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Use of Earned Value Management Trends to Forecast Cost Risks

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This article uses earned value management trend analysis to forecast trends in BAC and BCWP. The resulting equations are then used to solve for the expected month at completion. With the month at completion date in hand, the article uses trend analysis to find the EAC at that month along with the BAC at that month far in the future to solve for VAC. By using variance against a baseline, the article shows how much risk this program will incur by the date at completion. A monthly risk burndown chart is developed to illustrate how the program burns down risk during life of the program. It indicates that the rate of risk burndown may very well be more rapid than the rate of accomplishment of remaining work. The article concludes that program managers would be well advised to require analysis of EVM trends to understand how much additional schedule is being added to a contract with each addition of scope as measured by the increase in BAC over time.

Introduction

As Director of Business Operations for the Titan IV System Program Office in the early 1990s at the USAF Space and Missile Systems Center, I wrote an article (Smoker & Crawford, 1993) with D. Crawford entitled, "A Cost Risk Analysis Metric (Technical Application Guide)" that developed a cost risk control chart with upper (UCL) and lower (LCL) control limits following the approach of W. E. Deming (1982). A cost risk analysis of variance at complete (VAC), based on a monthly cost performance report (CPR) data (EVM terms and definitions; see DOD Extension, 2003), provided program insight into the empirical risk for the program rather than relying on a Monte Carlo simulation of an unknown risk probability distribution characterized by a triangular assessment of low, medium, and high judgments of subject matter experts.

With advances in computer capabilities since the early 1990s, it appears the time is ripe to revisit the process of analyzing earned value management (EVM) trends of performance. I have obtained a series of 43 EVM data points for a program whose details are no longer of interest (and so will not be discussed), except insofar as its earned-value (EV) data illustrate common trends in program progress. This article approaches the measurement of cost risk analysis by using the first 18 months of the 43-month series of CPR data to forecast the program's cost risk. First, a view of both the cost and schedule trends based on all 43 months of data is depicted to characterize key events in the program. Next, using only the first 18 data points, projections of equations that estimate budgeted cost of work performed (BCWP) and budget at complete (BAC) are solved simultaneously to identify the value of BCWP that equals the value of BAC at some future date in time. Recognizing that BCWP/BAC = 1.0 is the point at which the program is 100% complete; it is then possible to use the estimated BAC level as a true constant in the denominator

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of the monthly percent-complete values and solve for percent complete (PC) as a function of time.[1] Having in hand both an estimated value for BAC that should stop growing monthly when PC is equal to 100% and a solution for the month that the program will achieve BCWP = BAC, it is possible to develop other useful measures of EV metrics. The projection of PC as a function of time is used to estimate the most likely date of completion, as well as an early and a late date of completion based on 95% confidence bounds. Since the BAC and the corresponding estimate at complete (EAC) continue to grow throughout the program, forecasts of both trends are plotted. As the data series stops before the program has achieved 100% complete, a forecast of the expected completion date is used to determine both the expected BAC and EAC at the completion date. The accuracy of the equation used to predict the completion date is cross-checked against the 43rd or last data point in the series, which represents about 82.6% of completion against a BAC of $7,684.25 million on contract in the actual data for the 67th month. Note that this value of BAC at the 67th month will be less than the predicted BAC value further in the future for the month in which 100% complete is expected to be achieved. Finally, using this future date (which will be shown to be in the 92nd month), other measures of EV metrics will be calculated and the difference between the EAC and BAC will be used to forecast the variance at complete (VAC). The VAC is then used to develop a cost-risk metric to serve as an empirical measure of how the program burns down risk as progress is made in solving technical, schedule, and programmatic problems. The results of the trend analysis are then compared with the standard EVM formula application to highlight the difference between applying one of the many EAC formulas vice performing a trend analysis.

EVM Trend Data

The data series for the program's earned value begins in September 1995 and ends when the program appears to be about 82.5% complete in March 1999. It is noted that the first 18 months of the data represent dates from September 1995 through February 1997. Figure 1 is a Deming control chart depicting UCL and LCL bounds indicating that the cost performance index (CPI) should be between them 95% of the time for the entire data set of 43 months. The first observation is of the two blips in the CPI data. The first anomaly, in December 1996, appears to be a one-month anomaly in which the CPI jumps from 0.95 up to 0.99 and then immediately drops to 0.94 in January 1997, returning to its original downward trend. Note that this blip occurs in the first 18 months of data that end in February 1997. The second observed anomaly appears in November 1997 and runs through January

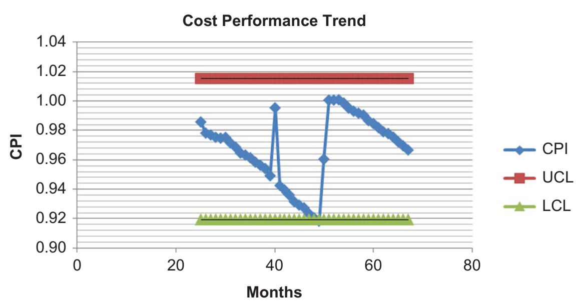

FIGURE 1 43-Month CPI trend analysis (color figure available online).

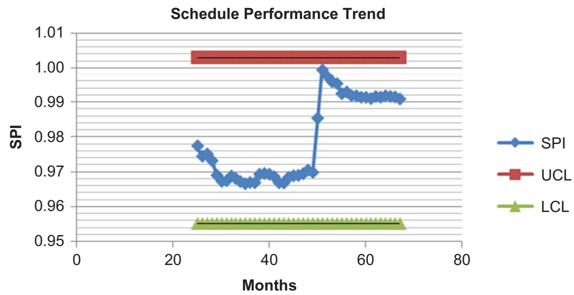

FIGURE 2 43-Month SPI trend analysis (color figure available online).

1998, where the CPI is reset to just above 100% before returning to a downward slope that appears to be slightly less steep than the original downward trend.

