AD-E501 360

Copy 18 of 43 copies

(2)

IDA PAPER P-2401

ESTIMATING FIXED AND VARIABLE COSTS OF AIRFRAME MANUFACTURERS

Stephen J. Balut
Thomas P. Frazier
James Bui

March 1991

INSTITUTE FOR DEFENSE ANALYSES
1801 N. Beauregard Street, Alexandria, Virginia 22311-1772

IDA Log No. HQ 90-35536

DEFINITIONS

IDA publishes the following documents to report the results of its work.

Reports

Reports are the most authoritative and most carefully considered products IDA publishes. They normally embody results of major projects which (a) have a direct bearing on decisions affecting major programs, (b) address issues of significant concern to the Executive Branch, the Congress and/or the public, or (c) address issues that have significant economic implications. IDA Reports are reviewed by outside panels of experts to ensure their high quality and relevance to the problems studied, and they are released by the President of IDA.

Group Reports

Group Reports record the findings and results of IDA established working groups and panels composed of senior individuals addressing major issues which otherwise would be the subject of an IDA Report. IDA Group Reports are reviewed by the senior individuals responsible for the project and others as selected by IDA to ensure their high quality and relevance to the problems studied, and are released by the President of IDA.

Papers

Papers, also authoritative and carefully considered products of IDA, address studies that are narrower in scope than those covered in Reports. IDA Papers are reviewed to ensure that they meet the high standards expected of refereed papers in professional journals or formal Agency reports.

Documents

IDA Documents are used for the convenience of the sponsors or the analysts (a) to record substantive work done in quick reaction studies, (b) to record the proceedings of conferences and meetings, (c) to make available preliminary and tentative results of analyses, (d) to record data developed in the course of an investigation, or (e) to forward information that is essentially unanalyzed and unevaluated. The review of IDA Documents is suited to their content and intended use.

The work reported in this document was conducted under contract MDA 903 89 C 0003 for the Department of Defense. The publication of this IDA document does not indicate endorsement by the Department of Defense, nor should the contents be construed as reflecting the official position of that Agency.

UNCLASSIFIED

REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 2220-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.			
1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE March 1991	3. REPORT TYPE AND DATES COVERED Final Report, Dec 1988 – Dec 1990	
4. TITLE AND SUBTITLE Estimating Fixed and Variable Costs of Airframe Manufacturers			5. FUNDING NUMBERS IDA Independent Research Program
6. AUTHOR(S) Stephen J. Balut, Thomas P. Frazier, and James Bui			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Institute for Defense Analyses 1801 N. Beauregard Street Alexandria, VA 22311-1772			8. PERFORMING ORGANIZATION REPORT NUMBER IDA-P-2401
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Not applicable.			10. SPONSORING/MONITORING AGENCY REPORT NUMBER
11. SUPPLEMENTARY NOTES			
12A. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited.			12B. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This report presents a model for separating annual costs at airframe manufacturing plants into fixed and variable components. The use of the model is to aid defense analysts in estimating the cost to manufacture aircraft systems when the manufacturer has not yet been determined or when proprietary models for the specific firms are not available. The material is unclassified and non-proprietary.

14. SUBJECT TERMS			15. NUMBER OF PAGES
Costs, Indirect Costs, Defense Contractors, Account Classification Method			39
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

UNCLASSIFIED

IDA PAPER P-2401

ESTIMATING FIXED AND VARIABLE COSTS OF AIRFRAME MANUFACTURERS

Stephen J. Balut
Thomas P. Frazier
James Bui

March 1991

INSTITUTE FOR DEFENSE ANALYSES
IDA Independent Research Program

PREFACE

This paper was prepared by the Cost Analysis and Research Division of the Institute for Defense Analyses (IDA). The research was sponsored by IDA using Central Research funds. The objective of the research was to provide defense cost analysts with a practical way to separate fixed and variable costs when estimating the costs of defense systems. The data used in the analysis were derived from prior IDA studies. In this regard, IDA is indebted to the Office of the Assistant Secretary of Defense, Program Analysis and Evaluation, the office that funded the prior studies.

This paper was reviewed by Mr. Dean C. Graves, Mr. Stanley A. Horowitz, and Dr. Matthew S. Goldberg, all members of the IDA staff.

EXECUTIVE SUMMARY

This report presents a model for separating annual costs at airframe manufacturing plants into fixed and variable components. It is argued that this separation also applies at the contract level. The use of the model is to aid defense analysts in estimating the cost to manufacture aircraft systems when the manufacturer has not yet been determined or when proprietary models for the specific firms are not available. The material in this report is unclassified and non-proprietary.

Discussions of fixed costs in the literature are mostly theoretical. Practical techniques for identifying such costs by analysts outside the firm of interest are lacking. A few recent empirical studies address this topic.

Fixed costs are assumed to be those that do not vary with output. A mathematical model is presented that represents plantwide overhead as the sum of a constant term, a term that varies with changes in the value of capital at the plant, and a term that varies with output. The portion of overhead that excludes costs that vary with output is considered "fixed."

Data covering 15 years of cost experience at four major airframe manufacturers were used to estimate model parameters. Experience at these firms indicates that overhead had grown from about 38 percent of total business in 1973 to about 49 percent by 1987. Extrapolation of this trend indicates that overhead will reach about 54 percent by the year 2000. The data, aggregated and transformed to conceal proprietary information on individual firms, were used in a pooled regression modeling technique that results in a weighted average across the four firms. The estimated coefficients indicate that, as of 1987, a 1-dollar increase in the value of capital results in an increase of 63 cents in overhead, and a 1-dollar increase in output results in an increase of 38 cents in overhead.

The form of the model allowed estimation of the portion of overhead that was fixed. In 1973, this amounted to about 50 percent. Estimates of this portion increase steadily over the period, reaching about 61 percent by 1987. Extrapolations indicate this portion is at about 63 percent in this year, 1990, and will grow to about 66 percent by the year 2000.

Estimates of the portion of total business that was overhead and the portion of overhead that was fixed were combined to estimate that portion of total business that was fixed. This quantity, estimated at about 24 percent in 1973, increased to about 30 percent by 1987. Extrapolation to the year 2000 indicates fixed costs will increase to about 35 percent of total business by then. These estimates apply at both the plant and contract levels. This fact allows extrapolations of these estimated fractions to be applied to future contracts under certain assumptions.

CONTENTS

FIGURES

TABLES

A. INTRODUCTION

Manufacturing a weapon system, such as a tactical aircraft, requires a mix of capital (e.g., land, buildings, and equipment), labor (e.g., engineering and manufacturing), and materials (e.g., raw materials and purchased parts). The cost of some of those factors vary directly with the number of items produced. For example, the total cost of aluminum or steel required to manufacture a lot of aircraft is closely related to the number of aircraft in the lot. Costs that vary directly with the quantity produced are referred to as "variable costs." Other costs do not vary with output or revenue and are referred to as "fixed costs." Examples include rent, plant security, and building maintenance.

Although fixed costs do not vary with output, they do vary for other reasons. For example, when management makes a fundamental change in the way the company does business, fixed costs may vary. Such a change could result from a substantial investment in capital (e.g., build another plant, open a new production line, replace old equipment with new), and can be expected to both increase the level of fixed costs and change the proportion of total costs that are fixed.

Analysis of future business activities is facilitated by the availability of projections of fixed and variable costs. Cost accounting departments routinely provide such projections. Standard textbook techniques use this separation to establish budgets, select new product lines, set unit prices, make capital budgeting decisions, identify theoretical long-run equilibria, determine theoretical shutdown points, and make a host of other decisions.

Much of the theories of economics, cost accounting, business, and finance are predicated on projections of costs in fixed and variable categories. Unfortunately, the road between theory and application is bumpier here than one might expect, particularly for those who are not members of the accounting department of the contractor of interest. This is because industry accounting systems do not provide visibility into fixed costs. This cost component is estimated, even by the accountants within the firm.

