PARAMETERS IN PARAMETRIC COST ESTIMATING

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INTRUDCUTION

Many different estimating methodologies, such as discrete estimate, level of effort (LOE) estimate, comparison estimate, cost estimating relationships (CER) methods, and commercial estimating tools like Price System and SEER System are used in aircraft weapon system program. These commercial estimating systems have a universal parameter. First, in order to use either system, the estimators have to calibrate the parameters to meet the industrial environments of there company. Second the system produces a high level estimate rather than level of discipline, such as structural engineering, electrical engineering, system engineering, and propulsion/environmental. For those reasons, most industries do not use the commercial estimating system for related government projects for estimating. In addition, no government agency requires use of a commercial estimating system for a whole proposal.

Purpose

The parametric estimating method is one of the most desirable and is a high creditable estimating method available because this method used actual hours to estimate the weapon system development effort. The purpose of this paper is to study how to create a parametric estimating model in a weapon system, especially in an aircraft system. A cargo aircraft system engineering organization will be utilized for generating estimating model.

METHODOLOGY

Parameters in Engineering Performance Activity

The first step in a parametric model build-up is to find parameters in engineering performance activities in the engineering organization. The second step is to find a relationship among the engineering performing groups in order to build a parametric estimating method. Engineering organization can be divided into the following three categories based on the engineering performance activities (1) Engineering Design Group, (2) Engineering Design Support Group, and (3) Engineering Support Group. The brief efforts of these groups and considerable estimating parameters are delineated below.

Engineering Design (ED) Group

The main efforts of this group are design structures and engineering system design groups. Engineering groups within to this ED group are Wing Structure, Electrical Systems, Fuselage, Final/Mission Systems, Hydro/Mechanical Systems, and Propulsion/Environmental Systems.

Estimating parameter in ED Group. Engineering drawing is a primary parameter of this group. Engineering drawings are required in order to complete the structures and engineering system design according to the specification and requirement of the weapons system.

Engineering Design Support (EDS) Group

The primary efforts of this group are supporting only the ED group. Engineering departments within to this EDS group are Engineering Release (ER) group which handles engineering drawings and Technical Design Service (TDS). Material, Process and Standards Engineering (M&PE), Design Assurance, UG II Support, and Design Integration also belong to this group.

Estimating parameter in EDS Group. Two parameters belong to this EDS group: engineering drawings and ED group hours. Engineering drawings, which are produced from the ED group, have a relationship with Engineering Release group. Further the ED group hours have a relationship with Technical Design Service group's hours.

Engineering Support (ES) Group

The ES group supports the Total Engineering Group which consists of the Engineering Design Group and the Avionics/Flight Controls (AVFC) Group. The ES group includes Change Management, Configuration Management, Aerodynamics, Performance (Aerodynamics, mass property, performance) Supportability Analysis (System Safety/Survivability, System Safety, Human Factors), and System Engineering.

Estimating parameter in ES Group. ED group and AVFC hours are the primary parameter in this group. The primary efforts of the ES group are to support the ED group and AVFC. If the ED group and AVFC have no effort, then the ES group also will have no effort.

Parametric Model Build Up

The parametric estimating model explains an appropriate and valid relationship between independent variables and dependent variable. Statistically, the model has provided a good fit to the sets of data and provided a good estimate of the mean value of dependent variable, and it can be a good predictor of the future of the estimate.

Independent Variables and Definition

Engineering Order (IR & AIR). Based on the engineering design performance, the drawing, in general, can be divided into Initial Release (IR) and After Initial Release (AIR). IR is the first release of all drawings for a given project. In some cases this is a new drawing and in some cases this may be an existing drawing that is being modified for the project.

Any subsequent release of that drawing with a Configuration Change Board (CCB) number is identified as an AIR. As the exceptions, Special Engineering Orders (SEOs), Reissues, and Non Production Release (NPR) are excluded from AIR count. Engineering Order (EO) means IR plus AIR. Drawings and EO have the same meaning in this paper.

Engineering Design Group Hours. Engineering hours accrued from engineering design group.

Total Engineering Hours. Engineering design hours plus Avionics and Flight Control Group hours.

Dependent Variables and Definition

The dependent variables in this study are the cost estimate hours, such as Engineering Design Group, Engineering Design Support Group, and Engineering Support Group.

Hypotheses Test and Research Models

The three hypotheses described are the key for the model to be developed for this study. The three models based on the hypotheses can be delineated as follows:

Hypothesis 1 and Research Model 1

Ho: There is no relationship between the numbers of EO and the ED group hours.

Ha: There is a relationship between the numbers of EO and the ED group hours.

Model 1: EDG Hours = $\beta_0 + \beta_1 EO + \varepsilon$

Hypothesis 2 and Research Model 2

Ho-1: There is no relationship between the numbers of EO and the ER hours.

Ha-1: There is a relationship between the numbers of EO and the ER hours.

Ho-2: There is no relationship between the Engineering Design hours and the TDS hours.

Ha-2: There is a relationship between the Engineering Design hours and the TDS hours.

Model 2-1: ER Hours = $\beta_0 + \beta_1$EOs + ε

Model 2-2: EDSG Hours = $\beta_0 + \beta_1$EDG Hours + ε

Hypothesis 3 and Research Model 3

Ho: There is no relationship between the Total Engineering hours and the ES group hours.

