A STUDY TO DETERMINE IF NEWLY DEVELOPED BUDGET AT COMPLETION (BAC) ADJUSTMENT FACTORS IMPROVE THE SUCCESS OF PREVALENT INDEX-BASED ESTIMATE AT COMPLETION (EAC) TECHNIQUES

THESIS

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AFIT/GCA/LAS/94S-3

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THESIS

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the Graduate School of Logistics and Acquisition Management
of the Air Force Institute of Technology
Air University
in Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Cost Analysis

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Abstract

The purpose of this study was to develop Budget At Completion (BAC) adjustment factors (BAFs) which, when used in conjunction with existing Estimate At Completion (EAC) techniques, improve the success of existing EAC techniques. These factors attempted to account for changing contract requirements which are certain to occur on DoD contracts. These changing requirements often result in a need to add scope and budget to a contract, or can cause contract cost overruns requiring additional budget.

Improving the success of these EAC techniques is increasingly important because of the budget cuts being experienced by the DoD in today's changing economic environment. An accurate estimate of future costs is necessary to ensure adequate funding levels to meet DoD requirements.

The BAFs were constructed by compiling actual data from 534 DoD contracts. They were then used with existing EAC techniques to predict final contract completion costs. Descriptive statistics were used to determine if the BAFs improved the success of these EAC techniques.

Unfortunately, the BAFs did not increase the success of the EAC techniques. Although these particular factors did not improve the success of these EAC techniques, research is still needed in this area. Accurate estimates of contract costs is still important.

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I. Introduction

General Issue

Department of Defense (DoD) contracts for new weapon systems frequently experience large cost overruns. "Cost growth in weapons has been a serious problem for the past thirty years" (Weida, 1987:135). Specifically, one source stated, "the average cost overrun on a weapon system has been around 40 percent" (Gansler, 1989:4). Predicting final costs for DoD contracts has been attempted in many fashions, but is still difficult.

"Congress plays the key political role in the defense contracting process because it controls the purse strings" (Mayer, 1991:11). An Air Force Times staff writer quoted Representative Ronald V. Dellums, D-California, whom he referred to as "the liberal House Armed Services Committee chairman, who has made no secret of his belief that the nation spends too much on defense, as saying, 'I see this budget as steady funding for too costly programs'" (Maze, 1994:14). The DoD, Congress, and the American Taxpayer all have a vested interest in controlling the costs of future weapon systems. "Both economic and political factors combine to form the defense budget" (Weida, 1987:10). As the economic and political priorities of the US government shift, a growing trend within the DoD is to extend the acquisition schedule of defense systems.

> Stretching out a program means extending research and production over more years than planned in order to make them affordable each year. The down side is that overall costs can rise when fewer planes are built each year, ultimately driving up the total cost and potentially forcing the Air Force to cut the number of units purchased. (Watkins, 1994:30)

Reducing the total number of weapon systems purchased has an obvious effect upon the operational use and strategy of a defense system. Thus, the ability to accurately predict the cost impact of such reductions is crucial to the DoD, as it struggles to decide which weapon systems provide the most economical means of defending the country.

In line with this political climate, initial cost estimates for new weapon systems have been unrealistically low in an attempt to obtain Congressional support for the program (Gansler, 1989:8). This practice puts program officials in a difficult management position, wherein, they must "accomplish the improbable task of managing [their] overspecified and underfunded program to a successful conclusion" (Gansler, 1989:147). This assertion was also supported by another author, who stated, "Early cost calculations are noteworthy because they are set forth with great confidence, are backed up with reams of analysis, and are always wrong" (Mayer, 1991:51).

The DoD has been aware of the problems associated with contract cost overruns for a number of years. "The Department of Defense has initiated a number of major management improvements in its acquisition process, specifically aimed at overrun reductions" (Gansler, 1978:268). Improved management of defense acquisition programs is a primary method for controlling program costs. "Certainly the taxpayers' willingness to support a strong defense establishment depends in large measure on their perception of the effectiveness and efficiency with which the funds are spent" (Gansler, 1989:141). Savings realized by better management of DoD contracts can benefit other programs consistent with overall government fiscal policy. Specifically, cost savings on Defense contracts can be applied to other areas of fiscal interest. As the United States Government budgeting priorities shift from Defense to domestic programs, it is essential that the DoD avoid wasting its limited funding. Kenneth R. Mayer, author of The Political Economy of Defense Contracting, reported that:

> Former chairman of Council of Economic Advisers Murray Weidenbaum summarized the major trends over the past fifty years: "Different ways of gauging

> resource use of the past half century yield the same point: defense outlays have accounted for a declining share of GNP; defense spending has been a declining portion of the federal budget; defense manpower has represented a declining fraction of the nation's workforce: defense has received a diminishing portion of the nation's research and development funding . . . over a very significant time period, military activities have been a steadily smaller factor in the American Economy. (Mayer, 1991:268)

The DoD must get the most out of its future weapon systems' development and procurement budgets. "The ever-shrinking defense budget continues to press the service into considering more programs for termination or drastic restructuring" (Watkins, 1994:34). In light of this, final contract cost predictions are becoming even more crucial.

The Navy's A-12 program is a prime example of what can happen when program management does not accurately or timely predict and report final contract costs. Among other reasons, the A-12 program was said to be canceled because large discrepancies were discovered in its estimated completion cost (Morrison, 1991:30). For DoD contracts, both the contractor and the government program office develop an estimate of final contract cost, known as an Estimate at Completion (EAC). Specifically, when problems arise, an EAC is required of the contractor, known as the contractor's Latest Revised Estimate (LRE). Additionally, the government program office often calculates independent

EACs to test the reasonableness of the contractor's LRE (Christensen, 1992:6).

The EAC can be compared to the funds available to accomplish the contract, known as the budget at completion (BAC), to determine if the contract can be completed within allocated funds. If the EAC exceeds the BAC, program management needs to take necessary action to ensure contract completion. If possible, program management might seek additional funding or reduce contract requirements and constraints. Based on potential cost overruns, an accurate and timely technique is needed to inform program management when an adjustment to technical or program requirements is necessary. Prompt and accurate management decisions can avoid wasting government funding and potentially save a program. "By Public Law (Nunn-McCurdy Amendment), Congress must consider canceling defense contracts when they exceed certain unit-cost thresholds" (Christensen, 1992:5).

Specific Problem

The purpose of this research was to determine whether newly developed BAC adjustment factors improved the success of existing EAC techniques in predicting the final cost of DoD weapon system contracts.

Research Scope and Objectives

Specific research objectives for this study were:

1. Determine the EAC methods currently being used and believed to be successful.

2. Determine the work done in the area of estimates at completion, specifically, index-based (linear) methods.

3. Determine the scoring methodologies that have been used to rate the success of EAC forecasting techniques.

4. Use historical data to develop BAC adjustment factors, which are used in conjunction with current EAC methods, to predict final contract costs at various points in the life of DoD contracts.

5. Determine if the BAC adjustment factors developed in research objective four improved the success of the prevalent EAC methods determined in research objective one.

Historical contract cost performance report (CPR) data contained in the Defense Acquisition Executive Summary (DAES) database were used for this study. There were some limitations using this database, such as, the origin of the information. The data within the DAES database came from contractor financial reports submitted to the program office. These reports were generated by contractor performance measurement systems that were supposed to be validated by the government to ensure the accuracy and reliability of the data. If the government mistakenly validated a performance measurement system that was not valid or contained bias, the data received in the financial reports may not have been indicative of the contractor's performance. For the purposes of this research, the assumption was made that the data were from properly validated systems and were accurately reported.

Another limitation of the DAES database was it did not indicate the method used by the program office to develop its EAC. As a result, conclusions were limited to general statements of how the newly developed BAC adjustment factors might help better predict contract completion costs. Conclusions did not include statements concerning specific EAC techniques used by the system program office (SPO). A third limitation was that the data in the DAES Database did not include contract cost information through the one hundred percent completion point. In most cases, the data only included information through the 80% or 90% completion point. For this reason, it was necessary to extrapolate contract costs to the 100% completion point to establish the actual completion costs used to measure the EAC techniques' success.

This chapter has introduced the general problem associated with contract cost overruns facing program management within the Defense Industry today. It has also highlighted how better estimates at completion for DoD contracts can aid top defense and other national leaders in their attempts to restructure the U.S. defense budget. Chapter Two is a review of the most notable literature on Estimate at Completion research. Chapter Two identifies the most prevalent EAC techniques to be tested in the analysis portion of this research. Chapter Three describes the methodology used to compare the success of the different EAC techniques. Chapter Four discusses the analysis and provides the results of the EAC technique comparison. Finally, Chapter Five lists general conclusions and findings on EAC technique success based upon the comparative analysis completed and described in Chapters Three and Four.

II. Literature Review

Chapter Overview

The primary purposes of reviewing other literature were to avoid duplicating EAC work already accomplished and to discover what areas of EAC research and methodology needed further attention. In addition, the review of other EAC literature helped determine which EAC methods have been considered successful. Hence, the literature review assisted in scoping the comparative portion of this analysis to those EAC techniques which have previously been recommended. For a more detailed review of these EAC studies, see Christensen, et al.

Before discussing the findings of the literature review, a brief description of the terminology that will be used is in order. A series of definitions are important to understand the process of computing an Estimate at Completion (EAC). The following narrative outlines applicable terms.

First of all, an EAC consists of the current costs incurred on a contract, plus an estimate of the cost of work remaining to complete the contract. Typically, contractors submit a similar figure, called the Latest Revised Estimate (LRE), which includes their own estimate of the cost of work remaining to complete the contract. The current costs incurred on the contract are referred to as the Actual Cost of Work Performed (ACWP), while the work remaining is called the Budgeted Cost of Work Remaining (BCWR). The budget identified for the known work on a contract is referred to as Budget at Completion (BAC). The BCWR is defined as the BAC minus the budgeted cost of work performed (BCWP) to date.

The Cost Performance Index (CPI) and the Schedule Performance Index (SPI) are commonly used in calculating an EAC. The CPI is the ratio of the BCWP to the ACWP, while the SPI is the ratio of the BCWP to the planned cost of work scheduled. The planned cost of work scheduled is called the Budgeted Cost for Work Scheduled (BCWS). For the purposes of this study, both indexes will be computed from cumulative data.

$$CPI = \frac{BCWP_{CUM}}{ACWP_{CUM}} \tag{2.1}$$

$$SPI = \frac{BCWP_{CUM}}{BCWS_{CUM}} \tag{2.2}$$

There are a number of other terms pertinent to this study. The contract Cost at Completion (CAC) is the actual cost of the contract at its close. In addition, chapter 14 of Air Force Material Command Pamphlet (AFMCP) 173-4 defines other applicable terms in the following manner (AFMCP 173-4, 1992:108). The time-phased cumulative total of all work within a contract is referred to as the Performance Measurement Baseline (PMB). The amount of total allocated budget withheld for management control purposes is called the Management Reserve (MR). The Contract Budget Baseline (CBB) is the negotiated contract cost plus the estimated cost of authorized unpriced work. The Over Target Baseline (OTB) is a PMB resulting from formal reprogramming by the contractor, with customer approval, which establishes budget allocations in excess of the CBB. The Total Allocated Budget (TAB) is the sum of all allocated budgets. The following formulas will help describe the relationship between the PMB, MR, OTB, and the TAB.

$$CBB = BAC \text{ of the } PMB + MR \tag{2.3a}$$

$$TAB = CBB + OTB \tag{2.3b}$$

Having stated these definition, the remainder of the literature review can proceed.

A logical starting point for the literature review was to identify those EAC forecasting techniques that were currently being used. Many weapon system acquisition programs in the United States Air Force use the Performance

Analyzer (PA) (Version 4.0) Software "to streamline the analysis and reporting process associated with Cost Performance Reports (CPR), Cost/Schedule Status Reports (C/SSR) and Contract Funds Status Reports (CFSR)" (Software User's Manual for the Performance Analyzer, 1991:i). One of the capabilities of this software is allowing the cost analyst in a System Program Directorate (SPD) to compute and display an EAC at the touch of a key on his computer keyboard. Historically, the cost analyst could choose from a list of about ten different EAC techniques. The list of possible EAC techniques has changed over the years as subsequent versions of the PA Software have been released. The most current version, Version 4.0, was released on 24 June 1994. As with any software product, feedback from its users is considered before the release of subsequent versions. Therefore, the list of forecasting techniques in PA represented a sample of EAC methodologies currently being used in Air Force, Army, and Navy SPDs.

Starting with this list of EAC techniques, the literature review focused on studies which tested the success of certain EAC techniques available in PA. Since the intent of this study was to compare the success of current EAC methods used with, and without, newly developed BAC adjustment factors, the focus of the literature review was also on techniques that could be computed using data in the DAES database. The DAES database only contains cumulative contract performance data at sporadic intervals. That is, the DAES data were not reported at regular monthly, quarterly, or annual intervals. For these reasons, the literature review centered on the following PA forecasting techniques:

Cumulative Cost Performance Index (CPI)

$$EAC1 = ACWP_{CUM} + \frac{BAC - BCWP_{CUM}}{CPI} \tag{2.4}$$

Weighted Cost and Schedule

$$EAC2 = ACWP_{CUM} + \frac{BAC - BCWP_{CUM}}{A(CPI) + B(SPI)} \tag{2.5}$$

where: A = the cost weighting
B = the schedule weighting
A + B must equal 1

The most common weighting scheme encountered during the literature review was 0.8 for cost and 0.2 for schedule. Therefore, this was the weighting scheme used in the analysis portion of this study as well.

NAVSEA 90's Formula

$$EAC3 = ACWP_{CUM} + CBB + OTB - BCWP_{CUM} + \tag{2.6}$$

$$\left[\left(\frac{(CBB + OTB - BCWP_{CUM})}{CCPI} - CBB - OTB + BCWP_{CUM}\right) * \frac{BCWP_{CUM}}{CBB + OTB}\right]$$

where:

$$CCPI = \left(\frac{BCWP_{CUM}}{2*ACWP_{CUM}}\right)*\left(1+\frac{BCWP_{CUM}}{BCWS_{CUM}}\right)*\left(1+\frac{BCWS_{CUM}-BCWS_{CUM}}{CBB+OTB}\right)$$

These first three index-based EAC techniques, along with a fourth technique, the Schedule Cost Index (SCI), were included in this study. Even though it is not directly available within Performance Analyzer, the SCI was evaluated with positive results in three of the studies reviewed; therefore, it was included in this study.

SCHEDULE COST INDEX (SCI) EAC

$$EAC4 = ACWP_{CUM} + \frac{BAC - BCWP_{CUM}}{CPI*SPI} \qquad (2.7)$$

The reviewed literature was summarized, and arranged in chronological order. Then, conclusions were drawn; and the EAC methods that seemed to perform well, as well as the scoring techniques used to evaluate their success, were identified. Results are summarized in Table 2-1. The left hand column of Table 2-1 lists the authors of the five EAC comparative studies that were reviewed. In cases where there were more than one author, only the name of the first author was listed. See the Bibliography for a complete reference. The top row of Table 2-1 lists the EAC forecasting techniques that were selected for inclusion in this study. Reading across the rows and down the columns, to the intersection of an author and a technique, there is a brief explanation as to how well that particular technique performed within that author's study. An N/A means that particular EAC technique was not included in that author's study. As can be seen from the table, conclusions on the success of the EAC techniques varied. The last column of Table 2-1 lists the scoring methodology used within each study. A more detailed discussion of the results and the scoring methodologies can be found in the following paragraphs on each study.

Land and Preston

A thesis accomplished for the Air Force Institute of Technology, Air University, compared two cost forecasting models. The models compared were The Automated Financial Analysis Program, Electronic Systems Division (ESD), November 1976, and A Cost Performance Forecasting Concept and Model, Aeronautical Systems Division (ASD), November 1974 (Land and Preston, 1980:2). The ESD model consisted of six index based methods, while the ASD model included two non-linear regression based methods for forecasting the cost at completion for various DoD programs (Land and Preston, 1980:6). The comparison was accomplished using actual cost data from 25 ASD programs, plus 5 aircraft programs, all

TABLE 2-1

RESULTS OF LITERATURE REVIEW

	FORECASTING TECHNIQUES				
Author (Year)	Cumulative CPI	Weighted Cost&Sched.	NAVSEA90	SCI CPI X SPI	Scoring Method
Land (1980)	Smallest MAPE 4.57%	N/A	N/A	N/A	MAPE, ANOVA, and LSD were evaluated to determine lowest error.
Covach (1981)	Recommend (0-60% Complete)	Included[1]	N/A	Recommend (0-60% Complete)	Tabulating number of times EAC was +/- 10% of CAC.
Bright (1981)	Good 81-100% Complete	Good 0-30% Complete	N/A	Good/Excel. 0-100% Complete	Lowest PE scoring and graphical comparison of PE's.
Price (1985)	Close 2nd to "Best Predictor	"Best Predictor"[2]	N/A	N/A	Linear regression: highest R^2 was best estimator.
Riedel (1989)	Included[3]	Included[3]	N/A	Included[3]	Comparison and rank order scoring of MAPEs.

1 - Rarely met pre-conditions for use. That is, SPI data was not used if it would have reduced the cost overrun, and not at all in the latter 40% of the contract. CPI usually deteriorated more than SPI.

2 - The actual technique was a variant of the Weighted Cost & Schedule technique, where:

$$EAC = ACWP + [100 - (Cost\ Var\ \%) + .75 \times (Sched\ Var\ \%)] \times \frac{(BAC - BCWP)}{100}$$

3 - Results depended upon the completion stage, as well as the type of contract (Research and Development or Production). General conclusions were made, but were questionable.

with periods of performance greater than 12 months (Land and Preston, 1980:20).

