Assessing Earned Value Management and Earned Schedule Forecasting

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Abstract

Recent research indicates cost and schedule forecasting from EVM data is improved when the performance factor, PF = 1, is used. This paper uses a small set of real data to examine the research finding, to either confirm or refute. As well, the application of PF = 1 is employed in statistical forecasting; results are tested and compared to the index method. Observations from the research and this study are made referencing historical studies. Further research is encouraged on these topics, but with some precaution when real data is used.

Introduction

The 2015 paper, "Empirical Evaluation of Earned Value Management Forecasting Accuracy for Time and Cost" authored by Batselier and Vanhoucke, is the inspiration for this article [Batselier et al, 2015]. Their paper is an impressively comprehensive examination of forecasting from the use of Earned Value Management (EVM) data taken from 51 projects, predominantly construction.

In the history of EVM and Earned Schedule (ES) research, covering 25 years for cost and 15 years for schedule, one type of forecasting formula, incredibly, has been ignored. Included in these past studies are several published by Christensen[1], Vanhoucke[2], Crumrine[3], and Lipke[4]. Uniquely, Batselier and Vanhoucke (B&V) examine several methods of forecasting. B&V demonstrate overwhelmingly in their analysis this ignored formula yields forecasts more often better than the ones most frequently employed by EVM and ES practitioners.

This article, using a smaller set of data than that used by B&V, attempts to corroborate their finding. The primary objective, however, is to implement the improvement shown

[1] See references: Christensen et al, 2002(-1,-2), 1995, 1993(-1,-2)).
[2] See references: Vanhoucke et al, 2007, 2006.
[3] See reference: Crumrine et al, 2013.
[4] See references: Lipke, 2017, 2016, 2015, 2014, 2012, 2011, 2009-1, 2006.

for deterministic forecasting into statistical forecasting. The focus is to assess whether the improved nominal forecast translates to better statistical forecasts. As well, the investigation may reveal logical reason for the B&V results.

The subsections following, EVM & ES Forecasting, and Statistical Forecasting, provide background for understanding the remainder of the article.

EVM & ES Forecasting

EVM and ES forecasting formulas are very similar. They each have the same basic construct; i.e., the forecast is equal to the current value plus the remainder yet to accomplish divided by a selected performance factor.

Before discussing the formulas, the following EVM and ES terminology is introduced in table 1. It is assumed the reader has a fundamental understanding of EVM and ES. If a more complete description is needed, please reference the following: *Practice Standard for Earned Value Management* [PMI, 2011], and *Earned Schedule* [Lipke, 2009-2].

Earned Value Management		Earned Schedule Management	
BAC	Budget at Completion	PD	Planned Duration
EV	Earned Value	ES	Earned Schedule
AC	Actual Cost	AT	Actual Time (Duration)
CPI	Cost Performance Index CPI = EV / AC	SPI(t)	Schedule Performance Index (time) SPI(t) = ES / AT
IEAC	Independent Estimate at Completion IEAC = AC + (BAC - EV) / PF_C	IEAC(t)	Independent Estimate at Completion (time) IEAC(t) = AT + (PD - ES) / PF_S
PF_C	Performance Factor - Cost PF_C = 1, CPI	PF_S	Performance Factor - Schedule PF_S = 1, SPI(t)

Table 1. EVM and ESM Terminology and Formulas

In the B&V paper several performance factors (PF) are examined for EVM and ES forecasting. For this paper, only four are used. As depicted in table 1, cost applies 1 and CPI, while schedule uses 1 and SPI(t). The reason only these are studied is to corroborate the B&V finding that use of PF = 1 provides in most instances a better forecast of the actual outcome than does the most often used cumulative value for the performance indexes.

For many years, it has generally been conceded that overall the performance indexes provide the most reliable of the possible EVM and ES forecasting methods. Some rationale for reliance on the cost index comes from Dr. Chistensen's conclusion that CPI tends to worsen as the project progresses toward completion [Christensen, 1993]. As well, Christensen determined that forecasts using CPI are optimistic, which he termed the "low bound" [Christensen et al, 2002-1). His research indicates that the forecast using CPI will be better than PF = 1; i.e., the CPI forecast will be optimistic, but PF = 1 will be even more so. This comparative deduction may be the reason PF = 1 had not been seriously examined prior to the B&V paper.

