EVM's Potential for Enabling Effective Integrated Cost-Risk Management

by
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Stove-pipe cost-risk chaos is the term I think most aptly describes a situation that has existed for decades within many DoD programs. And I don't think this is really overstating the case. When I was an EVM analyst I never got involved with cost-risk although I did get involved with schedule risk a small bit. I never spoke to cost estimators who, at least post-1990, began to quantify cost-risk as a part of their cost estimates about cost-risk. But by the 1990s I had joined the cost estimating discipline and became a big promoter of credibly quantifying cost-risk on Air Force, Intelligence Community and NASA programs. However, I would informally run into engineers who worked on risk management teams and we would commiserate that while each of our separate disciplines worked on risk, we never worked together on it. Schedule analysts sometimes did work with the risk management teams on at least trying to quantify the risk reasons behind schedule slippages. The EVM analysis discipline seemed to be falling way behind the cost estimators, schedule analysts and risk management teams in dealing with risk in trying to cost-quantify it. Hence, the stove-pipe chaos that I think still reigns between these three communities today.

This paper will take the reader through a high-level examination of what each discipline does with respect to dealing with risk (or not) and propose a solution to this cost-risk chaos that involves the essential inclusion of EVM analysis and two EVM cost-risk tools that facilitate eliminating this chaos. Not to give short-shrift to schedule analysis and schedule-risk analysis because schedules too are deeply affected by risks, however, the focus of this paper will be on only the cost-risk impacts on budgets if for no other reason than just in the interest of time. Schedule-risk analysis is just as important as cost-risk analysis and much related but covering both in the limited time allowed could not do justice to either.

As illustrated in Fig. 1 below, Stovepipe 1, the estimating distribution (Cost Estimate, Y-axis) is formed by combining the low end, the mode and the high end of the cost estimate distributions driven by inputting the respective values from the technical input variable distribution. Estimating cost-risk is defined by the variation around the mode of the resulting combined cost estimate distribution. Of course, each point along each of the cost estimate distributions results from Monte Carlo simulations and the resulting combined cost estimate distribution is formed from the statistical addition of all these distributions during the simulations. The cost-risk so identified is the result of the uncertainty around the CER driven by the scatter in the historical data points. The technical risk distribution is the variation in the estimated technical cost driver, in this case weight, around its most likely estimated value. None of this cost-risk results from any risk management team's identification and assessment of any other specific technical risks that may potentially affect the program.

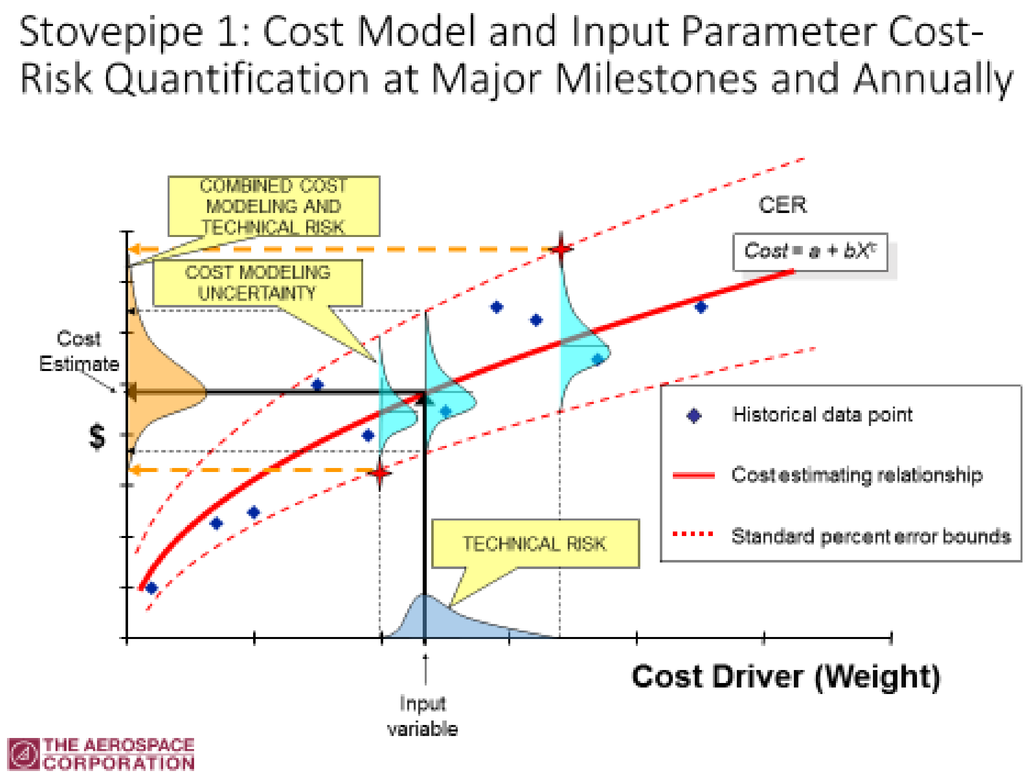


Fig. 1

Fig. 2 illustrates Stovepipe 2 and introduces a standard risk matrix. It is consistent with the Ms Goodwrench technical risk briefing from the DAU Intermediate EVM course (EVM 201).

