

Earned Schedule Application to Projects with Performance Interruption^{1,2}

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Abstract

The interruption of project execution by stop work and down time conditions impact the values computed for Earned Schedule indicators. The distorted values, in turn, have the potential to affect management decisions. To address the problem, a special calculation method for handling these conditions is presented and examined using four sets of notional data. Comparisons of the computed values from special and normal ES calculation methods indicate significant improvement using the special calculations.

Introduction

Earned Schedule (ES) is an extension to Earned Value Management (EVM) providing the capability of schedule analysis.³ ES was introduced in 2003 by my article “Schedule Is Different” [Lipke, 2003]. From 2003 until the present much has happened. For those applying ES, the method is broadly considered to be a significant advancement to the practice of EVM. ES has propagated across the world, including the USA, Australia, United Kingdom, Belgium, Spain, Canada, India, Japan and other countries, as well. It is being used across all industries applying EVM for all sizes of projects. Furthermore, the method is being used in research, instructed in several universities, and is included in recent project management texts and the newer EVM analysis tools. Recently, standards and guides have been published by the Project Management Institute and the International Standards Organization, including Earned Schedule in the practice of EVM. Earned Schedule is no longer a novel idea; it is accepted practice.

The measure of ES has provided schedule analysis and forecasting capability to those using EVM, previously not believed possible. Parallel to forecasting final cost using EVM measures, ES

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² A version of this article was published in the April 2011 issue of *PM World Today* (Vol XIII, Issue IV), titled, “Earned Schedule Application to Small Projects.” The article presented methods for handling project interruptions. Due to the world-wide Covid-19 virus pandemic many projects have experienced execution work stoppages. The on-line journal *PM World Today* has ceased publishing, making the original article difficult to obtain. This article re-creates the calculation methods needed for schedule performance management, when project performance is interrupted.

³ The article assumes a reasonable understanding of EVM and ES. If more explanation of EVM is desired see [Humphreys, 2002]. For the fundamentals of ES see [Lipke, 2009].

facilitates a simple calculation for the forecasting of project duration and completion dates. Furthermore, it has been shown that the forecasting is enhanced through the application of statistical methods [Lipke, 2009]. Additionally, another measure has been derived from ES, “Schedule Adherence” [Lipke, 2009]. This measure, in turn, has provided the capability to perform detailed analysis, yielding identification of process constraints and impediments and specific tasks having the likelihood of future rework. Recently, additional analysis methods, derived from the idea of schedule adherence, have been developed for forecasting rework cost and analyzing schedule duration impacts [Lipke, 2019; Lipke, Jan 2020; Lipke, Apr 2020]. These advancements are freely available for study and exploration through the literature and calculation tools at the Earned Schedule website, www.earnedschedule.com.

Broadly speaking, the ES methods have proven to perform very well. However, there are conditions during execution that can cause error in the calculated values for the ES indicators and duration forecasts. These conditions are the following:

- 1) *Down Time* – periods within the schedule where no work is scheduled
- 2) *Stop Work* – periods during execution where management has halted performance

However, it is worthy to note that even when down time and work stop conditions are encountered, normal ES calculations converge to the correct duration forecast and the final schedule variance result. The remainder of this paper will discuss the method of handling the two conditions and describe the results from application to notional data.

Down Time and Stop Work

Let’s begin with a clear understanding of the terminology “down time” and “stop work.” Below is Table 1 showing cumulative earned value (EV) and planned value (PV) for 30 periods of performance. You will note that EV and PV are shown preceded by an “i.” The symbol “i” denotes that the strings of data are discontinuous; i.e., they are “interrupted.”

Period	1	2	3	4	5	6	7	8	9	10
iEVcum	93	644	975	1275	1739	XX	XX	2292	3331	3869
iPVcum	93	644	1710	2397	3060	3923	4722	5743	7369	9005
Period	11	12	13	14	15	16	17	18	19	20
iEVcum	4612	5527	6575	7991	9193	10831	12946	14295	16051	17808
iPVcum	10850	12218	13921	15417	XX	XX	XX	XX	18170	20022
Period	21	22	23	24	25	26	27	28	29	30
iEVcum	19666	21178	22839	24873	26310	27720	29113	30298	30765	31821
iPVcum	21936	24418	26186	27972	29397	30899	31821			

Table 1. EV & PV Data with Stop Work & Down Time

First, viewing the iEVcum rows, it is observed that periods 6 and 7 do not have data and instead show “XX.” The XX entries indicate that management imposed a stop work for those two periods of time. For the iPvcum rows, it should be understood that XX entered for the periods 15 through 18, indicates no work was planned, i.e., four down periods of time.

