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PREDICTING THE COST OF INITIAL SPARES

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Predictive relationships are developed for the cost of initial spares for aircraft programs. Initial spares support the deployment of new aircraft. A close relationship is found between initial spares cost and weapon systems cost. Initial spares cost is also related to aircraft characteristics, such as weight, speed, and type of aircraft. Some anomolous findings regarding interactions among initial spares cost, weapon systems cost, and aircraft characteristics indicate that a better understanding of underlying causal relationships is needed.

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INSTITUTE FOR DEFENSE ANALYSES

IDA Independent Research Program

PREFACE

This document was prepared by the Institute for Defense Analyses (IDA) for IDA's Independent Research Program, under contract MDA 903 89 C 0003. The objective of the project was to investigate the possibility of developing quantitative relationships for predicting the costs of initial spares.

This paper was reviewed within IDA by Mr. James L. Wilson and Dr. Matthew S. Goldberg, and by Dr. Thomas R. Gulledge, an IDA consultant.

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I. INTRODUCTION

This paper reports the results of efforts to develop Cost Estimating Relationships (CERs) for initial spares. Initial spares are those that accompany the first deployments of each new aircraft squadron, and that are intended to satisfy the squadron's needs for a short time until the system establishes a regular flow of replenishment spares. Because this analysis is concerned with initial spares only, we will use the term "spares" to refer to initial spares.

The beneficiaries of a CER for spares are service and OSD budget planners who must program funds for these support items. Initial spending plans must be made long before any aircraft are deployed. Spares funds must therefore be programmed before failure data has been generated, and budget planners sometimes rely on historical data for existing or past aircraft with similar characteristics of weight, speed, mission, complexity, etc. These analysts sometimes, for example, use the ratio of spending for initial spares to spending for flyaway or weapon system costs, and use these ratios to estimate costs for a new aircraft. We have tried a larger class of relationships in searching for CERs.

In this analysis, we assume that what the services *have* spent is a proxy for how much they *should* have spent. This, of course, ignores questions of operational performance that are important in making ultimate judgments of whether a budget is adequate. (Did the sortie rate suffer because initial spares were unavailable?) These considerations were beyond the scope of this study. We have, however, based our estimating relationships on actual budgets, rather than programmed funds. Programmed figures are often not "serious" until the time comes for actual spending. Using a CER based on past spending thus serves the purpose of requiring budget analysts to insert realisitic funds early in the programming process.[1]

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[1] Even "actual" budgets ignore the re-programming that occurs during the budget year.

II. METHODOLOGY

We constructed CERs for initial spares by hypothesizing relationships and applying statistical regression techniques to historical data for 21 past Navy and Air Force aircraft programs. In each case, the dependent variable was one of several measures of spending on initial spares. The explanatory, or independent variables included spending on weapon system cost, the empty weight and maximum speed of the aircraft, and dummy variables to control for the type of aircraft.

We selected a sample of aircraft programs in the following manner. We considered only those aircraft for which we had data for the entire program. This eliminated programs still in progress in FY 1994, the last year of the data. We also eliminated programs that had already begun in the first year of the data, 1972. The entries for this year are, in reality, for "1972 and prior," and adjusting these figures to constant dollars would have required us to guess at how the then-year dollars were distributed over the prior years, and thus what deflators to use.

Finally, to avoid the unreality of programmed budgets, we included only those programs for which at least 70 percent of the spending (in constant dollars) occurred in FY 1988 or prior, the last year of "actual" budgets in the data source we used. (Only one of the programs was 70 percent "actual"; the remainder were at least 96 percent.)

We looked for relationships that satisfied several criteria: (1) positive signs for the coefficients of the explanatory variables (faster aircraft, for example, should require more or costlier spares), (2) high R^2, indicating that the regression explained a large percentage of the variability in spares expenditures, and (3) high t-statistics (high statistical significance) for the coefficients of the independent variables. (High R^2 was given more weight than high t-statistics, since the goal of the analysis was to develop a predictive relationship for spares expenditures, rather than to identify the specific contribution of each explanatory variable.)

III. DATA

The data are shown in Table 1. The column titles are the names of variables used in reporting the results of the regressions; complete definitions are given at the bottom of the table.

