

Applying Statistical Methods to EVM¹ Reserve Planning and Forecasting

By Walt Lipke, PMI Oklahoma City Chapter



Abstract

Generally speaking, statistical methods is an area of mathematics most people avoid, including those that plan and manage projects. Looking past this mental roadblock, the use of statistics offers significant potential to enhance both planning and project control. Risk planning can be improved through using statistics coupled to historical data. Correspondingly, the potential for improved project control comes from more reliable outcome forecasting for both project cost and duration. This article develops these applications of statistics and provides examples of their use. The outcome desired for this discussion is that the “fear” of statistics will be lessened and the reader will be inspired to try the methods in his or her own project environment. The statistical methods put forth are created and described from the perspective of schedule but are readily translatable and usable for cost.

Introduction to Statistics

The statistical applications for planning and forecasting are the Z-score (Z) and confidence limits (CL). Before discussing these statistical tools, two fundamental components are introduced: mean (M) and standard deviation (σ). It is emphasized that Z, CL, M, and σ depend on the distribution of the data being analyzed as being normal (Crow et al., 1960).

M is simply the computed average of the values obtained for the observations (O_i):

$$M = \Sigma O_i / n$$

where Σ indicates the sum of the observed values
n is the number of observations.

The σ is a measure of the variation in the observed values. The equation for σ follows:

$$\sigma = \sqrt{(\Sigma(O_i - M)^2 / (n - 1))}$$

This description applies to observations within a sample. When the application is to several samples of equal size, the σ of the sample means (σ_M) may be of interest:

$$\sigma_M = \sigma / \sqrt{n}$$

where n, in this instance, is the number of samples.

With these definitions, Z and CLs can be defined. Z is a determination of the displacement of an observed value from the mean, scaled to the σ :

$$Z = (O_i - M) / \sigma$$

When the object of interest is the distribution of samples, Z is computed using σ_M . Because Z is a measure used with the normal distribution, its value can be converted to probability. This computational capability is used throughout the chapter for both the planning and forecasting applications.

Confidence limits describe the uncertainty in the computed mean; i.e., they provide a range of possible values for an associated probability. The mathematical description for CL follows:

$$CL(\pm) = M \pm Z \times \sigma_M$$

CLs are frequently calculated at 90% or 95% levels. For these so-called “confidence levels”, Z = 1.6449 or 1.9600, respectively. Note that as the percentage increases so does the value of Z. Thus, the CLs for 95% are further from the M than are those for 90%.

Because the formulas previously introduced depend on the normal distribution, it is necessary to examine the appropriateness of their use with earned value management (EVM) and earned schedule (ES). From a study using 10 years of EVM data, it was shown through hypothesis testing for normality that the statistical distribution of the natural logarithm (ln) of the periodic indexes, CPI_p and $SPI(t)_p$, can be assumed to be normal (Lipke, 2002). Thus, normal statistics are appropriate when applied to the logarithmic values.

Before moving into the planning and forecasting applications, there are two additional data characteristics which need explanation, *number of observations* and *finite population*. With regard to the number of observations, when the number is less than 30, it is recommended to use the value of *t* from the *t* distribution instead of *Z*. The *t* distribution is similar to normal with the exception that its shape is dependent on the number of observations (Crow et al., 1960).

The final characteristic concerns the fact that projects are finite, whereas statistical analysis assumes the population of data is infinite. Projects do not meet that assumption; they have a start and an end. For finite populations, the statistical calculations are adjusted.

The adjustment factors required for our needs are derived from $\sqrt{((N - n) / (N - 1))}$, where *N* is the total number of observations and *n* is the number of observations in the sample of *N* (Crow et al., 1960). The substitutions necessary for adapting the statistics formula are shown in Table 1.² Making the appropriate substitutions, the adjustment factors for cost (*AF_c*) and schedule (*AF_s*) become:

$$AF_c = \sqrt{((BAC - EV) / (BAC - EV_{avg}))}$$

$$AF_s = \sqrt{((PD - ES) / (PD - ES_{avg}))}$$

Combining the elements from the preceding discussion yields the general equation for *CL*:

$$CL(\pm) = M \pm Z \times \sigma_M \times AF$$

The effect of the finite population adjustment factor is that, as the project moves toward completion, the adjustment causes the upper and lower *CLs* to approach each other, and at project completion, the upper and lower limits converge to the same value, the mean.

