



# Independent Estimates at Completion – Another Method

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*This article reviews the most frequently used Earned Value Management formulas for calculating the Independent Estimate at Completion (IEAC). The formulas are examined and discussed with reference to the findings from several studies. Some formulas appear to be inconsistent with the determinations from the studies of the Cost Performance Index (CPI). An alternative method of calculating IEAC is proposed, which is in agreement with the generalizations and conclusions from the IEAC and the CPI studies. This method shows promise.*

The calculation of the Independent Estimate at Completion (IEAC) is significant to project management. It is a quick method facilitated by using Earned Value Management to predict the final project cost. Project managers (PM) and cost analysts often use IEAC to validate the bottoms-up forecast made by contract sources. When the IEAC result is substantially different from the contractor's estimate, more than likely the PM will question the discrepancy. The PMs also use the IEAC to justify continuation of the project to upper management. Thus, you can see IEAC has far reaching implications.

During the last 10 years, primarily due to the interest generated from the cancellation of the Navy's A-12 Avenger acquisition program, studies of the predictive accuracy of the various methods for calculating IEAC have been made. These studies considered and included several IEAC formulas and regression calculation methods. In general, no single specific method has been shown to be superior.

Although no particular method provided accurate results for all periods or phases of a project, some fundamental characteristics were observed. With the establishment of these characteristics, the application of some of the IEAC formulas and calculation methods appears to be questionable. However, these fundamentals have provided inspiration for proposing new IEAC methods in this article.

## Studies of IEAC and Cost Performance Index

There are several popular formulas for calculating IEAC. In general, the equations use the cost to date added to the forecast cost for the work remaining. For the formulas identified here, the Cost Performance Index (CPI) and Schedule Performance Index (SPI) are the cumulative values unless otherwise noted<sup>1</sup>. The following are the IEAC formulas most often seen and used:

- $IEAC_1 = ACWP + (BAC - BCWP) / CPI$
- $IEAC_2 = ACWP + (BAC - BCWP) / SPI$
- $IEAC_3 = ACWP + (BAC - BCWP) / (SPI * CPI)$
- $IEAC_4 = ACWP + (BAC - BCWP) / (wt_1 * SPI + wt_2 * CPI)$
- $IEAC_5 = ACWP + (BAC - BCWP) / CPI_x$

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**“Using the range of outcomes for the CPI from the statistical method and IEAC<sub>1</sub>, a range for the estimates at completion can be calculated. The range may be computed for any statistical confidence level desired ...”**

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For IEAC<sub>3</sub> the product, SPI \* CPI, is sometimes identified in literature as SCI. The abbreviations wt<sub>1</sub> and wt<sub>2</sub> of IEAC<sub>4</sub> are numbers between 0.0 and 1.0 used to weight the influence of the two indexes; the sum of wt<sub>1</sub> and wt<sub>2</sub> is equal to 1.0. The CPI<sub>x</sub> in IEAC<sub>5</sub> is the cumulative value of the last x performance periods.

Two studies were performed in the 1990s that examined the prediction capability of the various formulas and regression methods [1, 2]. The generalizations and conclusions reached by these studies of IEAC are as follows:

1. The accuracy of regression-based forecasting has not been established. A

recommendation was made to further study the method.

2. The accuracy of index-based formulas depends upon the system in development, and the stage and phase of the project. The formula most frequently appearing in the tabulated results, regardless of type and stage, is IEAC<sub>3</sub>.
3. The index-based formulas, including SPI are better applied early in the project. For projects behind schedule, SPI falsely improves as percent complete increases. Thus, the influence of SPI on the computation is not in agreement with actual schedule performance.
4. The accuracy of IEAC<sub>4</sub> with wt<sub>1</sub> = 0.2 and wt<sub>2</sub> = 0.8 is not supported.
5. The accuracy of IEAC<sub>5</sub> is better for middle and late stages of the project.

A second set of studies was performed that examined the behavior of the CPI throughout the life of a contract [3, 4, 5]. Two of the studies are very recent – spring and winter 2002 – and performed the analysis using statistical hypothesis testing. The three studies provided the following to PMs for assessing the validity of estimates at completion:

1. The result from IEAC<sub>1</sub> is a reasonable estimate of the lower bound of the final cost.
2. The cumulative value of the CPI stabilizes by the time the project is 20 percent complete. Stability is defined to mean that the final CPI does not vary by more than 0.10 from the value at 20 percent complete.
3. The value of the CPI tends only to worsen from the point of stability until project completion.

