Use of EVM Trends to Forecast Cost Risks

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OVERVIEW

- **Introduction**
- **EVM Trend**

  CPI SPI BCWS BCWP ACWP BAC EAC
- **Develop equations to forecast from 1st 18 months**

  $BCWS_{xx}$ $BCWP_{xx}$ BAC_{xx} EAC_{xx}
- **Examine %Completion Trends**
- **Solve for the Estimated Completion Date**
- **Compare VAC Estimates**
- **Develop the following forecasts**
  - **%Complete**
  - **%Work Remaining**
  - **%Risk Burn down**

INTRODUCTION

This presentation will provide a means to use EVM trend analysis to forecast:

a) An estimated completion date

b) Both a budget at completion and an estimate at completion

c) The associated variance at completion

d) A graph of the risks burned down during accomplishment of contract tasks

EVM ACRONYMS

- ACWP: Actual Cost of Work Performed
- ATP: Authority To Proceed
- BAC: Budget At Completion
- BCWP: Budgeted Cost of Work Performed
- BCWS: Budgeted Cost of Work scheduled
- C-Month: Completion month
- CPI: Cost Performance Index
- CUMM: Cumulative
- EAC: Estimate at Completion
- EVM: Earned Value Management
- LCL: Lower Control Limit
- LRE: Latest Revised Estimate
- M: Millions
- %Comp: Percent Completion
- SPI: Schedule Performance Index
- TY $: Then Year Dollars
- UCL: Upper Control Limit
- VAC: Variance At Completion

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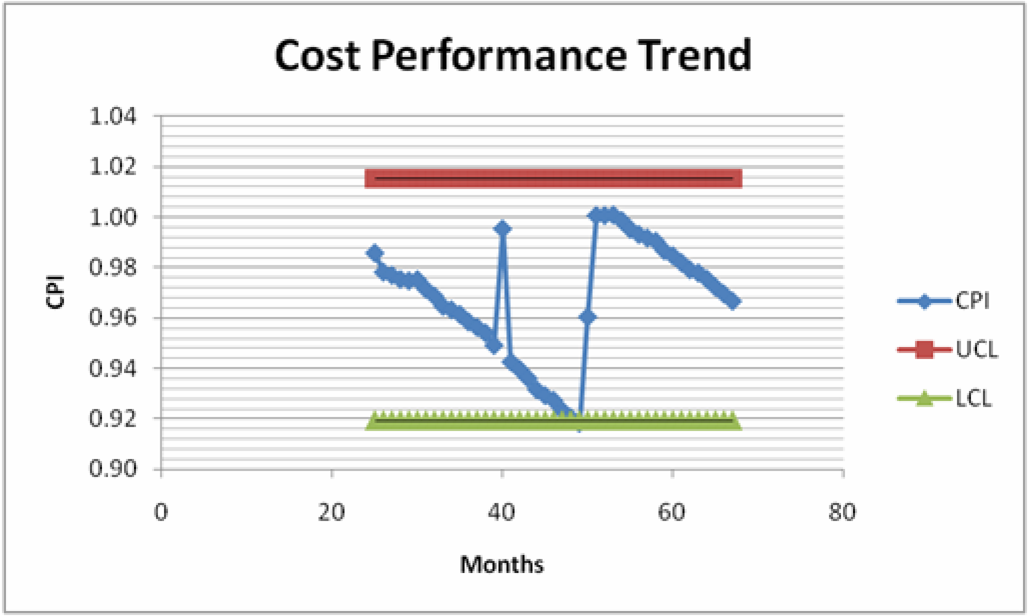
EVM Trend Data* For CPI

This chart provides a visual of the data available for study. The CPI starts above 0.98 and declines from Sep95 to Oct97. BASELINE is reset in Nov97 two months after breaking the lower control limit. CPI remains at about 1.0 for three months. Then the downward trend returns but at a slightly reduced rate.

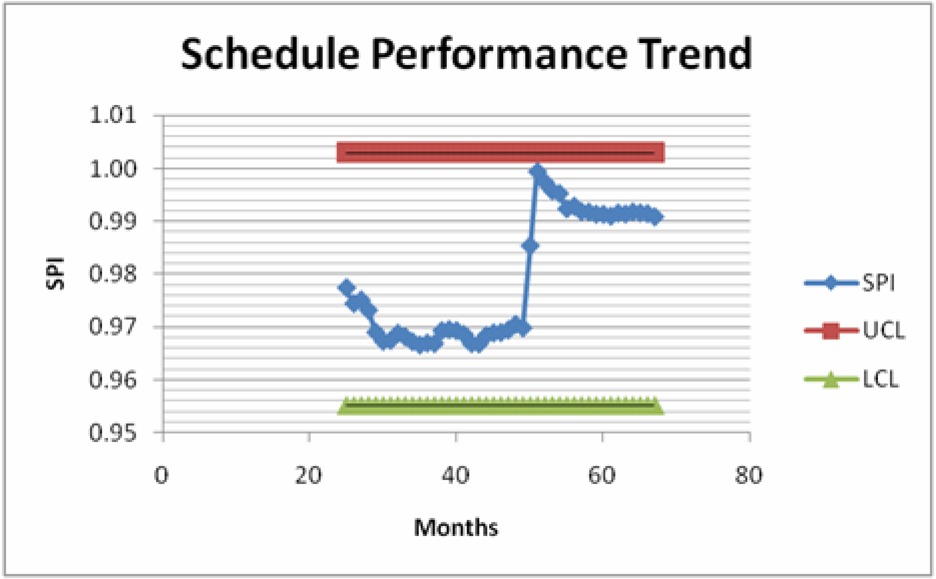


Deming upper and lower control limits (UCL and LCL) are set at $\alpha = 0.025$ level of significance. This indicates that the CPI should be between the upper and lower control limits 95% of the time.

