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Wright-Patterson Air Force Base, Ohio

Accession For	
NTIS GRA&I	☒
DDC TAB	☐
Unannounced	☐
Justification	
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Distribution/	
Availability Codes	
Dist.	Avail and/or special
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(11) J...

(9) Master's thesis,

(14) AFIT-LSSR-23-80

(12) 75

(6) A COMPARATIVE ANALYSIS OF TWO COST PERFORMANCE FORECASTING MODELS: THE AUTOMATED FINANCIAL ANALYSIS PROGRAM, ELECTRONIC SYSTEMS DIVISION, NOVEMBER 1976 VERSUS A COST PERFORMANCE FORECASTING CONCEPT AND MODEL, AERONAUTICAL SYSTEMS DIVISION, NOVEMBER 1974.

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USAF SCN 75-20B AFIT Control Number LSSR 23-80

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER LSSR 23-80	2. GOVT ACCESSION NO. AD-A087	3. RECIPIENT'S CATALOG NUMBER 500
4. TITLE (and Subtitle) A COMPARATIVE ANALYSIS OF TWO COST / PERFORMANCE FORECASTING MODELS: THE AUTOMATED FINANCIAL ANALYSIS PROGRAM, ELECTRONIC SYSTEMS DIVISION, NOVEMBER 1976 VERSUS A COST PERFORMANCE CONCEPT AND MODEL, AERONAUTICAL SYSTEMS DIVISION, NOVEMBER 1974		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Thomas J. Land, Captain, USAF Edward L. Preston, Captain, USAF		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS School of Systems and Logistics Air Force Institute of Technology, WPAFB OH		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Department of Communication and Humanities AFIT/LSH WPAFB OH 45433		12. REPORT DATE June 1980 13. NUMBER OF PAGES 62
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

APPROVED FOR PUBLIC RELEASE AFR 190-17.

Fredric C. Lynch

FREDRIC C. LYNCH, Major, USAF
Director of Public Affairs

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Cost Performance Forecasting
Linear Model
Non-linear Model
"Constrained" Model
"Unconstrained" Model

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

Thesis Chairman: James M. Masters, Major, USAF

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UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

The authors investigated the comparative accuracy of linear and non-linear cost forecasting models in estimating a contractor's cost at completion. Using cost performance reporst for 20 completed aircraft programs, the authors generated estimates covering the span of the programs. The mean absolute percentage errors for each method and program were analyzed using ANOVA. Where indicated by ANOVA, Fisher's least significant difference test statistic was used to test the differences and established set groupings. The authors conclude, based on the sample that the linear cost forecasting model is as accurate as the non-linear cost forecasting model.

LSSR 23-80

A COMPARATIVE ANALYSIS OF TWO COST PREFORMANCE FORECASTING MODELS: THE AUTOMATED FINANCIAL ANALYSIS PROGRAM, ELECTRONIC SYSTEMS DIVISION, NOVEMBER 1976 VERSUS A COST PERFORMANCE FORECASTING CONCEPT AND MODEL, AERONAUTICAL SYSTEMS DIVISION, NOVEMBER 1974

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics Management

By

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June 1980

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This thesis, written by

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has been accepted by the undersigned on behalf of the faculty of the School of Systems and Logistics in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN LOGISTICS MANAGEMENT
(ACQUISITION LOGISTICS MAJOR)

DATE: 9 June 1980

COMMITTEE CHAIRMAN

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Chapter 1

PROBLEM STATEMENT

To the acquisition program manager, accurate cost information is essential for effective program management. Congress, and the public in general, demand accountability for the spending of tax dollars particularly for dollars spent in the acquisition of complex defense systems. At the product divisions within Air Force Systems Command (AFSC), the program manager is held accountable for the technical success and cost of an acquisition program. He is the key decision maker. Cost information must be provided in a form and at a time useful to him (1:33).

For his cost information, the program manager relies on a cost analyst. The cost analyst looks at the cost performance data he is receiving from the contractor to decide what information he should emphasize and how the information should be presented to the program manager. Depending on the dollar threshhold and type of contract, the contractor is required to submit either a monthly cost performance report (CPR) or cost/schedule status report (C/SSR) to the program office. The contractor provides data in these reports which; indicates work in progress, relates cost, schedule and technical performance, provides valid, timely, and auditable training, and supplies DOD managers with a practicable level of summarization (2:2-1).

A critical item of information the contract cost analyst supplies to the program manager is an estimate of the contract cost at completion (CAC). The estimate is used to; assess the program's budget and its phasing, and to forecast cost overruns (or underruns) and support funding requirements. Cost analysts in the Air Force often make use of one of two cost forecasting models to generate an estimate at completion (EAC): 1) the Automated Financial Analysis Program, a User's Guide, Electronic Systems Division, November 1976; or 2) a Cost Performance Forecasting Concept and Model, Aeronautical Systems Division, November 1974. The purpose of this thesis is to compare these two cost forecasting models by noting their respective accuracy when applied to actual observations of historical acquisition programs.

Both models cited above utilize monthly cost and schedule data supplied by the contractor in one of two reports; the Cost/Schedule Status Report (C/SSR), or the Cost Performance Report (CPR). The Cost/Schedule Status Report is applicable to Air Force contracts which have estimated Research, Development, Test, and Evaluation (RDT&E) costs between $2 million and $25 million or which have estimated production costs of between $2 million and $100 million. The Cost Performance Report is applicable to contracts which have estimated RDT&E or production costs greater than $25 million or $100 million, respectively. These reports serve as the basis by which the contract cost analyst can assess the contractor's progress toward meeting the schedule and cost specified in the contract.

At the onset, the reader must clearly recognize that this thesis does not address initial weapon system cost estimating or pricing. This thesis deals with two models which forecast or estimate a contractor's cost position at the completion of the contract. To remember this distinction, it is helpful to keep in mind that a contract has already been awarded and of interest is the contractor's performance. Additionally, the reader should recognize that the two models under discussion in essence represent mathematical manipulations of historical cost performance data. This approach is but one pursued by the contract cost analyst. Cost performance is also estimated using technical assessments and information provided by program office engineering personnel. A mathematical approach should not be viewed in isolation but rather used to support or in conjunction with other available information.

TERMS AND DEFINITIONS

The reader requires a basic understanding of the measures provided in the contractor's monthly C/SSR or CPR. Fortunately, these measures are few and are briefly defined as follows:

Budgeted Cost for Work Scheduled (BCWS) - BCWS is the time-phased budget which is the result of associating a budget for each task a contractor will perform with the appropriate schedule for that task. The time-phased budgets for tasks are aggregated yielding a plan in terms of dollars and time against which actual task accomplishment can be measured.

Budgeted Cost for Work Performed (BCWP) - BCWP is the sum of the budgets assigned to completed work plus an assessment of in-progress work. BCWP represents all work completed from the beginning of the contract through the end of the current accounting period. It in essence represents the physical accomplishments of a task, in which case BCWP for a completed task equals BCWS for that task. For in-process work, BCWP is derived by actual measurement or an assessment of the status of that task. For example, suppose $100 is budgeted to accomplish 10 hours of an engineering task. If the task has been accomplished, BCWP equals $100. If 5 hours of the task has been accomplished and the cost account manager estimates the task is indeed 50 percent complete, BCWP for the in-process work is $50.

Actual Cost for Work Performed (ACWP) - ACWP represents those direct and indirect costs identified specifically to the contractual efforts being reported. It represents the consumption of labor, material, and other resources. Again returning to the simplistic example of the engineering effort cited above, if the engineering task actually required 11 hours of effort at $10 per hour, the ACWP for the task would equal $110.