The XX periods impact the ES indicators and the forecast duration and completion date. The indicators may not describe the true performance while, generally, the forecast is caused to have larger error. When management imposes a stop work, the opportunity has been removed to accrue EV. The impact of down time is somewhat different. It extends the planned period of completion. However, management can choose to not have the down period(s) and instead continue to work. As seen from the iEVcum entries in Table 1, the project manager (PM) chose to work through the planned down periods (15 through 18), thereby minimizing the completion delinquency. Oppositely, if the plan had been followed, XX would instead appear for the iEVcum entries during the down time periods.

Schedule Performance Indicators

Table 2 displays the normal and amended, or special, ES indicators that account for the imposed stop work. Observed for the periodic time-based schedule variances, $SV(t)_{wk}$ and $iSV(t)_{wk}$, both have a value of negative 1.0 for the stop work periods (6 and 7). Clearly, no work was accomplished; therefore, for both indicators, a period of opportunity to accrue EV was lost for each stop work period. This fact is shown, as well, for the periodic schedule performance efficiencies, $SPI(t)_{wk}$ and $iSPI(t)_{wk}$; both are equal to zero for the two periods.

The cumulative values for the indicators in Table 2, however, show differences. The normal $SPI(t)_{cum}$ indicates schedule performance efficiency is decreasing during the stop work, whereas the $iSPI(t)_{cum}$ value remains constant. If the project team had chosen to work and accomplished nothing, then decreasing performance is an expectation. In this case, there is no way of knowing if performance has changed; thus, the value for $iSPI(t)_{cum}$ remains at 0.6084, i.e., the value from the last performance period (5) in which work was not stopped.

The differences for the values of $SV(t)_{cum}$ and $iSV(t)_{cum}$ are the result of the impact from the planned down time. Two $iSV(t)_{cum}$ values are computed and shown in Table 2. One includes the impact of down time while the other does not. The two values are identified as $iSV(t)_{cumDT}$ and $iSV(t)_{cum\cancel{DT}}$, respectively.

Returning to the example computations, the four periods of down time (15-18) are in the future with respect to the stop work periods (6-7). As such, they represent periods available for accomplishing work. For the special indicator, $iSV(t)_{cum\cancel{DT}}$, its value will be identical to $SV(t)_{cum}$ until the periods of down time occur. As Table 2 indicates, this is the condition for periods 6 and 7 and, as shown, the values for $SV(t)_{cum}$ and $iSV(t)_{cum\cancel{DT}}$ are equal.

Normal Indicators					Special Indicators				
SPI(t)wk	SPI(t)cum	SV(t)wk	SV(t)cum	Period	iSPI(t)wk	iSPI(t)cum	iSV(t)wk	iSV(t)cum	iSV(t)cum
								w/o Down time	+ Down Time
0.4503	0.6084	-0.5497	-1.9578	5	0.4503	0.6084	-0.5497	-1.9578	2.0422
0.0000	0.5070	-1.0000	-2.9578	6	0.0000	0.6084	-1.0000	-2.9578	1.0422
0.0000	0.4346	-1.0000	-3.9578	7	0.0000	0.6084	-1.0000	-3.9578	0.0422

Table 2. Stop Work Indicators

The values in the column representing $iSV(t)_{cumDT}$ account for the available down time. Using the values in Table 2 it can be deduced that adding the four periods of down time to $SV(t)_{cum}$ yields $iSV(t)_{cumDT}$. As the down time periods occur, they accrue and no longer have potential for performing work. To obtain $iSV(t)_{cumDT}$, the value of down time remaining is subtracted from $iSV(t)_{cumDT}$. As an example, using the data from period 7, the number of down time periods (4) is subtracted from 0.0422 to yield minus 3.9578 for $iSV(t)_{cumDT}$.