Ha: There is a relationship between the Total Engineering hours and the ES group hours.

Model 3: ES Group Hours = $\beta_0 + \beta_1$Total Engineering Hours + ε

Assumptions and Limitations

The following assumptions and limitations are formulated for this research:

1. The Research method and procedures used in the conduct of this study are appropriate.
2. The Producibility Enhancement and Performance Improvement (PE/PI) projects that are issued drawings are selected for this study.
3. For the regression analysis, the data set should be more than eight.
4. If the regression analyses are not appropriated, then a factor method will be used.
5. Outliers in the data set are omitted.

PE/PI PROJECT

Introduction

A cargo aircraft system (PE/PI) contracts started after First Flight and Production Enhancement. The PE/PI effort incorporates new design, modifies the aircraft systems, and updates new technology for the First Flight aircraft (T-1). A PE/PI contract can be summarized as (a) Perform studies and analyses, (b) Design, develop, test, and prototype C-17 weapon system improvement and enhancement, (c) System engineering investigation for software block upgrade analyses, studies, and plans final design including software lab infrastructure, and (d) Flight test maintains testing capability. The PE/PI projects, therefore, operate separately with the production of aircraft. The outcomes of PE/PI projects applied to the T1 are incorporated into the production.

Three Phases of C-17 PE/PI

The cargo aircraft PE/PI program has more than 15 years ago in August 1995 after four years after the first flight September 15, 1991. The engineering character of PE/PI contracts can be categorized in three phases in view of aircraft system development modification. The aircraft system development and modification can be explained by engineering drawings (EO)

After the first flight, some structure required a modification or update from the original structural design. The first phase, from 1995 through 2000, had structure oriented contracts. Most contract work was structure related projects, therefore, engineering design groups, such as Fuselage, Wing Structure Mission Systems, Propulsion/Environment, Hydraulic/Mechanical Engineering including Electrical Engineering were heavily involved in the first phase. Chart 1 shows the engineering order (EO) output from the engineering design group in the Phase 1.

In the second phase, from 2001 through 2004, the period of the engineering design effort slowly declined and the Avionics and Flight Controls group's effort started to grow. In the third phase, from 2004 through 2010, projects of the Avionics and Flight

Control's activity were had a very high volume, along with electrical engineering group, which supporting Avionics/Flight Control's boxes or instruments.

Chart 1: The cargo aircraft EO produced by Engineering Design Group for PE/PI

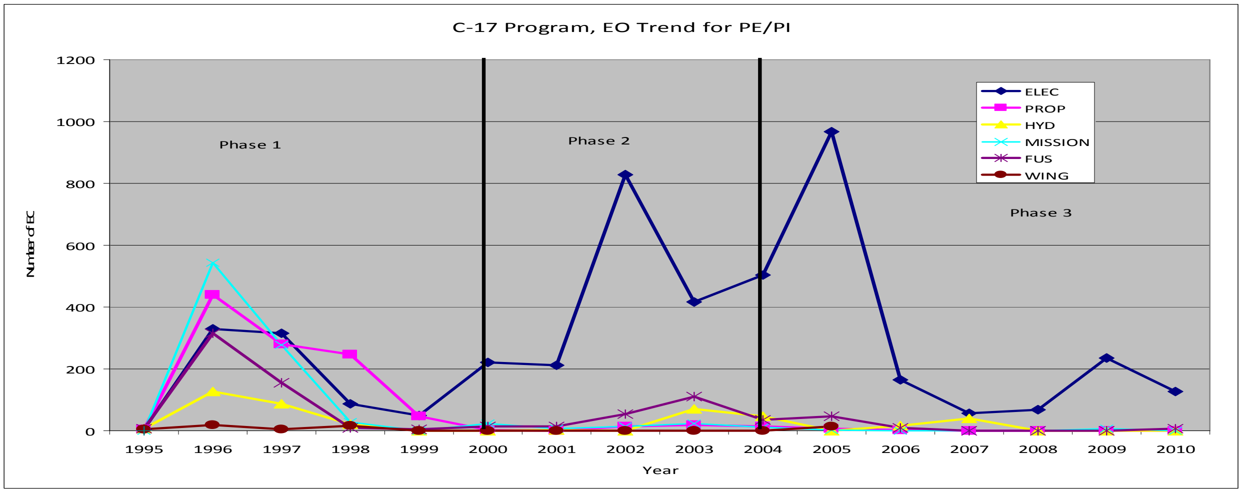
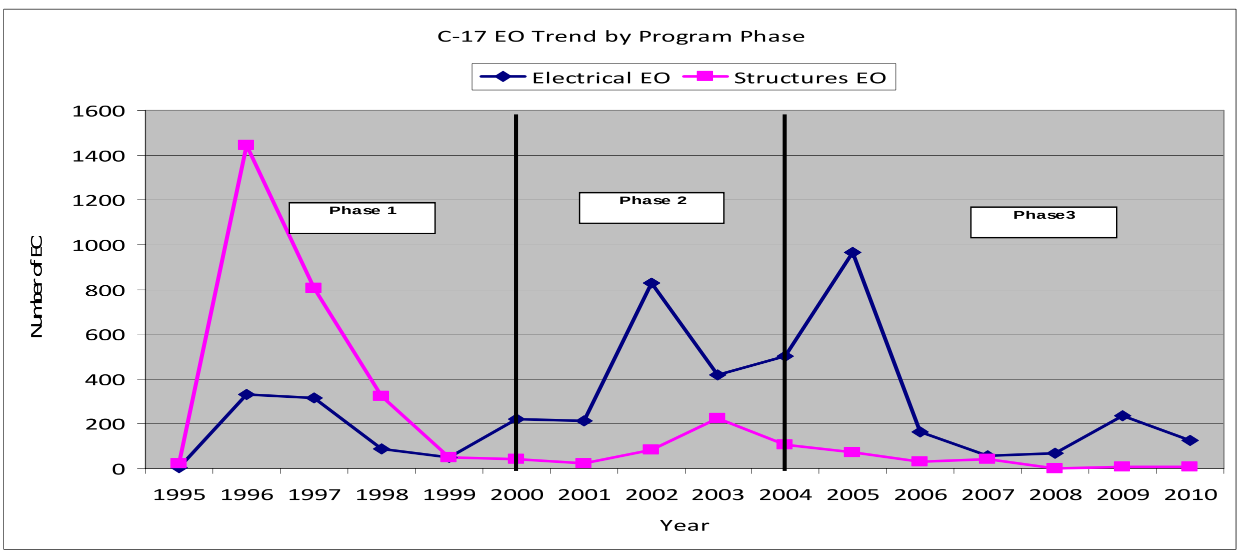