Reserve Planning

In the parlance of project management, “risk” is the term used to describe the uncertainty in project outcome. A possible outcome is completing under

budget and early. Although this is an example of uncertainty, from the perspective of a project manager (PM), it is not considered to be a risk, rather a blessing. The risk for projects is just the opposite, i.e., exceeding funding and delivering late. The mitigation of this possibility through the use of statistical uncertainty is our next focus.

In the statistical application for planning, we will see that the accommodation of risk affects the price and the product delivery commitment, as you would expect. As the mitigation of risk is increased, accordingly project price increases and delivery schedule is lengthened. Thus, when there is competition for performing the project, management has a critical trade-off question to answer: How much risk can be accommodated and still remain sufficiently competitive to win the contract? Answering the question leads to more-informed, better business decisions.

Before proceeding, let me offer a brief explanation of task estimating strategy. In general, there is a strong tendency by planning teams and PMs to insert risk mitigation into the task estimates and then have additional reserves as well. Taking this approach overstates the overall planned cost and duration considerably. It also causes the actual cost and duration to escalate as we know from an old axiom: “Work tends to grow to the time and money available.”

The planning strategy recommended and to be understood for this section is: The cost and duration estimates created are such that the probability of successful project completion is 50%. Setting the estimates at this level appropriately challenges the project team and places the risk mitigation collectively into the reserves, as it should be.

With this planning philosophy as background, we can continue the discussion of risk. Fundamentally, project risk is established in the planning process from bottom-up evaluation of the risks foreseen. For the risks considered, each is evaluated as to impact and probability of occurrence. The total risk is the sum over all risks identified, compositely portrayed in terms of funding and time. Their mitigation is reflected in the values chosen for the management reserves for cost and schedule.

Table 1. EVM and ES substitutions.

	N	n	1
EVM	BAC	EV	EVavg
ES	PD	ES	ESavg

² The *EVavg* and *ESavg* shown in Table 1 are the averages computed during project execution; i.e., their respective total amounts divided by the number of observations for the accruals to date.

This planning practice has considerable arbitrariness. There is little to validate the risk computed. Oftentimes, the evaluation is overwhelmingly complex and time consuming. Without going into more detail, it is also evident that there are many business forces affecting both validating the risk and the reserve amounts committed to the project. In short, the method of risk mitigation in use is incomplete and needs enhancing.

The missing element is the connection between reserves and the probability of success. Currently, the PM has little understanding of probability with regard to the risk mitigation. The association of the probability with the amount of schedule reserve (MR_s) may be recognized but only qualitatively. The absence of this connection can lead to poor decisions. For example, as frequently occurs, the MR_s created from the planning process is reduced during business strategy discussions to make a contract bid more appealing. When this happens, the PM and his/her superiors cannot evaluate the negative impact; the reduction has the potential to cause the project outcome to be unsuccessful. The PM does not have a method to corroborate the sufficiency of MR_s ; he/she has no way to argue that a reduction in reserves imperils project success. The application of statistics is intended to resolve this deficiency.

As we readily know, the periodic values of the time-based Schedule Performance Index, $SPI(t)_p$, vary during the execution of a project; i.e., the performance efficiency is different from one period to the next. This variation embodies the uncertainty of the schedule outcome.

In previous discussion, it was determined that the statistical distribution of the $\ln SPI(t)_p^{-1}$ can be assumed to be normal. It follows then that the average or M of the values for $\ln SPI(t)_p^{-1}$ is, also, normally distributed. Conveniently, M is determined from the natural logarithm of the cumulative index, $\ln SPI(t)_c^{-1}$ (National Institute of Science and Technology, 2010).