The estimator's problem is illustrated in Figure 1. Using data gathered by IDA over the past decade from defense aerospace contractors, total annual cost base at a typical contractor is disaggregated into standard accounting categories and then regrouped into fixed and variable components. Materials and subcontracts typically represent about 39 percent of total cost, and are accounted for as direct costs (i.e., costs that are directly attributable to a specific end item or contract). About 61 percent of total cost of an aircraft system is value added (i.e., conversion cost) at the manufacturer's plant and general and administrative (G&A) expenses. Conversion costs include manufacturing and engineering labor (accounted for as direct costs) and their labor-related overhead, such as engineering and factory burden. G&A consists of overhead that pertains to all business activity. Direct labor, at 16 percent of total cost, and direct material, at 39 percent, together constitute total direct costs. The remaining 45 percent is overhead. Company accounting systems record information down to this level (level 3 in Figure 1) only. Fixed and variable costs, as shown at level 4 are not recorded. Rather, they are estimated.

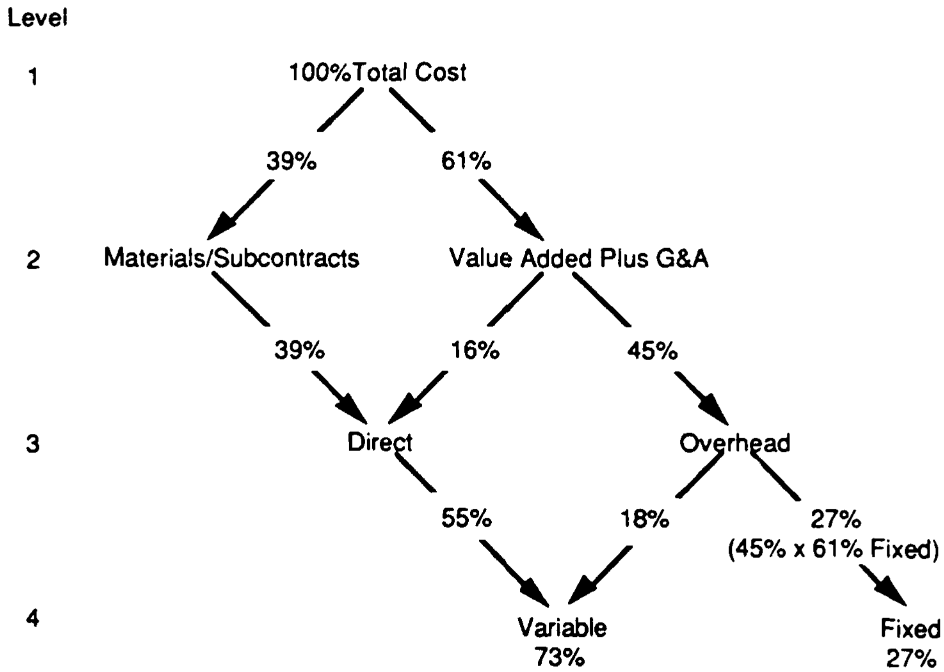


Figure 1. Levels of Data for Analyses of Total Cost

Two estimating methods are in common use: an accounting approach called the account classification method [1] and regression analysis. The account classification method (ACM) requires a thorough understanding of the particular manufacturing operation and the manner in which individual accounts mirror these activities. This estimating method is best applied by the contractor's accounting department. The results are considered proprietary. Regression methods are also used by internal accounting departments to estimate the proportion of costs that do not vary (statistically) with revenues or appropriate measures of output. The accuracy of statistically derived equations can be assessed by company cost accountants through comparisons with the results of the account classification method. Regression estimates of fixed costs derived internally are also considered proprietary.

The customer of defense aerospace contractors, the Department of Defense, estimates the costs of future weapon systems. These estimates are included in budgets submitted to Congress. The cost information used by defense analysts to make these estimates is obtained from contractor accounting systems. Cost experience on past and current acquisitions is routinely reported in standard formats such as the Contractor Cost Data Report (CCDR). The data are used to derive cost-estimating relationships (CERs) and cost progress curves. CERs generally address variable costs only (e.g., direct manufacturing labor hours and direct engineering labor hours). Cost progress curves, on the other hand, are often applied at more aggregate levels. When used to estimate system costs, cost progress curves include an assumption that all costs vary with quantity. This introduces a tolerable level of error as long as the portion of costs that are "fixed," or quantity-invariant, remains small. However, research [2 through 7] clearly indicates that the fixed component of cost is increasing as industry moves more towards the automated factory. Fixed cost is currently estimated to be approximately 31 percent for airframe manufacturers; it was estimated to be about 19 percent just two decades ago.

The magnitude and trend of fixed costs clearly indicates a need for better methods of estimating the costs of weapon systems by defense analysts. The assumption that all costs are variable is no longer acceptable. Almost one-third of total cost is fixed and the proportion is increasing. Further, internal proprietary estimates of fixed costs are not available outside the firm.

Methods for estimating weapon system costs that take the fixed cost component explicitly into account are appearing [8]. These methods are variations on the cost progress curve approach that estimates fixed and variable components separately and combines them to arrive at total cost. Variable costs are estimated in the traditional way using cost progress curves. What is novel about this approach is that fixed costs are estimated separately and allocated to output.

This paper focuses on regression methods for estimating fixed costs at defense aerospace plants. (Subsequent allocation to output is not addressed here.) These techniques are integral to the new methods described in the previous paragraph. The intended user is the defense analyst that has limited access to contractor information.

B. LITERATURE REVIEW

A review of the literature concerning estimation of the fixed and variable components of costs is characterized by a dominate paradigm: given a linear regression with total cost as the dependent variable and some measure(s) of output as the independent variable(s), fixed costs are assumed to be equal to the value of the intercept term and variable costs are assumed to be equal to the value of the estimated regression coefficient times the value of the independent variable(s).

The use of this model cuts across a variety of academic disciplines. For example, *The Accountants' Cost Handbook* [1] suggests using it as one method of apportioning overhead costs. An example of its use in the production/cost engineering field is found in Boger [9] (a study of the same industry under consideration in this paper—aircraft manufacturing). Two examples of empirically estimating the fixed portion of overhead costs in the economics literature can be found in [10 and 11].

Some interesting theoretical extensions and applications of the model have been made. In regulatory economics the model has been used in the study of joint products and costs as a means of allocating fixed overhead costs among various users [12]. For example, a study by the U.S. Department of Transportation [13] employed the linear model. That study formed the basis for allocating the cost of the nation's airport and airway system to its users (i.e., commercial, general aviation, and military). Fixed costs were estimated to be the intercept term in a regression where total system cost was the dependent variable and the independent variables were the number of aircraft handled for each of the three categories of users. The fixed costs were then apportioned to each of the users based upon the relative size of their variable regression coefficient.

Recent work in the area of empirically estimating overhead costs has extended the model to account for the temporal dimension of overhead costs (discussed in the previous section of this paper) and its related fixed and variable components. Kaplan [14] suggests two methods to capture the dynamic component of overhead costs as contractors move to a more automated production scheme. One method adjusts for jumps or shifts in the fixed component of overhead costs. The other method accounts for the steady increase over time in fixed overhead. The two methods are represented by Equations (1) and (2), respectively.

$$OH_t = a_1 + b_1DL_t + b_2SHIFT_t \ , \tag{1}$$

$$OH_t = a_2 + b_3DL_t + b_4TIME_t \ . \tag{2}$$

In both equations the dependent variable is overhead (OH) in time period t, and the variable component is represented by DL_t, which is some measure of the direct labor employed in time period t. Equation (1) has a binary dummy variable that takes account of a shift in overhead costs, whereas Equation (2) uses a time trend variable to account for a steady increase in overhead costs over time. Kaplan defines the fixed portion of overhead for each of the two equations to be:

$$\text{Fixed overhead}_t = a_1 + b_2 \text{SHIFT}_t \,, \tag{1a}$$

$$\text{Fixed overhead}_t = a_2 + b_4 \text{TIME}_t \;. \tag{2a}$$

Womer [15], in a paper focusing on estimating learning curves using monthly data, also recognized that fixed costs have a temporal dimension. He estimated a distributed lagged model that permitted some of the labor hours incurred each month to be elements of fixed costs.

It is interesting to note that economists are also becoming aware that their view of fixed costs requires some modification. Economists have regarded fixed costs as dependent on the amount of time required to adjust to changed circumstances. This view is becoming obsolete in light of new production technologies (such as computer-aided design, numerically controlled machine tools, and robotics) that make production change-overs and set-ups almost instantaneous in some cases [16].