Before presenting two additional data elements important in performance report analysis, the three measures defined above are viewed together using the simplistic engineering task. Suppose the contract consisted solely of one task, the engineering effort, scheduled to be accomplished by time t, with a budgeted cost of $100. The budgeted cost for work scheduled at time t, is $100. If at time t, the engineering effort is incomplete, however, and an assessment is that 75 percent of the task has been accomplished, then BCWP equals $75. Suppose further that to accomplish this effort the contractor has encountered technical difficulties and accrued actual costs of $110, then ACWP at time t, equals $110.

Budgeted at Completion (BAC) - BAC equals the total budget for a particular element throughout the life of the program. In other words, BAC equals the summation of BCWS for the element. The BAC for any element reported in the performance report consists of the original budget for the element adjusted for contractual changes, internal replanning, assignment of undistributed budget, or application of management reserves.

Latest Revised Estimate (LRE) - The LRE is the current estimate of costs developed by the contractor based on past performance and future conditions which are expected to influence the contract. The LRE should be revised by the contractor as required to provide an accurate and timely estimate of final costs.

The five data elements defined above; BCWS, BCWP, ACWP, BAC, and LRE are the crucial elements of performance report analysis. To be sure, additional data elements are presented throughout this analysis. However, a definition and explanation of construction will be provided when a new term or measure is used. Having defined the crucial elements of performance report analysis, a general description of the ESD and the ASD models is provided.

GENERAL MODEL DESCRIPTIONS

The ESD cost at completion (CAC) forecasting model is actually comprised of six methods. All six methods calculate a performance factor (PF) based on a relationship between BCWP and ACWP. The performance factor is multiplied by the budgeted cost of work remaining (BCWR), calculated by subtracting the cumulative BCWP from the BAC, to generate an estimated cost for the remaining contractual effort. The estimate for remaining work is added to cumulative actual costs to data to provide an estimated cost at completion. Specifically, the performance factor is calculated as follows:

$$\text{Performance Factor} = 1.0 - \frac{\text{BCWP} - \text{ACWP}}{\text{BCWP}} \qquad (3\text{:A2-1})$$

All of the methods are linear, however two of methods use performance factors determined by a subjective process. Although not included in this analysis, the two methods using a subjective PF are valuable. The methods allow the program office to adjust the PF when a contractor's past cost performance is not indicative of his anticipated future performance.

The ASD cost at completion forecasting model is comprised of two estimating methods. Both ASD methods are based on a non linear relationship between BCWP and ACWP. Rather than a straight line as in the ESD model, the long term growth relationship in the ASD model is represented by a curve-linear form. The assumed relationship is:

$$ACWP = b_1 \; BCWP^{b_2}$$

where:

b_1 and b_2 represent the growth parameters of the relationship.

In one ASD method, monthly CPR or C/SSR observations of ACWP and BCWP are used to compute both parameters, b_1 and b_2. This method is referred to as the "unconstrained exponential method". A cost at completion estimate is calculated by substituting the current BAC in the equation. In the second ASD method, a value is assumed for b_2. After estimating the remaining parameter b_1, a forecast is calculated following the same procedure described above. The second ASD method is known as the "constrained exponential method" (4:19).

The potential utility of the "constrained" exponential method is explained in cost research report No. 117;

> . . . if a large family of completed program samples are similar in their [growth] characteristics and $y = b_1 x^{b_2}$ is a reasonable behavioral relationship then: (a) one may use the relationship to extrapolate an EAC after each CPR is submitted throughout the program life. (b) It is reasonable to expect that the computed parameters b_1 and b_2 would reflect these similarities. . .[4:15].

OBJECTIVES

A number of terms are defined in proceding paragraphs and subsequent chapters which may be confusing to an individual uninitiated in contract cost analysis. A general overview of the use of the terms places them in context. A contractor plans his effort associating budgets to tasks over time. This budget expressed over time is BCWS, his schedule. The budget for a task irrespective of time is in essence BCWP, the planned cost of the task. Actual costs are accumulated and compared to the planned budget. If actual cost for an effort exceeds planned cost, the contractor is in an overrun position. If actual cost is less than planned cost, the contractor is in an underrun position.

This study intends to achieve three specific objectives stated as follows:

1) Determine which of the two forecasting models is more accurate in forecasting the cost at completion of a contract.

2) Determine for aircraft acquisition programs parameter values of b_2 for use in the "constrained" cost performance forecasting method.

3) Determine which of the two forecasting models is more accurate when the contract is; less than 25 percent complete, greater than 25 but less than 50 percent complete, greater than 50 percent but less than 75 percent, and greater than 75 percent complete.

Preliminary analysis of the two forecasting models reveals fundamental mathematical differences in their construction. Linear percentage cost variance extrapolation methods apply the current or adjusted cost variance percentage to the budgeted cost of work remaining to generate an estimate at completion. The exponential methods, on the other hand, are based on an underlying non-linear performance relationship.

First Hypothesis

The exponential methods are more accurate than the linear cost variance extrapolation methods in forecasting an estimate at completion.

Second Hypothesis

The exponential methods are more accurate than the linear cost variance extrapolation methods in forecasting estimates at completion when a program is; less than 25 percent complete, greater than 25 percent but less than 50 percent complete, and greater than 50 but less than 75 percent complete.

Third Hypothesis

When estimates are generated for a program which is greater than 75 percent complete, one model is not significantly more accurate than the other. As a program approaches completion, the models yield the same results.

Fourth Hypothesis

If a sample of completed aircraft acquisition programs are similar in their characteristics, the parameters b_1 and b_2 reflect these similarities. A premise upon which the ASD model hinges is that the extreme values of the exponent b_2 is narrow, between 1.18 and .97, and in the majority of cases b_2 falls between 1.10 and 1.0 (4:15).

Prepared by the contract cost analyst, an estimate of cost at completion is a useful item of information to the program manager. The estimate is used to assess the program budget and support funding requirements. General descriptions of two cost forecasting models are provided noting the mathematical differences in estimate calculation. Chapter 2 is a review of literature providing additional information regarding the two models under analysis and descriptions of other models which are used in cost forecasting.

Chapter 2

LITERATURE REVIEW

The review of applicable literature is concentrated in three areas; literature descriptive of the two models under analysis, basic reference materials which explain the mathematical concepts upon which the models are based, and reference material describing other cost forecasting models used to estimate a CAC.

The Automated Financial Analysis Program, a User's Guide, published by the Cost Analysis Division, Comptroller, Electronic Systems Division, November 1976, provides the basic description and algorithms of six methods of forecasting a Cost at Completion (CAC). The methods of computing a cost at completion are based on the assumption that the computed cumulative percent cost variance

$$\left(\frac{BCWP - ACWP}{BCWP} \times 100 \right)$$

may be linearly extrapolated to the end of a program as an estimate of final cost.

The AFSC Guide for the Use of Contractor-Reported Cost Data, dated 1 July 1972 examines and describes the application of the percentage cost variance extrapolation and cumulative performance index techniques to generate an Estimate at Completion (EAC). The Cumulative Performance

Index (CPI = BCWP/ACWP) is applied to the BAC using the equation, EAC = BAC/CPI. Results generated by either procedure are identical. A shortcoming noted regarding the techniques is their failure to account for the overall completion status of a program, i.e, whether the program is 5 percent or 95 percent completed. Estimates generated with these techniques near program completion tend to be quite accurate, while estimates generated in the early stages of the contract may be misleading (2:A-6).