Table 3 provides information about the indicators during the planned down time periods. The normal and special periodic SPI(t) values are equal, as we should expect; the ES progress for the performance period is not affected by the down time. However, $SPI(t)_{cum}$ is shown to be less than $iSPI(t)_{cum}$; the result of the previous stop work periods. As expressed earlier, the true schedule performance efficiency is given by the special indicator.

The differences in the computed values for $SV(t)_{cum}$ and the two $iSV(t)_{cum}$ indicators were described in the discussion of Table 2. To assure understanding a few calculations for period 15 from Table 3 follow:

$$\begin{aligned}
 iSV(t)_{cumDT} &= SV(t)_{cum} + \text{Total Planned Down Time} \\
 &= -4.8981 + 4.0 \\
 &= -0.8981 \text{ periods}
 \end{aligned}$$

$$\begin{aligned}
 iSV(t)_{cumDT} &= iSV(t)_{cumDT} - \text{Down Time Remaining} \\
 &= -0.8981 - 3.0 \\
 &= -3.8981 \text{ periods}
 \end{aligned}$$

Although the periodic values are equal for the two methods of computing schedule performance efficiency, those for schedule variance are not. Down time causes the periodic values of the normal and special schedule variance to differ by 1.0; i.e., $iSV(t)_{wk}$ is equal to $SV(t)_{wk}$ plus 1.0 to account for the down time associated with the period of performance. As an example, when the project stops work in accordance with the scheduled down time, $SV(t)_{wk}$ is

equal to minus 1.0; the normal indicator is influenced by the stop work only. However, because of the down time, $iSV(t)_{wk}$ is equal to zero ($-1.0 + 1.0 = 0$).

Normal Indicators				Period	Special Indicators				
SPI(t)wk	SPI(t)cum	SV(t)wk	SV(t)cum		iSPI(t)wk	iSPI(t)cum	iSV(t)wk	iSV(t)cum w/o Down time	iSV(t)cum + Down Time
0.8685	0.6700	-0.1315	-4.6198	14	0.8685	0.7817	-0.1315	-4.6198	-0.6198
0.7217	0.6735	-0.2783	-4.8981	15	0.7217	0.7771	0.7217	-3.8981	-0.8981
0.8878	0.6869	-0.1122	-5.0103	16	0.8878	0.7850	0.8878	-3.0103	-1.0103
1.4378	0.7310	0.4378	-4.5725	17	1.4378	0.8285	1.4378	-1.5725	-0.5725
0.8225	0.7361	-0.1775	-4.7500	18	0.8225	0.8281	0.8225	-0.7500	-0.7500

Table 3. Down Time Indicators

The message to be taken from this discussion is when stop work or down time conditions occur, the normal indicators do not accurately portray performance and have the potential to cause inappropriate management decisions. The special indicators provide better management information. At this point it may be confusing as to why there are two values for $iSV(t)_{cum}$. The $iSV(t)_{cum}^{DT}$ is the true schedule variance and is intended for project performance analysis. The $iSV(t)_{cum}^{DT}$ is made available for management to know the position of the project should the schedule be compressed such that the remaining down time is taken away.

Forecasts

A significant advantage from applying ES is that the method provides the capability to forecast the project duration and the expected completion date. Other methods exist; however, through studies it has been shown that ES is the most reliable forecasting method using EVM data [Lipke, 2008; Vanhoucke, 2007]. Nevertheless, in the introduction segment of this article it was mentioned that the interrupting conditions cause some amount of error in the ES forecasts. At the conclusion of the introduction, emphasis was made that, even with the interrupting conditions, the normal ES forecasting always converges to the actual duration. Knowing this, the question arises: Is it worthwhile to calculate the forecast differently? I'll attempt to show the improvement is significant enough that when the interrupting conditions of work stop and down time arise, the alternative method should be used.

The idea of the alternative calculation is fairly simple, yet complex. In general, the forecast is made as if the interrupting conditions are not present. Then, using the undistorted forecast, add in the interruption effects as they occur. Thus, to begin, instead of computing the forecast using the normal $SPI(t)_{cum}$, the true performance index, $iSPI(t)_{cum}$, is used.

The first step, as previously described, is to calculate an initial forecast as if the planned down time does not exist. Therefore, the period of performance used in the calculation is shortened; the numerator in the forecasting formula becomes the planned duration (PD) minus the total number of down time periods (DT_T). Having the numerator and denominator, the normal ES forecasting formula, $IEAC(t) = PD / SPI(t)_{cum}$, is modified to become the initial forecast formula : $IEAC(t)_{sp1} = (PD - DT_T) / iSPI(t)_{cum}$.