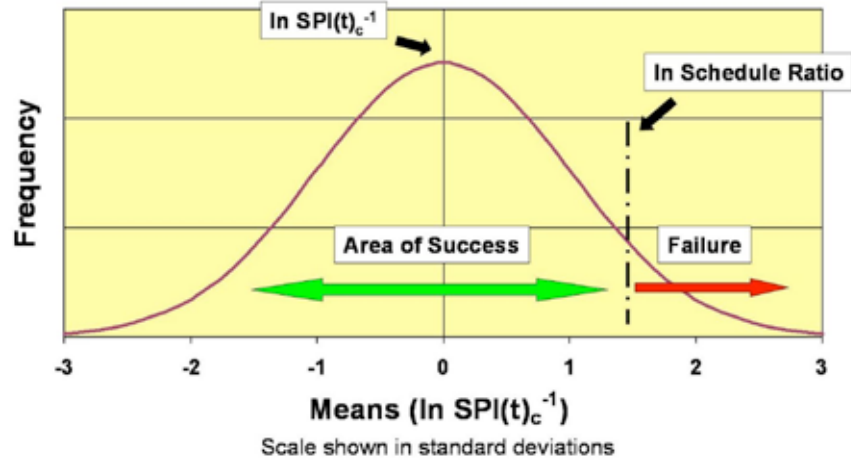


Figure 1. Distribution of $\ln SPI(t)_c^{-1}$

The distribution appropriate for planning the amount of schedule reserve is graphically portrayed in Figure 1, where $SPI(t)_c^{-1}$ is equal to 1.00. At the time of planning, we assume that the project can be executed as it is planned. Thus, the distribution is centered on zero.³

Also shown in Figure 1 are two areas, one identified as the “Area of Success” and the other as “Failure.” The areas are separated by a vertical dashed line tagged with “ln Schedule Ratio.” For these areas to be meaningful, the schedule ratio (SR) must be understood.

The SR is equal to the negotiated duration (ND) divided by the planned duration (PD), where $ND = PD + MR_s$. Obviously ND is larger than PD. Thus, SR is greater than 1.00 and the amount in excess of 1.00 represents the schedule reserve, MR_s .

The portion of the distribution to the right of the SR line identifies an area of possible final values for $\ln SPI(t)_c^{-1}$. These values yield schedule performance durations exceeding ND; in other words, failure. Conversely, values of $\ln SPI(t)_c^{-1}$ to the left of the SR line indicate successful outcomes. The value computed for the area beneath the normal curve in the successful area is the probability of success (P_s).

At this point, although the mechanism may not be completely clear, it should be understood that there is a relationship between MR_s and P_s . The component not obvious in this relationship is the dependence on the normal curve. The interdependence is made evident in the next few paragraphs.

³ $\ln SPI(t)_c^{-1} = \ln 1.00 = 0.00$, as shown in Figure 1.

Let us suppose the σ is one-half of the value used to make the graph for Figure 1. We can visualize this by mentally changing the scale, whereby the 1s become 2s, the 2s are 4s, etc. The plot for the normal distribution would be one-half as wide, become taller and appear much steeper. If the SR line remains in the same location, there is virtually no area in the failure region and P_s will compute to be very nearly 100%.

The statistical equation that connects performance variation, schedule reserve and probability of success is the Z formula introduced previously in the Statistics section. For our application it is represented as shown:

$$Z = (\ln SR - \ln \text{SPI}(t)_C^{-1}) / \sigma_M$$

The equation is general in that it may be applied during project execution to calculate the forecast probability of success. For the planning use, the equation is simplified due to the second term in the numerator vanishing; for this instance, recall that $\ln \text{SPI}(t)_C^{-1} = 0.0$.