Cost Research Report No. 117, a Cost Performance Forecasting Concept and Model, published by the Cost Analysis Division, Comptroller, Aeronautical Systems Division, November 1974, provides the description of two methods of developing an exponential curve-linear form for forecasting an estimate at completion. The exponential relationship chosen is of the form $y = b_1 x^{b_2}$ with the parameters b_1 and b_2 estimated by using a non-linear least squares technique. The "unconstrained" technique uses BCWP and ACWP values given to date in the function $ACWP = b_1 BCWP^{b_2}$. Both b_1 and b_2 are calculated using a least squares technique. In turn, the computed parameters and current BAC are used to compute an estimate at completion given by the function $EAC = b_1 BAC^{b_2}$. The "constrained" technique specifies a value for the parameter b_2 based on historical data. After solving for the parameter b_1, an EAC is generated in the same manner as with the "unconstrained" technique. It is suggested in the

ASD report that the collection of CPR data from many historical programs and then estimating the parameters by type of acquisition could improve the accuracy of the "constrained" forecasting technique (4:29).

The ESD and ASD models selected for comparison in this study are but two of a number of forecasting models available for the cost analyst to use. This study would be remiss without mentioning some of the other models which are available.

A model developed and used by the Army is the Time Series Analysis for Army Internal Systems Management (TSARISM). A time series is a collection of observations on a characteristic generated sequentially in time. The objective of the time series analysis is to discover the relationship between variables and for each variable describe its behavior over time. The TSARISM program identifies a generalized model which may be either an autoregressive model, a moving average model, a mixed autoregressive-moving average model, or an integrated form of all three models. The procedure followed with the program is; 1) identify the possible models, 2) select a model and estimate the parameters, 3) form the forecasting equation, 4) test the model for adequacy through residual analysis, and 5) forecast with the model (5). TSARISM is a direct application of the Box-Jenkins time series methodology (6). As the above explanation indicates, the TSARISM program is quite complicated. Further, the model requires approximately twelve or more observations to estimate the parameters and evaluate the fitted model. Use of the TSARISM program basically implies a dedicated program analyst due to its complexity. We are studying the ESD and ASD models basically because of their simplicity and ease of application.

A model proposed by Daniel E. Busse is identical in functional form to the ASD model where ACWP = $\bar{z}$ (BCWP)$^{\bar{e}}$. In this model $\bar{e}$ is a sensitivity factor calculated as the change in ACWP over cumulative ACWP divided by the change in BCWP over cumulative BCWP. In essence, the relationship says that actual program cost as a function of planned cost is proportional to the current ratio of these variables (7:25). The proportionality constant is the sensitivity factor $\bar{e}$ and $\bar{z}$ is an offset coefficient. The difference between this model and the ASD model is that one month's data is used with this model to calculate $\bar{e}$ whereas the ASD model uses a least mean squares technique applied to a number of observations. In the Busse model, $\bar{e}$ is calculated as follows:

$$\bar{e} = \frac{ACWP/ACWP_{cum}}{BCWP/BCWP_{cum}}$$

Once the sensitivity factor $\bar{e}$ is determined, the offset coefficient $\bar{z}$ is calculated using the following equation;

$$\bar{z} = \frac{ACWP_{cum}}{(BCWP)^{\bar{e}}}$$

The entire process is summarized as follows:

1. Use the information in the latest Cost Performance Report to determine the parameters $\bar{e}$ and $\bar{z}$.

2. Use the latest revised BAC furnished by the contractor in the functional relationship to estimate final cost.

3. Repeat the process each month as new cost performance data is received.

The appropriateness of the model is questionable since the sensitivity factor, $\bar{e}$, may fluctuate widely as the program evolves. The forecasting procedure gives an indication of final cost only if the current existing cost performance trend continues. One similarity of particular importance in regard to this model and the ASD and ESD models is that they make use of data contained in Cost Performance Reports without requiring a subjective performance factor. A model which does require a subjective performance factor is discussed in the next paragraph.

One model which incorporates a subjective performance factor is a model presented by J. B. Holeman Jr., titled "A Product Improved Method for Developing a Program Management Office Estimated Cost at Completion". The basic formula of the model is as follows:

$$EAC = ACWP_{cum} + (BCWR \times PPF)$$

where:

EAC is the Estimated Cost at Completion

$ACWP_{cum}$ is the total Actual Cost for Work Performed to date

BCWR is the Budget Cost of Work Remaining

PPF is the Predicted Performance Factor or a prediction of what it will actually cost for each $1.00 worth of planned work remaining (8:22).

The model actually consists of three options for determining a predictive performance factor. Option one uses a cost performance index (CPI). This cost performance index is calculated as cumulative ACWP divided by cumulative BCWP. The option is similar to the performance factor used in the ESD model. The CPI does not explicitly take into consideration a number of important factors which could affect the EAC, such as schedule variations, inflation, and technical risks. Despite these shortcomings, the simplicity of the CPI makes its use attractive.

The second option to determine a PPF is based on five factors which contribute significantly to cost change: changes in requirements, inflation, schedule variations, overhead, and unexpected technical problems. Schedule and requirement changes are incorporated into the model by increasing BCWR. The effects of inflation, overhead rates, and technical problems are reflected in the performance factor. This option is particularly useful given knowledge of the expected rate of the inflation and the change in overhead rates.

The third option to determine a PPF is basically an extension of the first two. Instead of determining a single value for the PPF, a range is specified. This option is used at the lowest level of the Work Breakdown Structure (WBS) consistent with the practicality of getting the needed information. Estimated Costs at Completion ranges for lower WBS items are summed to the aggregate level. The second and third options can be very useful when knowledge of the five factors discussed above is available to the cost analyst.

The final model reviewed is documented in the Space and Missile Systems Organization (SAMSO) Cost Performance Forecasting Study dated June 1977. The model is actually comprised of two methods. One method uses a six month straight line moving average projection of ACWP and BCWP to generate an EAC. BCWP data for six months is used to fit a straight line via least squares regression. The BCWP fitted regression line is then projected to a point in time where it equals current BAC. In turn, six months of ACWP data is used to fit a straight line which is projected to the time period in which BCWP equals BAC. The result is an estimate of the contract cost at completion (9:8).

The second method uses an equation that more closely fits the expenditure data than a straight line.

The curve that showed the best results was a modified Erlang equation:

$y = ax^b e^{cx}$ $\quad\quad\quad$ $\$ =$ ACWP, BCWP, BCWS

$$\$ = B_1 X^{B_2} e^{B_3 x} \qquad x = \text{month}$$

Then the ASD model was used to provide a "better" non-linear least squares regression fit of the cum of this equation.

$$y = \sum_{x=0}^{n} a x^{b} e^{cx} \qquad [9:21]$$

The monthly cumulative BCWP observations are used to fit the curve form which is projected as described above to a point in time where BCWP equals BAC. Similarly, monthly ACWP is fitted with a curve form. As with the six month straight line moving average projection method, the second method generates an EAC by projecting the fitted ACWP curve form to the point in time where BCWP equals BAC.

Indeed, all of the above models are useful and each may be particularly appropriate when applied to a specific type of program (e.g., missile procurement). The ASD and ESD models are chosen for their simplicity and ease of application. The cost variance percentage extrapolation model (ESD) is intuitively straight forward. The ASD model is log-linear for easy computation of the parameters but is a curve form. The ESD model is compared with the ASD model because the assumed functional relationship between ACWP and BCWP in the ASD model is non linear. A straight line relationship between cumulative ACWP and BCWP does not seem to represent the long term growth relationship.

