AN EVALUATION OF CPRA ESTIMATE AT COMPLETION TECHNIQUES BASED UPON AFWAL COST/SCHEDULE CONTROL SYSTEM CRITERIA DATA

THESIS

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THESIS

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Preface

The purpose of this study was to build a database and provide preliminary research on the performance of various estimate at completion techniques. This thesis provides a simple answer to a complex problem and will hopefully encourage further research resulting in a more definitive set of estimate at completion selection guidelines.

I would like to thank my faculty advisor Lt Col Thomas L. Bowman for his continued assistance and patience. I would also like to acknowledge the contributions of my thesis reader, Lt Col Joseph Coleman and of Major Anthony Presutti for his review of this effort. Finally, I wish to thank my wife Jean who was encouraging when I needed encouragement, understanding when I needed to be understood, and who gave birth to and cared for our son, James, while I wrote this thesis.

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Abstract

This thesis examined techniques used to derive estimates of the cost at completion for various research and development programs. The six methods examined were the methods used in the Cost Performance Report Analysis (CPRA) computer program to calculate estimates at completion.

The analysis is based on a linear regression between the cost at completion and the estimate at completion for each technique available. The techniques were ranked by coefficient of determination and a general linear test was performed to test for equality among the regression lines.

The results of this investigation indicate that an estimate at completion based upon weighted cost and schedule indices minimizes the unexplained error (as a percentage of total error) and is thought to be the superior forecaster of costs at completion. The general linear test for equality among the regression lines generated by the different techniques did not indicate the existence of commonality between regression lines. This means that each technique tested provided a unique estimate at completion.

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I. Introduction

General Issue

The Department of Defense (DOD) implemented the Cost/Schedule Control Systems Criteria (C/SCSC) as a "tool for use in assessing a contractor's cost management system circa 1967" (1:32). "The objective of DOD in applying C/SCSC to a contract is to obtain assurance that the management system of a contractor has the capability to adequately plan and measure actual contract performance and that the management system can provide financial and related progress reports from a common auditable data base" (2:12). Therefore, as a minimum a contractor's management control system must provide for:

A. Realistic budgets for work scheduled within responsibility assignments (3:5).

B. Accurate accumulation of costs related to progress of the planned work (3:5).

C. Comparison between the actual resources applied and the estimated resources planned for specific work assignments (3:5).

D. Preparation of reliable estimates of costs to complete remaining work (3:5).

E. Support of an overall capability for managers to analyze available information to identify problem areas in sufficient time to take remedial action (3:5).

While management systems adhering to this criteria present cost and schedule data in a standardized manner, "the great potential for better cost and schedule control is lost if the data is not analyzed and made to produce essential management information needed by the Program Manager and senior managers" (4:273). Indeed, if this data is analyzed properly, it can provide management with both a historical and projected cost perspective. The projected cost, called an Estimate At Completion (EAC), is one of the analyst's key measures of the contractor's performance (4:277).

In fact, "the contract status information on the [Cost Performance Report] provides a basis for verifying the contractor's estimate of cost at completion, or for developing an independent estimate thereof" (4:277). "Early visibility of cost and schedule problems must result in the reassessment of the ultimate cost and timely changes to program budgets and fiscal plans" (4:277). For this reason, the EAC is one of the primary items needed by the government to make effective management decisions (2:73). Therefore, it is important that the analyst understand the techniques and methods for developing EACs and their limitations.

Specific Problem

Six methods are used to develop EACs at the Air Force Wright Aeronautical Laboratories (AFWAL) at Wright-Patterson Air Force Base (WPAFB), Ohio. Currently, the method employed to develop an EAC is selected by the analyst based on that analyst's experience (5). In some instances analysts will generate six EACs using the Cost Performance Report Analysis (CPRA) computer program, and use their arithmetic average as the "true" EAC (5). The problem with averaging the six EACs is that if the actual program cost at completion differs substantially from one or more of the six EACs, that EAC's inclusion in the averaged EAC will actually increase the variance the analyst wishes to minimize (6:72-73). If the past performance of one EAC technique had been shown to outperform the others under given conditions, the analyst could rule out those EAC(s) more likely to degrade the quality of the final prediction. The desirability of understanding the available techniques and their application was noted in Holeman's 1974 essay; "there does not appear to have been any attempt to conduct in-depth or independent reviews of any of these automated approaches to offer unbiased and expert guidance on when and where they should or should not be used" (7:40). Holeman adds, "these techniques . . . could be considered analytically sophisticated and many analysts in program offices would probably have difficulty in fully understanding the supporting documentation" (7:40-41). As implied above, this lack of understanding may cause the analyst to misestimate completion costs. This thesis attempts to evaluate the EAC techniques used by the AFWAL's automated analysis program for C/SCS generated data.

Background

"C/SCSC resulted from the realization that a contractor receives payment not only for a defense system development and production program, but also for management" (8:43). Government personnel knew that "to achieve reliable visibility of the contractor's adequacy of planning, the government must use the same data the contractor used in preparing his plan" (7:37). Early attempts to access this data were implemented by the Air Force's Cost/Schedule Planning and Control Specifications, C/SPCS" (2:3,8:43). "This criteria approach was monitored closely by the other military services and gradually evolved into the present C/SCSC" (2:3). "'Criteria' is the key word in C/SCSC" (9:32). Simply put, "it is a criteria or a set of standards that a contractor's management system, whatever it may be, must meet in undertaking development of a major defense system" (9:32). "Surprising to most contractors since that time [validation of the first contractor's management system] has been the fact that a good existing system is generally 90% satisfactory insofar as the criteria are concerned" (4:263-4). Much of C/SCSC's success has been attributed to the fact that it is not a system, but a set of criteria and therefore does not mandate a particular managerial style or technique (9:33).

"Essentially what C/SCSC does is ensure that data provided by a contractor, such as the monthly Cost

Performance Report (CPR) [or the Cost/Schedule Status Report (C/SSR), depending on the dollar value of the contract], is accurate and timely" (9:32-33). At a minimum, contractor's management and control systems should provide for "support of an overall capability for managers to analyze available information to identify problems areas in sufficient time to take remedial action" (3:5). One of the major concepts that C/SCSC addresses is that of accurately measuring and relating incurred costs and budgeted costs (3:5). In other words, C/SCSC requires that the contractor maintain the capability to compare the Actual Cost of Work Performed (ACWP) with the Budgeted Cost of Work Performed (BCWP), and the BCWP with the Budgeted Cost of Work Scheduled (BCWS) (3:5). These terms, when mathematically related to each other, are the basis for EAC formulation (10,11:17-19). A complete discussion of C/SCSC can be found in Air Force Systems Command Pamphlet (AFSCP 173-5) titled Cost Analysis[:] Cost/Schedule Control Systems Criteria Joint Implementation Guide (3). A subset of common C/SCSC terms are defined in the next section.