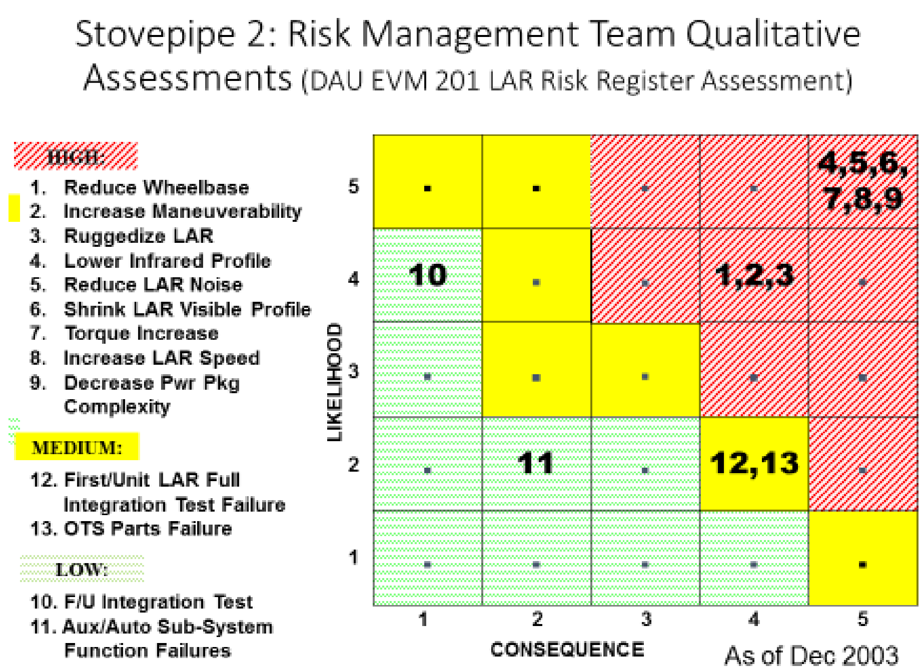


Fig. 2

Many new risks have been identified during the course of the prototype development of the LAR vehicle and are displayed in the LAR Risk Register categorized as high, medium and low risks in a qualitative manner. No attempt was made to quantify the cost impact of these risks by the LAR risk management team. No attempt was made to reach out to either the cost estimators or EVM analysts to assist in trying to quantify the cost impacts these risks may pose for the LAR program's cost.

Fig. 3 below illustrates Stovepipe 2's rating scales for the likelihoods and cost consequences. If there were some mechanism by which the likelihoods and cost consequences could be used in quantifying the cost-risk posed by the risks then the PM would have some way of applying resources to eliminate or mitigate the cost effects these risks presented to the program's budget.

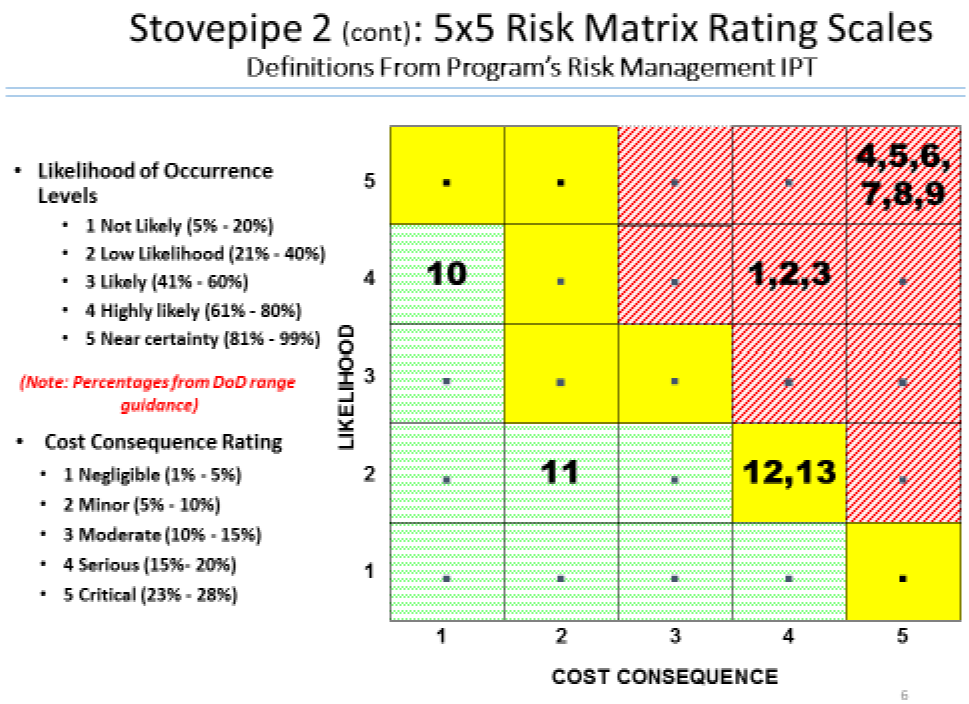
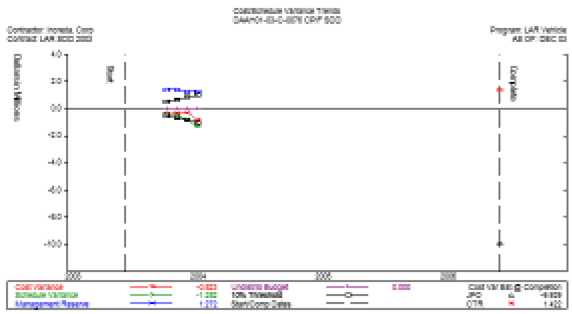