Chapter 3

METHODOLOGY

Overview

Chapter 3 consists of five sections. The first two sections describe the population of interest and the data collection plan. The raw data elements are discussed noting how the elements are collected and from where. Section 3 presents the computational formulas used in each method to forecast an estimate at completion. Four ESD methods and the two ASD methods are explained. In section 4, a measure of accuracy is defined as well as its calculation. The fifth section explains the testing procedure. The test design is related to the objectives and hypotheses of the comparative analysis. To test for the equality of treatment means a single factor analysis of variance (ANOVA) is used with a randomized complete block design. ANOVA indicates if there are differences between treatments, but exactly which treatments differ is not specified. To determine which treatments differ Fisher's least significant difference test is applied between treatment means.

Sample/Population

The universe is defined as all DOD procurement programs which require contractor submittal of either a cost/

schedule status report (C/SSR) or cost performance report (CPR). In essence, these reports are applicable to RDT&E contracts and/or production contracts equal to or greater than $2 million in value. The populations of interest consist of aircraft and avionics RDT&E and procurement contracts. The measurement variables collected from either of the two reports are of the ratio scale. The importance of the scale cannot be overlooked as geometric and harmonic means can be used as measures of central tendency.

A random sample consisting of 25 programs is drawn from the completed program contracts library at Aeronautical Systems Division. All contracts in the sample have periods of performance greater than 12 months. Five additional aircraft programs are chosen and added to the sample for measuring the increase in accuracy of using a specified value of b_2 with the "constrained" estimating method. At best the results of this study can be generalized to other aircraft and avionics contracts. The parameters calculated based on the sample for use in the "constrained" method are applicable only to similar aircraft procurement programs. The study indicates however, whether or not the process of calculating parameters for use with the constrained estimating technique is useful in increasing the accuracy of estimates. If accuracy is improved, the procedure could be applied to other contract types (e.g., software and missiles).

Data Collection Plan

The data for this study is collected from cost performance reports (CPR's) and cost/schedule status reports (C/SSR's) on file in the program contracts library at Aeronautical Systems Division. Monthly CPR and C/SSR data is filed in the library for contracts requiring its submittal. From the ASD library completed contracts are selected for aircraft procurements and avionics contracts respectively, with periods of performance greater than 12 months. Completed programs are selected because the last CPR submitted contains, by definition, the final cost for the contract. It is important to note that final cost is being addressed as distinct from the final price which may include fee.

For each contract for each month, the following monthly cumulative data elements are transcribed from the CPR's to a columnar working sheet; BCWS - the budgeted cost of work scheduled, BCWP - the budgeted or planned cost for the work actually performed, ACWP - the actual cost of work performed, BAC - the budget at completion, that is, the planned value of effort to be accomplished by the contractor, and LRE - the contractor's latest revised estimate of the cost to perform the contracted effort. A separate working sheet is used for each contract. The format for the working sheets is presented in Appendix A.

Each worksheet contains the cumulative monthly data elements described above from the beginning to the end of the contract. For each contract, the monthly data elements are used to generate an estimate at completion. Estimates are generated beginning with the sixth month for all methods. Although several procedures can generate estimates with as little as three months of data, the "unconstrained" procedure in the ASD model requires at least six months of data for estimating the parameters by the least squares technique. The two estimating models are applied to each contract. The individual methods comprising each model with their computational formulas are discussed in the next section.

Methods of Estimating a Cost at Completion - ESD Model

The ESD Automated Financial Analysis Model is actually comprised of six methods which can be used to generate a cost at completion (CAC). In this study, four of those methods are employed which do not require a subjective performance factor. Often, a dedicated program analyst possesses knowledge of how future performance is anticipated to vary from past performance. The analyst can evaluate and allow for potential future changes in performance. The use of a subjective performance factor is dependent upon the analyst's knowledge of known technical risks yet to come which may not be reflected in past performance. Obviously, the insight required to make use of a subjective performance factor is not available. As such, two of the ESD methods are omitted from consideration in this study. The four methods drawn from the ESD model are presented with step by step instructions on their calculation.

Method 1. This method is calculated using a performance factor based on current month cost performance (3: A2-1). It is calculated as follows:

1. Compute current month BCWP ($BCWP_{cr}$)

$$BCWP_{cr} = \text{cumulative BCWP } (\text{month}_t) - \text{cumulative BCWP } (t-1)$$

2. Compute current month ACWP ($ACWP_{cr}$)

$$ACWP_{cr} = \text{cumulative ACWP } (\text{month}_t) - \text{cumulative ACWP } (t-1)$$

3. Compute the performance factor (PF)

$$PF = 1.0 - \frac{BCWP_{cr} - ACWP_{cr}}{BCWP_{cr}}$$

4. Compute quantity of work remaining (BCWR)

$$BCWR = BAC - \text{cumulative BCWP}$$

5. Compute the estimate to complete (ETC)

$$ETC = PF \times BCWR$$

6. Compute the cost at completion (CAC)

$$CAC = ETC + \text{Cumulative ACWP}$$

Method 2. This method is based on a three month moving average of current month cost performance to calculate the performance factor (3:A2-2). It is calculated as follows:

1. Compute current month $BCWP_{cr}$

   $BCWP_{cr}$ = cumulative BCWP ($month_t$) - cumulative BCWP ($month_{t-1}$)

2. Compute current month $ACWP_{cr}$

   $ACWP_{cr}$ = cumulative ACWP ($month_t$) - cumulative ACWP ($month_{t-1}$)

3. Compute current BCWP for first prior month ($BCWP_{cr-1}$)

   $BCWP_{cr-1}$ = CUM BCWP ($month_{t-1}$) - CUM BCWP ($month_{t-2}$)

4. Compute current ACWP for first prior month ($ACWP_{cr-1}$)

   $ACWP_{cr-1}$ = CUM ACWP ($month_{t-1}$) - CUM ACWP ($month_{t-2}$)

5. Compute current BCWP for second prior month ($BCWP_{cr-2}$)

   $BCWP_{cr-2}$ = CUM BCWP ($month_{t-2}$) - CUM BCWP ($month_{t-3}$)

6. Compute current ACWP for second prior month ($ACWP_{cr-2}$)

$$ACWP_{cr-2} = CUM\ ACWP\ (month_{t-2}) - CUM\ ACWP\ (month_{t-3})$$

7. Compute cost variance indexes for second prior, first prior, and current month

$$CV_3 = \frac{BCWP_{cr-2} - ACWP_{cr-2}}{BCWP_{cr-2}}$$

$$CV_2 = \frac{BCWP_{cr-1} - ACWP_{cr-1}}{BCWP_{cr-1}}$$

$$CV_1 = \frac{BCWP_{cr} - ACWP_{cr}}{BCWP_{cr}}$$

8. Compute performance factor

$$PF = 1.0 - \frac{(CV_1 + CV_2 + CV_3)}{3}$$

9. Compute quantity of work remaining (BCWR)

$$BCWR = BAC - CUM\ BCWP$$

10. Compute estimate to complete (ETC)

$$ETC = PF \times BCWR$$

11. Compute cost at completion (CAC)

$$CAC = ETC + CUM\ ACWP_{cr}$$

Method 3. Method 3 is calculated using a performance factor based on cumulative cost performance (3:A2-4). Step by step, it is calculated as follows:

1. Compute the performance factor (PF)

$$PF = 1.0 - \frac{\text{CUM BCWP}(\text{month}_t) - \text{CUM ACWP}(\text{month}_t)}{\text{CUM BCWP}(\text{month}_t)}$$

2. Compute quantity of work remaining (BCWR)

BCWR = BAC - CUM BCWP

3. Compute the estimate to complete (ETC)

ETC = PF x BCWR

4. Compute the cost at completion (CAC)

CAC = ETC + CUM ACWP

Method 4. This method is based on a performance factor calculated by using the last quarter cost performance (3:A2-10). Step by step, it is calculated as follows:

1. Compute current $BCWP_{cr}$ $(month_t)$
2. Compute current $ACWP_{cr}$ $(month_t)$
3. Compute first prior $BCWP_{cr-1}$ $(month_{t-1})$
4. Compute first prior $ACWP_{cr-1}$ $(month_{t-1})$
5. Compute second prior $BCWP_{cr-2}$ $(month_{t-2})$
6. Compute second prior $ACWP_{cr-2}$ $(month_{t-2})$

7. Compute BCWP for last quarter ($BCWP_q$)

$$BCWP_q = BCWP_{cr} + BCWP_{cr-1} + BCWP_{cr-2}$$

8. Compute ACWP for last quarter ($ACWP_q$)

$$ACWP_q = ACWP_{cr} + ACWP_{cr-1} + ACWP_{cr-2}$$

9. Compute performance factor (PF)

$$PF = 1.0 - \frac{BCWP_q - ACWP_q}{BCWP_q}$$

10. Compute quantity of work remaining (BCWR)

$$BCWR = BAC - CUM\ BCWP$$

11. Compute estimate to complete (ETC)

$$ETC = PF \times BCWR$$

12. Compute cost at completion (CAC)

$$CAC = ETC + CUM\ ACWP$$

The methods drawn from the ESD model presented above are similar in that they make use of a performance factor which is multiplied by the quantity of work remaining. The differences between methods lie in the calculation of the performance factors. Method 1 is based on the current month cost performance as reflected in the latest CPR. Method 2 again uses current month cost data but averages the last three months to construct the performance factor. Method 3 is based on cumulative cost performance data reported in the last CPR while method 4 is an adaptation where BCWP and ACWP are summed over the last three months to calculate the performance factor. The ASD model of estimating the cost a completion for a contract differs fundamentally from the ESD model and is explained in the next section.

Methods of Estimating a Cost at Completion - ASD Model

The ASD cost performance forecasting model is comprised of two methods; an "unconstrained" exponential method and a "constrained" exponential method. The "unconstrained" exponential method (Method 5) makes use of a least squares regression analysis technique for developing trend characteristics and the assumed relationship, $y = b_1 \cdot x^{b_2}$. The relationship was selected for the following properties;

a. In most samples a straight line relationship between cumulative ACWP and cumulative BCWP does not represent the long term growth relationship and so a curve linear relationship is considered more realistic.

b. The curve linear form $y = b_1 \cdot x^{b_2}$ can easily be compared to the case where the contractor is not experiencing a cost growth. When the parameters b_1 and b_2 both equal one, $y = x$. When b_2 is greater than one, y has a tendency to increase faster than x which produces an accelerating growth curve;

c. The exponential functional form is easily transformed to a linear relationship by taking the natural logarithms of the function. Thus taking the logarithms of the functional form $ACWP = b_1 \ BCWP^{b_2}$ transforms the ·tion to the linear form $LOG\ ACWP = LOG\ b_1 + b_2\ LOG\ BCWP$. transformed relationship allows application of the least squares technique to compute the values of b_1 and b_2 (4:13-14). A step by step summary of the computational process is described as follows:

Method 5. 1. Given the sample of monthly cumulative values available to data for ACWP and BCWP and the functional form $ACWP = b_1 \cdot BCWP^{b_2}$, the function is transformed to a linear relationship $LOG\ ACWP = LOG\ b_1 + b_2\ LOG\ BCWP$. The least squares technique computes the values of the parameters b_1 and b_2.

2. Using the current value of the budget at completion (BAC) and the computed values of b_1 and b_2, an estimate at completion or cost at completion is calculated using the function $EAC = b_1 \cdot BAC^{b_2}$.

3. Steps 1 and 2 are repeated with the addition of subsequent monthly CPR data (4:16).

The important point to note in the use of the "unconstrained" method is that the parameters are recalculated as additional observations are available. Both parameters b_1 and b_2 are free to fluctuate. The "constrained" method (Method 6) is constrained in that a value is specified for the parameter b_2. The parameters calculated from a few early samples are inadequate estimates of the parameters that will be obtained after the entire population of data elements for a given contract are available. The "constrained" method is an attempt to reduce the error of small sample sizes by substituting a subjective value for b_2. It was noted that diverse completed samples produced sets of parameters in which the extremes of the exponent, b_2, was narrow. In essence, the "constrained" method attempts to reduce the error in the parameters by placing the error in a historical context (4:19). In regard to this study, 20 historical aircraft procurement programs are used to calculate b_2 parameters for aircraft procurements. The calculated parameters are compared with the results that are specified in the ASD model, namely that the range of b_2's is narrow and most parameter values fall between 1.10 and 1.0 (4:15).

One does not know the exact value of the exponent until after submission of the final CPR. In this study, the historical parameters for similar completed aircraft programs of 1.0, 1.06 and 1.10 are used as subjective values of b_2. A step by step summary of the computational process for generating an estimate at completion is as follows:

<u>Method 6</u>. 1. Specify the value of b_2 to be used in the functional form $ACWP = b_1 \cdot BCWP^{b_2}$. Given the sample of monthly cumulative values available to date for ACWP and BCWP and the transformed function $LOG\ ACWP = LOG\ b_1 + b_2\ LOG\ BCWP$, the least squares technique is used to compute the value of b_1. Note: b_2 is a constant in this method.

2. Using the current value of the budget at completion (BAC) and the computed value of b_1 and the specified value for b_2, an estimate at completion or cost at completion is calculated using the function $EAC = b_1 \cdot BAC^{b_2}$.

3. Steps 1 and 2 are repeated with the addition of subsequent monthly CPR data.

The preceding sections explained the procedure and computational formulas used in the various methods to generate a cost at completion. In review, one can easily recognize that the two models are quite diverse. Having examined the computational procedures for each method, the next section describes measures of accuracy required in testing for differences between the methods.

Measures of Forecasting Accuracy

In this study the monthly sample data and methods 1 through 6 are used to generate estimates of the cost at completion (Q_{itp}). As explained earlier, estimates are generated beginning with the sixth month of cost performance data. For each procedure or method, a separate cost at completion estimate is generated with an additional month's cost data until completion of the program. The measure of accuracy is defined to be the absolute difference between the estimated cost at completion and the final ACWP value reported in the last CPR expressed as a percentage of final ACWP (D_{itp}). For each method by contract, the mean of the monthly absolute percentage differences is calculated ($\bar{M}_{ip}$). A summary of the measures of accuracy is provided below for easy reference:

1. Q_{itp} = estimate of CAC for procedure i generated in month t for program p.

2. D_{itp} = absolute percentage difference of Q_{itp} minus the final ACWP for program p.

$$D_{itp} = \frac{Q_{itp} - ACWP_p}{ACWP_p}$$

3. $\bar{M}_{ip}$ = mean absolute percentage difference for procedure i and program p. It is the sum of D_{itp} divided by the number of cost estimates (n) generated with procedure i for a given program.

$$\bar{M}_{ip} = \frac{\Sigma Q_{itp}}{n}$$

Accuracy can be measured in a number of ways. The sum of absolute errors, the mean square error (MSE), and the mean absolute percentage error (MAPE) are but a few measures. The MSE and sum of error measures of accuracy are absolute measures of the magnitude of error. The disadvantage is that they do not allow for comparison across treatments. Intuitively, an error associated with a large dollar value program can easily distort comparisons (10:8). For this reason, the error is expressed as a percentage with the major advantage being that the treatments can be compared.