From this initial formulation, the impact of the stop work and down time conditions are introduced into the calculation as they occur. The running total of stop work (SW) periods is added to the initial formula, creating a second forecast expression: $IEAC(t)_{sp2} = IEAC(t)_{sp1} + SW$.

For the final forecast formula, $IEAC(t)_{sp}$, the total number of down time periods (DT_T) is added to $IEAC(t)_{sp2}$. As the down time periods occur, they are counted (DT_L) and then subtracted from DT_T , thereby reducing the remaining potential for void performance periods. At this point, the formulation of the final forecast is complete with one exception. In the event the forecast from $IEAC(t)_{sp2}$ computes a duration (SP2) less than PD, the number of down time periods between SP2 and PD is counted. This conditional quantity (DT_C) is included as a subtraction, which completes the special forecasting formula:

$$IEAC(t)_{sp} = (PD - DT_T) / iSPI(t)_{cum} + SW + DT_T - DT_L - DT_C$$

Now, we will use this formula and examine its forecasting performance.

From the data shown in Table 1 the normal ES forecast, $IEAC(t)$, is computed and compared to the special ES forecast. The computed results are compiled by period of performance in Table 4. As seen in the table, the two forecasts begin with comparable values. When stop work periods 6 and 7 occur, $IEAC(t)$ increases significantly more than does the special forecast. Over the two periods, $IEAC(t)$ increases from the value of 44.4 to 62.1 periods, whereas $IEAC(t)_{sp}$ increases by only two from 41.8 to 43.8.

For periods 8 through 14, both forecasts decrease with the $IEAC(t)$ value consistently higher; the difference between the two begins at 14.2 periods and narrows to 4.9. During the down time periods, 15 through 18, each forecast continues to decrease, with the $IEAC(t)$ values higher by 5.5 to 6.9 periods. Once the down time conditions have passed, both forecasts quickly converge to values very close to the actual duration.

For this set of data, it is reasonably clear that $IEAC(t)_{sp}$ produces a better forecast than $IEAC(t)$. In the next section four cases are examined to further evaluate the forecasting of the two methods, when interrupting conditions are present.

Period	1	2	3	4	5	6	7	8	9	10
IEAC(t)sp	27.0	27.0	33.9	39.5	41.8	42.8	43.8	41.9	36.3	37.0
IEAC(t)	27.0	27.0	35.1	41.7	44.4	53.3	62.1	56.1	45.7	45.5
Period	11	12	13	14	15	16	17	18	19	20
IEAC(t)sp	36.2	35.5	35.7	35.4	34.6	33.3	30.8	29.8	29.5	29.8
IEAC(t)	43.3	41.6	41.2	40.3	40.1	39.3	36.9	36.7	28.1	28.6
Period	21	22	23	24	25	26	27	28	29	30
IEAC(t)sp	29.6	29.7	29.8	29.7	29.7	29.8	29.6	29.7	30.3	30.0
IEAC(t)	28.6	28.8	29.1	29.1	29.3	29.4	29.4	29.5	30.2	30.0

Table 4. Stop Work/Down Time Forecast

Case Comparisons

The four cases to be examined are characterized as follows:

- 1) Case 1 is an early finish project with a three week stop work condition.
- 2) Case 2 is a late finish with work stopped during four weeks of down time.
- 3) Case 3 is a late finish with work accomplished through four weeks of down time.
- 4) Case 4 is a late finish having 2 weeks of stop work followed by 4 weeks of worked down time.⁴

For each case a figure is presented containing a graph and column chart. The graph plots by performance period the special and normal forecasts along with the planned and actual durations. The column charts are comparisons of the standard deviation of the forecasts from the final duration for four ranges of percent complete. The ranges are 10 to 100, 25 to 100, 50 to 100, and 75 to 100 percent. The graph provides a good visual for how well the IEAC(t)sp and IEAC(t) forecasting methods perform. Separately, the column charts display the characteristic of convergence to the actual duration.