EAC technique performance was measured using the Mean Absolute Percentage Error (MAPE) (Land and Preston, 1980:32). The MAPE was used because percentages eliminated the impact of dollar magnitude difference between contracts. The test hypothesis was that the non-linear methods were more accurate than the linear index based methods. A single factor analysis of variance (ANOVA) was used to test if the MAPE from one method was significantly different than the others. If there was no significant difference between MAPE's, then the test hypothesis was not supported. Additionally, if one or more MAPE's tested significantly different from the others, Fisher's least significant difference (LSD) test was applied to determine the true differences between MAPE's. The methods were evaluated over various types of contracts at different percents complete. The study concluded that the hypothesis that non-linear methods are more accurate than linear models at forecasting costs at completion could not be supported (Land and Preston, 1980:53). The Land and Preston conclusion is applicable to this study because this study will only be reviewing linear methods for estimating costs at completion. Additionally, the CPI(Cum) MAPE proved slightly lower than the other methods tested (Land and Preston, 1980:40). This further supports the inclusion of the CPI(Cum) EAC technique in this study.

Covach, et al

The Mantech report consisted of testing the accuracy, timeliness, and stability of 12 index-based, and 12 regression-based EAC techniques on 27 Navy contracts. Methods based on manpower consumption and lower level Work Breakdown Structure (WBS) elements were also evaluated. The study concluded that certain index-based methods were more accurate than others depending on the stage of the program's life (early, middle, or late).

The scoring technique used in the Mantech report evaluated an EAC technique's performance based upon four subjectively established evaluation questions. These questions are as follows:

> 1. How many months out of the contract life would each method produce an EAC that is within plus/minus 10% of the CAC?
> 2. How many months would each method's EAC be closer to the CAC than the Budget at Completion (BAC) is?
> 3. How many months in the contract life will a method's EAC be superior to the contractor's LRE?
> 4. If the contract life is divided into fifths (quintiles) based on budgeted dollars, how would the various methods behave at the various stages of the contract? (Covach, 1981:22)

A numerical grade was computed for each method by awarding a +1.0 to each success and a -1.0 for each failure in its ability to be within plus/minus 10% of the CAC, or outperform the BAC, or LRE. This was also accomplished for the various stages of the contract (i.e. quintiles). Based upon this numerical grade subjective recommendations were made for use of different EAC techniques depending upon the stage of the contract. The Mantech report recommended CPI(Cum) and SCI for contracts in the 0-60% complete range. Two limitations of the study were the relatively small data sample (only 27 contracts) and the fact that index-based and regression-based methods were not compared to each other. No specific conclusions were made concerning the manpower techniques; and lower level analysis was "not significantly more accurate than estimates based on aggregate budget dollars" (Covach, 1981:3).

Bright and Howard

A paper written for the Cost Analysis Division, US Army Missile Command, compared EAC forecasting techniques that were employed in their Automated Contractor Performance Measurement System (ACPMS) (Bright and Howard, 1981:2-3). Their analysis included nine index based and two regression based EAC techniques on eleven Army contracts. Bright and Howard recommended certain techniques over others depending on the completion stage of the contract (0-30%, 31-80%, or 81-100% complete). They also concluded that "CPI X SPI (or

SCI) appeared to provide better overall forecasts than the other methods" (Bright and Howard, 1981:19).

The scoring technique used in the Bright and Howard paper included two approaches: graphic and rating. The graphic approach consisted of plotting average percent errors of the different EAC techniques versus percent complete of the contract. Percent errors are calculated by dividing the error (EAC-CAC) by the final contract cost (CAC). Only selected example graphs were provided in the report making relative comparisons based on the graphic approach of all the EAC techniques studied impossible. The second approach was a scoring system, similar to the Mantech scoring technique, that gave one point to the forecast that performed the best for each month. That is, the EAC technique that had the lowest percent error. Fractions of points were given to other forecasts depending on how close they were to the best technique for that particular month. The rules for assigning fractions of points were not provided. In addition, the overall scores for each technique using the rating approach were not provided as back-up to support the final conclusions and recommendations. The database used in Bright and Howard's paper included eleven Army Missile Command (MICOM) contracts.

An additional benefit in reviewing Bright and Howard's paper was that it included discussion on the treatment of budget being added to contracts when additional scope is added to the contract, and when the contract is rebaselined due to cost overruns. They used an approach in their analysis of adjusting the rebaselined data to be consistent with the budget prior to rebaselining. In order to use an index-based forecasting technique, it is necessary to obtain a dollar figure which represents the work remaining to be done on the contract. This dollar figure is rather easy to compute at any given point of the contract. The work remaining to be accomplished on a contract, or Budgeted Cost of Work Remaining (BCWR) is normally calculated as follows: BCWR = BAC - BCWP. However, if after that particular point, the contract is rebaselined and/or scope is added, the BAC used to compute BCWR was understated. The result of using this understated BCWR when forecasting the actual contract completion costs was an understated forecast, or EAC.

Therefore, Bright and Howard attempted to obtain a better dollar figure for the contract work remaining as follows: "when computing work remaining the final BAC was used rather than the BAC immediately following the rebaseline and an adjusted final BAC was used in place of the BAC immediately prior to rebaselining" (Bright and

Howard, 1981:11). In other words, when applying a forecasting technique on data subsequent to a rebaseline, the BCWR was obtained by subtracting cumulative BCWP from the final contract BAC. For example, given that total BAC after a rebaseline was $100 and cumulative BCWP was $50, if the final BAC was $150, then BCWR was computed to be $100, ($150 - $50). When applying a forecasting technique on data accumulated prior to a rebaseline, the BCWR was obtained by subtracting cumulative BCWP from an adjusted final BAC. Using the same data from the previous example, if the BAC prior to the rebaseline was $70 and the cumulative BCWP was $45, then a BCWR of $30 was computed as follows:

$$BCWR = \left[FinalBAC * \frac{(BAC_{prior\ to\ rebaseline} - BCWP_{prior...})}{(BAC_{rebaselined} - BCWP_{rebaselined})} \right] - BCWP_{prior...} \quad (2.8)$$

$$BCWR = \left[\$150 * \frac{(\$70 - \$45)}{(\$100 - \$50)} \right] - \$45$$

The result of using this adjusted final BAC was that $75 was used as the BAC at that particular point in the contract instead of the true BAC of $70. In both examples (prior and subsequent to rebaselines), the increased BAC that was used accounted for the additional budget that was eventually added to the contract.

In addition, the final cost that Bright and Howard compared with their forecasts was also adjusted to account for scope being added after a particular forecast was made. Their final cost was adjusted as follows:

$$\text{Final Cost} = \frac{\text{BAC (time of forecast)}}{\text{BAC (final)}} * \text{Actual Final Cost} \quad (2.9)$$

These data adjustment techniques were easy to apply on contract cost information from completed contracts. However, cost analysts who are trying to forecast an EAC for their program can not use this method, because they have no idea of what the BAC (Final) is going to be.

The problem of not adjusting the data for reasons of rebaselines and added scope is that the forecasting techniques currently being used, especially the index-based ones which include the BCWR in their formulas, are not capable of predicting when budget will be added to contracts for scope additions and rebaselines. By adjusting the historical data, as was accomplished in the Bright and Howard thesis, the EACs would only appear more accurate. When in fact, what is needed is a forecasting technique which can account for these types of budget additions. The uncertainty of budget being added to contracts for reasons of additional scope, and rebaselines due to cost overruns is an important component of the proposed BAC adjustment factors to be developed in this research.

Price

The Price thesis examined how well five index-based EAC techniques and one regression-based EAC technique performed in estimating a program's cost at completion. It also tested the statistical equivalence of the different EAC methodologies. The index based EAC techniques included current month CPI, three month CPI, cumulative CPI, a variant of the weighted cost and schedule (see note 2 in Table 2-1), and a fifth method defined in the following manner:

$$EAC = EACC + ETCS \tag{2.10}$$

where: $EACC = [.12 * EAC(\text{current month CPI}) + .24 * EAC(\text{three month CPI}) + .64 * EAC(\text{cumulative CPI})]$

$ETCS = (\text{months behind schedule}) * ACWP_{rate} * (.75)$

$ACWP_{rate} = ACWP_{cum} / TNUM$

TNUM = number of months from beginning of contract to latest CPR

This fifth index based EAC technique was rather involved. The regression based technique was based on ACWP regression. It used a least-squares-best-fit on ACWP to establish a trend line which was extended to the zero work remaining point to become the EAC (Price, 1985:11). The conclusion of the thesis was that two of the index-based methods were selected as the best predictors. "It is clear . . . that the WEIGHTED CPI/SPI and the CUMULATIVE CPI are closely matched in their respective predictive power" (Price, 1985:32).

The scoring technique used in the Price thesis consisted of formulating a univariate (a single dependent variable) regression line based on the CAC (dependent variable) and the EAC generated by each technique (independent variable), and computing the coefficient of determination, R-square. The highest R-squares were deemed the best estimators. It was also necessary for Price to make certain assumptions when using linear regression. These assumptions were as follows:

> 1. For any fixed value of X, Y is a random variable with a certain probability distribution.
> 2. The mean value of Y . . . is a straight line function of X.
> 3. The variance of Y is the same for any X. This assumption is called the assumption of homoscedasticity.
> 4. For any fixed value of X, Y has a normal distribution. (Price, 1985:19-20)

These assumptions were successfully tested, except for the assumption of homoscedasticity. In that case, Price assumed that "while the data did exhibit heteroscedastic tendencies they did not severely degrade the analysis" (Price, 1985:21).

The database included 57 on-going research and development programs. A short-coming of the thesis was that, since the programs were still on-going, the latest cumulative ACWP and BCWP were used as estimates for the final contract cost at completion (CAC) and budget at completion (BAC). The EAC techniques were then used to predict what the costs would be for the work completed to date.

Riedel and Chance

A paper written for the Directorate of Cost, Aeronautical Systems Division, compared the success of seven index-based EAC formulas on 18 Aeronautical Systems Division (ASD) programs (Riedel and Chance, 1989:4-6). They chose the seven formulas in their analysis after reviewing the results from several data sources they had gathered: an Air Force Institute of Technology (AFIT) Thesis, a Defense Systems Management College (DSMC) Course, an AFIT Short Course Text, and an article from Program Manager. Their study only included EAC formulas that were recommended for use by the reviewed data sources (Riedel and Chance, 1989:Ch 1). Riedel and Chance concluded that certain EAC methods performed better than others depending upon the completion stage and type of contract (research and development or production contracts).

The scoring technique used by Riedel and Chance consisted of two methods. "The first, was based on the average absolute value of the deviation percentages . . .

the second was based on the average rank order of the deviation percentages" (Riedel and Chance, 1989:18). Their average absolute value of the deviation percentages was essentially a comparison of the Mean Absolute Percentage Errors (MAPE). After EACs are calculated using the different techniques, the absolute value of the difference (error) between the EAC and the CAC is summed and divided by the number of EACs generated to arrive at a MAPE. The average rank order of the deviation percentages was essentially a cross-check of the first method. Instead of looking at the raw MAPE values, the EACs' MAPEs were rank ordered (lowest = 1, etc.). The average rank order for each method was calculated by summing the EAC technique's rank order for all programs and dividing by the number of programs. Those EAC methods with the lowest percentage deviation and percentage deviation rankings (computed by averaging all the programs) at various stages of contract completion were deemed the best EAC techniques for those stages. Those EAC methods with the lowest overall average deviation and overall average deviation rankings (computed by averaging the percentage deviations at each contract stage) were deemed the best overall EAC techniques. They admitted in their recommendations that the database used in certain facets of their analysis was relatively small (Riedel and Chance, 1989:80). Only eight aircraft, five avionics, and five engine programs were analyzed.

Other EAC Related Papers

The following papers, studies, etc. were reviewed to see if any further EAC research had been conducted since the publication of the previously reviewed studies. The review of these other EAC related papers would eliminate any possible duplication of effort by this research study.

Major David S. Christensen, et al, published a paper comparing 25 EAC studies (Christensen, et al, 1992:208). The EAC studies were categorized into one of the following categories: index based, regression and other. The index based methods included various combinations of the budgeted and actual costs of work performed. Indexes were used to adjust the cost of work still to be completed on the contract. Regression based models reviewed included both linear and non-linear relationships between two variables, typically budgeted and actual cost of work performed. The final category, "other," was used to include all models that did not fall into the first two categories.

Christensen's review produced two generalizations. First, the "accuracy of regression-based models over index-based formulas has not been established" with respect to work that has currently been accomplished (Christensen, et al, 1992:220). Results are inconclusive as to which method is superior. And second, the "accuracy of index-based formulas depends on the type of system, and the stage and phase of the contract" (Christensen, et al, 1992:221). Specifically, no one formula is best in all situations.

An article presented in the National Contract Management Journal, evaluated the stability of the Cost Performance Index (CPI) (Christensen and Heise, 1993:7). The CPI is an index used to analyze cost and schedule performance data reported by defense contractors. The study evaluated the CPI using cost data from 155 contracts from 44 different programs (Christensen and Heise, 1993:9). The study concluded that "the cumulative CPI was stable from the 20 percent completion point with 95 percent confidence. Stability was defined in terms of CPI range being less than .200" (Christensen and Heise, 1993:13). This finding was significant because it showed that the government could conclude with some confidence that a contract was in trouble when the contract overran the budget at the 20% completion point. The cumulative CPI stability is important to this thesis effort because cumulative CPI is one of the techniques that will be evaluated.

Excessive optimism in cost overrun projections was highlighted in a study published in the Acquisition Review Quarterly (Christensen, 1994:25). The study examined cost overrun data from 64 completed acquisition contracts. The study evaluated the overruns through various contract types, phases, types of weapon systems and military service responsible (Christensen, 1994:32). On a summary level, the government estimate was lower than the actual overrun, and the contractor estimate was even lower still. The study concluded that both the government and contractor estimates were significantly lower than actual cost overruns. This conclusion shows the need for more realistic and more accurate estimating techniques.

Conclusions

The literature review revealed that no single EAC method outperformed all other techniques. Much of the past research recommended different EAC techniques. Many of their recommendations suggested using different EAC techniques at different times in a programs life-cycle (early, middle, or late). Additionally, the literature review identified certain index-based EAC techniques that were considered successful by various studies. Two of the four PA EAC methods, listed previously, which this literature review focused on, were found to be successful. These were the Cumulative CPI, and the Weighted Cost and Schedule methods. Riedel and Chance used a 0.8 weight on cost and a 0.2 schedule weighting in the Weighted Cost and Schedule EAC technique available in PA. This was consistent with Air Force Material Command Pamphlet (AFMCP) 173-4, which advocates the use of the 0.8 and 0.2 weightings for cost and schedule, respectively (AFMCP 173-4, 1992:19). An Aeronautical Systems Division (ASD) reserve study, an Air Force Systems Command (AFSC) EAC study, and an AD study of the AFSC EAC showed this to be a reliable forecasting formula (AFMCP 173-4, 1992:19).

The identification of these commonly successful EAC techniques and the accomplishment of this literature review answered the first three research objectives:

1. Determined the EAC methods currently being used and believed to be successful.
2. Determined the work done in the area of estimates at completion, specifically, the index-based methods.
3. Determined the scoring methodologies that have been used to rate the success of EAC forecasting techniques.

Even though the techniques listed in this review were considered successful, a limitation was often highlighted in the literature: the use of a relatively small database. The DAES database used in this research tests the success of the techniques on a much larger sample of contracts. Moreover, a common theme in these EAC techniques is the dependence upon the Budgeted Cost of Work Remaining (BCWR), BAC - BCWP. However, these techniques fail to account for budget that may be added to contracts because of additional scope, cost overruns, or rebaselines. The next chapter will present the methodology used to address this specific problem as well as accomplish the fourth and fifth research objectives of this study:

4. Use historical data to develop BAC adjustment factors, used in conjunction with current EAC methods, to predict final contract costs at various points in the life of DoD contracts.
5. Determine if the BAC adjustment factors developed in research objective four improved the success of the prevalent EAC methods determined in research objective one.

III. Methodology

Chapter Overview

The methodology used to compare the success of the different EAC techniques in this study involved simple descriptive statistics. However, prior to the actual comparison of the different EAC techniques, BAC adjustment factors were developed. These adjustment factors increase the BAC used in EAC calculations to account for increases in scope and cost overruns. A more detailed discussion of the need for these adjustment factors is included in the background section, later in this chapter. In addition, the development of these adjustment factors is described step by step in the Analysis Method section at the end of this chapter. The essence of this chapter, however, is a description of the methodology used to compare the success of the various EAC techniques, both with and without the BAC adjustment factors.

Hypothesis

The general hypothesis of this study was that index-based EAC techniques provide better predictions of the actual final costs at completion of DoD contracts when used in conjunction with the BAC adjustment factors. In order to compare the success of the different EAC techniques, the definition of what makes an EAC method successful, when compared to other EAC methods, was developed. As can be seen in the literature review of this research, prior EAC comparative studies used various scoring methodologies to determine which EAC techniques were most successful.

For this study, success was defined to include accuracy, bias, and what is commonly referred to as precision. In other words, not only must the EAC technique generate EACs that are close to the costs at completion (CAC), but it must do so consistently and without unfavorable bias.

Testing Procedures

Unfortunately, hypothesis testing was inappropriate for analysis in this study. This was because of the interdependence between each of the EAC calculations and the actual contract completion costs. Each of the index-based EAC techniques would be utilizing actual contract costs. This interdependency grows stronger as the contract progresses through its life. For instance, at the 99% completion point, an EAC generated by one of the index-based techniques would consist almost totally of actual contract costs: the ACWP portion of the EAC formula (see Formulas 2.4 through 2.7). This would result in extremely high collinearity. These interdependencies would invalidate any hypothesis test used to test the success of an EAC at predicting the contract completion cost.

Various descriptive statistics were used to determine the success of an EAC method. Specifically, an EAC technique which produced a smaller mean absolute percentage error (MAPE), a smaller median absolute percentage error (MdAPE), and which had smaller standard errors in the MAPE or MdAPE was considered more successful. Standard error was a good measure of how consistently the technique was successful. Another measure of accuracy was the number of times a technique's EAC was within 10% of the cost at completion.

Percentage errors, as opposed to raw errors, were chosen as decision criteria to account for the varying orders of magnitude of costs between contracts. Absolute values were selected to prevent positive and negative errors from canceling each other out. The reason for examining the MdAPE as well as the MAPE was because the MAPE is considered to be too sensitive to outliers (Armstrong and Collopy, 1992:77). "The Median APE (MdAPE) reduces the bias in favor of low forecasts, thus offering an advantage over the MAPE" (Armstrong and Collopy, 1992:71).