C/SCSC Terms and Definitions. The following terms are used throughout this section and are defined for the convenience of the reader.

A. Work Package - Detailed short span jobs, or material items, identified by the contractor for accomplishing work required to complete the contract (3:6).

B. Actual Cost of Work Performed (ACWP) - The costs actually incurred and recorded in accomplishing the work performed within a given time period (3:5).

C. Budgeted Cost for Work Performed (BCWP) - The sum of the budgets for completed work packages and completed portions of open work packages, plus the appropriate portion of the budgets for level of effort and apportioned effort (3:6).

D. Budgeted Cost for Work Scheduled (BCWS) - The sum of the budgets for all work packages scheduled to be completed, plus the budget for the portion of in-process work (open work packages) scheduled to be accomplished, plus the budgets for LOE and apportioned effort scheduled to be completed during the period (12).

E. Latest Revised Estimate (LRE) - The latest revised estimate of contract costs at the completion of the contracted effort. Generally, LRE and EAC are synonymous acronyms; in this paper the convention of using LRE to refer to a contractor estimate and EAC to refer to a government generated estimate will be employed.

F. Budget at Completion (BAC) - The budgetary goal, excluding management reserve, for doing all the authorized work (13:16). The BAC is the endpoint of the Performance Measurement Baseline (13:17).

G. Performance Measurement Baseline (PMB) - A graphical depiction of the BAC spread over the time allotted for performance. A time-phased budget plan. The progressive accumulation of the BCWS to be accomplished in each increment of time throughout the contract period of performance (13:17).

Cost Performance Report Analysis (CPRA) Program. The CPRA program is a computer program which, based upon contractor performance measurement data discussed earlier, performs the calculations necessary to develop EACs. The program is written in FORTRAN IV and resides on the Aeronautical Systems Division's Cyber computer. Although the CPRA program provides the AFWAL analyst with many different types of analyses, the EACs that are generated are the focus of this thesis.

The program uses three constructs to generate EACs. These constructs are based on a cost index, a schedule index and trend analysis. These methods are explained in detail in the "EAC Formulas" section of this report. The EAC techniques used by the CPRA program were duplicated on the Zenith Z-100 microcomputer. This was done because of the expense associated with using a mainframe (large) computer to accomplish a task capably performed by a microcomputer (small). The results obtained from the CPRA simulation were fed into a computer based* statistics program, the Statistical Package for Social Sciences** (SPSS) program, which performed the majority of the statistical calculations described in the "Methodology" section of this report. Many

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* Devore notes that, "Whenever possible it is preferable to do regression analysis using a standard statistical computer program package; in addition to β_0 and β_1, the resulting output will yield much more useful information" (14:429).

** SPSS is a well known, well documented statistical package which began its development in 1965 at Stanford University (15:xxii). This statistical package is now being used at nearly 600 installations, including conversions to almost 20 different operating systems and computers (15:xxi).

of the techniques used in the CPRA program are common knowledge among C/SCS analysts. In fact, some of these techniques may be found in "Estimates at Completion" (10:5-18), a pamphlet distributed in the SYS 362, Cost/Schedule Control Systems Criteria (C/SCSC) course at the Air Force Institute of Technology, Wright Patterson AFB, Ohio.

Description of CPRA Terms and Formulas. The following information is provided to help the reader understand the mechanics of the CPRA program for calculating EACs and has been reproduced from the CPRA Users Manual. In some equations it is necessary to reference two similar performance measurement data points (for example, two different ACWP measurements) in one equation; in this instance the following convention will be used. The measurement will retain its usual label, for example "ACWP", and will also have an array position indicator added. The indicator "(CUM)" will be added to the label to indicate the latest month's cumulative data point. For example, if our last data point were June 198X, the actual cost of work performed from the start of the contract through the month of June would be represented by "ACWP(CUM)". The array position indicator for the preceding month, May, would be determined by its relationship to the current month. In other words, since May is one month before June, its indicator would be (CUM-1) and the cumulative ACWP for

May would be represented as "ACWP(CUM-1)". "(CUM)" will always refer to the latest month's cumulative data and all other points will take the general form "(CUM-n); where "n" is the relative number of months before the latest month. If there is no "(CUM)" indicator in an equation, the latest month's cumulative data is being used.

A. Cost Variance % = [(BCWP - ACWP) / BCWP] x 100

Positive value indicates work performed is costing less than planned by this percentage. Negative value indicates work performed is costing more than planned by this percentage (11:12).

B. Current Month CPI = $\frac{\text{BCWP(CUM)} - \text{BCWP(CUM-1)}}{\text{ACWP(CUM)} - \text{ACWP(CUM-1)}}$

This index is a measure of cost performance for the latest month's work (11:12).

C. 3 Month CPI = $\frac{\text{BCWP(CUM)} - \text{BCWP(CUM-3)}}{\text{ACWP(CUM)} - \text{ACWP(CUM-3)}}$

This index is a measure of cost performance over the last three months (11:12).

D. Cum CPI = BCWP(CUM) + ACWP(CUM)

This index is a measure of cost performance from beginning of contract through the current month (11:14).

E. Schedule Variance % = [(BCWP-BCWS) / BCWS] x 100

Positive value indicates more work than planned has been performed by this percentage. Negative value indicates less work than planned has been performed by this percentage (12).

F. Current Month SPI = $\frac{BCWP(CUM) - BCWP(CUM-1)}{BCWS(CUM) - BCWS(CUM-1)}$

This index is a measure of schedule efficiency for work performed this month. It indicates the efficiency with which the contractor has accomplished the planned amount of work (12).

G. 3 Month SPI = $\frac{BCWP(CUM) - BCWP(CUM-3)}{BCWS(CUM) - BCWS(CUM-3)}$

This index is a measure of schedule efficiency for work performed in the last 3 months (12).

