C-17 Program, The Boeing Company

Using C-17 Program's Data to Build a Parametric Model for the Engineering Organization

Introduction

The Boeing Company, C-17 program, located in Long Beach, California has produced more than 171 cargo aircraft to the U.S. Air Force after its first flight on September 15, 1991. The Boeing C-17 Program Office has responsible for managing the Producibility Enhancement/Performance Improvement (PE/PI) contracts. The major efforts under the PE/PI contract are:

- Perform studies and analyses
- Design, develop, test and prototype C-17 Weapon System improvements and enhancement
- Develop change proposal for Production and retrofit incorporation into aircraft

Purpose of the Study

When a new program starts, discrete estimating method is used because there is not enough historical data to utilize other methods such as an analogy estimating method or parametric estimating method. The C-17 program has been successful for more than 16 years since its first flight and there is enough data to create a Cost Estimating Relationships (CERs) using PE/PI projects' data.

Research Question

The main purpose of engineering labor estimate is to calculate the required labor hours for each PE/PI project. We can ask, "Is there any relationship among engineering labor hours, drawings, and period of the PE/PI project?" We can treat the engineering labor hours as dependent variable and number of drawings that produce by drawing design groups and the period of PE/PI project as independent variables.

Procedures and Methodology

Null Hypothesis

There are three possible research questions for this study:

Hypothesis 1: There is no relationship between engineering design labor hours and number of drawings including period of the project.

Hypothesis 2: There is no relationship between engineering design labor hours and number of drawings.

Hypothesis 3: There is no relationship between Total Supporting Group labor hours which were Drawing Design Group (DDG) Support labor hours plus Engineering Support Group (ESG) labor hours and Total Engineering hours which were DDG hours and Avionics/Flight Control Group labor hours.

Alternative Hypothesis

There are three alternative hypotheses for this study:

Hypothesis 1: There is a relationship between engineering design labor hours and number of drawings including period of the project.

Hypothesis 2: There is a relationship between engineering design labor hours and number of drawings.

Hypothesis 3: There is a relationship between Total Supporting Group labor hours which were DDG Support labor hours plus ESG labor hours and Total Engineering hours which were DDG hours and Avionics/Flight Control Group labor hours.

Functional Restructure of Engineering Group

In order to generate the CER, the Engineering organization has restructured as four major groups such as Design Drawing Group (DDG), Avionics/Flight Control Group, DDG Supporting Group, and Engineering Supporting Group (ESG). The restructured organization is based on the functional commonality.

DDG includes six drawing design groups such as Wing Structure, Fuselage, Electrical, Mechanical/Hydraulic, Final/ Mission Systems, and Propulsion/Environmental engineering groups. Avionics/Flight Control Group consists of Avionics, Flight Controls, Avionics Systems, Software Planning and Requirement Analysis, and Avionic Design. DDG Supporting Group such as Engineering Drawing Release, Material and Process Engineering, and Design Integration is a group to support DDG group. ESG such as Configuration Management, Change Management, System Safety, System Engineering, Weight, and Supportability which includes Reliability and Maintainability, Aerodynamics, and human factors involves to support DDG and also Avionics/Flight Control Group.

Data Preparation and Statistical Criteria

Data Preparation

The criteria of compiled historical data from the PE/PI project are as follows:

1. Used PE/PI projects from inception, August 1995 to ending December 2007.
2. Compiled PE/PI projects which were completed more than 90% as of December 2007.
3. Collected number of drawings, period of PE/PI projects, and labor hours were based on criteria #2.
4. PE/PI project with less than 50 labor hours or no issued drawing was eliminated from the Design Drawing Groups' Database.
5. Project had less than 10 drawings were not counted in the drawing data compiling.
6. "AV/FC Hours" less than 100 hours and no drawing issued in the projects were eliminated from the Engineering Support Groups (ESG) supporting data compiling.
7. Software related projects were not counted from ESG supporting data compiling.

Statistical method

A factor method or regression analysis will be applied for this study.

Level of Significance

The level of significance used for this study was 0.05 with a one-tail rejection region.

Statistical Analysis

We can rewrite the three hypotheses as follows

Case 1: Engineering design labor hours = f (# of drawings and period of the project)

Case 2: Engineering design labor hours = f (# of drawings)

Case 3: Total Supporting Group hours = f (Total Engineering hours)

Statistical Test Case 1 and Case 2

First we will study hypothesis 1 and 2, which one has more statistically significance than the other in view of three statistical analysis; coefficient of determination (R^2), t-Test, and Analysis of Variance (ANOVA).

The coefficient of determination (R^2)

The coefficient of determination (R^2): The coefficient of determination (R^2) is a statistic that will give some information about the goodness of fit of a model. In regression, the Adjusted R^2 is more meaningful than R^2. Under this study we used two different independent variables.