SPARES, WSC and QTY were all obtained from the historical Procurement Annex for FY 1989 covering the fiscal years 1972-1994. SPARES is the total obligational authority (TOA) for procurement of initial spares during the life of the program. The then-year dollars in the Procurement Annex were inflated to FY 1989 using deflators for "Procurement of Aircraft, Navy" and "Procurement of Aircraft, Air Force."

WSC stands for "Weapon System Cost," which consists, for the most part, of total procurement TOA less spares.[2]

Empty weight and maximum speed of the aircraft were obtained from "Standard Aircraft Missile Characteristics" (a series of documents on military aircraft, distributed by the Aeronautical Systems Division at Wright-Patterson Air Force Base, Ohio) and "Jane's All The World's Aircraft" (a standard reference on all aircraft, published yearly). Some of the figures are approximations, equal to values for different models of the same basic aircraft, or for the civilian version of the military aircraft.

C_1 and C_2 are dummy variables describing the type of aircraft. C_1 was set to 1 for the more complex, fixed-wing aircraft (attack, fighter, electronic and bombers) and to 0 for all other aircraft. C_2 was set to 1 for the cargo and tanker fixed-wing aircraft, and to 0 for all other aircraft. Helicopters are the excluded case, for which both C_1 and C_2 are 0.

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[2] More specifically, WSC consists of flyaway cost (non-recurring plus recurring costs for airframe, propulsion and avionics, program management, test and evaluation, allowances for engineering changes) plus training, peculiar support equipment and site costs. Procurement TOA consists of Weapon System Cost less advance spending for the prior year, plus advance spending for the next year, plus spending for initial spares.

Table 1. Data

Aircraft	SPARES	WSC	QTY	WEIGHT	SPEED	C_1	C_2
A-10A	511.4	7,431.7	687	21,500	362	1	0
A-7K	27.7	500.9	30	21,300	569	1	0
C-13OH	31.0	1,939.4	130	76,800	335	0	1
C-20A	22.1	217.6	11	38,000	501	0	1
CH-47C	3.0	119.7	24	20,400	165	0	0
E-3A	423.2	4,438.5	31	170,700	473	1	0
E-4A/B	5.1	279.3	3	307,300	536	1	0
F-5B	0.3	31.2	7	8,400	710	1	0
F-5E/F	0.5	57.6	6	10,000	915	1	0
KC-10A	301.3	4,332.5	60	236,500	529	0	1
KC-13OT	5.7	402.1	20	66,200	326	0	1
UH-60A	10.1	65.3	11	10,600	160	0	0
VH-3D	19.0	111.9	11	10,800	144	0	0
VH-60	41.3	178.3	9	10,600	160	0	0
C-5B	165.1	7,747.8	50	374,000	571	0	1
A-6	358.3	6,003.3	205	24,600	561	1	0
F-15D/E	2,625.6	38,359.9	1,128	26,800	1,434	1	0
CH/MH-53	276.8	3,086.3	152	23,100	186	0	0
SH-2F	27.5	689.4	60	7,000	143	0	0
AV-8B	740.4	6,862.1	276	13,100	533	1	0
B-1B	1,616.2	25,584.2	100	192,000	630	1	0

Notes: SPARES = Total-program TOA for initial spares in millions of FY 1989 dollars. WSC = Total-program TOA for weapon system cost in millions of FY 1989 dollars. QTY = Total-program procurement quantity. WEIGHT = Aircraft empty weight in pounds. SPEED = Aircraft maximum speed in knots. $C_1 = 1$ for attack, fighter, electronic, and bomber aircraft; 0 for all others. $C_2 = 1$ for cargo and tanker aircraft; 0 for all others.

IV. ANALYSIS

We found four predictive equations for spares cost that passed our criteria, two using weapon system cost as the dependent variable, and two using procurement quantity and the characteristics of the aircraft (weight, speed, and the type dummies). These will be discussed in turn.