EAC Formulas. The formulas used in the CPRA program to estimate the cost of a program at completion have been reproduced from the CPRA Users Manual and are shown below. The EAC techniques have been numbered 1 through 6 and are referenced by the acronym EAC with a reference number, "n", appended to the "EAC" stem. For example the first technique developed is based on the current month CPI and is referred to as EAC1, the second technique is referred to as EAC2 and so on. "EACn", where "n" is a reference number from 1 to 6, will be used to describe a particular technique throughout the remainder of this thesis.

A. Based on Current Month CPI:

EAC1 = ACWP(CUM) + $\frac{BAC(CUM) - BCWP(CUM)}{CUR\ MON\ CPI}$

This calculation assumes the remaining work will be accomplished at the same budget efficiency (CPI) as that exhibited last month (11:17).

B. Based on Cumulative CPI (11:17):

$$EAC2 = ACWP(CUM) + \frac{BAC(CUM) - BCWP(CUM)}{CUM\ CPI}$$

This calculation assumes remaining work will be accomplished at the same budget efficiency as has been exhibited cumulatively since the beginning of the contract (12).

C. Based on Three Month CPI (11:17):

$$EAC3 = ACWP(CUM) + \frac{BAC(CUM) - BCWP(CUM)}{THREE\ MON\ CPI}$$

This calculation assumes the remaining work will be accomplished at the same budget efficiency as was exhibited cumulatively during the last three months (12).

D. Based on ACWP Regression: This calculation uses a least-squares-best-fit on ACWP to establish a trend line. This trend line is then hypothetically extended to the point in time when there is zero work remaining. The hypothetical ACWP at this point is EAC4 (12).

E. Based on Weighted SPI/CPI:

$$ETC = [100. - (COST\ VAR\ \%) + .75 \times (SCHEDULE\ VAR\ \%)] \times \frac{(BCWR)}{100}$$

$$EAC5 = ETC + ACWP$$

This method calculates EAC5 based on one-time* completion of the program. This calculation is only made after there is [sic] six months of data for the line item. The calculation assumes the Cost Variance % will remain constant to the end of the program. A

* Logically, it would appear that a program may be completed just once, therefore the author has assumed that "one-time completion" actually means "on-time completion" or more appropriately "on schedule completion".

penalty of 3/4 of [the] schedule variance is used to calculate catch-up (11:18).

F. Based on Trend Weighted SPI/CPI:

EACC = (.12 x EAC1) + (.24 x EAC3) + (.64 x EAC2)

Cost to catch up schedule is calculated by the following (11:18):

ETCS = (MONTHS BEHIND SCHEDULE) x ACWP RATE* x .75

These are then added together to form EAC6 (11:18):

EAC6 = EACC + ETCS

This prediction assumes a schedule catch-up penalty (based on 75% of the spend rate)and a budget probability based on the current month cost performance index, last three months cost performance index, and cumulative cost performance index EAC weighted at 12%, 24% and 64% respectively (12).

Scope and Limitations

The information presented as background material in this chapter is the result of a literature review of material gathered from the following sources: The Defense Technical Information Center (DTIC); The Electronic Systems Division (ESD) Cost Library at Hanscom Air Force Base, Massachusetts; The Aeronautical Systems Division (ASD) Cost Library at Wright Patterson Air Force Base (WPAFB) Ohio; and The Air Force Institute of Technology Library, also located at WPAFB.

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* ACWP RATE is defined in the body of the CPRA program as ACWP(CUM) / TNUM where TNUM is the number of months from contract start to the last month for which data is available.

This research effort conducted a statistical evaluation of the forecasting effectiveness of each EAC technique used by the CPRA program. It should be noted that all EAC's which result from the CPRA program (and CPR/CSSR analysis in general) rely on past performance to predict future performance. Therefore, the ability of the CPRA program to accurately predict variations in a program which, to date, has experienced no significant variation is limited. Additionally it should be noted that engineering change proposals, contract stretches due to "external" influences (congressional, labor strike, etc.) are facts of life in the acquisition environment and may have a confounding impact on the ability to measure the effectiveness of the CPRA forecasting techniques. The data contained in the AFWAL CPR and C/SSR database and the EACs generated from that database using the CPRA program techniques were the inputs to this analysis and are, therefore, subject to the aforementioned anomalies.

Research Objectives.

The research hypothesis is that statistical evaluation of the past performance of each method used to derive EACs may indicate a preferred method of formulation. The objective of this research was to identify this preferred method, if one exists.

Investigative Questions. The following investigative questions will be answered.

1. Are the lines formed by a plot of the CPRA program EACs and estimated cost at completion linear?

If present, linearity between the actual cost at completion and the estimate at completion permits the use of regression analysis for evaluating the CPRA EAC techniques.

2. Which regression line has the highest coefficient of determination?

Since the coefficient of determination is a regression model's ratio of explained variation to its total variation (14:455), the regression model which has the highest coefficient of determination will minimize the unexplained variation. In this thesis, the technique with the greatest coefficient of determination is defined as the "best estimator".

3. Are there significant differences between the regression lines used to estimate the EACs?

If a general linear test shows that a pair of regression lines are statistically equivalent, the techniques used to generate them are also equivalent. This test, therefore, enables the analyst to determine whether 2 EACs with different formulas for calculation are, in reality, just different ways of expressing a single EAC.

II. Methodology

The Database

The database used in this research was obtained from the Air Force Wright Aeronautical Laboratory (AFWAL). The database is comprised of performance measurement data from 57 on-going research and development programs and contains more than 800 data records*. The following programmatic data was available for each of the 57 programs: contract name and number; current and original target cost; contract start and stop date and contract type. Each data record contained the following elements: BCWS, BCWP, ACWP, MR (management reserve), BAC, LRE and DATE (month and year of data observation). The database was reformatted to include the programmatic data in each data record. Program numbers were assigned sequentially to each program. These numbers were used to facilitate the referencing of individual programs when performing calculations.

EAC Generation. The contractor performance measurement data described in the previous paragraph was used as input for a FORTRAN computer program which generated EACs using techniques from the CPRA program.

The CPRA program does not calculate EAC5 or EAC6 until eight months of program data have been accumulated. The CPRA

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* A data record is comprised of all the data elements (individual descriptors) needed to completely define a single month's performance measurement data set.

User's Manual offers no explanation of the eight month minimum data requirement and a review of the C/SCSC literature did not validate this seemingly arbitrary decision rule. Therefore, this restriction on the application of these techniques has not been imposed when formulating the EAC database used in this thesis.