Our work extends the work of Kaplan and Womer in several ways. First, we argue that the results presented in the literature could be improved by making the models sensitive to the well-known fact that the overhead costs are a function not only of labor but also of the stock of capital facilities and equipment employed in the production process. We contend that models that ignore this capital component in the cost equations are misspecified and produce bias and (because capital and labor tend to be correlated) inconsistent estimates [17]. Second, we redefine the fixed component of overhead costs to include the capital measure. Third, we pool our cross-sectional and time series data to produce an industry-wide model rather than a contractor-specific model of overhead costs.

C. FIXED AND VARIABLE OVERHEAD COST MODELING

This section first describes the data used for our analysis and then the method used for separating plantwide overhead costs into fixed and variable components.

1. Data

The data for this study were extracted from prior IDA studies of airframe manufacturers' costs. From these studies, an extensive database was carefully complied and examined and the data on overhead and direct costs were standardized. During the course of its studies of defense contractors, IDA derived a standard set of "account groups" (e.g., indirect labor) and a standard set of "functions" (i.e., Engineering, Manufacturing G&A, and Material), to which it assigned a contractor's overhead accounts and overhead pools, respectively. This standardization permits comparisons among contractors [18 and 19] and pooling of data for quantitative analysis [20].

Data on the following contractors were included: General Dynamics–Fort Worth Division [4], Grumman Aerospace Corporation [5], Northrop Aircraft Division [6], and McDonnell Aircraft Company [7]. The actual data from these studies are proprietary and thus cannot be presented. The transformed data are shown in Appendix A. Individual contractor data sets included fifteen data points. All costs were converted to constant 1987 dollars.

The cost data used in the analysis were plantwide overhead, total direct costs, net book value, and business base.

Plantwide overhead consists of nine account groups, that is, indirect labor, fringe benefits, facilities-related, data processing, corporate office allocation, independent research and development/bids and proposals (IR&D/B&P), other expenses, secondary allocation, and credits. Indirect labor costs consist primarily of salaries and wages. Fringe benefits consist of payroll allowances and benefits earned by employees in addition to their wages and salaries. Facilities-related costs consist of depreciation, rent, taxes, utilities, insurance, and maintenance (excluding the salaries, wages, and benefits of maintenance employees). Data processing costs are for computer services and supplies. Corporate office allocation costs consist of corporate office charges. IR&D/B&P costs are labor and materials costs for IR&D/B&P activities. Other expense costs are those costs not already included in the previous groups. Secondary allocations and credits are for credits to the plant's overhead for secondary pool service functions and should net to zero except for functions undertaken for the benefit of organizations outside of the plant.

Total direct costs consist of direct labor, direct material, and other direct costs.

The contractors in our sample provided data on capital investment and net book value. The capital investment data were reported by asset type. Net book value was used as a proxy for the economic value of assets in use ("capital stock").

Business base can be described as the total cost input of a contractor and is the total of the direct costs and plantwide overhead described above.[1]

2. The Theoretical Model

The theoretical model is shown in Figure 2. On the left, total costs are separated according to standard accounting practices. "Direct" includes direct labor, direct material and other direct charges. "Overhead" includes total indirect costs, including general and administrative (G&A) expense. The task is to separate the overhead portion into its fixed and variable components in order to combine the variable portion of overhead with direct costs, which are assumed to be variable. The resulting division of costs, as shown on the right side of the figure, allows application of traditional methods to the variable portion, and other, more appropriate methods to the rest.

The model is based on the assumption that overhead is made up of two components:

- One that varies with production-related activity in the plant, such as quantity produced, or direct costs, and
- One that does not, but rather represents ownership costs that change if the plant itself is expanded, contracted, or reconfigured.

The first component includes costs accounted for as direct labor, direct material, and other direct costs. The latter component includes but is not limited to time-related costs such as rent, taxes, and depreciation. It also includes, for example, a portion of indirect labor costs.

---

1 For all the contractors except two, business base equates to the total cost input of the firm. For McDonnell Aircraft Company (MCAIR) and General Dynamics–Fort Worth Division (GD-FWD), however, we have excluded certain costs identified as "external business base" costs, and include only "in-plant business base." The external business base cost elements excluded are major subcontract costs and customer-furnished equipment such as purchased avionics. The major subcontract costs for MCAIR cover the major subsections of the F-18 built by Northrop and of the AV-8B built by British Aerospace; for GD-FWD, the F-16 components are built by European factories. We believed that the in-plant business base was the appropriate base for this analysis.

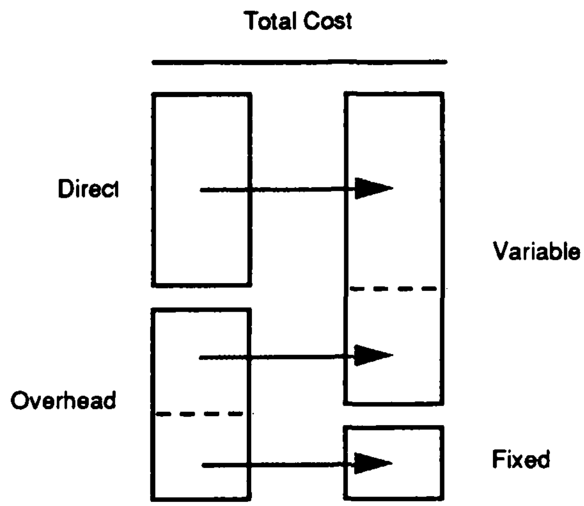


Figure 2. The Theoretical Model

3. The Statistical Model

Under these assumptions, a regression equation was formulated that had plantwide overhead as the dependent variable and at least two independent variables, one representing production activity in the plant (the quantity-sensitive variable) and another representing the capital stock of plant facilities and equipment (the variable associated with quantity-invariant costs). We knew from prior research that certain measures of the plant's direct costs tend to be related, statistically, to overhead costs and would very likely provide excellent quantity-sensitive independent variables. Considerably less is known about the relationship between overhead costs and quantity-invariant measures; however, one would expect that stock of land, buildings, and equipment is related to the cost to own and maintain them and that investments that change the mix of these assets will change ownership costs.

The regression formulated is as follows:

$$Y = a + bK + cDC + e \quad , \tag{3}$$

where

Y = plantwide overhead
K = net book value (used as a proxy for value of capital)
DC = direct costs (used as a proxy for output)
a = intercept term
b = regression coefficient of K

c = regression coefficient of DC

e = error term with a mean of zero and a constant variance (used to accommodate measurement error and the unsystematic effects of omitted variables).

The time subscript t associated with the dependent and independent variables is assumed but omitted for convenience. "Net book value" is capital investment minus depreciation, plus or minus transfer of assets.

The following criteria were used to evaluate the model:

- Plausible signs of the coefficient (we expected positive signs.)
- Significant t-scores (95-percent level)
- Reasonable magnitude of coefficient, as indicated by our earlier research
- High coefficient of determination (R-square).

Serial correlation correction was performed because the data are time series. (See Appendix B for a discussion of the serial correlation correction procedure.)

Operationally, we define the variable (i.e., output-related) portion of overhead as follows:

$$\text{Variable overhead} = cDC \ . \tag{4}$$

The fixed (output-invariant) portion of overhead is defined as follows:

$$\text{Fixed overhead} = (a + bK) \ . \tag{5}$$

In the remaining discussion, we refer to the "fraction of overhead that is fixed." This quantity is calculated as follows:

$$\text{Fraction of overhead that is fixed} = (a + bK)/Y \ . \tag{6}$$

In addition, we refer to the "fraction of total business that is fixed." This quantity is calculated by multiplying the fraction of overhead that is fixed by the fraction of total business that is overhead:

$$\text{Fraction of total business that is fixed} = [(a + bK)/Y] \times [Y/\text{total business}] \ . \tag{7}$$

D. FINDINGS

This section discusses the estimates of model parameters, the model validation procedure, the account classification method comparison, the model's sensitivity and application, and projections to the year 2000.

