COST PERFORMANCE INDEX STABILITY[1]

David S. Christensen
Scott R. Heise

INTRODUCTION

The Cost Performance Index (CPI) is a key indicator used to analyze cost and schedule performance data reported by defense contractors. The importance of the index was highlighted by the cancellation of the Navy's A-12 Stealth medium-bomber program.[2] And while Chester P. Beach, the Navy's inquiry officer who investigated the A-12 cancellation, referred to the index in his report (2:12):

> 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 18% of contract performance; in fact, it tends to decline.

The index is typically used to compute an estimate of the final cost of the completed contract, termed the Estimate at Completion (EAC). A stable CPI is important because it is used as a benchmark to assess the potential for cost overruns. In addition, although the index is stable, it is reported to only get worse. Accordingly, Beach was critical of the A-12 Program Officer for using the EAC based on the cumulative index as a ceiling rather than a floor for the estimated cost of the A-12 program. As a result of the A-12 cancellation, the Office of the Under Secretary of Defense for Acquisition (OUSD(A)) now requires that EAC's lower than that calculated using a cumulative CPI be specifically justified by the government program office (9:16-H-6).

Although the stability of the cumulative CPI has long been asserted by OUSD(A) and others, until recently there have been no empirical studies supporting this assertion. Using data from a sample of completed Air Force contracts, Christensen/Payne (6) established that the cumulative CPI did not change by more than 10 percent from the value at the 20 percent contract completion point. This study examines the generalizability of these findings to other contract types, programs, and services.

BACKGROUND

The CPI is one of several indicators used in the evaluation of a contractor's performance. It is calculated from data that the contractor provides monthly in either the Cost Performance Report (CPR) or the Cost/Schedule Status Report (C/SSR). DOD Instruction 5000.2 and its related manual (DOD 5000.2M) require that a CPR be submitted for contracts that require compliance with DOD Cost/Schedule Control Systems Criteria (C/SCSC) (9:20-7). For contracts not required to comply with C/SCSC, the C/SSR is usually required.

C/SCSC is a set of criteria designed to define an adequate contractor cost and the schedule management control system. The criteria are not a management system. Instead they describe or establish minimal standards for the management control system used by the contractor and have two objectives: (1) for contractors to use effective internal cost and schedule management control systems and (2) for the government to be able to rely on timely and auditable data produced by those systems for determining product-oriented contract status (7:v). Implicit in these objectives is the assumption that if the contractor's management control systems comply with criteria, the data generated by those systems will be reliable.

Data summarizing the contract's cost and schedule performance is reported in the CPR for C/SSR. Key elements include Actual Cost of work Performed (ACWP), Budgeted Cost of Work Scheduled (BCWS), Budgeted Cost of Work Performed (BCWP), Budget at Completion (BAC), and EAC. It is from these data elements that the CPI and other performance indexes derived.

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[1] *National Contract Management Journal*, 25:7-15 (1993)
[2] With the project final costs of $1 billion over contract price, and at least on year behind schedule, the A-12 contract was "terminated for default" on January 7, 1991. The contractors are contesting the action.

An analysis of these basic data elements creates information having both feedback value and predictive value. First, through detailed variance analysis the government is able to continuously identified problems and monitor management actions taken to resolve those problems. Although it might not be possible to completely solve an identified problem, variance analysis can at least warn management of schedule slips and potential cost overruns in enough time to initiate some corrective action. Second using the basic data elements from the CPR or C/SSR, the analysts can compute an independent EAC for comparison purposes. The reasonableness of the contractor's estimates can be assessed by computing independent EAC's. In the A-12 program, for example, independent EAC's computed by the government were as much as $1 billion more than contractor's EAC.

The effectiveness of variance analysis depends on an organizational culture. In a healthy culture a variance is a treasure. A variance discovered is an opportunity for improvement. An unhealthy culture uses variance analysis for fault finding and punishment. In a "shoot-the-messenger" culture, overly optimistic that data is revealed an unfavorable data is suppressed. Although routine analysis in the A-12 program revealed adverse trends, the significance of the unfavorable cost and schedule variances was not in the size to senior civilian decision makers. According to Beach, the EACs supported by both the contractor and the government program manager were unrealistic and not supported by the facts (2).