Chart 2: The cargo aircraft Engineering Orders (EO) for PE/PI



All combined EOs produced from the ED group except the Electrical engineering group are shown in the Chart 2. Electrical engineering drawings showed high volume of EO because this group required the support of software design and avionics design.

Electrical engineering drawings, therefore, showed were high numbers in the second half of Phase 2 and first half in the Phase 3 EO count.

Technology transfer involves the process of sharing skills, knowledge, technologies, methods of manufacturing, and facilities among governments and other institutions. Many industries can use then further to develop and exploit the technology into new products, processes, applications, materials or services. Technology changes in software are remarkably developing in many areas that impact the avionic and flight control area in the aircraft. For example, in the third phase, from 2005 through 2010, the Avionics/Flight Controls group's efforts including electrical system engineering were growing in order to install and upgrade software engineering systems because of the technology changes by time.

STATISTICAL ANALYSIS AND DISCUSSION

Introduction

This section presents the results of statistical analysis from the complied data of engineering labor hours and engineering drawings by projects. For this study, the analysis involved two major steps. The first step was data preparation, which organized the data for analysis. The second step was inferential statistics, which tested the hypotheses and models.

A part of the research process required statistical analysis in order to evaluate the statistical significance of the gathered engineering data. Researchers who use quantitative research for experimental studies employ statistical methods for analysis of the measurement and causal relationships between independent and dependent variables, which generate the hypotheses to be tested. The statistical analysis was applied to investigate the research hypotheses directly related to the independent variables in an engineering organization described in this research.

PE/PI Data Preparation

Data preparation involved setting up a procedure for logging the information from a company's accounting system and keeping track of it in order to do a comprehensive data analysis. After the data had been compiled, the researcher used various methods to summarize the data. Next the researcher checked all the data to ensure that the data were within acceptable limits and boundaries. Finally, the researcher transferred the data and developed and documented a database that integrated the various measures.

Statistical Analysis

For the research analysis, the major inferential statistics for regression model analysis included Analysis of Variance (ANOVA) and coefficients analysis.

An ANOVA table presents five statistical indicators (a) correlation coefficient, (b) R-squared, (c) Adjusted R-square, (d) standard error, and (e) F-value. Correlation coefficient of (Pearson's r) measured the strength of the linear relationship between two variables, IV and DV.

The Correlation coefficient (Pearson's r) or Multiple R denoted as R is an indication of the relationship between two variables. In simple terms, if R is greater than zero and close to one, then the two variables are closely related. An increase in X will result in a corresponding increase in Y. If R is less than zero and close to minus one, then the two variables are closely related but inversely. An increase in X will result in a corresponding decrease in Y. R being near zero means that the two variables are not related at all. A change in X will not necessarily result in a change in Y.

R-squared (Coefficient of determination) presents the proportion of the total sample variability around the mean of DV and is explained by the linear relationship between IV and DV. Another factor that might be seen is "Adjusted R Squared." which takes into account the number of data points. If there is a subset of the total data, then the accuracy of the result will generally be less. Furthermore, a smaller standard error implies a more reliable prediction and, therefore, smaller confidence interval.

ANOVA provides the statistical results for the overall model fit in terms of the F ratio. The *F*-test determines the relationship between IV and DV is large enough to be meaningful. If the *F*-test is significant, then the relationship is linear, therefore, the model significantly predicts the required engineering cost estimates. For this study, the critical value of *F* is 4.0 with $\alpha = 0.05$. When all computed value of the *F*-test statistics fall in the rejection category, where the computed *F*-value greatly exceeds *F*-critical value of 4, the data provide strong evidence that at least one of the model's coefficients is non zero.

Level of Significance: The level of significance used for this study was 0.05 with a one-tail rejection region (Mendenhall & Sincich, 2003).

Hypotheses Test Results

Finally, this study was conducted to support regression method. An analysis was performed for each hypothesis and model to gauge the independent effect in the models. Statistically, the model provided a good fit to the sets of data, which provided a reliable estimate of the mean value of engineering hours and proved be a good predictor of the future of the engineering hours.