Testing Procedure

As a general explanation, each of the procedures (Methods 1-6) is applied to the sample of completed programs. After calculating the measures of accuracy discussed above, the $\bar{M}$'s are tested to determine whether or not a significant difference exists between treatment means. A single factor analysis of variance (ANOVA) with a randomized complete block design is used to test for treatment mean equality. A randomized block design is used in the ANOVA model since differences among programs contribute to the variability observed in the measure of accuracy. As a result, the measure of accuracy reflects both random error and variability between programs. A design to remove the variability between programs is to test each method on each program. This strategy improves the accuracy of the comparisons between methods. Using an F test for the equality of treatment means, the alternative conclusions are;

$$H_o: \mu_1 = \mu_2 = \cdot \cdot \cdot \mu_6$$

$$H_1: \text{Not all } \mu\text{'s are equal}$$

The decision rule to control the α risk is:

$$\text{If } F^* \leq F\ (1-\alpha;\ r-1,\ n_j-r), \text{ conclude } H_o$$

$$\text{If } F^* > F\ (1-\alpha;\ r-1,\ n_j-r), \text{ conclude } H_1$$

where $F^* = \frac{MSTR}{MSE}$, and $\alpha = .05$ (11:532-535).

If H_0 is rejected, Fisher's least significant difference (LSD) test is applied to detect the true differences between treatment means. The LSD test specifies which treatment means are significantly different from others (12:48-49). Having discussed the general testing procedure, the test design is related to the objectives and hypotheses presented in Chapter 1.

The first phase of testing is designed to address the overall accuracy of the methods irrespective of the type of program being estimated. Methods 1-5 are applied to the entire sample of 30 programs. After calculating the measures of accuracy, the statistical tests discussed above are applied. The results of these tests indicate whether or not one method is preferable overall to another. It should be noted that method 6 is not run against the entire sample of 30 programs. The specified values of b_2 ranging from 1.0 to 1.10 are applicable to aircraft procurements only. Method 6 is evaluated by running the procedures against those aircraft programs included in the sample. Likewise, analysis of the b_2 parameter is based on aircraft programs in the sample.

The second phase of testing is designed to answer the second the third hypotheses. The basic question addressed is as the percentage of contract completion changes is one method preferable to another? To answer this question, the following design is employed:

1. Determine the months in which the contractor has performed 25, 50, and 75 percent of the contractual effort.

$$\% \text{ complete } (25, 50, \text{ or } 75) = \frac{\text{CUM BCWP}}{\text{BAC}}$$

2. Calculate D_{itp}'s in same manner as previously described.

3. Group the D_{itp}'s into four classes as follows:

a. D_{itp}'s generated with data where contract is equal to or less than 25 percent complete.

b. D_{itp}'s generated with data where contract is greater than 25 percent complete but less than 50 percent complete.

c. D_{itp}'s generated with data where contract is greater than 50 percent complete but less than 75 percent complete.

d. D_{itp}'s generated with data where contract is greater than 75 percent complete.

4. For each class, $\bar{M}_{ip}$ is calculated, however, n is replaced by the number of D_{itp}'s for a program included in each class.

ANOVA and the LSD test are applied to each class. For method 6, three variations of the method are used where b_2 is set equal to 1.0, 1.06, or 1.10. Additionally, it is noted that the sample for this phase of testing consists of all aircraft programs (20 programs).

The final phase of testing is really an examination of the computed b_2 parameters for the aircraft programs in the sample. The ASD model hinges on the premise that b_2 parameters for aircraft programs have a narrow range between .97 and 1.18, and in the majority of cases b_2 falls between 1.0 and 1.10 (4:15). The b_2 values computed for the 20 aircraft programs are analyzed by calculating the mean b_2 value and sample standard deviation. Following the test design described above, Chapter 4 presents the test results of the analysis.

Chapter 4

RESULTS

Chapter 4 presents the results of this study. Each hypothesis is restated along with its alternative conclusions. The pertinent ANOVA tables are provided noting the significance of the F test. Where a significant difference between methods is indicated by ANOVA, the Fisher least significant difference (LSD) test statistic is calculated. As a visual representation, a number line is used to portray treatment mean location and significant differences.

First Hypothesis

Are the exponential methods more accurate than the linear case variance extrapolation methods in forecasting an estimate at completion? The measure of accuracy is a monthly mean absolute percentage error (MAPE) computed and averaged over the total span of a program. The alternative conclusions are:

H_0: $\mu_1 = \mu_2 = \cdots = \mu_6$

H_1: not all μ's are equal

where μ_1, μ_2, μ_3, and μ_4 are the means of the distributions of absolute average percentage differences for the ESD methods previously described, μ_5 is the ASD "unconstrained" method, and μ_6 is the ASD "constrained" method with b_2 equal to 1.0

Table 1 is a single-factor ANOVA table generated by running the above methods with all 30 sample programs. The F test statistic (1.173) is not significant at $\alpha = .05$. Therefore, H_0 is not rejected and it is concluded that the distributions of the average percentage differences have the same mean when the six methods are applied to the overall sample of 30 programs.

Table 1

Single Factor ANOVA Table: All Programs Using Six Estimating Methods

Source of Variation	Sum of Squares	DF	Mean Square	F	Significance of F
Method of Forecasting	240.214	5	48.043	1.173	0.325
Blocking for Individual Programs	9175.857	30	305.862		
Residual	6143.866	150	40.959		
Total	15,559.937	185	84.108		

The linear and non-linear methods are applied to the sample of 20 aircraft programs. Again, the first hypothesis is addressed; that the exponential methods are more accurate than the linear cost variance extrapolation methods in forecasting the contract cost at completion. The alternative conclusions are similar:

H_0: $\mu_1 = \mu_2 = \cdots = \mu_8$

H_1: not all μ's are equal

where μ_6, μ_7, and μ_8 are the means of the distributions of average percentage differences for the ASD "constrained" method specifying b_2 values of 1.0, 1.06, and 1.10, respectively.

Table 2 is a single-factor ANOVA table generated by running the above methods with the sample of 20 aircraft programs. The F test statistic (5.978) is significant at $\alpha = .05$. Therefore, H_0 is rejected and it is concluded that not all distributions of the average percentage differences have the same mean. At least one mean is significantly different from another. Additional information is provided to assess the difference in treatment means.

Table 2

Single-factor ANOVA Table: Aircraft Programs Using Eight Estimating Methods

Source of Variation	Sum of Squares	DF	Mean Square	F	Significance of F
Method of Forecasting	615.301	7	87.900	5.978	0.000
Blocking for Individual Programs	1286.728	19	67.723		
Residual	1955.667	133	14.704		
Total	3857.696	159	24.262		

Table 3 presents the mean absolute percentage error for each treatment or method. The Fisher LSD test statistic is calculated as follows:

$$\text{Fisher's LSD} = t_{\alpha/2,\ \nu} \sqrt{\frac{2\ \text{MSR}}{n}}$$

where ν = degrees of freedom, MSR = mean square residual, and n = the sample size.