Fig. 3

Fig. 4 below, Stovepipe 3, illustrates traditional EVM analysis results in descriptive statistics of cost and schedule variance trends and the use of various formulas to project Independent Estimates at Completion (IEACs). While negative cost and schedule variance trends may be driven by actual risks of some sort, there is nothing in the projections of these trends that identify any of these risks so the PM does not have any specific identification of where in the program to apply resources to eliminate or mitigate those risks and remove the sources of these negative trends. Some clues can be gleaned from Format 5 of the monthly Cost Performance Report but often times the explanations in Format 5 do not identify these risk sources clearly enough nor to which WBS elements they affect for the PM to be useful. However, if these risk sources could be identified and assessed at the WBS element level, the use of EVM IEAC cost techniques on budgets for WBS element work remaining would give the PM useful information on where to apply resources to try and eliminate or mitigate the negative cost impacts these risks present. Furthermore, there may be different, new risks in the future that could present problems about which program engineers are aware that EMV IEAC techniques would be very helpful in quantifying potential cost impacts posed by these new risks.

Stovepipe 3: Monthly EVM Analysis & Independent EAC (no explicit cost-risk)



Statistical and Independent Forecasts

3 PER AVG			4,464.2	3,939.9	4,044.5	4,780.4
6 PER AVG			4,464.2	3,939.9	4,044.5	4,717.5
CUM CPI			4,464.2	3,939.9	4,044.5	4,717.5
CUR CPI			4,464.2	3,446.5	4,185.5	6,358.2
COST & SCH			4,287.7	3,681.9	3,827.7	4,264.3
LINEAR REG			4,043.7	3,446.5	3,811.4	4,704.6
PERF FACTOR			4,060.6	4,038.1	4,078.0	4,178.9
USER EAC			0.0	0.0	0.0	0.0
CPI*SPI			4,535.4	3,375.3	3,606.2	4,399.2
MICOM EAC			4,535.4	3,375.3	3,606.2	4,399.2

Notes

Weighted VAR: Cost = 50.0% Schedule = 50.0% Performance Factor = 1.00
Forecasts are generated independently for each level.

Fig. 4

There are distinct benefits to be derived by participants from the three Stovepipes collaborating. EVM analysts bring a credible cost projection discipline based on performance to date; risk management team engineers bring insight into potential risks, their likelihoods of occurring and qualitative assessment of cost consequences; and, cost estimators bring techniques for projecting estimates of new systems based on actual cost data and expertise in the use of estimating models (e.g., ACEIT) into the risk assessment, analysis and quantification of cost-risk processes. What has been a challenge is how to get these stove-pipes to bring their beneficial skills to bear to improve cost-risk assessment and analysis.

EVM analysts do not participate enough in the quantification and management of cost-risk when, in fact, they are strategically positioned to do so. A very important aspect in the enabling of effective integrated cost-risk management is the work rhythms of all essential participants. The EVM analysts and risk management teams have the same work rhythms, their work gets done on a monthly cycle. Under most circumstances the cost estimators are only in synch with the other two participants annually in support of the president's budget and at major milestones because that is when the cost estimates are updated. However, there is no reason the cost estimators cannot participate on a monthly basis. They can gain the benefit of witnessing the realization (or not) of cost-risk as projected in their latest cost estimate and take that information under consideration in future cost estimates.

Most often, risk management teams stop short of cost-quantifying identified and assessed risks resulting in a lot more hand-wringing and talking than actually doing something about the risks. What's needed is a concrete reason for motivating more of the 'doing' over the hand-wringing and talking. When qualitative assessments of risk are made quantitative, a motivating reason is created for action. The action is seen to be urgently needed because of the concrete, estimated cost consequences that could result if the risks were not eliminated or mitigated. Risk and cost-risk management requires 'Organizing Vehicles' that focus risk management teams, EVM analysts and cost estimators in coordinating their perspectives on risk and cost-risk. Organizing Vehicles are tools enabling contributions from different perspectives to produce useable results. This paper will briefly discuss two Organizing Vehicles, the Integrated Cost-Risk Model (ICRM) and the EVM Trend Tool (EVMTT).

The first Organizing Vehicle this paper highlights is called the Integrated Cost-Risk Model (ICRM) and it is implemented in the government owned/Tecolote Research maintained Automated Cost Estimating/Integrated Tools (ACEIT) model. Fig. 5 below illustrates the sequence of steps from the bottom up in the ICRM. The first step in the ICRM process is calculating Independent Estimates at Completion (IEAC) at WBS element levels based on the use of a single performance factor such as the CPI, SPI, CPI*SPI, or some other EVM performance factor. Next, using multiple performance factors, low, most likely and high IEAC estimates can be made so that a range of possible IEACs is created as a triangular distribution and developed into a continuous distribution through the Monte Carlo (Latin Hypercube) simulation capabilities of ACEIT. Next, the Risk Register results from the Risk Management Team are input into ACEIT and likewise processed simultaneously within the Monte Carlo simulation capability of ACEIT. Finally, both the EVM and Risk Register results are statistically summed in ACEIT so that an integrated IEAC distribution is developed. From that distribution, a discrete result within the distribution at an appropriate confidence level, e.g., 50%, 60%, 80%, etc., is identified that represents the Program Manager's IEAC.

