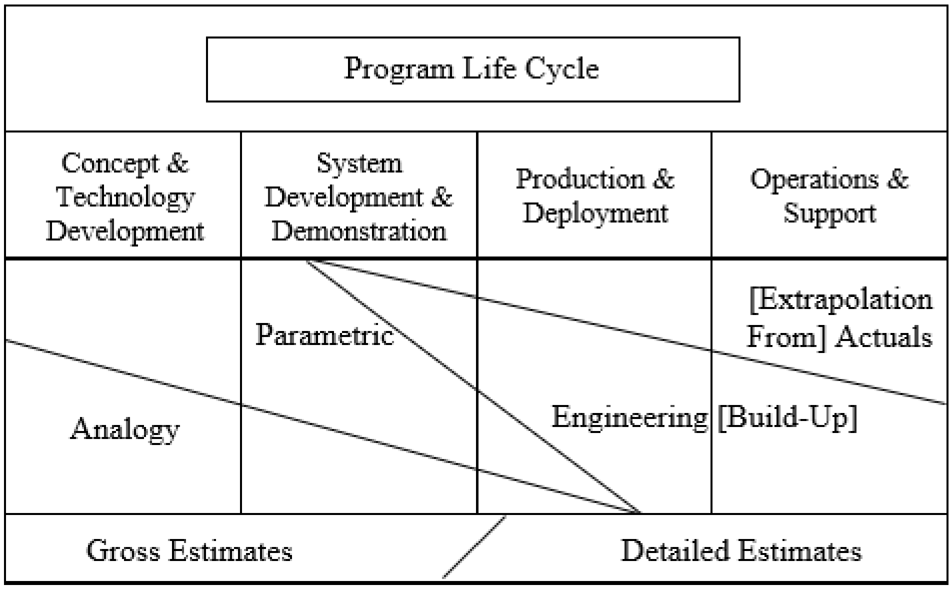

Figure 1. Selection of Methods
(AFCAA, 2007)

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 (GAO, 2009). 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 produce a reliable estimate. 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). 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 (GAO, 2009).

Elements of the Work Breakdown Structure (WBS)

The WBS concept in Major Defense Acquisition Programs (MDAP) has remained relatively constant over the past several decades (DoD, 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 DoD Instruction 5000.2; this DoD publication aims to maintain uniformity in definition and consistency of approach for programs developing a WBS (DoD, 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 (DoD, 2005).

The WBS consists of three primary hierarchical levels, with a fourth and fifth sometimes included in expanded forms; for this paper, only the second level is addressed. Level II of the WBS captures major elements subordinate to the system identified by level I and consists of prime mission products, including all hardware and software elements. Level II 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 (DoD, 2018). These common elements at level II of the WBS are the focus for developing factors in this paper. Benefits of the WBS structure mandated by MIL-STD-881D include ease of normalization of data and information across a variety of commodity types and DoD agencies and the ability to reference past and current MDAPs to better understand and forecast their own costs, schedules, and overall program.

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, creating a gap in cost analysts' ability to employ the technique effectively. While the Air Force acquisition cost analyst community has conducted previous studies by Wren (1998) and Otte (2015) in the Engineering and Manufacturing Development (EMD) phase of the lifecycle, these were all very narrow in scope and applied solely to a limited subset of aircraft programs. Large gaps exist for 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 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 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' prominence 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 is used by 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). 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.

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. The shortcomings of the use and structure of historical data and information are illustrated by large projects' consistent cost overruns (Riquelme & Serpell, 2013). 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 scrutiny to ensure accuracy and applicability, but the time invested in this pursuit yields more effective estimates. 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 new additional analysis would be 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 scrutiny 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, 2013). Using the level II 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 II 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.

Methodology

Data

The data gathered in this paper 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 MDAPs targeted for this research. 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. 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. 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
Excluded Commodity Types	35	154
No EMD Data	25	129
1921 File Format Not .XLS	27	102
Final Dataset for Analysis		102

Programs containing only initial 1921 data 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 1980s or earlier and in many instances contained illegible data.

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

Factor Calculation

The cost element factors contained in this research are the ratio (percentage) of the individual level II 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 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 versus sub), a specified period for a certain commodity type, and many more. An averaged cost factor represents a more accurate factor as it guards against the skewness that can result from calculations based on single data points.

Descriptive 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. 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 categories: service, commodity type, contractor designation, contract type, and development type. Table 3 lists the categories and respective sub-categories for which factors were established in this research.

Table 3. Categories for Comparison Analysis

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

Results and Analysis

Systems Engineering/Program Management (SEPM)

The 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. Table 4 shows the distribution of SEPM values after exclusions were made and provides descriptive statistics utilized in further analysis.

Table 4. SEPM Descriptive Statistics

Max	1.4655	**Mean**	0.3884
75%	0.5319	**Std Dev**	0.3015
Median	0.3038	**N**	406
25%	0.1643		
Min	0.0043		

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. Table 5 displays an example of the descriptive statistics broken out by category for the SEPM WBS element. The detailed analysis displayed in Table 5 for subsequent WBS elements (Training, Data, PSE, CSE, Site Activation, Other, and Spares) is not provided in this paper due to space constraints but is available upon request.