* The data set is from a real, completed program.

EVM Trend Data for SPI

This chart graphically displays the SPI trend data available for analysis.
The SPI starts above 0.975 and declines slowly to about 0.965.
The SPI never breaks the lower control limit.
It jumps back to 1.00 in Nov97 with the reset and then declines gradually to about 0.99

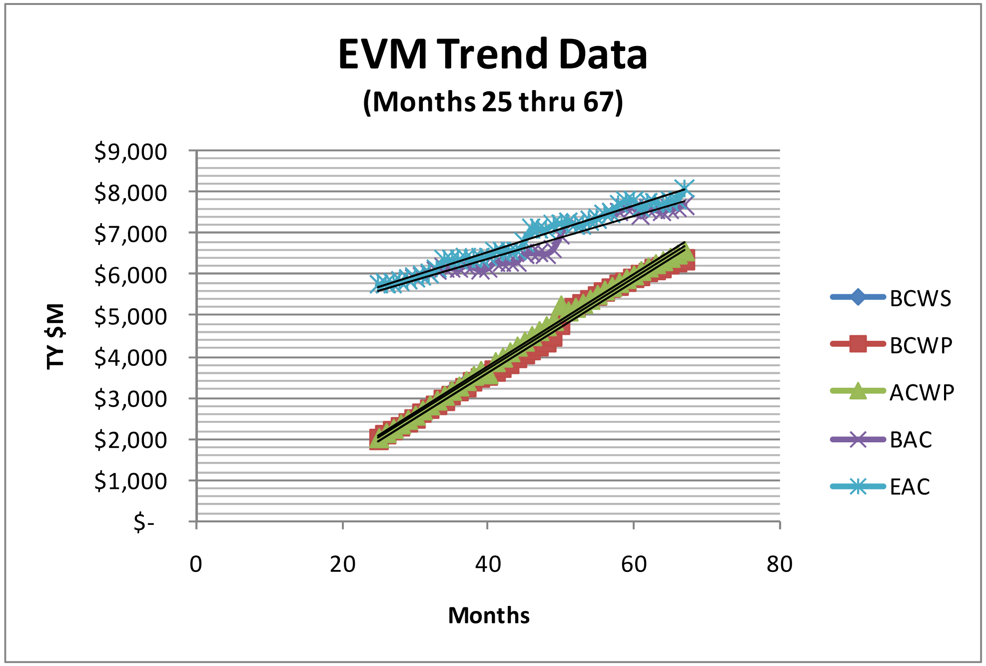


Deming upper and lower control limits (UCL and LCL) are set at $\alpha = 0.025$ level of significance. This indicates that the SPI should be between the upper and lower control limits 95% of the time.

Essentially Linear Data

Question: What do you get when you remove the initial start up months and the contract closeout months from the usual S-curve?
Answer: A data set that exhibits the graphic forms shown here. Note, there is a hint of an S-curve without the usual tails.

Research: Can we predict the performance of a long term contract from only 18 months of data covering months 25 thru 42 using linear assumptions.



We know:
- Monthly BAC but not the final BAC
- Monthly EAC but not the final EAC
- Monthly VAC but not the final VAC

We don't know the month of the final VAC

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18 Months of Data

CRITICAL THINKING. SOLUTIONS DELIVERED.

Equations:

(1) $BCWS_{18}$ = \$89.12M * Months
(0.7525) T-stat = 118.44 $R^2 = 0.9988$

(2) $BCWP_{18}$ = \$86.35M * Months
(0.6925) T-stat = 124.68 $R^2 = 0.9989$

(3) BAC_{18} = \$4,970.56M + \$31.76M * Months
(86.92) (2.56) $R^2 = 0.9056$
T-stats 57.19 12.39

(4) EAC_{18} = \$4,393.13M + \$52.62M * Months
(106.65) (3.15) $R^2 = 0.9459$
T-stats 41.19 16.73

Regressions run in Excel.

EOM	# 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-95	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

All Cost are \$M

Note: Even with the significance in the parameters in these equations there is a good degree of variability as indicated by their standard errors in parenthesis.