In addition, the EAC techniques were tested for bias. This was accomplished by evaluating the mean percentage errors (MPE) and the median percentage errors (MdPE); note that these are non-absolute value statistics. Values other than zero for the MPE and MdPE indicated bias in either the positive or negative direction. From a decision makers standpoint, perfect accuracy in an EAC is preferred. However, when planning for future costs, it is evident that a decision based on slightly inflated values would be safer. Therefore, a technique with a slight positive bias would be favored.

The MAPE for a given EAC technique was defined to be the sum of the absolute percentage errors for all estimates generated by an EAC technique divided by the number of estimates generated by that technique. As mentioned previously, the use of a percentage error compensates for the varying degrees of magnitude between contracts. These varying degrees refer to the different dollar amounts utilized on each of the contracts. The following is an example of how the MAPE was calculated for each EAC technique in this study. The EAC column represents EACs generated by an EAC technique, and the Error column represents the differences between the generated EACs and the contract costs at completion (CAC). The Absolute % Error is defined as the absolute value of the Error, divided by the CAC, times 100. It is necessary to multiply the Absolute % Error by 100 to show it as a percentage, rather than as a decimal. The numbers used in this example are for illustrative purposes only.

EAC	CAC	Error	Absolute % Error
120	170	-50	29.4
1000	1300	-300	23.1
550	750	-200	26.7
800	780	+20	2.6
2500	3000	-500	16.7
			98.5

98.5 = sum of Absolute % Errors

98.5 / 5 = 19.7 = MAPE

A lower MAPE for a given EAC technique, relative to other EAC techniques, was deemed more successful (accurate).

To determine the median absolute percentage error (MdAPE), the absolute percentage errors (APEs) were calculated the same way as in the example for the MAPE. The APEs were then rank ordered from low to high. The following equations were used to determine the MdAPE:

$$\text{MdAPE} = \text{Observation } \frac{n+1}{2} \text{ if } n \text{ is odd, or} \qquad (3.1a)$$

$$\text{Observation } \frac{n}{2} + 1 \text{ if } n \text{ is even,} \qquad (3.1b)$$

where, n = number of estimates generated.

As mentioned previously, the next statistic calculated to compare the success of the EAC techniques was the standard errors for the MAPE and MdAPE of each EAC technique. This calculation was used to incorporate a measure of variability into the evaluation of the EAC techniques' success. The need to assess variability was derived from this study's definition of EAC success, wherein, a smaller variation in the MAPE and MdAPE was deemed to be more successful (the precision element of success).

The computation of a standard error for each MAPE and MdAPE was accomplished with the following equation:

$$s = \sqrt{\frac{\sum_{i=1}^{n} (APE_i - M(Md)APE)^2}{n-1}} \qquad (3.2)$$

where: s = standard error
APE = Absolute Percentage Error
M(Md)APE = Mean (Median) Absolute Percentage Error
n = number of estimates generated

A lower standard error for a given EAC technique, relative to other EAC techniques, was deemed more successful (precise).

The bias of the EAC techniques was determined by calculating the MPE and MdPE. Calculations for these statistics were essentially the same as for the MAPE and MdAPE, except the absolute value was not taken before summing the APEs (see previous examples). A negative value for the MPE or MdPE indicated that the technique tended to estimate lower than the CAC, while a positive value would indicate estimates higher than the CAC. The computation of a standard error for each MPE and MdPE was accomplished with the following equation:

$$s = \sqrt{\frac{\sum_{i=1}^{n} (PE_i - M(Md)PE)^2}{n - 1}} \qquad (3.3)$$

where: s = standard error
PE = Percentage Error
M(Md)PE = Mean (Median) Percentage Error
n = number of estimates generated

In this case, a lower standard error indicated a stronger conclusion about the bias, meaning, the smaller the standard error, the closer the values are to the MPE and MdPE. Smaller errors indicate a stronger bias. For example, if the MPE or MdPE is a small negative number, but the standard error is large, then it indicates that the actual percentage errors range both positive and negative. Whereas, if the MPE or MdPE is a small negative number and the standard error is small, it is likely that the majority of the percentage errors are small negative values.

Data and Sample

The potential population for this study was all completed DoD contracts that met Cost Performance Report (CPR) reporting criteria as specified in DoDI 5000.2. The sample data for this study were obtained via the Defense Acquisition Executive Summary (DAES) database, as collected by the Office of the Under Secretary of Defense, Acquisition, OUSD(A). The data consisted of cost performance measurement information from 536 DoD contracts for the period June 1977 through June 1993.

Contract inclusion in this study was based on final reported percent complete (PC). This study included the 534 DoD contracts that were at least 80% complete. Percent complete was determined by dividing the final reported budgeted cost of work performed (BCWP) by the final budget at completion (FBAC) for the entire contract. This information was available in the DAES database. Note that FBAC and BAC were identical amounts for the last set of CPR data reported for a contract. The contracts in the database varied with respect to the final percent complete reported. Data for some contracts was not provided up to 100% completion point, while some contracts went beyond 100% complete. This was due to the fact that the final reported BCWP was greater than the final reported BAC. For purposes of this study, contracts with percent completes computed to be over 100%, as defined above, were assumed to be 100% complete and were included in this study.

The reason this study included the 534 DoD contracts that were at least 80% complete was because contract completion costs were needed to compare the success of the EAC techniques. In addition, final budgets at completion (FBAC) were needed to develop the BAC adjustment factors. The BAC and ACWP for contracts in the sample that were reported as over 80% but under 100% complete were extrapolated to the 100% completion point. Extrapolating contract completion costs for contracts below 80% complete would not contribute to the validity of this research, as the confidence in the extrapolated completion costs would be low. Extrapolating contract completion costs from CPR data that did not indicate a contract to be at least 80% complete would have added an extra level of uncertainty to the analysis.

For the BAC, this was accomplished by dividing the total allocated budget (TAB) by the respective reported percent complete (PC). Similarly, to extrapolate the ACWP, the actual cost of the work performed (ACWP) was divided by the respective percent complete. For contracts computed to be over 100% complete, the last government estimate at completion (EAC) was referenced as the cost at completion (CAC). Similarly, the TAB was used as the final budget at completion (FBAC) for contracts computed to be over 100% complete.

Contracts of all types, phases, and issuing service were included in the sample because this study attempted to develop BAC adjustment factors that could be applied to any DoD contract. Specifically, both fixed price and cost plus contracts were included in the sample, as well as contracts from all three services (Air Force, Navy, and Army). Fixed price contracts have fixed prices which the government agrees to pay the contractor, regardless of the actual cost of the contract. On the other hand, in a cost plus contract, the government agrees to reimburse the contractor for all allowable and reasonable costs. In addition, both research and development (R&D), as well as, production contracts were included. In a research and development contract, the government usually pays for concepts or paper designs. In other words, the contractor spends a majority, if not all, of the contract funds on designing and developing a weapon system. Whereas, in a production contract, the majority of the contractual effort is spent on manufacturing and assembling the weapon system. Furthermore, the data were broken into quartile percent completion points to compare the success of the different EAC techniques at different contract completion stages.

Data Limitations

The data used in this analysis were initially generated by Defense Department contractors. As such, data reliability and validity were dependent upon the DoD contractors' correct utilization of their Performance Measurement Systems (PMS). As discussed in Chapter Two, it was assumed that contractors' PMS systems were validated by an official government review team. Therefore, it was assumed that the data originally produced by the Defense contractors were reliable.

Background for the BAC Adjustment Factors

The development of the BAC adjustment factors stems from the basic method in which index-based EAC techniques estimate the final cost of contracts. The following is a somewhat generic formula which, in one form or another, most index-based EAC techniques follow:

$$EAC = ACWP + \frac{BAC - BCWP}{INDEX} \qquad (3.5)$$

The standard, or shared, variables among most index-based EAC methods in this formula are the ACWP and the BCWP. By definition, ACWP and BCWP are known dollar amounts since they describe the results of costs that have already been incurred or work that has already been performed. On the other extreme, it is the Index in the generic formula (3.5) that differentiates one index-based method from another.

Some of the various Indexes incorporate past cost performance, past schedule performance, or combinations of both, in an attempt to predict the final cost at completion of a contract. The development of an Index can be simple or extremely complicated, such as in the NAVSEA 90's Formula (2.6). The EAC comparative studies examined in this study's literature review attempted to discover which indexes were reported to most successfully estimate final contract completion costs. Unfortunately, the Index is not the only variable in the generic index-based EAC formula (3.5) that is not fixed, or known with certainty.

At the time an estimate is made, a contract's final BAC is almost never known. Historically, BAC grows through the life of a contract due to added scope from changing requirements. This fact makes the use of BAC in the generic formula (3.5) disputable. "Rebaselining a contract may be necessary for cost control when budgets become unrealistic at the work package level, but it causes problems when using C/SCSC reports to measure and predict performance" (Bright and Howard, 1981:10). Therefore, the use of BAC, as it is known at the time of an estimate at completion is made, will almost undoubtedly result in an unrealistically low estimate of the final contract completion cost. This is due to the fact that the amount of work remaining, the budgeted cost of work remaining, or BCWR (BAC - BCWP), will be understated if the BAC is understated.

In order to account for not knowing what the final BAC will be, a certain number of replacements for BAC in the generic formula (3.5) have been recommended. One replacement for BAC is the Latest Revised Estimate (LRE). This approach can account for future budget which may be approved on the contract, but which has not been incorporated into the contractor's performance measurement system. In addition, using the LRE can account for past cost overruns as well as future cost overruns (future cost overruns only to the extent a contractor is willing to report them in his LRE). Other EAC techniques, like the NAVSEA 90's formula (2.6), attempt to account for the use of Management Reserve (MR) and Over Target Baselines (OTB). However, these replacements for BAC still fail to account for unknown budget which could be added to the contract in the future. For this reason, the BAC adjustment factors developed as part of this research, attempt to account for these unknown budget additions, based on historical data.

If the BAC adjustment factors improve the success of EAC forecasting techniques, then their benefits will be two-fold. First, it provides the program manager, as well as higher level management, a potentially more accurate projection of the budget or scope that might be added to the contract before completion. Second, they can help provide the program manager, and higher level management, a potentially accurate forecast of the cost at completion for the contract.

Analysis Method

The exact methodology used in this study is presented in a step by step fashion to facilitate its understanding.

1. The DAES database was obtained from OUSD(A), and was generally reviewed for content and suitability. This included reviewing data for completeness, especially the parameters necessary to utilize the various techniques.

2. Data were sampled based on the criteria outlined in the Data and Sample section of this chapter. This lead to the exclusion of two contracts that were not reported as at least 80% complete.

3. The BACs and ACWPs for the contracts that were reported over 80% complete, but less than 100% complete, were extrapolated to the 100% completion point.

4. The C/SCSC contract data were separated into quartiles. They were further separated by contract type, meaning fixed price or cost plus. This categorization was selected because the situation surrounding the two types of contracts allow or restrict costs in different ways. For instance, a fixed price contract tends to restrict costs to an initially agreed upon amount, while cost plus contracts reimburse the contractor for all allowable costs incurred. The two contract philosophies seem quite different, therefore the respective adjustment factors may be different as well. The analysis was accomplished by quartile for the entire sample, as well as for fixed price and cost plus type contracts independently. Each of the following outlined procedures was accomplished for each quartile for the entire sample, as well as each category.

5. The factors to account for additional budget being added to a contract (which are used in conjunction with different index-based EAC techniques to estimate contract completion costs) were developed.

a. A ratio of the difference (Difference Ratios) between the final budget at completion and the BAC at the time the C/SCSC data were reported was computed: (FBAC - BAC)/BAC.

b. The Difference Ratios computed in part 5a were summed.

c. The mean of the Difference Ratios was calculated.

d. The Mean Difference Ratios calculated in part 5c were changed into factors by adding one to them. The BAC of a contract can be multiplied by these factors (the BAC adjustment factors), thereby producing an estimate of what the final BAC is going to be (EFBAC).

The following is an example of how these factors were computed. Difference Ratio is defined as (FBAC - BAC)/BAC.

BAC(0-25% Quartile)	FBAC	Difference Ratio
50	100	1.000
500	800	0.600
350	450	0.286
125	120	-0.040
250	600	1.400
		3.246

3.246 = sum of Difference Ratios

3.246 / 5 = 0.649 = Mean Difference Ratio

1.0 + 0.649 = 1.649 = BAC Adjustment Factor

In this example, the mean difference ratio shows that the average BAC is nearly 65% lower than the FBAC. Therefore, the BAC should be increased by a factor of 1.649.

6. The selected EAC techniques: cumulative CPI, weighted cost and schedule, NAVSEA 90, and the schedule cost index (SCI), were utilized with the data set to project estimates at complete (EACs). The formulas, numbered 2.4, 2.5, 2.6, and 2.7, respectively, are listed in chapter two of this study.

7. The selected EAC techniques were used in conjunction with the BAC adjustment factors created in step 5 above to project EACs.

8. A comparative analysis was accomplished. The Mean Absolute Percentage Error (MAPE) and Median Absolute Percentage Error (MdAPE), as well as their standard errors, were calculated for: 1) the EAC methods recommended through review of applicable literature, and 2) the same EAC techniques adjusted using the factors developed in step 5. The methods were compared to determine which method was more successful (i.e. lowest MAPE, lowest MdAPE and lowest standard error).

9. The number of times an EAC was within 10% of the CAC was tabulated. Conclusions were drawn as to which techniques were more consistently within this range.

10. A comparative analysis was accomplished. The Mean Percentage Error (MPE) and Median Percentage Error (MdPE),

as well as their standard errors, were calculated for: 1) the EAC methods recommended through review of applicable literature, and 2) the same EAC techniques adjusted using the factors developed in step 5. The methods were compared to determine which methods were biased (i.e. higher MPE and higher MdPE). The lower the standard error, the stronger the bias conclusion. Conclusions were drawn about which methods were more biased. For example, if MPE or MdPE was -5.5 and had a standard error of 3.0, the technique would be deemed bias in the negative direction. However, if the standard error was 45, then it would indicate that the percentage errors were both positive and negative, decreasing the certainty of the bias conclusion.

11. Recommended EAC methods that proved to be successful as defined in this study (i.e. more accurate and less unfavorably biased) for the various quartiles, for the entire contract life, and for the various contract categories.

IV. Results and Discussion

Chapter Overview

Chapter III outlined the methodology followed in testing the success of the EAC techniques. This chapter is a presentation and discussion of the results from accomplishing the prescribed methodology. This chapter is sectioned by categories of contracts evaluated: non-categorized, cost-type contracts, and fixed price contracts. They are further categorized by completion stage quartile. The results for each of the categorizations are reported in a similar manner. For each categorization, a table is provided with the specific numerical results of the evaluation. Accompanying each table are graphs depicting the relationship of the descriptive statistics (MAPE, MdAPE, etc.) for each of the EAC techniques. Preceding all of the tables and graphs is a brief discussion of the results of this analysis.

The first of the three graphs accompanying each table includes the measures of accuracy and precision: Mean Absolute Percent Error (MAPE), Median Absolute Percent Error (MdAPE), and their respective standard errors (SE). The second graph for each category includes the bias measures: Mean Percent Error (MPE), Median Percent Error (MdPE), and their respective standard errors (SE). The final graph shows the results of counting how many times an EAC technique predicted a cost that was within 10% of the actual final contract completion cost.

BAC Adjustment Factor (BAF) Development

Before discussing the results of the EAC comparison, the development of the BAC adjustment factors (BAFs) is presented. Table 4-1 shows the information that was generated to calculate the BAC adjustment factors for each quartile: the sum of the errors (between the EAC and the CAC) and the number of CPR line items in the database for which an EAC was computed. Please refer to step 5 of the Analysis Method Section of Chapter 3 for a more detailed discussion of how these factors were developed.

As indicated in Table 4-1, separate BAC adjustment factors were developed for each quartile of the non-categorized, cost-type, and fixed price contracts. As expected, the BAC adjustment factors decreased going from the first quartile to the last quartile. This was expected because contracts that are still early in their life-cycle are more likely to experience budget additions or cost overruns before their completion, than are contracts late in their life-cycle. Intuitively, a contract that is only 10% complete will experience more contractual and technical requirements changes before its completion, than a contract that is already 90% complete. Noteworthy also, the BAFs are somewhat higher for the cost-type contracts than they are for the fixed price contracts.

Table 4-1
BAC ADJUSTMENT FACTORS

All Contracts (Non-categorized)

% Complete	0-25%	26-50%	51-75%	76-100%
Sum Errors	537.9828	500.4079	544.2819	837.5972
Line Items	1001	1197	1739	3234
Factor	1.5374	1.4181	1.3130	1.2590

Cost-Type Contracts

% Complete	0-25%	26-50%	51-75%	76-100%
Sum Errors	202.3507	226.2420	231.7277	362.0979
Line Items	278	382	633	1312
Factor	1.7279	1.5923	1.3661	1.2760

Fixed Price-Type Contracts

% Complete	0-25%	26-50%	51-75%	76-100%
Sum Errors	335.6321	274.0152	311.7049	474.4430
Line Items	723	814	1101	1915
Factor	1.4642	1.3366	1.2831	1.2478

Notes:

Sum Errors = the sum of the difference between the FBAC and BAC at the time the data was reported for all line items.

Line Items = total number of data points (CPRs reported) for that quartile.

Factor = (Sum Errors / Line Items) + 1

The next section of this chapter presents the results of the EAC comparative analysis. As previously mentioned, the tables and graphs are sectioned by category of contract evaluated: non-categorized, cost-type contracts, and fixed price contracts. The sections are further categorized by completion stage quartile.

Results and Discussion

As the accuracy/precision figures depict, the techniques without the BAFs were more accurate and precise. These figures also reveal that the NAVSEA 90 formula had a slightly lower MAPE and MdAPE, and was, therefore, slightly more accurate and precise than the other methods for each contract category and quartile. The SCI formula was typically the second most successful in terms of accuracy and precision.