In the process of transforming the contractor's reported data into information, numerous performance ratios may be computed (8:12-15). Two ratios important to this study are the CPI and the To Complete Performance Index (TCPI):

$$CPI = BCWP/ACWP$$

$$TCPI = (BAC - BCWPcum) / (BAC - ACWPcum)$$

The CPI indicates the cost efficiency with which contractual work has been accomplished. A CPI of less than one implies a cost overrun; of more than one implies an on target condition. The values for BCWP and ACWP can be monthly, cumulative, or average, as long as they are consistent. The analyst must decide which values to use.

The TCPI represents the efficiency level that the contractor must achieve in the remaining work to meet the budgetary goal. In the second equation, the budgetary goal is BAC. If the budgetary goal is another number, such as the contractor's reported EAC, then the *denominator* in the second equation should be changed, where EAC replaces the BAC. The analyst must again decide what budgetary goal is appropriate. In any case, if the CPI is stable, it is an effective benchmark to assess the likelihood of a cost overrun.

The Importance of a Stable CPI

A stable CPI has relevance to the information generated by government analysts. First, the CPI is heavily weighted in several of the formulas that generate EACs. One expert claims that the CPI is used in many EAC formulas because of its asserted stability (3). Second, a stable CPI may be evidence of criteria-complaint management control systems. For example, a stable CPI is evidence that variances are being identified at appropriate detailed levels and are being corrected in a timely manner. Finally, a stable CPI has a significant value as a benchmark for comparison with the TCPI. If the TCPI is significantly larger than the CPI, the contractor will have to significantly improve the efficiency of the remaining contractual effort. Clearly, if the CPI is stable after a contract is 20 percent complete and is significantly less than the TCPI, it is unlikely that a contractor will be able to meet the budgetary goal despite any optimistic claims of the contractor. Based on a presentation to the National Security Industrial Association in January 1991, an analyst from OUSD(A) reported that at the 48 percent completion point in the A-12 program, the TCPI based on the BAC was 1.22 (4). The cumulative CPI was only 0.76. The contractor would thus have to operate at the efficiency level of nearly twice that achieved to avoid an overrun.

Evidence of CPI Stability

Until 1990 there was no published study supporting the stability of the cumulative CPI. Given the potential usefulness of a stable CPI, Payne (11) collected CPR data from the cost library of Aeronautical Systems Division (Air Force Systems Command) on seven completed aircraft procurement programs to test the hypothesis that the cumulative CPI was stable from the 50 percent completion point. In addition, the sensitivity of the results was tested at earlier points of completion. The 50 percent completion point was chosen because of a well-known heuristic: *once a contract is 50 percent complete, the cumulative CPI does not change by more than 10 percent* (3,5). Percent complete was defined as cumulative BCWP divided by BAC. Stability was defined using the range of the cumulative CPI from the 50 percent completion point to the end of the contract. For a given contract, a range of less than .2 defined a stable CPI; otherwise the CPI was defined as unstable.

Payne's results confirmed the hypothesis. The cumulative CPI was stable for all contracts from the 50 percent point. Sensitivity analysis showed that the index was also stable for all contracts from the 40, 30, and 20 percent points. At the 10 percent point, the cumulative CPI was stable for all but one of the contracts.

Given the limited sample size, it was difficult to generalize Payne's results to other services, programs, and contracts. Additional research with a broader database was needed. Accordingly, Heise (10) extended Payne's work to include a broader database and an examination of noncumulative CPIs.

METHODOLOGY

Data

Data selected fro the DAES database was obtained from the OUSD (A). This database contains contractor cost/schedule performance data on more than 400 defense contracts summarized quarterly by program offices from each service since June1970. Details regarding DAES reporting requirements are in Part 16 of DOD 5000.2M, "Defense Acquisition Management Documentation and Reports" (9).