Of the three independent variables, some individual variables might have a stronger statistical relationship than the others. Further, all of these analyses and supporting hypotheses are just assumptions until the actual information or data collected by the survey and statistical analysis have been concluded.

This section presents three hypotheses and models employing two tables: (a) regression statistics and ANOVA and (b) coefficients analysis and research model. All three statistics indicated how well the independent parameters predict the criterion variable which is the engineering hours. The three hypotheses, related models, and inferential statistics are delineated below by three phases.

The Cargo Aircraft System Phase 1 (August 1995 – December 2000)

Hypothesis 1 and Research Model 1

Hypothesis 1: There is a positive relationship between the Engineering Orders (EO) and Engineering Design hours.

Model 1: ED Hours = $\beta_0 + \beta_1 EO + \varepsilon$

Model 1 regression statistics and ANOVA. Table 1 presents six statistical indicators for the Model 1. The interpretation of a Multiple r or correlation coefficient, also known Pearson's r, depends on the context and purposes. A correlation of 0.9 may be very low if the researcher is verifying a physical law by using high-quality instruments, such as medical or aerospace instruments, but it may be regarded as very high in the social sciences in which there may be a great contribution from complicating factors. Parson (1933) prepared an evaluation of correlation coefficients table in order to interpret the Pearson's r. If the numeric value for R is lower than 59%, it is defined as a poor category, 60-79% as moderate, and 80-90% as high. The Pearson's r is a measure of the strength of the linear relationship between EO and Engineering Design Group hours; the higher correlation coefficient, the stronger the relationship and hence the greater the predictive accuracy.

Table 1: Model 1 Regression Statistics and ANOVA

Department Name	Obs	Multiple R	R-square	Adj R-square	SE	F-value
Electrical Engineering	13	52.4%	27.4%	20.8%	7,825.9	4.16
Fuselage	8	94.4%	89.2%	87.4%	29,530.0	49.37

Based on the evaluation of correlation coefficients in the Table 1, Electrical Engineering (52.4%) is too low: however, Fuselage (94.4%) in Model 1 has a high Pearson's r. Therefore, the Fuselage group statistics appear only useful model in Model 1. The *R*-squared, coefficient of determination, explains the probability of accounting for the prediction of the engineering design hours in the model. For example, Model 1, Fuselage, can be explained as 89.2% by the independent variable of EO. In addition, because four other groups, such as Wing Structure, Final/Mission Systems, Hydraulic Mechanical, and Propulsion/Environmental Systems had less than 8 observations, these group's regression statistics were not included in the Table 1.

Model 1 coefficients analysis. Table 2 explains four different statistics in the coefficients table (a) coefficients that are parameter estimate, negative or positive, (b) standard error, a smaller standard error implies more reliable prediction and, therefore, is the smaller confidence interval, (c) t-statistics, small or greater than t critical value, and (d) p-value, smaller or greater than 0.02. Furthermore, p-value was used to determine any meaningful coefficients of predictive power that dependent variables have over a given period of time. Analyses of coefficients show a validation of a regression and also indicate an efficient of the coefficients.

Table 2: Model 1 Coefficients

	Coefficient		SE		t-stat		P-value	
Department Name	Intercept	EO	Intercept	EO	Intercept	EO	Intercept	EO
Electrical Engineering	(2,886.1)	189.6	5,314.9	93.0	(0.54)	2.04	0.66	0.07
Fuselage	2,335.0	81.5	1,241.2	11.6	1.88	7.03	0.11	0.00

The t-statistics and P-value are the main statistical data to validate the simple regression. Analyzing the intercept coefficient of the fuselage model, the intercept of t-stat and P-value are 1.88 and 0.11, respectively. Upon the interception of t-stat, 1.88 is less than t critical value of 2.201 and for the P-value of intercept, 0.11 is greater than 0.02. As a result, the intercept of 2,338.0 does not have a strong impact the Fuselage parametric estimating model. On the other hand, the coefficient of EO has a good parameter in the Model 1 more than the intercept. The t-stat and P-value of the coefficient are 7.03 and 0.00 respectively, which are in the region of the acceptable criteria.

In summary, only the Fuselage model is statistically significant in the Model 1. The usable Fuselage cost estimating model is

Fuselage Hours = 81.5 * EO + 2,335.0

Hypothesis 2 and Research Model 2

Ha-1: There is a relationship between numbers of EO and the ER hours.

Ha-2: There is a relationship between Engineering Design hours and the TDS hours.

Model 2-1: ER Hours = $\beta_0 + \beta_1$EOs + ε

Model 2-2: EDSG Hours = $\beta_0 + \beta_1$EDG Hours + ε

Model 2 regression statistics for ANOV and Coefficient. Tables 3 and 4 present two groups statistical indicators for the model 2.