1. Model

Ordinary least squares (OLS) regression, which minimized the sum squared errors for a given data set, and serial correlation correction (described in Appendix B) were used to estimate the coefficients in Table 1.

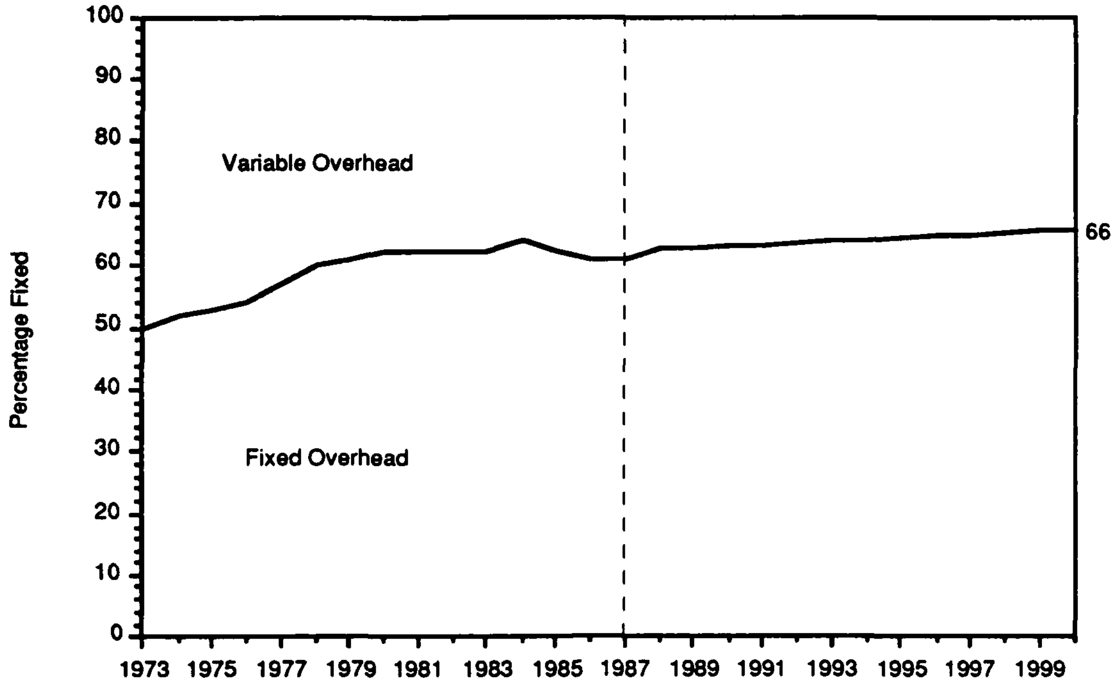
Table 1. Regression Results for 1973-87

Variable	Thousands of 1987 Dollars Coefficient	Standard Error	t-Score
a (intercept)	258,203		
b (net book value)	0.63	0.111	5.7
c (total direct costs)	0.38	0.050	7.6
Adjusted R-square	0.759		
F-statistic	81.7		
Sample Size	71		

All coefficients in Table 1 carry the expected positive sign. The value of capital coefficient, b, indicates that a 1-dollar increase in net book value results in a 63-cent increase in plantwide overhead. The value of the output coefficient, c, indicates that a 1-dollar increase in direct costs results in a 38-cent increase in plantwide overhead. Both the capital and direct cost coefficients had significant t-score statistics.

The R-square statistic indicates that 76 percent of the variation in plantwide overhead can be explained by these two independent variables. This suggests the model can be used with modest confidence for predicting overhead costs for an average airframe manufacturer based on the capital and direct cost inputs and under certain assumptions (which are discussed later).

Equation (6) was used to estimate the fraction of plantwide overhead that is fixed. (Appendix C contains the original data.) The estimated results are shown in Figure 3 for 1973-87. The fixed portion increased from 50 percent in 1973 (the first year where data were available for all the contractors) to 61 percent in 1987. Also shown in Figure 3 is a trend line showing the fixed portion of plantwide overhead to the year 2000. The trend line indicates the fixed percentage would be 63 percent this year, 1990, and would range from 63 percent to 65 percent over the years in the current Six Year Defense Program, 1991-1996.



Note: The years 1988-2000 are forecasts.

Figure 3. Fixed Portion of Plantwide Overhead

2. Validation of the Model

The coefficients in Table 1 were used in equation (3) to estimate the weighted (based on business base) average annual plantwide overhead totals for 1973-1987, the years for which data were available for all four contractors. These estimates were compared with the calculated weighted average annual plantwide overhead totals for the contractors in our sample. We refer to these amounts as "actuals." The comparison, presented in Figure 4, shows that the model's estimates track fairly well with the actuals.

This comparison, along with model statistics, indicates to us that the model produces reasonably good estimates of plantwide overhead and can be used for this purpose under certain assumptions. The key assumption is that the manufacturing technologies associated with the forecasting situation are consistent with the evolution of these technologies as reflected in our sample. That is, contractors were steadily upgrading technology and making increasing use of automation in design and manufacturing. The mix of factor inputs was shifting somewhat from labor to capital. If we assume that the evolution will continue at roughly the same rate over the period of interest, and if the scale of the operation under consideration is similar, use of the model to forecast into that period seems reasonable.

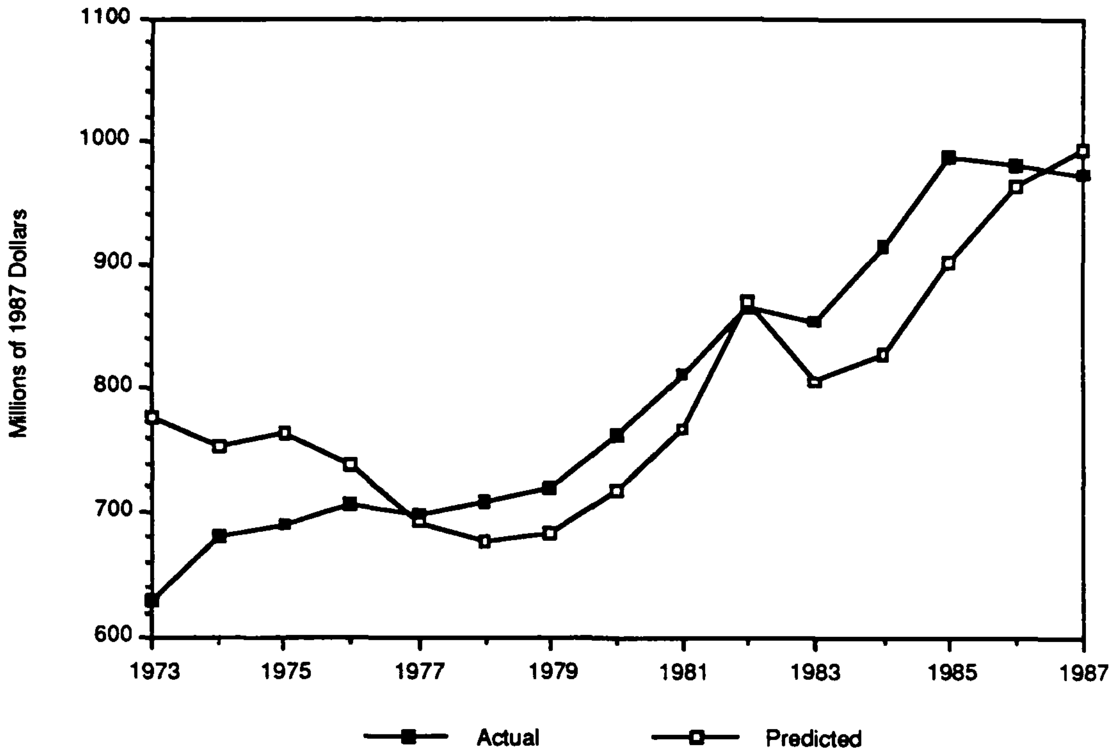


Figure 4. Weighted Average Actual and Predicted Plantwide Overhead

3. Comparison With the Account Classification Method

As mentioned previously, we know of only two methods of estimating the fixed portion of overhead—the regression method and the account classification method (ACM). The regression method is used by analysts both within and outside the firm of interest, and is the only viable method for those outside the firm. This is because the ACM requires a detailed understanding of the contractor's operations and how they are mirrored by the accounting system. Company accountants, working with company engineers, have access to such information. DoD analysts do not, and neither do we.