Figure 2 displays the schedule performance index (SPI), again for all 43 months of data. Here, the SPI initiates a turn from its original downward trend in January 1996 and bounces along just above the lower control limit until October 1997, at which point it bounces up from the LCL to about 0.985 the month before the over target baseline (OTB) reset is implemented in November 1997. The SPI then jumps to 100% for the reset month (November 1997) before turning downward toward the 0.99 level over the next 17 months. Again, the UCL and LCL bounds are set such that the SPI should remain between them 95% of the time.

Using the first 18 months of this data set, we make a projection of BCWP and BAC. The resulting equations are derived from the data contained in Table 1, in which the first

TABLE 1 18 Months of EVM data ($M FY1999)

EQM	# Months	Cum BCWS	Cum BCWP	Cum ACWP	BAC	LRE EAC
Sep-95	25	$2.034	$1, 988	$2, 017	$5, 750.00	$5, 750.00
Oct-S5	26	$2, 150	$2, 095	$2, 142	$5, 776.00	$5, 776.00
Nov-95	27	$2, 247	$2, 191	$2, 243	$5, 785.00	$5, 785.00
Dec-95	28	$2, 358	$2, 294	$2, 353	$5, 822.94	$5, 823.00
Jan-96	29	$2, 477	$2, 400	$2, 462	$5, 870.95	$5, 871.00
Feb-96	30	$2, 586	$2, 501	$2, 565	$5, 906.54	$5, 917.00
Mar-96	31	$2, 705	$2, 617	$2, 694	$5, 961.16	$5, 972.00
Apr-96	32	$2, 817	$2, 729	$2, 817	$6, 000.22	$6, 017.00
May-96	33	$2, 921	$2, 828	$2, 932	$6, 088.19	$6, 146.00
Jun-96	34	$3, 038	$2, 939	$3, 051	$6, 160.98	$6, 350.00
Jul-96	35	$3, 152	$3, 047	$3, 169	$6, 156.54	$6, 344.00
Aug-96	36	$3, 245	$3.138	$3, 274	$6, 132.15	$6, 352.00
Sep-96	37	$3, 370	$3, 258	$3, 407	$6, 211.78	$6, 401.00
Oct-96	38	$3, 479	$3, 373	$3, 535	$6, 173.79	$6, 363.00
Nov-96	39	$3, 579	$3, 470	$3, 656	$6, 118.34	$6, 396.00
Dec-96	40	$3, 667	$3, 554	$3, 571	$6, 145.90	$6, 424.00
Jan-97	41	$3, 765	$3, 647	$3, 869	$6, 292.16	$6, 570.00
Feb-97	42	$3, 866	$3, 738	$3, 978	$6, 269.68	$6, 548.00

month of observed data is month 25. This implies the contract was awarded in August 1993. While the entire data series covers 43 months, only data for months 25 through 42 are going to be used to derive the equations necessary to forecast BCWP, BAC, and other EVM metrics. Since this program presumably began just over two years before our first observation, the program appears to be past the ramp-up phase where the S-curve for the planned budgeted cost of work scheduled (BCWS) is making its initial upward turn. An assumption is made that the major section of the S-curve between the 25% completion and the 82% completion level is essentially linear but with some variability. This is especially true since the program would have yet to begin winding down toward contract close-out in the right tail of the curve. W. Lipke (2003) has shown, for forecasting the duration of a project, an earned-schedule method that is linear in the rate at which the remaining work is accomplished. Since Lipke's measure of earned schedule is based on time, time measured in months may be a good precursor of the key measures of BCWS, BCWP, BAC, and EAC. However, Lipke did not address the problem of a baseline where the BAC scope is growing monthly (Lipke, 2009). The full 43 months of data for the key monthly earned value management metrics are graphed in Figure 3, and the relative linearity is clearly observable. Furthermore, the three key measures of BCWS, BCWP, and ACWP appear to point backward in time to the point of zero cost at month zero. This implies that for any month of actual BCWP measured, the PC will drop as the BAC grows. Note the BCWP line represented by squares underneath the ACWP triangles in Figure 3 appears already to be turning to a flatter rate of growth after a small inflexion point in the middle of the series. This implies that the intercept of BCWP and BAC is moving to the right somewhat faster than at the beginning of the program. The question becomes: "When will the scope changes in BAC stop, so that PC can grow to equal 100%?" Now, if our linear assumption is correct, it is possible to forecast not only BCWS and BCWP but also BAC and EAC, since these measures are reported at the end of each respective month.

Hence, ordinary least-squares linear regression relationships are hypothesized for BCWS, BCWP, BAC, and EAC. The BCWS and BCWP equations are constrained to begin at zero, while the BAC and EAC equations have a positive intercept term, as the earliest estimate of the cost of a new system usually forms the basis for the budget used to negotiate a contract value. The BAC intercept is representative of the initial contract value that then grows across time to a higher level as work proceeds, requirements become better defined and understood, and planned effort not put on contract in the original basic negotiation gets

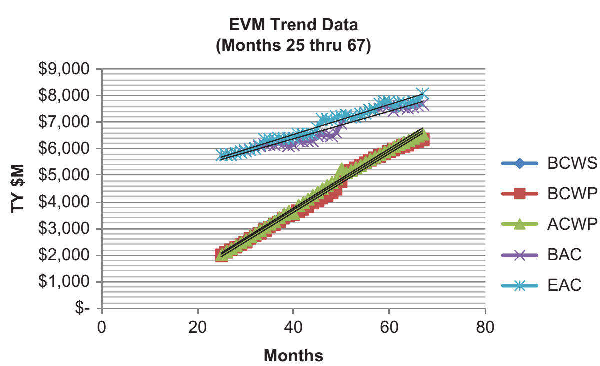

FIGURE 3 EVM metric trend data appear to be linear in time (color figure available online).

added to the contract later. Equation (1) indicates that BCWS has been planned at an average rate of \$89.12M dollars a month with some degree of variability. Note that this equation is based on the 18 months of data from month 25 through month 42. That is, Equations (1) through (4) assume that time now is at the end of month 42, which represents February 1997 in Table 1. As time is measured in relatively equal increments of months, it can serve as an independent variable to forecast the values of the dependent variables out to the position where BAC and BCWP are equal. That is, they are both for the month in which 100% completion is achieved for some as yet unknown BAC dollar total. In Equations (1) through (4), the subscript 18 implies that the data series used for the regression was comprised of the 18 observations for months 25 through 42. Using the 18 months of data known at the end of month 42, and with Equations (1) through (4), it will show that the risks associated with scope additions to the contract for this program can be anticipated and a chart developed to show how those risks get burned down.