The bias figures represent the relative bias of the different EAC techniques. These are the second figures associated with each table. The four techniques without the BAFs were always negatively biased, while the addition of the BAFs always caused a positive bias. Furthermore, while at the aggregate level, the addition of the BAFs caused a positive bias (positive MPE and MdPE), the large SEs indicated that the actual range most likely included both negative and positive errors. Similarly, the EAC techniques without the BAFs also had large SEs relative to their MPEs and MdPEs indicating that the range of errors was both positive and negative.

An additional measure of accuracy and precision was the number of times, converted to a percent, the Absolute Percent Error (APE) between the EAC and CAC was less than or equal to 10%. This measure is depicted in the figures entitled, APE < 10%. These are the third figures associated with each table. Using this measure, the NAVSEA 90 formula EACs fell within 10% of the CACs more often than the other techniques. The SCI technique was again, most often, a close second. Additionally, inclusion of the BAFs, decreased the accuracy of the EAC techniques.

In general, the results of this study indicate that the NAVSEA 90 technique was the most successful. The results were unaffected by contract category: noncategorized, cost-type, and fixed price. In addition, the results were the same, regardless of the contract quartile examined.

Table 4-2
First Quartile - Noncategorized (1001 Line Items)
BAC Adjustment Factor (BAF) = 1.5374

	ACCURACY / PRECISION				BIAS				
EAC	MAPE	SE	MdAPE	SE	MPE	SE	MdPE	SE	APE < 10%
CPI	29.4	25.4	25.2	25.7	-21.9	32.1	-21.9	32.1	25.9%
WC/S	28.1	23.3	22.9	23.9	-21.7	29.4	-20.4	29.4	26.0%
N90	24.4	22.3	18.3	23.1	-18.3	27.5	-13.9	27.8	37.4%
SCI	33.8	54.9	24.0	55.8	-10.0	63.7	-15.3	63.9	24.9%
CPI+BAF	37.4	37.9	31.5	38.3	11.9	50.0	20.0	49.3	17.5%
WC/S+BAF	37.2	32.6	32.2	33.0	20.5	45.1	22.6	45.1	16.8%
N90+BAF	39.7	28.5	39.0	28.5	25.3	41.8	32.4	42.4	14.6%
SCI+BAF	54.4	91.9	38.0	93.3	39.3	99.3	30.0	99.5	12.1%

CPI - Cumulative CPI
WC/S - Weighted Cost & Schedule
N90 - NAVSEA 90
SCI - Schedule Cost Index (SCI)

CPI+BAF - Cumulative CPI + (BAF)
WC/S+BAF- Weighted Cost & Schedule + (BAF)
N90+BAF - NAVSEA 90 + (BAF)
SCI+BAF - Schedule Cost Index (SCI) + (BAF)

MAPE - Mean Absolute Percent Error
MdAPE - Median Absolute Percent Error
MPE - Mean Percent Error
MdPE - Median Percent Error
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APE - Average Percent Error

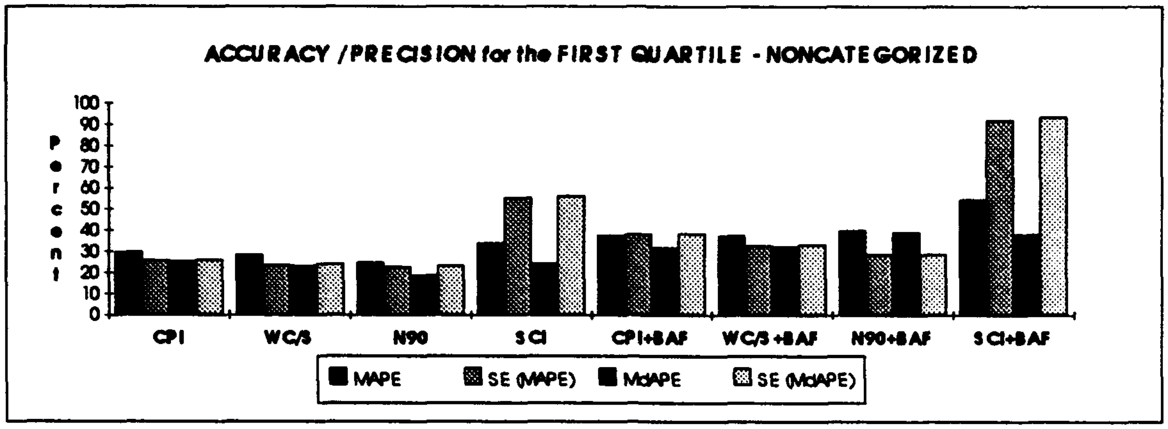

Figure 4 - 1

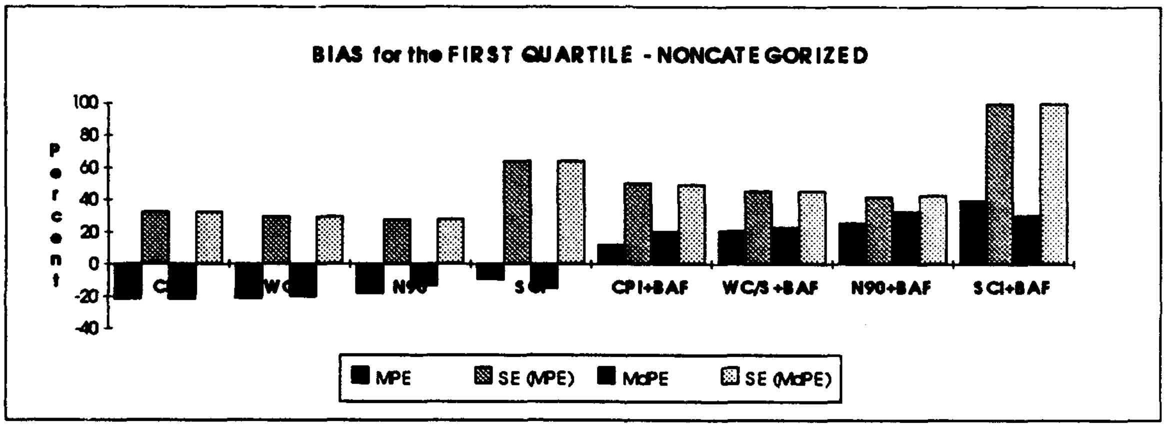

Figure 4 - 2

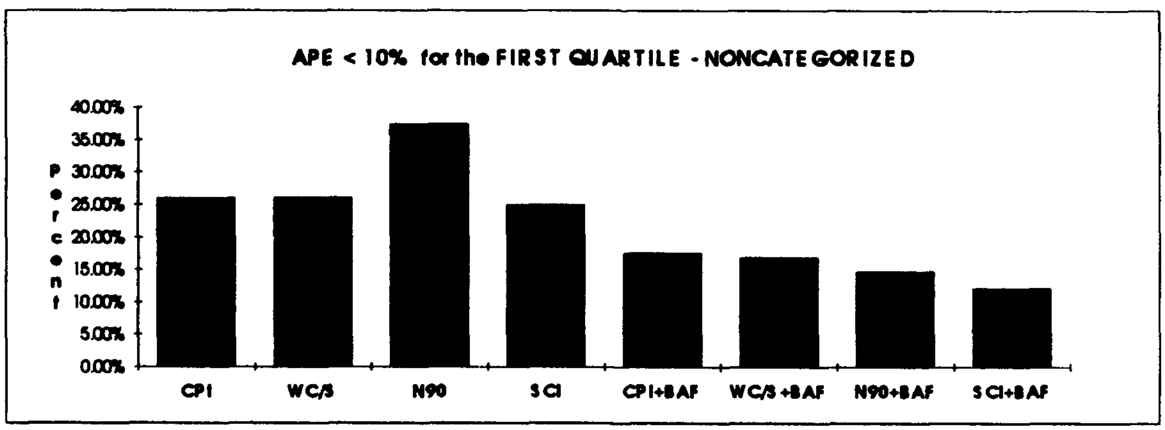

Figure 4 - 3

Table 4-3
Second Quartile - Noncategorized (1197 Line Items)
BAC Adjustment Factor (BAF) = 1.4181

	ACCURACY / PRECISION				BIAS				
EAC	MAPE	SE	MdAPE	SE	MPE	SE	MdPE	SE	APE < 10%
CPI	24.9	19.4	15.9	22.1	-21.2	22.3	-14.8	22.1	36.4%
WC/S	24.5	19.2	15.4	19.4	-20.7	33.9	-14.3	21.9	37.5%
N90	22.8	18.9	12.2	19.8	-16.4	31.2	-10.3	23.0	43.2%
SCI	23.4	19.7	13.6	20.3	-15.2	24.6	-9.6	24.6	41.1%
CPI+BAF	33.8	21.8	27.0	21.1	20.0	31.2	20.8	31.3	19.1%
WC/S+BAF	34.4	21.3	27.6	20.6	20.8	31.0	21.6	31.1	18.3%
N90+BAF	35.2	22.7	27.0	22.1	16.2	34.2	19.4	34.6	17.1%
SCI+BAF	41.4	27.6	32.1	26.9	30.1	36.1	28.9	36.0	15.3%

CPI - Cumulative CPI
WC/S - Weighted Cost & Schedule
N90 - NAVSEA 90
SCI - Schedule Cost Index (SCI)

CPI+BAF - Cumulative CPI + (BAF)
WC/S+BAF- Weighted Cost & Schedule + (BAF)
N90+BAF - NAVSEA 90 + (BAF)
SCI+BAF - Schedule Cost Index (SCI) + (BAF)

MAPE - Mean Absolute Percent Error
MdAPE - Median Absolute Percent Error
MPE - Mean Percent Error
MdPE - Median Percent Error
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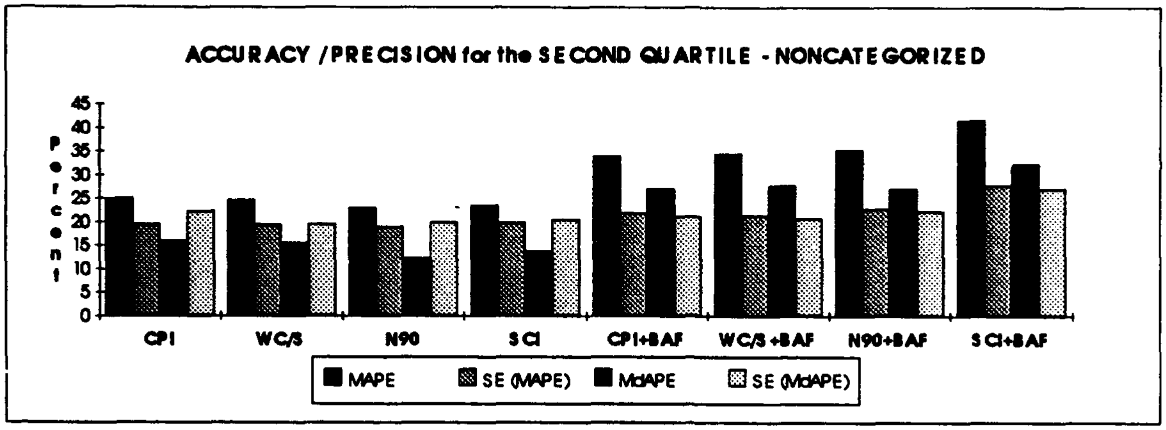

Figure 4 - 4

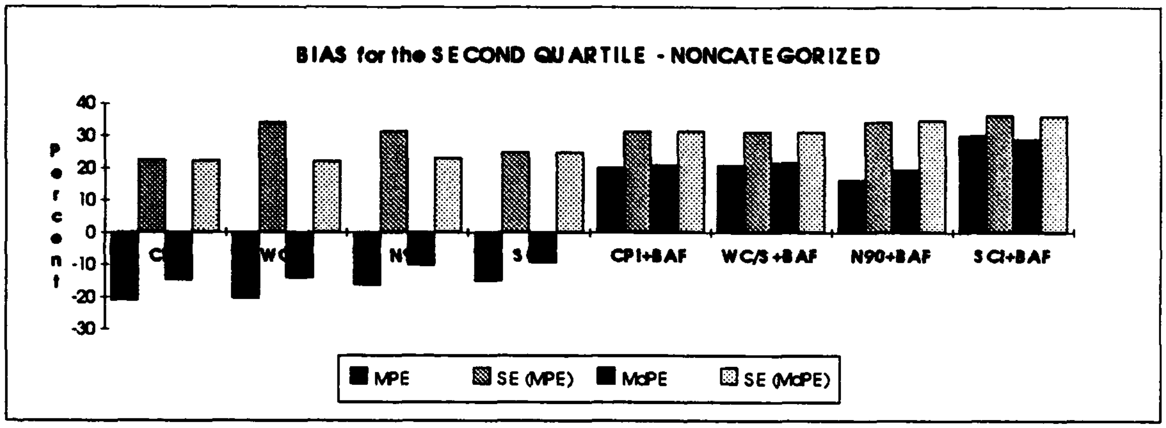

Figure 4 - 5

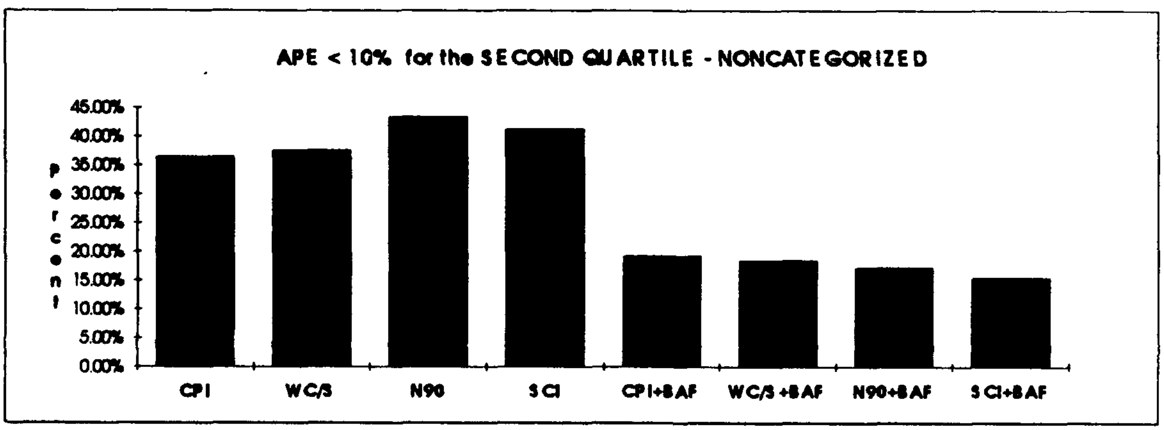

Figure 4 - 6

Table 4-4
Third Quartile - Noncategorized (1739 Line Items)
BAC Adjustment Factor (BAF) = 1.3130

	ACCURACY / PRECISION				BIAS				
EAC	MAPE	SE	MdAPE	SE	MPE	SE	MdPE	SE	APE < 10%
CPI	26.3	21.6	8.5	19.7	-20.8	22.9	-7.4	21.2	54.6%
WC/S	26.5	21.6	8.6	19.6	-20.9	32.1	-7.4	25.2	54.6%
N90	24.7	21.2	7.4	19.6	-13.8	27.6	-4.1	23.8	58.0%
SCI	25.2	21.8	13.5	19.0	-17.5	22.7	-4.7	22.3	58.3%
CPI+BAF	42.6	26.6	24.0	19.5	27.0	29.5	21.6	27.8	16.6%
WC/S+BAF	42.8	26.6	24.0	19.4	27.0	30.0	21.6	27.9	16.6%
N90+BAF	44.5	30.5	21.8	24.2	19.8	34.2	16.1	33.4	19.8%
SCI+BAF	47.7	29.5	26.6	21.5	33.3	32.4	24.7	29.6	13.5%

CPI - Cumulative CPI
WC/S - Weighted Cost & Schedule
N90 - NAVSEA 90
SCI - Schedule Cost Index (SCI)

CPI+BAF - Cumulative CPI + (BAF)
WC/S+BAF- Weighted Cost & Schedule + (BAF)
N90+BAF - NAVSEA 90 + (BAF)
SCI+BAF - Schedule Cost Index (SCI) + (BAF)

MAPE - Mean Absolute Percent Error
MdAPE - Median Absolute Percent Error
MPE - Mean Percent Error
MdPE - Median Percent Error
SE - Standard Error
APE - Average Percent Error