Statistical Forecasting

The use of statistical methods for inferring outcomes is a longstanding proven mathematical approach. The statistical forecasting method for duration has been demonstrated to perform reasonably well [Lipke et al, 2009-3].

The current statistical method of duration forecasting is derived from the ES equation, IEAC(t) = PD / SPI(t), where using the cumulative value of SPI(t) yields the nominal deterministic forecast. The associated high and low Confidence Limits[5] (CL) are computed from the variation of ln $SPI(t)_P$, i.e., the logarithm of the periodic index values. As well, the statistical forecasting method for duration is equally applicable to cost by using the appropriate indexes.

Because B&V have shown PF = 1 to provide better forecasts, curiosity is raised concerning its use in statistical forecasting. Thus, It is desired to adapt PF = 1 forecasting such that comparison can be made to the present method. The adaptation is not difficult, but does need some explanation.

Let's begin with the $PF_S = 1$ duration forecasting expression:

$$IEAC(t) = AT + PD – ES$$

First, multiply and divide the ES term by AT. Then by arranging terms, the formula is transformed to:

$$IEAC(t) = AT + PD – AT \bullet (ES/AT)$$

[5] Information about Confidence Limits may be found in [Crowe et al, 1960]. Confidence Limits are sometimes misunderstood to be thresholds for management action. The limits, instead, describe the region containing the "true" value of the parameter at the prescribed probability, i.e. Confidence Level.

$$= AT + PD - AT \bullet SPI(t)$$

This expression facilitates the statistical use of the cumulative and periodic index values; the identical values used in the current statistical method. Thus, the forecast confidence limits are computed using the index limits in the current method.[6] That is, for example, the high forecast limit becomes:

$$IEAC(t)_H = AT + PD - AT \bullet e\text{^}(CL_L)$$

where e = the base number for natural logarithms
subscript H denotes the high confidence limit for the forecast
subscript L denotes the low confidence limit for the logarithm of the index

Analogously, the $PF_C = 1$ formula for IEAC is transformed for statistical forecasting of cost:

$$IEAC = AC + BAC - AC \bullet CPI$$

Methodology

EVM data from 16 projects are included in the study. The project data comes from three sources and is highly varied: two projects are information technology; twelve come from high technology product development; two are construction type projects. The projects range in duration from a few months to several years. There is no indication in the data of reserves for cost or duration. Although it cannot be verified with certainty, it is believed the projects have not undergone re-planning. The use of projects void of re-planning and other anomalies such as stop work and planned down time, enables a cleaner, less encumbered evaluation of the study results. Disturbances such as these impact the computations and the subsequent analysis.

Utilizing the PF = 1 formulas derived for IEAC(t) and IEAC, the nominal and confidence limit forecasts are computed for each project. The forecasts are then analyzed utilizing four hypothesis tests, two each for schedule and cost forecasts. The hypothesis test applied is the Sign Test [NIST, 2017]. The test is made for the null hypothesis, identified as Ho. When there is insufficient statistical evidence to support Ho, the test result is the alternate hypothesis, Ha.

[6] For a more complete description of Confidence Limit calculations using EVM and ES data consult the following reference [Lipke, 2016].

The four hypothesis tests for evaluating the forecast confidence limits, expressed in the form of the alternate hypothesis, are defined below:

1) H_1: Final Cost is less than $IEAC_H$
2) H_2: Final Cost is greater than $IEAC_L$
3) H_3: Final Duration is less than $IEAC(t)_H$
4) H_4: Final Duration is greater than $IEAC(t)_L$

It should be clear from the test definitions that the testing determines the likelihood that the outcome value (final cost or final duration, as appropriate) resides between the computed forecast confidence limits. Should the testing indicate the final value is likely outside of the confidence limits, the statistical forecast is not considered reliable.

For each of the four tests, the test statistic is computed and compared to a significance level (α) equal to 0.05.[7] When the test statistic value is less than or equal to 0.05, there is enough evidence to reject the null hypothesis. The test statistic for the Sign Test is computed using the binomial distribution with each trial having a success probability of 0.5.

Results/Analysis

To verify that duration forecasting formula $PF_S = 1$ produces, generally, better results than $PF_S = SPI(t)$, Mean Absolute Percentage Error (MAPE)[8] calculations were made. As observed in table 2, of the 16 projects, the deterministic forecasts using formula $PF_S = 1$ had lower error for 12.