The CPRA program assigns the value of .1 to data points which otherwise would result in division by zero. This practice also appeared to be arbitrary in nature and was not adopted. For example, when determining the current month's CPI, (BCWP / ACWP), ACWP(CUM-1) is subtracted from ACWP(CUM) to calculate a single month's index and if ACWP(CUM) - ACWP(CUM-1) = 0, the denominator in the current CPI will equal zero and any further calculations which use the current CPI as a divisor, such as EAC1, will yield an undefinable answer as a result of division by zero. Of the 819 data points in the database, 5 data points resulted in division by zero. These data points were treated as missing values and excluded from this analysis. The remaining EAC techniques and their application were fully detailed in the previous chapter.

Assumptions Made When Generating EACs. In order to test which EAC formula in the CPRA program is the better predictor of actual cost at completion, it would have been ideal to analyze data from completed programs (12). However, data for completed programs, necessary for retroactively evaluating EACs, is not maintained in the CPR database. Since the database was comprised of on-going programs in various stages of completion, it was necessary to arbitrarily select a point which could simulate the actual cost at completion. The last available ACWP measurement for each program [ACWP(CUM)] was chosen to represent this cost at completion point (12). Effectively, this creates a program within a program by using the program data to date as if it were data from a completed program. This makes it possible to calculate EACs based upon this subset of data and to evaluate the capability of each EAC technique to forecast the actual cost of work performed to date. This value, the the last reported ACWP, will be referred to as the Estimated Cost at Completion (ECAC). Because ACWP(CUM) has been chosen to represent the actual cost at completion, it is also necessary, for calculation purposes, to choose a data value to simulate Budget at Completion (BAC). The latest reported BCWP(CUM) is the logical choice since it represents the budgetary value for the same amount of work for which the latest ACWP(CUM) is reported (12).

To illustrate the above methodology, assume an on-going program had the following performance measurements:

Original Target Cost	=	200
Current Target Cost	=	205
BCWP	=	70
BCWS	=	65
ACWP	=	85

The estimated cost at completion (ECAC) would be 85 (the latest ACWP). The budget at completion (BAC) would be assumed to be 70 (because this is the budget goal for the work performed to date, BCWP). The remaining performance measurement values would not be affected by these assumptions. These assumptions provide the performance measurement data necessary to calculate EACs using the CPRA techniques.

Statistical Methodology

The problem faced by the researcher is one of choosing the proper statistical technique "to describe the extent, direction, and strength of the relationship between several independent variables and a continuous dependent variable" (16:11). Regression analysis* is well suited for this purpose (16:11) and has been selected as the analytical tool for this thesis. This section describes the "statistical problems of finding the curve (e.g., straight line, parabola, etc.) that best fits the data in such a way as to closely approximate the true (but unknown) relationship between X and Y" (16:37).

> There are several strategies for studying the relationship between two variables by means of regression analysis. The most common of these is called the forward method. This strategy begins with a simply structured model,

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* The reader who is not familiar with regression techniques may wish to consult Devore's Probability and Statistics for Engineering and the Sciences (14) or Neter and Wasserman's Applied Linear Statistical Models (17).

usually a straight line and then adds more complexity to the model in successive steps, if necessary (16:38).

Kleinman and Kupper define several variations of this strategy, but deem the forward method of regression "the most reasonable strategy to use in the absence of experience or theory to indicate otherwise" (16:39).

Regression Strategy. A univariate* linear regression was used to formulate a regression line based on the ECAC (the dependent variable or DV) and the EAC (the independent variable or IV). The regression equation that exhibited the highest sample coefficient of correlation was defined as the "best estimator" of the cost at completion (i.e. the better EAC formula).

Assumptions for Regression. Certain assumptions must be made to satisfy the straight line assumption made when using linear regression (16:39). These assumptions are:

1. For any fixed value of X, Y is a random variable with a certain probability distribution (16:41).

2. The mean value of Y . . . is a straight line function of X (16:42-44).

3. The variance [σ^2] of Y is the same for any X. This assumption is called the assumption of homoscedasticity** (16:44).

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* "The term univariate statistics [univariate regression in this case] typically refers to analyses in which there is a single DV" (6:2).

** The roots of the term "homoscedasticity" are "homo", meaning "the same" and "scedastic" meaning "scatter" (16:44).

4. For any fixed value of X, Y has a normal distribution (16:44).

<u>Testing the Assumptions</u>. The tests of the assumptions for regression will be examined and explained in this section. "Examination of the residuals scatterplots provides a test of the assumptions of normality, linearity, and the homoscedasticity between predicted DV scores and errors of prediction" (6:93). A sample size greater than 30 is usually considered to be of adequate dimension to invoke the Central Limit Theorem and to assume approximate normality (14:201). Therefore, the 815 data records in the CPRA database are assumed to have a normal distribution.

Linearity of relationship between predicted DV scores and the errors of prediction is also assumed (6:94). If nonlinearity is present, the overall shape of the [residuals] scatterplot will be curved instead of rectangular" (6:94-95). Examination of the scatterplots for each regression did not reveal a curvilinear pattern among the residuals. Therefore, linearity has been assumed.

The assumption of homoscedasticity can be tested by examining the width of the band in which most of the residuals fall (6:95). If the width of this band is relatively constant, the residuals are homoscedastic; otherwise the residuals are heteroscedastic. "When heteroscedasticity prevails but the other conditions of the model are met, the estimators b_0 and b_1 obtained by ordinary least squares procedures are still unbiased and consistent, but they are no longer minimum variance unbiased estimators" (17:131). This data did exhibit heteroscedastic tendencies (i.e. the band width was not relatively constant), however, the procedures are robust for these violations.

"Although the assumptions are important in derivation of the statistics, they are frequently less important in application of them to a data set" (6:77). "Univariate tests of significance are reasonably robust with respect to violations of assumptions (e.g. the F test is robust to violations of normality and homogeneity of variance, as long as sample sizes are relatively equal, but not to skewness)" (6:77). Unfortunately, the extent of the robustness of various test to various violations is not currently known (6:77). Probably, however, the researcher need only be concerned about flagrant violations of the assumptions (6:77). While the data did exhibit heteroscedastic tendencies they did not severely degrade the analysis.

The General Linear Test.

Once the regression lines were developed, it was possible to perform a series of general linear tests (GLTs) among them to determine if any of the fitted regression lines were statistically equal. As hypothesized in Chapter 1, the equality of two (or more) regression lines would indicate that the two different techniques used to generate EACs were in fact different expressions of the same EAC.

