Connecting Earned Value to the Schedule

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Abstract. *For project cost, analysts can predict the final value with some confidence using the Independent Estimate at Completion (IEAC) formulas from Earned Value Management (EVM).[1] The formulas provide a means to understand the financial health of a project without having to reassess the cost value for each of the unfinished tasks. Earned value analysts cannot assess the health of schedule performance in the same manner. EVM does not provide IEAC-like formulas by which to predict the final duration of a project. Many who are knowledgeable of earned value express the opinion that schedule information derived from EVM is of little value. This paper discusses the problem and develops a methodology for calculating the predicted project duration using EVM data. The methodology uses the concept of Earned Schedule and introduces an additional measure required for the calculation.*

Introduction

Earned Value Management (EVM) is a wonderful management method connecting in a very unique way, cost, schedule, and technical performance. It provides capability which facilitates a more scientific approach to project management; i.e. through the use of EVM, project status is now described from numerical evidence. Although this advancement in management method is tremendously significant, EVM has three major deficiencies:

1) *The performance indicators are not directly connected to project output. For example, milestone completion or delivery of products may not meet the customer's expectation, yet EVM indicator values are acceptable.*
2) *The schedule indicators are flawed. For projects completing late, the indicators always show perfect schedule performance.*
3) *The performance indicators are not explicitly connected to appropriate management action. Even with EVM data, the project manager remains reliant upon his intuition as to any action needed.*

The first two deficiencies cited are reasons as to why EVM is generally regarded as a cost management tool; the information relating to schedule performance is inadequate. In fact, there are many knowledgeable users who express the opinion that the prediction of project duration from the use of the schedule indicators is an exercise in futility.

Although there are barriers to having an estimating formula for predicting final project duration from EVM data, it remains a desired capability. Project managers (PM) need the ability to generate reasonable estimates of the duration. Furthermore, they need to be able to estimate a revised completion date at every reporting period without having to exhaustingly evaluate the tasks remaining each time. That is, to manage cost and schedule equally well, PMs need comparable analysis capability for both.

For the remainder of the paper, I'll discuss what is known about project performance. I'll then describe the mechanisms which may cause the behavior. From this foundation, a new performance measure is proposed. The new measure provides the connection of project output to EVM indicators and facilitates the estimation of final project duration.

Behavior of the Cost Performance Index

During the 1990s and through 2002, a considerable amount of research was performed concerning the independent estimate at completion (IEAC) formulas and the cost performance index (CPI) from Earned Value Management [2,3,4,5,6]. The research, inspired by the cancellation of the Navy's A-12 Avenger acquisition program, focused, primarily, on the accuracy of the various formulas for IEAC. However, some of the studies examined the behavior of CPI over the life of the project.

The findings from the IEAC studies were mostly generalizations. Possibly, the most significant result is that the equations using the schedule performance index (SPI) in the performance factor (PF) are better applied early in the project.

In my opinion, the studies of CPI are extremely significant to project management. Important observations were made as to how the cost index behaves from the project's beginning until its completion. This behavior explains the findings from the IEAC studies, and validates the use of IEAC = BAC / CPI to predict final cost (BAC is the project Budget at Completion). The CPI study findings are the following:

1) The result from IEAC = BAC / CPI is a reasonable running estimate of the low value for final cost.
2) The cumulative value of 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 CPI tends only to worsen from the point of stability until project completion.

These results have come from applying methodical statistical testing to as many as 200 large Department of Defense projects. Finding number 2 is established at the statistical confidence level of 95 percent. Thus, in the very early stage of a project, approximately 20 percent complete, the project manager has a good estimate of the high and low bounds of final cost. As the project progresses, the low bound is refined by using the knowledge from finding number 1. Finally, finding 3 indicates that risk impacts tend to occur late in the project; it reminds us to monitor and manage the risks to minimize the worsening of cost efficiency as the project progresses. These are extremely useful PM tools.

What Causes CPI to Worsen?

In struggling to answer this question, I began to think about what happens in the execution of the planned project tasks. Early in the project there are many tasks available to work, but as the project moves toward completion the number grows smaller. If impediments occur early, the PM may not take notice because a worker was shifted from the stalled task to another for which he could gain EV. On the other hand, when impediments occur late, there may not be other EV to work. If that is the case, cost efficiency suffers …*and so would schedule performance*. And certainly, the PM will become very aware of the impediment and what effects it is having upon his project's performance.

This deduction, seemingly, is reasonable and the rationale qualitatively explains why the studies observed CPI worsening as EV increased. But, then I wondered, "Do the early impediments cause late impacts, as well?" At first, it wasn't obvious that they might, but I soon realized performing work out of sequence is a likely cause of rework.