The performance depicted in Figure 1 is of a project planned for 28 periods that completes in 26. The effect of three weeks of stop work is observed in the graph. The normal forecast, IEAC(t), increases dramatically during the stop work, while the special forecast increases at a slower rate. By period 15, the IEAC(t)sp forecast has converged and is accurately forecasting the final duration. After the stop work period the normal forecast gradually decreases, eventually converging to the actual duration.

⁴ Case 4 is the example project discussed in the previous sections of the paper.

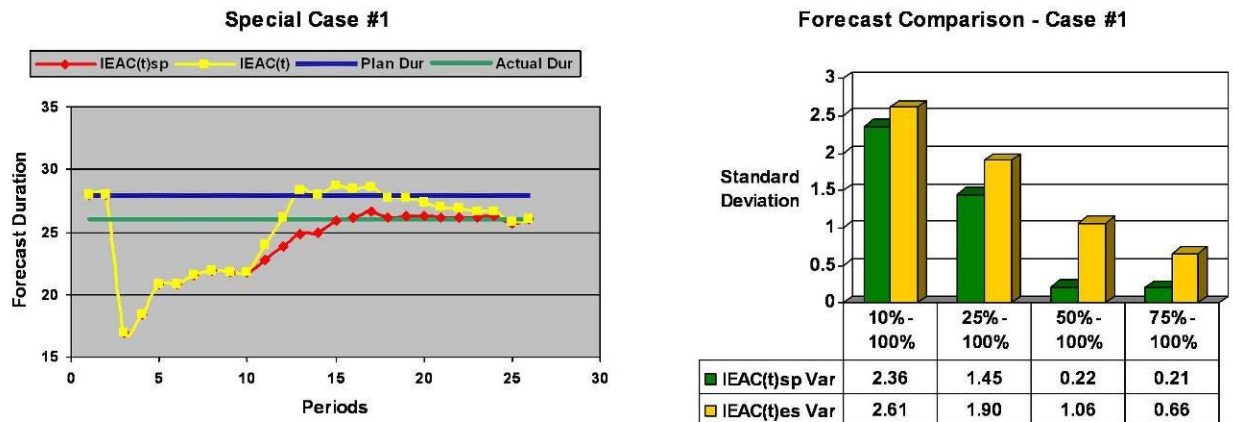


Figure 1. Early Finish – 3 week stop work (11-13)

The Figure 1 column chart shows that both methods of forecasting converge. The characteristic of convergence is indicated by the standard deviation becoming smaller and smaller as the data range becomes more biased toward completion. Each forecasting method indicates increasing accuracy as the project progresses; however, it is observed to be much more pronounced for IEAC(t)sp.

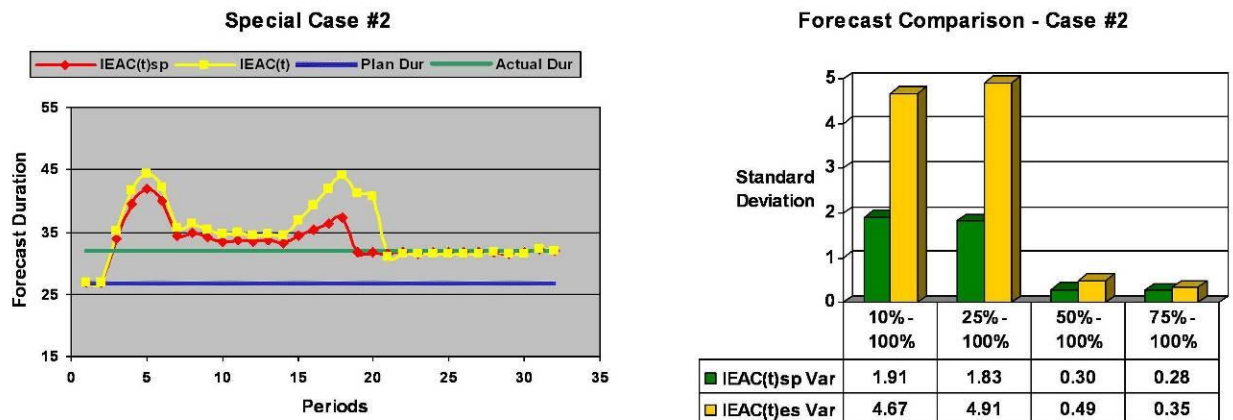


Figure 2. Late Finish – 4 periods of down time (15-18)

Figure 2 portrays the performance of a late finish project, planned for 27 periods, in which there are four periods of down time. Just as for Figure 1, the impact of stopping work, as planned, causes the normal forecast to increase rapidly. The special forecast increases, as well, but the durations calculated are shorter. It is seen that the special forecast very accurately predicts the final duration beginning at period 19 with the normal forecast becoming comparable at period 21. For Case 2 the column chart indicates convergence for both methods with the special forecast considerably better for the two larger percent complete ranges and marginally better for the two shorter ranges.