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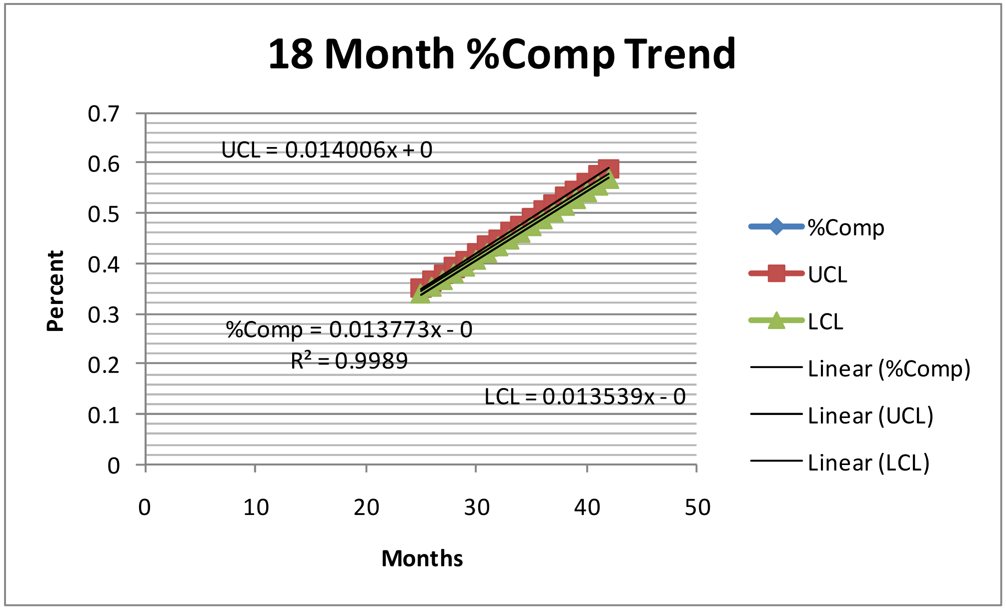
Regression Control Limits are Tight

Here %Completion is based on the 42nd month BAC of \$6,269.7M and is calculated as the monthly $BCWP/BAC_{42}$ Note the equation has a zero intercept. Hence, 1/0.013773 = 72.6 months as the estimated completion month. From our equations in the previous chart, we know that the BAC is growing with time. What does that say about the %Completion metric?



Upper and lower control limits (UCL and LCL) are taken as the upper 95% and the lower 95% values from the Excel regression.

%Completion Regression

SUMMARY OUTPUT

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

%Comp = 0 + 0.013772546 *Month

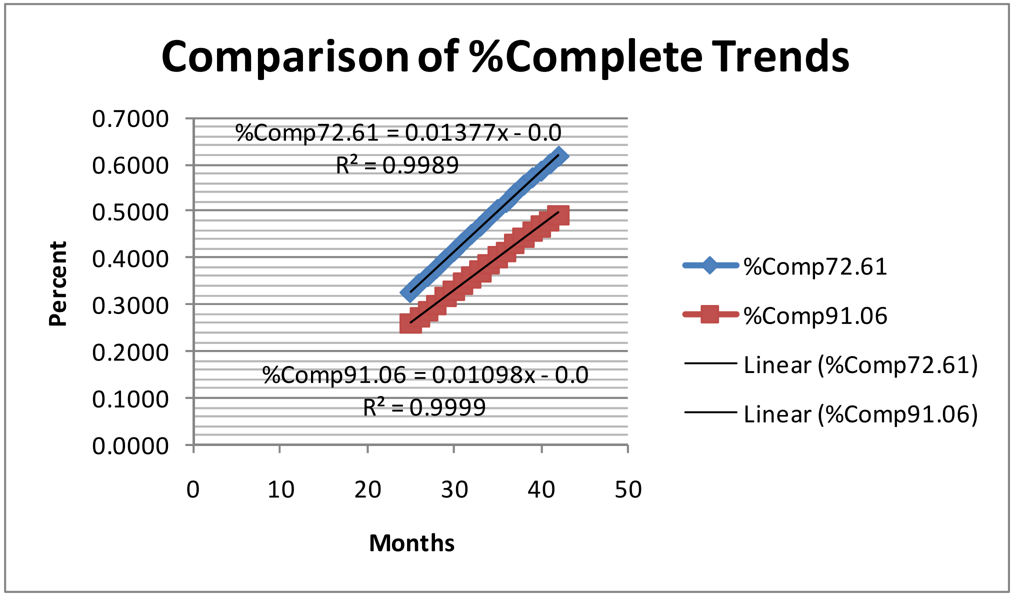
ANOVA

	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
	72.6 months				73.85	71.40

Estimated Completion Date Shift

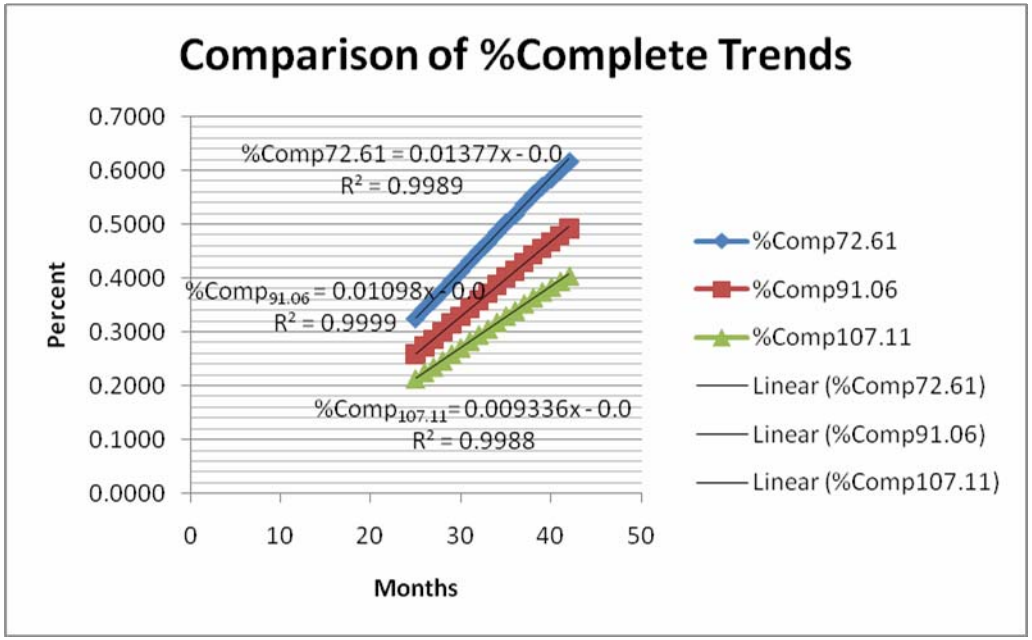
As BAC increases due to addition of Authorized Un-priced Work being added to the BASELINE, the %Completion shifts from the top downward and to the right but always points back to the zero intercept. This implies the estimated completion date (ECD) is moving to the right with each addition to BAC.