In the remainder of this section, I provide examples for clarifying the Z equation's application to planning. To begin, it is recommended that the value for σ be derived from historical records of a completed project similar to the one being planned. When historical records do not exist, proceed by making a qualitative evaluation of risk. Using the assessment of the risk, create a value for σ from the associated range shown in Table 2. For example, we evaluate the project as high risk. From the given range for σ , the value 0.80 is selected.

To demonstrate further, let us use the high-risk estimate to perform an example calculation. Our fictional project is planned to execute over 28 months. Status is to be observed monthly; thus $n = 28$. From

the bottom-up risk evaluation process, MR_s has been estimated to be 4 months. With PD and MR_s known, $SR = (28 + 4) / 28 = 1.143$.

The Z-score is computed as follows:

$$\begin{aligned} Z &= \ln SR / \sigma_M = \ln (1.143) / (0.80 / \sqrt{28}) \\ &= 0.1334 / 0.1512 = 0.8823 \end{aligned}$$

For this value of Z, P_s is computed to be 81.1%. This probability would not likely be acceptable to the PM or his/her superiors. More than likely, a management decision would need to be made as described earlier, i.e., either schedule reserve is increased or the company accepts the probability of late delivery (~20%).

Another approach for planning is to begin by stating the desired probability of success and then calculate the associated schedule reserve. Let us require P_s to equal 95%. To obtain the equation for MR_s from Z, some algebra is needed. As an exercise, the reader is left to derive the formula:

$$MR_s = PD (e^{(Z \times \sigma_M)} - 1)$$

where the symbol ^ indicates the mathematical operation of raising the number e (2.718...) to the power ($Z \times \sigma_M$). Additionally, the reader is to determine why the value of Z for this instance is equal to 1.6449.

Substituting the values for PD, Z and σ_M into the equation, MR_s is computed:

$$\begin{aligned} MR_s &= 28 \times (e^{(1.6449 \times 0.1512)} - 1) \\ &= 28 \times (1.282 - 1) = 28 \times 0.282 = 7.9 \text{ months} \end{aligned}$$

These calculations are not difficult, although there is some degree of complexity. Certainly, they are fairly easy to perform on your own, using a hand-held calculator; however, the project planning analysis is simplified and further enhanced through the use of the Statistical Planning Calculator, available from the Earned Schedule web site.⁴ This calculator is a very simple to use spreadsheet and can be downloadable for free. An advantage the calculator affords is parameters (P_s , MR, σ) can be changed, iteratively, to arrive at an acceptable risk mitigation strategy.

An observation made from application is that when historical information is available, the σ obtained from the data may be larger than what occurs in the execution of the new project. This effect has the potential to overstate the reserves needed. A

Table 2. Risk – standard deviation.

Risk	Standard Deviation
Very low	0.00 – 0.15
Low	0.20 – 0.35
Medium	0.40 – 0.60
High	0.65 – 0.95
Very High	1.00 – ∞

⁴ The Statistical Planning Calculator is freely available for download from www.earnedschedule.com/Calculator.shtml.

reason for this occurrence is most likely related to the extent of new project similarity and the learning gained from the historical project.

As a real example, the cost and schedule standard deviations from a historical project were 0.40 and 0.46, respectively. Using the values, the reserves planned for the new project were created with the expectation of P_s equal to 90% for both cost and schedule. During execution of the new project, the standard deviations were significantly smaller. The values of σ for cost and schedule were 0.21 and 0.34, effectively raising the probability of success to 99% and 95%, respectively.

Admittedly there remains a considerable amount of subjectivity in reserves planning; however using statistics as described is a significant step enabling better informed planning and management decisions.

Forecasting

As presented in literature and research, ES offers calculation methods yielding reliable results, which greatly simplify final duration and completion date forecasting. This section advances the practice of project duration forecasting, another step forward.