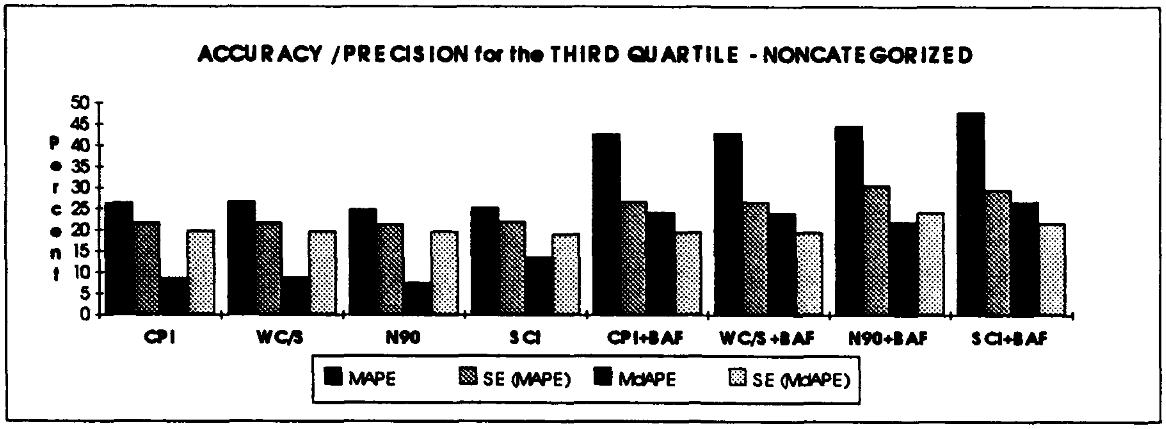

Figure 4 - 7

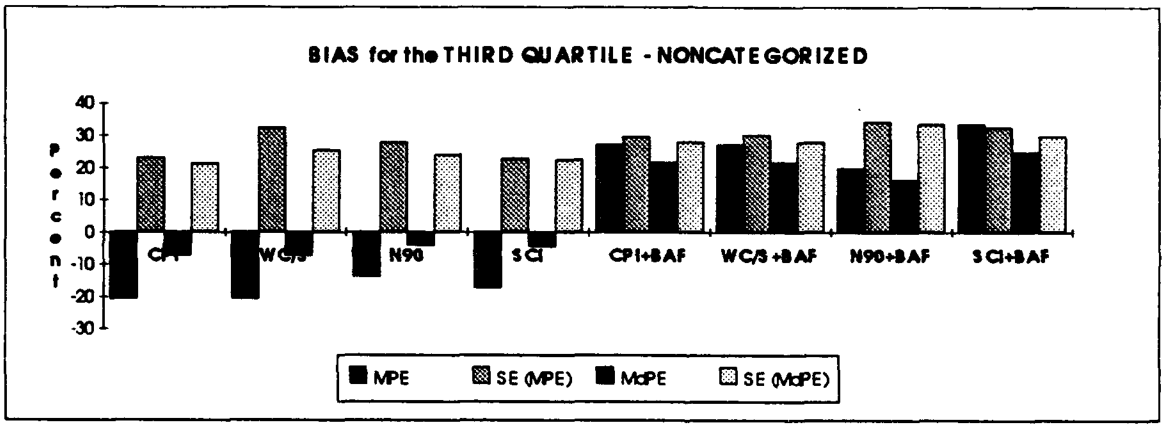

Figure 4 - 8

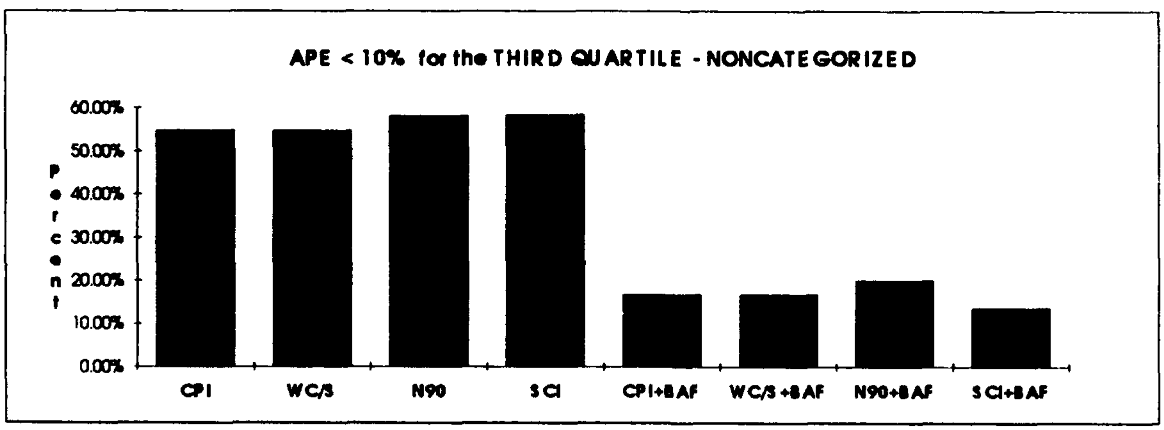

Figure 4 - 9

Table 4-5
Fourth Quartile - Noncategorized (3234 Line Items)
BAC Adjustment Factor (BAF) = 1.2590

	ACCURACY / PRECISION				BIAS				
EAC	MAPE	SE	MdAPE	SE	MPE	SE	MdPE	SE	APE < 10%
CPI	35.3	32.2	2.6	22.7	-25.0	26.6	-1.6	22.8	73.3%
WC/S	35.4	21.4	2.7	22.6	-25.2	34.0	-1.8	23.7	73.3%
N90	28.1	27.3	3.7	19.8	-5.1	21.5	0.2	21.0	79.8%
SCI	35.2	30.3	2.6	22.5	-24.1	25.9	-1.2	26.5	74.0%
CPI+BAF	79.8	59.1	25.2	21.2	52.2	45.8	23.9	29.3	10.3%
WC/S+BAF	79.1	58.5	24.7	21.1	51.4	45.3	23.3	29.1	10.7%
N90+BAF	89.1	69.6	24.9	32.5	64.9	58.5	23.6	37.7	10.2%
SCI+BAF	82.7	61.0	25.8	21.5	55.4	47.8	24.9	29.7	9.4%

CPI - Cumulative CPI
WC/S - Weighted Cost & Schedule
N90 - NAVSEA 90
SCI - Schedule Cost Index (SCI)

CPI+BAF - Cumulative CPI + (BAF)
WC/S+BAF- Weighted Cost & Schedule + (BAF)
N90+BAF - NAVSEA 90 + (BAF)
SCI+BAF - Schedule Cost Index (SCI) + (BAF)

MAPE - Mean Absolute Percent Error
MdAPE - Median Absolute Percent Error
MPE - Mean Percent Error
MdPE - Median Percent Error
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APE - Average Percent Error

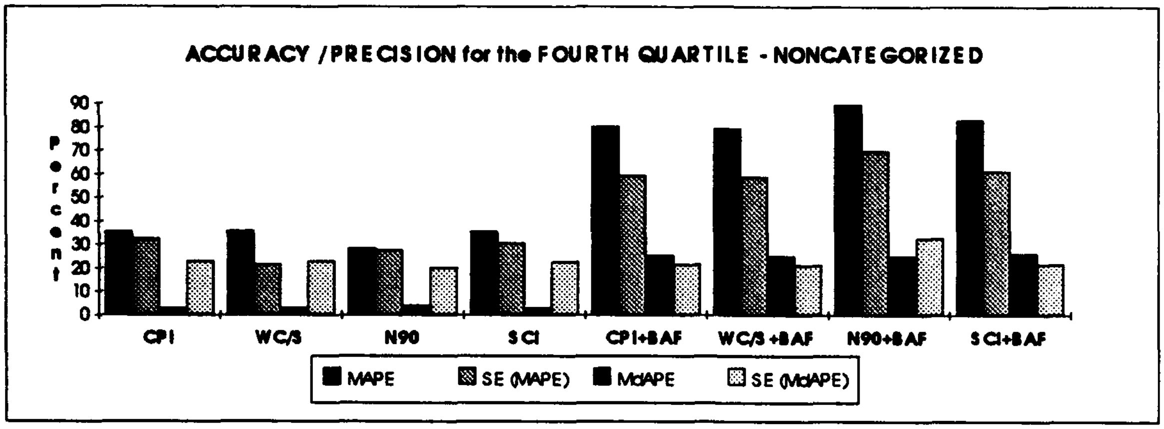

Figure 4 - 10

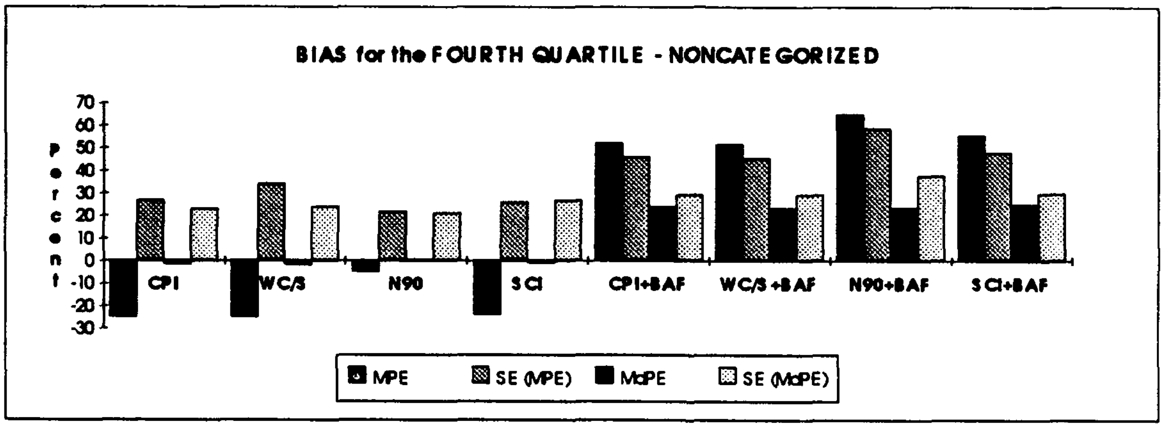

Figure 4 - 11

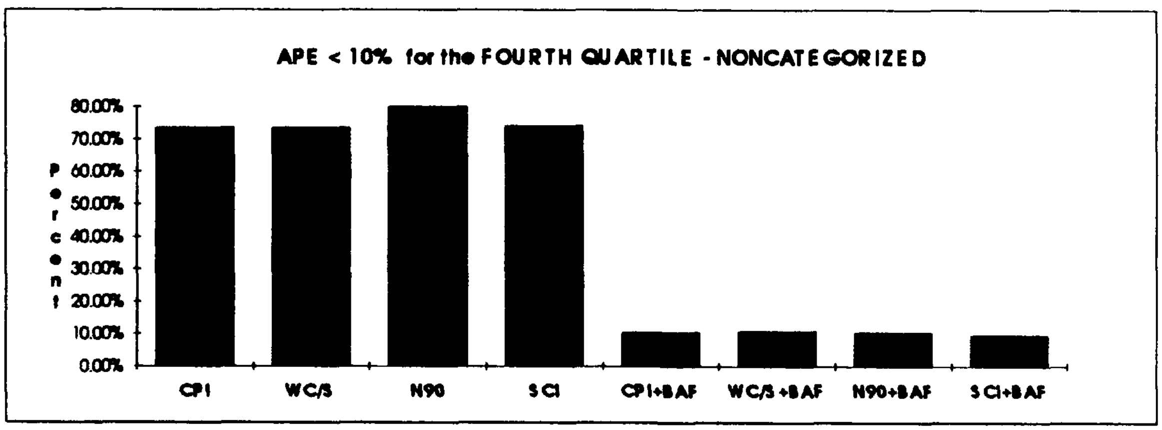

Figure 4 - 12

Table 4-6
First Quartile - Cost Contracts (278 Line Items)
BAC Adjustment Factor (BAF) = 1.7279

	ACCURACY / PRECISION				BIAS				
EAC	MAPE	SE	MdAPE	SE	MPE	SE	MdPE	SE	APE < 10%
CPI	33.8	31.2	29.8	31.4	-22.8	39.9	-25.9	40.1	25.9%
WC/S	31.6	25.4	29.1	25.5	-23.6	33.0	-24.8	33.0	25.5%
N90	27.7	23.4	24.1	23.6	-22.9	28.1	-21.5	28.1	32.0%
SCI	32.6	33.1	27.0	33.6	-16.6	43.4	-20.7	43.6	24.5%
CPI+BAF	50.0	58.0	38.7	59.1	33.3	69.0	28.1	69.2	14.4%
WC/S+BAF	47.8	43.8	39.4	44.6	32.0	56.5	29.9	56.5	14.4%
N90+BAF	47.7	31.6	47.6	31.6	32.3	47.2	35.0	47.3	11.9%
SCI+BAF	58.0	65.8	44.8	67.1	44.9	75.4	39.7	75.6	12.2%

CPI - Cumulative CPI
WC/S - Weighted Cost & Schedule
N90 - NAVSEA 90
SCI - Schedule Cost Index (SCI)

CPI+BAF - Cumulative CPI + (BAF)
WC/S+BAF- Weighted Cost & Schedule + (BAF)
N90+BAF - NAVSEA 90 + (BAF)
SCI+BAF - Schedule Cost Index (SCI) + (BAF)

MAPE - Mean Absolute Percent Error
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MPE - Mean Percent Error
MdPE - Median Percent Error
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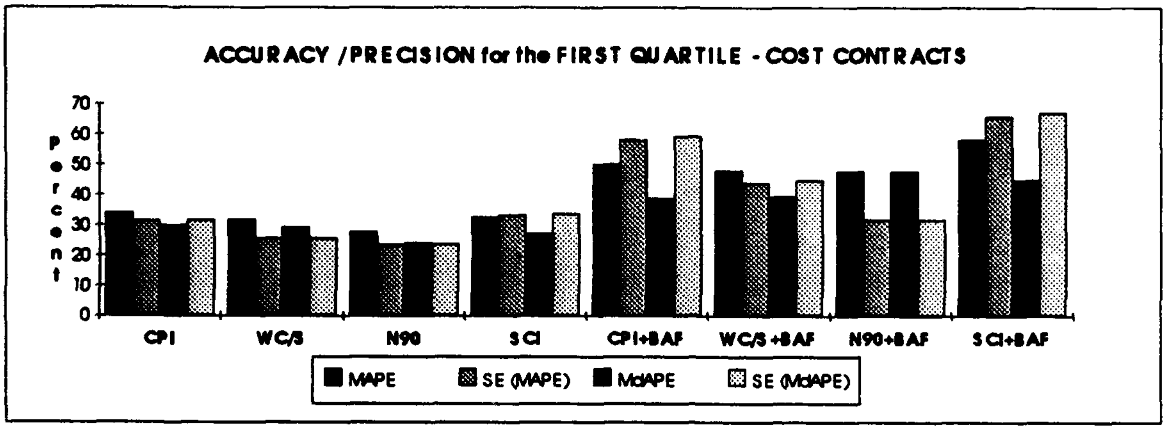

Figure 4 - 13

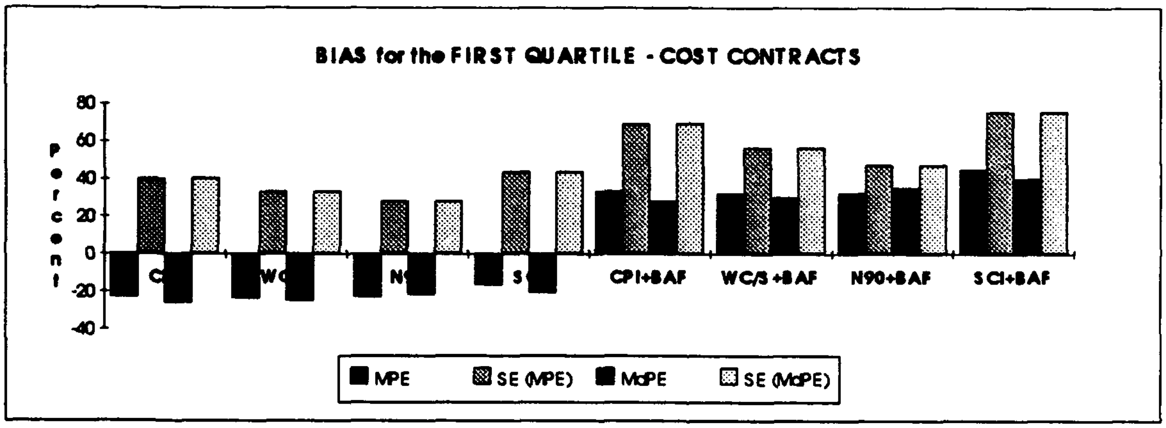

Figure 4 - 14

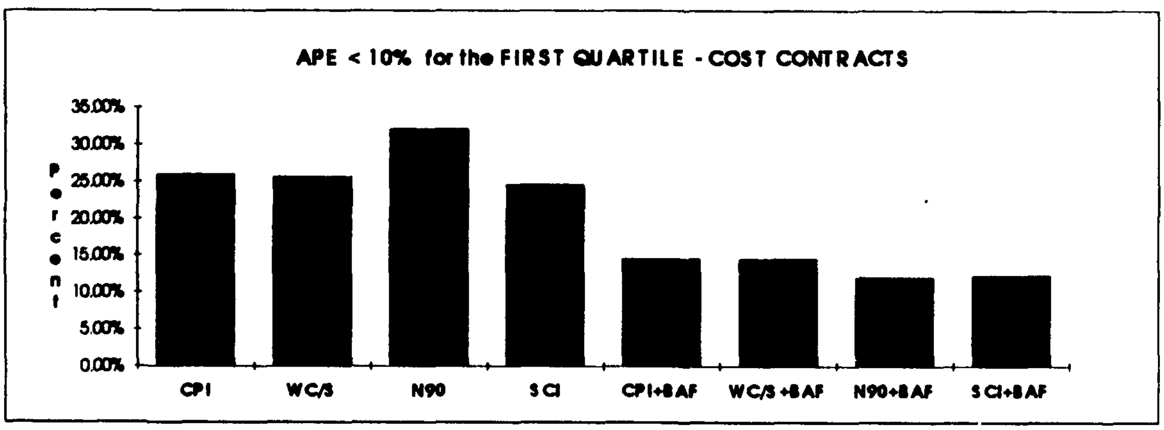

Figure 4 - 15

Table 4-7
Second Quartile - Cost Contracts (382 Line Items)
BAC Adjustment Factor (BAF) = 1.5923

	ACCURACY / PRECISION				BIAS				
EAC	MAPE	SE	MdAPE	SE	MPE	SE	MdPE	SE	APE < 10%
CPI	24.5	20.6	18.5	21.4	-22.3	2.9	-17.4	23.5	30.6%
WC/S	24.3	20.7	17.8	21.7	-22.2	23.5	-17.2	23.4	31.9%
N90	23.0	20.1	16.2	21.3	-20.1	23.1	-17.6	23.2	37.4%
SCI	22.8	20.2	16.4	21.2	-18.9	23.8	-14.8	24.2	35.6%
CPI+BAF	36.89	23.1	37.1	23.1	23.7	36.5	31.5	37.3	13.1%
WC/S+BAF	37.2	22.8	38.2	22.8	23.9	36.5	32.0	37.4	13.1%
N90+BAF	38.2	23.8	40.6	23.9	26.2	36.7	33.4	37.4	14.4%
SCI+BAF	41.8	25.8	41.7	25.8	30.5	38.5	36.6	39.0	12.3%

CPI - Cumulative CPI
WC/S - Weighted Cost & Schedule
N90 - NAVSEA 90
SCI - Schedule Cost Index (SCI)