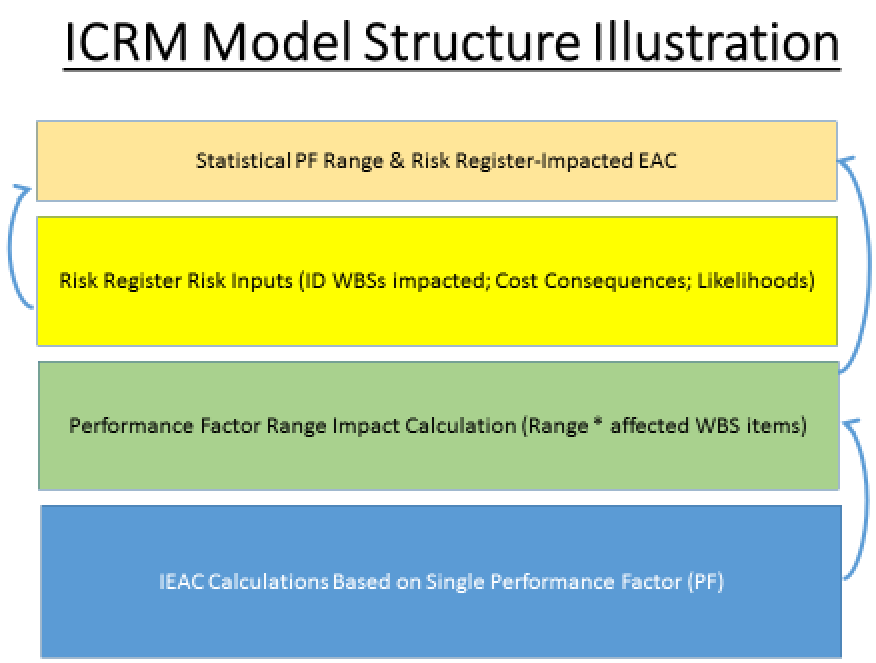


Fig 5

EVM information for cumulative BCWS, BCWP and ACWP is entered into the ICRM along with the current BAC. Fig. 6 below illustrates the entry of the Defense Acquisition University (DAU) Light Assault

Reconnaissance Vehicle's (LAR) EVM Oct 2004 Case Study data with a screenshot from the ICRM.