## Commentary

The understanding of the behavior of the CPI, over the life of the project, provides insight regarding the study results for the IEAC equations. For IEAC<sub>2</sub>,

IEAC<sub>3</sub> and IEAC<sub>4</sub>, the divisor containing expressions of the present cumulative values of the SPI and CPI correlate to the final CPI, when the project is not performing as planned. We know from the study of CPI behavior that the final CPI is likely to be less than the present value; thus, having a SPI less than 1.0, or less than the CPI, will cause the estimate at completion to be larger than the result from using IEAC<sub>1</sub>, as we know it must be. Regarding IEAC<sub>5</sub>, it makes sense that this equation is a reasonably good predictor because the CPI<sub>k</sub> is constructed from recent data. However, the limited amount of data used for creating the CPI<sub>k</sub> causes IEAC<sub>5</sub> to oftentimes exhibit erratic behavior.

From these correlations, there appears to be insufficient reason to continue to use IEAC equations two through five. We know from the winter 2002 study [5] that the calculated result from IEAC<sub>1</sub> is a good estimate of the lower bound for the final cost. Also, it is known with 95 percent confidence that the absolute value of the difference between the CPI at 20 percent complete (CPI<sub>20</sub>) and the CPI at project completion (CPI<sub>100</sub>) will not be greater than 0.10 [4]. Thus the result from IEAC<sub>1</sub>, when using the projected extreme values for the CPI<sub>100</sub>, is expected to yield the upper and lower bounds for the final cost. Only the IEAC<sub>1</sub> equation is needed to predict the range of project cost outcomes with 90 percent confidence<sup>2</sup>. (*A 90 percent confidence for the estimate at completion (EAC) range is equivalent to 95 percent confidence that  $|CPI_{20} - CPI_{100}| \leq 0.1$ .*)

## Alternative Calculation Methods

An alternative to the presently employed IEAC calculation methods (the five formulas cited previously) is to compute the statistical range of outcomes for the CPI. I have described and illustrated this method in a prior publication [6]. Using the range of outcomes for the CPI from the statistical method and IEAC<sub>1</sub>, a range for the estimates at completion can be calculated. The range may be computed for any statistical confidence level desired; in my article referenced above, the range is  $\pm$  three standard deviations, but it just as well could be 90 percent.

If the CPI for each performance period of the project behaves independently from when it occurs, then this method should yield very good results. Without proof, I believe that the method will still provide reasonable results, even when there is an underlying relationship

between the cumulative value of the CPI and the period of performance in which it occurs. The reason for my assertion is the value of the CPI is updated each period; therefore, it is moving toward its final value. And, the standard deviation of the periodic values is likely large enough to encompass the value for the CPI at project completion. Therefore, it is very likely the actual final cost will be within the 90 percent confidence range calculated using IEAC<sub>1</sub>. For this method, the predicted estimate at completion will always be optimistically biased; i.e., it is likely the computed nominal value will be less than the final actual cost.

A second IEAC alternative calculation method is similar to the first, but it should reduce the optimistic bias. The characteristic of the CPI worsens from the point of stability until completion, reported in the 1993 study [3], indicates there may be a mathematical relationship between cumulative CPI and the percentage of project completion: *Beginning at 20 percent complete, the CPI is regarded as stable and proceeds to*

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**“ ... I believe that the method will still provide reasonable results, even when there is an underlying relationship between the cumulative value of the CPI and the period of performance in which it occurs.”**

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*decrease as percent complete increases, but does not fall more than 0.10 from its stable value.*

Having the periodic cumulative values of the CPI indicate increasingly inefficient cost performance as the project nears completion makes intuitive sense. During the early and middle stages of a project there are many tasks for which effort expended will gain earned value. In these stages, if an impediment for a task stands in the way of its accomplishment, there is generally opportunity to do another task. However, if an impediment occurs as the project nears completion, it is highly likely the worker will waste effort until the task can be completed because other tasks are not available. In actuality, what I have

described occurs.