CPI+BAF - Cumulative CPI + (BAF)
WC/S+BAF- Weighted Cost & Schedule + (BAF)
N90+BAF - NAVSEA 90 + (BAF)
SCI+BAF - Schedule Cost Index (SCI) + (BAF)

MAPE - Mean Absolute Percent Error
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MPE - Mean Percent Error
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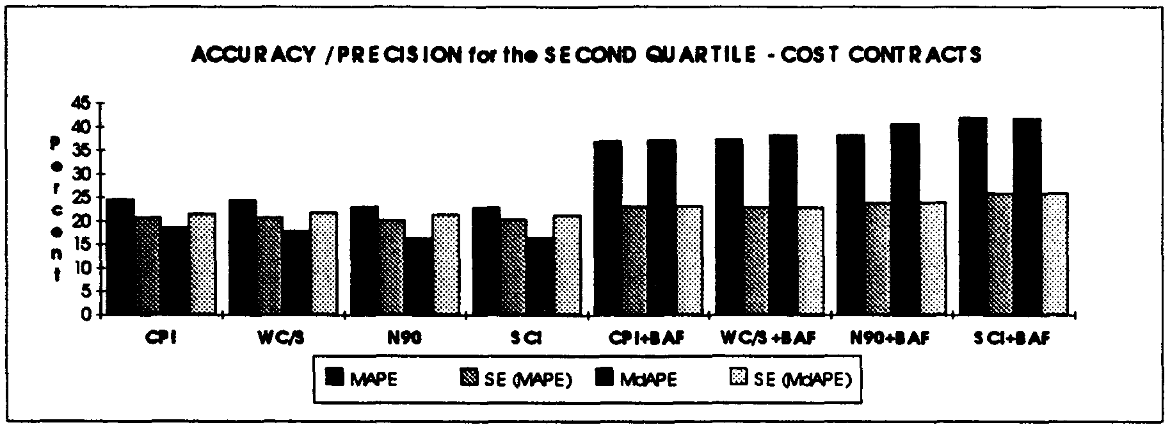

Figure 4 - 16

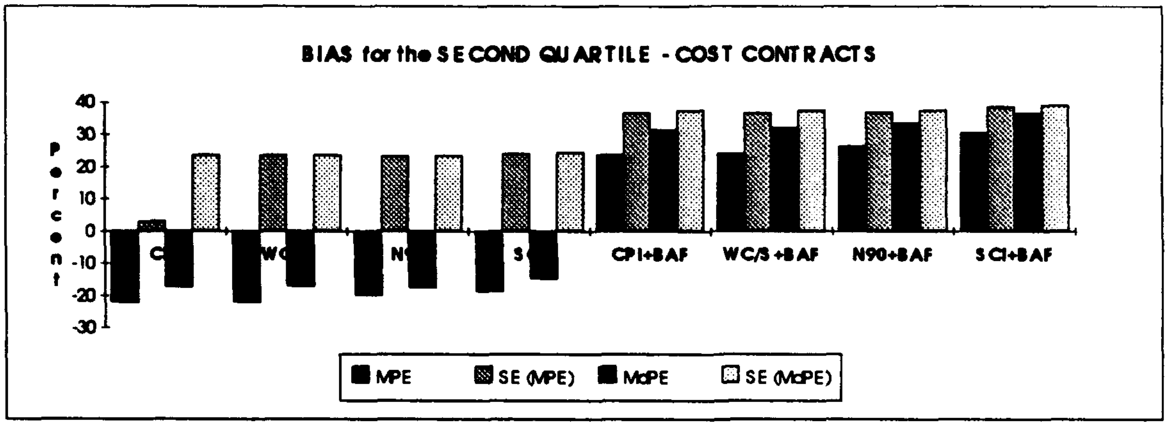

Figure 4 - 17

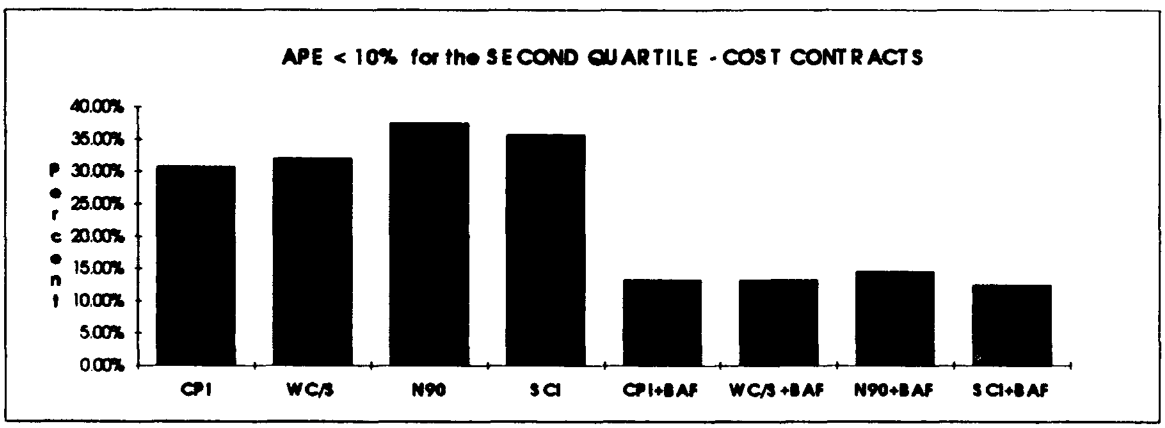

Figure 4 - 18

Table 4-8
Third Quartile - Cost Contracts (633 Line Items)
BAC Adjustment Factor (BAF) = 1.3661

	ACCURACY / PRECISION				BIAS				
EAC	MAPE	SE	MdAPE	SE	MPE	SE	MdPE	SE	APE < 10%
CPI	17.9	19.6	10.7	20.9	-14.5	22.2	-9.2	22.9	47.6%
WC/S	17.9	19.7	10.6	21.0	-14.5	22.3	-9.3	22.9	47.9%
N90	17.2	19.3	9.7	20.8	-11.5	23.2	-6.4	23.8	50.4%
SCI	17.1	19.6	9.4	21.0	-13.1	22.4	-7.9	23.0	51.8%
CPI+BAF	28.3	20.2	28.3	20.2	16.8	30.4	24.0	31.3	14.8%
WC/S+BAF	28.3	20.2	28.1	20.2	16.7	30.5	23.9	31.4	14.5%
N90+BAF	30.9	21.5	30.3	21.5	20.2	31.8	26.9	32.5	13.4%
SCI+BAF	30.2	20.8	30.2	20.8	19.7	31.0	26.6	31.7	12.8%

CPI - Cumulative CPI
WC/S - Weighted Cost & Schedule
N90 - NAVSEA 90
SCI - Schedule Cost Index (SCI)

CPI+BAF - Cumulative CPI + (BAF)
WC/S+BAF- Weighted Cost & Schedule + (BAF)
N90+BAF - NAVSEA 90 + (BAF)
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MAPE - Mean Absolute Percent Error
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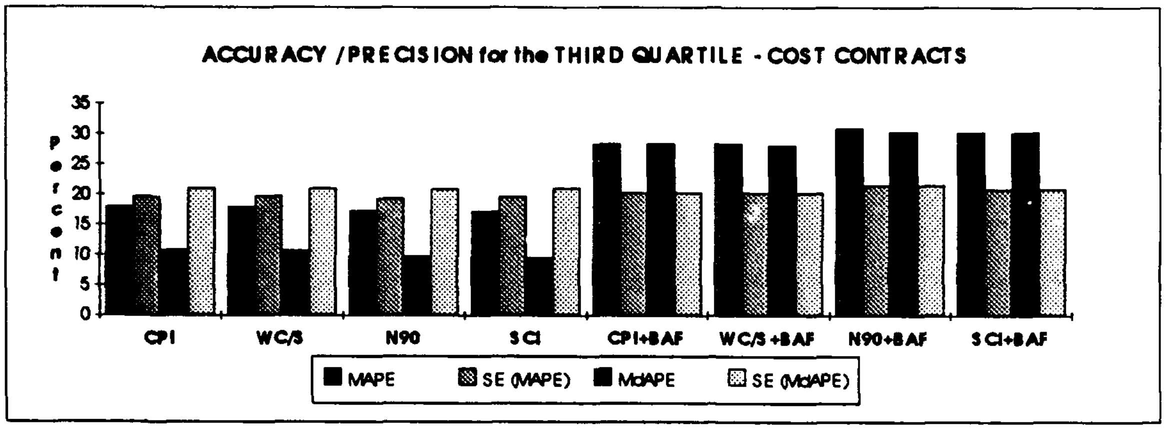


Figure 4- 19

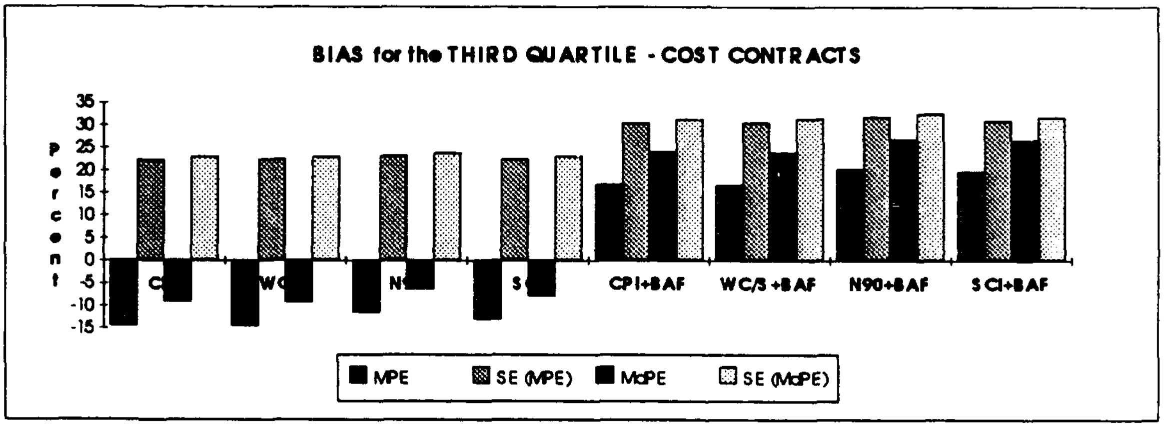
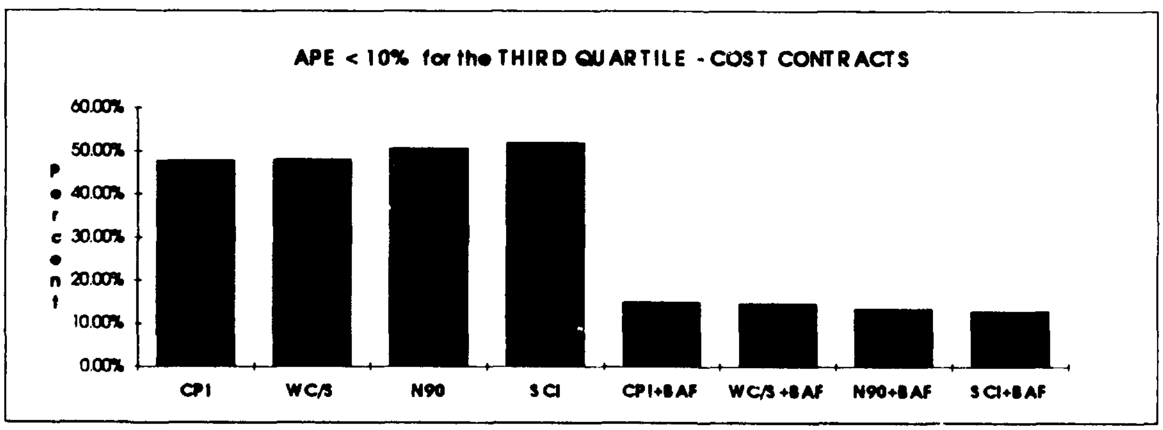


Figure 4 - 20



Figi re 4 - 21

Table 4-9
Fourth Quartile - Cost Contracts (1312 Line Items)
BAC Adjustment Factor (BAF) = 1.2760

	ACCURACY / PRECISION				BIAS				
EAC	MAPE	SE	MdAPE	SE	MPE	SE	MdPE	SE	APE < 10%
CPI	14.5	26.2	3.8	28.3	-9.2	28.5	-2.9	29.2	67.8%
WC/S	14.5	26.2	3.8	28.3	-9.2	28.5	-3.0	29.2	67.8%
N90	11.2	24.5	3.8	25.6	-2.9	26.8	-0.2	27.0	74.8%
SCI	14.5	26.3	3.7	28.4	-9.0	28.7	-2.8	29.3	68.4%
CPI+BAF	27.4	28.7	26.2	28.7	15.9	36.4	23.8	37.2	9.8%
WC/S+BAF	27.2	28.5	28.9	28.6	15.6	36.2	26.2	37.7	9.9%
N90+BAF	29.3	29.1	27.5	29.2	23.5	34.0	26.9	34.2	7.5%
SCI+BAF	34.6	31.4	35.2	31.4	25.0	39.4	33.3	40.3	8.8%

CPI - Cumulative CPI
WC/S - Weighted Cost & Schedule
N90 - NAVSEA 90
SCI - Schedule Cost Index (SCI)

CPI+BAF - Cumulative CPI + (BAF)
WC/S+BAF- Weighted Cost & Schedule + (BAF)
N90+BAF - NAVSEA 90 + (BAF)
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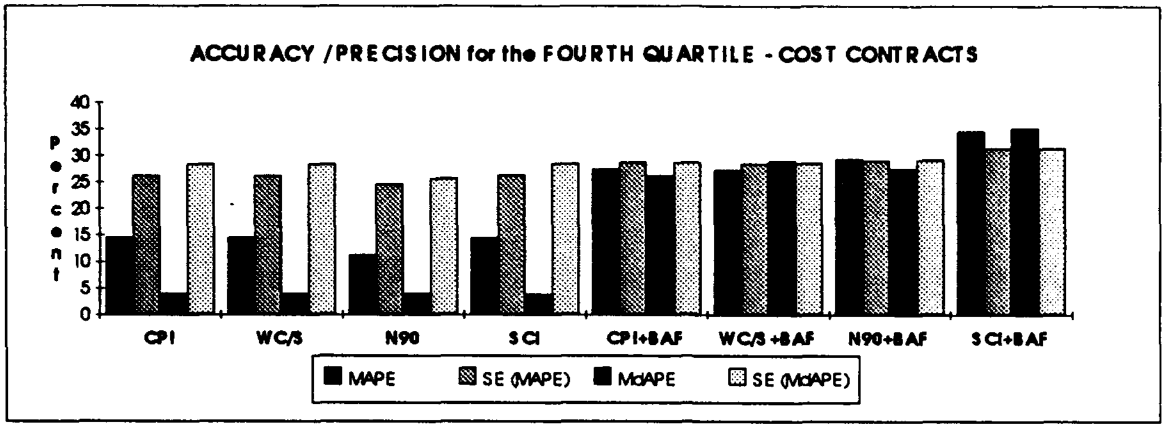

Figure 4 - 22

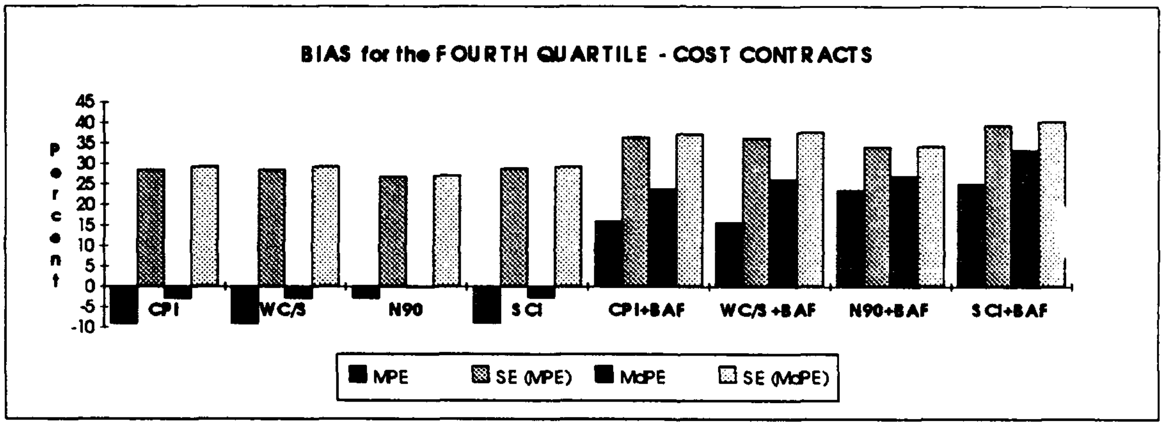

Figure 4 - 23

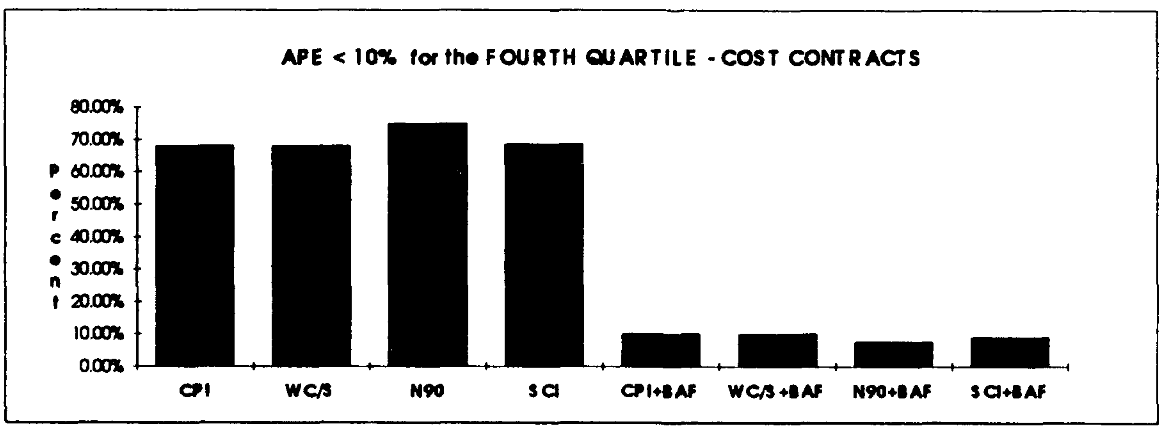

Figure 4 - 24

Table 4-10
First Quartile - Fixed Price Contracts (723 Line Items)
BAC Adjustment Factor (BAF) = 1.4642