A Program Duration Solution

From the data in Table 1, we find the following linear solutions using Excel:

$$\begin{aligned} \text{BCWS}_{18} = {} & \$89.12\text{M} * \text{Months}, \\ & (0.7525) \quad \text{T-stat} = 118.44, \quad \text{R}^2 = 0.9988 \end{aligned} \tag{1}$$

$$\begin{aligned} \text{BCWP}_{18} = {} & \$86.35\text{M} * \text{Months}, \\ & (0.6925) \quad \text{T-stat} = 124.68, \quad \text{R}^2 = 0.9989 \end{aligned} \tag{2}$$

$$\begin{aligned} \text{BAC}_{18} &= \$4,970.56\text{M} + \$31.76\text{M} * \text{Months}, \\ & \quad (86.92) \quad (2.56) \quad \text{R}^2 = 0.9056 \\ \text{T-stats} & \quad 57.19 \quad 12.39 \end{aligned} \tag{3}$$

$$\begin{aligned} \text{EAC}_{18} &= \$4,393.13\text{M} + \$52.62\text{M} * \text{Months}. \\ & \quad (106.65) \quad (3.15) \quad \text{R}^2 = 0.9459 \\ \text{T-stats} & \quad 41.19 \quad 16.73 \end{aligned} \tag{4}$$

For Equations (1) through (4), the numbers in parentheses represent the standard errors of the parameters, the T-stat is measured as the parameter value divided by the standard error, and R^2 is the measure of the variability of the dependent variable explained by the independent variable. Equation (1) indicates that BCWS was planned to be performed at an average expenditure rate of \$89.12M a month with a degree of variability. Equation (2) indicates that the cumulative BCWP has been growing at an average rate of \$86.35M a month, again with a degree of variability. For now, the PC projection is not provided because BAC appears to be growing monthly as illustrated in Figure 3.

A projection of PC as a function of time measured in months is provided in Figure 4 with the actual completion percentage tracking along the middle black line. The UCL and LCL based on the 95% confidence values from the regression in Table 2 are displayed as lines symbolized by squares and triangles, respectively. Note the statistical equation has an R^2 of 0.99 and a standard error of 0.004. The PC was measured as the raw value of each monthly BCWP divided by the value of the BAC for month 42. That is, the PC was

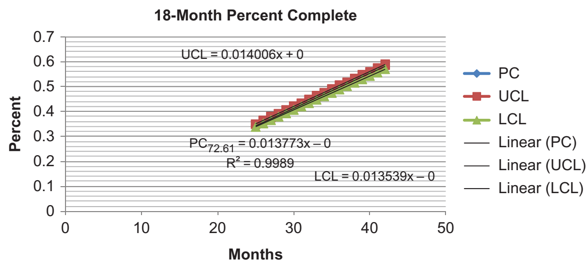

FIGURE 4 18-Month PC (color figure available online).

adjusted each month by normalizing all of the BACs (for months 25 through 42) to the BAC of month 42. This has the effect of reducing the original slopes of the PC to go through the PC for month 42. Note from the PC chart (Figure 4) that the first data point is September 1995. This is month 25, as the contract was awarded in August 1993, so the available series of data begins just over two years after the award of the prime contract. From these data, it is known that the contract ramp-up of the workforce occurred earlier in the program and is not reflected in the data. That is, the lower tail of a normal S-curve would have occurred during the first year of ramp-up. By month 25, the contract workforce should be relatively stable.

Table 2 is a standard Summary Output from a regression run in Excel. Here the 18 data observations analyzed in the regression are those in Figure 4. In addition to the regression statistics for goodness of fit, Table 2 also displays degrees of freedom, regression sum of squares (SSR, namely, the sum of squared differences between the individual estimates and the mean of all the actuals), residual sum of squares (SSE, the sum of squared differences between the individual estimates and their corresponding actuals), and total sum of squares (SST, the sum of SSR and SSE). The R^2 value is measured as 1 - SEE/SST. The coefficients are the parameter values for the regression, and each is shown with its standard error. As noted earlier, PC always starts at the value of zero; hence, the intercept for this equation has a pre-set coefficient of zero. The small standard error for the Month coefficient results in a relatively large t-statistic. The F-statistic of 15545.99 is measured by the ratio of the mean square of the regression to the mean square of the residual. The associated P-value indicates significance of the overall equation as it is less than the 5% level of significance cut-off point. The P-value measures the probability, in this case extremely low, that the observed correlations would occur if all of the parameters were equal to zero. With the regression data, it is now possible to express the PC as shown in Equation (5):

$$\text{PC} = +0.01377 \times \text{Month}. \tag{5}$$

As seen in Table 2, the monthly PC is 1.377% so that the expected completion month to meet the \$6,269.68M BAC on contract in month 42 is (1/0.01377 =) 72.61 months with some variability as measured by the 95% confidence interval in the regression from (1/0.01401 =) 71.40 early to (1/0.01354 =) 73.86 late completion. This compares favorably with the independent estimate at completion (IEAC(t)) at time t. The following earned-schedule estimate from the data at month 42 for actual time (AT) uses Lipke's formula (Lipke, 2009). That is,

$$\text{IEAC}(t) = \text{AT} + (\text{BAC} - \text{BCWP})/\text{WorkRate}, \tag{6}$$

where at month 42, the data in Table 1 indicate that:

TABLE 2 18-Month percent complete trend for BAC at $6,269.68

SUMMARY OUTPUT

Regression statistics	
Multiple R	0.9994537
R Square	0.9989077
Adjusted R Square	0.9400841
Standard Error	0.0158867
Observations	18

PC = 0 + 0.013772546 *Month

ANOVA

	df	SS	MS	F	Significance F
Regression	1	3.923593414	3.923593	15545.99	2.45322E-25
Residual	17	0.004290566	0.000252		
Total	18	3.92788398			

	Coefficients	Standard error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	0	#N/A	#N/A	#N/A	0	0
Month	0.0137725	0.00011046	124.6835	1.28E-26	0.013539496	0.0140056

$$\text{AT} = 42,$$
$$\text{BAC} = \$6,269.68\text{M},$$
$$\text{BCWP} = \$3,737.55\text{M}.$$

Work rate is measured as:

$$\text{BCWP/month} = \$88.99\text{M}.$$

Therefore, from Equation (6) we get IEAC(t) = month 70.45.

However, as noted in Figure 3, BCWP growth appears to be flattening out as time moves to the right. Therefore, it may be expected that 72.61 months will not be adequate to complete the program at a higher BAC level.

As noted above, the scope, as measured by BAC, is still growing and, therefore, PC for BAC_{42} will be reduced by month 67 and any future month where the BAC continues to grow with changes in scope. That is, the slope of the PC line based on time will continue to be reduced as scope increases with time since BAC is in the denominator of the PC calculation. As the PC slope gets reduced with each scope increase to BAC, the time to reach 100% increases. At some future month, BCWP effort will grow to be equal to the final BAC scope at 100% completion. Since most contracting offices put only a portion of a total program's scope on contract at any point in time, the cumulative value of contract scope continues to grow until all of the anticipated work has been placed on contract and the BAC stops growing. This implies there are risks to the program that are not yet on contract and, so, have yet to be considered in the Risk Management Plan. Hence, if one knew the total amount of work that would be placed on this contract to complete the program, then that total estimated scope value could be used as the denominator of the PC formula to arrive at the true PC for each month accomplished to date in the program. Further, since both BAC and BCWP appear as linear functions of time measured in months, it is possible to solve Equations (2) and (3) above for the number of months from contract award until BCWP effort is equal to the final BAC scope. That is, we may be able to identify a future month when the anticipated work for this contract is complete and BAC stops growing. Table 3 displays the Excel-derived parameter values with the lower and upper 95% values that provide the best- and worst-case scenarios for when BCWP will equal BAC.

At 100% complete, BCWP effort will equal BAC scope; therefore, we may set Equation (2) equal to Equation (3) and solve for the corresponding number of months since the contract began. That is, we can solve for the program duration between authority to proceed (ATP) and final date of completion. We now have Equation (6) where BCWP is assumed to be equal to BAC, and BCWP is represented by Equation (2) while BAC is represented by Equation (3). That is:

$$\$86.35\text{M} * \text{Months} = \$4,970.56\text{M} + \$31.76\text{M} * \text{Months}. \tag{7}$$

Solving for the number of months represented by t in Equation (6), we find the expected completion month by solving Equation (7) for the unknown "months":

$$\text{Months} = \$4,970.56\text{M}/(\$86.35\text{M} - \$31.76\text{M}) = 91.06\text{Months}. \tag{8}$$

TABLE 3 BCWP as a function of time measured in months

SUMMARY OUTPUT

Regression statistics					
Multiple R	0.99945368				
R Square	0.99890766	BCWP =	0 +	86.34945705	*Month
Adjusted R Square	0.94008414				
Standard Error	99.6043306				
Observations	18				

ANOVA

	df	SS	MS	F	Significance F
Regression	1	154232091.3	154232091	15545.9872	2.45322E-25
Residual	17	168657.3854	9921.0227		
Total	18	154400748.7			

	Coefficients	Standard error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	0	#N/A	#N/A	#N/A	0	0
Month	86.349457	0.692548923	124.68355	1.2781E-26	84.88830655	87.8106075

TABLE 4 Variability in the months of program duration ($M FY1999)

Variable	Constant		Rate	Complete
Best Case BCWP =	0		$84.89	
BCWP =	0	+	$86.35	*Month
Worse Case BCWP =	0		$87.81	
Best Case BAC =	$4,786.31		26.326	
BAC =	$4,970.56	+	31.762	*Month
Worse Case BAC =	$5,154.82		37.197	
Setting	BAC	=	BCWP	Month
Best Case C-Month =	$4,786.31	=	$58.562*Mo.	81.731
Completion Month =	$4,970.56	=	$54.588*Mo.	91.056
Worse Case C-Month =	$5,154.82	=	$50.614*Mo.	101.846

Further, we may examine the variability in the program duration by applying a similar logic to the lower and upper bounds of both BCWP and the BAC as illustrated in Table 4.

From Table 4, we find that completion will most likely occur about two days into the 92nd month after the start of the contract, i.e., April 2001. Note that completion could occur as early as month 81.7 (May 2000) and as late as month 101.8 (February 2002). Now, from Equation (2) we find that by April 2001:

$$\text{BCWP} = \$86.35\text{M} * 91.06 = \$7,862.64\text{M}. \quad (9)$$

While from Equation (3), we find that scope increases will reach a BAC level of:

$$\text{BAC} = \$4,970.56\text{M} + \$31.76\text{M} * 91.06 = \$7,862.64\text{M}. \quad (10)$$

As we suspected earlier, our PC formula that indicated 100% completion at month 72.6 understates the true PC due to the fact that BAC scope is continuing to grow. It is interesting to note that Lipke's formula in Equation (6) works well for this new scope level of BAC. That is, for a BAC of $7,862.62M, Equation (6) yields an estimated completion month of 89.77, about 1.3 months short of the 91.06 months obtained from Equation (8). This is about a 1.4% variation in the program duration. The difference in the approach here is that the scope BAC value is known about four years (91.06 - 42 = 49.06 months) earlier than it would become available for entry into Lipke's formula.