Given $\alpha = .05$, $\nu = 7$, MSR = 14.704, and n = 20

$$\text{LSD} = t_{.025,\ 7} \sqrt{\frac{2(14.704)}{20}}$$

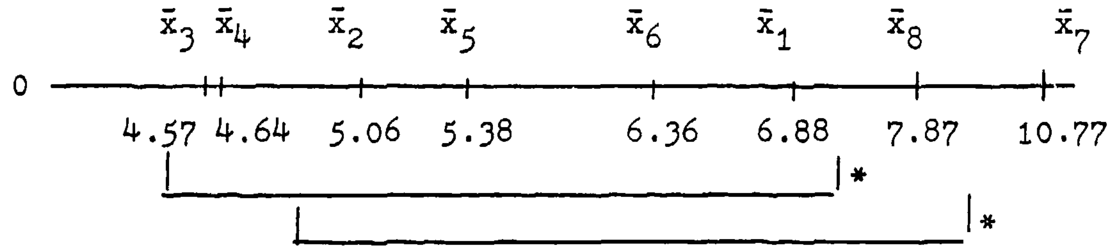
$$= 2.571 \sqrt{1.470}$$

$$= 3.18$$

Table 3

Mean Absolute Percentage Error For Each Method: All Aircraft Programs

Forecasting Method	Mean Absolute Percentage Error
1. Current Month P.F.	6.88%
2. Moving Average P.F.	5.06%
3. Cumulative P.F.	4.57%
4. Quarterly P.F.	4.64%
5. Unconstrained	5.38%
6. Constrained (1.0)	6.36%
7. Constrained (1.06)	10.77%
8. Constrained (1.10)	7.87%



*MAPE 's within brackets are not significantly different at $\alpha = .05$

Figure 1. Treatment Mean Locations: Aircraft Programs

As portrayed in Figure 3, the absolute percentage error for Method 7 differs significantly from the means for Methods 1, 2, 3, 4, 5, and 6. Method 8 differs significantly from Methods 3 and 4. Since Methods 7 and 8 are non-linear, the general hypothesis that the non-linear model is more accurate than the linear model is not supported.

Second Hypothesis

The next hypothesis states that the exponential methods are more accurate than linear cost variance extrapolation methods in forecasting an estimate at completion when;

a. the contract is less than 25% complete

b. the contract is greater than or equal to 25% but less than 50% complete

c. the contract is greater than or equal to 50% but less than 75% complete.

For all classes the alternative conclusions are the same:

H_o: $\mu_1 = \mu_2 = \cdots = \mu_8$

H_1: not all μ's are equal

Table 4 is a single-factor ANOVA table generated by running the above methods with 12 aircraft programs. Only estimates generated while the programs are less than 25% complete are considered. The F test statistic (1.226) is not significant at $\alpha = .05$.

Table 4

Single-factor ANOVA Table: Contract Completion Less than 25% Complete

Source of Variation	Sum of Squares	DF	Mean Square	F	Significance of F
Method of Forecasting	613.906	7	87.701	1.226	0.299
Blocking for Individual Programs	4018.715	11	365.338		
Residual	5509.900	77	71.557		
Total	11,142.521	95	106.763		

Therefore, h_o is not rejected and it is concluded that the distributions of the average percentage errors have the same mean. The non-linear methods are not more accurate at forecasting than the linear methods when the contract is less than 25% complete.

In Table 5, the eight estimating methods are used to generate estimates while the program is greater than or equal to 25% but less than 50% complete. The methods are applied to 19 aircraft programs. As indicated in the single factor ANOVA table, the F test statistic (1.009) is not significant at $\alpha = .05$. H_0 is not rejected and it is concluded that the non-linear model is not more accurate at forecasting over the 25% to 50% completion range.

Table 5

Single-factor ANOVA Table: Contract Completion
Greater than or equal to 25% and less than 50%

Source of Variation	Sum of Squares	DF	Mean Square	F	Significance of F
Method of Forecasting	472.469	7	67.496	1.009	0.428
Blocking for Individual Programs	4289.929	18	238.329		
Residual	8427.281	126	66.883		
Total	13,189.678	151	87.349		

Applying the eight estimating methods to 19 aircraft programs over the completion range greater than or equal to 50% and less than 75%, results in ANOVA table 6. As indicated in the table, the F statistic (3.490) is significant at $\alpha = .05$. The null hypothesis is rejected, allowing the conclusion that not all distribution means are equal.

Table 6

Single-factor ANOVA Table: Contract Completion Greater than or equal to 50% and less than 75%

Source of Variation	Sum of Squares	DF	Mean Square	F	Significance of F
Method of Forecasting	585.147	7	83.592	3.490	0.002
Blocking for Individual Programs	1454.940	18	80.830		
Residual	3018.093	126	23.953		
Total	5058.181	151	33.498		

Table 7 provides the MAPE values for each method. The LSD test statistic is calculated below:

$$\text{Fisher's LSD} = t\alpha/2,\ \nu \sqrt{\frac{2\ \text{MSR}}{n}}$$

Given α = .05, ν = 7, MSR = 12.953, and n = 19

$$\text{LSD} = 2.365 \sqrt{\frac{2(23.953)}{19}}$$

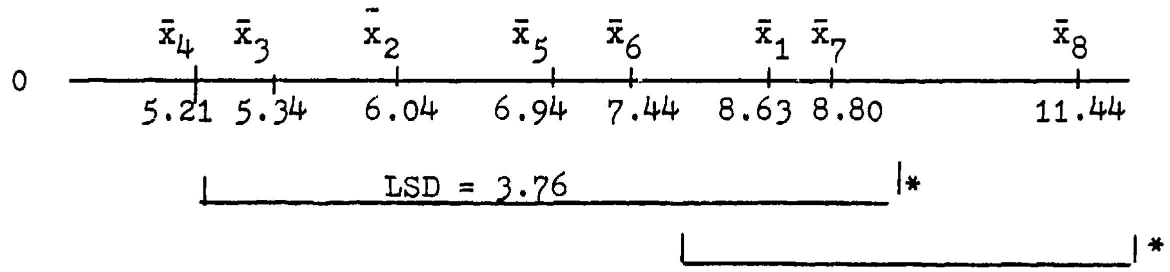
$$= 3.76$$

Table 7

Mean Values for Each Method: 50% to 75% complete

Forecasting Method	Mean Absolute Percentage Error
1. Current Month P.F.	8.63%
2. Moving Average P.F.	6.04%
3. Cumulative P.F.	5.34%
4. Quarterly P.F.	5.21%
5. Unconstrained	6.94%
6. Constrained (1.0)	7.44%
7. Constrained (1.06)	8.80%
8. Constrained (1.10)	11.44%

Figure 2 visually depicts the mean absolute percentage error by method on a number line. Using the calculated LSD statistic, the mean of Method 8 differs



* MAPE's within brackets are not significantly different at $\alpha = .05$.

Figure 2. Treatment Mean Locations: 50% to 75% complete.

from the means of Methods 2, 3, 4, 5, and 6.

A significant difference between treatment means exists as indicated by ANOVA. However, since Method 8 is a non-linear method the hypothesis that non-linear methods are more accurate is not supported.

Third Hypothesis

When estimates are generated for a program which is greater than or equal to 75% complete, a linear model or non-linear model is not significantly more accurate as a program approaches completion. The alternative conclusions remain unchanged:

H_0: $\mu_1 = \mu_2 = \ldots = \mu_8$

H_1: not all μ's are equal.

For Table 8, the eight estimating methods are applied to generate estimates where the programs are equal to or greater than 75% complete. Based on a sample size of 19 aircraft programs, the F statistic (8.180) indicates that all treatment means are not equal at $\alpha = .05$. The Fisher LSD test statistic is calculated as follows:

$$\text{Fisher's LSD} = t\alpha/2,\ \nu \sqrt{\frac{2\ \text{MSR}}{n}}$$

Given $\alpha = .05$, $\nu = 7$, MSR = 11.589, and n = 19

$$\text{LSD} = 2.365 \sqrt{\frac{2(11.589)}{19}}$$

$$= 2.61$$

Table 8

Single-factor ANOVA Table: Contract Completion Equal to or Greater Than 75%

Source of Variation	Sum of Squares	DF	Mean Square	F	Significance of F
Method of Forecasting	663.614	7	94.802	8.180	0.000
Blocking for Individual Programs	1269.141	18	70.508		
Residual	1460.193	126	11.589		
Total	3392.947	151	22.470		

Using the calculated value for LSD and treatment mean values provided in Table 9, it is determined that a significant difference exists between Method 8 and all other Methods. Method 7 differs significantly from Methods 2, 3, 4, and 5. These results are portrayed in Figure 3. The null hypothesis is rejected and it is concluded that some methods are preferable to others when estimating a cost at completion even when the contract is greater than 75% complete.