Here we see how the %Completion line shifts as BAC increases from $6,269.7M to $7,862.6M. The ECD also shifts from month 72.61 to month 91.06.

A Shift of BAC to $9,546M

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



BAC	Completion Month
$6,269.7M	72.61
$7,862.6M	91.06
$9,546.0M	107.11

The BAC trend dictates the month in which the dollar value matches the cost estimate.

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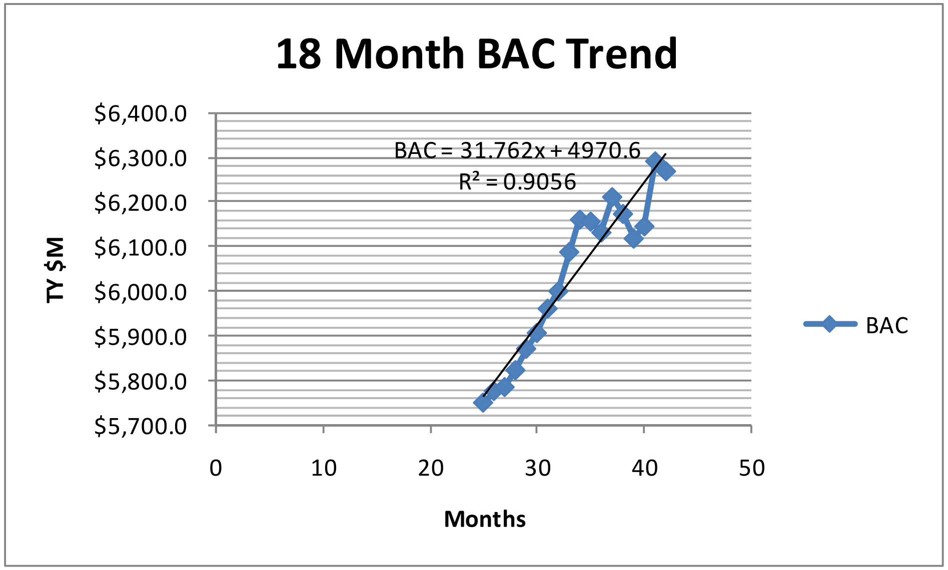
BAC as a Function of Time

While BAC also appears linear, it shows significant variability – first increasing, then decreasing and increasing again. This variability indicates the program office is changing the content of the contract. These changes create uncertainty in the amount and duration of the effort planned for the contract.

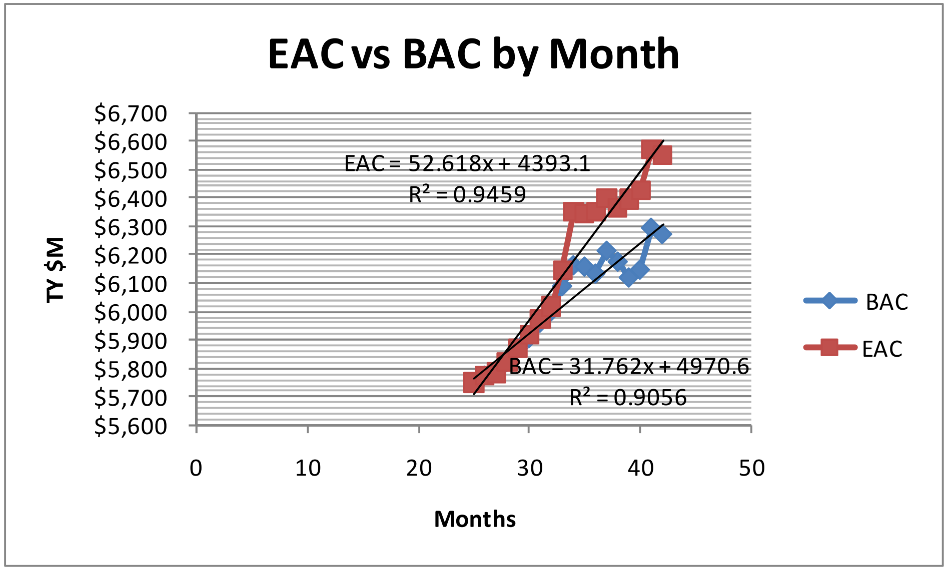


Note, the BAC formula has an intercept term of $4,970.6M indicating that the initial contract value was let at near this level. BAC has grown at an average rate of $31.8M per month since the contract was let.

EAC as a Function of Time

CRITICAL THINKING. SOLUTIONS DELIVERED.

