

PROJECT ADVOCACY AND THE ESTIMATE AT COMPLETION PROBLEM¹

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ABSTRACT

According to some authors, an accurate estimate of a contract's completion cost is not always tolerated by project managers, especially when the estimate may jeopardize the project. Instead, less accurate but more optimistic estimates are supported as the "most likely" completion cost. This paper provides evidence that supports this observation. Using data from sixty-four completed defense contracts, cumulative cost and schedule performance indices were used to estimate contract completion costs, termed "Estimates at Completion" (EACs). These index-based estimates were then compared to estimates supported by contractor and government project managers. Results showed that the average EAC derived from the cumulative cost performance index (EACcpi) was a floor to the final cost. Results also showed that the estimates supported by the contractor and government were highly correlated to the EACcpi and less correlated to higher, more accurate index-based estimates.

INTRODUCTION

When Secretary of Defense Cheney canceled the Navy's A-12 program in January of 1991, he complained that no one could tell him the final cost of the program [17]. In fact, there were many estimates of the program's final cost, and some of them were more credible than others [2]. According to some authors, determining the most accurate estimate has never been the objective of contractor or government project managers [13:100; 16:52-53]. Instead, the objective has been to protect the project and the careers of its managers, even if that meant understating projected completion costs.

When a military Chief of Staff makes it known that he wants his service to undertake a weapons acquisition program, it is highly unlikely that unfavorable information will ever reach the Secretary of Defense through official channels . . . Analysis and documentation prepared in support of a Chief of Staff's favorite programs will suppress relevant information, if necessary, rather than reveal any data likely to raise doubts in the Office of the Secretary of Defense or in Congress [13:100].

It is unclear if this statement is empirically grounded or mere speculation. However, similar problems have been reported in the private sector. Instead of canceling a project when analysis clearly indicates that the project has failed, the manager will ignore or suppress the adverse information, and actually increase resources to the project [4,18].

In the *President's Private Sector Survey of Cost Control*, the Grace Commission (1983) concluded that there was a reluctance to report 'bad news' in the area of the cost to management" [19]. The reluctance to report adverse information about a project, sometimes termed a "shoot-the-messenger culture," is a serious problem to the efficient management of any project. For a project funded with public money, a shoot-the-messenger culture seems especially harmful because the senior civilian managers are the resource providers. In the case of the A-12, the Navy's chief Inquiry Officer, Chester P. Beach, concluded that an adverse organizational culture effectively suppressed information from senior civilian decision makers to ensure the project's continued funding [2:35].

A related cultural problem illustrated in the cancellation of the A-12 is the natural optimism of senior managers. In testimony before Congress about the A-12 project, Navy Secretary Garrett characterized the senior managers as "can do" people who did not admit to failure lightly [15]. Although optimism can be useful, it can also be dangerous when it blinds the manager to the truth or suppresses adverse information from senior management.

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Near the end of the Navy's report on the A-12 cancellation, Beach speculated that the "abiding cultural problem" identified in the A-12 project was not unique to the Navy:

There is no reason to believe that the factors which made these officials choose to respond the way they did are unique to this Military Department. Indeed, experience suggests that they are not. Unless means can be found to solve this abiding cultural problem, the failures evidenced in this report can be anticipated to occur again in the same or a similar form [2:35].

Subsequent research has supported this assertion by establishing that estimated contract completion costs supported by contractor and government project managers have been excessively optimistic: Despite the widely known fact that recoveries from cost overruns on defense contracts are extremely rare [9], an analysis of 64 completed defense contracts showed that the final cost overruns estimated by contractor and government project managers were less than current cost overruns [5]. In essence, most project managers have optimistically claimed that recoveries from cost overruns on their projects were probable.

This paper extends Christensen's research [5] by examining several popular index-based formulas for estimating the cost of a defense contract. The estimated cost of a defense contract, termed the "Estimate at Completion" (EAC), may be computed using a performance index. A popular performance index used for this purpose is the cumulative "Cost Performance Index" (CPI). Beach was highly critical of the A-12 program office for relying on the cumulative CPI as a ceiling, rather than a floor, to higher estimates [2:6-7]. At the time, it was widely assumed that the CPI-based EAC represented a reasonable floor to the cost at completion. This assumption was based on DoD experience with hundreds of completed contracts, and was commonly emphasized by senior defense analysts in presentations at DoD schools that teach EAC methods [1]. As indicated by Beach,

DoD experience in more than 400 programs since 1977 indicates that without exception the cum[ulative] CPI does not significantly improve during the period between 15% and 85% of contract performance; in fact, it tends to decline. Accordingly, extrapolation from the cum[ulative] CPI tends to produce a lower EAC than extrapolations based upon more recent periods of performance [2:6].

Despite the fact that recent, worsening performance on the A-12 project indicated higher EACs were more likely, the program manager chose to ignore the advice of his own analyst and supported a lower EAC:

The PM [project manager] apparently chose to rely upon the cumulative CPI as a ceiling, rather than a floor for his own estimate, notwithstanding the other, higher estimates briefed to the Program Office. [2:7]

This research provides evidence that Beach's criticism applies to other programs. Based on a sample of completed contracts extracted from the Defense Acquisition Executive Summary database, EACs were computed for each contract using cumulative cost and schedule performance indices. Average EACs were then compared to the average completion costs. Results showed that the average EAC based on the cumulative CPI was a floor to the average cost at completion. As such, this study is the first direct empirical confirmation of observations made by senior analysts at the Office of the Under Secretary of Defense for Acquisition (OUSDA).

The results also showed that the average EACs supported by contractor and government program managers were highly correlated with the average EAC based on the cumulative CPI. Other common index-based EACs were found to be larger and more accurate, but less correlated to the contractor and government estimates. In particular, the results showed that the average EAC based on the cumulative "schedule cost index" (SCI) was generally the most accurate of the cumulative index-based EACs, significantly larger than, and least correlated to the estimates supported by the contractor and the government.

This research is considered preliminary because it reviews EACs computed from only cumulative indices. EACs derived from noncumulative indices were not used because they were not directly available from the database used in this study. Subsequent research will include an analysis of noncumulative indices and be accomplished on a larger sample of completed defense contracts.

The paper is organized into several sections. Following a brief description of performance measurement terminology and a review of EAC research, the methodology and results of this study are described. The paper concludes with a discussion of actions taken by the government to encourage more realistic estimates.

BACKGROUND

Data on the cost and schedule progress of a major defense contract are prepared by the contractor and submitted to the government on a cost management report. The monthly report is considered reliable if the contractor has met certain government standards for cost and schedule performance measurement, termed "Cost/Schedule Control Systems Criteria" (C/SCSC) [11,12]. Today, most major defense contractors have management reporting systems that have been found to be C/SCSC-compliant.

The cost management report typically lists performance data using the framework of a product-oriented work breakdown structure. Key data elements include the budgeted cost of work scheduled (BCWS), the budgeted cost of work performed (BCWP), and the actual cost of work performed (ACWP).