Comparison of Completion Trends for Different BACs

If the scope, as measured by BAC, were to stop growing by month 91.06, one wonders what parameters the true PC formula would have. Since we have now solved for the BAC at month 91.06 and found that BAC equals $7,862.64M, we can now divide our original monthly BCWPs for months 25 through 42 by this new BAC and obtain corrected PCs on which to rerun our regression. The new regression results for PC are given in Table 5.

Note, from Table 5, that the PC-per-month parameter is equal to the reciprocal of the number of months at completion of 91.06 from Equation (7) above, which is greater than the original 72.6 months at completion estimate. We can now overlay the new PC trend on the chart in Figure 4 to observe how the PC curve shifts as BAC scope is increased. This comparison is provided in Figure 5. From Figures 4 and 5, it is apparent that increasing the level of the BAC shifts the PC curve downward and to the right as the BCWP observations

TABLE 5 Percent complete regression for BAC at $7,862.64M

SUMMARY OUTPUT

Regression statistics					
Multiple R	0.99945368				
R Square	0.99890766	PC =	0 +	0.010982246	*Month
Adjusted R Square	0.94008414				
Standard Error	0.01266805				
Observations	18				

ANOVA

	df	SS	MS	F	Significance F
Regression	1	2.494812	2.494812303	15545.9872	2.45322E-25
Residual	17	0.002728	0.00016048		
Total	18	2.49754			

	Coefficients	Standard error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	0	#N/A	#N/A	#N/A	0	0
Month	0.01098225	8.81E-05	124.6835482	1.2781E-26	0.010796412	0.011168

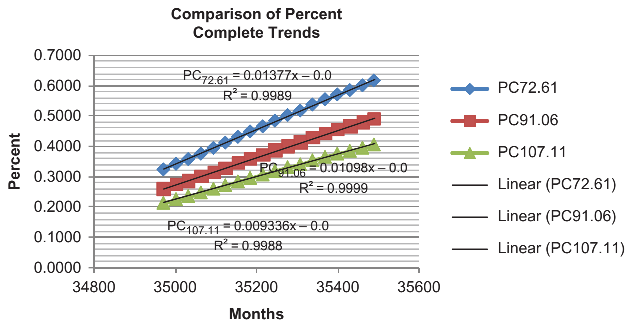

FIGURE 5 Comparison of percent complete trends (color figure available online).

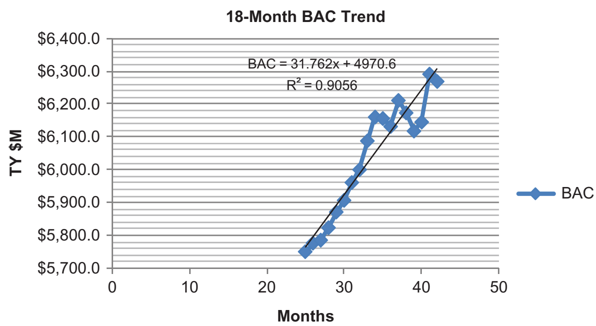

FIGURE 6 18-Month BAC trend (color figure available online).

from Figure 3 were the same for both curves in Figure 5. Further, this shift will continue until the level of scope BAC stops increasing in the future. That is, until the amount of effort added to the contract through negotiations between the Government and the prime contractor stops growing. For now, let's assume that the scope BAC on contract stops growing at $7,862.64M and that month 91.06 represents completion. We can then examine how the rest of the earned value measures may be forecast consistent with this expected completion month. We could also increase the scope BAC to a higher level, such as $9,546M, and observe the shift in the PC values supporting this scope BAC. A comparison of PC trends for different BAC scope values ($6,269.7M, $7,862.6M, and $9,546.0M) is provided in Figure 5. These correspond, respectively, to estimated program duration or months from ATP to completion of 72.61, 91.06, and 107.11.

Here, the line represented by triangles is a further shift of the PC line. This new line has a lower rate of growth in PC per month as shown by the parameter value of 0.009336. Also, 1/0.009336 indicates that the most likely month of completion for the contract value of $9,546M is month 107.11. In fact, for each of the other PC lines, the reciprocal of the parameter gives the expected completion month.

Recall from Figure 3 that there is significant variability in the scope BAC. Let's again examine months 25 through 42 and identify how well the linearity assumption applies. In Figure 6, one can see the variability in scope BAC, first increasing and then decreasing and then increasing again, especially in months 35 through 42. This demonstrates uncertainty in the negotiating actions on the part of the Government. The contractor and Government teams are changing the scope or content of the effort to be performed on the contract. This contract uncertainty contains unknown risks and creates variability in the amount and duration of the effort planned for the contract. And, as most program managers know, EAC

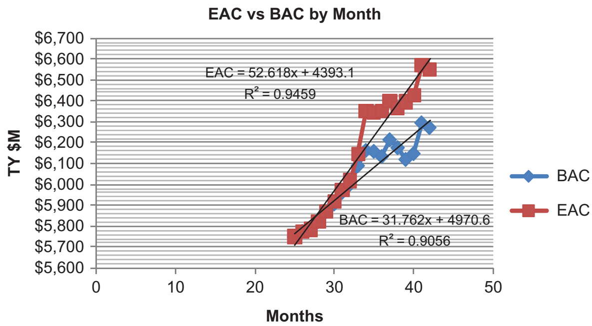

FIGURE 7 EAC vs. BAC by month (color figure available online).

is never equal to BAC. So, let's see how EAC compares with the BAC level of $7,862.64M. Figure 7 displays EAC vs. BAC for each of the 18 months being used for forecasting (i.e., months 25 through 42).