Nevertheless, we were determined to compare the estimates produced by the regression approach to estimates produced by the only alternative method, the ACM. We applied the method, but our application suffered from lack of information required (i.e., information readily available to a company accountant). We made a number of heroic assumptions and moved forward. We made subjective judgements (more arbitrary than informed) about the fractions of certain accounts that were fixed and the fractions that were variable. We had no basis for modifying these fractions with time as manufacturing technologies evolved and capital was substituted for labor.

The procedure we used to apply the ACM is as follows. We reviewed indirect personnel by function within accounting pools for each manufacturer. Material and administrative personnel were considered to be 100 percent fixed. The remainder of indirect personnel in the engineering and manufacturing pools were considered to be 15 percent fixed to allow for supervision and other fixed functions. The percentage of indirect personnel estimated to be fixed was then applied to indirect labor dollars to obtain an estimate of indirect labor dollar fixed costs. Second, the percentage of fixed indirect personnel to total employment, direct and indirect, was computed. This percentage was then applied to total dollars of fringe benefit costs. Third, the "pure" fixed costs that make up the bulk of facilities-related costs were considered to be 100 percent fixed. Such costs include depreciation, rent, taxes, insurance, utilities, and maintenance. Fourth, data processing costs were reviewed and an estimate was made that 50 percent of these costs were fixed. The corporate G&A allocation and IR&D/B&P costs were estimated to be 100 percent fixed. Miscellaneous overhead costs were considered to be 25 percent fixed. Finally, the categories were summed and compared with total plantwide overhead to compute an estimate of fixed overhead.

The results of our application of the ACM to aggregate data for the four contractors are graphed in Figure 5. The fraction estimated to be fixed is about 50 percent across all years. The lack of variation derives from our lack of bases for modifying our judgements with the passage of time and evolution of manufacturing processes as a company accountant would. The estimates produced by the regression model, also graphed in Figure 5, equal the ACM estimates early in the period. However, the regression model estimates increase well above 60 percent by the mid-1980s and then decline in the second half of the 1980s. It is interesting to note that the increases align with the military buildup during the Reagan administration and the declines, with the down-turn in the defense budget starting in FY 1985.

This comparison cannot be viewed as a validation of the regression method because we lacked the information required to make the ACM sensitive to changes in capital structure.

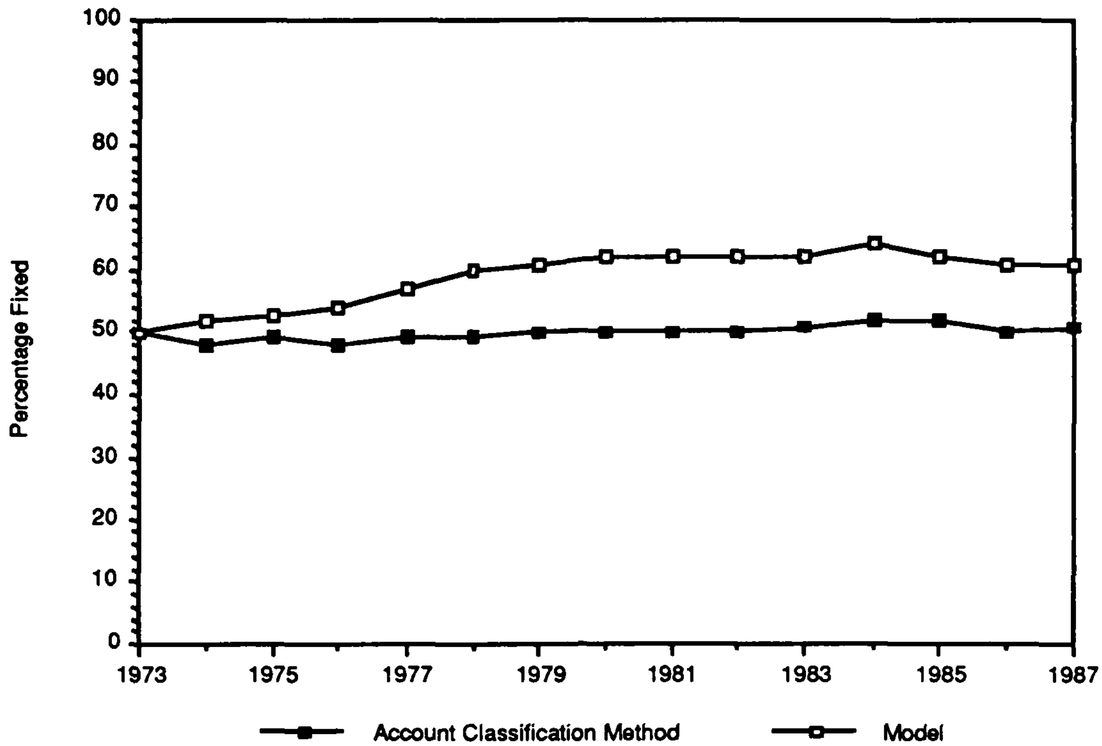


Figure 5. Predictions of the Fixed Portion of Overhead

4. Model Sensitivity

We calculated the sensitivity of model estimates of the fixed portion of plantwide overhead to variations in the values of the independent variables, capital and direct costs. This information may be informative to analysts who would like to apply the model but have difficulty producing values for the independent variables. We used data for the latest year for which data were available, 1987, and varied the values of the variables from half the 1987 value to twice that value.

The results for changes in the capital variable, K, holding all else constant, are presented in Figure 6. The fixed portion of overhead was estimated by the model to be 61 percent in 1987. As the value of the capital variable, net book value, was reduced from K to K/2, the fixed portion decreased to about 52 percent, reflecting a lower fixed burden associated with supporting a smaller basket of capital assets. Going in the other direction, as the value of the capital variable is increased to 2K, representing a doubling of the net book value of capital assets, the fixed burden increases to about 71 percent.