From past studies performed on EVM measures obtained from historical records of large defense contracts, managers and analysts have gained confidence in their ability to reliably forecast the final cost of projects.⁵ The ability to advance forecasting beyond its current status, that is to projects which are neither defense related nor large (as are many software or information technology projects), is hampered by the lack of accessible broad-based data for research. Consequently, researchers have little facility to test their hypotheses, and the capability to control non-defense projects through EVM remains questionable.

To circumvent the lack of data for experimentation, I propose applying a statistical forecasting method. Using statistical methods for inferring outcomes is a longstanding, proven mathematical approach. The statistical forecasting method described for duration (and cost, as well) is relatively simple in concept and, from the statistical hypothesis testing of real data, has been demonstrated to perform rather well (Lipke et al., 2009). In fact, from the testing results provided in the reference citation, the overall prediction is better for schedule than for cost.

The 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 forecast. The probable high and low forecast values come from the confidence limits, derived from the variation of $SPI(t)_p$ discussed previously:

$$CL_s(\pm) = \ln SPI(t)_c \pm Z \times \sigma_M \times AF_s$$

The results obtained from the CL computations are natural logarithms of the cumulative index. In turn, the limit values for $\ln SPI(t)_c$ are used to calculate the estimates of the bounds for final cost and duration. For example, the forecast of the high bound for schedule, $IEAC(t)_H$, is calculated using the low CL value, $CL_s(-)$, as follows:

$$IEAC_H = BAC / e^{CL_s(-)}$$

To add clarification, example calculations are performed for a set of notional PV and EV data provided in Table 3. As depicted, the complete PMB is included along with the EV data reported through the thirteenth period. From this data, the following determinations are made: $PD = 27$ periods, $ES = 15.7$ periods, $AT = 13$ periods = n , $\sigma = 0.380$, and $SPI(t)_c = 1.209$. Proceed

Table 3. Notional data – statistical forecast.

AT	1	2	3	4	5	6	7	8	9
PV	93	644	975	1275	1739	2292	3331	3869	4612
EV	93	644	1710	2397	3060	3923	4722	5743	7369
AT	10	11	12	13	14	15	16	17	18
PV	5527	6575	7991	9193	10831	12946	14295	16051	17808
EV	9005	10850	12218	13921					
AT	19	20	21	22	23	24	25	26	27
PV	19666	21178	22839	24873	26310	27720	29113	30298	31821

⁵ Several studies of CPI and IEAC have been performed by Dr. David Christensen in conjunction with other researchers. These studies are identifiable and made available for download from www.suu.edu/faculty/christensend/ev-bib.html.

ing, the values for PD and $SPI(t)_C$ are utilized for calculating the nominal forecast:

$$IEAC(t) = PD / SPI(t)_C = 27 / 1.209 = 22.3 \text{ periods}$$

Next, the CLs are determined. To compute the CLs, the values for Z , σ_M , and AF_S are needed. Z is determined from the confidence level or probability desired. For our purposes, the confidence level is 90% and, thus, $Z = 1.6449$. The σ of the means is calculated from σ and n to be:

$$\sigma_M = \sigma / \sqrt{n} = 0.380 / \sqrt{13} = 0.105$$

The calculation of AF_S is as follows:

$$\begin{aligned} AF_S &= \sqrt{((PD - ES) / (PD - ES_{avg}))} \\ &= \sqrt{((27 - 15.7) / (27 - (15.7/13)))} \\ &= \sqrt{(11.3 / 25.8)} = 0.662 \end{aligned}$$

Having determined Z , σ_M , and AF_S , the CLs are computed to be:

$$\begin{aligned} CL_S(\pm) &= \ln SPI(t)_C \pm Z * \sigma_M * AF_S \\ &= \ln(1.209) \pm 1.6449 * 0.105 * 0.662 \\ &= 0.190 \pm 0.114 = 0.304, 0.076 \end{aligned}$$

The high and low bounds at 90% confidence can now be computed:

$$\begin{aligned} IEAC(t)_H &= PD / e^{0.304} = 27 / 1.355 \\ &= 19.9 \text{ periods} \end{aligned}$$

$$\begin{aligned} IEAC(t)_L &= PD / e^{0.076} = 27 / 1.079 \\ &= 25.0 \text{ periods} \end{aligned}$$