As shown in Figure 1, BCWS is the time-phased budget for increments of work on the project. When cumulative BCWS is graphed, it forms a characteristic s-shaped curve, known as the performance measurement baseline. The end-point of the baseline, termed the "budget at completion" (BAC), represents the total budget for all the identified work on the contract. The EAC is the actual cost of the completed work (cumulative ACWP) plus the estimated cost of the remaining work. When the EAC exceeds the BAC, an adverse "variance at completion" (VAC) is identified.

Two other variances are also identified on the report. When BCWP is less than BCWS, less work has been accomplished than was planned to be accomplished, and an adverse "schedule variance" (SV) is identified. When ACWP exceeds BCWP, the cost of the work has exceeded its budget, and an adverse "cost variance" (CV) is identified. Figure 1 thus illustrates the typical condition of a defense contract: behind schedule, over-budget.

When these variances are judged to be significant, the contractor will investigate, document the causes, and develop a corrective-active plan. The intent of variance reporting is not to find fault but to identify and correct problems before they become more serious.

The variance analysis may also indicate that the projected final cost of the project (EAC) needs to be adjusted. Equation 1 shows the generic formula for the EAC.

$$EAC = ACWP + (BAC - BCWP)/Performance Index \quad [1]$$

This formula is often used by the government to develop independent EACs. The independent EACs are used by the government to evaluate the reasonableness of the contractor's estimate. Contractors may also use this formula to evaluate the reasonableness of their own "grass roots" estimates that were developed by other methods. The C/SCSC require that contractors develop comprehensive EACs at least annually. The comprehensive EAC is then updated, as required, in the monthly report to the government. As such, the monthly EAC, also termed the "Latest Revised Estimate," may reflect the influence of an index-based EAC.

As indicated in Equation 1, the EAC is equal to the cost of the completed work plus an estimate of the cost to complete the remaining work on the project. Because the budget for the remaining work (BAC - BCWP) is typically understated, a performance index is used to adjust the budget upward.

There are four kinds of performance indices:

$$\text{Cost Performance Index (CPI)} = BCWP / ACWP \quad [2]$$

$$\text{Schedule Performance Index (SPI)} = BCWP / BCWS \quad [3]$$

$$\text{Composite Index} = W1 \times \text{SPI} + W2 \times \text{CPI} \quad [4]$$

$$\text{Schedule Cost Index (SCI)} = \text{SPI} \times \text{CPI} \quad [5]$$

The CPI compares performance to actual cost. When the CPI is less than one, the cost of the completed work has exceeded its budget. The SPI compares actual performance to planned performance. When it is less than one, the work is behind schedule. The other two indices combine the SPI and the CPI.² The composite index is the weighted sum of the two indices, where the weights (W1 and W2) add to one. The SCI is the product of the SPI and the CPI.³

Clearly, there are many possible EACs. The performance index may be derived from monthly, cumulative, or averaged data. In addition, the weights chosen for the composite index are often systematically changed, with the SPI receiving greater weight in the early stages of a project. Accordingly, determining a "most likely" EAC, or even a range of likely EACs is a problem. Research has shed light on this issue.

EAC RESEARCH

There have been dozens of EAC studies over the past twenty years. The usual procedure in an EAC study is to compute a variety of EACs from a sample of completed contracts. The EACs are then compared to the final costs of the completed contracts to determine the relative accuracy of the formulas. Based on a review of 25 EAC studies, no single EAC formula is always the most accurate [8]. The predictive accuracy of the formula depends on project-specific factors, such as the phase and type of contract, the type of weapon system, and the military service that managed the project.

However, it may be possible to establish that the EAC derived from the cumulative CPI is a lower bound to the final cost of a contract. Although no prior research has examined this issue directly, the results of two EAC studies indirectly support the CPI-based EAC as a floor to the final cost [9,14].

Based on a review of 21 completed or nearly completed Navy contracts in 1982, Haydon and Reither [14] reported that a range of EACs bounded each contract's final cost sixty-four percent of the time. In most cases the final costs were greater than the EACs derived from the cumulative CPI. In addition, when the contractor's EAC was smaller than the CPI-based EAC, the CPI-based EAC was more accurate seventy-nine percent of the time. More recent research [9] explains why the cumulative CPI may be used to establish a floor for the EAC.

Based on an analysis of 155 completed defense contracts in 1991, Christensen and Heise [9], demonstrated that once a project is twenty percent completed, the cumulative CPI does not change by more than ten percent; in fact, in most cases it only worsens. Because cost overruns are rarely reversed, the EAC computed using a cumulative CPI usually represents a floor to the other EACs and the contract's final cost.

The A-12 program is illustrative. Figure 2 shows EACs reported by the contractor and the government on the A-12 program [2:7]. All the other EACs on the graphs were computed using performance indices, and are generally consistent with the theory explained above. The EAC computed using the cumulative SCI was the largest in the range. The EAC computed using the cumulative CPI was the smallest of the index-based estimates. The other EACs shown in the figure were derived from CPIs averaged over three month periods (CPI3) and six month periods (CPI6). As explained by Beach, estimates computed using performance indices averaged over shorter periods will likely be higher, especially when the newly completed work is experiencing large adverse cost variances [2:6-7]. The SCI-based EAC is often the largest because the SCI is the product of the CPI and the SPI, each of which is usually less than one.

2 An appropriate alternative terminology for the combination of schedule and cost indices is a "performance factor."

3 An alternative terminology for the indices in Equations 4 and 5 is "weighted index" and "composite index," respectively.

An analysis of index-based EAC formulas further explains the relative order of the EACs. First, if the CPI is less than the SPI, then the EAC derived from the CPI (EACcpi) will be larger than the EAC derived from the SPI (EACspi). The reverse is also true; if the CPI is greater than the SPI, then the EACcpi will be less than EACspi. Second, if the CPI is not equal to the SPI, then the EAC derived from the weighted sum of the SPI and the CPI (EACw) will always be between the EACcpi and the EACspi. Third, if the CPI and the SPI are each less than one, then the EAC derived from the SCI (EACsci) will be greater than either the EACcpi or the EACspi. The reverse is also true; if the CPI and SPI are each greater than one, then the EACsci will be less than either the EACcpi or the EACspi. When considered together, the following inequality equations are apparent:

Contract Status	EAC relationships	
CPI < SPI < 1	EACsci > EACcpi > EACw > EACspi	[6]
SPI < CPI < 1	EACsci > EACspi > EACw > EACcpi	[7]
CPI > SPI > 1	EACsci < EACcpi < EACw < EACspi	[8]
SPI > CPI > 1	EACsci < EACspi < EACw < EACcpi	[9]

Because the usual condition of a defense contract is behind schedule and over-budget, the SPI and the CPI are each less than one by definition. Therefore, the relative order of the EACs derived from performance indices on defense contracts will usually be as described in Equations 6 or 7. Furthermore, because the SPI is forced to unity as a contract proceeds to completion, the relative order of EACs computed in the late stages of a contract will usually be as described in Equation 6, where the EACsci is the largest and the EACspi is the smallest. In the early to middle stages of a contract, the relative order of the EACs will usually be as expressed in Equation 7, where the EACsci is the largest and the EACcpi is the smallest. Of the four equations, Equation 7 is probably the most important because it reflects the relative positions of these common index-based EACs at stages in the contract when accurate estimates are most valuable.