	ACCURACY / PRECISION				BIAS				
EAC	MAPE	SE	MdAPE	SE	MPE	SE	MdPE	SE	APE < 10%
CPI	27.8	2.7	23.6	2.8	-21.6	4.5	-19.9	4.4	25.9%
WC/S	26.8	22.3	21.2	23.0	-20.9	27.9	-18.3	50.3	26.1%
N90	23.2	22.8	15.8	15.5	-16.6	45.3	-11.7	41.1	39.4%
SCI	34.2	34.0	23.1	22.9	-7.4	74.1	-13.7	77.8	25.0%
CPI+BAF	32.7	32.5	28.5	28.3	14.8	34.8	17.4	33.6	19.4%
WC/S+BAF	33.0	32.9	29.4	29.2	15.9	33.5	20.2	31.5	16.6%
N90+BAF	36.1	35.9	35.0	34.8	21.9	30.6	28.1	28.3	15.8%
SCI+BAF	52.3	52.2	34.5	34.4	36.5	97.8	26.5	100.0	13.8%

CPI - Cumulative CPI
WC/S - Weighted Cost & Schedule
N90 - NAVSEA 90
SCI - Schedule Cost Index (SCI)

CPI+BAF - Cumulative CPI + (BAF)
WC/S+BAF- Weighted Cost & Schedule + (BAF)
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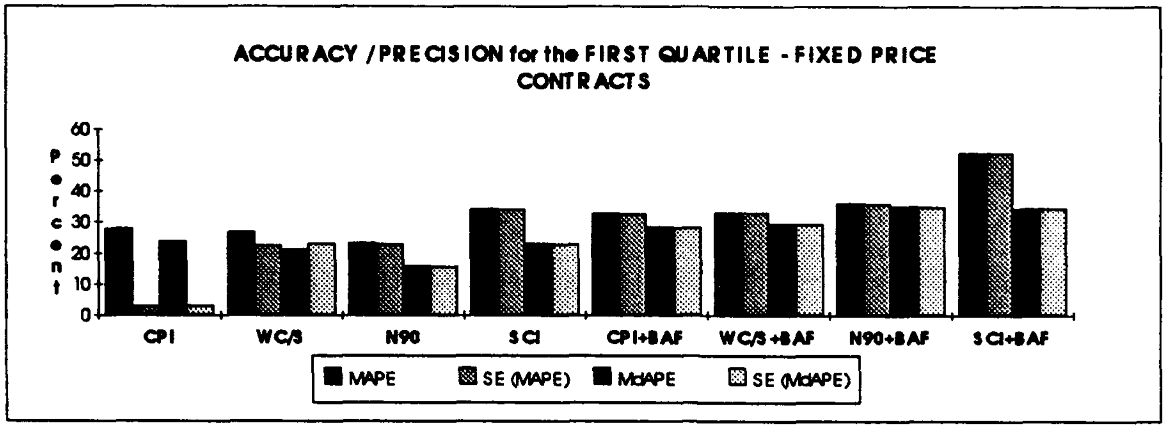


Figure 4 - 25

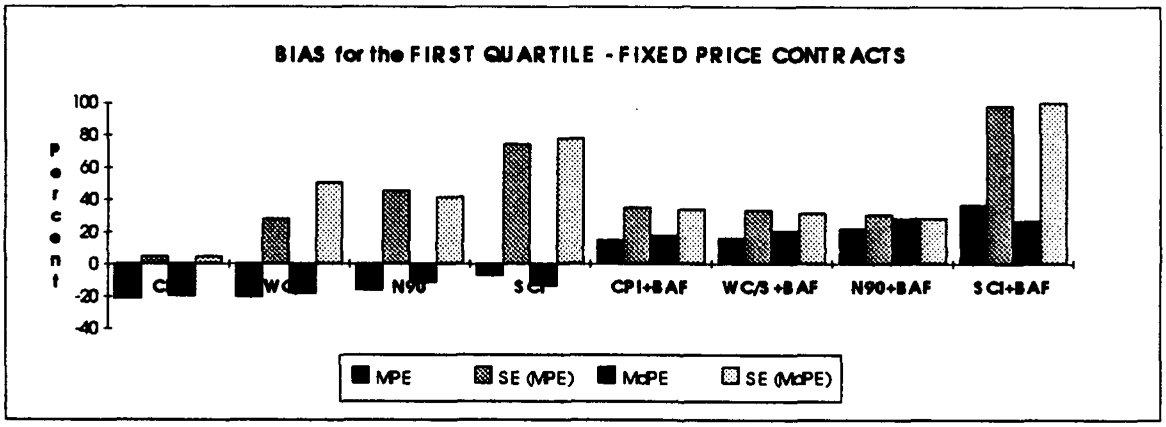


Figure 4 - 26

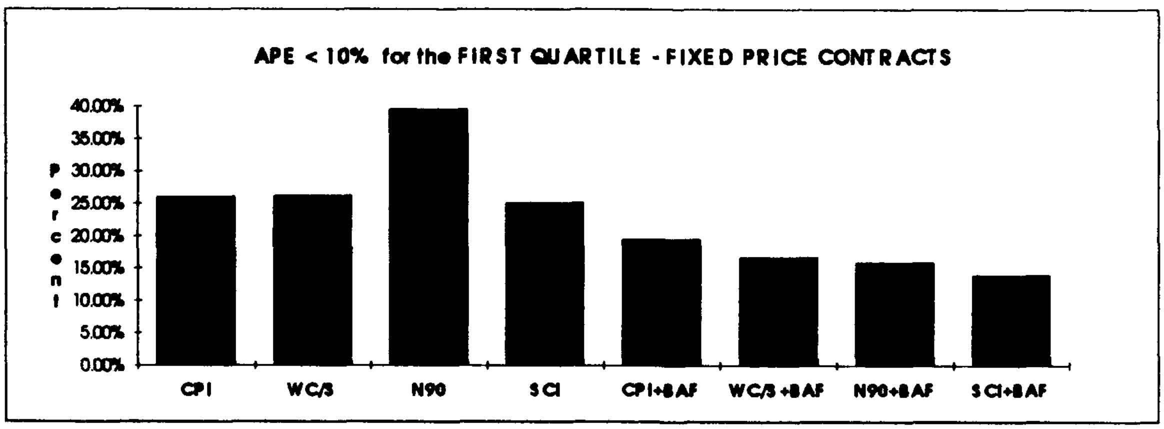


Figure 4 - 27

Table 4-11
Second Quartile - Fixed Price Contracts (814 Line Items)
BAC Adjustment Factor (BAF) = 1.3366

	ACCURACY / PRECISION				BIAS				
EAC	MAPE	SE	MdAPE	SE	MPE	SE	MdPE	SE	APE < 10%
CPI	19.0	18.0	14.7	18.5	-15.5	21.1	-13.2	21.2	39.1%
WC/S	18.7	17.5	14.3	18.0	-15.0	20.8	-13.2	36.4	40.0%
N90	17.2	16.7	11.1	10.6	-10.7	32.9	-8.1	30.7	45.8%
SCI	18.1	17.7	8.6	8.2	-9.8	33.7	-14.2	37.4	43.6%
CPI+BAF	23.5	23.3	21.9	21.6	12.9	22.8	7.8	25.6	24.8%
WC/S+BAF	24.0	23.8	22.4	22.2	13.7	22.0	16.0	21.1	24.3%
N90+BAF	27.6	7.4	26.6	8.4	19.0	23.3	22.6	22.2	21.6%
SCI+BAF	30.0	29.9	26.3	26.1	21.8	27.6	23.6	27.2	19.2%

CPI - Cumulative CPI
WC/S - Weighted Cost & Schedule
N90 - NAVSEA 90
SCI - Schedule Cost Index (SCI)

CPI+BAF - Cumulative CPI + (BAF)
WC/S+BAF- Weighted Cost & Schedule + (BAF)
N90+BAF - NAVSEA 90 + (BAF)
SCI+BAF - Schedule Cost Index (SCI) + (BAF)

MAPE - Mean Absolute Percent Error
MdAPE - Median Absolute Percent Error
MPE - Mean Percent Error
MdPE - Median Percent Error
SE - Standard Error
APE - Average Percent Error

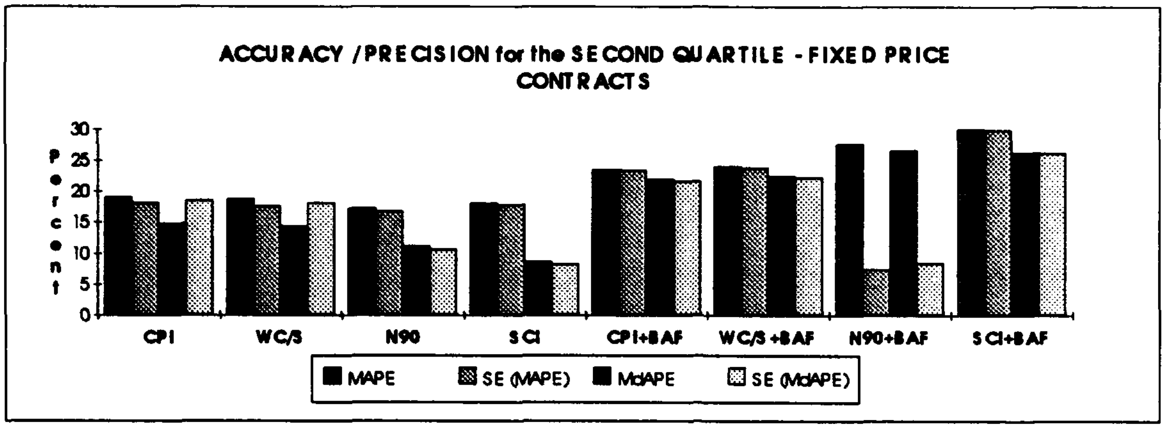
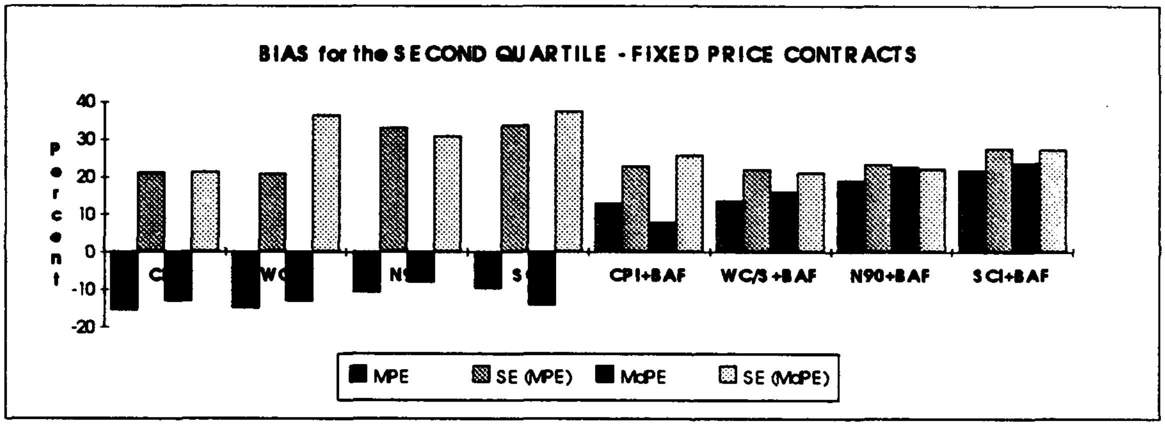


Figure 4 - 28



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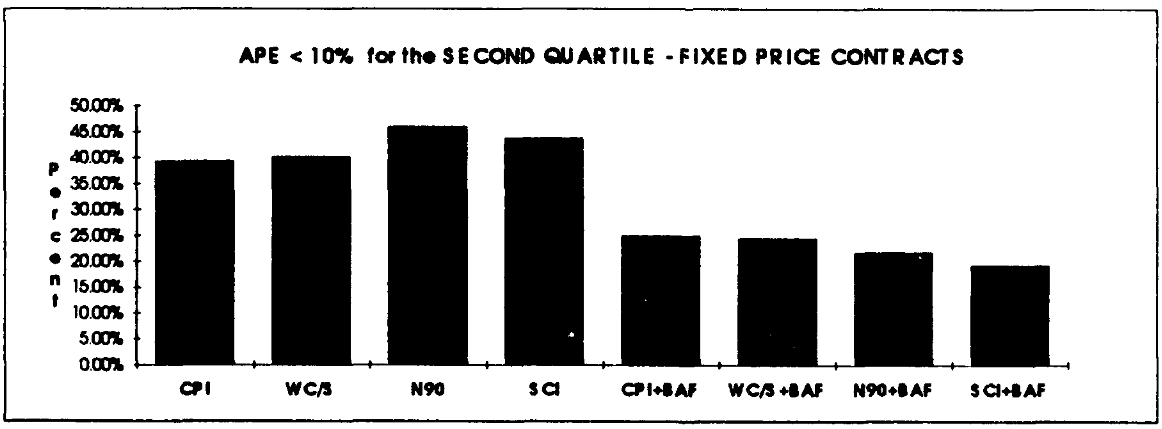

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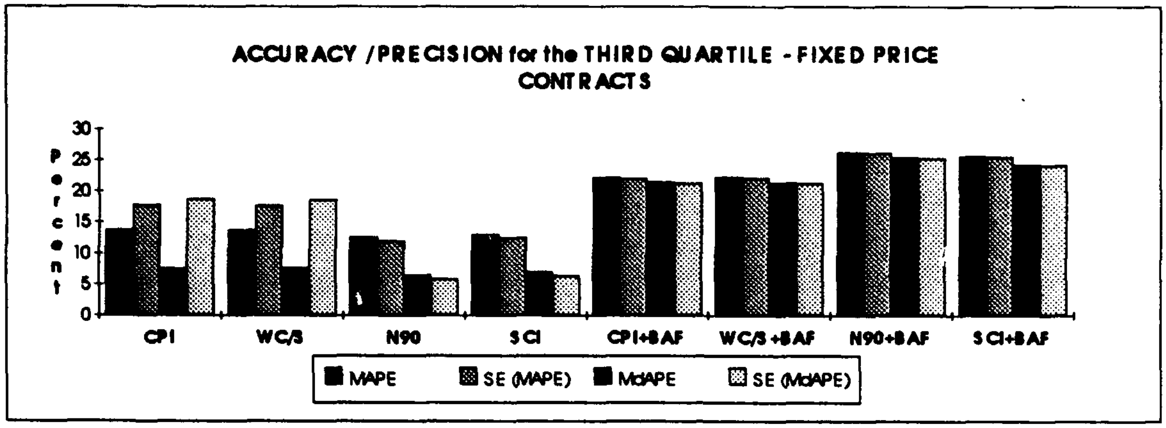
Table 4-12
Third Quartile - Fixed Price Contracts (1101 Line Items)
BAC Adjustment Factor (BAF) = 1.2831

	ACCURACY / PRECISION				BIAS				
EAC	MAPE	SE	MdAPE	SE	MPE	SE	MdPE	SE	APE < 10%
CPI	13.7	17.7	7.5	18.7	-10.6	19.7	-6.79	20.0	58.5%
WC/S	13.7	17.6	7.6	18.6	-10.6	19.7	-6.8	27.0	58.3%
N90	12.5	11.9	6.4	5.8	-5.9	25.5	-3.0	2.5	62.2%
SCI	13.0	12.4	6.9	6.3	-8.4	28.3	-4.9	25.8	61.9%
CPI+BAF	22.2	22.0	21.5	21.3	14.7	20.4	19.6	19.2	19.4%
WC/S+BAF	22.3	22.1	21.4	21.3	14.7	20.4	19.5	19.1	19.5%
N90+BAF	26.3	26.1	25.4	25.3	20.3	21.5	23.9	20.8	14.1%
SCI+BAF	25.6	25.5	24.3	24.2	18.8	22.7	23.0	21.8	15.1%

CPI - Cumulative CPI
WC/S - Weighted Cost & Schedule
N90 - NAVSEA 90
SCI - Schedule Cost Index (SCI)

CPI+BAF - Cumulative CPI + (BAF)
WC/S+BAF- Weighted Cost & Schedule + (BAF)
N90+BAF - NAVSEA 90 + (BAF)
SCI+BAF - Schedule Cost Index (SCI) + (BAF)

MAPE - Mean Absolute Percent Error
MdAPE - Median Absolute Percent Error
MPE - Mean Percent Error
MdPE - Median Percent Error
SE - Standard Error
APE - Average Percent Error



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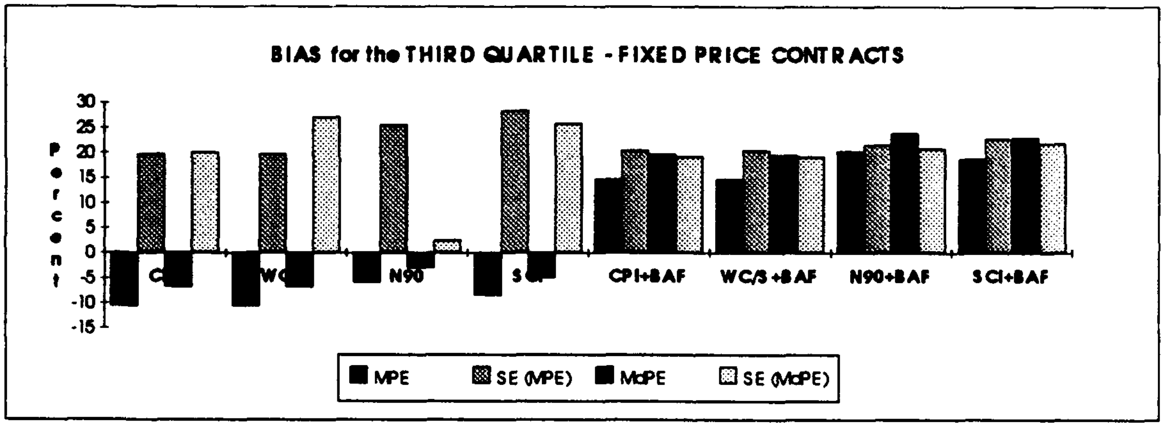