Table 3: Model 2 Regression Statistics and ANOVA

Department Name	Obs	Multiple R	R-square	Adj R-square	SE	F-value
Engineering Release	25	56.3%	31.7%	28.7%	1,970.4	10.66
Technical Design Service	17	70.6%	49.8%	46.4%	394.2	14.87

Table 4: Model 2 Coefficients

	Coefficient		SE		t-stat		P-value	
Department Name	Intercept	EO	Intercept	EO	Intercept	EO	Intercept	EO
Engineering Release	864.6	7.1	458.2	2.2	1.89	3.27	0.07	0.00

	Coefficient		SE		t-stat		P-value	
Department Name	Intercept	EDG	Intercept	EDG	Intercept	EDG	Intercept	EDG
Technical Design Service	(122.5)	0.0	144.3	0.0	(0.85)	0.39	0.41	0.00

In summary, both groups are not acceptable in Model 2 as can be seen in Tables 3 and 4.

Hypothesis 3 and Research Model 3

Hypothesis 3: There is a relationship between Total Engineering (TE) hours and the ES group hours.

Model 3: ES Group Hours = $\beta_0 + \beta_1$TE Hours + ε

Model 3 regression statistics for ANOV and Coefficient. Tables 5 and 6 show four statistical indicators for the Model 3. In summary, the engineering support group is unacceptable in Model 3 as can be seen in the tables 5 and 6.

Table 5: Model 3 Regression Statistics and ANOVA

Department Name	Obs	Multiple R	R-square	Adj R-square	SE	F-value
Engineering Support	11	57.2%	32.8%	25.3%	585.9	4.38

Table 6: Model 3 Coefficients

	Coefficient		SE		t-stat		P-value	
Department Name	Intercept	Eng Total	Intercept	Eng Total	Intercept	Eng Total	Intercept	Eng Total
Engineering Support	351.2	0.0	217.6	0.0	1.61	2.09	0.14	0.07

Hypothesis 1 and Research Model 1

Hypothesis 1: There is a positive relationship between the Engineering Orders (EO) and Engineering Design hours.

Model 1: ED Hours = $\beta_0 + \beta_1 EO + \varepsilon$

Model 1 regression statistics for ANOV and Coefficient. Tables 7 and 8 present ANOVA and Coefficient Analysis indicators for the Model 1. Only electrical engineering has more than eight statistical data and also the electrical engineering is acceptable to use as parametric estimating tool based on two tables, Table 7 and Table 8. In addition, because five other groups had less than 8 observations, these group's regression statistics were not included in the Table 7.

Table 7: Model 1 Regression Statistics and ANOVA

Department Name	Obs	Multiple R	R-square	Adj R-square	SE	F-value
Electrical Engineering	13	79.5%	63.1%	59.8%	11,526.8	18.86

Table 8: Model 1 Coefficients

	Coefficient		SE		t-stat		P-value	
Department Name	Intercept	EO	Intercept	EO	Intercept	EO	Intercept	EO
Electrical Engineering	2,235.0	146.9	3,790.0	33.8	0.59	4.34	0.57	0.00

In summary, the electrical engineering model is statistically significant in the Model 1. The p-value of intercept, 0.57, is greater than 0.22, therefore, the intercept of 2,235.0 does not strongly support of the Electrical parametric model. The usable Electrical engineering estimating model is:

Electrical Hours = 146.9 * EO + 2,235.0

Hypothesis 2 and Research Model 2

Ha-1: There is a relationship between numbers of EO and the RE hours.

Ha-2: There is a relationship between Engineering Design hours and the TDS hours.

Model 2-1: ER Hours = $\beta_0 + \beta_1$EOs + ε

Model 2-2: EDSG Hours = $\beta_0 + \beta_1$EDG Hours + ε

Model 2 regression statistics and ANOVA. Table 9 presents statistical indicators for the model for the two groups', Engineering Release and Technical Design Service.

Tables 9 and 10 present ANOVA and Coefficient Analysis indicators for the Model 2. Both groups have good statistical data but the TDS model is more acceptable to use as parametric estimating tool than Engineering Release.

Table 9: Model 2 Regression Statistics and ANOVA

Department Name	Obs	Multiple R	R-square	Adj R-square	SE	F-value
Engineering Release	10	82.2%	67.6%	63.5%	5765.9	16.66
Technical Design Service	8	86.8%	75.3%	71.2%	2,798.10	18.3

Table 10: Model 2 Coefficients

	Coefficient		SE		t-stat		P-value	
Department Name	Intercept	EO	Intercept	EO	Intercept	EO	Intercept	EO
Engineering Release	(2,146.2)	28.0	2,294.2	6.9	(0.94)	4.08	0.38	0.00

	Coefficient		SE		t-stat		P-value	
Department Name	Intercept	EDG	Intercept	EDG	Intercept	EDG	Intercept	EDG
Technical Design Service	(426.8)	0.1	1,368.2	0.0	(0.31)	4.28	0.77	0.01

Note that there is a negative intercept. Because the negative Engineering Release or TDS hours are not possible, this environment seems to make the models nonsensical. Thus, the y-intercept, negative values which are, by definition, at X = 0 is not within the range of sampled values of X and is not subject to meaningful interpretation. The model parameters, however, should be interpreted only within the sample range of the independent variable.

In summary, the TDS group and engineering release group have strong statistical data as can be seen in Tables 9 and 10. The two groups' parametric equations are:

Engineering Release hours = 28.0 * EO – 2,146.2

TDS hours = 0.1 * ED group hours – 426.8

Hypothesis 3 and Research Model 3

Hypothesis 3: There is a relationship between Engineering Total (ET) hours and the ES group hours.