No one can say for sure if the EACs supported by the A-12 program managers or the index-based EACs listed in Figure 2 were accurate because the program was canceled before completion. However, a review of completed defense contracts can establish whether EACs in general are optimistic. Specifically, *given that most programs do not recover from cost overruns, do most program managers still claim that recoveries are probable?* If so, then such claims are unrealistically optimistic. In addition, *have managers of these completed programs supported estimates that were the same or nearly the same as the EAC derived from the cumulative CPI?* If so, then this is additional evidence of optimism, because the other index-based EACs would likely be higher (as demonstrated in Equation 7), and possibly more accurate (as suggested in a number of EAC studies [3,8] and by respected analysts at OUSD(A) [1]).

The answer to the first question has been answered. Based on a sample of 64 completed defense contracts, Christensen [5] demonstrated that EACs were unrealistically optimistic: The average cost overrun experienced at various stages of percent complete was shown to be significantly greater than the average final overruns predicted by the contractor and the government⁴. This result was invariant to the contract type (fixed price, cost reimbursable), the contract phase (development, production), the type of weapon system (air, ground, sea), or the managing military service (air force, army, navy). This paper reports the answer to the second question.

METHODOLOGY

Based on the same sample, this research tests whether the average EAC derived from the cumulative CPI (EACcpi) is less than the average final cost (CAC). It also tests whether the average EACs supported by contractor (EACk) and government (EACg) management were the same or nearly the same as the average EAC derived from the cumulative CPI. The following table summarizes these hypotheses:

Hypotheses	Interpretation
H1o: EACcpi ≥ CAC	EACcpi is not a floor to CAC

4 Using the more specialized jargon of C/SCSC, the average adverse "cost variance" was more negative than the average adverse "variance at completion."

H1a: $EAC_{cpi} < CAC$	EAC_{cpi} is a floor to CAC
H2o: $EAC_g \neq EAC_{cpi}$	EAC_g not optimistic
H2a: $EAC_g \approx EAC_{cpi}$	EAC_g optimistic
H3o: $EAC_k \neq EAC_{cpi}$	EAC_k not optimistic
H3a: $EAC_k \approx EAC_{cpi}$	EAC_k optimistic

If H1o is rejected, then the EAC derived from the cumulative CPI is a floor to the final cost. Assuming that it was generally known that the EAC derived from a cumulative CPI was considered to be a likely floor to the final cost, then rejecting H2o and H3o is additional evidence that the estimates supported by the contractor and government managers were optimistic.

To test these hypotheses, a judgment sample of sixty-four completed contracts was extracted from the Defense Acquisition Executive Summary (DAES) database. The database contains information from cost management reports on over five hundred completed contracts since 1977 [10]. Since most of these contracts were C/SCSC-compliant, the data are considered reliable. However, not all of these contracts are completely documented from start to finish. In addition, many of the contracts in the database experienced drastic revisions to their original budgets⁵. These constraints and others limited the sample size to sixty-four. The fact that the sample was purely judgmental constitutes a significant limitation of this analysis.

The size of the contracts in the sample varied significantly [5]. To reduce the potential distortion created by large projects on sample means, each of five EACs for each contract was normalized into Deviation from the CAC (DCAC):

$$DCAC = (EAC - CAC) / CAC \quad [9]$$

Three of the EACs were derived from cumulative indices (CPI, SPI, and SCI); the other two were the estimates supported by the contractor and the government. The EAC derived from a composite index (Equation 4) was not included because its value will always be between the EAC_{cpi} and the EAC_{spi} .

Means of DCACs were then computed for the entire sample and various categories of the sample, and the first hypothesis was evaluated using a one-tailed t-test at an alpha level of .05.⁶ If the mean deviation based on the EAC_{cpi} was significantly less than zero, then H1o was rejected. For comparison purposes and to assist in testing the other hypotheses, the mean deviations based on the other EACs were similarly tested.

Determining an appropriate statistical test for hypotheses two and three was a problem. Neither parametric nor nonparametric difference testing was appropriate because the EACs were not independent variables⁷. This is especially apparent for the index-based EACs because they share common terms (ACWP, BCWP, and BAC). Instead, a two-fold approach was used to evaluate the relative association between the EACs. First, graphs of the EACs and the related performance indices were used to get a visual impression of the relative association between the five EACs. Second, Spearman's rank correlation matrix of the five EACs was used to confirm what the graphs suggested⁸. If the EACs supported

5 When replanning of the budget baseline results in a total allocated budget that is greater than the budget for all of the authorized work, the contract is said to be in an "over-target-baseline" (OTB) condition. When this happens, cumulative cost and schedule variances may be eliminated, and the analysis of cost overruns is significantly confused.

6 The nonparametric Wilcoxon signed rank test was also used to test the first hypothesis because some of the samples did not pass the Kolmogorov-Smirnov test for normality at an alpha level of .05. Overall, the results of the nonparametric tests were not different from the t test.

7 This is a problem similar to multicollinearity, where the variances of the regression coefficients are inflated.

8 Because the deviations in some of the samples were not normally distributed, Spearman's rank correlation matrix was used instead of Pearson's product-moment correlation matrix.

by the contractor and government management were more correlated to the EACcpi than to the larger and more accurate index-based EACs, then null hypotheses two (H2o) and three (H3o) were rejected. This conclusion assumes that the contract and program managers involved understood that the CPI-based EAC was a likely floor to the final cost.

To facilitate the preparation of the graphs, each deviation (DCAC) was assigned to discrete stages of percent complete. Deviations occurring up to the 10 percent completion point were assigned to the 10 percent category; deviations between the 10 and 20 percent completion points were assigned to the 20 percent category, *et cetera*.

The three hypotheses were then evaluated at three stages of completion (early, middle, late). The early stage included deviations computed at the 10, 20 and 30 percent completion points. The middle stage included deviations at the 40, 50, and 60 percent completion points. The late stage included deviations computed at the 70, 80 and 90 percent completion points.

As shown in Equation 10, the Budget at Completion (BAC) was used to compute percent complete.

$$\text{Percent Complete} = \text{Cumulative BCWP} / \text{BAC} \quad [10]$$

Other possible bases, such as the contract budget base and total allocated budget were also used, but the results were insensitive to the choice of the base.

RESULTS

Null hypothesis one (H1o) was rejected. The average EACcpi was a floor to the average final cost of the contracts examined. The average deviation based on the EACcpi was significantly less than zero at a alpha level of .05. Overall, and at each stage of completion, this result was invariant to the phase of the contract (development, production), the type of the contract (fixed price, cost reimbursable), and the military service that managed the contract (air force, army, navy). Table 1 through 4 summarize these results for the entire sample, and for the selected categories.

Null hypotheses two (H2o) and three (H3o) were also rejected. In general, the average EACs reported by the contractor and government managers were most correlated to the EACcpi and least correlated to the larger and more accurate EACsci. Figure 3 illustrates these results for the entire sample. Figures 4 through 7 illustrate the results for the selected categories⁹. In addition, an analysis of the correlation matrix for the five EACs confirmed what the graphs illustrated. As shown in Table 5, for all stages of completion the EACK was more correlated to the EACcpi than to the other index-based EACs, especially the EACsci, which was the most accurate and largest EAC. When all stages were included, the EACg was also more correlated to the EACcpi than to the other index-based EACs. In the middle and late stages, however, the EACg was slightly more correlated to the EACspi. (This may be due to the fact that the EACspi was becoming less accurate than the EACcpi as the stage of completion moved from middle to late.) The results of the correlation analysis were generally consistent across all the categories examined; however, tables that detail this are not provided here.