The Case 3 project is planned for 27 periods including four periods of down time. During execution the manager chose to work through the down time, thereby reducing the late completion to one period. From the graph it is seen that the normal forecast sharply decreases during the scheduled period of down time, while the special forecast decreases more gradually. The special forecast becomes very accurate beginning at period 17, while the normal forecast doesn't achieve comparable accuracy until period 24. Each method shows convergence from the column chart with the special method consistently showing better forecasting accuracy.

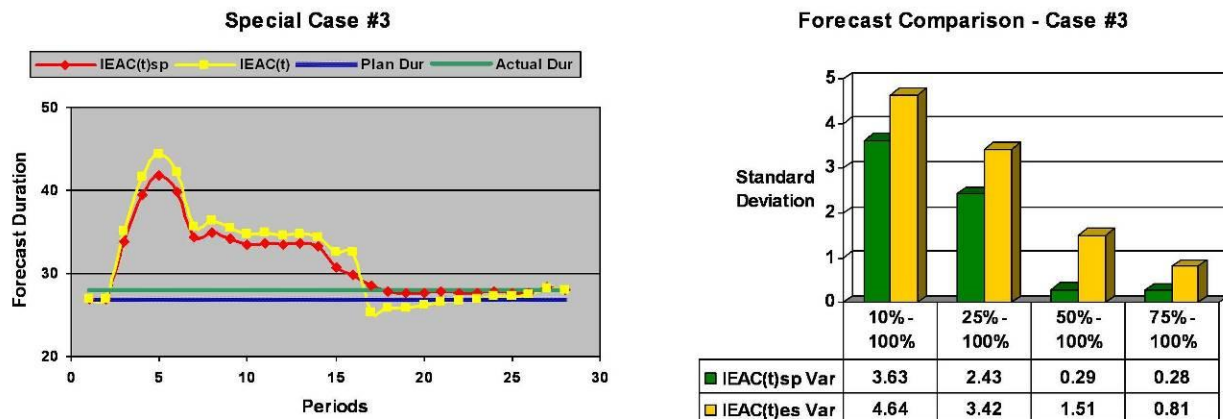


Figure 3. Late Finish – work through 4 periods of down time (15-18)

Figure 4 portrays the performance for a 27 period project having a combination of interruptions. During the execution, performance is halted for two periods. Later, to minimize the impact of the delay, the project team works through the four periods of down time, delivering the product three periods late.

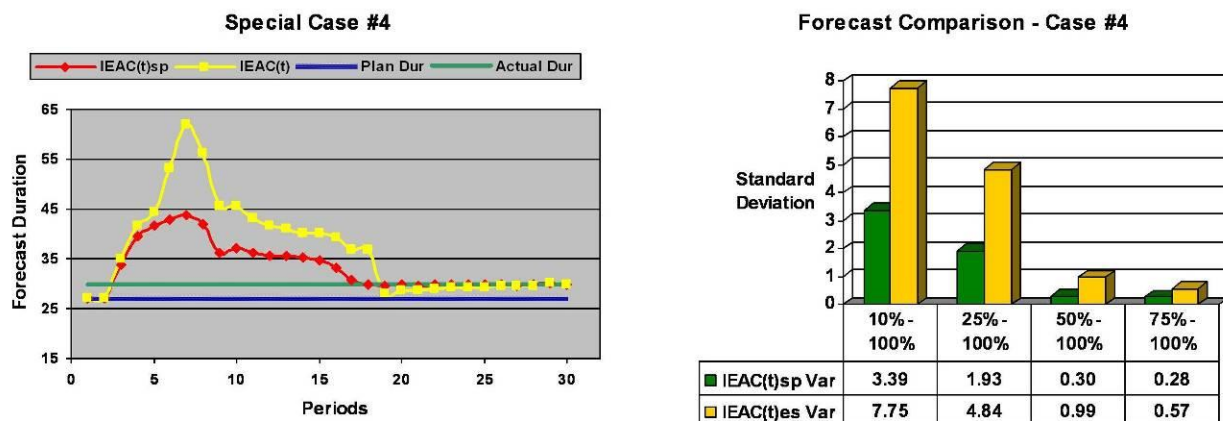


Figure 4. Late Finish – 2 period stop (6-7) and work 4 down time periods (15-18)