Model 3: ES Group Hours = $\beta_0 + \beta_1$ET Hours + ε

Model 3 regression statistics and ANOVA. Table 11 presents four statistical indicators for the model 3.

Table 11: Model 3 Regression Statistics and ANOVA

Department Name	Obs	Multiple R	R-square	Adj R-square	SE	F-value
Engineering Support	12	89.2%	79.6%	77.6%	1,080.7	39.12

Model 3 coefficients analysis. Table 12 shows four different statistics in the coefficients.

Table 12: Model 3 Coefficients

	Coefficient		SE		t-stat		P-value	
Department Name	Intercept	Eng Total	Intercept	Eng Total	Intercept	Eng Total	Intercept	Eng Total
Engineering Support	863.3	0.02	384.9	0.00	2.24	6.25	0.05	0.00

In summary, the parametric model of the Engineering Support group is acceptable in Model 3 as can be seen in Table 11 and 12. The engineering support group's cost estimating model is:

ES group Hours = 0.02 * ET hours + 863.3

The Cargo Aircraft System Phase 3 (January 2005 – June 2010)

Hypothesis 1 and Research Model 1

Hypothesis 1: There is a positive relationship between the Engineering Orders (EO) and Engineering Design hours.

Model 1: EDL = $\beta_0 + \beta_1$EO Hours + ε

Model 1 regression statistics for ANOV and Coefficient. Tables 13 and 14 present ANOVA and Coefficient Analysis indicators for the Model 1. Electrical is acceptable to use as parametric estimating tool based on two tables, Table 13 and Table 14. In addition, because five other groups had less than 8 observations, the egression statistics of these groups were not included. In summary, the parametric equation for the electrical engineering cost estimating is:

Electrical Engineering Hours = 105.9 * EO + 609.1

Table 13: Model 1 Regression Statistics and ANOVA

Department Name	Obs	Multiple R	R-square	Adj R-square	SE	F-value
Electrical Engineering	8	98.1%	96.3%	95.7%	5,171.3	157.2

Table 14: Model 1 Coefficients

	Coefficient		SE		t-stat		P-value	
Department Name	Intercept	EO	Intercept	EO	Intercept	EO	Intercept	EO
Electrical Engineering	609.1	105.9	2,226.5	8.5	0.27	12.50	0.79	0.00

Hypothesis 2 and Research Model 2

Ha-1: There is a relationship between numbers of EO and the RE hours.

Ha-2: There is a relationship between Engineering Design hours and the TDS hours.

Model 2-1: ER Hours = $\beta_0 + \beta_1$EOs + ε

Model 2-2: EDSG Hours = $\beta_0 + \beta_1$EDG Hours + ε

Model 2 regression statistics and ANOVA. Tables 15 and 16 present ANOVA and Coefficient Analysis indicators for the two groups', Engineering Release and Technical Design Service, Model 2. Both groups have statistical data but the TDS is more acceptable than Engineering Release to use as parametric estimating tool. Engineering Release group's statistics are acceptable based on the statistics of Table 16. In summary, the parametric equation for the Engineering Release cost estimating is:

Engineering Release hours = 3.4 * EO – 255.4

Table 15: Model 2 Regression Statistics and ANOVA

Department Name	Obs	Multiple R	R-square	Adj R-square	SE	F-value
Engineering Release	12	88.8%	78.8%	76.7%	452.3	37.3
Technical Design Service	16	59.5%	35.5%	30.8%	1,888.5	7.7

Table 16: Model 2 Coefficients

	Coefficient		SE		t-stat		P-value	
Department Name	Intercept	EO	Intercept	EO	Intercept	EO	Intercept	EO
Engineering Release	(255.4)	3.4	192.1	0.6	(11.70)	6.10	0.27	0.00

Hypothesis 3 and Research Model 3

Hypothesis 3: There is a relationship between Engineering Total (ET) hours and the ES group hours.

Model 3: ES Group Hours = $\beta_0 + \beta_1$ET Hours + ε

Model 3 regression statistics and ANOVA. Tables 17 and 18 present statistical indicators for the model 3.

Table 17: Model 3 Regression Statistics and ANOVA

Department Name	Obs	Multiple R	R-square	Adj R-square	SE	F-value
Engineering Support	19	59.0%	34.8%	31.0%	2,483.9	9.08

Table 18: Model 3 Coefficients

	Coefficient		SE		t-stat		P-value	
Department Name	Intercept	Eng Total	Intercept	Eng Total	Intercept	Eng Total	Intercept	Eng Total
Engineering Support	2,162.6	0.02	798.5	0.01	2.71	3.01	0.01	0.01

In summary, the parametric model of Engineering Support group is unacceptable in Model 3 as can be seen in Tables 17 and 18.

Discussion of Research Findings

Engineering parametric models in previous chapters produced 4 equations by 3 Models in the three phases. As predicted, each phase has a unique character of engineering performance in various groups. Only structure engineering and electrical engineering had acceptable statistical results in Phase 1, however, structure engineering had better statistical value than did electrical statistics. The engineering design support group (Model 2) and engineering support group (Model 3) had unacceptable statistical results.

In Phase 2, only the electrical engineering, the engineering design support group (Model 2), and the engineering support group (Model 3) had a strong regression relationship. Because the structure of the first aircraft (T-1) had most likely been improved or modified in Phase 1, the electrical engineering effort continued to grow along with other design support groups, such as engineering release group, technical design service, and engineering support group. Furthermore, Avionics and Flight Controls had a strong start in engineering performance because of technical changes.