CONCLUSION

This research demonstrates that the CPI-based EAC is a reasonable lower bound to the final cost of a defense contract. It also demonstrates that estimates supported by government and contractor management were not significantly different from the CPI-based EAC. Despite the widely documented relative accuracy of other EACs [8], such as the EACsci, contractor and government management did not support the higher, but more accurate estimates. To the extent that the EACcpi was understood by these managers to be a reasonable floor, then these results are additional evidence of optimism and suggest that the cultural problem identified in the A-12 program may be a DoD-wide epidemic.

9 The vertical scales of the figures have been aligned to facilitate a comparison of the EACs across contract types, contract phases, and military services. However, a discussion of such comparisons is beyond the scope of this paper.

Fortunately, this potential problem has not been ignored. Changing an organization's culture is no easy task, and must be encouraged from the top. Since the A-12, the military services and the Department of Defense have re-iterated the policy of fully disclosing adverse information. In a policy letter signed by the former Assistant Secretary of the Air Force, for example, program directors were encouraged to tell the truth:

A program director (PD) must be an advocate of his or her program. . . The PD's advocacy must not cross the line into attempting to "sell" the program, but must clearly be viewed as supportive to the user's requirements. The PD must articulate the pros and cons, as well as the "maturity curve" status, in a clear and comprehensive manner to preclude unfulfilled expectations or surprises. Such advocacy must be based on honesty and integrity to accurately portray program status [20].

In a speech regarding the A-12 cancellation, the former Under Secretary of Defense for Acquisition, made a similar statement:

We can't afford to understate, sit on, or cover up problems in any program -- at any time -- at any level. They must be brought forward. This includes not just "show stoppers" but also "show slowers [21].

It is not clear if such statements will be effective. Regarding the EACcpi, however, the DoD now requires that EACs which are lower than the EACcpi be specifically justified in reports to the Office of the Secretary of Defense [12].

This preliminary research is being extended to include a larger sample size and an examination of noncumulative performance indices. In addition, a few major defense projects have experienced early cost overruns but finished within budget. Research that documents such "success stories" is badly needed.

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TABLE 1
AVERAGE DEVIATION FROM FINAL COST
64 Contracts

Type of EAC	Early stage (10-30%) (n=192)			Middle stage (40-60%) (n=192)			Late stage (70-90%) (n=192)			All stages (10-90%) (n=576)		
	μ	σ	t	μ	σ	t	μ	σ	t	μ	σ	t
EACsci	-0.031	0.396	-1.07	0.000	0.202	0.00	0.001	0.101	0.20	-0.010	0.264	-0.89
EACspi	-0.069*	0.329	-2.90	-0.056*	0.170	-4.54	-0.033*	0.089	-5.15	-0.053*	0.221	-5.72
EACg	-0.150*	0.211	-9.87	-0.094*	0.154	-8.45	-0.025*	0.101	-3.44	-0.090*	0.170	-12.70
EACk	-0.156*	0.192	-11.20	-0.105*	0.125	-11.63	-0.038*	0.080	-6.65	-0.100*	0.148	-16.11
EACcpi	-0.174*	0.200	-12.08	-0.101*	0.132	-10.54	-0.028*	0.091	-4.25	-0.101*	0.160	-15.17

The asterisk (*) indicates that the mean deviation is significantly less than zero for $\alpha = .05$.

TABLE 2
AVERAGE DEVIATION FROM FINAL COST
By Phase of Contract (Development, Production)

25 Development Contracts												
Type of EAC	Early stage (10-30%, n=75)			Middle stage (40-60%, n=75)			Late stage (70-90%, n=75)			All stages (10-90%, n=225)		
	μ	σ	t	μ	σ	t	μ	σ	t	μ	σ	t
EACsci	-0.109*	0.207	-4.57	-0.055*	0.120	-3.98	-0.027*	0.068	-3.41	-0.064*	0.147	-6.48
EACspi	-0.136*	0.181	-6.49	-0.115*	0.119	-8.40	-0.062*	0.083	-6.46	-0.104*	0.138	-11.38
EACg	-0.164*	0.192	-7.39	-0.113*	0.129	-7.61	-0.037*	0.079	-4.04	-0.105*	0.150	-10.43
EACk	-0.181*	0.199	-7.90	-0.135*	0.132	-8.89	-0.057*	0.087	-5.64	-0.124*	0.155	-12.01
EACcpi	-0.201*	0.198	-8.78	-0.126*	0.127	-8.57	-0.049*	0.083	-5.06	-0.125*	0.157	-11.95
39 Production Contracts												
	Early stage (10-30%, n=117)			Middle stage (40-60%, n=117)			Late stage (70-90%, n=117)			All stages (10-90%, n=351)		
	μ	σ	t	μ	σ	t	μ	σ	t	μ	σ	t
EACsci	0.020	0.473	0.45	0.035	0.234	1.64	0.019	0.113	1.86	0.025	0.312	1.49
EACspi	-0.026	0.390	-0.72	-0.018	0.187	-1.03	-0.015*	0.088	-1.80	-0.019	0.255	-1.43
EACg	-0.141*	0.222	-6.90	-0.082*	0.168	-5.29	-0.018*	0.113	-1.70	-0.080*	0.180	-8.35
EACk	-0.139*	0.187	-8.06	-0.086*	0.116	-7.95	-0.026*	0.072	-3.96	-0.084*	0.141	-11.09
EACcpi	-0.158*	0.200	-8.54	-0.085*	0.133	-6.87	-0.015*	0.093	-1.69	-0.086*	0.160	-10.04

The asterisk (*) indicates that the mean deviation is significantly less than zero for $\alpha = .05$.

TABLE 3
AVERAGE DEVIATION FROM FINAL COST
By Type of Contract (Fixed Price, Cost Reimbursable)