The assumptions for the general linear test include those assumptions already made for regression and the additional assumption of the equality of variance ($\sigma_1^2 = \sigma_2^2$) between test groups. An F test was used to check the assumption of homogeneity for the sample variances (17:165). The hypotheses are:

C_1: $\sigma_1^2 = \sigma_2^2$

C_2: $\sigma_1^2 \neq \sigma_2^2$

The test statistic is then calculated as:

$$F^* = [(SSE_1 + (n_1 - 2)) / (SSE_2 + (n_2 - 2))]$$

The critical F value is:

$$F_{(\alpha, n_1 - 2, n_2 - 2)}$$

where

α = the probability level

n_1 = the number of cases in data group 1

n_2 = the number of cases in data group 2

This resulted in an $F_{critical}$ of $F_{(.05, \infty, \infty)} = 1.0$ As noted earlier "the F test is robust to . . . violations of homogeneity of variance as long as the sample sizes are relatively equal" (6:77). The results of these tests indicated that the variances of the test groups were equal or that the test was robust because of relatively equal sample sizes in all but one case. Theoretically, a transformation of the data to stabilize the variances between the two samples could have been performed, however, the GLT F^* statistic was so strong that a transformation was not warranted (6:77). The results of this test are given in tabular form in the Results chapter of this thesis.

General Linear Test Procedure. The data which generated the parameters β_0 and β_1 for each of the two test lines was combined into a common data base and a new regression equation calculated. Next, the error portion of the new line, referred to as the reduced model, was compared to the combined error of the test lines and referred to as the full model. The term SSE(R) is used to describe the sum of the squared error for the reduced model. The terms SSE_1 and SSE_2 describe the sum of the squared error for regression lines 1 and 2 respectively. Neter and Wasserman describe the steps performed in comparing the respective SSEs below (17:161).

> 1. Fit the full, or unrestricted, model and obtain the error sum of the squares SSE(F). The SSE for the full model is $SSE(F) = SSE_1 + SSE_2$ (17:161).
>
> 2. Obtain the reduced, or restricted, model under C_1*, fit it, and determine the error sum of squares SSE(R) for the reduced model (17:161).
>
> 3. Calculate the F^* statistic . . . which involves the difference SSE(R) - SSE(F). The greater the difference, the more the data support [hypothesis] C_2; the smaller the difference, the more the data support [hypothesis] C_1 (17:161).

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* C_1 and C_2 have been used to permit the reader to follow the lengthy discussion of the general linear test in Neter and Wasserman's Applied Linear Statistical Models (17:160-165). Introductory statistics texts such as Devore's Probability & Statistics for Engineering and the Sciences (14) use the more common terminology of H_0 for the null hypothesis and H_a for the alternative hypothesis.

where C_1 and C_2 are the hypotheses,

C_1: $\beta_{01} = \beta_{02}$ and $\beta_{11} = \beta_{12}$

C_2: Either $\beta_{01} \neq \beta_{02}$ or $\beta_{11} \neq \beta_{21}$ or both

If the two regression lines are the same (C_1), both the intercept and the slope terms must be equal. If the regression lines are not the same (C_2), they must differ with either respect to the intercept or the slope or with respect to both (17:163).

The test statistic used to evaluate the hypotheses was the F statistic. The components of the test statistic are shown below.

$$F_N = \frac{SSE(R) - SSE(F)}{(n_1 + n_2 - 2) - (n_1 + n_2 - 4)}$$

$$F_D = \frac{SSE(F)}{n_1 + n_2 - 4}$$

Next, the test statistic F^* was calculated

$$F^* = F_N + F_D$$

Finally, the critical value of F was obtained in the form

$F_{(1 - \alpha; 2, n_1 + n_2 - 4)}$ where

α = the probability level

n_1 = the number of cases in data group 1

n_2 = the number of cases in data group 2

The decision rule for controlling the risk of a Type 1 error at α is (17:165):

If $F^* \leq F_{(1 - \alpha; 2, n_1 + n_2 - 4)}$, conclude C_1, the regression lines being tested are equal.

or

If $F^* > F_{(1 - \alpha; 2, n_1 + n_2 - 4)}$, conclude C_2, the regression lines being tested are not equal.

The α, or level of significance, used for the statistical tests conducted for this thesis was $\alpha = .05$

III. Results

This chapter presents the results of the statistical procedures described in the Methodology chapter of this thesis. First, the results of the regression of the estimated cost at completion (ECAC) with each CPRA EAC technique are summarized in Table 3.1. Second, the results of the intermediate steps necessary to conduct the general linear test have been summarized and displayed. These steps consist of the test for homogeneity (equality) of variance (Table 3.2) among the samples and the regression of the ECAC with any two CPRA EACs (Table 3.3). Finally, the results of the general linear test for equality among the EAC regression lines have been arranged in tabular form and are displayed in Table 3.4.

Linear Regression Results for EACs. The following results were generated with SPSS, the computer based statistical analysis program described earlier. The results shown in Table 3.1 are a summary of the results obtained by regressing each EAC technique and the estimated actual cost at completion. The results of each individual regression may be found in Appendix A.

TABLE 3.1

EAC Regression Summary

	R SQUARE	SSE
EAC1	.16509	.97163E+15
EAC2	.93771	.73215E+14
EAC3	.89534	.10589E+15
EAC4	.80030	.15436E+15
EAC5	.93801	.72680E+14
EAC6	.73172	.31338E+15

The R SQUARE shown in this table is the coefficient of determination. Since the R SQUARE value is the ratio of explained variance to total variance, the EAC with the highest R SQUARE value explains the most variance and has previously been defined as the better predictor.

General Linear Test Data. The results of the test for homogeneity of variance and the application of linear regression to the combinations of data required to perform the general linear tests described in the methodology chapter are summarized in the tables below. The results of the test for homogeneity of variance are summarized in Table 3.2.