Recognizing that the $PF_S = 1$ forecast is not always better, a limited investigation was made to see if a combination of the two methods would yield results having less error. For this, attention was shifted to cost forecasting.

To begin, recall Dr. Chistensen's observation, cited earlier, that CPI generally decreases as the project progresses. If this is true then it follows that, at some point in project completion, index forecasting should converge to the final outcome faster than PF = 1. As well, when CPI or SPI(t) forecasting is used, it is commonly observed that computed results are volatile early in project execution. In fact, many analysts discount the first 15-20 percent of the execution because they believe the EVM and ES indicators

[7] Complete descriptions of the terms "test statistic" and "significance level" are available in mathematics books of statistics [Crowe, et al, 1960].
[8] $MAPE = 1/n \bullet (\Sigma |AD – Forecast(i)|/AD)$, where Forecast(i) is one of the n forecasts.

are not reliable enough for making management decisions. Thus, it is reasonable to believe PF = 1 forecasting should be superior in the early stages of the project.

Mean Absolute Percentage Error																
Forecasting Formula	●●●●●●●●						Projects			●●●●●●●●						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$PD/SPI(t)_C$	0.209	0.085	0.571	0.136	0.036	0.036	0.065	0.068	0.052	0.149	0.138	0.185	0.348	0.072	0.104	0.090
AT + PD - ES	0.132	0.091	0.069	0.049	0.016	0.066	0.086	0.034	0.094	0.065	0.131	0.080	0.333	0.035	0.079	0.047

Green color identifies which of the forecasting methods provided the better overall forecast for the specific project

Table 2. Comparison of Forecasting Accuracy

With these two thoughts, consideration was given to creating a composite forecast using both forecasting formulas: PF = 1 for the initial two-thirds of project performance, with PF = index for the final third. After several trials, the composite approach did not produce improved forecasts. Although not nearly as comprehensive as the B&V study, the investigation corroborated their finding of PF = 1 performing well in every partition of project completion.

Having established for the 16 projects that $PF_S = 1$ generally provides the superior forecast it was thought that statistical forecasting may, likewise, show improvement in comparison to the index method. The tabulation of the hypothesis test results for CLs computed at 90 percent confidence level are presented in table 3. To assist with interpreting the results, recall the general meaning of Ho and Ha:

1) Ha indicates the confidence limit encapsulates the final outcome
2) Ho indicates the outcome lies outside of the confidence limit

Examining the table, it is readily seen: the low CL encapsulates the final outcome for both cost and schedule, whereas high CL generally does not. The low CL for cost had the test result Ha for all 16 projects, while for schedule the low CL was observed for 14 projects. For the cost high CL, 15 of the 16 projects indicate the test result Ho. For schedule, 9 of 16 have Ho results

Hypothesis Test Results @ 90% Confidence > 10% Complete																
Conf Lim	***** Project Number *****															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Cost High	Ho	Ha	Ho	Ho	Ho	Ho	Ho	Ho	Ho	Ho	Ho	Ho	Ho	Ho	Ho	Ho
	1.000	0.045	1.000	1.000	0.332	1.000	1.000	0.905	0.186	1.000	0.685	0.999	0.746	0.252	1.000	0.578
Cost Low	Ha	Ha	Ha	Ha	Ha	Ha	Ha	Ha	Ha	Ha	Ha	Ha	Ha	Ha	Ha	Ha
	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000
Schedule High	Ho	Ho	Ha	Ha	Ha	Ho	Ho	Ha	Ho	Ho	Ho	Ha	Ha	Ho	Ha	Ho
	1.000	0.992	0.000	0.000	0.000	0.333	1.000	0.000	0.617	0.385	0.500	0.000	0.002	0.058	0.000	0.423
Schedule Low	Ha	Ha	Ha	Ha	Ha	Ha	Ha	Ha	Ha	Ha	Ha	Ho	Ho	Ha	Ha	Ha
	0.000	0.000	0.007	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.910	0.000	0.011	0.000
Ho = Null Hypothesis Ha = Alternate Hypothesis Numbers are the computed values for the test statistic																

Table 3. Hypothesis Test Results

These results are tabulated as probabilities and shown in table 4. The numbers in the table indicate the probability that the confidence limit encapsulates the final value. The results shown for PF = CPI and SPI(t) come from a previous study [Lipke et al, 2009-3]. As readily seen, statistical forecasting using the indexes produces considerably more reliable CLs.