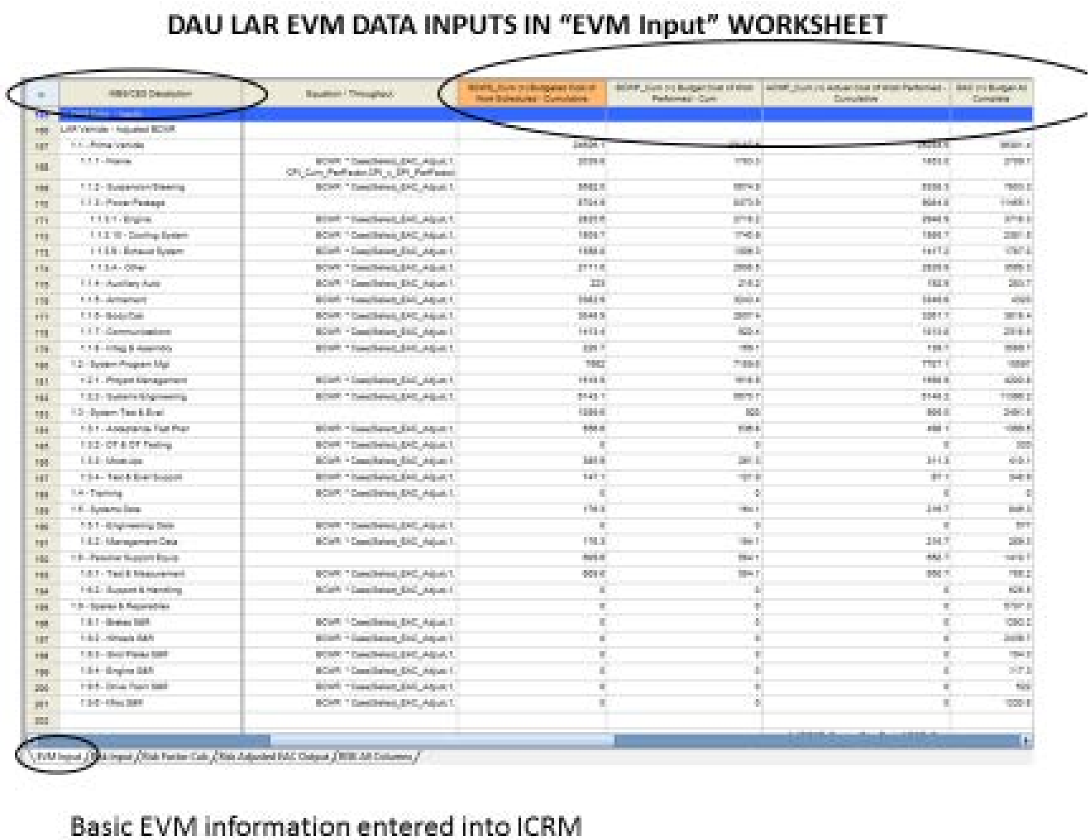
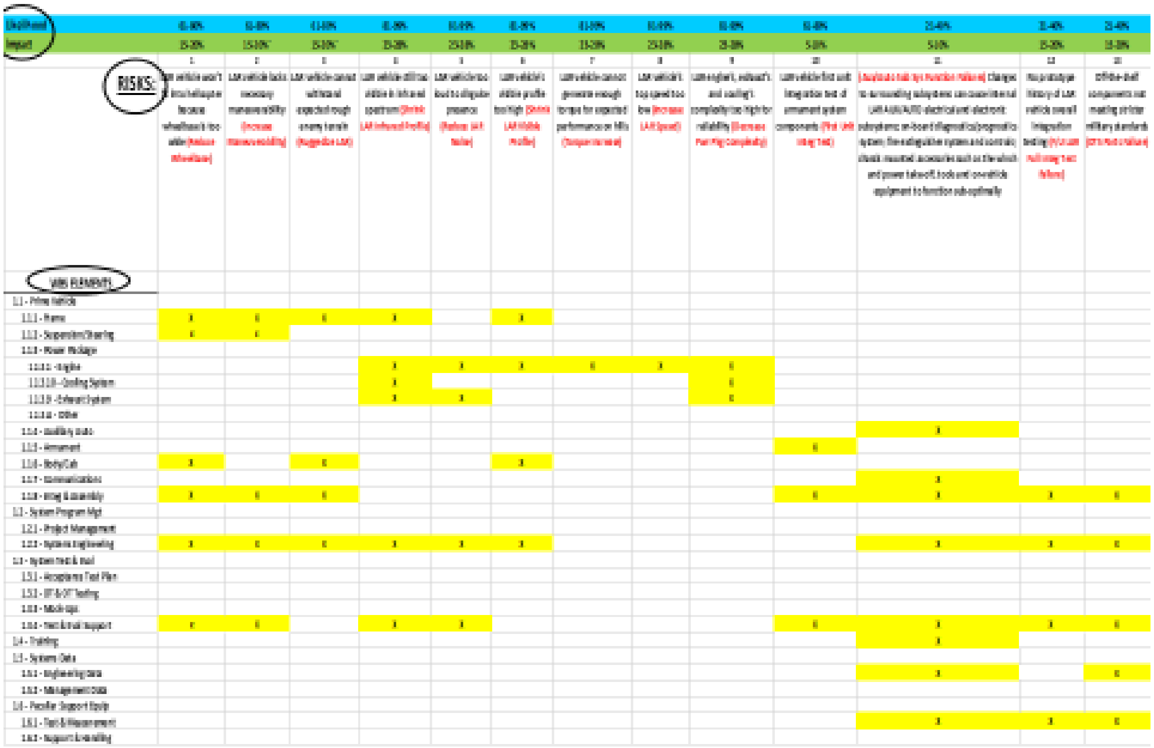


Fig. 6

The EVM analyst and cost estimator work with the risk management team's engineers to structure a matrix that shows which WBS elements are impacted by which risks. This process requires the EVM analyst and cost estimator to dialogue with the members of the Risk Management Team's engineers in order to identify which risk will affect what WBS element. After each Risk Management Team meeting, this matrix should be updated to show if any risks have been eliminated and pose no more problems to WBS elements they may have affected in the past and to introduce potential new risks having an effect on any WBS elements. The Risk/WBS Element matrix, as illustrated in Fig 7 below, shows that a risk can affect more than one WBS element and many risks can affect the same WBS element. This matrix forms the basis for the likelihood and cost consequence rating scale information to be entered into the ICRM. Fig. 7 below illustrates the Risk Register/WBS Element matrix and Fig. 8 below that illustrates what this information looks like when input into the ICRM.

RISK REGISTER/WBS ELEMENT MATRIX



- Affected WBS elements inherit each risk likelihood and cost impact percentage that affects it