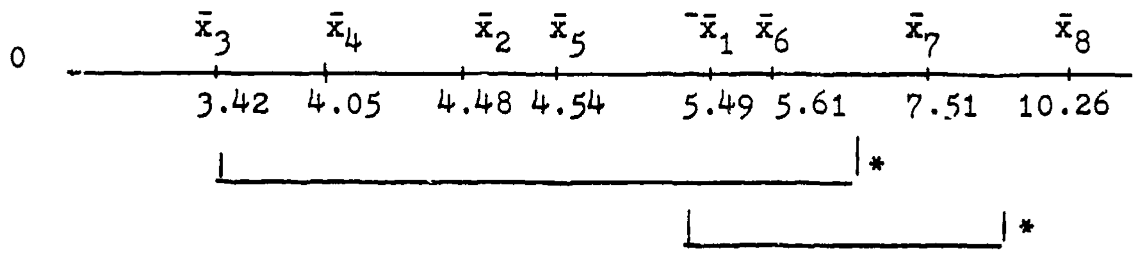
Table 9

Mean Values for each Method: Greater than 75% complete

Forecasting Method	Mean Absolute Percentage Error
1. Current Month P.F.	5.49%
2. Moving Average P.F.	4.48%
3. Cumulative P.F.	3.42%
4. Quarterly P.F.	4.05%

Table 9 (Continued)

Forecasting Method	Mean Absolute Percentage Error
5. Unconstrained	4.54%
6. Constrained (1.0)	5.61%
7. Constrained (1.06)	7.51%
8. Constrained (1.10)	10.26%



* MAPE's Within brackets are not significantly different at $\alpha = .05$.

Figure 3. Treatment Mean Locations: Greater than 75% complete.

Fourth Hypothesis

The fourth hypothesis is really an examination of the parameter b_2. Use of the "constrained" ASD method hinges on the distribution of b_2 which was noted to have a range between .97 and 1.18 and in the majority of cases b_2 falls between 1.0 and 1.10. Appendix B contains the calculated b_2 parameters for the sample of 20 aircraft programs. The range for the sample b_2 values is .9098 to 1.1209. The mean sample b_2 value is 1.0338 with a standard deviation and variance of .0564 and .0030, respectively. Based on the observations of b_2 and assuming the sample is normally distributed, a 95% confidence interval has upper and lower limits of .9232 and 1.144, respectively. Fourteen of the 20 sample program b_2 parameters fall within the stated range of 1.0 to 1.10. The sample observation values of b_2 support the assertion that b_2 in the majority of cases falls between 1.0 and 1.10.

Chapter 5

ANALYSIS AND RECOMMENDATIONS

Summary of the Research Effort

In Chapter 1 the hypotheses under investigation are presented. In general the hypotheses state that the non-linear estimating model is preferable to the linear model in estimating a contract cost at completion. A measure of accuracy mean absolute percentage error (MAPE) was defined equal to the estimated value minus the actual final cost at completion divided by the actual final cost. The six estimating methods described in Chapter 3 were first applied to a sample of 30 programs. ANOVA results did not indicate a significant difference among treatment means. Eight estimating methods, three of which used specified values for b_2 of 1.0, 1.06, and 1.10, were applied to a sample of 20 aircraft programs. ANOVA indicated at least one treatment mean was significantly different from another. Using Fisher's LSD test statistic it was determined that a non-linear method had a higher treatment mean which was significantly different. The result is contrary to the general hypothesis and is discussed further below.

Review of Findings

The array of estimates for each program and method was divided into four classes where the program is less than 25% complete, greater than for equal to 25% but less than 50% complete, greater than or equal to 50% but less than 75% complete, and greater than or equal to 75% complete. ANOVA did not indicate a significant difference among treatment means for either of the first two classes. ANOVA indicated inequality of treatment means in the third class. Two non-linear methods had MAPE's which were significantly higher than linear MAPE's. The same pattern held for the fourth class. Two non-linear treatment means were significantly higher. Again, these results are contrary to the general hypothesis.

Conclusions and Implications

The higher mean absolute percentage errors for Methods 7 and 8 may be a result of specifying too high a value for b_2 in the "constrained" method. For the sample of 20 aircraft programs, the mean b_2 parameter value is 1.033 not 1.06 or 1.10 as specified in Methods 7 and 8, respectively. When used in the functional form $y = b_1 x^{b_2}$, an estimate is calculated by substituting BAC for x. The significance of this point can be highlighted by considering a simple example where BAC equals 1 million, b_1 equals a constant (1.0), and b_2 equals 1.03, 1.06, or 1.10. If b_2 equals 1.03, y equals 1.51 million. If b_2 equals 1.06 or 1.10, y equals 2.29 or 3.98 million, respectively. Specifying a value or range of values for b_2 is a crucial step in applying the non-linear model.

Another special case to consider with regard to the "constrained" estimating method is the case where b_2 is set equal to 1.0. When b_2 equals 1.0, the estimating relationship reduces to $y = b_1$, BAC where b_1 is in essence a performance factor. In this form, the b_1 parameter is multiplied by the aggregate budget at completion. The ESD methods still differ fundamentally in their construction. In the ESD methods, the performance factor is multiplied by the budgeted cost of work remaining (BCWR) and not the aggregate budget term. BCWR is calculated by subtracting cumulative BCWP from BAC. As described in Chapter 3, the performance factor used in the ESD model can be calculated in a number of ways using current monthly data or cumulative data.

Areas for Future Research

As indicated above, the observed range of b_2 values if used with the "constrained" method would not improve the accuracy of the model. To improve accuracy a narrow range needs to be specified. As a suggestion for further research, a detailed analysis of aircraft programs by type of aircraft may help to narrow or specify a value for b_2. Additionally, a detailed analysis may indicate that b_2 varies depending whether or not the contract is a follow-on production option.

This analysis compared but two of a number of models for estimating a contract cost at completion. Other methods should be evaluated particularly those mentioned in Chapter 2. It is important to note that any model represents a mathematical manipulation of the information available. Technical assessment of a contractor's performance provided by a SPO's engineering personnel is just as valuable as a performance factor calculated on past cost performance. Further it should be recognized that the models discussed use contractor provided cost data. Inaccurate input invalidates the usefulness of the models.

Concluding Remarks

In summary, the results obtained in this analysis do not support the general hypothesis that a non-linear model is more accurate at forecasting an estimate at completion than a linear model. The ESD linear methods were found to be just as accurate as the ASD methods. This analysis does not content that either model be abandoned but rather that the models can be used in conjunction with each other.

APPENDICES

APPENDIX A

SAMPLE PROGRAM WORKSHEET

PROGRAM TITLE

ASD FILE NUMBER

		CUMULATIVE			
MONTH	BCWS	BCWP	ACWP	BAC	LRE
1	XXXX	XXXX	XXXX	XXXX	XXXX
2					
3					
.					
.					
.					
n					

APPENDIX B

b_2 PARAMETER VALUES FOR 20 AIRCRAFT PROGRAMS

PROGRAM	t_2 VALUE
1	.9216
2	1.1209
3	1.0405
4	1.1000
5	1.0338
6	1.0142
7	1.0661
8	1.0303
9	.9767
10	1.0842
11	1.0082
12	1.0062
13	1.0000
14	1.0362
15	1.1068
16	1.0584
17	1.0209
18	1.0416
19	.9098
20	1.1005

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