41 Fixed Price Contracts												
Type of EAC	Early stage (10-30%, n=123)			Middle stage (40-60%, n=123)			Late stage (70-90%, n=123)			All stages (10-90%, n=369)		
	μ	σ	t	μ	σ	t	μ	σ	t	μ	σ	t
EACsci	-0.016	0.469	-0.37	0.025	0.233	1.19	0.011	0.109	1.08	0.007	0.309	0.42
EACspi	-0.050	0.387	-1.43	-0.033*	0.192	-1.89	-0.027*	0.091	-3.26	-0.037*	0.255	-2.75
EACg	-0.148*	0.195	-8.39	-0.099*	0.168	-6.50	-0.024*	0.112	-2.38	-0.090*	0.170	-10.18
EACk	-0.165*	0.195	-9.37	-0.101*	0.125	-8.96	-0.033*	0.077	-4.69	-0.099*	0.151	-12.65
EACcpi	-0.201*	0.193	-11.53	-0.106*	0.137	-8.56	-0.025*	0.089	-3.18	-0.111*	0.162	-13.07
23 Cost Reimbursable Contracts												
	Early stage (10-30%, n=69)			Middle stage (40-60%, n=69)			Late stage (70-90%, n=69)			All stages (10-90%, n=207)		
EACsci	-0.058*	0.207	-2.32	-0.045*	0.118	-3.13	-0.015	0.080	-1.55	-0.039*	0.146	-3.85
EACspi	-0.102*	0.181	-4.69	-0.097*	0.111	-7.23	-0.045*	0.084	-4.39	-0.081*	0.135	-8.69
EACg	-0.155*	0.236	-5.44	-0.086*	0.125	-5.71	-0.027*	0.077	-2.91	-0.089*	0.169	-7.60
EACk	-0.139*	0.187	-6.19	-0.112*	0.125	-7.46	-0.048*	0.083	-4.82	-0.100*	0.144	-10.01
EACcpi	-0.128*	0.204	-5.19	-0.092*	0.123	-6.18	-0.032*	0.095	-2.82	-0.084*	0.153	-7.87

The asterisk (*) indicates that the mean deviation is significantly less than zero for $\alpha = .05$.

TABLE 4
AVERAGE DEVIATION FROM FINAL COST
By Managing Service (Air Force, Army, Navy)

18 Air Force Contracts												
Type of EAC	Early stages (10-30%, n=54)			Middle stage (40-60%, n=54)			Late stage (70-90%, n=54)			All (10-90%, n=162)		
	μ	σ	t	μ	σ	t	μ	σ	t	μ	σ	t
EACsci	-0.102*	0.218	-3.43	-0.066*	0.129	-3.77	-0.013	0.068	-1.44	-0.061*	0.156	-4.94
EACspi	-0.113*	0.211	-3.95	-0.100*	0.126	-5.80	-0.039*	0.077	-3.70	-0.084*	0.152	-7.01
EACg	-0.123*	0.217	-4.14	-0.081*	0.145	-4.13	-0.009	0.062	-1.08	-0.071*	0.162	-5.58
EACk	-0.137*	0.223	-4.52	-0.086*	0.144	-4.37	-0.018*	0.073	-1.82	-0.080*	0.166	-6.15
EACcpi	-0.183*	0.205	-6.57	-0.117*	0.133	-6.47	-0.027*	0.072	-2.78	-0.109*	0.161	-8.67
28 Army Contracts												
	Early stages (10-30%, n=84)			Middle stage (40-60%, n=84)			Late stage (70-90%, n=84)			All (10-90%, n=252)		
	μ	σ	t	μ	σ	t	μ	σ	t	μ	σ	t
EACsci	0.070	0.535	1.20	0.069	0.256	2.48	0.020	0.121	1.52	0.053	0.350	2.41
EACspi	0.010	0.434	0.21	-0.004	0.205	-0.16	-0.024*	0.092	-2.38	-0.006	0.283	-0.33
EACg	-0.150*	0.200	-6.88	-0.104*	0.178	-5.35	-0.029*	0.126	-2.08	-0.094*	0.178	-8.40
EACk	-0.168*	0.195	-7.93	-0.112*	0.117	-8.81	-0.043*	0.078	-5.05	-0.108*	0.148	-11.59
EACcpi	-0.186*	0.218	-7.83	-0.102*	0.138	-6.73	-0.026*	0.095	-2.51	-0.105*	0.172	-9.67
18 Navy Contracts												
	Early stages (10-30%, n=54)			Middle stage (40-60%, n=54)			Late stage (70-90%, n=54)			All (10-90%, n=162)		
	μ	σ	t	μ	σ	t	μ	σ	t	μ	σ	t
EACsci	-0.116*	0.190	-4.47	-0.042*	0.117	-2.61	-0.013	0.087	-1.08	-0.057*	0.145	-4.98
EACspi	-0.147*	0.173	-6.22	-0.093*	0.119	-5.72	-0.042*	0.095	-3.27	-0.094*	0.140	-8.55
EACg	-0.178*	0.217	-6.02	-0.092*	0.120	-5.65	-0.036*	0.086	-3.05	-0.102*	0.162	-7.99
EACk	-0.154*	0.151	-7.51	-0.113*	0.114	-7.24	-0.051*	0.085	-4.43	-0.106*	0.127	-10.62
EACcpi	-0.147*	0.159	-6.79	-0.082*	0.119	-5.09	-0.031*	0.100	-2.29	-0.087*	0.137	-8.08

The asterisk (*) indicates that the mean deviation is significantly less than zero for $\alpha = .05$.

TABLE x
AVERAGE DEVIATION FROM FINAL COST
By Type of Weapon System (Air, Ground, Sea)

43 "Air" Contracts												
Type of EAC	Early stage (10-30%, n=129)			Middle stage (40-60%, n=129)			Late stage (70-90%, n=129)			All stages (10-90%, n = 387)		
	μ	σ	t	μ	σ	t	μ	σ	t	μ	σ	t
EACsci	0.040	0.439	1.02	0.042	0.220	2.18	0.014	0.106	1.45	0.032	0.291	2.15
EACspi	-0.003	0.356	-0.08	-0.026	0.187	-1.56	-0.025	0.093	-3.07	-0.018	0.239	-1.46
EACg	-0.118*	0.185	-7.27	-0.083*	0.173	-5.41	-0.020	0.116	-1.99	-0.074	0.166	-8.75
EACk	-0.131*	0.185	-8.02	-0.088*	0.135	-7.40	-0.030	0.088	-3.93	-0.083	0.147	-11.07
EACcpi	-0.162*	0.186	-9.93	-0.082*	0.137	-6.85	-0.022	0.093	-2.63	-0.089	0.155	-11.29
13 "Ground" Contracts												
Type of EAC	Early stage (10-30%, n=39)			Middle stage (40-60%, n=39)			Late stage (70-90%, n=39)			All stages (10-90%, n = 117)		
	μ	σ	t	μ	σ	t	μ	σ	t	μ	σ	t
EACsci	-0.186*	0.254	-4.56	-0.110*	0.106	-6.46	-0.044*	0.062	-4.45	-0.113*	0.173	-7.08
EACspi	-0.204*	0.237	-5.36	-0.130*	0.106	-7.66	-0.070*	0.067	-6.48	-0.135*	0.164	-8.86
EACg	-0.200*	0.237	-5.25	-0.131*	0.088	-9.32	-0.037*	0.053	-4.34	-0.123*	0.164	-8.11
EACk	-0.218*	0.234	-5.82	-0.154*	0.092	-10.51	-0.061*	0.054	-7.11	-0.145*	0.162	-9.66
EACcpi	-0.235*	0.263	-5.59	-0.178*	0.097	-11.49	-0.066*	0.062	-6.71	-0.160*	0.180	-9.62
8 "Sea" Contracts												
Type of EAC	Early stage (10-30%, n=24)			Middle stage (40-60%, n=24)			Late stage (70-90%, n=24)			All stages (10-90%, n = 56)		
	μ	σ	t	μ	σ	t	μ	σ	t	μ	σ	t
EACsci	-0.156*	0.178	-4.31	-0.049*	0.128	-1.88	0.010	0.099	0.51	-0.065*	0.155	-3.56
EACspi	-0.206*	0.147	-6.88	-0.097*	0.107	-4.45	-0.017	0.086	-0.98	-0.107*	0.139	-6.49
EACg	-0.240*	0.251	-4.69	-0.096*	0.117	-4.01	-0.032*	0.069	-2.29	-0.123*	0.186	-5.59
EACk	-0.186*	0.111	-8.24	-0.117*	0.090	-6.35	-0.043*	0.058	-3.64	-0.115*	0.106	-9.21
EACcpi	-0.142*	0.125	-5.59	-0.073*	0.111	-3.23	0.001	0.100	0.03	-0.071*	0.126	-4.79

The asterisk (*) indicates that the mean deviation is significantly less than zero for $\alpha = .05$.