Understanding the stability and inefficiency characteristics, a mathematical model of the CPI decreasing as the project moves toward completion can be created. With the proposed equation, it should be understood that the model only deals with the two characteristics and thus has little theoretical substantiation. The mathematical form chosen, after some experimentation, is the following:

$$\ln \text{CPI} = A + B * (X \wedge 3)$$

where,

A and B are unknown parameters, X is the percentage completion of the project, and ln is the natural logarithm.

The calculated result from the equation is considered to be valid when the project is within the range of 20 percent to 100 percent complete. An advantage of the model's mathematical form is that it has only two unknown parameters: A and B. Parameter A can be either positive or negative; however, B can only be negative. By constraining B to be negative, the tendency of the CPI to worsen from the point of stability to project completion is imposed in the model [4]. The rate of decrease of the CPI is dependent upon B and the power to which X (percent complete) is raised. After some trials, I chose the power 3. It seems reasonable that noticeable efficiency roll-off should begin to occur when X equals 0.5; the power equal to 3 provides this behavior.

Using this model with curve-fitting software, statistical prediction is easily accomplished. The software produces the nominal values for A and B along with their corresponding 90 percent confidence limits.<sup>2</sup> When applying the curve fitting software, the variables A and B are constrained such that the CPI<sub>100</sub> is within 0.1 of the CPI<sub>20</sub>. As mentioned previously, the variable B is further restricted to have only negative values. The constrained values for A and B are computed for each paired data values of the CPI and percent complete using the following equations:

$$\begin{aligned} A_{\text{con}} &= \ln(\text{CPI}_{2n} + 0.1) - B_{\text{max}} \\ B_{\text{con}} &= \ln(\text{CPI}_{2n} - 0.1) - A_{\text{min}} \end{aligned}$$

where,

A<sub>con</sub> and B<sub>con</sub> are the constraint values for the variables A and B; A<sub>min</sub> and B<sub>max</sub> (= 0) are the minimum and maximum values of A and B, respectively; and the CPI<sub>2n</sub> is the value occurring at the first percent com-

Percent Complete	The CPI	Percent Complete	The CPI
0.05	1.07896	0.50	1.04279
0.10	1.01511	0.60	1.03634
0.15	1.05731	0.70	1.02942
0.20	1.05961	0.80	1.01076
0.25	1.05844	0.90	0.99260
0.30	1.05211	1.00	0.97287
0.40	1.04970		

Table 1: *Percent Complete and the CPI Data (notional)*

plete greater than 0.2. The value of the  $CPI_{2n}$  is assumed to approximate the  $CPI_{2n}$ .

Applying the constraints in the curve-fitting software for each new data point maintains proper behavior of the CPI model. The  $A_{con}$  constraint is the maximum nominal value of the A variable from the curve fit. Similarly, the variable B is constrained between zero and  $B_{con}$ . Because the constraints may affect the curve fit, the nominal value of A should be reviewed for change. If it has changed, use the new value as  $A_{min}$  in the  $B_{con}$  equation to recalculate the constraint value of B. Enter the computed value for  $B_{con}$  and re-perform the curve fit.

The confidence limits produced from the software assume that the data population is infinite. However for our application, project data is finite. For example, the project may execute for two years; if earned value status is taken monthly, the project has 24 data points. Because projects are finite, the confidence limits for ln CPI from the curve fit require adjustment. Multiplying the confidence interval by the following factor will perform the adjustment:

$$\sqrt{((BAC - BCWP) / (BAC - BCWP_{avg}))}$$

where,

$BCWP_{avg}$  is equal to BCWP divided by the number of periodic observations.

The effect of the adjustment factor is to decrease the range for the possible outcomes of the estimates, as the project moves toward completion. For example, at project completion having a range of possible outcomes has no meaning. The adjustment factor reduces the range to zero when the project is finished.

Using the adjusted confidence interval, the 90 percent confidence limits for ln CPI can be computed. Of course, by applying the antilog the upper and lower CPI values are determined. These quantities are then used in  $IEAC_1$  to calculate the 90 percent confidence limits of the EAC. The calculation may yield a confidence limit outside of the upper and lower bounds for EAC, especially when percent complete is less than 0.5. In agreement with the studies cited earlier, the lower bound is estimated by dividing the  $CPI_{2n}$  plus 0.1 into BAC, while the upper bound is BAC divided by  $CPI_{2n}$  minus 0.10.