The forecasting calculations developed and illustrated with the notional data are applied in practice at each periodic observation. From the calculated results, forecasting graphs are then created and used for recognizing trends. Figures 2 and 3 are graphs depicting cost and duration forecasting, generated from analysis of real data. Each graph has four plots against percent complete, the nominal, high and low forecasts and the actual final result. The confidence level used for the high and low plots is 90%. The project containing the real data did not have a re-plan, while producing a high-technology item.

To gain a better understanding of the informative nature of the graphs, place a piece of paper over most of the area so that you are viewing only a small portion of the left side. By doing so, you are seeing only the information an analyst or PM would have at that point in time. The first thing you will notice as the paper is moved to the right is the narrowing of the vertical separation between the high and low forecast values. The next observation is that, for the cost graph, there is an appearance of symmetry with

very little trending; however for the schedule duration graph, non-symmetry and upward trending is seen. The last observation as the paper moves to the right is what was seen early on is a good indication of the final result.

Regarding this last observation, it is critical to understand that for the project analyzed no re-plan occurred. The impact of a re-plan could (and usually will) overcome the forecast implications. Thus, understanding that management has impact on project outcome, the statistical forecast should be interpreted as: The statistical forecast is the outcome expectation when project execution continues without the intervention of a re-plan.

Using the forecast in this manner provides a basis for making appropriate management decisions.

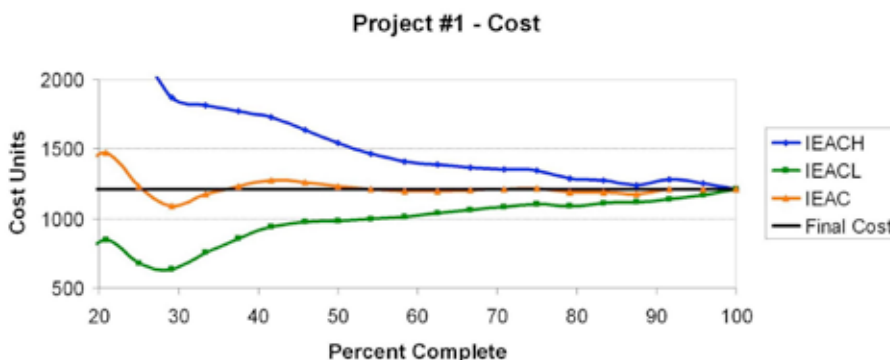


Figure 2. Statistical forecasting — cost.

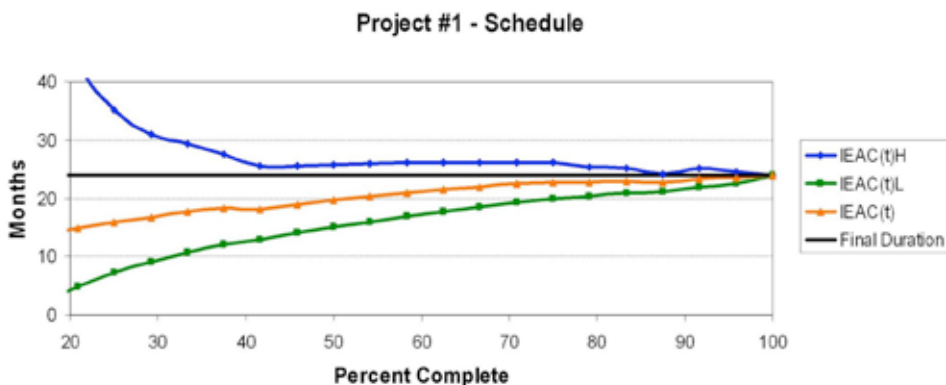


Figure 3. Statistical forecasting — schedule.