Cumulative BCWP, cumulative ACWP, BAC, contract type and phase, service, program type, and contract dates were collected from 155 contracts from 44 different programs. Due to time constraints, not every contract in the DAES database was selected. Although the sampling technique was purely judgmental, the number and variety of programs, contract types, and contract phases are considered sufficiently large to establish generalizability. Programs selected included airplanes, ammunition avionics, engines, ground electronics, helicopters, missiles, rockets, satellites, software, submarines, support equipment, and torpedoes. Contact phases included demonstration/validation, full-scale development, follow-on development, low-rate-initial production, full-rate production, and construction. Contract types included fixed-price-incentive-fee, cost plus, cost-plus-fixed-fee, cost-plus-incentive-fee, and cost-plus-award-fee. The period of performance for these contracts ranged from June 1971 to February 1991.

Hypothesis Testing

For cumulative and noncumulative (three month, six month, and six-month moving average) CPI values, the hypothesis was: *the CPI is stable when a contract is greater than 50 percent complete.* This study employed the same definitions for CPI stability and percent complete as used by Payne. As in Payne's work, the sensitivity of the results was tested against earlier points of completion (40, 30, 20, 10, and zero percent). Cumulative CPI was calculated using the first equation with the data elements extracted directly from the DAES database. Noncumulative CPIs were calculated as follows:

$$CPI = (BCWP_1 – BCWP_2) / (ACWP_1 – ACWP_2)$$

$BCWP_1$ and $ACWP_1$ represent current cumulative values. For the three-month CPI, $BCWP_2$ and ACWP2 represent the cumulative values reported three months before the current cumulative values. For the six-month and six-month moving average CPIs, $BCWP_2$ and $ACWP_2$ represent the cumulative values reported six months before the current cumulative values. The difference between the two six-month calculations is that the moving average calculation is performed at three-month instead of six-month intervals.[3]

Trend Analysis

Trends in cumulative CPI movement were identified using the method of least squares. The expectation was that the cumulative CI tends to decline as the contract progresses. The method of least squares consists of finding a line that minimizes the sum of squared vertical deviations between the estimated line and the plotted points (CPIs). In the study, the slope of the best fitting line indicated the direction and magnitude of the cumulative CPI trend.

Additional Analysis

The relationship between CPI stability and contract characteristics was examined. The 153 contracts were divided into 26 groups using combinations of fixed price (FP), cost plus (CP), production (P), development (D), stable baseline (S), and unstable baseline (U) characteristics. (For some contracts, when a substantial amount of new effort was added to the contract during the period under investigation the percent complete could actually decline. These contracts were classified as having unstable baselines.) Production contracts included contracts in full-rate construction. Development contracts included contracts in full-scale development, follow-on development, demonstration/ -validation. The number of contracts possessing a certain set of characteristics was determined; then the percentage of these contracts having stable CPIs was calculated.

RESULTS

Non-cumulative CPI

As shown in Table 1, noncumulative CPIs were not shown from the 50 percent completion point. The mean range of the noncumulative three-month, six-month, and six-month moving average CPI exceeded .2 for most of the contracts examined. Only 6 percent of the contracts had stable three-month CPIs after the 50 percent completion point; 32 percent of the contracts had stable six month CPIs, and 19 percent of the contracts had stable six month moving average CPIs. A 95 percent confidence interval for each type of noncumulative CPI is also listed.

Table 2 details the relationship between noncumulative CPI stability and contract characteristics. The 155 contracts were divided into 26 groups using combinations of FP, CP, P, D, S, and U contract characteristics. For example, FL/P represents contracts that were fixed price and in initial production, full-rate production, and construction phases.

Listed next to the contract characteristics column is the column identifying the number of contracts with the stated characteristics. For example, of 101 FP contracts, 75 were in a production phases (FP/P) and 26 were in a development phase (FP/D). Of the 75 that were FP/P, 61 had stable baselines (FP/P/S) and 14 had unstable baselines (FP/P/U).

The remaining three columns list the number of contracts that had stable three-month, six-month, or six-month moving average CPIs as a percentage of all contracts in the same category. For example, from the 50 percent completion point, 8 percent of the 101 FP contracts had stable three-month CPIs, 36 percent had stable six-month CPIs, and 23 percent had stable six-month moving average CPIs. Contracts categorized as FP/D/S (fixed price, developmental phase, stable baseline) had the most stable noncumulative CPIs. For this category, 20 percent had stable three-month CPIs, 47 percent had stable six month CPIs, and 27 percent had stable six-month moving average CPIs. None of the contracts categorized as FP/D/U (fixed price, development phase, unstable baselines) had stable noncumulative CPIs.