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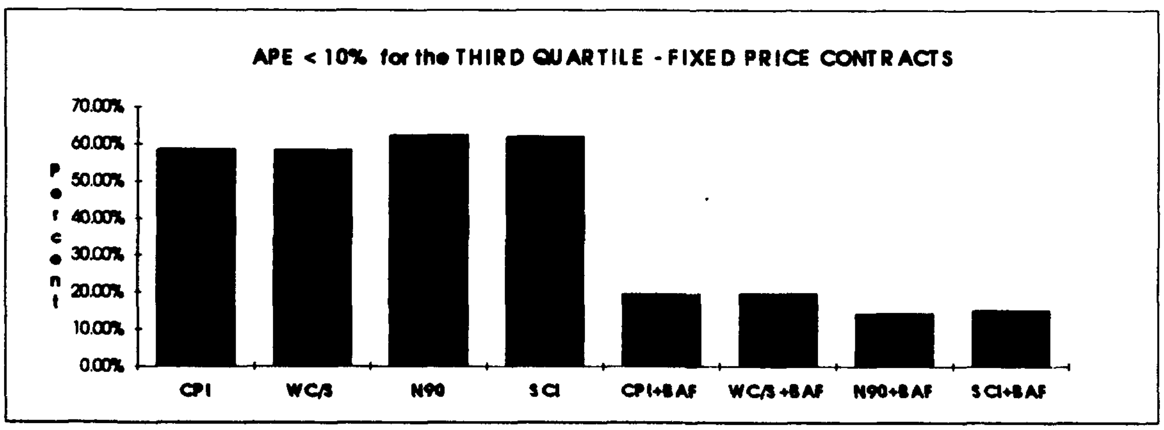

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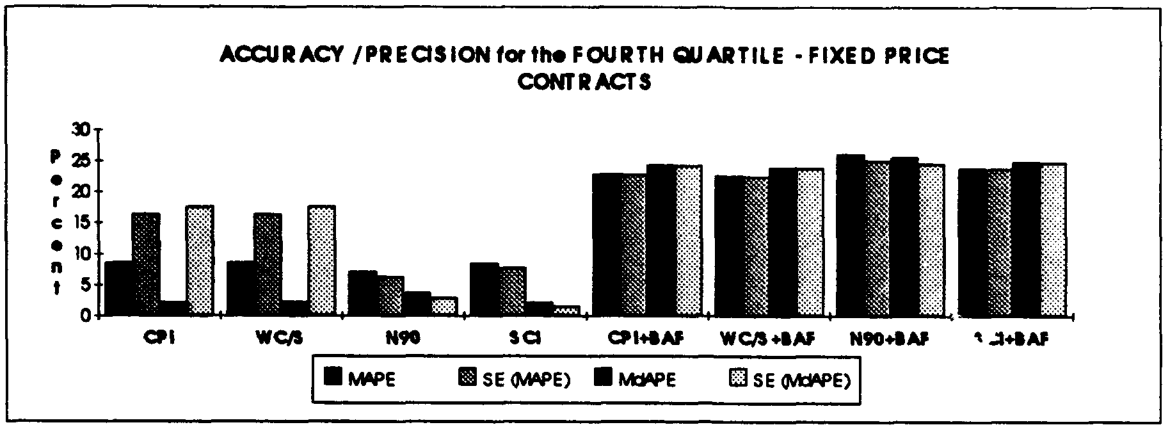
Table 4-13
Fourth Quartile - Fixed Price Contracts (1915 Line Items)
BAC Adjustment Factor (BAF) = 1.2478

	ACCURACY / PRECISION				BIAS				
EAC	MAPE	SE	MdAPE	SE	MPE	SE	MdPE	SE	APE < 10%
CPI	8.5	16.3	2.1	17.5	-6.8	17.1	-0.8	18.1	77.05
WC/S	8.5	16.3	2.2	17.5	-6.8	17.1	-1.0	18.9	76.9%
N90	7.0	6.2	3.6	2.8	-0.7	16.0	0.7	15.4	83.2%
SCI	8.4	7.7	2.1	1.4	-6.4	22.2	-0.5	18.7	77.7%
CPI+BAF	22.8	22.7	24.3	24.2	16.3	15.7	23.8	14.4	10.9%
WC/S+BAF	22.5	22.4	23.9	23.8	16.1	15.6	23.0	14.2	11.1%
N90+BAF	26.0	25.0	25.5	24.5	23.4	23.3	25.2	25.1	6.3%
SCI+BAF	23.8	23.7	24.8	24.7	17.5	15.9	24.5	14.6	9.4%

CPI - Cumulative CPI
WC/S - Weighted Cost & Schedule
N90 - NAVSEA 90
SCI - Schedule Cost Index (SCI)

CPI+BAF - Cumulative CPI + (BAF)
WC/S+BAF- Weighted Cost & Schedule + (BAF)
N90+BAF - NAVSEA 90 + (BAF)
SCI+BAF - Schedule Cost Index (SCI) + (BAF)

MAPE - Mean Absolute Percent Error
MdAPE - Median Absolute Percent Error
MPE - Mean Percent Error
MdPE - Median Percent Error
SE - Standard Error
APE - Average Percent Error



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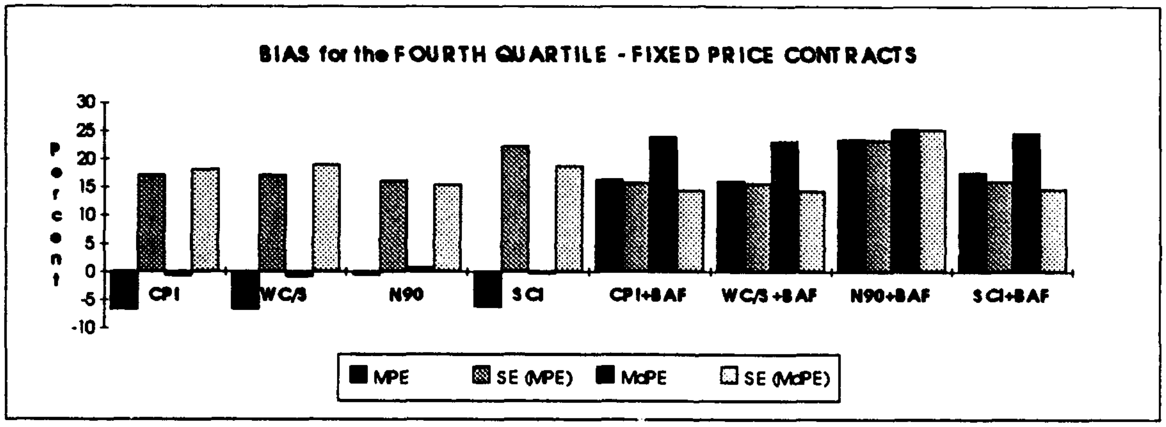

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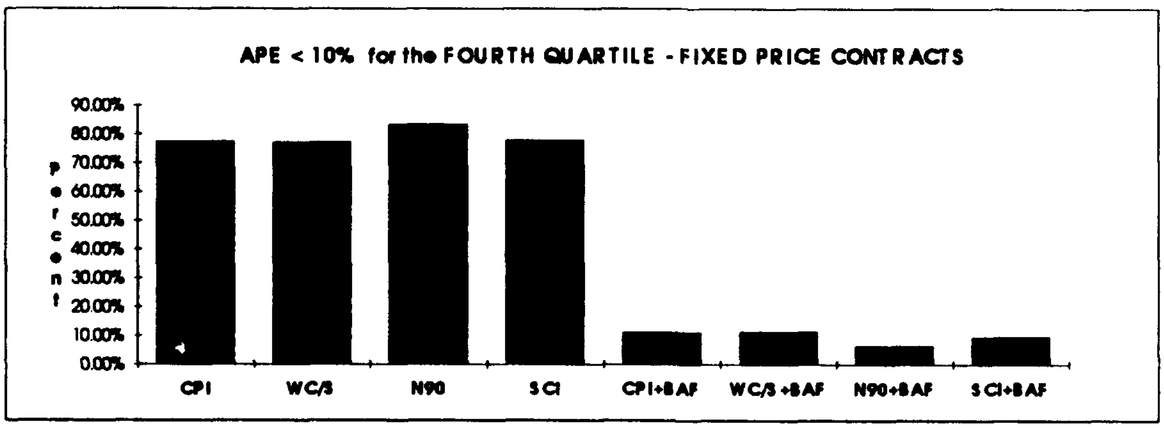

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Chapter Summary

This chapter provided the results of the analysis performed in this research effort. Commonly used, index-based EAC techniques were compared, both with and without newly developed BAC adjustment factors (BAFs). The comparison included the calculation of the following descriptive statistics: MAPE, MdAPE, MPE, and MdPE, along with their respective standard errors (SEs). In addition, the number of times an EAC technique prediction came within 10% of the CAC was also counted.

The statistics were used to compare the success of the different EAC techniques. In Chapter Three, success was defined to include accuracy, bias, and precision. The following chapter, Chapter Five, discusses the conclusions that were drawn, and recommendations that were made, based upon the analysis performed in this chapter, Chapter Four. Chapter Five will also list some recommendations for further research in this area.

V. Conclusions and Recommendations

Chapter Overview

Summary findings and conclusions of this research effort are presented in this chapter. First, a brief restatement of the findings from Chapters One, Two, and Three, and a summary of the results from Chapter Four are provided. Next, general conclusions regarding this overall research effort are discussed. This discussion includes a comparison of the results of this research effort to the conclusions of the literature reviewed in Chapter Two. Finally, recommendations on areas for future related research are presented.

Review of Chapters One, Two, Three, and Four

Chapter One. This chapter introduced the problem of contract cost overruns in the Defense Industry. In addition, it pointed out that better estimates at completion for DoD contracts can help top defense and other national leaders make better or more educated decisions in restructuring the U.S. defense budget. Chapter One guided this research effort towards developing a better technique to estimate contract completion costs for DoD contracts.

Chapter Two. This chapter summarized the findings of the literature review accomplished for this research effort.

The primary purposes of reviewing other literature were to avoid duplicating research already accomplished and to discover what areas of EAC research needed further attention. The literature review revealed that no single EAC method outperformed all other techniques all of the time. Different studies recommended that different EAC techniques were appropriate at different times in a program's life-cycle. In addition, the literature review identified the various scoring methodologies that have been used to compare the success of EAC techniques. The literature review helped to answer the first three research objectives:

1. Determined the EAC methods currently being used and believed to be successful.
2. Determined the work done in the area of estimates at completion, specifically, the index-based methods.
3. Determined the scoring methodologies that have been used to rate the success of EAC forecasting techniques.

Chapter Three. This chapter outlined the methodology used to compare the success of the different EAC techniques included in this research effort. It also identified the methodology used to develop the BAC adjustment factors. The BAC adjustment factors were used in EAC calculations to account for increases in cost overruns and scope additions.

In general, accuracy/precision was compared by computing the Mean Absolute Percentage Error (MAPE), Median Absolute Percentage Error (MdAPE), and their respective standard errors. Bias was compared through the use of the Mean Percentage Error (MPE), Median Percentage Error (MdPE), and their respective standard errors. As an additional measure of accuracy, the number of times a technique estimate was within 10% of the actual final contract completion cost was tabulated.

Chapter Four. This chapter provided the results of the analysis performed in this research effort. Commonly used, index-based EAC techniques were compared, both with and without newly developed BAC adjustment factors (BAFs). The comparison included preparation of tables and figures depicting the following descriptive statistics: MAPE, MdAPE, MPE, and MdPE along with their respective standard errors (SEs). The number of times an EAC technique came within 10% of the CAC was also counted and graphically depicted. In addition, research objective four was accomplished within this chapter:

4. Using historical data, BAC adjustment factors were developed which were used in conjunction with current EAC methods to predict final contract costs at various points in the life of DoD contracts.

General Conclusions

The overriding conclusion of this research effort was that the BAC adjustment factors did not improve the success of the existing index-based EAC techniques. This conclusion is overwhelmingly obvious after reviewing the tables and figures in Chapter Four. This general conclusion answered the fifth and final research objective:

5. Determined if the BAC adjustment factors developed in research objective four improved the success of the prevalent EAC methods determined in research objective one.

Beyond the primary focus of this research effort, which was to test whether or not the BAFs improved an EAC technique's success, it was possible to extract additional general conclusions. The following discussion focuses on the EAC techniques without the inclusion of the BAFs.

NAVSEA 90. The NAVSEA 90 technique was clearly the most successful technique examined. It performed as good or better than all the other techniques in all contract quartiles and contract categories: noncategorized, cost-type, and fixed price. Unfortunately, none of the previous EAC studies reviewed in Chapter Two included the NAVSEA 90 technique.

Schedule Cost Index (SCI). This technique was also successful. It came in a close second to the NAVSEA 90 technique in many of the contract quartiles and categorizations. Although the SCI technique never really outperformed the NAVSEA 90 formula, its performance did improve in the latter contract quartiles. This conclusion reaffirms the conclusion of two previous EAC studies: the Covach study and the Bright and Howard research. Both of these studies recommended the SCI technique.

Weighted Cost and Schedule. This EAC technique was not as successful as the NAVSEA 90 or SCI techniques. However, on occasion, the Weighted Cost and Schedule technique outperformed the SCI technique, but was never better than the NAVSEA 90 technique. The Bright and Howard research concluded that the Weighted Cost and Schedule technique was successful in the early contract phases. The Price study recommended the Weighted Cost and Schedule technique throughout the life of the contract. The Bright and Howard study conclusions and the Price study conclusions were contrary to the findings in this study. This is most likely due to the fact that neither study included the NAVSEA 90 formula. Furthermore, the Price study didn't even include the SCI formula.

<u>Cumulative Cost Performance Index (Cum CPI)</u>. Cum CPI was the least successful technique examined in this research effort. The large negative bias suggests that this EAC technique almost always produced low estimates. This means that a contract will more than likely have an actual cost at completion (CAC) that is higher than an EAC generated with the Cum CPI technique. Although this conclusion might be drawn about the other three techniques, the results of this research suggest that it is more clearly the case for the Cum CPI technique. Nearly all of the previous EAC studies stated that the Cum CPI was a good technique either overall or in specified contract life-cycle phases (see Table 2-1). However, this is probably due to the fact that none of them included the NAVSEA 90 technique, and a few of them did not include the SCI technique.

It should be noted that the results of this research may differ from previous studies because of the different databases that were used. In addition, the scoring methodology to determine which EAC techniques were successful was different than the methodologies used in previous EAC research efforts.

The generic index based formula (3.5), discussed in Chapter Three, revealed that an EAC is dependent upon how much work remains to be done on a contract. On DoD weapons system contracts, this is know as the Budgeted Cost of Work Remaining (BAC - BCWP = BCWR). Although the addition of the BAC adjustment factors (BAFs) diminished the success of the EAC techniques, the concept of adjusting the remaining budget on a contract (BCWR) for reasons of added scope or cost overruns was not entirely unsupported.

It was concluded in this study that the success of the EAC techniques, when used in conjunction with the BAFs, was drastically degraded because of the magnitude of the positive bias resulting from the BAFs. Too much positive bias skews the estimate to the high side. The inflated estimate resulting from the BAF is probably more unrealistic than the low estimates from the unadjusted techniques.

Areas for Future Related Research

In general, the concept of adjusting the remaining budget on a contract (BCWR) for reasons of added scope or cost overruns when using an index-based EAC technique needs further exploration. The contractor's performance to date is reflected in the Index that is chosen in the generic index-based formula (3.5). Having the capability to include an estimate of the remaining work, as well as the contractor's performance to date, would be extremely beneficial. Specifically, a different methodology to develop the BAFs is in order. Given the amount of positive bias that resulted from the methodology used in this research, an examination, and possible deletion, of extreme outliers in the database is another area that might be explored.

In addition, in this study, there were only four distinct BAFs corresponding with contract quartiles: 0-25%, 26-50%, 51-75%, and 76-100% complete. This was done for each contract category: noncategorized, cost-type, and fixed price (see Table 4-1). Another methodology might be to construct an equation for the BAFs, with percent complete as the independent variable, and the BAF as the dependent variable. This would help smooth out the application of the BAFs. The following is a generic formula representing this relationship:

$$BAF = f(\text{Percent Complete}) \tag{5.1}$$

Future research might focus on a different equation for each contract category: noncategorized, cost-type, and fixed price.

Finally, additional contract categories might be established. For example, BAFs could be developed and analyzed for Air Force, Army, and Navy contracts.

Additionally, Research and Development (R&D) and Production contracts could be separated.

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13. ABSTRACT *(Maximum 200 words)*

The purpose of this study was to develop Budget At Completion (BAC) adjustment factors (BAFs) which, when used in conjunction with existing Estimate At Completion (EAC) techniques, improve the success of existing EAC techniques. These factors attempted to account for changing contract requirements which are certain to occur on DoD contracts. These changing requirements often result in a need to add scope and budget to a contract, or can cause contract cost overruns requiring additional budget. Improving the success of these EAC techniques is increasingly important because of the budget cuts being experienced by the DoD in today's changing economic environment. An accurate estimate of future costs is necessary to ensure adequate funding levels to meet DoD requirements. The BAFs were constructed by compiling actual data from 534 DoD contracts. They were then used with existing EAC techniques to predict final contract completion costs. Descriptive statistics were used to determine if the BAFs improved the success of these EAC techniques. Unfortunately, the BAFs did not increase the success of the EAC techniques. Although these particular factors did not improve the success of these EAC techniques, research is still needed in this area. Accurate estimates of contract costs is still important.

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