From Table 1 in the Appendix, Airframe 2, Aircraft System 1, and Aircraft System 2 have better adjusted R^2 with two independent variables, however Airframe 1, Aircraft System 3, and Aircraft System 4 have better adjusted R^2 with one independent variable.

t-Test

The following Table "t-Test Comparison of Independent Variables" shows that the t-statistics and t-test calculations in Case 1 and Case 2. Five departments except Airframe 1 calculated t-value exceeds the critical t-value at the 0.05 level of significance. Therefore, there are a statistically significant relationship between the DDG labor hours and number of Engineering Order (EO) itself and number of EO & period of project.

For the following reason, when we define a drawing it means an Engineering Order (EO) and the EO is Initial Release (IR) plus After Initial Release (AIR).

The IR and AIR can be defined as follows.

The definition of IR is: (a) the first release of all drawings for a given project (identified by the CCB number) is considered the IR drawing and (b) in some cases this is a new (i.e. no change letter) drawing and in some cases this may be an existing drawing that is being modified for the project.

The definition of AIR is: (a) any subsequent release of that drawing with that CCB number is countered as an AIR, (b) in addition, any subsequent release of that drawing with an

"MC" CCB number where the Work Authority is a line stopper and the system log date is greater than the ACOR date of the previous change letter and the BUNFA is within 6 ships after the IR effectivity, is counted as an AIR, (c) the AIR count is determined by the number of drawings, not the number of Work Authorities.

t-Test Comparison of Independent Variables

	Two Independent Variables				One Independent Variable		
	Critical t-value	Calculated t-value			**Critical t-value**	Calculated t-value	
		EO	**Months**	**df**		**EO**	**df**
Airframe 1	**2.015**	0.7	0.42	5	**1.943**	3.42	6
Airframe 2	**1.734**	3.89	2.15	18	**1.729**	6.31	19
Aircraft System 1	**1.682**	5.5	4.32	42	**1.681**	9.1	43
Aircraft System 2	**1.753**	1.26	2.05	15	**1.746**	2.19	16
Aircraft System 3	**1.943**	5.35	-0.45	6	**1.895**	9.46	7
Aircraft System 4	**1.782**	7.67	0.37	12	**1.771**	13.67	13

Analysis of Variance (ANOVA)

When the value of Significance F and P-value is less than 0.05, then the independent variables have significant role in the regression. There are two ANOVA tables. Table 2 has ANOVA with two independent variables and Table 3 has ANOVA with one independent variable.

From Table 2 (ANOVA with two IVs), only Aircraft System 1 has both the value of Significance F and P-value less than 0.05 and Airframe 2 has just marginal, however the remaining departments are larger than 0.05 in both values, Significance F and P-value.

From Table 3 (ANOVA with one IV), the values of Significance F and P-value in all departments are less than 0.05. Therefore, one IV which is EO has more significantly impact on the regression than two IVs, the period of project and EO.

Statistical Test Case 3

Case 3 examined in view of three statistical analyses; coefficient of determination (R^2), t-Test, and Analysis of Variance (ANOVA).

The coefficient of determination (R^2)

From the Table 4, Engineering Support Group Summary Output, the Adjusted R^2 had 87.5% which was very significant.

t-Test

In the aspect of Aviations and Flight Contrls (AVFC) from Table 4, the null hypothesis 3 was not rejected since the calculated t-value of 0.002 does not exceeded the critical t-value of 1.703 at the 0.05 alpha level of significance. However, the calculated t-value of EO (15.025) exceeded the critical t-value of 1.703 at the 0.05 alpha level of significance. Therefore, EO has statistically significant.

Analysis of Variance (ANOVA)

The p-value of AVFC and EO has 0.99 and 0.0, respectively. That means the independent variable of AVFC has not significantly impact on the Total Engineering Supporting Hours.

Conclusions

We concluded that the period of project is not statistically impacted on DDG hours than EO. In other words, the EO has stronger impact on the DDG labor hours than EO & period of project. Second, there is no significant relationship between ESG hours and Total Engineering hours.

Further Study

The results obtained in this study were specific to the development non-recurring engineering effort during a production cycle. These results were limited drawing design group, drawing design supporting group, and engineering supporting group. This limitation left out a study in Avionics and Flight Controls.

Total Engineering Support Group hours and Total Engineering hours have no true relationship, therefore we could use a factor method. The factor method can be studies in two aspect. First is a relationship (ratio) between DDG support group hours vs. DDG hours. The second is a relationship (ration) between Engineering Support Group hours vs. Total Engineering Hours.