In Phase 3, the electrical engineering group in Model 1 and the engineering release group in Model 2 showed a strong relationship, whereas the technical design service group had poor statistics. As predicted, technology changes in software remarkably impacted the avionic and flight control areas in the aircraft. The technical phenomena provided many software related projects including electrical engineering effort in order to support Avionic equipments.

CONCLUSION

As predicted, each phase has a unique character of engineering performance in various groups. Below is a summary.

Phase 1 Models. In Model 1, the Fuselage engineering group had acceptable statistics and Model 2 and 3 were unacceptable as a parametric estimating model.

Phase 2 Models. Only the Electrical engineering group had acceptable as estimating tool in Model 2. Model 2and Model 3 were also acceptable as parametric estimating model.

Phase 3 Models. Only the Electrical engineering group in Model 1 and Engineering Release group in Model 2 had acceptable statistics, and Model 3 was unacceptable as parametric estimating model.

In conclusion, although this research explored, identifiable characteristics and engineering performance in engineering environment, this paper supports and establishes the relative degree of importance between engineering hours and engineering parameters through simple regression. As practical use of an estimating tool, the method should use all estimates, not only partial use.

In reviewing all models in the three phases, the partial parametric estimating tool cannot be used to estimate PE/PI projects. The answer for this solution is to use a factor method. The factor estimating method is the most desirable estimating method in detail and will be explained in the next section.

Factor Estimating Method

The factor estimating method can be a successful tool to use for the development projects cost estimates. The factor estimating method can provide a good estimate for each department in a project costs development in the development phase for a weapon system. This factor estimating method uses historical data in developing projects by applying a valid relationship among engineering groups.

The prepared engineering base build factors on the three engineering functional areas, which will be explained in the next section. The relationship among the three engineering functional areas was described in the Hypotheses Test and Research Models section.

The first factor method in engineering design group is hours per EO. The second factor method is a piggyback factor method between the engineering design group and the engineering design support group. The last method is another piggyback factor method for the total engineering effort and the engineering support group. The prepared factor method in the three phases of the C-17 program as an example can be seen in Table 19. The three areas of engineering organization and how to apply to the cost estimates will explained in the next section.

Engineering Design Group

Hours per EO. All six design departments are using hours per EO for a project estimates.

Application. First, when a project requires estimates, the estimator prepares to find out the required drawing which is initial release (IR) for the project. Then, the estimator calculates the EO (IR+AIR) by applying "IR vs AIR" ratio as shown in the Table 19.

Table 19: Recommendations for Factor Method (Sample)

	1995 - 2000			2001 - 2004			2005 - 2010		
Department Name	**Hours**	**EOs**	**Hours/EO**	**Hours**	**EOs**	**Hours/EO**	**Hours**	**EOs**	**Hours/EO**
Wing Structure	2,545.4	25	**101.8**	5,606.5	20	**280.3**	6,992.3	13	**537.9**
Electrical	102,103.4	713	**143.2**	143,947.3	782	**184.1**	203,834.5	2,810	**72.5**
Fuselage	84,346.8	487	**173.2**	42,000.6	188	**223.4**	18,933.5	92	**205.8**
Final/Mission Systems	101,750.2	841	**121.0**	24,492.7	72	**340.2**	12,510.5	25	**500.4**
Hyrdro Mechanical	22,374.0	213	**105.0**	7,821.3	36	**217.3**	24,101.9	121	**199.2**
Propulsion/Environmental System	33,951.3	293	**115.9**	129,312.9	751	**172.2**	12,088.2	32	**377.8**
Eng Design (ED) Group Total (A)	**347,071.1**	**2,572**		**353,181.3**	**1,849**		**278,460.9**	**3,093**	
Standards		32			34			51	
Avionics/Flight Controls		109			23			92	
Others		20			154			179	
	Total EOs	**2,733**		**Total EOs**	**2,060**		**Total EOs**	**3,415**	
		% to EDG	**Hours/EO**		**% to EDG**	**Hours/EO**		**% to EDG**	**Hours/EO**
Engineering Release	41,446.4		**15.2**	35,419.0		**17.2**	7,776.2		**2.3**
M & P /Standards	2,595.5	0.7%		7,403.3	2.1%		17,930.1	6.4%	
Design Assurance	810.6	0.2%		10,656.1	3.0%		15,276.7	5.5%	
UG II Support	1,687.0	0.5%		7,238.2	2.0%		0.0	0.0%	
Design Integration	167.5	0.0%		3,736.0	1.1%		30,728.9	11.0%	
Design Support Total	**5,260.6**	**1.5%**		**29,033.6**	**8.2%**		**63,935.7**	**23.0%**	
Avionics	175,991.0			132,881.3			190,331.2		
Flight Controls	22,820.5			8,013.3			85,583.8		
Core Integration Processor	244,148.8			341,323.3			764,583.2		
Avionics System & Integration	0.0			5,610.4			337,470.5		
Sumulators	27,544.7			510.2			1.0		
AV/FLT Integration	3,065.4			7,692.0			9,636.1		
Avionics/Flight Controls Total (B)	**473,570.4**			**496,030.5**			**1,387,605.8**		
Total Engineering (A + B)	**820,641.5**			**849,211.8**			**1,666,066.7**		
		% to Eng Base			**% to Eng Base**			**% to Eng Base**	
Contract Compliance	718.6	**0.1%**		7,474.9	**0.9%**		4,403.0	**0.3%**	
Configuration Management	4,266.3	**0.5%**		6,616.0	**0.8%**		14,108.7	**0.8%**	
System Engineering	n/a			5,120.6	**0.6%**		44,080.7	**2.6%**	
Performance	840.4	**0.1%**		8,196.3	**1.0%**		10,975.6	**0.7%**	
Sub Total	5,825.3	**0.7%**		27,407.8	**3.2%**		73,568.0	**4.4%**	
Department Name	**IR**	**AIR**	**IR vs AIR Ratio**	**IR**	**AIR**	**IR vs AIR Ratio**	**IR**	**AIR**	**IR vs AIR Ratio**
Wing Structure	24	1.0	**0.04**	20	0	**0.00**	12	1	**0.08**
Electrical	513	200.0	**0.39**	511	271	**0.53**	1,980	830	**0.42**
Fuselage	318	169.0	**0.53**	119	69	**0.58**	77	15	**0.19**
Final/Mission Systems	488	353.0	**0.72**	62	10	**0.16**	20	5	**0.25**
Hyrdro Mechanical	80	133.0	**1.66**	18	18	**1.00**	81	40	**0.49**
Propulsion/Environmental System	169	124.0	**0.73**	253	498	**1.97**	27	5	**0.19**