When impediments occur early and workers are redirected to perform tasks out of sequence with the plan, I reasoned they must do so at risk. It is a risk because the tasks performed not in accordance with the plan do not have all of the inputs necessary. When inputs aren't fully defined, significant task rework can be expected; the workers are having to fill-in the missing inputs using their own intuition and technical knowledge. When they anticipate well, all is fine; but if not, the task can expect rework, possibly, of the order of 50 percent, or even greater. The rework for the task will appear later in the project and is likely to ripple into subsequent tasks, as it is discovered that functions don't perform as expected.

In general, processes have limitations; i.e., there are bottlenecks or constraints which, when overloaded, limit task progress. The aggregation of rework can overcome the work flow planned in the project schedule and cause overloading of the process constraint. The PM, to keep work flowing when a limiting constraint is encountered, may knowingly shift workers to alternative tasks. By taking this proactive approach, the PM inadvertently creates more rework. At this point it is apparent, rework cascades and causes performance efficiency to suffer, increasingly.

Possibly, these thoughts explain the reason for the exorbitant rework associated with software development projects. *Software development rework is reported to be approximately 40 percent* [7]. Consistent with the preceding discussion this statistic would indicate the developers on the project team frequently vary from the development plan. Or, even worse, it may indicate there is little requirements definition in software development projects and likely, only very cursory project planning and task definition. We know from the March 2004 report prepared by the United States General Accounting Office, *Stronger Management Practices Are Needed to Improve DOD's Software Intensive*

Weapon Acquisitions, that these conditions are predominantly true in the software industry [7].

From this correlation of the state of software engineering practice to the cause of rework, we have qualitative confirmation as to why CPI tends to worsen as the project progresses. By induction, it is likewise reasonable to assert that the impact of rework causes the lengthening of schedule, as well. Thus, my hypothesis, derived from the foregoing discussion, is that lack of adherence to the execution of the project schedule is the primary cause for declining performance for both, cost and schedule, as the project moves toward completion. This hypothesis is the foundation for the remainder of the paper.

Measuring Schedule Adherence

The practice today for project managers is to use the EVM cost indicators for managing project cost and the Critical Path for managing schedule performance [8]. Seemingly, they are managed as separate, independent, entities. Everyone knows project cost and schedule are interrelated, but we have no facility to make direct connection between the two. Therefore, PMs have little choice, except to treat cost and schedule separately. *The challenge is to make this connection.*

To begin, I'll make this assertion: *If tasks are not interdependent, nor are there process constraints, then tasks can be performed in any sequence, using any resource loading; i.e., the critical path doesn't exist.* For these conditions rework caused by lack of schedule adherence is of no concern. As a consequence, the cost and schedule performance would likely not have the general characteristic of declining as the project moves toward completion. Therefore under this condition, it is deduced that the equation IEAC = BAC / CPI would be very good predictor of final cost.

The previous paragraph describes a condition that would make project management a much simpler endeavor. But, the lack of task interplay can never occur; it must be present. Thus, in order for PMs to better predict project outcomes, a method must be created for understanding schedule progress in a way that is directly connected to earned value data. If this can be accomplished, the EVM community will have the "bridge" between cost and schedule, and management tools will become much more integrated than those that exist today. A logical outcome from having increased understanding for the connection between cost and schedule is management of projects should improve and the rate of project successes should increase.

Recall from the introduction at the beginning of the paper, I identified three deficiencies of EVM. The primary focus of most of the discussion thus far is the first one: *EVM is not directly connected to output, or schedule.* The second deficiency of EVM is involved, as well: *the schedule indicators are flawed.* They do not represent schedule performance very well. In fact, it is well known that they fail completely for projects which lag the planned schedule.

The method which overcomes the deficiency of the EVM schedule indicators is Earned Schedule (ES) [9]. Whereas EVM schedule indicators are cost-based, the

ES indicators are time-based. The ES indicators are derived from the time association with earned value and the performance management baseline (PMB) as depicted by Figure 1, Earned Schedule Concept.[3] The application of ES is the facilitator for creating the bridge between cost and schedule management.