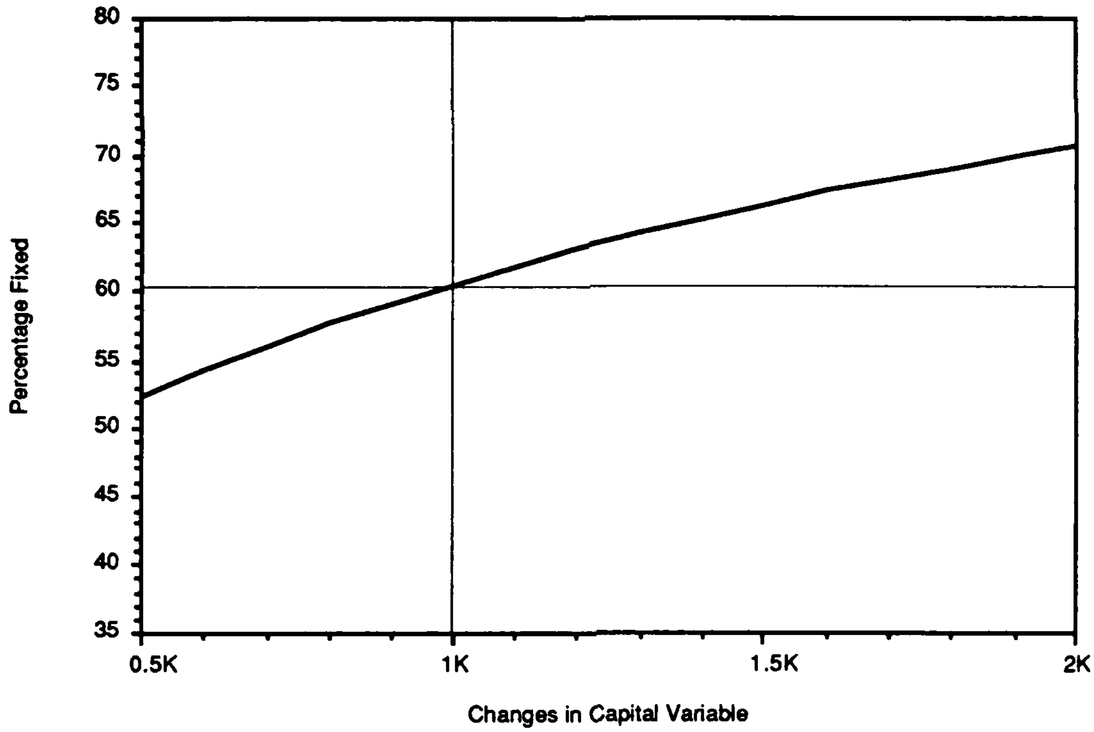


Figure 6. Capital Variable Sensitivity

The results for changes in the direct costs variable are presented in Figure 7. The range in variation in the independent variable, direct costs, was the same as for the capital variable discussed above. The results of this calculation are the reverse of the results for capital. That is, an increase in direct costs results in a decrease in the fixed portion. This can be seen by noting in Equations (3) and (4) that the direct costs variable in the equation is associated with variable overhead while the capital variable is associated with fixed overhead. Thus, as direct costs increase, holding capital constant, the portion of overhead that varies with direct costs increases while fixed overhead costs remain constant. This results in the fixed proportion decreasing, as shown in the figure. Decreasing the value of the direct costs variable by half increases the fixed portion of overhead costs from 43 percent to about 77 percent. Doubling the value decreases the fixed portion to about 37 percent.

The results of these sensitivity analyses indicate that estimates of the fixed portion of overhead are modestly sensitive to changes in the capital variable. Estimates are more sensitive to changes in the output variable. This suggests to us that, in applying this fraction (i.e., about 63 percent in 1991) to a particular estimating scenario, the analyst may want to consider investigating the possibility of a drastic change in output during the period of the estimate, which would suggest an adjustment to the fraction. As might be expected, the possibility to watch for would be a drastic reduction in output. This outcome could be expected to result in a large increase in the fixed portion of costs in the absence of a reduction in plant capacity and supporting infrastructure.

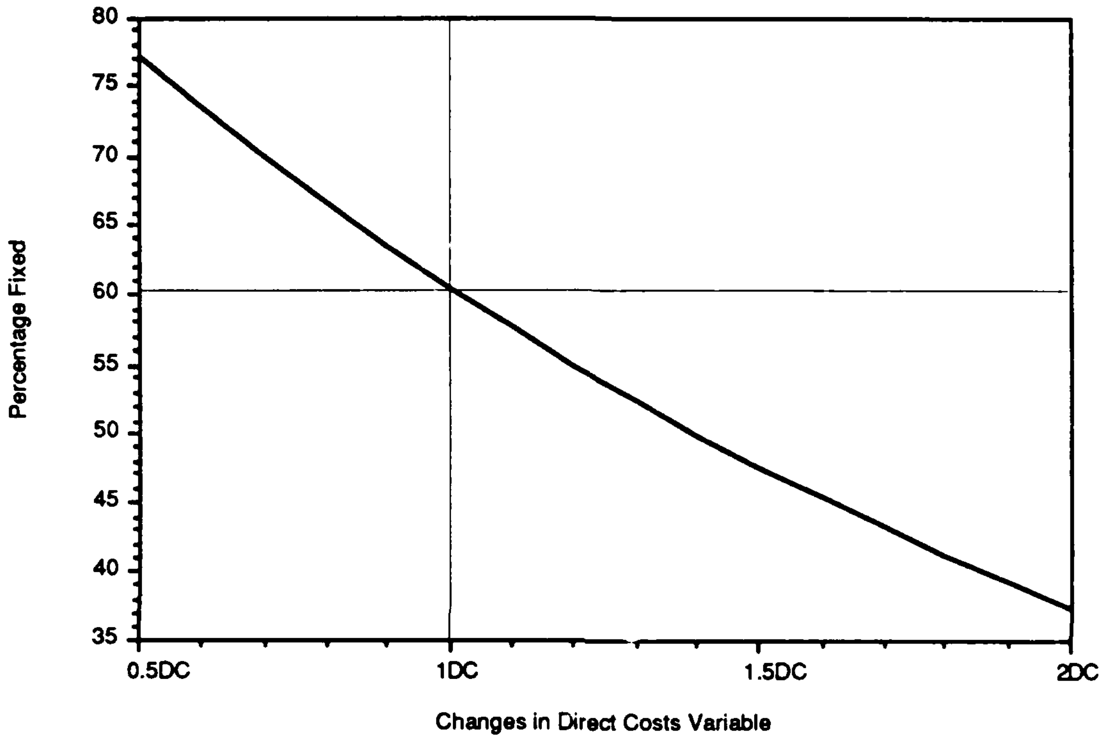
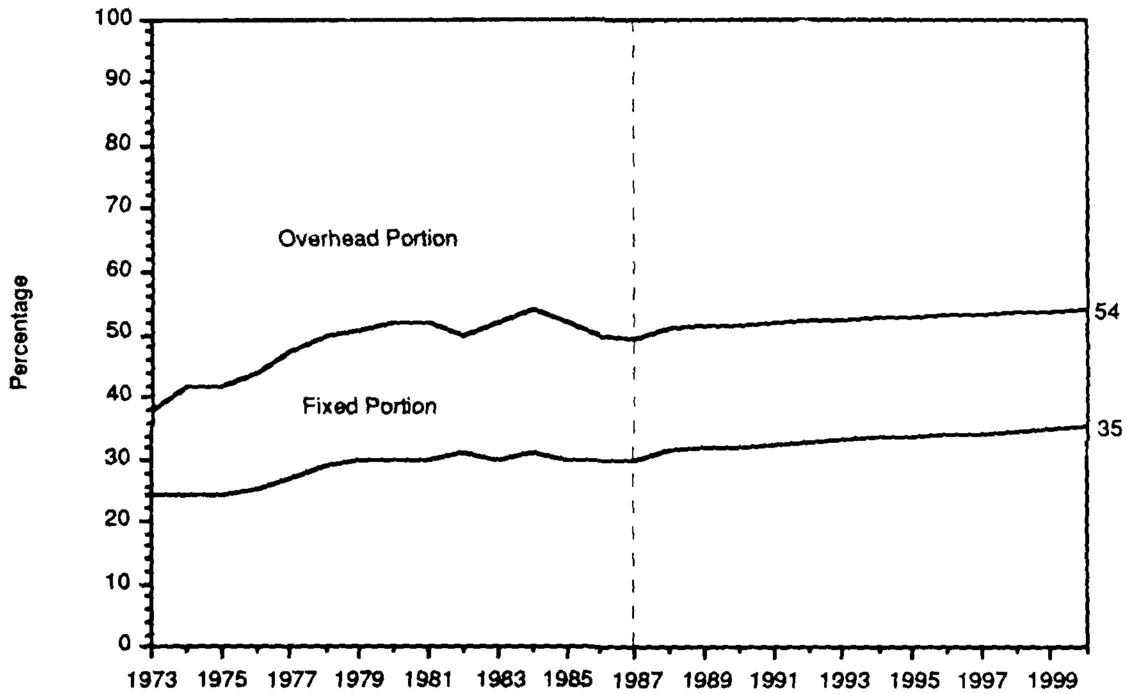


Figure 7. Direct Costs Variable Sensitivity

5. Application

The purpose of the model presented in this paper is to separate the total annual costs of a contract (e.g., for a lot of airframes) into fixed and variable portions, as described in Section C. The purpose of the separation is to allow fixed and variable costs to be estimated separately and then added (as described in Reference [8]). Note that while the application is at the individual contract level, the model was developed with plantwide data that included all of the contractors' contracts. Since fixed costs are a part of overhead and overhead is allocated to all contracts in process using the same procedure, the plantwide model applies to both the plant and contract levels.

To determine the proportion of annual contract costs that are fixed, we estimate the portion of plantwide costs that are fixed and apply the factor to contract expenditures in that year. Development of the annual factor requires application of Equation (6) to determine the fraction of plantwide overhead costs that is fixed, and then application of Equation (7) to determine the fraction of total business that is fixed.[2] Given these equations, the procedure is identical to the technique described in References [8 and 21]. The results of these calculations are graphed in the lower left portion of Figure 8. The fixed portion of total business for our sample of contractors increased from about 24 percent in 1973 to about 30 percent by 1987. These findings are consistent with the findings of prior IDA studies [4, 5, 6, and 7].