A. USING WEAPON SYSTEM COST AS THE EXPLANATORY VARIABLE

The first model (eq. 1) involves a linear relationship between spares cost and WSC: each increase of a billion dollars in WSC leads to a \$66.7 million increase in spares cost. The equation has high explanatory power: the value of R^2 indicates that the equation accounts for fully 97 percent of the variability in spares cost. The asterisks indicate that the coefficient of WSC has high statistical significance. (One, two and three asterisks represent significance at the 10, 5 and 1 percent levels, respectively.) Adding the dummy variables to the equation had little effect on the coefficients, t-statistics or R^2, indicating that the relationship between spares cost and WSC does not vary greatly with the type of aircraft.

$$\text{SPARES} = -1.23 + \underset{***}{.0667}\ \text{WSC} \qquad R^2 = .97 \qquad (1)$$

In the second model (eq. 2), the relationship between spares cost and weapon system cost is a proportional one: Every 10 percent increase in WSC leads to an 11 percent (10% x 1.10) increase in spares cost.[3] The equation's predictive power (R^2) is somewhat lower; and, as before, controlling for aircraft type made little difference.

$$\text{SPARES} = .0242\ (\text{WSC})^{\underset{***}{1.10}} \qquad R^2 = .86 \qquad (2)$$

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[3] The regressions in eq. (2) and (4) were obtained by expressing the variables (excluding the dummy variables) in logarithmic form, performing a linear regression, and then taking the anti-log of the result to obtain the more convenient exponential form given in the text.

Choosing between the linear and log (exponential) form of a CER depends on the analyst's best intuition about the underlying relationships. We plan to explore this question more fully in later work.

B. USING QUANTITY, WEIGHT AND SPEED AS THE EXPLANATORY VARIABLES

The final regressions illustrate the kinds of relationships that budget analysts could use if they lack estimates of weapon system cost but have at least *initial estimates* of the aircraft's weight, speed, and procurement quantity. In equation 3, quantity, weight and speed have a linear effect on spares cost: Each additional aircraft adds approximately \$1.5 million to spares cost, each additional 1,000 pounds of weight adds about \$700,000, and each 10 knot increase in speed adds \$6.2 million. The explanatory power of this model is less than for the models that predict cost from WSC, but the R^2 of .72 suggests that the equation might be useful as a first cut. As before, controlling for the type of aircraft did little to increase the equation's predictive power.

$$\text{SPARES} = -225.4 + \underset{***}{1.53}\ \text{QTY} + 0.000705\ \text{WEIGHT} + \underset{*}{0.620}\ \text{SPEED} \qquad (3)$$

$$R^2 = .72$$

The final model (eq. 4) is *an exponential relationship of the same variables.* It has somewhat higher predictive power than the linear form. The dummy variables for aircraft type now make a measurable contribution; the fact that the coefficients of these variables are both negative suggests that budget analysts have been buying fewer spares (in dollar terms) for the fixed-wing aircraft than for helipcopters (the excluded case, in which $C_1 = C_2 = 0$).

$$\text{SPARES} = .0000163\ \underset{***}{\text{QTY}^{1.28}}\ \underset{***}{\text{WEIGHT}^{0.974}}\ \text{SPEED}^{0.171}\ e^{-1.22C_1}\ e^{-2.21C_2} \qquad (4)$$

$$R^2 = .79$$

V. DISCUSSION

We have found several models that exhibit good fits and intuitively pleasing results.[4] These results show that funds for initial spares are not random, but can be related to variables such as program cost and aircraft characteristics.

However, we tried many other models that appeared attractive but failed to meet our criteria on one or more grounds: negative signs for the coefficients of weight and speed, low R^2, low t-statistics. We obtained poor results, for example, in trying to predict unit spares cost, and also the ratio of spares cost to weapon system cost. A particularly surprising result is the case in which we used the proportional specification to relate spares cost to both the program variables (WSC and procurement quantity) plus the aircraft characteristics (weight and speed). The R^2 was almost .93 and the variables were all highly significant, but quantity, weight and speed all had negative signs! This suggests that there are missing important variables, and we need to obtain a better understanding of the results.

To help in this regard, we plan in future work to construct separate explanatory variables for airframe, engine and avionics. (Using separate weights for each component is a possibility.) We will also attempt to increase the number of aircraft programs in the sample. Finally, we will explore the pattern of how budget planners have apportioned funds for initial spares over the program years. The eventual goal is a set of relationships that will help planners decide not only how large a spares budget is needed for a new aircraft program, but also how to program this budget over time.

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[4] One possible interpretation of these results is that we have simply discovered the "rule" that analysts have been using in budgeting for initial spares. This might be a compelling hypothesis if our data was taken primarily from aircraft programs that have not yet reached IOC (initial operational capability). However, as we discussed earlier, all of the programs are well over half completed, and the spending data are largely "actuals" rather than future projections. Whatever budgetary manipulations may have gone on before, we assume that once an aircraft reaches deployment, the Services have taken care to buy enough spares to support the aircraft adequately.