The uncertainty in the BAC based on the program office decisions to remove work and add work to the contract also create uncertainty in the EAC as shown here. However, both equations based on 18 monthly observations are significant and can be used to predict the growth of both BAC and EAC thru time.



With EAC growing faster than BAC, the question is when will this contract reach completion so that VAC stops growing?

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Solve for Completion Date

Recall from an earlier chart the following equations:

(1) $BCWP_{18}$ = \$86.35M * Months
(0.6925) T-stat = 124.68 $R^2 = 0.9989$

(2) BAC_{18} = \$4970.56M + \$31.76M * Months
(86.92) (2.56) $R^2 = 0.9056$
T-stats 57.19 12.39

Now by definition the cumulative BCWP equals BAC at the completion date. Hence,

\$86.35M * Months = \$4,970.56M + \$31.76M * Months

So that solving for Months yields:

Months = \$4,970.56M/(\$86.35M - \$31.76M) = 91.06

Completion Date is Measured in Months from ATP

Variability in Completion Date

CRITICAL THINKING. SOLUTIONS DELIVERED.

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**

All Cost are $M

The confidence intervals about each equation's parameters are set at 95%. That is, the BAC and BCWP have a 95% probability of completing between the best case and worse case values obtained from the respective Excel regression.

We Can Calculate the Final VAC

- **Recall:**

(3) BAC_{18} = \$4,970.56M + \$31.76M * Months
(86.92) (2.56) $R^2 = 0.9056$
T-stats 57.19 12.39

(4) EAC_{18} = \$4,393.13M + \$52.62M * Months
(106.65) (3.15) $R^2 = 0.9459$
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Inserting the 91.06 months at completion into BAC and EAC yields

$VAC_{91.06}$ = \$7,862.6M - \$9,184.3M = - \$1,321.7M

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Normal EAC at Month 42

- Using our 18th observation at Month 42, the EAC calculation is:
- EAC_{42} = ACWP + (BAC - BCWP)/(CPI*SPI)
  = \$3,978M + (\$6,269.7M-\$3,737.5M)/(.9395*.9668)
  = \$3,978M + (\$2,532.2M)/(0.9054)
  = \$6,542.3M
- BAC_{42} = \$6,269.7M
- VAC_{42} = -\$272.6 M

- Also VAC_{67} = -\$278.4M - \$600M Reset
  VAC_{67} = -\$ 878.4M

Degree of Variability

From our earlier equations we can get a Best and Worse Case around the estimated value. These are reflected here for BAC, EAC and VAC for months 42, 67, 91 and 101.8. The confidence intervals here are taken as 95% from the Excel regression results for each equation.

Variable	Constant		Rate	Month	42	67	91	101.8
Best Case BAC =	$ 4,786.31		$ 26.33		$ 5,892.01	$ 6,550.17	$ 7,183.47	$ 7,467.53
BAC =	$ 4,970.56	+	$ 31.76	*Month	$ 6,304.55	$ 7,098.58	$ 7,862.64	$ 8,205.35
Worse Case BAC =	$ 5,154.82		$ 37.20		$ 6,717.08	$ 7,647.00	$ 8,541.81	$ 8,943.16
Best Case EAC =	$ 4,167.05		$ 45.95		$ 6,096.91	$ 7,245.63	$ 8,350.98	$ 8,846.77
EAC =	$ 4,393.12	+	$ 52.62	*Month	$ 6,603.09	$ 7,918.54	$ 9,184.32	$ 9,752.07
Worse Case EAC =	$ 4,619.20		$ 59.29		$ 7,109.27	$ 8,591.45	$ 10,017.67	$ 10,657.38
Best Case VAC =	$ 619.26		$ (19.62)		$ (204.89)	$ (695.47)	$ (1,167.51)	$ (1,379.24)
VAC =	$ 577.44	+	$ (20.86)	*Month	$ (298.54)	$ (819.96)	$ (1,321.69)	$ (1,546.73)
Worse Case VAC =	$ 535.61		$ (22.09)		$ (392.19)	$ (944.45)	$ (1,475.86)	$ (1,714.22)

All Cost are $M

VACs Compared w/in 18 Month Observation Period

Trend Analysis	Forecast*	Actuals	Monthly Formulas	Difference
Best Case BAC_{42} =	$5,892.01			Above Best Case
BAC_{42} =	$6,304.55	$6,269.68	$6,269.68	-0.6%
Worst Case BAC_{42} =	$6,717.08			Below Worst Case
Best Case EAC_{42} =	$6,096.95			Above Best Case
EAC_{42} =	$6,603.16	$6,548.00	$6,765.65	-0.8%
Worst Case EAC_{42} =	$7,109.38			Below Worst Case
Best Case VAC_{42} =	-$204.94			Above Best Case
VAC_{42} =	-$298.61	-$278.32	-$272.60	-6.8%
Worst Case VAC_{42} =	-$392.30			Below Worst Case

All Cost are $M

Normal Calculation of VAC_{42} = - $272.60M

For estimates within the period of the observations, the actuals and the normal VAC calculation are in close agreement with a difference of about 2% while the forecast VAC_{42} is higher by about 6.8%.