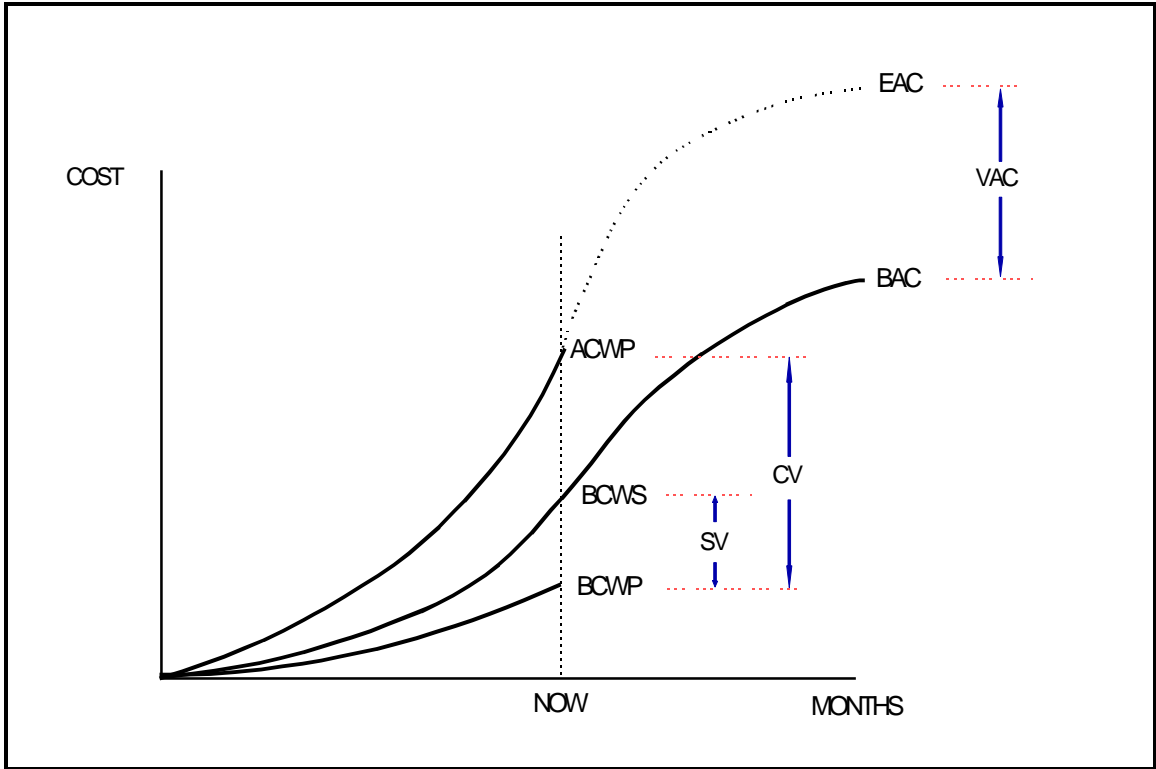


Figure 1. The Estimate At Completion (EAC).

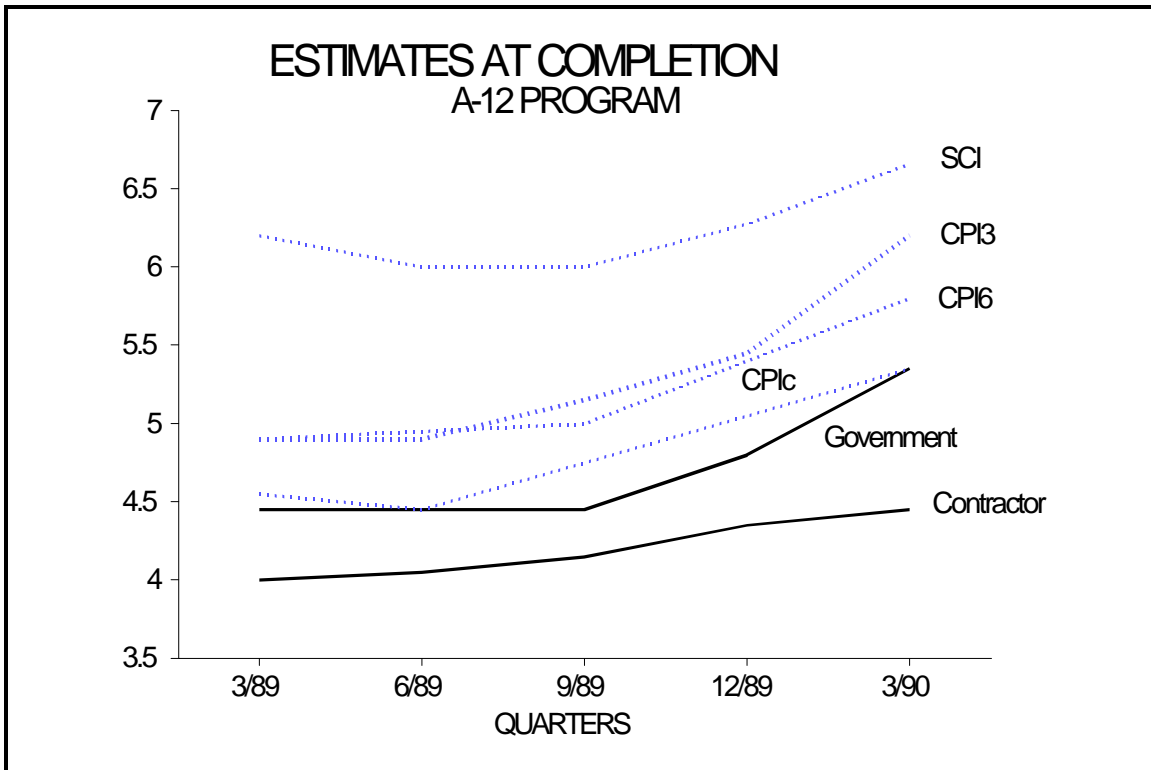


Figure 2. EACs for A-12 Program [2].