Cost		Schedule	
High CL	Low CL	High CL	Low CL
0.026	1.000	0.402	1.000

Result using Power Factor = 1

Cost		Schedule	
High CL	Low CL	High CL	Low CL
0.613	1.000	1.000	0.997

Result using Power Factors, CPI & SPI(t)

Table 4. Comparison of Confidence Limit Probability

In the previous study (PF = index), 98 percent confidence level was examined with the following resulting probabilities: Cost High CL = 0.927, Low CL = 1.000; Schedule High CL = 1.000, Low CL = 0.997 [Lipke et al, 2009-3]. The consistency of the probability values indicates the CLs are very reliable. For the present study (PF = 1), increasing confidence level did not cause appreciable increase in probability. Thus, it is reasoned the PF = 1 statistical forecasting is unreliable.

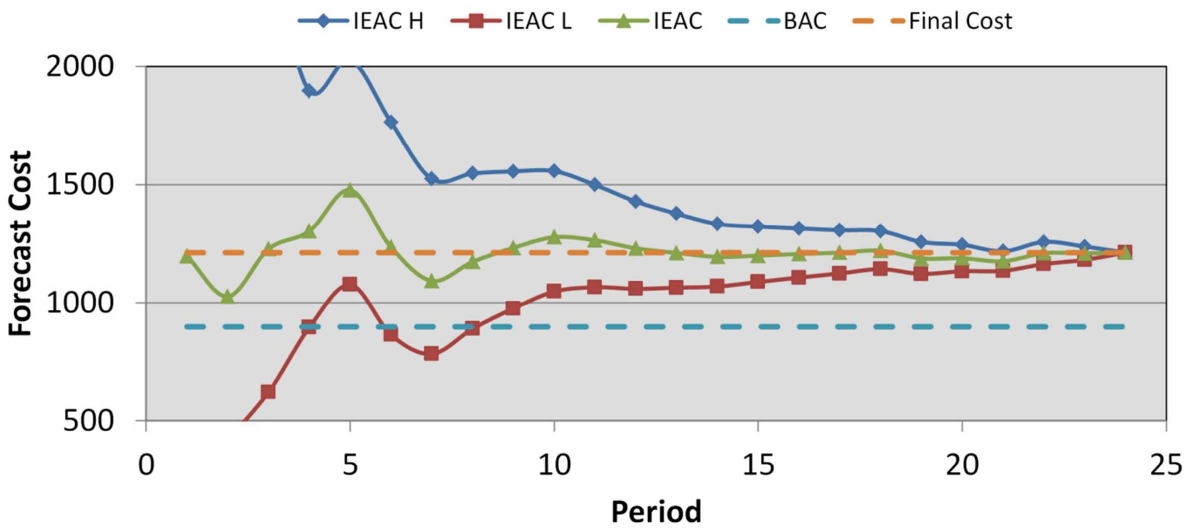

Figure 1. Cost Forecast, PF_C = CPI

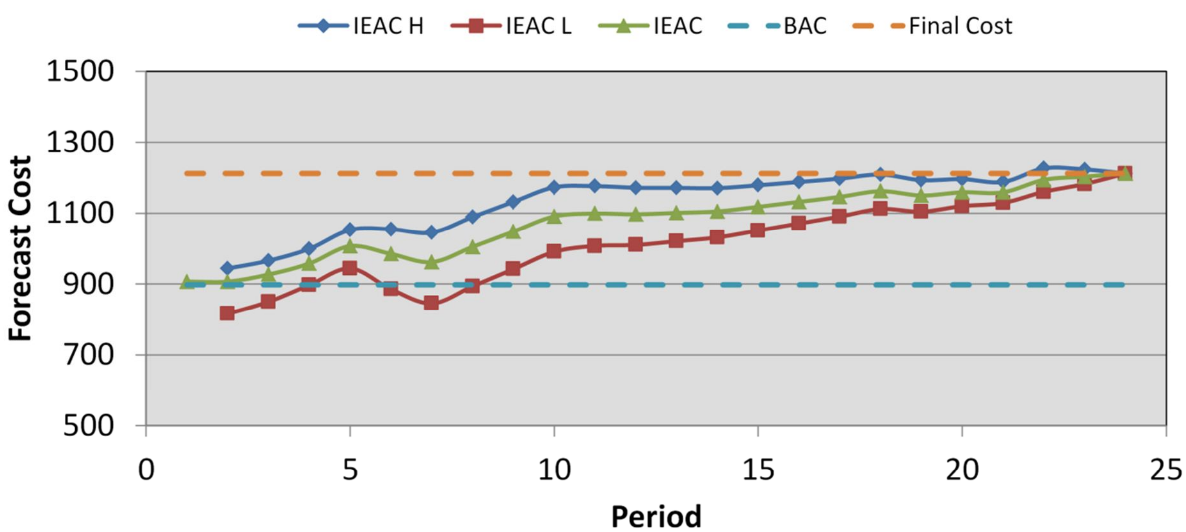

Figure 2. Cost Forecast, PF_C = 1

From these results it appears the CLs from PF = 1 forecasting are optimistically biased. Visually, this can be deduced from graphs for cost and schedule, comparing the statistical forecasts from each computation method. Figures 1 and 2 clearly illustrate the optimistic bias of forecasting using PF_C = 1, as well as showing PF_C = CPI forecasting yields more reliable CLs.

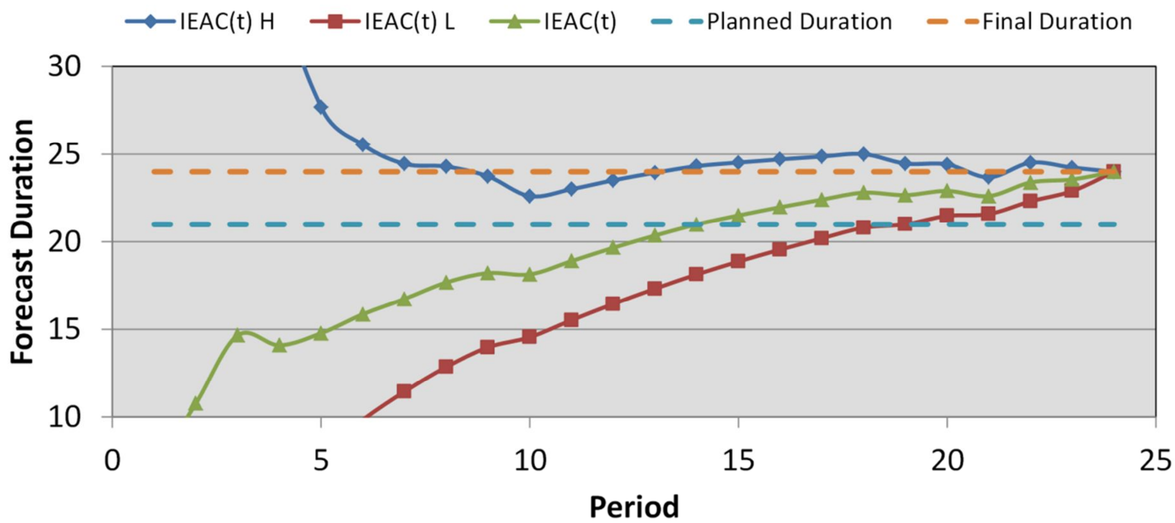

Figure 3. Schedule Forecast, PF_S = SPI(t)

