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COST ESTIMATING RELATIONSHIPS FOR FIXED WING AIRCRAFT; LIST PRICE VS EMPTY WEIGHT

WILLIAM JOEL DITTO

OPERATIONS RESEARCH ANALYST

SEPTEMBER 1985

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U.S. ARMY
AVIATION
SYSTEMS COMMAND

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COST ESTIMATING RELATIONSHIPS FOR FIXED WING AIRCRAFT

LIST PRICE VS. EMPTY WEIGHT

SEPTEMBER 1985

WILLIAM J. DITTO

U.S. ARMY AVIATION SYSTEMS COMMAND
OPERATIONAL COST ANALYSIS DIVISION
DIRECTORATE FOR SYSTEMS AND COST ANALYSIS
4300 GOODFELLOW BOULEVARD
SAINT LOUIS, MISSOURI 63120-1798

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This Cost Estimating Relationship (CER) for Fixed Wing Aircraft was developed to estimate the unit cost of a twin engine, commercial, turbo-prop aircraft procured "off the shelf". The Army has a limited fixed wing capability and most of this capability is procured in a commercial environment instead of through a typical rotor wing procurement cycle.

The list price in the commercial market includes both engines and standard avionics, while in a typical Government rotor wing procurement these items

20. ABSTRACT (continued)

are Government Furnished Equipment. Therefore, this CER was developed using the parameter of empty weight and aircraft commercial list price.

The data collected was analyzed using the Statistical Analysis System (SAS) on the AVSCOM Scientific and Engineering Computer System. The program developed is a linear regression of the form (y = a + bx), and the results are shown in the report.

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I. SUMMARY.

A Cost Estimating Relationship (CER) for Fixed Wing Aircraft was first developed by James P. Boxx in 1977, to estimate the unit cost of a commercial turbine engine, turbo-prop aircraft procured "off the shelf". The CER was developed relating the parameters of aircraft empty weight and aircraft commercial list price. This CER has now been updated to reflect the latest data available. The parameters chosen remain the same as in the previous model; empty weight and aircraft list price.

The CER developed using the new data is:

Commercial List Price (\$84) = 242.22 * (empty weight)

R^2 = .97

Coefficient of Variation = 18.96

Standard Error = 9.55

This CER is based on commercial data for the aircraft listed in Table 1. Many factors will have a bearing upon the list price and all users of this CER should be aware that the aircraft price can vary significantly depending upon the equipment purchased with the aircraft.

II. Introduction.

The CER was orginally developed to improve the methods of estimating the cost to procure fixed wing aircraft. Future programs requiring "off the shelf" procurement of a twin engine, turbo-prop aircraft will be able to use this CER. A summary of the results using this CER to predict the cost is presented in Table 1.

III. General Approach.

A. <u>Selection of Candidate Variables.</u>

In 1976, the Rand Corporation was commissioned by the Assistant Secretary of Defense to examine the variables that they thought would explain airframe cost. Two variables, weight and speed, were found to be significant. In the CER developed for this study, only the weight variable was found to be significant. Therefore, the variable used in this study was the empty weight of the candidate aircraft selected (Table 1).

B. CER Derivation and Computation.

The Scientific and Engineering computer in the Directorate for Management Information Systems (DMIS) of the U.S. Army Aviation Systems Command (AVSCOM) was utilized to run the necessary linear regression to perform the analysis. This system has the capability to access the Statistical Analysis System (SAS) program. A test for heteroscedsticity was performed. In this test a linear regression of the residuals squared against the independent variable empty weight was performed. The results showed that the conditions of heteroscedasticity existed. The variance showed an increase corresponding to an increase in the independent variable weight. The suspected cause of this condition is related to the equipment installed in the aircraft. The increased variability of the cost as the weight increases could possibly be attributed to more or less expensive avionics, and different crew and passenger accomodations. This leads to the same airframe being built up for different levels of passenger comfort and crew work load. The SAS family of routines was used to perform the actual regressions shown in the results.

C. Heteroscedasticity

The first analysis performed showed that a problem existed with the data collected. This problem was determined to be one of heterosced-sticity. In a basic regression model, it is assumed that the variance is constant. However, in some cases this assumption is not true; i.e., the variance is non-constant. When this condition exists the model is said to be heteroscedastic and, therefore, the variance of the residuals is said to depend upon the value of one of the regressors. A standard estimation procedure can not be implemented because the value of the co-variance between the residuals and the regressor variable will not be zero. The assumption that must be made to account for the heteroscedasticity and to assume that the co-variance between the residuals and the regressor is zero, is that, whatever the value of the regressor, the mean of the variance of the residuals is constant. This assumption implies that the residuals are not correlated with either of the variables.

The effect of heteroscedasticity on the basic equation is on the the variances of the parameter estimators. The result of using normal procedures to estimate the variances is that the resulting test of hypotheses and confidence intervals will be held in some doubt.