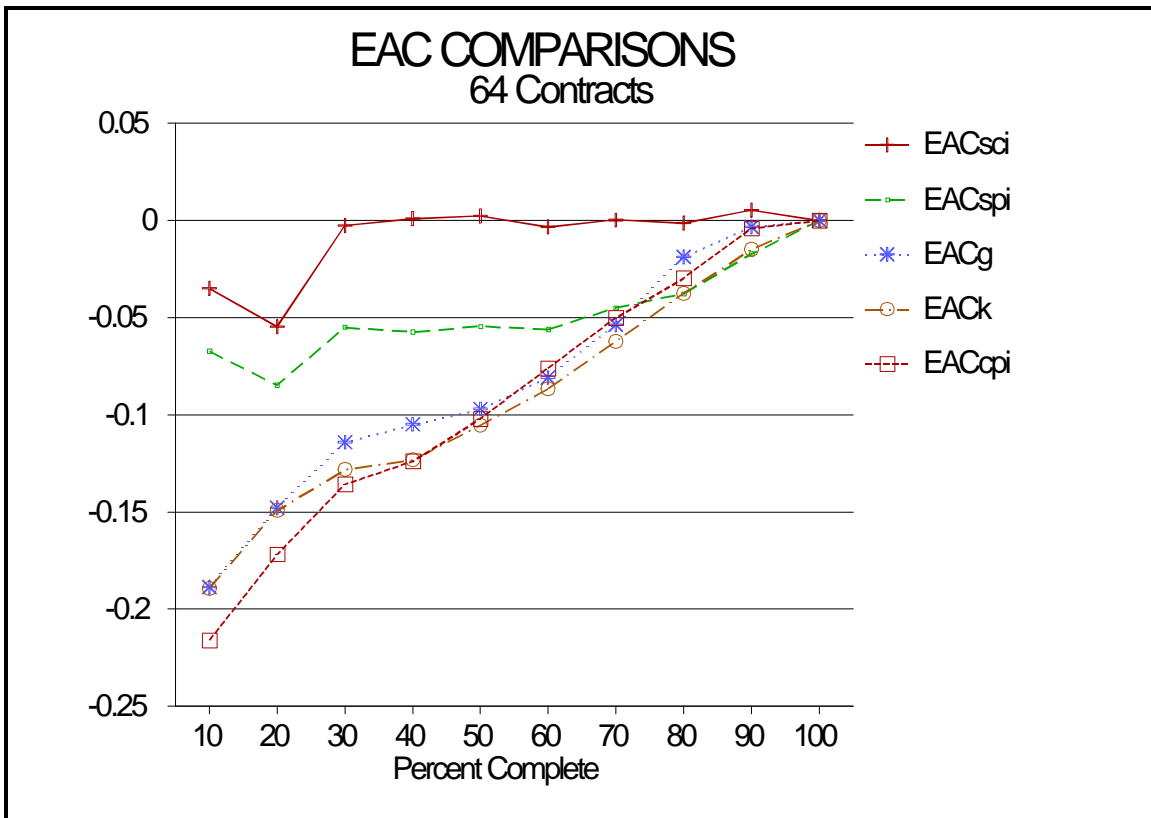
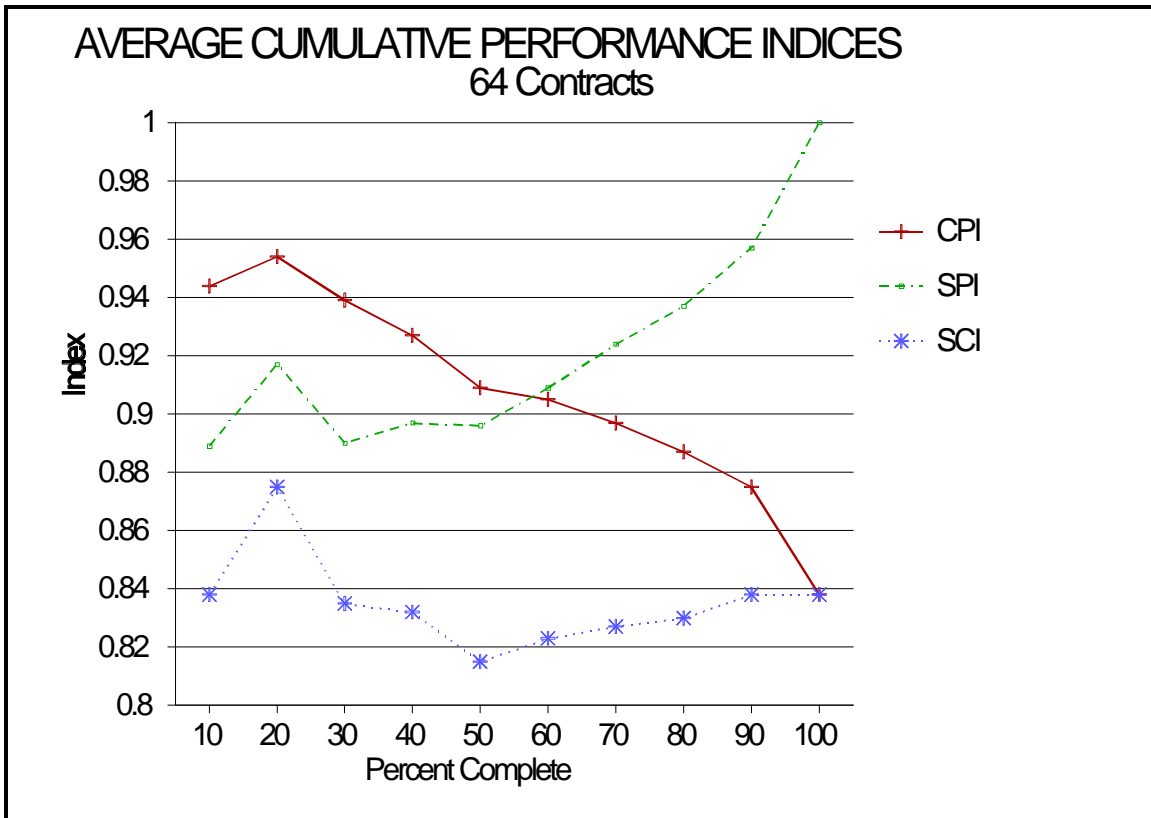
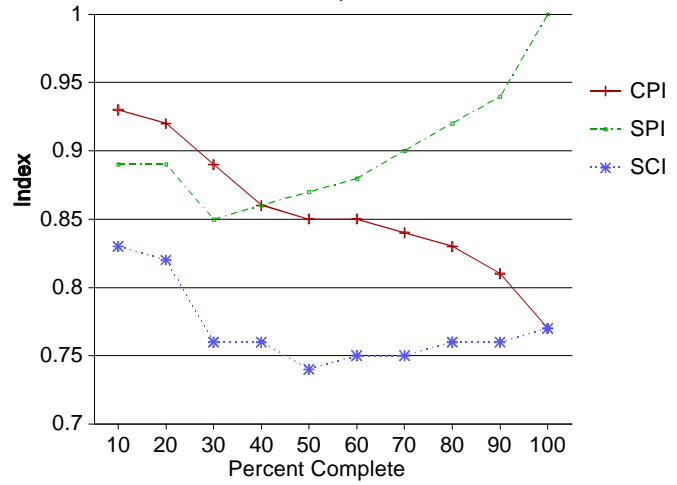
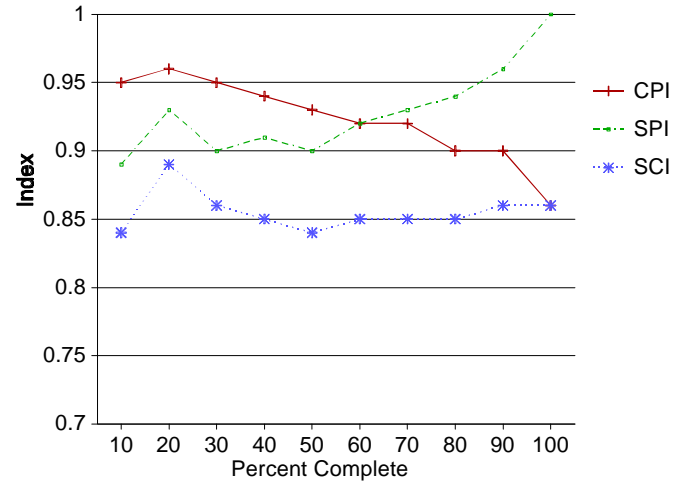


Figure 3. Comparison of Performance Indices and EACs.