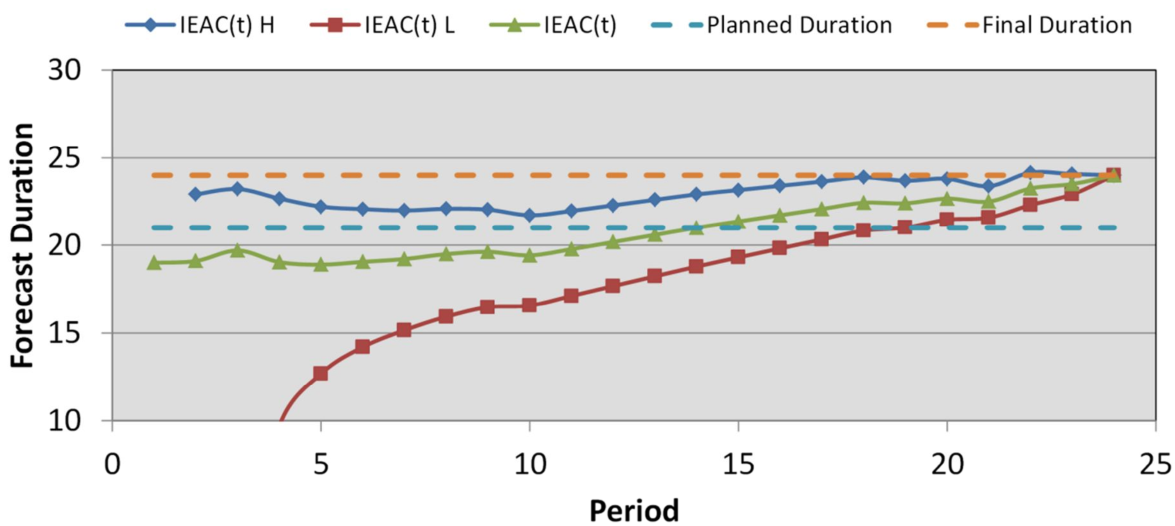

Figure 4. Schedule Forecast, PF_S = 1

Similar results are obtained for duration forecasting, using the same EVM data as was used for the cost graphs, Figure 3 illustrates PF_S = SPI(t) statistical forecasting, while figure 4 shows PF_S = 1. In general, both graphs have plots portraying optimistic forecasts. However, the high CL for the PF_S = SPI(t) does satisfy the hypothesis test and graphically shows a feature seen consistently. There is a graphical component to interpreting the statistical forecasts produced from PF = index. It is observed in both the cost and schedule graphs; the most horizontal plot is generally a very good forecast of the actual outcome. For the index graphs, figures 1 and 3, the most horizontal plots are the nominal forecast for cost and high CL for schedule.

Observations

Some exploration was made with notional data. The objective was to see if there is something generally true about the two forecasting methods, PF = 1 and PF = index. If a characteristic could be discovered, then possibly project managers would have information as to when a particular forecasting formula should be applied.

The exploration was not very structured. Nevertheless, it did show that when the index is constant, this method of forecasting is superior to PF = 1. However, as the variation in performance increased, PF = 1 became the more accurate. Possibly, this is an area for future study. There may be a variation value which demarcates regions for which each forecasting PF produces its best forecasts.

This observation about variation led to reflection on how organizations handle EVM data. Non recognition of re-plans, stop work, and down time can inflate index variation, thereby causing index forecasting to appear worse than it should.

●●●●●●●●● Measures ●●●●●●●●●				●●●●● Forecasts ●●●●●			●●● Absolute Error ●●●		
AT	PV	EV	ES	PD/SPI(t)c	AT + (PD - ES)	IEAC(t)sp	SPI(t)c	PF = 1	IEAC(t)sp
1	1.0	0.5	0.50	30.00	15.50	25.00	0.2000	0.3800	0.0000
2	2.0	1.0	1.00	30.00	16.00	25.00	0.2000	0.3600	0.0000
3	3.0	1.5	1.50	30.00	16.50	25.00	0.2000	0.3400	0.0000
4	4.0	2.0	2.00	30.00	17.00	25.00	0.2000	0.3200	0.0000
5	4.0	2.0	2.00	37.50	18.00	25.00	0.5000	0.2800	0.0000
6	5.0	2.5	2.50	36.00	18.50	25.00	0.4400	0.2600	0.0000
7	6.0	3.0	3.00	35.00	19.00	25.00	0.4000	0.2400	0.0000
8	6.0	3.0	3.00	40.00	20.00	25.00	0.6000	0.2000	0.0000
9	7.0	3.5	3.50	38.57	20.50	25.00	0.5429	0.1800	0.0000
10	7.0	3.5	3.50	42.86	21.50	25.00	0.7143	0.1400	0.0000
11	8.0	4.0	5.00	33.00	21.00	25.00	0.3200	0.1600	0.0000
12	8.0	4.0	5.00	36.00	22.00	25.00	0.4400	0.1200	0.0000
13	9.0	4.5	5.50	35.45	22.50	25.00	0.4182	0.1000	0.0000
14	9.0	4.5	5.50	38.18	23.50	25.00	0.5273	0.0600	0.0000
15	10.0	5.0	6.00	37.50	24.00	25.00	0.5000	0.0400	0.0000
16		5.5	6.50	36.92	24.50	25.00	0.4769	0.0200	0.0000
17		6.0	8.00	31.88	24.00	25.00	0.2750	0.0400	0.0000
18		6.5	8.50	31.76	24.50	25.00	0.2706	0.0200	0.0000
19		7.0	10.00	28.50	24.00	25.00	0.1400	0.0400	0.0000
20		7.5	10.50	28.57	24.50	25.00	0.1429	0.0200	0.0000
21		8.0	12.00	26.25	24.00	25.00	0.0500	0.0400	0.0000
22		8.5	12.50	26.40	24.50	25.00	0.0560	0.0200	0.0000
23		9.0	14.00	24.64	24.00	25.00	0.0143	0.0400	0.0000
24		9.5	14.50	24.83	24.50	25.00	0.0069	0.0200	0.0000
25		10.0	15.00	25.00	25.00	25.00	0.0000	0.0000	0.0000
						MAPE =	0.3054	0.1376	0.0000