Note: The years 1988-2000 are forecasts.

Figure 8. Forecasts of Overhead and Fixed Costs Portions of Pusiness Base

This procedure for estimating fixed costs can be applied to future years given certain assumptions. If we assume that manufacturing technology associated with military airframes will continue to evolve in the future as it has over the past two decades, and if business volumes are similar to those in our sample, then extrapolations of the trends presented here in both overhead costs and the fixed portion of overhead can be expected to

2 Fixed overhead/total business = (fixed overhead/total overhead) × (total overhead/total business).

provide reasonable estimates of the fixed portion of costs for at least a few years into the future.

6. Projection

We extrapolated trends in both the plantwide overhead portion and the fixed portion of business base out to the year 2000 using the double smoothing method (see Reference [22][3]). This method minimizes the sum of squared errors between actual and forecasted data, as linear regression does, but it has the advantage of capturing the cumulative effects of all historical data.

The form of the forecasting equation is

$$F_t = a + b(F_{t-1}) \quad , \qquad (6)$$

where

F_t = forecast of time period t

a = constant fit from the data

b = coefficient fit from the data.

The fitted values of the parameters a and b were 0.346 and 0.0085 for the overhead forecasts and 0.020 and 0.0034 for the fixed cost forecasts. The projection to the year 2000 is presented in Figure 8. Assuming current trends persist, overhead will grow to represent about 54 percent of business base by the year 2000, and the fixed portion will increase to represent about 35 percent of both business base and annual contract cost.

E. SUMMARY

The purpose of this paper is to present an unclassified, non-proprietary description of a method for separating fixed and variable costs that has been applied at IDA for about six years. The methodology was built into cost-estimating models implemented in many cost analysis offices in the Department of Defense and other places. This research was possible because of the availability of detailed data collected from defense contractors over the past decade. These data describe both the direct and indirect costs at a level of detail that allowed normalization into a consistent, cross-company data set. These data were combined and transformed to protect the proprietary nature of the raw data.

---

3 An alpha value of 0.2 was selected for the overhead portion of business base and an alpha value of 0.15 was selected for the fixed portion of business base.

Plantwide overhead has been increasing steadily from about 38 percent of total business in 1973 up to about 50 percent by 1987. Extrapolation of past trends indicates this growth will continue up to about 54 percent by the year 2000.

The quantity needed to apply our method of estimating is the fraction of total business that is fixed, year by year. Estimates for that quantity started at about 24 percent in 1973 and increased steadily to about 30 percent by 1987. Based on extrapolations this quantity is about 32 percent this year and will reach 35 percent by the year 2000.

Cost analysts with detailed information on business, output, and capital at a particular firm of interest can use the approach described here to develop estimating equations for overhead, the portion of overhead that is fixed, and the the portion of total business that is fixed. Those without such information can use the graph of projections shown here to estimate the fixed portion of total business over the period of interest. This is the quantity needed to apply the estimating techniques in use at IDA and several Department of Defense offices.

REFERENCES

[1] Dickey, Robert I., ed. *Accountants' Cost Handbook.* New York: John Wiley & Sons, 1960.

[2] McCullough, James D., and Rosemary H. Jones. "Defense Industry Indirect Cost Analysis: Lockheed-California Company." Paper P-1771, Institute for Defense Analyses, April 1984.

[3] McCullough, James D., and Rosemary H. Jones. "Defense Industry Indirect Cost Analysis: Sikorsky Aircraft Division: United Technologies Corporation." Paper P-1741, Institute for Defense Analyses, April 1984.

[4] McCullough, James D., James K. Bui, and Thomas P. Frazier. "Defense Contractor Indirect Costs: General Dynamics–Fort Worth Division, 1969-87." Paper P-2244, Institute for Defense Analyses, August 1989.

[5] McCullough, James D., James K. Bui, and Thomas P. Frazier. "Defense Contractor Indirect Costs: Grumman Aerospace Corporation, Grumman Corporation, 1973-87." Paper P-2280, Institute for Defense Analyses, August 1989.

[6] McCullough, James D., James K. Bui, and Thomas P. Frazier. "Defense Contractor Indirect Costs: Northrop Aircraft Division, Northrop Corporation, 1967-87." Paper P-2190, Institute for Defense Analyses, August 1989.

[7] McCullough, James D., James K. Bui, and Thomas P. Frazier. "Defense Contractor Indirect Costs: McDonnell Aircraft Company, 1969-87." Paper P-2179, Institute for Defense Analyses, August 1989.

[8] Balut, Stephen J., Thomas R. Gulledge, Jr., and Norman Keith Womer. "A Method for Repricing Aircraft Procurement Programs," *Operations Research*, vol. 37, no. 2 (March-April 1989), p. 255-265.

[9] Boger, Dan C. "Statistical Modeling of Overhead Costs." *Engineering Cost and Production Economics*, vol.8 (1984), pp. 145-156.

[10] J. Johnston. *Statistical Cost Analysis.* New York: McGraw Hill, 1960.

[11] Dean, Joel. "Statistical Cost Functions of A Hosiery Mill," reprinted in Mansfield, Edwin , ed., *Microeconomics.* New York: W.W. Norton & Company Inc., pp. 115-124.

[12] Kahn, Alfred E. *The Economics of Regulation: Principles and Institutions, Vol 1. Economic Principles.* New York: John Wiley & Sons, 1970, pp. 78-83.

[13] U.S. Department of Transportation. *Airport and Airways Cost Allocation Study, Part I Technical Supplement*, November 1973.

[14] Kaplan, Robert S. *Advanced Management Accounting.* Englewood Cliffs: Prentice-Hall Inc., 1982, pp. 90-92.

[15] Womer, Norman K. "Estimating Learning Curves From Aggregate Monthly Data." *Management Science*, vol. 30, no. 8, 1984, pp. 982-992.

[16] Helfogott, Roy B. "On the Demise of the Long Run." *Journal of Economic Perspectives*, vol. 3, no. 4, 1989, pp. 149-152.

[17] G. S. Maddala, *Econometrics*. New York: McGraw-Hill Book Company, 1977, pp. 156-157.

[18] McCullough, James D., and Stephen J. Balut. "Defense Contractor Indirect Costs: Trends, 1973-82." Paper P-1909, Institute for Defense Analyses, March 1986.

[19] Balut, Stephen J., and James D. McCullough. "Trends in a Sample of Defense Aircraft Contractors' Costs." Document D-764. Institute for Defense Analyses, August 1990.

[20] Frazier, Thomas P., and Thomas Gulledge. "An Econometric Analysis of Aircraft Manufacturers." Paper P-2069. Institute for Defense Analyses, April 1988.

[21] Balut, S. J. "Redistributing Fixed Overhead Cost." *Concepts*, vol. 4, no. 2, Spring 1981, pp.63-76.

[22] Thomopoulos, Nick T. *Applied Forecasting Methods*. Englewood Cliffs: Prentice-Hall, Inc., 1980, pp. 82-83.

APPENDIX A.

REGRESSION DATA

APPENDIX A.

REGRESSION DATA

The masked data used in the regression analysis are shown in Table A-1. The data were transformed using the following equation:

$$Y'_{it} = \frac{Y_{it} - \overline{Y}_i}{S_i} ,$$

where

Y_{it} = the actual data for contractor i and time period t

$\overline{Y}_i$ = the sample mean for contractor i

S_i = the sample standard deviation for contractor i.