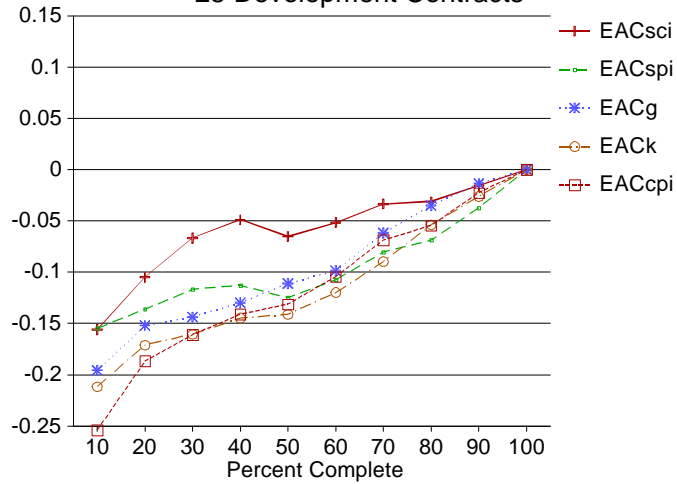
AVERAGE CUMULATIVE PERFORMANCE INDICES
25 Development Contracts



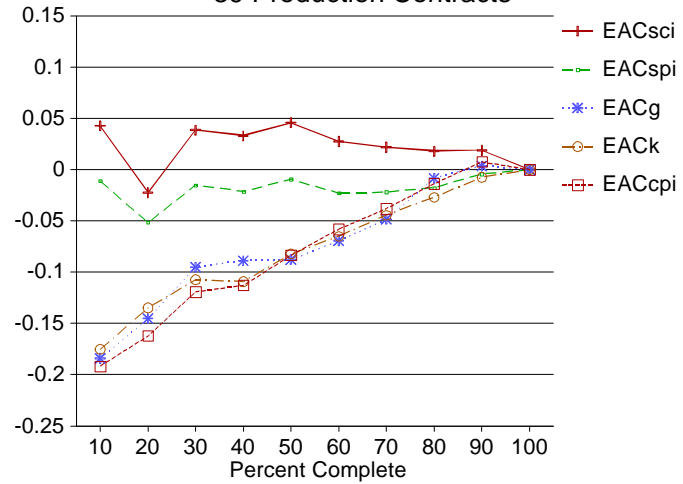
AVERAGE CUMULATIVE PERFORMANCE INDICES
39 Production Contracts



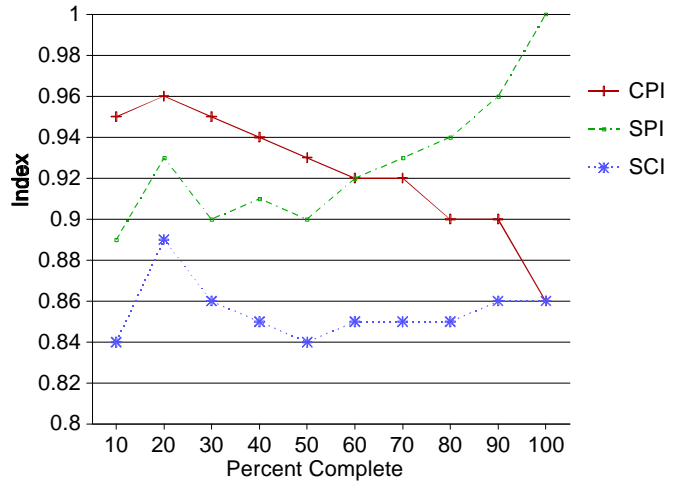
EAC COMPARISONS
25 Development Contracts



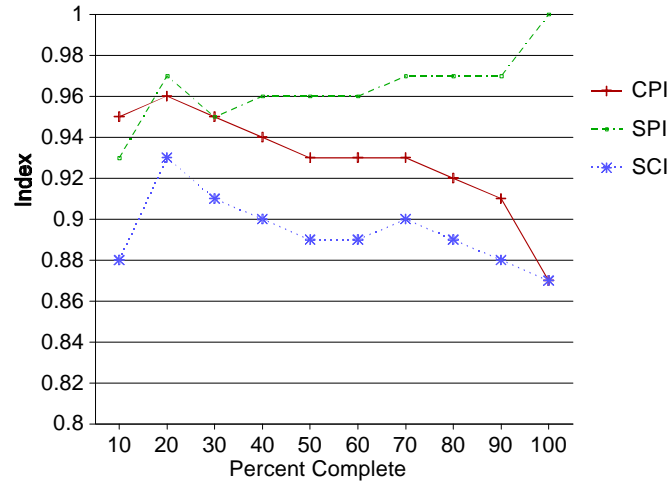
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39 Production Contracts



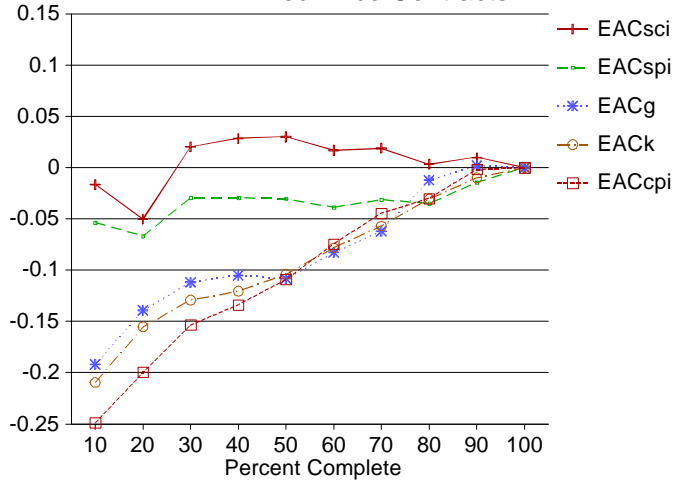
AVERAGE CUMULATIVE PERFORMANCE INDICES
41 Fixed Price Contracts



AVERAGE CUMULATIVE PERFORMANCE INDICES
23 Cost Reimbursable Contracts



EAC COMPARISONS
41 Fixed Price Contracts



EAC COMPARISONS
23 Cost Contracts