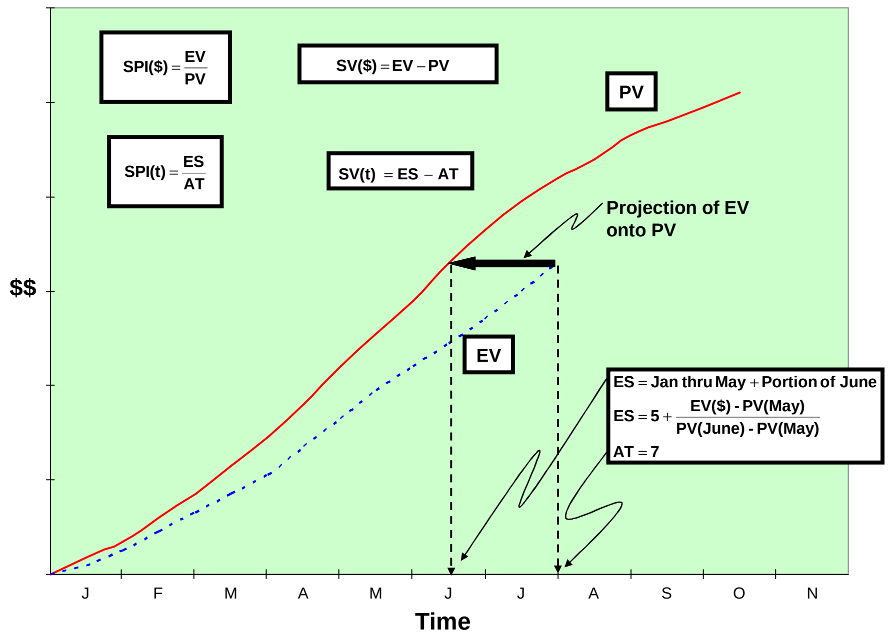

Figure 1. Earned Schedule Concept

The computed value of ES describes where the project should be in its schedule performance. Refer to Figure 2, Earned Schedule - *Bridges EVM to Schedule* (Plan). The figure shows a networked schedule at the top and the project management baseline beneath it. The project status is taken at *AT,* actual time; however, the time performance of the project management baseline is depicted, as shown in figure 1, by *ES*.

Earned Schedule provides a remarkable connection between EVM and the schedule. Regardless of the project's actual position in time, we have information describing the portion of the planned schedule which should have been accomplished. Specific tasks make up that portion of the schedule. If the schedule is adhered to we will observe in the actual performance the identical tasks at the same level of completion as the tasks which make up the plan portion attributed to ES. *(The darker shaded areas of the task blocks indicate the completed portions.)*

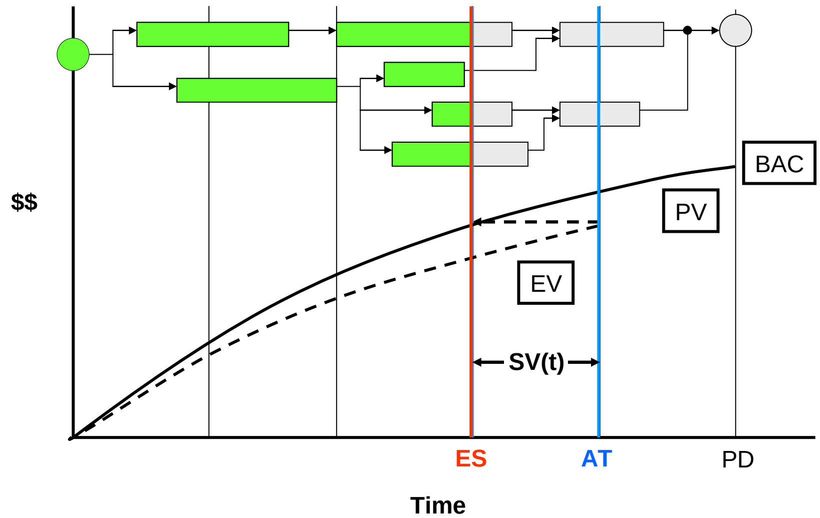

Figure 2. Earned Schedule - *Bridges EVM to Schedule* (Plan)

However, it is more than likely the project is performing as depicted in Figure 3, Earned Schedule – *Bridges EVM to Schedule* (Actual); i.e., EV is not being accrued in accordance with the plan. As seen, the earned value is the same as depicted in figure 2, but the task distribution is different. Figure 3 is a graphical illustration of the previous discussion, *"What Causes CPI to Worsen?"* The lagging performance for tasks to the left of ES indicates the possibility of a constraint or impediment. The EV indicated to the right of ES shows tasks performed at risk; they will likely have significant rework appearing later in the project.

Both sets of tasks, lagging and ahead, cause poor efficiency. Of course, for the lagging tasks, impediments and constraints make progress more difficult. *Concentrating management efforts on alleviating the impediments will have the greatest positive impact on project performance*. The tasks to the right of ES are performed without complete information. The performers of these tasks necessarily create the inputs expected from the incomplete preceding tasks; this consumes time and effort and has no associated earned value.

This discussion leads to measuring schedule adherence. By determining the earned value (EV) for the actual tasks performed congruent with the project schedule, a measure can be created. The adherence to schedule characteristic, P, is described mathematically as a ratio:

$$P = \Sigma\, EV_j / \Sigma\, PV_j$$

where PV_j is the planned value for tasks associated with ES

EV_j is the earned value at AT (actual time) corresponding to and limited by the planned tasks, PV_j

One observation of the P-Factor is that its value must be between zero and one; it cannot exceed one. A second characteristic is that at project completion it will exactly equal 1.0.