Fig. 7

RISK LIKELIHOODS & COST CONSEQUENCE IMPACTS INPUT INTO ICRM 'RISK Input' WORKSHEET

	WBS/CES Description	Phasing Method	Equation / Throughput	Probability % of Occurrence	Impacted_WBS_Items (*) What WBS items adj BCWR are impacted	Low_Cost_Impact (% (l) Low Cost	ML_Cost_Impact % (l) Most Likely	High_Cost_Impact % (l) High Cost
108								
109	*INPUT VARIABLES							
110								
111	** Risk Inputs							
112	* Risk Impacts - Inputs							
113	Risk 1	C	ML_Cost_Impact% / 100	70.5	Frame, Suspension, Body, I&A, SysEng, T&E	15	17.5	20
114	Risk 2	C	ML_Cost_Impact% / 100	70.5	Frame, Suspension, I&A, SysEng, T&E	15	17.5	20
115	Risk 3	C	ML_Cost_Impact% / 100	70.5	Frame, Suspension, Body, I&A, SysEng	15	17.5	20
116	Risk 4	C	ML_Cost_Impact% / 100	90	Frame, Eng, Cooling, Exhaust, Aux, SysEng, T&E	23	25	28
117	Risk 5	C	ML_Cost_Impact% / 100	90	Eng, Exhaust, SysEng, T&E	23	25	28
118	Risk 6	C	ML_Cost_Impact% / 100	90	Frame, Body, SysEng	23	25	28
119	Risk 7	C	ML_Cost_Impact% / 100	90	Engine	23	25	28
120	Risk 8	C	ML_Cost_Impact% / 100	90	Engine	23	25	28
121	Risk 9	C	ML_Cost_Impact% / 100	90	Engine, Cooling, Exhaust	23	25	28
122	Risk 10	C	ML_Cost_Impact% / 100	70.5	Armament, I&A, T&E	5	7.5	10
123	Risk 11	C	ML_Cost_Impact% / 100	30.5	Aux, Comm, I&A, SysEng, T&E, Train, EngData, T&M	5	7.5	10
124	Risk 12	C	ML_Cost_Impact% / 100	30.5	I&A, SysEng, T&E, T&M	15	17.5	20
125	Risk 13	C	ML_Cost_Impact% / 100	30.5	I&A, SysEng, T&E, EngDataT&M	15	17.5	20

EVM Input / Risk Input / Risk Factor Calc / Risk Adjusted EAC Output / RISK All Columns /

Fig. 8

Fig. 9 reflects the Cumulative Distribution Function (CDF) results for the IEAC when only the traditional EVM performance factor-based IEAC is considered. Note the location in the CDF of the Point Estimate, which represents an IEAC value that assumes all future work will be accomplished at a CPI equal to 1.0, that is, exactly according to planned work accomplishment even though past work accomplishment may be inefficient, less than a CPI equal to 1.0. It represents a value that has only a 10% confidence of being achieved. There is a 90% chance that the final number will be greater.

"LAR Vehicle – Independent EAC" LEVEL CDF (no Risk Register Results)

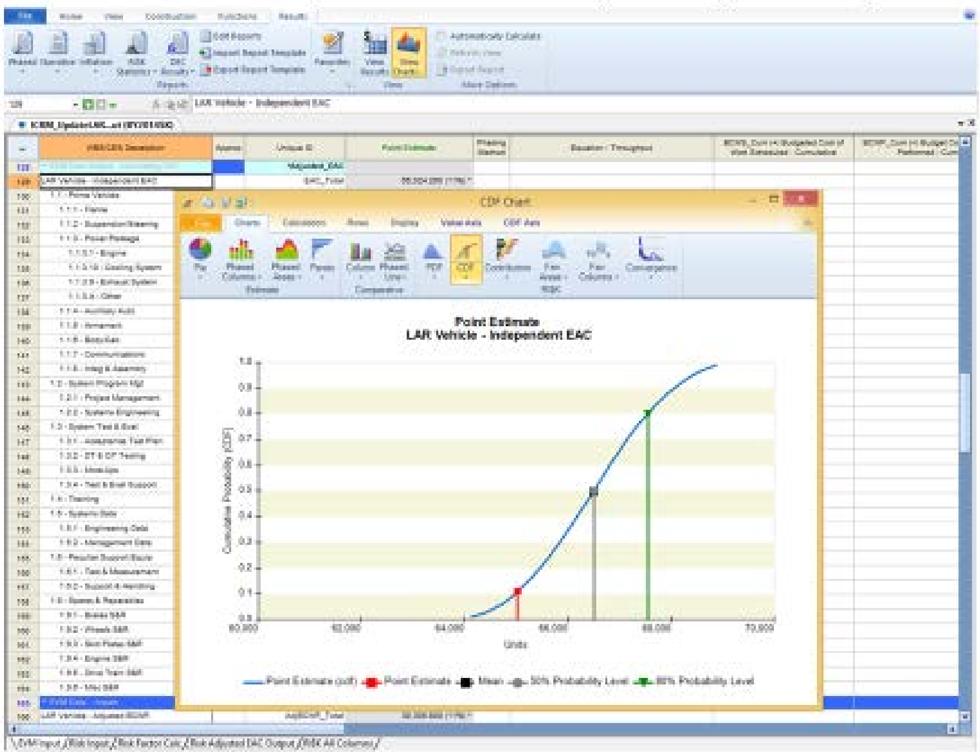


Fig. 9

Fig. 10 below reflects what the IEAC CDF looks like when the Risk Register results are included along with the more traditional EVM performance factor-based IEACs. Note that the Point Estimate is so understated it doesn't even make it into the CDF.