### Example Application

To provide an example of the proposed IEAC calculation method, notional data

has been created for percent complete and the cumulative CPI. The data is shown in Table 1.

Beginning with  $X \geq 0.2$ , the nominal values of A and B, and their 90 percent confidence limits, are repeatedly obtained from the curve-fit as each new data point is included in the data set. A minimum of three data points is required to determine A and B and their limits. The high and the low values for ln CPI, calculated from the model's formula, are determined by pairing the high values of A and B, and the low values, respectively. The high and low ln CPI limits are then modified by the finite project adjustment factor, as described in the previous section. These adjusted limits are the 90 percent confidence limits for ln CPI.

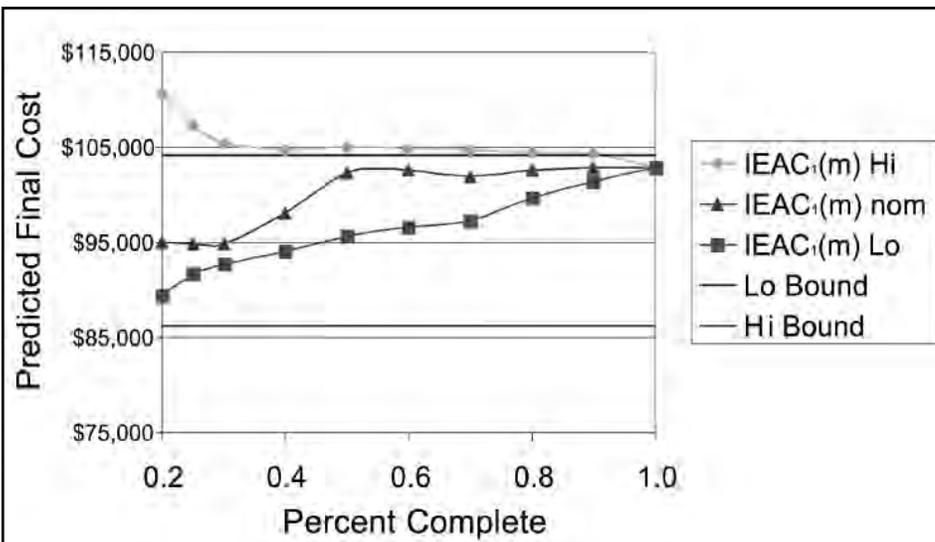
The antilogarithms of the nominal, and the adjusted high and low values, of ln CPI are used in the  $IEAC_1$  equation to calculate estimate at completion. The calculation produces the most likely value for EAC along with its 90 percent confidence limits. For the Budget at Completion (BAC) equal to \$100,000, the result of the curve fit for our IEAC model ( $IEAC_1(m)$ ) is shown in Figure 1.

As can be observed, the model rapidly converges and accurately predicts (\$102,817) the final cost (\$102,788), after only a few data points are included in the curve fit. Likewise, it is seen that the 90 percent confidence limits,  $IEAC_1(m)$  Hi and  $IEAC_1(m)$  Lo, converge and eventually fall within the high and low boundaries for EAC. For reference, the high and low bounds for EAC are shown in the figure as Hi Bound and Lo Bound. The value for the high bound is \$104,209, while the low bound is \$86,236. Thus, it can be said that the results from the IEAC model are well behaved with respect to the predicted extremes of the estimate at completion.

To further illustrate the model's performance, the results from computing  $IEAC_1$  and  $IEAC_3$  are compared to our model. Recall that  $IEAC_3$  uses  $CPI_3$ , which is the cumulative value of the CPI from the last three periodic observations. Figure 2 graphically depicts the percent difference from the final cost for each of the calculation methods.  $IEAC_1$  and  $IEAC_3$  are calculated using the equations cited earlier, while  $IEAC_1(m)$  and  $IEAC_1(m)$  Lo are the nominal and low confidence limit values from Figure 1.