Table 5. Notional Data

To illustrate this problem, a notional set of data was created. It is shown in table 5. The PV, EV, and ES data have five highlighted entries. Each of these entries is a repeat of the entry just prior. If all of the highlighted entries were removed, the planned duration would be 10 periods with project completion occurring in period 20. It is fairly easy to deduce with the yellow entries removed that SPI(t) = 0.5 and has no variation. In this circumstance the index forecast of final duration is better than the PF = 1 forecast.

Now, let's consider what these entries might be. Possibly each is a re-plan. Or, it could be that each of the yellow PV entries is planned down time. Then, when the down time occurred, conditions were such that it was not possible to accomplish work and, thus, EV did not progress. When EV does not increase, neither does ES. For the remainder of the discussion, let's assume the entries describe down time and stop work.

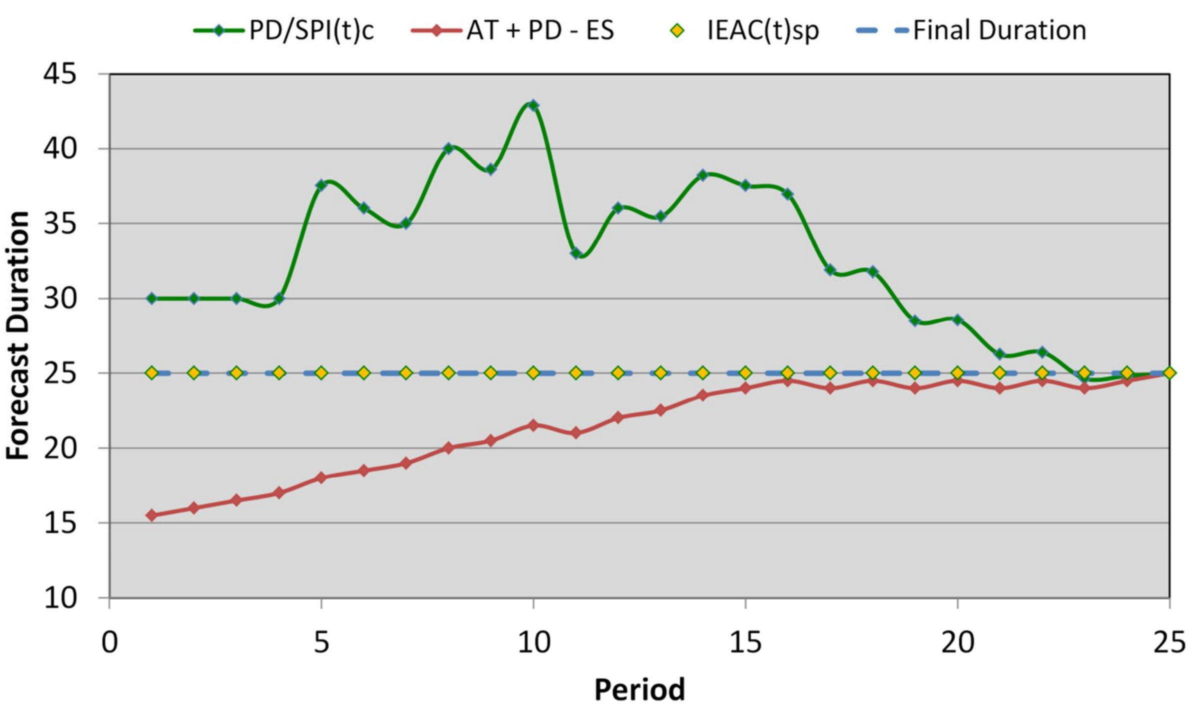

Figure 5. Notional Data Forecasting Comparison

In the table, there are three deterministic duration forecasts: PD/SPI$(t)_C$, AT + (PD – ES), and IEAC(t)sp. As each method is discussed it may be helpful to view figure 5. The figure graphically portrays the performance of the three methods.