Table 5. 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

System Test & Evaluation (ST&E)

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. 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. Table 6 depicts the ST&E distribution as well as its accompanying descriptive statistics. Table 7 displays an example of the descriptive statistics broken out by category for the ST&E WBS element.

Table 6. ST&E Descriptive Statistics

Max	1.0776	**Mean**	0.2144
75%	0.2999	**Std Dev**	0.2027
Median	0.1611	**N**	374
25%	0.0658		
Min	0.0012		

Table 7. 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
Variant	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

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 values 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. Table 8 shows the distribution and descriptive statistics for the 192 values analyzed for the Training WBS element. The detailed analysis similar to Table 5 for Training is available upon request.

Table 8. Training Descriptive Statistics

Max	0.4237	**Mean**	0.0342
75%	0.037	**Std Dev**	0.0648
Median	0.0101	**N**	192
25%	0.0031		
Min	0.0006		

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 the right 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. Table 9 provides a look at the descriptive statistics for the Data WBS element. The detailed analysis similar to Table 5 for Data is available upon request.

Table 9. Data Descriptive Statistics

Max	0.3935	**Mean**	0.0364
75%	0.0367	**Std Dev**	0.0568
Median	0.0186	**N**	267
25%	0.0074		
Min	<0.0001		

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.

Peculiar Support Equipment (PSE)

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. Table 10 shows the descriptive statistics for PSE. The detailed analysis similar to Table 5 for PSE is available upon request.

Table 10. PSE Descriptive Statistics

Max	0.44	**Mean**	0.0584
75%	0.0629	**Std Dev**	0.0867
Median	0.0217	**N**	149
25%	0.0074		
Min	0.0001		

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.

Common Support Equipment (CSE)

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 distribution for CSE lacks any major shape with data points spread several standard deviations from the mean value of 0.015. Full descriptive statistics for the CSE WBS element are shown in Table 11. The detailed analysis similar to Table 5 for CSE is available upon request.

Table 11. CSE Descriptive Statistics

Max	0.1272	**Mean**	0.0151
75%	0.0115	**Std Dev**	0.0291
Median	0.0019	**N**	50
25%	0.0006		
Min	<0.0001		

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 Table 12. The detailed analysis similar to Table 5 for Site Activation is available upon request.

Table 12. Site Activation Descriptive Statistics

Max	0.3464	**Mean**	0.0386
75%	0.0432	**Std Dev**	0.0706
Median	0.004	**N**	47
25%	0.0005		
Min	<0.0001		

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.

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 Table 13. The detailed analysis similar to Table 5 for Spares is available upon request.

Table 13. Spares Descriptive Statistics

Max	0.226	**Mean**	0.0362
75%	0.0574	**Std Dev**	0.0436
Median	0.0174	**N**	84
25%	0.0035		
Min	<0.0001		

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.

Timeframe Specific Analysis

Recall from the initial dataset exclusion criteria in Table 1, 27 programs were excluded due to inaccessible files or illegible data entries (largely programs from the 1980s or before). To determine whether this exclusion of these older programs had an effect on the factors developed, a timeframe specific analysis on a subset of the data spanning the past two decades was accomplished using 1998 as the cut-off date. Table 14 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 14. 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. The consistency displayed 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.

Analysts should always be as specific as possible when establishing estimates, especially for the SEPM WBS element. However, for the majority of the remaining WBS elements, analysts can include a broader dataset to arrive at an estimate, at least until greater levels of detail are available.

Purpose Specific Analysis

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 15 shows the CV means for each WBS element.

Table 15. 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, statistical analysis will likely not identify differences in certain instances where a cost analyst may identify differences through practical analysis. An example scenario is provided to demonstrate the utility of filtering data down to lower levels through utilization of program-specific information in a hypothetical initial cost estimate.

Scenario Example

This scenario pared the dataset down to only prime contractor data for Army MDAPs in the electronic/automated software commodity type. The development type category was examined, looking only at the SEPM WBS element. Through knowledge of the unique program characteristics, the analyst is able to reduce the CV in this illustrative example by more than 20% for the SEPM element. This is just one example (of numerous) in which program-specific knowledge can utilize the factors developed here to create more accurate estimates.

Conclusions

This research resulted in 443 new cost factors created from a multitude of diverse programs. Factors were developed by *development type* (commercial derivative, modification, new design, prototype, variant, and subsystem), *contractor type* (prime and sub), *Service* (Air Force, Army, Navy, and Multiple), *contract type* (various) and *commodity type* (aircraft, electronic, missile, ordnance, space, and UAV).

The descriptive statistics were examined for each category, as well as each level II WBS element. This revealed large standard deviation values and large CV values, pointing to the conclusion that each 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 many 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.

Practical analysis provides 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. This research serves as a precursor to statistical analysis to be conducted on this dataset. 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 paper represents one of the largest DoD factor studies for MDAPs in the EMD phase conducted to date. Previous efforts within the Air Force Lifecycle Management Center

(AFLCMC; Wren, 1998; Otte, 2015) established factor values for specific purposes and System Program Offices (SPOs), whereas this effort is intended for wider-access distribution accessible to analysts across the DoD to accomplish individualized analysis. The compilation of EMD data contained in 443 separate Cost Data Summary Reports (CDSRs) 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 quickly. 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.

Summary

This paper 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 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.

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