As seen from Figure 2, the three methods produce comparably poor results for percent complete equal to 20 percent through 30 percent. Beginning at 40 percent there is a marked departure; the model's prediction of final cost becomes

Figure 1: *IEAC<sub>1</sub> Model*



significantly improved and is better than the other estimates. Beginning at 50 percent and continuing through project completion, the method used to calculate  $IEAC_i(m)$  produces cost estimates that have very small differences with the actual final cost. It is also noticeable that  $IEAC_i$  provides optimistic results as it should if, indeed, the CPI tends to worsen as percent complete increases [3, 4]. Likewise,  $IEAC_s$  produces optimistic results as percent complete increases, again, due to the tendency of the CPI to worsen. While not observed in the example, the CPI model can produce either optimistic or pessimistic results for  $IEAC_i(m)$ .

The final observation for Figure 2 is the comparison of  $IEAC_i$  to  $IEAC_i(m)$  Lo. Recall from the earlier discussion in the studies section of this article that  $IEAC_i$  was postulated to provide a good running estimate for the lowest value for final cost. The figure shows the two lines closely tracking beginning at percent complete equal to 0.40. Thus if the hypothesis concerning  $IEAC_i$  is valid, there is added credence to the nominal and high confidence limit values produced by the  $IEAC_i(m)$  calculation method.

Although the graphical result appears wonderful, the method is unproven. The data created conforms to the model itself; thus, the result should be good. Even so, what has been shown is significant. The model presented for the CPI behaves in accordance with the behavior characteristics determined by previous studies [3, 4, 5]:

1. The CPI stabilizes when project reaches 20 percent complete,  $CPI_{20}$ .
2. The CPI tends only to worsen from the point of stability until project completion.
3. With 95 percent confidence, the CPI at project completion will not be more than 0.10 from  $CPI_{20}$ .

If these characteristics are indeed true, then our example indicates the proposed model may provide good prediction capability for estimate at completion.

### Prototype Application

To further illustrate the curve fit model approach to calculating  $IEAC$ , results from prototyping actual project data are shown. The application is in progress. As can be seen, the results from the real data correlate well with the notional data presented earlier. Figure 3 is an output from the curve fit software. In agreement with the studies of the CPI, the  $\ln$  CPI is seen worsening as percent complete increases. As discussed earlier, the model accounts for degradation of cost performance as

the project nears completion. Figure 4 illustrates the model's rapid convergence to the predicted final cost. Observed in Figure 5 (see page 30), both  $IEAC_i$  and  $IEAC_s$  are predicting a more optimistic final cost than is the model. Lastly, the close tracking of  $IEAC_i(m)$  Lo  $IEAC_i$  is

strikingly similar to the observation made for the notional data.

### Summary

From several previous studies, it can be inferred that the behavior of the CPI, from its point of stability to project com-

Figure 2:  $IEAC$  Comparison

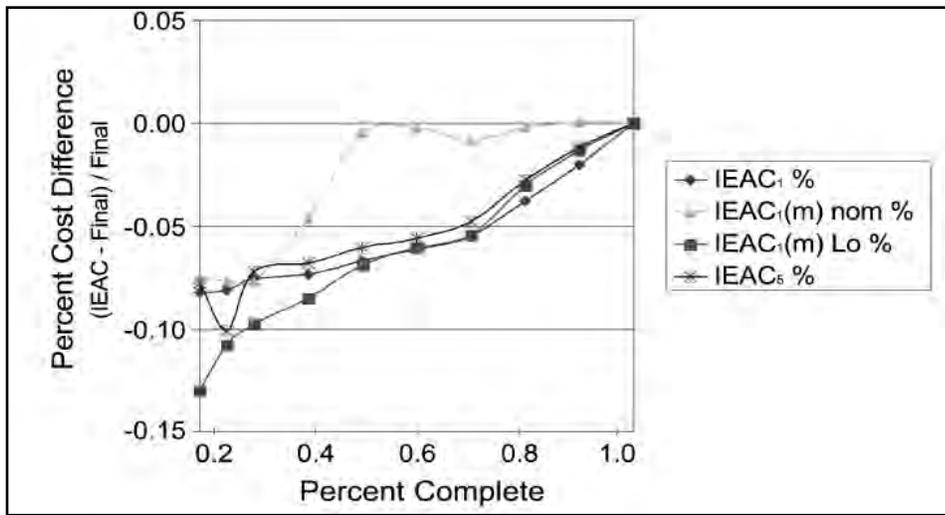


Figure 3:  $\ln$  CPI Versus Percent Complete (Prototype)