TABLE 3.2

Test Results for Homogeneity of Variance

TEST EACS	N_1	N_2	F^*
EAC1 AND EAC2	8.1E+02	8.1E+02	13.40
EAC1 AND EAC3	8.1E+02	7.0E+02	7.98
EAC1 AND EAC4	8.1E+02	5.4E+02	4.18
EAC1 AND EAC5	8.1E+02	8.1E+02	13.47
EAC1 AND EAC6	8.1E+02	8.1E+02	3.11
EAC2 AND EAC3	8.1E+02	7.0E+02	0.60
EAC2 AND EAC4	8.1E+02	5.4E+02	0.31
EAC2 AND EAC5	8.1E+02	8.1E+02	1.00
EAC2 AND EAC6	8.1E+02	8.1E+02	0.23
EAC3 AND EAC4	7.0E+02	5.4E+02	0.52
EAC3 AND EAC5	7.0E+02	8.1E+02	1.69
EAC3 AND EAC6	7.0E+02	8.1E+02	0.39
EAC4 AND EAC5	5.4E+02	8.1E+02	3.22
EAC4 AND EAC6	5.4E+02	8.1E+02	0.74
EAC5 AND EAC6	8.1E+02	8.1E+02	0.23

The $F_{critical}$ of $F_{(.05, \infty, \infty)} = 1.0$ had to be greater than the F^* value or the sample sizes had to be relatively equal to permit assumption of equality of variance among the samples. Table 3.2 indicates at least one of these conditions was met in all but one case. That case, EAC1 and EAC4, was discussed in the methodology chapter on general linear test procedures.

The regression data summarized in Table 3.3 is fully detailed in Appendix B. The SSE shown is the SSE(R) used when calculating the GLT F^* test statistic. These intermediate calculations were necessary to derive the SSE(R) values, without which, the general linear test could not have been performed.

TABLE 3.3

Summary for General Linear Test Regressions

	R SQUARE	SSE
EAC1 AND EAC2	.23580	.17875E+16
EAC1 AND EAC3	.22661	.16826E+16
EAC1 AND EAC4	.20918	.15318E+16
EAC1 AND EAC5	.23192	.17944E+16
EAC1 AND EAC6	.24130	.17692E+16
EAC2 AND EAC3	.91693	.18169E+15
EAC2 AND EAC4	.87683	.24000E+15
EAC2 AND EAC5	.93761	.14647E+15
EAC2 AND EAC6	.81252	.43936E+15
EAC3 AND EAC4	.85198	.26423E+15
EAC3 AND EAC5	.91543	.18473E+15
EAC3 AND EAC6	.79265	.45202E+15
EAC4 AND EAC5	.87304	.24703E+15
EAC4 AND EAC6	.75312	.47926E+15
EAC5 AND EAC6	.80890	.44728E+15

General Linear Test Results. Table 3.4 indicates the EACs which were tested, the F^* and $F_{critical}$ (F_c) values. The formula used to derive the F^* test statistic and the F_c may be found in the methodology chapter of this thesis. Since F^* was greater than F_c in all cases, all of the regression lines may considered unique.

TABLE 3.4

General Linear Test Results

TEST EACS	F^*	F_c
EAC1 AND EAC3	421.44	3.00
EAC1 AND EAC4	240.75	3.00
EAC1 AND EAC5	578.92	3.00
EAC1 AND EAC6	303.13	3.00
EAC2 AND EAC3	10.89	3.00
EAC2 AND EAC4	36.69	3.00
EAC2 AND EAC5	3.19	3.00
EAC2 AND EAC6	110.35	3.00
EAC3 AND EAC4	9.41	3.00
EAC3 AND EAC5	25.99	3.00
EAC3 AND EAC6	58.74	3.00
EAC4 AND EAC5	59.08	3.00
EAC4 AND EAC6	16.49	3.00
EAC5 AND EAC6	128.05	3.00

In other words, this data indicates that there no two EAC formulas yield the same EAC.

IV. Discussion and Conclusion.

A Review of the Hypothesis.

The research hypothesis stated that a statistical evaluation of the past performance of each EAC method would indicate whether a "better" method of formulation existed and, if so, the evaluation would identify that method. This hypothesis was tested by calculating EACs using each of the CPRA techniques and regressing them with the ECAC for each program.

Conclusion.

The regression model for EAC5 explained the highest percentage of variation and has been selected as the "best predictor". The CPRA EAC techniques are ranked from the highest to lowest percentage of explained variation (R SQUARE) in table 4.1.

TABLE 4.1

EAC Rankings

EAC NAME	R SQUARE	SSE
EAC5 - WEIGHTED CPI/SPI	.93801	.72680E+14
EAC2 - CUMULATIVE CPI	.93771	.73215E+14
EAC3 - 3 MON CPI	.89534	.10589E+15
EAC4 - ACWP REGRESSION	.80030	.15436E+15
EAC6 - TREND WEIGHTED CPI/SPI	.73172	.31338E+15
EAC1 - MONTHLY CPI	.16509	.97163E+15

Discussion.

It is clear from Table 4.1 that the WEIGHTED CPI/SPI and the CUMULATIVE CPI are closely matched in their respective predictive power. The remainder of the techniques did provide good (as measured by R SQUARE) predictive capability and deserve the attention of the analyst. EAC1, the MONTHLY CPI technique, was the only poor predictor of the six techniques tested. This may be due to the fact that any variation in monthly performance is completely projected into cost of the remaining work. For example, if one month's data indicated the the contractor was performing at a 50% efficiency level, EAC1 assumes the remaining work effort will be accomplished at that same 50% level of efficiency. Of course, this tends to result in significant variations from BAC.

The results of the General Linear Test for equality among the regression lines indicate that there was no redundancy among the EAC techniques used in the CPRA program.

Recommendations. Since these conclusions were based on the application of EAC calculation techniques on performance measurement data for on-going research and development programs, it may be appropriate to question their applicability to either full scale development or production programs. This issue is recognized, but has not been addressed in this thesis. This analysis has provided a simple decision rule for the selection of EAC techniques. Future research could analyze this data in terms of total contract cost, acquisition phase of the program, type of contract, or the percentage of the contract completed. Research in these area's would provide the field analyst a more precise guide to EAC technique application for a given set of conditions.