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[3] In another definition of average CPI, monthly CPIs are added together and then divided by the number of months involved. The definition used here has been found to be a better predictor of EACs than the alternative definition and is consistent with the definition used by *Performance Analyzer*, a popular CPR analysis software package.

Cumulative CPI

As shown in Table 3, the cumulative CPI was stable for nearly all of the contracts at the 50 percent completion point. The range of the cumulative CPI did not exceed .2 for 153 of the 155 contracts. The mean range of the cumulative CPI was only .069 ± .008, with 95 percent confidence. The table also shows the number and percentage of contracts with stable cumulative CPIs for earlier completion points. At the 20 percent completion point, for example, 134 of 155 contracts had stable cumulative CPIs. The mean range of the cumulative CPI was .115 ± .012 at the 95 percent confidence level.

Table 4 shows a relationship between cumulative CPI stability and contract categories. The first two columns are the same as used in Table 2, detailing contract categories and numbers in each category. The remaining columns list descriptive statistics (maximum, minimum, mean, standard deviation) for the stabilization points of each category. For example, of the 101 FP contracts, the mean stabilization point was at the 11 percent completion point; of the 54 CP contracts, the mean stabilization point was 12 percent. Therefore, considering single contract characteristics, fixed-price contracts stabilized slightly earlier than cost-plus contracts. Similarly, production contracts stabilized development contracts. Other comparisons between categories can be done in the same way.

Table 5 shows the results of the cumulative CPI trend analysis accomplished by the method of least squares. The first two columns identify the stabilization points observed and the frequency of their occurrence. The third and fourth columns list the number of times a positive and negative slope was observed. The next three columns report descriptive statistics (maximum, minimum, mean) of the slopes for each stabilization point. Of the 18 contracts at the 20 percent stabilization point, two had positive slopes, 16 had negative slopes, the maximum slope was 0.033, the minimum slope was -0.368 and the mean was -0.194. Overall, there were significantly more negative slopes than positive slopes, indicating that the cumulative CPI, though stable as early as the 10 to 20 percent completion point, usually declined as the contract proceeded to completion.

Analysis of Results

The cumulative CPI stabilizes largely because it is a cumulative index. As the contract progresses, monthly BCWP and ACWP have decreasing influence on cumulative BCWP and ACWP. Stated another way, the capability of future performance to significantly alter the cumulative record of past performance decreases as the contract progresses.

The significance of a stable cumulative CPI lies in its value as a benchmark for comparisons against the TCPI and for computing the EAC. Because the cumulative CPI is stable for most contracts, if the TCPI is significantly greater than the cumulative CPI, the contract will likely overrun the budgetary goal. Furthermore, because the cumulative CPI tends to decline, the EAC computed by the cumulative CPI is a reasonable floor for the final cost at completion.

CONCLUSION

Prior research demonstrated cumulative CPI stability using data from seven aircraft procurement programs. This research establishes the generalizability of the earlier findings to the other services, programs, and contract types. Based on an analysis of 155 contracts from the DAES database, the cumulative CPI was stable from the 20 percent completion point with a 95 percent confidence interval. Stability was defined in terms of CPI range being less than 0.200. Non-cumulative CPIs (three-month, six-month, six-month moving average) were not stable.

Knowing that the cumulative CPI is stable is important. The government can now conclude with some confidence that a contractor is in serious trouble when it overruns the budget beyond the 20 percent completion point. Beach, the inquiry officer who investigated the cancellation of the A-12, was justifiably critical of the optimistic estimates of both the contractor and the government.

Any estimates at completion lower than that computed using a cumulative CPI must be justified. It will be extremely difficult to justify optimistic estimates given the evidence presented in this research. The cumulative CPI is stable from the 20 percent completion point on most contracts, tends only to get worse, and is an excellent benchmark for comparison against the TCPI.