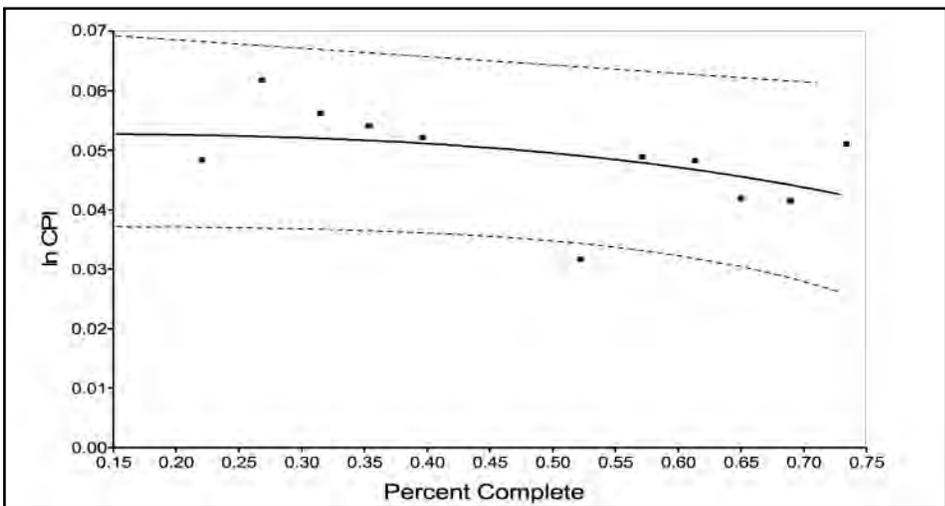
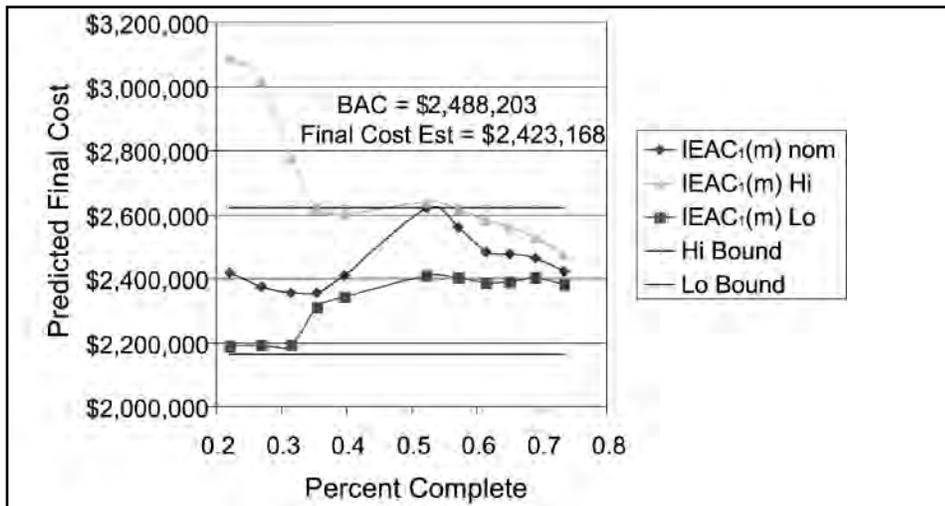


Figure 4:  $IEAC_i$  Analysis (Prototype)