Appendix A: Regression Results

TABLE A.1

Regression Results for EAC1

	MEAN	STD DEV	CASES
ECAC	827534.056	1203107.217	815
EAC1	1017017.360	3875706.202	805

MULTIPLE R	.40632		
R SQUARE	.16509	R SQUARE CHANGE	.16509
ADJUSTED R SQUARE	.16405	F CHANGE	158.78393
STANDARD ERROR	.11000E+07	SIGNIF F CHANGE	.0000

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE
REGRESSION	1	.19213E+15	.19213E+15
RESIDUAL	803	.97163E+15	.12100E+13

F = 158.78393 SIGNIF F = .0000

TABLE A.2

Regression Results for EAC2

	MEAN	STD DEV	CASES
ECAC	827534.056	1203107.217	815
EAC2	829206.599	1261568.983	813

MULTIPLE R	.96835		
R SQUARE	.93771	R SQUARE CHANGE	.93771
ADJUSTED R SQUARE	.93763	F CHANGE	12208.16803
STANDARD ERROR	300462.81409	SIGNIF F CHANGE	0

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE
REGRESSION	1	.11021E+16	.11021E+16
RESIDUAL	811	.73215E+14	.90278E+11

F = 12208.16803 SIGNIF F = 0

TABLE A.3

Regression Results for EAC3

	MEAN	STD DEV	CASES
ECAC	827534.056	1203107.217	815
EAC3	815483.312	1281310.244	700

MULTIPLE R	.94622		
R SQUARE	.89534	R SQUARE CHANGE	.89534
ADJUSTED R SQUARE	.89519	F CHANGE	5971.27998
STANDARD ERROR	389496.39744	SIGNIF F CHANGE	0

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE
REGRESSION	1	.90589E+15	.90589E+15
RESIDUAL	698	.10589E+15	.15171E+12

F = 5971.27998 SIGNIF F = 0

TABLE A.4

Regression Results for EAC4

	MEAN	STD DEV	CASES
ECAC	827534.056	1203107.217	815
EAC4	737831.309	1283567.883	535

MULTIPLE R	.89459		
R SQUARE	.80030	R SQUARE CHANGE	.80030
ADJUSTED R SQUARE	.79992	F CHANGE	2135.98328
STANDARD ERROR	538148.37577	SIGNIF F CHANGE	.0000

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE
REGRESSION	1	.61859E+15	.61859E+15
RESIDUAL	533	.15436E+15	.28960E+12

F = 2135.98328 SIGNIF F = .0000

TABLE A.5

Regression Results for EAC5

	MEAN	STD DEV	CASES
ECAC	827534.056	1203107.217	815
EAC5	800919.116	1232852.068	811

MULTIPLE R	.96851		
R SQUARE	.93801	R SQUARE CHANGE	.93801
ADJUSTED R SQUARE	.93793	F CHANGE	12241.41679
STANDARD ERROR	299733.06199	SIGNIF F CHANGE	.0000

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE
REGRESSION	1	.10998E+16	.10998E+16
RESIDUAL	809	.72680E+14	.89840E+11

F = 12241.41679 SIGNIF F = .0000

TABLE A.6

Regression Results for EAC6

	MEAN	STD DEV	CASES
ECAC	827534.056	1203107.217	815
EAC6	898976.353	1546542.481	808

MULTIPLE R	.85541		
R SQUARE	.73172	R SQUARE CHANGE	.73172
ADJUSTED R SQUARE	.73139	F CHANGE	2198.34905
STANDARD ERROR	623542.27794	SIGNIF F CHANGE	0

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE
REGRESSION	1	.85473E+15	.85473E+15
RESIDUAL	806	.31338E+15	.38880E+12

F = 2198.34905 SIGNIF F = 0

Appendix B: General Linear Test Results

TABLE B.1

General Linear Test for EAC1 and EAC2

MULTIPLE R	.48559		
R SQUARE	.23580	R SQUARE CHANGE	.23580
ADJUSTED R SQUARE	.23533	F CHANGE	498.63505
STANDARD ERROR	.10517E+07	SIGNIF F CHANGE	.0000

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE
REGRESSION	1	.55157E+15	.55157E+15
RESIDUAL	1616	.17875E+16	.11062E+13

F = 498.63505 SIGNIF F = .0000

TABLE B.2

General Linear Test for EAC1 and EAC3

	MEAN	STD DEV	CASES
ECAC	827534.056	1202737.882	1630
EACS	923280.594	2966990.159	1505

MULTIPLE R	.47603		
R SQUARE	.22661	R SQUARE CHANGE	.22661
ADJUSTED R SQUARE	.22609	F CHANGE	440.38882
STANDARD ERROR	.10581E+07	SIGNIF F CHANGE	0

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE
REGRESSION	1	.49302E+15	.49302E+15
RESIDUAL	1503	.16826E+16	.11195E+13

F = 440.38882 SIGNIF F = 0

Table B.3

General Linear Test for EAC1 and EAC4

	MEAN	STD DEV	CASES
ECAC	827534.056	1202737.882	1630
EACS	905551.287	3113703.421	1340

MULTIPLE R	.45736		
R SQUARE	.20918	R SQUARE CHANGE	.20918
ADJUSTED R SQUARE	.20859	F CHANGE	353.90767
STANDARD ERROR	.10700E+07	SIGNIF F CHANGE	.0000

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE
REGRESSION	1	.40517E+15	.40517E+15
RESIDUAL	1338	.15318E+16	.11448E+13

F = 353.90767 SIGNIF F = .0000

TABLE B.4

General Linear Test for EAC1 and EAC5

	MEAN	STD DEV	CASES
ECAC	827534.056	1202737.882	1630
EACS	908567.065	2872628.141	1616

MULTIPLE R	.48158		
R SQUARE	.23192	R SQUARE CHANGE	.23192
ADJUSTED R SQUARE	.23144	F CHANGE	487.34045
STANDARD ERROR	.10544E+07	SIGNIF F CHANGE	.0000

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE
REGRESSION	1	.54181E+15	.54181E+15
RESIDUAL	1614	.17944E+16	.11118E+13

F = 487.34045 SIGNIF F = .0000

TABLE B.5

General Linear Test for EAC1 and EAC6

	MEAN	STD DEV	CASES
ECAC	827534.056	1202737.882	1630
EACS	957887.085	2948351.882	1613

MULTIPLE R	.49122		
R SQUARE	.24130	R SQUARE CHANGE	.24130
ADJUSTED R SQUARE	.24083	F CHANGE	512.36274
STANDARD ERROR	.10480E+07	SIGNIF F CHANGE	0

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE
REGRESSION	1	.56268E+15	.56268E+15
RESIDUAL	1611	.17692E+16	.10982E+13

F = 512.36274 SIGNIF F = 0

TABLE B.6

General Linear Test for EAC2 and EAC3

	MEAN	STD DEV	CASES
ECAC	827534.056	1202737.882	1630
EACS	822857.425	1270337.714	1513

MULTIPLE R	.95757		
R SQUARE	.91693	R SQUARE CHANGE	.91693
ADJUSTED R SQUARE	.91688	F CHANGE	16678.65063
STANDARD ERROR	346764.56119	SIGNIF F CHANGE	.0000

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE
REGRESSION	1	.20055E+16	.20055E+16
RESIDUAL	1511	.18169E+15	.12025E+12