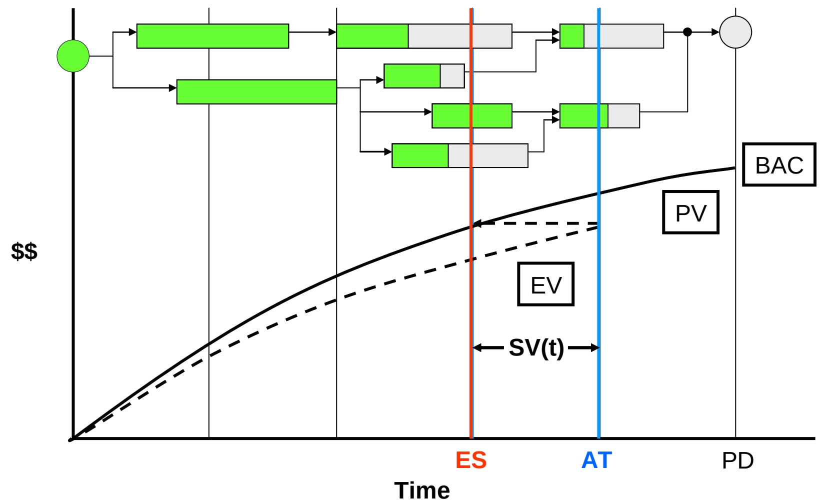

Figure 3. Earned Schedule - *Bridges EVM to Schedule* (Actual)

Making Use of the P- Factor

When the value for P is much less than 1.0, the project manager (PM) has a strong indication the project is experiencing an impediment, the overload of a constraint, or the workforce has poor process discipline. The PM thus has an indicator which enhances the description portrayed by EVM.

To understand how P can be used beyond its qualitative application, let's begin by identifying some fundamental relationships:

- Cumulative EV @ AT = EV =Σ EV_i @ AT = Σ PV_j @ ES
  where ΣEV_i includes all of the tasks completed or in work
- EV earned in accordance with the schedule: EV(p)= ΣEV_j @ AT = P $*$ EV
  where the subscript j identifies the planned tasks associated with ES
- EV earned not according to the schedule: EV(r) = EV – EV(p) = (1 – P) $*$ EV

The preceding definitions are extremely important to the remainder of the paper. As further explanation, the tasks planned to be completed or in work (i.e. those tasks in agreement with the schedule) are left of the ES line. The positioning of the ES line represents the earned duration of the project management baseline. This calculated value of ES thus identifies tasks completed and amount of in-work accomplishment in accordance with the schedule. The identified set of planned tasks, in turn, identifies which of the performed tasks are used for calculating EV(p); i.e., the EV_j for the tasks in consonance with the schedule. The EV_j for the performed tasks is limited to the PV_j at the duration equal to ES. It may be worth repeating at this point that the actual tasks lagging the planned performance at ES likely have constraints or impediments and those where actual exceeds the plan can expect future rework.

Now, let's examine the impact of rework. Recall, a portion of EV(r) is unusable and requires rework. Therefore, we need to determine the usable portion in terms of percentage of rework (R%):

- R% = unusable fraction of EV(r) / usable fraction of EV(r) = f(r) / f(p) where f(p) + f(r) = 1

- Substituting for f(r): f(p) + R% ∗ f(p) = 1

- Solving for f(p), we obtain: f(p) = 1 / (1 + R%)

Finally, with the relationships developed we can calculate the EV which effectively moves the project toward completion:

- Effective EV = EV(e) = EV(p) + usable portion of EV(r) = EV(p) + f(p) ∗ EV(r)

- EV(e) = EV(p) + [1 / (1 + R%)] ∗ EV(r)
  = P ∗ EV + [1 / (1 + R%)] ∗ [(1 – P) ∗ EV]
  = [P + {(1 – P) / (1 + R%)}] ∗ EV

- EV(e) = [(1 + P ∗ R%) / (1 + R%)] ∗ EV

Thus, it is determined that the plan adherence (P-Factor), along with rework, and cumulative earned value determine the effective earned value.