LAR VEHICLE CDF WITH POINT ESTIMATE, MEAN, 50% & 80% CONFIDENCE LEVELS
(includes Risk Register Results)

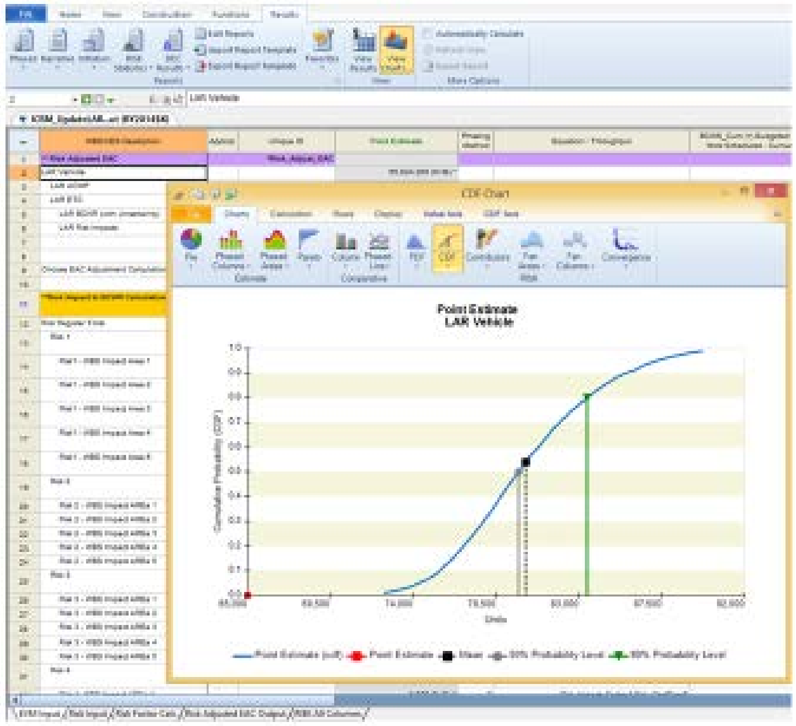
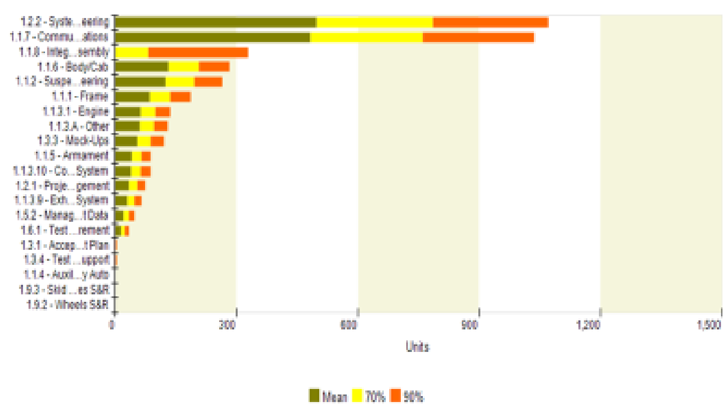


Fig 10

Fig. 11 below shows which WBS element contributes the most to the total IEAC in descending order.

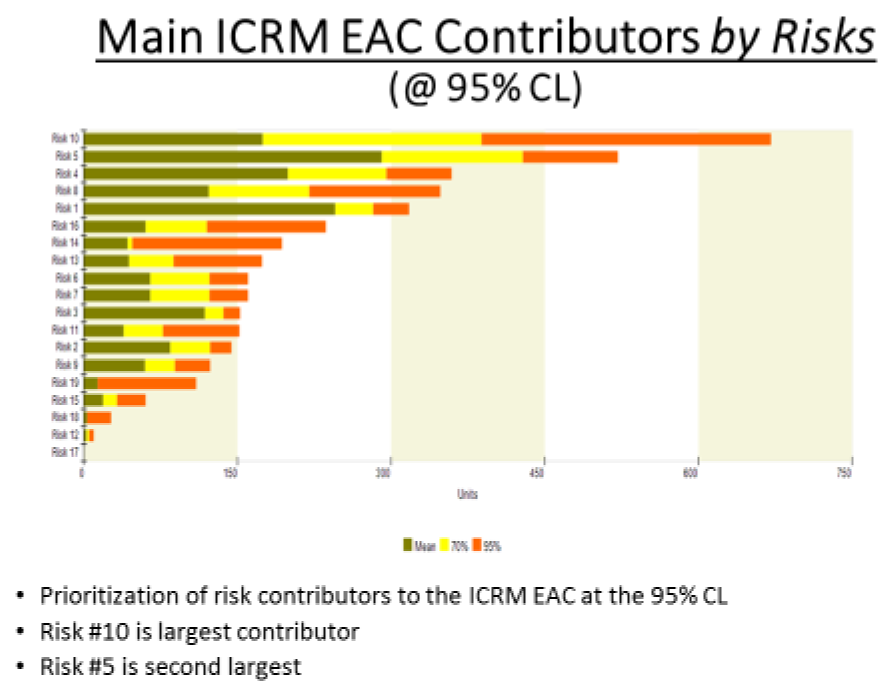
Main ICRM EAC Contributors *by WBS*



- Prioritization of main WBS element contributors to the ICRM's EAC at the 90% CL

Fig. 11

Fig. 12 shows which risk contributes the most to the total IEAC in descending order. Figures 11 & 12 are often referred to as a 'tornado' charts.