Comparison of VACs

From Figure 7 and the statistical equations in Tables 6 and 7, it is apparent that EAC is growing at an average rate of $52.6K per month, while BAC is growing at an average rate of $31.8K per month. This indicates that the VAC is also growing. From Figure 5, one can see that VAC_{42} at month 42 is over $300M. These trend equations may now be used to forecast out to month 91.06, the expected completion month derived from Equation (7) above. Now from Equation (3) we can derive $BAC_{91.06}$. That is:

$$BAC_{91.06} = \$4,970.56M + \$31.76 \times Months = \$7,862.64M. \quad (11)$$

Then, at month 91.06, the estimated $BAC_{91.06}$ is $7,862.64M. From Equation (4) we can derive $EAC_{91.06}$. Recall that the statistics of the estimates for both Equations (3) and (4) are given in Tables 6 and 7, respectively. So we now find:

$$EAC_{91.06} = \$4,393.12M + \$52.62M \times Months = \$9,184.32M. \quad (12)$$

So, we have an estimate of $EAC_{91.06}$ as a value of $9184.32M. Subtracting $EAC_{91.06}$ from $BAC_{91.06}$ yields $VAC_{91.06}$ estimated at about -$1,321.69M. This forecast appears reasonable once viewed against the actual data set that goes only to month 67. Now remember there was a $600M reset of the BAC at month 51 (November 1997) (see Figure 1), which brought the CPI back to 1.00. Because the VAC at month 67 (March 1999) is observed to be $386M, so the estimate of an additional $335.69M by month 91.06 (April 2001) appears very realistic.

Furthermore, the estimate of VAC_{67} may be used to crosscheck the accuracy of our equations based on trends from the early 18 months of the 43-month series. By inserting month 67 into Equation (3) for BAC and into equation (4) for EAC, estimating the best case as well as the worst case for each using the lower and upper, respectively, 95% bounds on the coefficients found in Table 6, and averaging them to get the mean estimate, one finds:

$$\text{Best Case } BAC_{67} = \$4,786.31M + \$26.33M \times 65.89 \text{ Months} = \$6,520.95M,$$

$$BAC_{67} = \$4,970.56M + \$31.76M \times 67.0 \text{ Months} = \$7,098.60M,$$

TABLE 6 Equation (3) for BAC as a function of time since contract award

SUMMARY OUTPUT

Regression statistics						
Multiple R	0.9516206					
R Square	0.9055818	BAC =	4970.563	+	31.76151496	*Month
Adjusted R Square	0.8996806					
Standard Error	56.43548					
Observations	18					

ANOVA

	df	SS	MS	F	Significance F
Regression	1	488760.612	488760.6	153.4588	1.29598E-09
Residual	16	50959.41451	3184.963		
Total	17	539720.0265			

	Coefficients	Standard error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	4970.5626	86.91542194	57.1885	6.21E-20	4786.31012	5154.815
Month	31.761515	2.563925093	12.38785	1.3E-09	26.32623661	37.196793

TABLE 7 Equation (4) for EAC as a function of time since contract award

SUMMARY OUTPUT

Regression statistics						
Multiple R	0.972574					
R Square	0.9459001	EAC =	4393.125	+	52.61816305	*Month
Adjusted R Square	0.9425189					
Standard Error	69.246552					
Observations	18					

ANOVA

	df	SS	MS	F	Significance F
Regression	1	1341421.14	1341421	279.7492	1.47699E-11
Residual	16	76721.36017	4795.085		
Total	17	1418142.5			

	Coefficients	Standard error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	4393.1249	106.645559	41.1937	1.14E-17	4167.046387	4619.2034
Month	52.618163	3.145946008	16.7257	1.48E-11	45.94905549	59.287271

$$\text{Worst Case BAC}_{67} = \$5,154.82\text{M} + \$37.19\text{M} \times 68.15 \text{ Months} = \$7,689.78\text{M}. \quad (13)$$

The actual BAC_{67} in the data series was $7,684.25M, which is 8.3% above the BAC_{67} forecast but 1.6% below the worst-case bound. Comparable conclusions are drawn for the EAC using the lower and upper, respectively, 95% bounds on the coefficients found in Table 7:

$$\text{Best Case EAC}_{67} = \$4,167.05\text{M} + \$45.95\text{M} \times 65.89 \text{ Months} = \$7,194.63\text{M},$$

$$\text{EAC}_{67} = \$4,393.12\text{M} + \$52.62\text{M} \times 67.00 \text{ Months} = \$7,918.54\text{M},$$

$$\text{Worst Case EAC}_{67} = \$4,619.20\text{M} + \$59.29\text{M} \times 68.15 \text{ Months} = \$8,659.63\text{M}. \quad (14)$$

The actual EAC_{67} in the data series was $8,070.0M, which is above the best-case and below the worst-case bounds and exhibits an error in the forecast of less than 2%. It follows that

$$\text{Best Case VAC}_{67} = \$672.19\text{M},$$

$$\text{VAC}_{67} = \$820.08\text{M},$$

$$\text{Worst Case VAC}_{67} = \$1,494.17\text{M}. \quad (15)$$

The actual data for VAC_{67} shows $385.75M. When the $600M over-target baseline is added to this value the actual VAC for month 67 is $985.75M. Here the actual reported VAC_{67} is 20% over the estimated most likely VAC_{67} from Equation (15) but only 9.3% over the worst case bound as shown in Table 8. By comparing the VACs in Table 8, one can see for the six cases evaluated where actual data are available; our estimates about BAC, EAC, and VAC are within 5% error in three of the six cases, within 10% error in two of six cases, and exceeds 10% error in one case. While the actual VAC exceeds the forecasted most likely VAC by 20%, it exceeds the worst-case VAC by only 1.6%. It should be noted that this degree of knowledge of the variability in the VAC was available at the end of February 1997, but the actual measurement of the VAC that exceeds the forecast upper bound was not available until two years later in March 1999.