For the hypothesis made earlier that for the tasks performed out of sequence rework is 50 percent, the equation for the effective earned value becomes:

$$EV(e) = [(1 + 0.5 * P) / (1 + 0.5)] * EV$$
$$= [(P + 2) / 3] * EV$$

Applying EV(e)

The effective earned value affects the values of cost and schedule performance efficiency to be used for predicting project outcomes. The cost performance index which describes the efficiency toward achieving completion of the project is:

CPI(e) = EV(e) / AC *[effective CPI]*

Similarly, the effective cost variance becomes:

CV(e) = EV(e) – AC *[effective CV]*

Proceeding, the well studied EVM formula for calculating independent estimate at completion discussed at the beginning of the paper, IEAC = BAC / CPI, is modified to use CPI(e). By replacing CPI with CPI(e) the equation becomes:

IEAC(e) = BAC / CPI(e) *[effective IEAC]*

In analyzing how this equation reacts over the duration of a project it is easily deduced that IEAC(e) will compute values which are equal to or larger than the values from IEAC = BAC / CPI; at project completion, IEAC(e) and IEAC will compute identical values. We know from the extensive studies of CPI that IEAC describes the low bound for cost throughout the project duration. Thus, the prediction of final cost by IEAC(e) is consistent with the findings from the studies cited earlier in the section of the paper, *Behavior of the Cost Performance Index*.

For schedule, EV(e) is used to determine a corresponding earned schedule, ES(e). The method, in effect, reduces the value of ES determined from the cumulative value of EV. Likewise, as described for the cost indicators, the time-based schedule indicators using effective earned schedule are:

SPI(te) = ES(e) / AT *[effective SPI(t)]*

SV(te) = ES(e) – AT *[effective SV(t)]*

Similarly to the computation for predicting final cost, the formula for prediction of final project duration is [10]:

IEAC(te) = PD / SPI(te) *[effective IEAC(t)]*

where PD is the planned project duration

It is conjectured that the prediction of schedule duration using this formula is subject to similar conditions as there are for cost. Recall, CPI is considered to be stable once the project has reached 20 percent complete; therefore until CPI has achieved stability, outcome prediction is considered to be extremely unreliable. It is reasonable then to assume SPI(t) and the P - Factor will require some period of performance before they can be considered stable, as well. Without having similar statistical testing results to those cited earlier for CPI, using the assumption of stability at 20 percent complete is a rational starting point.

Project Outcome Prediction

To illustrate the application of the P - Factor, I'll begin by first using notional data. Refer to Figure 4, Graphs of CPI, CPI(e) & P - Factor (notional data); observe the behavior of CPI. As discussed in the section, *Behavior of the Cost Performance Index*, CPI tends to worsen as the project moves toward completion and the final CPI will not be more than 0.10 below its value when the project is 20 percent complete. Recall, this behavior is well known from several studies [2,3,4,5,6]. The CPI graph depicts the final value of CPI to be approximately 0.10 less than its value at 20 percent complete. Thus, the plot shows the maximum expected change for CPI.

Now observe the behavior of the P- Factor. Its value begins at 0.73 and increases until it reaches 1.0 at project completion. The P - Factor has an innate characteristic of increasing as the project moves toward completion. Thus, the use of the P- Factor to adjust the earned value to a lower amount causes the effective value of the cost performance index, CPI(e), to better forecast the final CPI value, and hence an improved prediction of final cost.

This effect is seen in the plot of CPI(e). Of course, the perfect compensation indicated is an unreasonable expectation. Nevertheless, the concept should be understood; the application of the P - Factor causes CPI(e) to be a better forecast of the final CPI throughout the stable period of performance for the project.

One final thought before leaving this. From the definition of the P - Factor, its value indicates the portion of earned value accrued in congruence with the plan; i.e., the tasks which ought to be either completed or in work. Thus, for a project to drop 0.10 from its CPI value at 20 percent complete, our example tells us that approximately 30 percent of the project's task effort is performed not in accordance with the project plan. A project having 30 percent of its effort not following its plan is headed for disaster. Adherence to the plan must be heeded for the project to be successful. For this cited condition there may be any of the following problems: the workers have poor discipline, management is inept, the plan itself is poor, or more likely there are impediments or constraints that need to be removed. As discussed previously, the tasks possibly having constraints or impediments are identified as those whose earned value lags the planned value corresponding to the earned schedule result (reference figure 3).

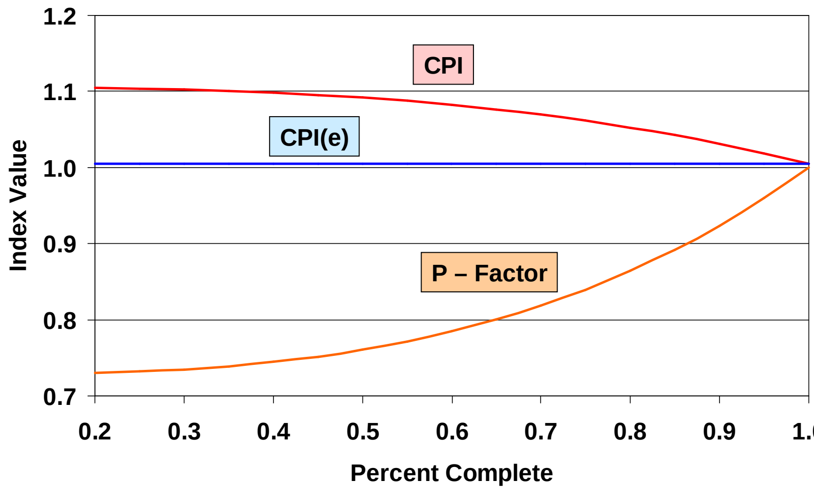

Figure 4. Graphs of CPI, CPI(e) & P - Factor (notional data)