The second Organizing Vehicle this paper highlights is called the EVM Trend Tool (EVMTT) based on the Dr. Roy Smoker (MCR) 2011 paper "Use of Earned Value Management Trends to Forecast Cost Risks" published in the Journal of Cost Analysis and Parametrics, 4:1, 31-5 and is implemented in Excel and free to all users. EVM analysts can easily initiate the cost-risk consequence identification process by using the EVMTT to project what the budget impacts could be when either the BAC continually grows, indicating a potential set of risk threats to the program's budget, or the rate of work accomplishment slows down, or both. These indications can quickly be identified on a monthly basis at the contract level using the EVMTT.

The key points of EVMTT analysis are:

1. Provides a 25,000 foot view of contract performance (EVMTT analysis is at total contract level monthly).

2. No traditional EVM performance efficiency used (e.g., CPI, SPI, SCI, etc.) in Dr. Smoker's paper, however, the EVMTT v2 produces them.

3. Utilizes a database of monthly CPR (or IPMR) EVM information to derive linear regression equations for $BCWS_{CUM}$, $BCWP_{CUM}$, BAC & LRE projections from linear sections of PMB & BAC data within which the coefficients in the equations are rate-of-growth (aka 'slopes') for $BCWS_{CUM}$, $BCWP_{CUM}$, BAC & LRE.

The key relationship in the EVMTT is that since $BCWP_{CUM}$ must equal BAC at end of effort. If the $BCWP_{CUM}$ and BAC regression equations are set equal to each other, the only remaining variable is months and solving for that results in an estimate for the effort's end month. To illustrate with Dr. Smoker's solution at month 42 in his paper's case study:

a) $BCWP_{42} = BAC_{42}$ ➔ \$86.35M*Months = \$4,970.56 + \$31.76M * Months
b) **Months = \$4,970.56/(\$86.35 - \$31.76)** = **91.06 mos**
c) Plug end month into BAC & LRE equations to get end month BAC & LRE estimates
d) Repeat this process each month with one more month of EVM information

A Very Important Note about $BCWP_{CUM}$ & BAC Coefficients

- Recall, **Completion Months = \$4,970.56/(\$86.35 - \$31.76)**
- \$86.35 and \$31.76 are BCWP & BAC coefficients (aka slopes) respectively

1. If these two slopes (aka rates of growth) get close to one another, what happens to the value of the completion months? (they get larger)
2. If these two slopes (aka rates of growth) equal one another, what happens to the value of the completion months? (any number divided by zero is undefined)
3. If the BAC slope is larger than the BCWP slope, what happens to the value of the completion months? (it becomes negative)
4. If either conditions #2 or #3 are the EVMTT result, the numerical results from the EVMTT are just indications that something fundamental is going wrong with the project and it is time to take a very hard look at the project, to possibly suspend work until the reasons for a faster rate of growth in the BAC than work is being accomplished can be determined and corrected.

The EVMTT also calculates the Earned Schedule end-of-contract month for comparison

1. $\text{Earned Schedule}_{42} = 42 + (BAC_{CPR\ 42} - BCWP_{CUM\ 42})/\text{WorkRate}_{42}$

   (WorkRate = $BCWP_{CUM}$/Months-to-Date (42)); so,

- $\text{Earned Schedule}_{42} = 42 + (6269.68 - 3737.55)/88.99 =$ **70.45 mos (< 91.06 mos)**
- Note that Earned Schedule underestimates the projection of total contract months as compared with the EVMTT result (70.45 months < 91.06 months) because it does not incorporate any BAC rate of growth to date. Earned Schedule simply uses the current CPR month's BAC whereas the EVMTT incorporates the BAC's past rate of growth and comes up with a longer contract duration if the BAC has been steadily growing.

The EVMTT also calculates a percent complete using the EVMTT estimate of end month BAC (with growth): $PC = BCWP_{CUM}/BAC_{EndMo} * 100\%$. The value of percent complete so calculated will be more conservative as long as BAC is increasing.

In Dr. Smoker's paper, 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 cost-risk projected at 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 performance and/or testing and generally associated with a negative variance.

If the EVMTT projects a continually rising BAC, the EVM analyst can alert the risk management team, the cost estimator and the schedule analyst that a 'deeper dive' into the WBS elements is called for to identify the potential risks driving such projections. The ICRM is useful at this point to perform that deeper dive at the WBS element level as previously discussed. This solution can motivate the PM to apply resources to the risks identified within the WBS elements to work towards eliminating or mitigating their cost impacts.

In this way, both the EVMTT and ICRM complement each other in providing first, a high-level assessment of risks driving contract costs higher and second, a tool to ferret out what the risks are, where they impact WBS elements and how much cost impact they can have. The EVMTT is implemented in a simple to use Excel file and is free to any user.

In summary and conclusion, we've described the present stove-piped nature of risk and cost-risk assessment and analysis; described the benefits each of the presently stove-piped participants bring to cost-risk assessment and analysis if they work together; described the 'Organizing Vehicles' of two new EVM cost-risk tools enabling such collaboration; and, illustrated these two new EVM cost-risk tools. All that remains is for these presently stove-piped participants in the risk and cost-risk assessment and analysis process to:

1. Use these tools
2. Work together with them and, by so doing
3. Improve the cost-risk process