The analysis of the data presented here should not be used to imply that one should wait to identify the direction and degree of growth in risks as measured by the VAC; rather, trend data should be used to help program managers understand the directional impacts of their decisions on controlling costs. By identifying the causes of scope changes and cost growth, it may be possible to reduce the degree of risk exhibited by the growth in the VAC. At the very least, identification of the potential magnitude of the cost growth up to four years in advance will allow program managers to set senior manager expectations earlier, plan appropriate budgets to carry the variances, and not be surprised by the magnitude of the EAC for the program as it works through the various elements of risk. Using EVM trend data based on the planned scope that is expected to be a part of the final contract value can assist program managers in understanding if the program will be completed within the planned schedule or if there are additional schedule risks yet to be incurred. If, for instance, the program has a planned initial operational capability (IOC) scheduled for month 70 (June 1999) and the solution identified for the estimated final program content is month 91.06 (April 2001) then the program manager can reset the expectation for accomplishment of IOC and be reasonably assured of meeting the April 2001 date.

TABLE 8 Comparison of VACs (all $ M)

Trend analysis	Forecast*	Actuals	Monthly formulas	Difference
Best Case BAC42 =	$5,892.01			Above Best Case
BAC42 =	$6,304.55	$6,269.68	$6,269.68	−0.6%
Worst Case BAC42 =	$6,717.08			Below Worst Case
Best Case EAC42 =	$6,096.95			Above Best Case
EAC42 =	$6,603.16	$6,548.00	$6,765.65	−0.8%
Worst Case EAC42 =	$7,109.38			Below Worst Case
Best Case VAC42 =	−$204.94			Above Best Case
VAC42 =	−$298.61	−$278.32	−$272.60	−6.8%
Worst Case VAC42 =	−$392.30			Below Worst Case
Best Case BAC67 =	$6,520.95			Above Best Case
BAC67 =	$7,098.60	$7,684.25	$7,684.25	8.3%
Worst Case BAC67 =	$7,689.78			Below Worst Case
Best Case EAC67 =	$7,194.63			Above Best Case
EAC67 =	$7,918.54	$8,070.00	$7,962.63	1.9%
Worst Case EAC67 =	$8,659.63			Below Worst Case
Best Case VAC67 =	−$673.68			Above Best Case
VAC67 =	−$819.94	−$985.70	−$878.38	20.2%
Worst Case VAC67 =	−$969.85			Above Worst Case
By month 67, we need to increase the VAC by the $60 0M reset. We then have VAC67 = $ −878.4M				
Best Case BAC91 =	$6,937.16			Forecast Best Case
BAC91 =	$7,862.64	Delayed 4 years	Delayed 4 years	49.06Months Early
Worst Case BAC91 =	$8,941.45			Forecast Worst Case
Best Case EAC91 =	$7,921.08			Forecast Best Case
EAC91 =	$9,184.32	Delayed 4 years	Delayed 4 years	49.06Months Early
Worst Case EAC91 =	$10,654.65			Forecast Worst Case
Best Case VAC91 =	−$983.92			Forecast Best Case
VAC91 =	−$1,321.69	Delayed 4 years	Delayed 4 years	49.06Months Early
Worst Case VAC91 =	−$1,713.20			Forecast Worst Case

*Actuals and Monthly Formula calculations based on end of month data. Forecasts are from EOM 42.
Legend: 49 Mos. Early ; <5% error 5% < error < 10% 10% < error

Trend Analysis vs. Traditional Monthly EAC Formulas

Now we are able to compare the results of our trend analysis with the results of traditional earned value EACs based on end-of-month-42 data. The formula for the estimate of EAC that is chosen for comparison is the DOD version of the EAC forecast defined in the Project Management Body of Knowledge (PMBOK®) as "the method most useful when the project schedule is a factor impacting the estimate to complete" (PMBOK® Guide, 2008). The formula is provided in Equation (16) and can be solved using data from Table 1.

$$\text{Est EAC}_{42} = \text{ACWP}_{42} + (\text{BAC}_{42} - \text{BCWP}_{42})/[(\text{BCWP}_{42}/\text{ACWP}_{42}) \times (\text{BCWP}_{42}/\text{BCWS}_{42})]. \quad (16)$$

So that,

$$\text{Est EAC}_{42} = \$3,978.1\text{M} + \$2,787.5\text{M} = \$6765.6\text{M}. \tag{17}$$

It is apparent from Equation (16) that the end-of-month EAC_{42} will predict the EAC based on the month-42 level of the BAC, which has been shown to be growing at the rate of over $31M per month. In fact, Equation (17) for EAC_{42} understates the most likely final EAC by over $2,418M. Hence, the traditional method in Equation (16) for EAC_{42} appears to yield a point estimate in time that understates the final EAC for this contract, the dollar value of which will grow each month as additional variances are incurred. For example, in Table 8, when comparing the formula EAC for month 42 with that of month 67, we see a difference of $1,197.9M or an average growth over this 25-month period of $47.9M. In fact, comparison with the actual EAC_{67} of $8,070M, which is still not the 100% completion date, shows that the most likely final EAC exceeds EAC_{67} by at least $1,114.2M against the final completion month 91.06. Thus, each of the monthly traditional-formula-based EAC estimates excludes the risks associated with the additional scope that is being added to the BAC for this contract on a continual basis. Only the use of trend analysis allows for both a growing BAC and a growing EAC due to the added scope being placed on the contract. And only the trend analysis captures the anticipated risks in the VAC related to that additional scope. If that scope were captured in the original cost estimate for the program, then it might be possible to substitute the original value of the cost estimate for the anticipated final BAC to serve as a basis for computing the PC and identifying the expected date of completion. This is an area that is left for future research, as the author does not have information on the value and content of the original cost estimate for this larger program.