Comparing VACs Beyond 18 Month Observation Period

Trend Analysis	Forecast*	Actuals	Monthly Formulas	Difference
Best Case BAC_{42} =	$5,892.01			Above Best Case
BAC_{42} =	$6,304.55	$6,269.68	$6,269.68	-0.6%
Worst Case BAC_{42} =	$6,717.08			Below Worst Case
Best Case EAC_{42} =	$6,096.95			Above Best Case
EAC_{42} =	$6,603.16	$6,548.00	$6,765.65	-0.8%
Worst Case EAC_{42} =	$7,109.38			Below Worst Case
Best Case VAC_{42} =	-$204.94			Above Best Case
VAC_{42} =	-$298.61	-$278.32	-$272.60	-6.8%
Worst Case VAC_{42} =	-$392.30			Below Worst Case
Best Case BAC_{67} =	$6,520.95			Above Best Case
BAC_{67} =	$7,098.60	$ 7,684.25	$7,684.25	8.3%
Worst Case BAC_{67} =	$7,689.78			Below Worst Case
Best Case EAC_{67} =	$7,194.63			Above Best Case
EAC_{67} =	$7,918.54	$ 8,070.00	$7,962.63	1.9%
Worst Case EAC_{67} =	$8,659.63			Below Worst Case
Best Case VAC_{67} =	-$673.68			Above Best Case
VAC_{67} =	-$819.94	$ (985.70)	-$878.38	20.2%
Worst Case VAC_{67} =	-$969.85			Above Worst Case
By month 67, we need to increase the VAC by the $600M reset. We then have VAC_{67} = $ -878.4M				
Best Case BAC_{91} =	$6,937.16			Forecast Best Case
BAC_{91} =	$7,862.64		Delayed 4 years	49.06Months Early
Worst Case BAC_{91} =	$8,941.45			Forecast Worst Case
Best Case EAC_{91} =	$7,921.08			Forecast Best Case
EAC_{91} =	$9,184.32		Delayed 4 years	49.06Months Early
Worst Case EAC_{91} =	$10,654.65			Forecast Worst Case
Best Case VAC_{91} =	-$983.92			Forecast Best Case
VAC_{91} =	-$1,321.69		Delayed 4 years	49.06Months Early
Worst Case VAC_{91} =	-$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

All Cost are $M

Comparison of Historical Actuals with a Forecast of VAC Trends

Actuals

VAC_{25} = $ 0.0

VAC_{42} = - $ 272.6M

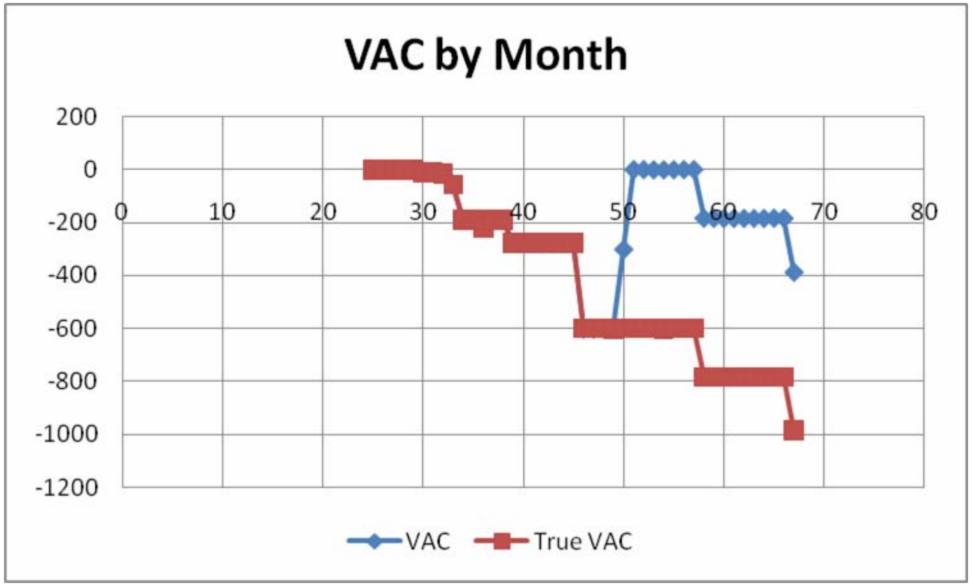
VAC_{67} = - $ 985.8M

Forecast

Best Case VAC_{91} = - $ 1,167.5M

VAC_{91} = - $ 1,321.7M

Worse Case VAC_{91}= - $ 1,475.9M



In the graph above, the difference in VAC and True VAC is the $600M reset that occurred in month 51. As long as new scope is getting added to the contract, the VAC will keep growing. If an original scope is known, then the amount of that scope that is expected to be added to the contract should serve as the BAC for the project. Then the equation for BAC for the contract as a function of time can be solved for the number of months the contract will take to reach the total project level of BAC.