The basic regression model assumes a constant variance and the estimation procedure produces an estimator of the constant. However, the variance of the residuals is itself a variable. The result of this is that the standard estimator will represent some average of the different variances of the residuals. This type of estimator will have little meaning and will not allow valid confidence intervals or t-ratios for the parameters of the equation. More reliable estimators of the coefficients and their variances can be obtained by incorporating into the estimation procedure information on the true properties of the residuals.

IV. PRESENTATION OF CER RESULTS

A. CER Description

The final CER developed was based on the aircraft empty weight and the catalog list price of commercial fixed wing twin-engine turboprop aircraft. Historical cost data was obtained for the aircraft listed in Table 1.

B. CER Equation and Statistics

The CER developed during the initial investigation showed that the y-intercept was insignificant. An examination of the scatter diagram showed that as the weight increased the cost variance increased. These conditions were corrected and the final CER was determined. Presentation of the CERs and their representative statistics are shown in Table 2. The actual and calculated values of the results are shown in Table 1.

C. CER Development and Selection

The CERs were evaluated by linear regression analysis. The first CER was modified to eliminate the effects of heteroscedasticity and to reflect the fact that the y-intercept was insignificant. These results are shown in Table 2.

TABLE 1

AIRCRAFT TYPE	DATA SOURCE	EMPTY WEIGHT	ACTUAL PRICE	CALCULATED PRICE
Pilatus B-N Turbine Engine	BCA	4,295	712,340	1,040,335
Piper T 1040		5,167	944,810	1,251,551
DeHavilland Twin Otter	BCA	7,593	1,800,000	1,839,176
DeHavilland Dash 8	BCA	21,590	6,000,000	5,229,529
Cessna CE-406	BCA/AW	5,621	1,200,315	1,362,518
Beech C99	BCA/AW	6,655	1,842,000	1,611,974
Beech 1900	BCA	9,355	2,842,000	2,265,968
Dornier Gmbh 228-101	BCA/AW	7,546	1,695,000	1,827,792
228-201	BCA	7,842	1,898,000	1,901,911
Embraer Bandeirante	BCA	8,350	1,943,000	2,022,537
Brasilla	BCA	15,068	4,716,000	3,649,771
IAI Arava	FA/BCA	9,434	1,900,000	2,285,103
Casa C212-300	BCA	10,141	2,450,000	2,456,353
Casa/Nurtanio CN-235	BCA/AW	20,725	5,300,000	5,020,010
Fairchild Metro III	BCA	9,020	2,500,000	2,184,824
IIIA	BCA	9,120	2,600,000	2,209,046
III(H)	BCA/AW	9,120	2,700,000	2,209,046
British Aero Jetstream 31	BCA	9,513	2,850,000	2,304,238
Shorts 330	BCA/AW	15,100	3,355,000	3,657,522
360	BCA/AW	16,900	4,400,000	4,093,518
Allsion 580	BCA	32,500	4,500,000	7,872,150
Saab-Fairchild	BCA	17,281	5,600,000	4,185,804
British Aerospace Super 748	BCA	27,234	6,000,000	6,596,619
Fokker Friendship F27-MK500	BCA	28,100	6,500,000	6,806,382
Aerospatiale Aeritalia	BCA	21,272	6,680,400	5,152,503

TABLE 2

ORIGINAL REGRESSION

DEP VARIABLE: PRICE1

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB > F
MODEL	1	6.72034E+13	6.72034E+13	210.402	0.0001
ERROR	21	6.70750E+13	319404831061		
C TOTAL	22	7.39109E+13			

ROOT MSE	565159	R-SQUARE	0.9092
DEP MEAN	3378979	ADJ R-SQ	0.9049
C.V.	16.72573		

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > F
INTERCEP	1	72618.797	256603	0.283	0.7799
BOWL	1	255.406	17.607825	14.505	0.0001

TEST FOR HETEROSCEDASTICITY

DEP VARIABLE: RZIDSQ

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB > F
MODEL	1	1.38339E+24	1.38339E+24	12.618	0.0019
ERROR	21	2.30235E+24	1.09636E+23		
C TOTAL	22	3.68574E+24			

ROOT MSE	331112937951	R-SQUARE	0.3753
DEP MEAN	291630497925	ADJ R-SQ	0.3456
C.V.	113.5385		

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > F
INTERCEP	1	-1.82750E+11	150337254483	-1.216	0.2376
BOWL	1	36644349	10315995	3.552	0.0019

TABLE 2 (CONTINUED)

FINAL REGRESSION DEP VARIABLE: PRE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB > F
MODEL	1	1114.176	1114.176	643.077	0.0001
ERROR	22	38.116517	1.732569		
U TOTAL	23	1152.292			

ROOT MSE	1.316271	R-SQUARE	0.9669
DEP MEAN	6.938971	ADJ R-SQ	0.9669
C.V.	18.96925		

NOTE: NO INTERCEPT TERM IS USED. R-SQUARE IS REDEFINED

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > F
WTEE	1	242.221	9.551688	0.0001	

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