Risk Burndown

Risk is measured in EVM terms as any deviation from the original baseline. That is, risk is anything that results in a variance. Therefore, VAC is the basic measure of risk encountered by the end of the contract effort, whether the risk is rooted in opportunity with a positive variance or is rooted in issues related to planning of scope, estimating, scheduling, or technical criteria that are identified during testing and generally associated with a negative variance.

Recall from Equation (7) that our estimated completion month was 91.06, which occurs during the 92nd month after contract award. Further, our $VAC_{91.06}$ was estimated to be about $1,322M. Using this $VAC_{91.06}$, we have an estimate of the total risk for the program as measured by the expected final value of the program's VAC. We can now build a risk burndown chart by month to show the rate that the program will be working the elements of risk. Figure 8 provides the graph of the monthly data for the ratio of the VAC in month "t" to the final VAC ($VAC_t/VAC_{91.06}$).

It is interesting to note in both Figures 4 and 7 that no VAC shows up in the data prior to month 25 (September 1995), the first data point in our series. Further, as the PC reaches 100% for the program, the amount of risk remaining to burn down goes to zero and the slope of the risk burndown line is steeper than the slope of the work remaining line (calculated as 1-PC). This implies that, early on in the program, as risks were identified they were worked off faster than known planned work remaining. Here, total measurable risk is being defined as the amount of VAC at month 91.06. If, however, BAC continues to grow to the level of $9,546M as anticipated in a Government budget forecast for this contract, then the expected completion date may be expected to move beyond April 2001. In such a case, a new PC equation would need to be calculated with the data for PC normalized to the value of BAC at $9,546M.

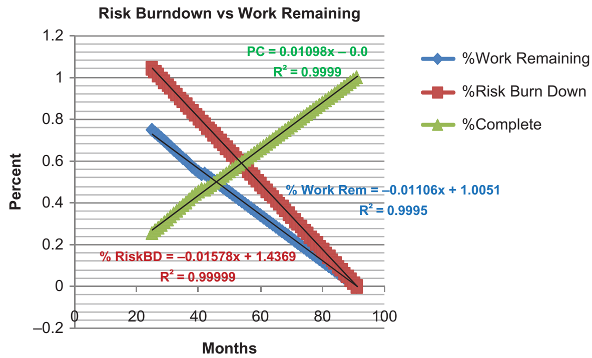

FIGURE 8 Program risk burndown over time (color figure available online).

Up to this stage, we have kept our estimated completion date at April 2001 and have not worried about the additional budget that appeared in the planning phase for possible placement on our prime contract. We have completed the linking of PC to the contract schedule and have forecasted the BAC, EAC, and VAC to an unknown but identifiable date of completion. Now we can think about how a program office analyst would integrate knowledge about future work not yet on contract into his or her forecast for a completion date that is expected to be a few more months or years further into the future than the time-now date. This issue is the primary subject of Driessnack, Freeman, and Barker (2010). Also, since time moves inexorably forward, the program office will need to perform periodic updates of its forecast based on the most current data available. Given additional monthly data, the program office can begin to use trend data to better understand the variability in the amount of work accomplished in each given month. By measuring this variability and then finding ways to reduce it, the program office can better control costs and deliver finished products on schedule.

Lessons Learned

Relative to contract scope, we have presented the following important facts:

a. The scope of a contract grows across time.
b. New work pushes out the expected completion date.
c. Each monthly PC drops as BAC grows.
d. There is a future date where:
    i. BCWP will equal BAC.
    ii. This is the expected completion date.
e. An S-curve with its tails removed exhibits significant linearity with variability at least for this contract's scope.

Relative to EVM data trends, we have offered the following observations:

a. Normal monthly EACs fall short of final EAC,
b. Trend analysis helps identify the completion date,
c. Trend analysis can then estimate the final EAC,
d. Trend analysis can then estimate the final BAC,
e. Final VAC can be estimated as final BAC, minus the final EAC, and
f. Final VAC may be used to measure how risks get burned down across the period of performance from ATP to estimated completion date.

Summary

Use of EVM trend data has been shown to provide a solution to the problem of scope growth by being able to establish a consistent estimate of the date of completion. By modeling the S-curve as essentially linear with some degree of variability, the solution to program duration provides a basis for equating BCWP and BAC to derive the final completion month. Further, when the linear model is also applied to the EAC, a final VAC may be calculated to estimate the entire set of risks the program may be expected to encounter. These risks arise not only from work currently on contract, but also from additional scope expected to be added to the contract in future months. Ideally, the actual causal factors associated with those risks will have been identified in the monthly contractor performance reports (CPRs). But as with any CPR data, we are looking only at the past. What a program manager needs is an estimate of future risks and how those risks may be worked off during the period of duration of the program. This article illustrates that it is possible to use EVM trend data to arrive at the forecast of risks as measured by a final contract completion date variance. It further indicates that the rate of risk burndown may very well be more rapid than the rate of accomplishment of work remaining.

It is the responsibility of program managers to demand consistent EVM reporting from their contractors and to use the data in those reports to improve the management of the contractual activities. One of these activities must be an understanding of how much risk is going to be incurred and how that risk is going to be worked down during the completion of effort on the program. Program managers would be well advised to require analysis of EVM trends to understand how much additional schedule is being added to a contract with each addition of scope as measured by the increase in BAC over time.

Note

1. This approach differs from that of J. E. Gayek (unpublished manuscript) in that here the BAC and completion date are forecast, while Gayek was investigating how PC changed from the then-current-month to the end-of-contract-month PC.

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