The graph and chart in Figure 4 depict the performance for Case 4. Clearly, the forecasts from IEAC(t)sp are better. They are shown to be more accurate for every set of computed values after period one. Likewise, the column chart illustrates that IEAC(t)sp calculations provided better forecasting and convergence for all performance data ranges.

The last three sentences in the previous paragraph portray, in general, the comparison results for cases 1, 2 and 3, as well. From the case examinations, it can be stated that when the interruptions of stop work and down time are encountered, the special method can be expected to produce more accurate forecasting results. Due to the case findings and their consistency, the special method is recommended for use.

Summary

Earned Schedule has been shown through research and use over several years to be a reliable schedule analysis extension to EVM. For large projects, stop work and down time conditions occurring for small portions of the project, in most instances, would not have much impact on the ES time-based indicators or the duration and completion date forecasts. However, it is a different matter for most projects. The interrupting conditions will usually distort the ES indicators and forecasts, possibly enough to affect management decisions.

Special calculation methods were introduced for enhancing the application of ES to projects having execution interruptions. The methods were described for the time-based schedule performance indicators and the forecasting of duration and completion date. The improvement to the indicators from the special methods was illustrated through an example set of EVM data.

The special and normal forecasting methods were applied to four sets of EVM data, having various combinations of stop work and down time conditions. For each case, forecasts were made using both calculations methods. The forecasts were then compared from two perspectives. Graphs were made for the forecast results of IEAC(t) and IEAC(t)sp by period. Included on the graphs are the planned and actual durations, as well. Additionally, column charts for four ranges of percent complete were constructed depicting the standard deviation of the forecast results with respect to the final duration.

For all four performance scenarios, the comparisons made in the graphs and charts clearly indicate that IEAC(t)sp reliably produced better forecasts. Although limited, notional, data sets were used, the results are compelling. Thus, for projects encountering stop work and down time conditions, the special ES method is recommended for calculating time-based indicators and forecasts.

Final Comment

Although the calculations to implement the special method are not difficult, they are incredibly tedious and the computations are mistake prone. To facilitate the application of ES for projects subject to the interruptions of down time and stop work, a calculator has been posted to the ES website (www.earnedschedule.com). The special ES calculator, *ES Calculator vs1f (Special Cases)*, is freely downloadable from the “es calculator” website page.

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Walt Lipke retired from federal service with over 35 years of experience in the development, maintenance, and management of software for automated testing of avionics. As a manager, a career highlight was his organization's winning of the Software Engineering Institute / Institute of Electrical and Electronics Engineers award for Software Process Achievement. Mr. Lipke is a graduate of the USA DoD course for Program Managers. He is a professional engineer with a master's degree in physics, and is a member of the physics honor society, Sigma Pi Sigma ($\Sigma\Pi\Sigma$). Lipke achieved distinguished academic honors with the selection to Phi Kappa Phi ($\Phi\text{K}\Phi$). He is the creator of Earned Schedule (ES). Mr. Lipke has published over ninety articles on the method, as well as two books, *Earned Schedule* and *Earned Schedule Plus*. Additionally, he has presented research on ES and its schedule performance analysis methods at several conferences in the United States, and internationally.

For his contribution to project control, the practice of EVM, and the creation of ES, Mr. Lipke has received several awards: 2007 Project Management Institute Metrics Specific Interest Group Scholar Award; 2007 Project Management Institute Eric Jenett Award for Project Management Excellence; 2013 Earned Value Management Europe Award; 2014 College of Performance Management Driessnack Distinguished Service Award; In 2017, the Australian Project Governance and Control Symposium honored Mr. Lipke by establishing the annual Walt Lipke Project Governance and Control Excellence Award. The award is made for excellence in research, expanding knowledge of the management and governance of projects, programs, and portfolios in Australasia.