References

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Appendixes

Table 1: Drawing Design Group Summary Output

Regression Statistics - with Two Independent Variables; EO and Period of Project						
	Airframe 1	Airframe 2	Aircraft System 1	Aircraft System 2	Aircraft System 3	Aircraft System 4
Multiple R	82.0%	86.2%	87.9%	63.2%	96.4%	96.7%
R Square	67.3%	74.3%	77.3%	39.9%	93.0%	93.6%
Adjusted R Square	40.8%	67.3%	74.4%	29.2%	75.2%	84.7%
Standard Error	1,147.42	5,894.24	7,330.88	9,024.75	1,814.98	8,902.98
Observations	7	20	44	17	8	14

Regression Statistics - with One Independent Variable; EO						
	Airframe 1	Airframe 2	Aircraft System 1	Aircraft System 2	Aircraft System 3	Aircraft System 4
Multiple R	81.3%	82.3%	82.0%	48.1%	96.3%	96.7%
R Square	66.1%	67.7%	67.3%	23.1%	92.7%	93.5%
Adjusted R Square	49.5%	62.4%	64.9%	16.8%	78.5%	85.8%
Standard Error	1,066.13	6,429.80	8,706.96	9,885.02	1,708.82	8,601.53
Observations	7	20	44	17	8	14

Table 2: ANOVA with Two Independent Variables

Airframe 1

	df	*F*	*Significance F*
Regression	2	5.15	0.08
Residual	5		
Total	7		

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0.00	#N/A	#N/A	#N/A
EO	94.90	135.51	0.70	0.51
Months	59.83	141.02	0.42	0.69

Airframe 2

	df	*F*	*Significance F*
Regression	2	26.01	0.00
Residual	18		
Total	20		

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0.00	#N/A	#N/A	#N/A
Months	233.36	108.69	2.15	0.05
EO	89.58	23.05	3.89	0.00

Aircraft System 1

	df	*F*	*Significance F*
Regression	2	71.66	0.00
Residual	42		
Total	44		

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0.00	#N/A	#N/A	#N/A
EO	66.37	12.07	5.50	0.00
Months	355.21	82.23	4.32	0.00

Aircraft System 2

	df	*F*	*Significance F*
Regression	2	4.98	0.02
Residual	15		
Total	17		

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0.00	#N/A	#N/A	#N/A
Months	316.28	154.41	2.05	0.06
EO	18.67	14.81	1.26	0.23

Aircraft System 3

	df	*F*	*Significance F*	
Regression	2	39.77	0.00	
Residual	6			
Total	8			
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0.00	#N/A	#N/A	#N/A
Month	-23.61	52.15	-0.45	0.67
EO	141.49	26.43	5.35	0.00

Aircraft System 4

	df	*F*	*Significance F*	
Regression	2	87.24	0.00	
Residual	12			
Total	14			
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0.00	#N/A	#N/A	#N/A
Month	83.88	228.69	0.37	0.72
EO	150.91	19.66	7.67	0.00

Table 3: ANOVA with One Independent Variable

Airframe 1

	df	*F*	*Significance F*	
Regression	1	11.72	0.02	
Residual	6			
Total	7			
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0	#N/A	#N/A	#N/A
EO	148.86	43.49	3.42	0.01

Airframe 2

	df	*F*	*Significance F*	
Regression	1	39.83	0.00	
Residual	19			
Total	20			
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0	#N/A	#N/A	#N/A
EO	121.43	19.24	6.31	0.00

Aircraft System 1

	df	*F*	*Significance F*	
Regression	1	88.37	0.00	
Residual	43			
Total	44			
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0	#N/A	#N/A	#N/A
EO	100.94	10.74	9.40	0.00

Aircraft System 2

	df	*F*	*Significance F*	
Regression	1	4.81	0.04	
Residual	16			
Total	17			
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0	#N/A	#N/A	#N/A
EO	31.96	14.58	2.19	0.04

Aircraft System 3

	df	*F*	*Significance F*	
Regression	1	89.51	0.00	
Residual	7			
Total	8			
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0	#N/A	#N/A	#N/A
EO	131.57	13.91	9.46	0.00

Aircraft System 4

	df	*F*	*Significance F*	
Regression	1	186.78	0.00	
Residual	13			
Total	14			
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0	#N/A	#N/A	#N/A
EO	156.67	11.46	13.67	0.00

Table 4: Engineering Support Group Summary Output

	Regression Statistics
Multiple R	95.7%
R Square	91.5%
Adjusted R Square	87.5%
Standard Error	2,883.206
Observations	29

ANOVA

	df	*F*	*Significance F*
Regression	2	145.632	0.000
Residual	27		
Total	29		

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0	#N/A	#N/A	#N/A
AVFC Hours	0.00	0.006	0.002	0.99
EO (*)	38.378	2.554	15.025	0.000