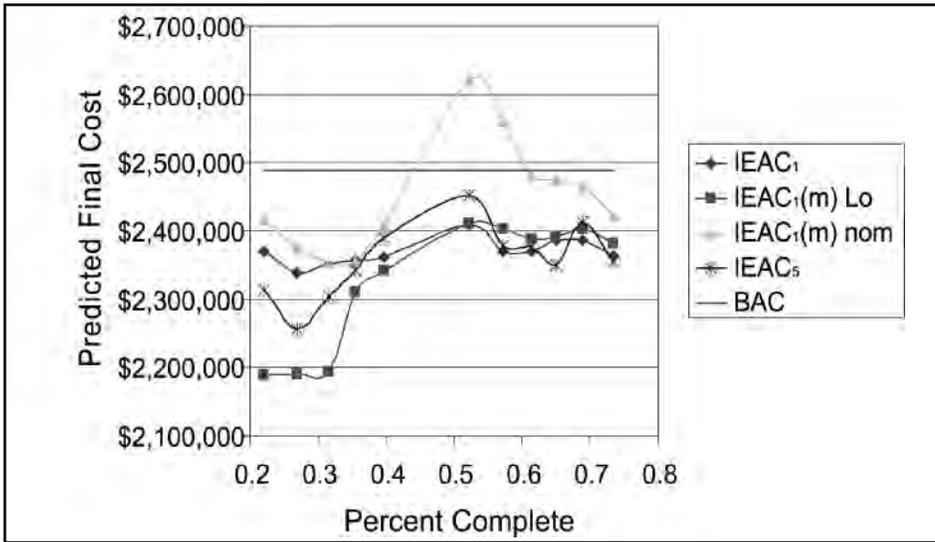


Figure 5: IEAC Comparison (Prototype)

pletion, explains why the various formulations of IEAC yield reasonable results for specific conditions. By incorporating this behavior into a mathematical model for the CPI, it is proposed the only formula needed for estimating the cost at completion is IEAC<sub>i</sub>; the cumulative value of the CPI is replaced in the formula by the value from the model.

The model for the CPI is constructed to behave in accordance with characteristics determined by past studies. The values of the CPI will tend to decrease as the completion percentage of the project increases. The amount of decrease is constrained to agree with the statistical testing studies.

Using the mathematical model for the CPI with curve-fitting software and associated statistical methods, the independent estimate at completion with its 90 percent confidence limits can be computed. As indicated from the application to both notional and real data, the proposed method yields excellent results. The method may be an improvement to the IEAC equations presently applied. ♦

### Recommendation

To validate for general application, the CPI behavior model and IEAC calculation method discussed in this article should have an independent study performed using data from the Department of Defense earned value database.

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### Notes

1. The definitions of the cost and schedule performance indexes (the CPI and SPI, respectively), and cost variance (CV) are as follows:

$$\begin{aligned} \text{The CPI} &= \text{BCWP} / \text{ACWP} \\ \text{SPI} &= \text{BCWP} / \text{BCWS} \\ \text{CV} &= \text{BCWP} - \text{ACWP} \end{aligned}$$

where,

$$\begin{aligned} \text{ACWP} &= \text{Actual Cost for Work Performed} \\ \text{BCWP} &= \text{Budgeted Cost for Work Performed (earned value)} \\ \text{BCWS} &= \text{Budgeted Cost for Work Scheduled (project performance baseline)} \end{aligned}$$

For a more in-depth explanation of earned value and its indicators, reference Quentin Fleming's book [7].

2. The Confidence Interval is the region surrounding the computed nominal value within which the true value lies with a specified level of confidence. The end points of the interval are the Confidence Limits. The equation for the Confidence Limits is:

$$\langle x \rangle \pm z (\sigma/\sqrt{n})$$

where,

$\langle x \rangle$  is the nominal value of  $x$ , while  $z$  is from the standard unit normal distribution and corresponds to the area selected (for this application,  $z = 1.6449$  at 90 percent of the distribution area),  $\sigma$  is the standard deviation of the observations of  $x$ , and  $n$  is the number of observations [8].

### About the Author



**Walt Lipke** is the deputy chief of the Software Division at the Oklahoma City Air Logistics Center. He has 30 years of experience in the

development, maintenance, and management of software for automated testing of avionics. In 1993 with his guidance, the Test Program Set and Industrial Automation (TPS and IA) functions of the division became the first Air Force activity to achieve Level 2 of the Software Engineering Institute's Capability Maturity Model® (CMM®). In 1996, these functions became the first software activity in federal service to achieve CMM Level 4 distinction. Under Lipke's direction, the TPS and IA functions became ISO 9001/TickIT registered in 1998. These same functions were honored in 1999 with the Institute of Electrical and Electronics Engineers' Computer Society Award for Software Process Achievement. Lipke is a professional engineer with a master's degree in physics.

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