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VAC as a Measure of Risk

- **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.**

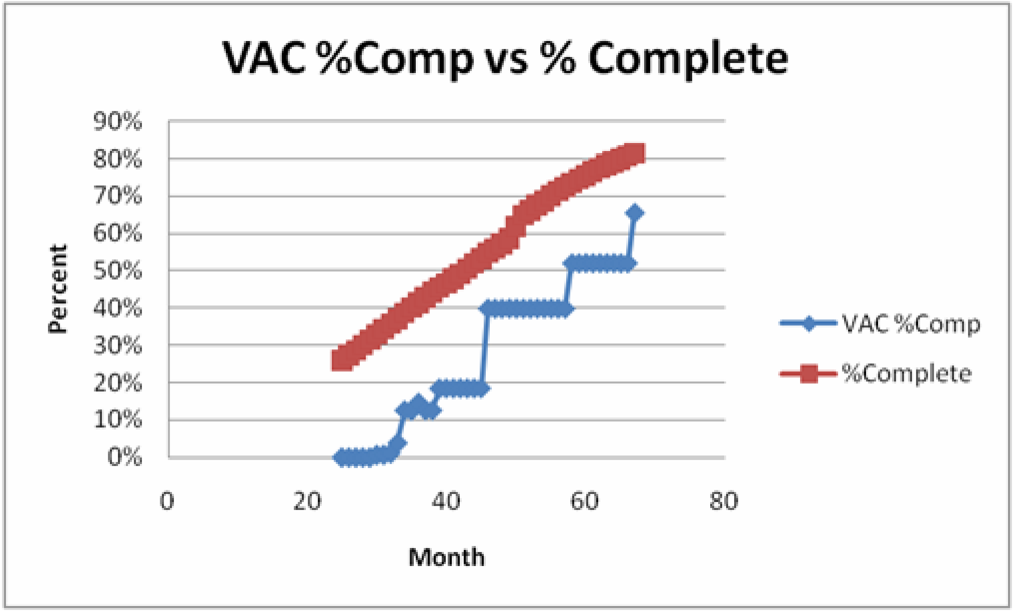
Risk Complete ≠ % Complete

- Here we see that for the formula:
  Risk = VAC

- VAC %Comp = Actual VAC/Final VAC

- VAC%Comp moves up in a step fashion and remains below the level of %Complete for the entire 43 month period of actual available data.

- Further, from the %Complete line, we can see that just under 20% of the work is remaining to be accomplished by month 67, the last month of our data reflecting actuals.



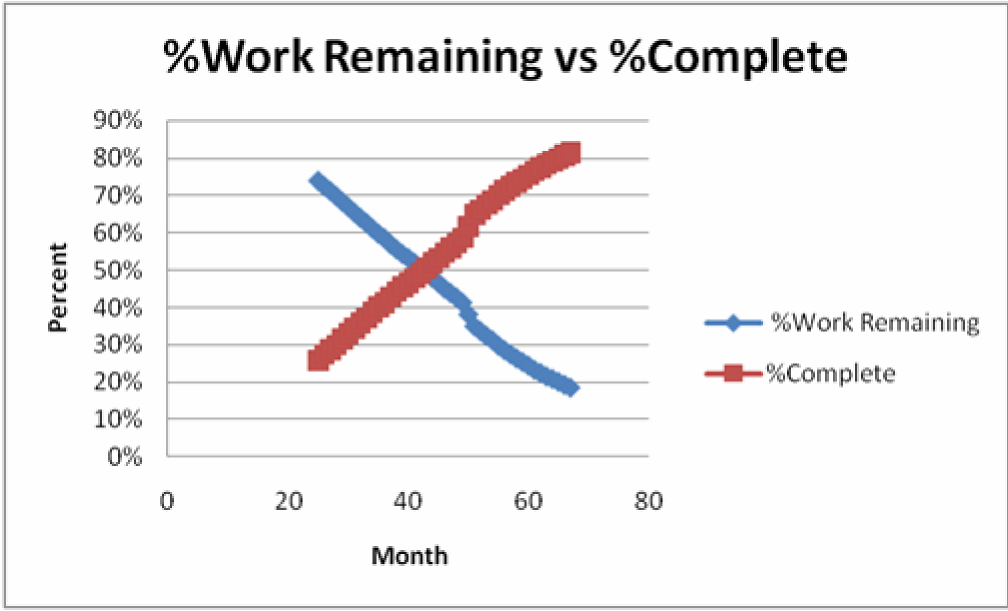
Work Remaining ≠ Risk Remaining

- Work remaining is based on the formula:

  %Work remaining = 100%- %Complete

- Work remaining is not a measure of Risk as it does not include a measure of VAC.
- Work remaining declines as %Complete approaches 100%.

- Still one does not yet know how much VAC is remaining. That is one does not know how much RISK has been burned down.



Risk Burn down (1 of 2)