Now let's look at the application of the P- Factor using real data from an in-work project. The data and computed results are portrayed below in Tables 1 and 2, Cost Prediction Comparison and Schedule Prediction Comparison, respectively, and Figure 5, Graphs of CPI & SPI(t) with the P - Factor. Other data required for understanding the analysis and discussion are: BAC ($2,488,203), percent rework assumed for out of sequence tasks (50%), planned duration (PD = 25.7 months).

There are two new terms shown in the tables, "Period" and "Pct Comp." Period is the number of the periodic observation of project status; for this data the period is monthly. "Pct Comp" is shorthand for percent complete and is calculated from the formula, Pct Comp = EV / BAC. All other data elements of the tables are common to the preceding portions of the paper.

Reading the tables is straight-forward. The values beneath the headings of tables 1 and 2 (*Period, Pct Comp, AC, EV, and PV*) are all data entries from the project plan or its performance, while the entries for the remaining headings are computed. For clarification, I'll discuss the first row of numbers for table 1. At period number 7, the project is 22.09 percent complete; the actual cost accrued is $523,766 and the cumulative earned value is $549,707. Corresponding to period 7, the P-Factor and IEAC are calculated to be 0.92977 and $2,370,790, respectively. Utilizing the P-Factor, the effective EV and IEAC are computed. EV(e) is shown to be $536,839, while IEAC(e) is $2,427,618.

The values shown in the IEAC column of table 1 are calculated by dividing BAC by CPI. The values in the IEAC(e) column are determined from the equation shown earlier:

IEAC(e) = BAC / CPI(e)

where CPI(e) = [(2 + P) / 3] ∗ CPI

Likewise, the IEAC(t) values in table 2 are determined from the equation, IEAC(t) = PD / SPI(t); whereas the IEAC(te) values are computed from

$$IEAC(te) = PD / SPI(te)$$

The effective time-based schedule performance index, SPI(te), is computed using

$$EV(e) = [(2 + P) / 3] * EV$$

for determining the effective earned schedule, ES(e). As a reminder, these IEAC formulas account for the 50 percent rework assumption.

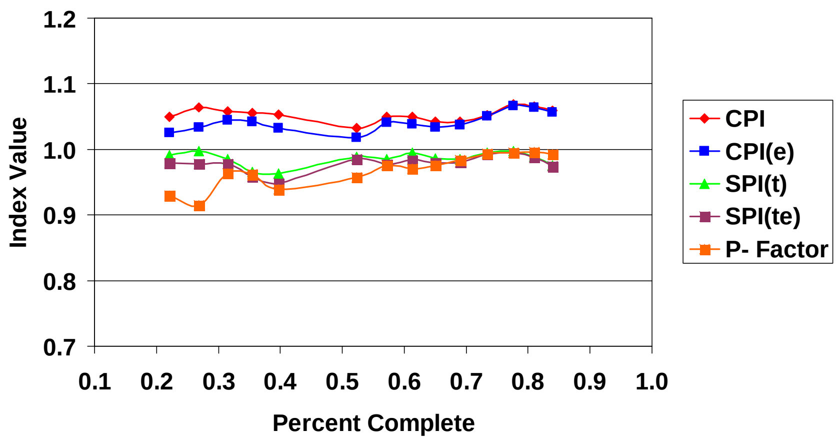

Figure 5. Graphs of CPI & SPI(t) with the P - Factor

From figure 5 it is seen that the value of the P - Factor is extremely high throughout the range. Beginning at 30 percent complete its value steadily increases from approximately 0.96 to nearly 1.0. Thus, an expectation from the theory is observed: when the value of P is high, CPI(e) and SPI(te) will not be much different from CPI and SPI(t), respectively. Another observation can be made, this project is performing exceptionally well; the cost performance is better than planned by, approximately, 5 percent, and the schedule performance is lagging by only 2 percent. Thus, it can be concluded, when the project plan is good, management is engaged, and the plan is followed (P – Factor approaching 1.0), a successful project is highly probable.