Second, the estimator applies the department's hours/EO to the calculated EO. However, a new project is not similar to the old projects because the project is a development related project. For that reason, the estimator establishes a "complexity factor" by comparing the requirements between the old project and new project. Finally, the estimator applies the calculated EO to hours/EO with applied the "complexity factor" if it is necessary for the project estimates.

Engineering Design Support Group

Hours per EO. The Engineering Release group uses hours per EO, which is all drawing produced in engineering departments including AVFC, Standards, and M&P Engineering.

Percent to ED. M&P engineering, Design Assurance, and Design integration department use certain percent to ED.

Application. Determine the total required drawing for the project and apply hour/EO for the engineering release department. Other groups in engineering design support group apply the related group percent to the engineering drawing groups' total hours.

Engineering Support Group

Percent to Total Engineering. All supporting groups' estimates are a certain percent to total engineering estimates which is total of engineering drawing groups' estimate and AFVC's estimates.

Application. All groups' estimates calculated using the related group's percent to the total engineering hours.

By reviewing the factor table, the engineering factors were increasing along with the phases. The reason could be that the company requires keeping a certain level of employees while workloads are declining. That might increase the factors.

RECOMMENDATIONS FOR FUTURE RESEARCH

Introduction

This study opens another avenue of opportunity in quantitative research toward not only engineering groups but also manufacturing groups. For further study, there is an argument about how much the other engineering group use parametric estimate or factor method. Some recommendation for future study subjects are discussed in the followings.

Avionics/Flight Controls (AVFC), Software Engineering Group:

Software Engineering Model.

Software Engineering Hours = f (hours per SLOC)

Software Engineering Hours = $\beta_0 + \beta_1$SLOC Hours + ε

Note: Effective SLOC = New SLOC + (Reused SLOC * (X1% * %Redesign) + (X2% * X3% Recode) + (X4% * Retest)))

Avionics/Flight Controls Test Lab

Avionics/Flight Controls Test Lab Model.

AV/FC Lab Hours = f (AVFC Lab Hours)

AVFC Lab Hours = $\beta_0 + \beta_1$AVFC Hours + ε

Flight Test

Flight Test Model.

Flight Test Hours = f (# of flight test and the hours associated with the flight test)

FT Hours = $\beta_0 + \beta_1$Number of Flight Test + ε

Business Management (BM) Group

BM Group Model.

BM Group Hours = f (number of business control account and the period of account)

BM Group Hours = $\beta_0 + \beta_1$Numer of CA + β_2Months of CA + ε

The above model may require multiple regressions and the Engineering Design group can add another parameter, project period of time associated EO.

Engineering Design Group Hours = $\beta_0 + \beta_1$EO + β_2Months of Project + ε

In a multiple regression two independent variables, such as the number of EO and the length of the project period in a project, may have multicollinearity; a case of multiple regression in which the independent variables are themselves highly correlated.

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Autobiography

Myung-Yul (M-Y) Lee is an estimator on the C-17 Transport Aircraft Performance Enhancement/Producibility Improvement (PEPI) group. M-Y Lee performs estimates for PE/PI projects, Engineering Change Proposals (ECPs), and Contract Change Proposals (CCPs) for the Air Force Integrated Defense Systems. M-Y Lee is responsible for collection and analysis of historical cost and non-cost (characteristic) data from C-17 engineering, including cost modeling, similar-to-analysis, and development of cost estimating relationships (CERs).

He has more than 35 years of Aerospace experience in various fields, such as project management, business management, and estimating for the three companies; Hughes Helicopter (Apache program), Rockwell International (B-1 B program), and McDonnell Douglas (C-17 Program). Now all these companies are under the Boeing Company.

He has received his Doctor of Business Administration degree from Argosy University and has completed Master of Science degree in Economics from Illinois State University.

His hobbies are oil painting and running.