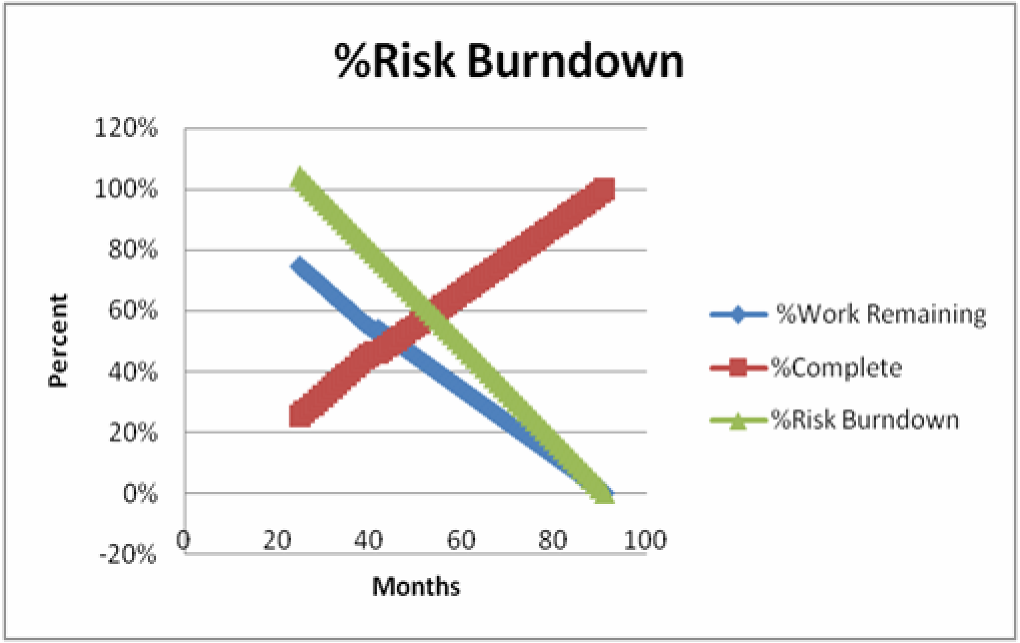
- **Risk Burn down may be measured as the amount of VAC that has been worked off.**
- **Therefore, it is possible to show the %Risk Burn down as the amount of VAC that has been incurred relative to the Final VAC.**
- **And as we saw on an earlier chart, the Final VAC may be estimated as the difference between the linear forecast of BAC and EAC.**

Risk Burn down (2 of 2)

- Here the green line represents the %Risk that has been burned down and measured as:

  1 - Cum VAC/Final VAC

- It is interesting to note that early in this program, risk is being burned down faster than the remaining work is being accomplished.
- Finally, Risk is burned down to zero as remaining work is reduced to zero and percent complete approaches 100%



Summary – Contract Scope

- **We have learned**
  - **The scope of a contract grows across time**
  - **New work pushes out the expected completion date**
  - **Each monthly %complete drops as BAC grows**
  - **There is a future date where**
    - **BCWP will equal BAC**
    - **This is the expected completion date**
  - **An S-curve with its tails removed exhibits significant linearity with variability**

Summary – Trend Analysis

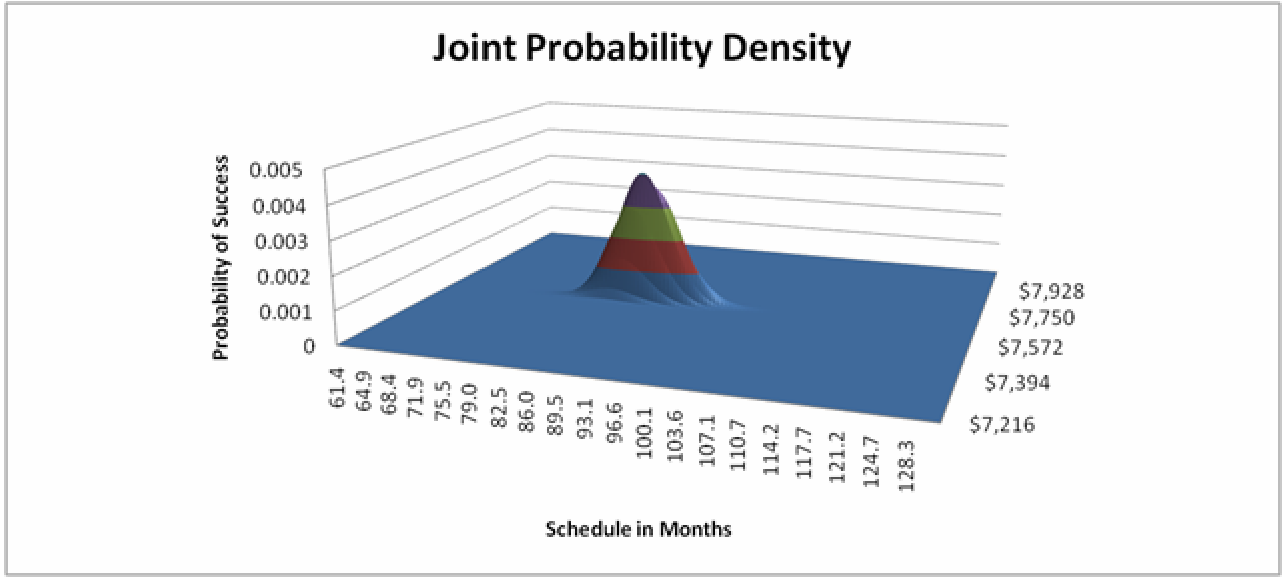
- **We have learned**
  - **Normal monthly EACs fall short of final EAC**
  - **Trend analysis helps identify the completion date**
  - **Trend analysis can then estimate the final EAC**
  - **Trend analysis can then estimate the final BAC**
  - **Final VAC can be estimated as final BAC – final EAC**
  - **Final VAC may be used to measure how Risks get burned down across the period of performance from ATP to Estimate Completion Date**

Conclusions

- A program's total cost estimate may be the best measure of BAC for the purpose of determining when a contract may be expected to be complete.
- VAC appears useful in measuring the value of a program's Risks (planning, estimating, scheduling, technical)
- Additional research is needed to fully understand the key three dimensions of
  - Cost
  - Schedule
  - Risks

Future Research

- **Build a 3-D chart connecting the interplay**
  - **Risk**
  - **Cost**
  - **Schedule**
  - **Use the probability density functions of each from EVM to do this:**



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