Period	Pct Comp	AC	EV	P-Factor	EV(e)	IEAC	IEAC(e)
7	22.09%	$ 523,768	$ 549,707	0.92977	$ 536,839	$2,370,790	$2,427,618
8	26.88%	$ 628,760	$ 668,776	0.91451	$ 649,717	$2,339,324	$2,407,945
9	31.53%	$ 741,662	$ 784,508	0.96302	$ 774,837	$2,352,310	$2,381,666
10	35.42%	$ 834,889	$ 881,288	0.96221	$ 870,186	$2,357,199	$2,387,274
11	39.65%	$ 936,419	$ 986,529	0.93897	$ 966,459	$2,361,817	$2,410,862
12	52.24%	$1,259,326	$1,299,880	0.95745	$1,281,444	$2,410,575	$2,445,256
13	57.15%	$1,354,241	$1,422,033	0.97531	$1,410,332	$2,369,583	$2,389,242
14	61.36%	$1,454,887	$1,526,842	0.97023	$1,511,692	$2,370,943	$2,394,703
15	65.03%	$1,551,561	$1,617,976	0.97544	$1,604,733	$2,386,068	$2,405,758
16	68.97%	$1,646,439	$1,716,130	0.98440	$1,707,204	$2,387,159	$2,399,639
17	73.43%	$1,736,040	$1,826,991	0.99423	$1,823,476	$2,364,336	$2,368,893
18	77.59%	$1,806,941	$1,930,651	0.99545	$1,927,721	$2,328,767	$2,332,305
19	81.02%	$1,892,554	$2,015,852	0.99582	$2,013,043	$2,336,014	$2,339,272
20	83.95%	$1,971,334	$2,088,967	0.99285	$2,083,990	$2,348,089	$2,353,696

Table 1. Cost Prediction Comparison

Period	PV	EV	ES	P-Factor	ES(e)	IEAC(t)	IEAC(te)
7	$ 556,918	$ 549,707	6.9415	0.92977	6.8371	25.90 mo	26.26 mo
8	$ 671,729	$ 668,776	7.9743	0.91451	7.8083	25.78 mo	26.29 mo
9	$ 801,718	$ 784,508	8.8676	0.96302	8.7932	26.06 mo	26.27 mo
10	$ 923,464	$ 881,288	9.6536	0.96221	9.5624	26.57 mo	26.81 mo
11	$1,029,381	$ 986,529	10.5954	0.93897	10.4059	26.63 mo	27.09 mo
12	$1,341,989	$1,299,880	11.8653	0.95745	11.8063	25.98 mo	26.10 mo
13	$1,441,133	$1,422,033	12.8074	0.97531	12.6893	26.07 mo	26.30 mo
14	$1,533,912	$1,526,842	13.9238	0.97023	13.7605	25.83 mo	26.13 mo
15	$1,639,209	$1,617,976	14.7984	0.97544	14.6726	26.04 mo	26.25 mo
16	$1,739,801	$1,716,130	15.7647	0.98440	15.6759	26.07 mo	26.21 mo
17	$1,835,812	$1,826,991	16.9081	0.99423	16.8715	25.83 mo	25.89 mo
18	$1,936,394	$1,930,651	17.9429	0.99545	17.9138	25.78 mo	25.82 mo
19	$2,036,976	$2,015,852	18.7900	0.99582	18.7621	25.98 mo	26.02 mo
20	$2,137,559	$2,088,967	19.5169	0.99285	19.4674	26.33 mo	26.38 mo

Table 2. Schedule Prediction Comparison

Another predicted result is also seen from tables 1 and 2. The values computed for IEAC(e) and IEAC(te) are consistently greater than the corresponding values for IEAC and IEAC(t), respectively. Recall from the IEAC and CPI studies cited that the result from IEAC = BAC / CPI is a reasonable running estimate of the low value for final cost. Logically, it must follow that the more pessimistic estimate of final cost, IEAC(e), should be a closer estimate of the final cost.

The schedule duration estimate from the equation IEAC(t) = PD / SPI(t) has yet to be studied sufficiently as to its predictive validity. At this time however, we do know that it is a better predictor than any other method now employed. The other prediction methods have calculations with mathematical flaws which prevent their proper functioning [10].

Readily observed from table 2 is the consistency of the predicted values for both IEAC(t) and IEAC(te). Also, just as for the cost prediction values listed in table 1, the schedule duration IEAC(te) is always longer than the corresponding IEAC(t). Until more study is completed, it remains conjecture that IEAC(te) is closer to the final project duration than is IEAC(t).