The PD/SPI$(t)_C$ forecast is made by simply using the data strings of PV and EV without regard to seeing a need for further review of the highlighted entries. The consequence is the forecast values are erratic, yet the calculation converges to the actual duration.

As well, the forecast method, AT + (PD – ES), does not examine the highlighted entries and uses the ES calculated values to make forecasts. It, too, converges to the actual duration. One observation is these forecasts are consistently optimistic.

Lastly, the IEAC(t)sp forecasts, a modified form of the index method, perfectly align with the final duration. These forecasts are made using the ES Calculator (Special Cases)[9]. This calculator takes into account down time and stop work. It filters through the interruptions to make a better forecast. For this example, the special cases calculator provided forecasting perfection; in general, improvement is expected when the conditions of down time and stop work exist, but not perfection.

The take-away from this exercise is that real EVM data used in testing forecasting methods needs close examination. If at all possible, data having re-plans should be avoided. For projects having down time and stop work, the places in the data where they occur need identification so that they can be handled appropriately.

Summary/Conclusion

Forecasts of project duration were made using real data from 16 projects. The forecasts using performance factors, SPI(t) and PF_S = 1, were compared using MAPE values; 12 of the 16 forecasts made with PF_S = 1 were observed to be have less error with respect to the final duration. This result is in agreement with the finding stated by B&V [Bastelier et al, 2015]; i.e., forecasts using PF_S = 1 are generally better. As well, a very limited examination confirmed the B&V finding that PF = 1 performs well throughout the project.

With confirmation that PF = 1 forecasts generally produce more accurate results, its use in statistical forecasting was explored. The examination revealed that the associated confidence limits are unreliable for both cost and schedule. The CLs are optimistically skewed. Thus, statistical forecasting with PF = 1 is not recommended.

Duration forecasting comparison was made using notional data which included down time and stop work. Three methods were compared; two ignoring the conditions and one recognizing them. The index method, PD/SPI(t), provided highly volatile pessimistic forecasts. The PF_S = 1 method was less volatile and consistently optimistic. The method recognizing the conditions, IEAC(t)sp, yielded an accurate forecast. The significant point derived from the exercise is real data needs to be closely examined and used

[9] The Earned Schedule Calculator (Special Cases) is available from the Earned Schedule website (www.earnedschedule.com).

appropriately when performing forecasting studies. Otherwise, the study results are suspect.

Suggested Research

In the limited investigations of this study it was observed, when the index is reasonably constant, the deterministic forecasts were better than those made with PF_S = 1. Thus, there may be a demarcation value for the variation of ln $SPI(t)_P$ identifying which forecasting method should be applied; i.e., below a specific value of variation the index method is used and above it, PF_S = 1 is preferred. It is suggested to researchers that this area be investigated.

At present, the application of Earned Schedule-Longest Path (ES-LP) forecasting has not been sufficiently tested. Possibly, the various forecasting formulas could be used with ES-LP to explore further improvements to forecasting.

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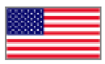

Walt Lipke retired in 2005 as deputy chief of the Software Division at Tinker Air Force Base, where he led the organization to the 1999 SEI/IEEE award for Software Process Achievement. He is the creator of the *Earned Schedule* technique, which extracts schedule information from earned value data.

Credentials & Honors:

- Master of Science - Physics
- Licensed Professional Engineer
- Graduate of DOD Program Management Course
- Physics honor society - Sigma Pi Sigma (ΣΠΣ)
- Academic honors - Phi Kappa Phi (ΦΚΦ)
- PMI Metrics SIG Scholar Award (2007)
- PMI Eric Jenett Award (2007)
- EVM Europe Award (2013)
- CPM Driessnack Award (2014)
- Australian Project Governance and Control Excellence Symposium established the annual *Walt Lipke Project Governance and Control Award* (2017)

Mr. Lipke can be contacted at waltlipke@cox.net