F = 16678.65063 SIGNIF F = .0000

TABLE B.7

General Linear Test for EAC2 and EAC4

	MEAN	STD DEV	CASES
ECAC	827534.056	1202737.882	1630
EACS	792941.183	1270657.850	1348

MULTIPLE R	.93639		
R SQUARE	.87683	R SQUARE CHANGE	.87683
ADJUSTED R SQUARE	.87674	F CHANGE	9582.01875
STANDARD ERROR	422264.01448	SIGNIF F CHANGE	.0000

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE
REGRESSION	1	.17085E+16	.17085E+16
RESIDUAL	1346	.24000E+15	.17831E+12

F = 9582.01875 SIGNIF F = .0000

TABLE B.8

General Linear Test for EAC2 and EAC5

	MEAN	STD DEV	CASES
ECAC	827534.056	1202737.882	1630
EACS	815080.275	1247006.818	1624

MULTIPLE R	.96830		
R SQUARE	.93761	R SQUARE CHANGE	.93761
ADJUSTED R SQUARE	.93757	F CHANGE	24377.09413
STANDARD ERROR	300504.61205	SIGNIF F CHANGE	0

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE
REGRESSION	1	.22013E+16	.22013E+16
RESIDUAL	1622	.14647E+15	.90303E+11

F = 24377.09413 SIGNIF F = 0

TABLE B.9

General Linear Test for EAC2 and EAC6

	MEAN	STD DEV	CASES
ECAC	827534.056	1202737.882	1630
EACS	863983.873	1410825.398	1621

MULTIPLE R	.90140		
R SQUARE	.81252	R SQUARE CHANGE	.81252
ADJUSTED R SQUARE	.81240	F CHANGE	7016.36954
STANDARD ERROR	520940.39336	SIGNIF F CHANGE	0

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE
REGRESSION	1	.19041E+16	.19041E+16
RESIDUAL	1619	.43936E+15	.27138E+12

F = 7016.36954 SIGNIF F = 0

TABLE B.10

General Linear Test for EAC3 and EAC4

	MEAN	STD DEV	CASES
ECAC	827534.056	1202737.882	1630
EACS	781844.590	1282346.701	1235

MULTIPLE R	.92303		
R SQUARE	.85198	R SQUARE CHANGE	.85198
ADJUSTED R SQUARE	.85186	F CHANGE	7096.85440
STANDARD ERROR	462924.17884	SIGNIF F CHANGE	0

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE
REGRESSION	1	.15208E+16	.15208E+16
RESIDUAL	1233	.26423E+15	.21430E+12

F = 7096.85440 SIGNIF F = 0

TABLE B.11

General Linear Test for EAC3 and EAC5

	MEAN	STD DEV	CASES
ECAC	827534.056	1202737.882	1630
EACS	807666.262	1255136.656	1511

MULTIPLE R	.95678		
R SQUARE	.91543	R SQUARE CHANGE	.91543
ADJUSTED R SQUARE	.91537	F CHANGE	16334.42277
STANDARD ERROR	349881.01760	SIGNIF F CHANGE	0

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE
REGRESSION	1	.19996E+16	.19996E+16
RESIDUAL	1509	.18473E+15	.12242E+12

F = 16334.42277 SIGNIF F = 0

TABLE B.12

General Linear Test for EAC3 and EAC6

	MEAN	STD DEV	CASES
ECAC	827534.056	1202737.882	1630
EACS	860219.637	1429701.872	1508

MULTIPLE R	.89031		
R SQUARE	.79265	R SQUARE CHANGE	.79265
ADJUSTED R SQUARE	.79251	F CHANGE	5757.11846
STANDARD ERROR	547855.53339	SIGNIF F CHANGE	.0000

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE
REGRESSION	1	.17280E+16	.17280E+16
RESIDUAL	1506	.45202E+15	.30015E+12

TABLE B.13

General Linear Test for EAC4 and EAC5

	MEAN	STD DEV	CASES
ECAC	827534.056	1202737.882	1630
EACS	775843.353	1253162.968	1346

MULTIPLE R	.93436		
R SQUARE	.87304	R SQUARE CHANGE	.87304
ADJUSTED R SQUARE	.87294	F CHANGE	9241.76050
STANDARD ERROR	428717.39021	SIGNIF F CHANGE	0

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE
REGRESSION	1	.16986E+16	.16986E+16
RESIDUAL	1344	.24703E+15	.18380E+12

F = 9241.76050 SIGNIF F = 0

TABLE B.14

General Linear Test for EAC4 and EAC6

	MEAN	STD DEV	CASES
ECAC	827534.056	1202737.882	1630
EACS	834782.311	1449169.993	1343

MULTIPLE R	.86783		
R SQUARE	.75312	R SQUARE CHANGE	.75312
ADJUSTED R SQUARE	.75294	F CHANGE	4090.87759
STANDARD ERROR	597822.50588	SIGNIF F CHANGE	0

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE
REGRESSION	1	.14620E+16	.14620E+16
RESIDUAL	1341	.47926E+15	.35739E+12

F = 4090.87759 SIGNIF F = 0

TABLE B.15

General Linear Test for EAC5 and EAC6

	MEAN	STD DEV	CASES
ECAC	827534.056	1202737.882	1630
EACS	849856.885	1398659.043	1619

MULTIPLE R	.89939		
R SQUARE	.80890	R SQUARE CHANGE	.80890
ADJUSTED R SQUARE	.80878	F CHANGE	6844.60388
STANDARD ERROR	525937.21652	SIGNIF F CHANGE	0

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE
REGRESSION	1	.18933E+16	.18933E+16
RESIDUAL	1617	.44728E+15	.27661E+12

F = 6844.60388 SIGNIF F = 0

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Associate Professor of Performance Management

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19. This thesis examined techniques used to derive estimates of the cost at completion for various research and development programs. The six methods examined were the methods used in the Cost Performance Report Analysis (CPRA) computer program to calculate estimates at completion.

The analysis is based on a linear regression between the cost at completion and the estimate at completion for each technique available. The techniques were ranked by coefficient of determination and a general linear test was performed to test for equality among the regression lines.

The results of this investigation indicate that an estimate at completion based upon weighted cost and schedule indices minimizes the unexplained error (as a percentage of total error) and is thought to be the superior forecaster of costs at completion. The general linear test for equality among the regression lines generated by the different techniques did not indicate the existence of commonality between regression lines. This means that each technique tested provided a unique estimate at completion.

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