Summary

The premise put forth by this paper is that Earned Value Management (EVM) is connected to the schedule through the use of the Earned Schedule (ES) concept. The computed value of ES is used to identify the tasks of the plan that should be completed or in-work. Furthermore, the ES value identifies the portion completed for the in-work tasks. *This attribute of ES is independent of schedule performance efficiency.*

By comparing the actual task distribution of the earned value to the planned execution, differences can be observed. For those tasks where earned value (EV) lags the expectation, impediments or constraints are the likely cause. This ability to segregate and identify impeded tasks should prove to be very useful to project managers. For tasks where EV exceeds expectation, the work is being performed without all of the task inputs satisfied; thus, rework can be expected at some future time. Both situations, task performance ahead and lagging with respect to the plan, cause costs to escalate and schedules to lengthen.

A measure is introduced to indicate the adherence to the project plan. The measure is the P - Factor, and is computed as the ratio of the EV corresponding to the plan divided by the total EV. This indicator is made possible through the application of the Earned Schedule (ES) concept, linking EV to the schedule.

The P - Factor in conjunction with rework is then used to form an adjustment factor. This factor adjusts the amount of EV to a lower amount, termed "effective earned value," symbolically noted EV(e). The reduced EV is then used to calculate effective ES; i.e., ES(e). These effective values are, in turn, used to calculate effective cost and schedule performance efficiencies, CPI(e) and SPI(te), respectively. Finally, the independent estimates at completion for cost and schedule are computed using these efficiencies.

The results from both notional and real project data, aggregated in the preceding tables and figures, are shown to be in agreement with the theory and several cited studies. *The P – Factor, derived from the application of Earned Schedule, provides the "bridge" connecting Earned Value Management to the project schedule.*

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References

1. Fleming, Q. *Cost/Schedule Control Systems Criteria, The Management Guide to C/SCSC*. Chicago: Probus, 1988.
2. Christensen, David S. "The Estimate at Completion Problem: A Review of Three Studies." *Project Management Journal*, Vol 24 (March 1993): 37-42.
3. Christensen, D. S., R. C. Antolini, J. W. McKinney. "A Review of Estimate at Completion Research," *Journal of Cost Analysis and Management*, Spring 1995: 41-62.
4. Christensen, D. S., S. R. Heise. "Cost Performance Index Stability," *National Contract Management Journal*, Vol 25 (1993): 7-15.
5. Christensen, D. S., C. Templin. "EAC Evaluation Methods: Do They Still Work?," *Acquisition Review Quarterly*, Spring 2002: 105-116.
6. Christensen, D. S., D. A. Rees. "Is the CPI-Based EAC A Lower Bound to the Final Cost of Post A-12 Contracts?," *Journal of Cost Analysis and Management*, Winter 2002: 55-65.
7. United States General Accounting Office. *Defense Acquisitions: Stronger Management Practices Are Needed to Improve DOD's Software-Intensive Weapon Acquisitions,* GAO-04-393 (March 2004).
8. Humphreys, G. C. *Project Management Using Earned Value.* Orange, CA: Humphreys & Associates, Inc, 2002.
9. Lipke, Walt. "Schedule is Different," *The Measurable News*, Summer 2003: 31-34.
10. Henderson, Kym. "Further Developments in Earned Schedule," *The Measurable News*, Spring 2004: 15-22.

Notes

1. 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.[2] The abbreviation BAC, used in the equations, is the Budget at Completion. Listed below are the IEAC formulas most often seen and used:

   a) $IEAC_1 = AC + (BAC - EV) / CPI = BAC / CPI$
   b) $IEAC_2 = AC + (BAC - EV) / SPI$

c) $IEAC_3 = AC + (BAC - EV) / (SPI * CPI)$
d) $IEAC_4 = AC + (BAC - EV) / (wt_1 * SPI + wt_2 * CPI)$
e) $IEAC_5 = AC + (BAC - EV) / CPI_x$

For $IEAC_3$ the product, $SPI * CPI$, is sometimes identified in the literature as SCI. The abbreviations wt_1 and wt_2 of $IEAC_4$ are numbers between 0.0 and 1.0 used to weight the influence of the two indexes; the sum of wt_1 and wt_2 is equal to 1.0. CPI_x in $IEAC_5$ is the cumulative value of the last *x* performance periods.

2. The definitions of the cost and schedule performance indexes, CPI and SPI, respectively, are:

$$CPI = EV / AC$$
$$SPI = EV / PV$$

where AC = Actual Cost
EV = Earned Value
PV = Planned Value (project performance baseline)

For more in-depth explanation of earned value, its associated indicators, and terminology, reference Quentin Fleming's book [1].

3. The Earned Schedule terminology shown in figure 1 and used in the paper is as follows:

ES = Earned Schedule
AT = Actual Time (total duration from the project beginning)
SV(t) = ES – AT (Schedule Variance expressed in units of time)

SPI(t) = ES / AT (the time-based Schedule Performance Index)

About the Author

Walt Lipke is the deputy chief of the Software Division at the Oklahoma City Air Logistics Center. The division employs approximately 600 people, primarily electronics engineers. 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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