Returning to the graphs of Figures 2 and 3, let us explore their interpretation further. For the cost graph, as mentioned previously, symmetry is observed. As a general statement, when the high and low bounds appear symmetrical around the nominal value, the nominal forecast will be fairly close to the final outcome. For Figure 2, it is seen that the IEAC forecast is very close to the final cost as early as 35% complete and does not vary significantly through project completion.

For the schedule graph, an upward trend is seen, i.e., schedule performance worsens as project completion moves forward. An interesting observation from the graph can be made: the high bound is slightly higher than the final duration and tracks it as a nearly horizontal line. This characteristic has been observed in several real data instances. The phenomenon is observed, as well, for when the trend is downward, i.e., improving performance. For this occurrence, the low bound will be slightly lower than the final result. Similarly to the deduction made for the symmetrical analysis, when a trend is evident, the appropriate bound provides a slightly exaggerated estimate of the final result. For the schedule graph, the high bound is observed to be a reliable, slightly high estimate of final duration beginning at approximately 40% complete.

The calculation methods and analysis techniques described in this section have been shown through statistical testing methods to be extremely reliable. The testing results indicate the statistical forecasting method is virtually infallible when using 98% confidence level (Lipke et al., 2009). At 90 and 95% confidence level, there is greater risk of the estimates providing faulty results.

From the preceding statements it appears 98% confidence should be the level of choice; however, there is a trade off: the larger the confidence percentage the greater is the likelihood that the bounds are overestimated. For this reason, it is recommended to use 90% confidence in the majority of circumstances.

To apply the statistical methods introduced in this article may seem overwhelming. To make matters

worse, the capability does not exist for the EVM and ES tools on the market at the time of this writing. Compounding the problem, developing a spreadsheet would require, beyond a solid understanding of the method, a good amount of effort. To fill in the gap, a fairly easy-to-use spreadsheet has been created and is available for download from the ES web site (Statistical Prediction Calculator).⁶

Final Remarks

I am hopeful that this article will create interest in the statistical methods for planning and forecasting. I encourage you to experiment using your own EVM data and ES measures with the two calculators freely available for download from the ES web site. I believe you will find that applying these spreadsheets is not that difficult, and, without much additional effort, you will gain very valuable management information, specifically, the probability of success and project outcome limits for both cost and duration. Neither capability has been available in the history of EVM application.

Finally, as the worth of these statistical methods become more fully realized, it is reasonable to speculate that several positive behaviors could be induced:

- Project data records would likely become more meticulous and, thus, become more useful for future analysis and planning purposes.
- As the use of statistical methods propagate, automated tools should emerge, further expanding the application.
- Data sharing may even occur, possibly leading to a common EVM data repository for researchers.

If these ideal outcomes should occur, project management and the EVM community will have taken a quantum step forward in advancing the practice.

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⁶ The Statistical Prediction Calculator is freely available for download from the ES website at the following link: <http://www.earnedschedule.com/Calculator.shtml>.

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About the Author



Walt Lipke retired in 2005 as deputy chief of the Software Division at Tinker Air Force Base. He has over 35 years of experience in the development, maintenance, and management of software for automated

testing of avionics. During his tenure, the division achieved several software process improvement milestones, including the coveted SEI/IEEE award

for Software Process Achievement. Mr. Lipke has published several articles and presented at conferences, internationally, on the benefits of software process improvement and the application of earned value management and statistical methods to software projects. He is the creator of the technique *Earned Schedule*, which extracts schedule information from earned value data. 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 ($\Phi\Kappa\Phi$). During 2007, Mr. Lipke received the PMI Metrics Specific Interest Group Scholar Award. Also in 2007, he received the PMI Eric Jenett Award for Project Management Excellence for his leadership role and contribution to project management resulting from his creation of the Earned Schedule method. Mr. Lipke was recently selected for the 2010 Who's Who in the World. Contact Mr. Lipke at 1601 Pembroke Drive, Norman, OK 73072 or 405.364.1594.



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