Table A-1. Normalized Regression Data

Year	Plantwide Overhead	Net Book Value	Direct Costs	Business Base
1969	6584.8	5346.4	7875.6	7416.5
	-1950.4	-4587.6	5179.7	37.9
1970	4692.1	1513.9	4836.6	4802.8
	-5562.9	-4724.8	4599.3	-3022.0
	-6103.7	-5547.8	-5385.5	-5839.5
1971	-827.0	-2141.3	-1127.1	-1017.3
	-7404.2	-5167.7	-2891.7	-6795.2
	-9175.6	-5927.4	-10065.7	-9769.4
1972	-4873.6	-5100.9	-5144.2	-5063.5
	-6538.6	-5442.0	-3892.1	-6412.6
	-8874.4	-5950.9	-9356.0	-9257.9
1973	-6505.0	-6273.8	-6376.9	-6454.2
	-6851.6	-4205.3	10039.7	3779.1
	-5765.3	-4221.9	-3878.3	-5791.6
	-7537.2	-5848.8	-6577.2	-7174.2
1974	-7863.9	-6996.7	-7841.8	-7885.1
	-4568.9	-4130.8	6642.0	2477.7
	-4587.2	-3830.4	-6179.8	-5560.0
	-4202.3	-5585.3	-2125.8	-3224.6
1975	-7659.9	-7228.6	-7475.4	-7579.2
	-3279.7	-3682.7	7073.7	3628.5
	-6797.1	-3776.2	-11720.4	-9027.2
	-2985.9	-5084.4	-1321.5	-2196.1
1976	-6048.9	-7078.5	-6862.2	-6581.4
	-3799.1	-3893.2	4233.0	1025.3
	-3052.4	-3801.9	6501.2	-434.5
	-2060.3	-4595.2	-1881.4	-2003.1
1977	-4310.2	-5210.0	-5543.0	-5095.8
	-4335.6	-3930.3	-586.2	-3175.7
	-2526.6	-3759.0	107.0	-1982.3
	-1063.2	-4390.6	-566.9	-830.4
1978	-2716.8	-2564.1	-3043.7	-2932.1
	-5046.4	-3921.4	-5886.9	-7871.8
	162.8	-3144.7	21.7	136.5
	640.7	-1769.6	1592.9	1129.9
1979	-1044.6	-545.6	460.2	-113.7
	-4310.5	-4074.3	-6807.1	-8150.9
	-586.8	-2058.9	-8217.4	-2996.1
	2324.6	-450.9	1169.5	1780.5
1980	1133.0	1623.0	-53.8	400.2
	-2354.4	-3148.0	-6552.6	-6726.1
	308.7	-155.9	-1089.7	-89.0
	2884.6	1676.6	1255.1	2110.8

Table A-1. Normalized Regression Data (Continued)

Year	Plantwide Overhead	Net Book Value	Direct Costs	Business Base
1981	759.4	2673.2	2055.9	1568.8
	-949.4	-2067.1	-5909.4	-5333.4
	3708.0	1598.4	2475.5	3719.1
	5612.9	4109.4	3546.1	4662.5
1982	907.8	2168.6	1140.1	1056.2
	72.1	-856.4	-4244.3	-3360.1
	5189.9	3307.1	3385.2	5180.9
	9293.6	10080.2	13539.9	11577.6
1983	851.4	2850.5	3221.1	2328.4
	2844.2	857.7	-4203.9	-1597.9
	4619.0	3724.3	1141.3	4035.2
	5233.5	4254.8	4104.9	4749.0
1984	2327.8	2359.5	2247.2	2288.0
	6716.5	3457.7	-2712.7	2014.8
	5523.3	5747.2	-3150.7	3436.0
	4665.0	5046.1	997.9	2894.4
1985	4214.1	4364.4	3133.2	3560.8
	10506.4	6906.6	1541.6	7792.8
	5835.6	7687.4	197.2	4715.1
	6726.7	6196.7	3642.0	5281.9
1986	7561.3	6505.7	7835.0	7765.0
	8611.4	10349.3	3027.0	7802.0
	9979.6	11030.4	6380.2	9922.6
	4383.6	6784.7	4998.7	4762.8
1987	12818.2	13734.3	10663.3	11535.4
	6745.0	12338.2	4346.3	7695.8
	9444.6	11576.1	11031.9	10927.0
	237.4	7002.2	2433.1	1345.7

APPENDIX B.

SERIAL CORRELATION CORRECTION

APPENDIX B.

SERIAL CORRELATION CORRECTION

To test for serial correlation, an estimate of the first-order correlation coefficient r was computed [B-1]:

$$r = \frac{\sum e_t e_{t-1}}{\sum e_t^2},$$

where e is the residual for time period t.

We assumed that each pair of consecutive residuals for a given firm (e_t, e_{t-1}) had a bivariate normal distribution with mean zero, common variance S^2, and correlation r. The variance and the correlation were assumed to be common across both firms and time period. The variance is estimated by the sum of squared residuals. The derived maximum-likelihood estimate of the first-order correlation coefficient under these assumptions was:

$$r = \frac{\sum_{i=1}^{n} \sum_{t=2}^{T_i} e_{i,t}\, e_{i,t-1}}{TS^2}$$

where

$i=1,\ldots, n$ = firms 1 through n

T_i = years of data for firm i

$$T = \sum_{i=1}^{n} T_i\ .$$

This equation represents the sum of products of consecutive residuals divided by the total sum of squared residuals. When r is on the order of 0.1 or 0.2, serial correlation is not a major concern.

When significant serial correlation was found, the Cochrane-Orcutt procedure [B-2] was used to obtain the estimates.[1] Under this procedure, an observation (Y_t, K_t, L_t) is replaced by ($Y_t - rY_{t-1}$, $K_t - rK_{t-1}$, $L_t - rL_{t-1}$), where r is an estimate of the first-order correlation coefficient. The transformed data from Appendix A were used for the regression to derive the coefficients for K and L. The intercept term was computed using the following equation:

$$\text{alpha} = \frac{\text{alpha}'}{(1 - r)} ,$$

where

alpha' = the intercept of the transformed data regression.

1 Schnedar [B-3] employed a Box-Jenkins transformation on quarterly overhead data. We could not use this method since it did not include an intercept term to separate the fixed portion of overhead costs.

REFERENCES

[B-1] Goldberger, Arthur S. *Econometric Theory*. New York: John Wiley and Sons, 1964, p. 243.

[B-2] Pindyck, Robert S., and Daniel L. Rubinfeld. *Econometric Models and Economic Forecasts*. New York: McGraw-Hill Book Company, 1976, pp. 111-112.

[B-3] Schnedar, Christopher P. "A Comparison of Projection Methods in the Forecasting of Overhead Costs for Seven Government Aerospace Contractors." Master's Thesis. Naval Post Graduate School, September 1987.

APPENDIX C.

ADDITIONAL DATA

Table C-1. Average Actual and Predicted Plantwide Overhead

	Thousands of 1987 Dollars			
	Actual	Predicted		
Year	Total	Total	Fixed Portion	Percentage Fixed
1973	$629,418	$777,418	$392,015	50%
1974	679,769	753,938	395,625	52
1975	690,811	762,663	400,913	53
1976	706,988	738,758	397,911	54
1977	698,688	692,963	395,105	57
1978	708,839	677,191	409,445	60
1979	718,206	683,246	419,575	61
1980	761,395	717,120	447,967	62
1981	811,449	766,469	478,257	62
1982	866,682	871,054	542,660	62
1983	854,311	806,125	502,331	62
1984	914,735	828,419	527,919	64
1985	987,903	902,765	562,843	62
1986	980,289	962,715	591,630	61
1987	973,420	993,699	601,478	61

Table C-2. Comparison of Estimates of Fixed Plantwide Overhead by Method

Year	IDA Model	Account Classification Method
1973	50%	50%
1974	52	48
1975	53	49
1976	54	48
1977	57	49
1978	60	49
1979	61	50
1980	62	50
1981	62	50
1982	62	50
1983	62	51
1984	64	52
1985	62	52
1986	61	50
1987	61	51

Table C-3. Model Estimates of Fixed Portion of the Business Base

	Thousands of 1987 Dollars		
Year	Business Base	Fixed Overhead	Percentage Fixed
1973	$1,643,636	$392,015	24%
1974	1,622,699	395,625	24
1975	1,642,785	400,913	24
1976	1,603,954	397,911	25
1977	1,482,524	395,105	27
1978	1,413,434	409,445	29
1979	1,412,077	419,575	30
1980	1,469,692	447,967	30
1981	1,569,903	478,257	30
1982	1,730,876	542,660	31
1983	1,653,768	502,331	30
1984	1,705,525	527,919	31
1985	1,882,435	562,843	30
1986	1,956,828	591,630	30
1987	2,005,581	601,478	30