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TABLE 1

Non-cumulative CPI Range Stability

	Three-Month	Six-Month	Six-Month Moving Average
Number of contracts	155	155	155
Contracts w/stable CPI	10	50	29
Percent Stable	6%	32%	29%
Maximum range	17.738	4.615	4.651
Minimum range	0.073	0.001	0.036
Mean range	1.072	0.419	0.530
Standard deviation	1.740	0.519	0.545
95% confidence interval	±.274	±.082	±.086

TABLE 2

Non-cumulative CPI Stability and Contract Characteristics

Characteristic	Number of Contracts	Three-Month	Six-Month	Six-Month Moving Average
FP	101	8%	36%	23%
CP	54	4%	26%	11%
P	93	5%	39%	23%
D	62	8%	23%	13%
S	109	8%	39%	24%
U	46	2%	15%	7%
FP/P	75	7%	39%	25%
FP/D	26	12%	27%	15%
FP/S	76	11%	43%	28%
FP/U	25	0%	12%	8%
CP/P	18	0%	39%	11%
CP/D	36	6%	19%	11%
CP/S	33	3%	30%	15%
CP/U	21	5%	19%	5%
P/S	75	7%	43%	25%
P/U	18	0%	22%	11%
D/S	34	12%	32%	21%
D/U	28	4%	11%	4%
FP/P/S	61	8%	43%	28%
FP/P/U	14	0%	21%	14%
FP/D/S	15	20%	47%	27%
FP/D/U	11	0%	0%	0%
CP/P/S	14	0%	43%	14%
CP/P/U	4	0%	25%	0%
CP/D/S	19	5%	21%	16%
CP/D/U	17	6%	18%	6%

FP=Fixed Price CP=Cost Plus P=Production
D=Development S=Stable baseline U=Unstable

TABLE 3
Cumulative CPI Range Stability

Percent complete:	0%	10%	20%	30%	40%	50%
Total contracts	110	152	155	155	155	155
Contracts w/ stable CPI	59	116	134	141	150	153
Percent stable	54%	76%	86%	91%	97%	99%
Maximum range	1.243	0.644	0.434	0.364	0.312	0.299
Minimum range	0.017	0.017	0.017	0.007	0.003	0.003
Mean range	0.262	0.145	0.115	0.096	0.081	0.069
Standard deviation	0.213	0.103	0.078	0.068	0.056	0.051
95% confidence interval	±0.040	±0.016	±0.012	±0.011	±0.009	±0.008

TABLE 4

Non-cumulative CPI Stability and Contract Characteristic

		Stabilization Point (Percent Complete)			
Contract Category	Number of Contracts	Maximum	Minimum	Mean	Standard Deviation
FP	101	70	0	11	14
CP	54	50	0	12	14
P	93	50	0	9	11
D	62	70	0	15	16
S	109	70	0	10	12
U	46	60	0	16	16
FP/P	75	50	0	10	12
FP/D	26	70	0	14	17
FP/S	76	70	0	11	14
FP/U	25	60	0	12	14
CP/P	18	10	0	6	5
CP/D	36	50	0	15	16
CP/S	33	20	0	7	6
CP/U	21	50	0	20	18
P/S	75	50	0	9	12
P/U	18	30	0	9	8
D/S	34	70	0	11	12
D/U	28	60	0	20	19
FP/P/S	61	50	0	10	13
FP/P/U	14	30	0	10	9
FP/D/S	15	70	0	14	17
FP/D/U	11	60	0	15	19
CP/P/S	14	10	0	6	5
CP/P/U	4	10	0	8	5
CP/D/S	19	20	0	8	6
CP/D/U	17	50	0	23	19

FP = Fixed Price   CP = Cost Plus   P = Production
D = Development   S = Stable Baseline   U = Unstable Baseline

TABLE 5

Cumulative CPI Trend Analysis

				Slope		
Stabilization Point	Frequency	Total (+)	Total (-)	Maximum	Minimum	Mean
70	1	0	1	-0.770	-0.770	-0.770
60	1	0	1	-0.701	-0.701	-0.701
50	3	0	3	-0.438	-0.564	-0.486
40	9	0	9	-0.209	-0.501	-0.384
30	7	1	6	0.067	-0.442	-0.187
20	18	2	16	0.033	-0.368	-0.194
10	57	13	44	0.149	-0.244	-0.059
0	59	13	46	0.132	-0.182	-0.059