Connecting the Dots: An Approach to Integrating Program Risks with the POE

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Section 1: Abstract
DoD guidance instructs program managers to include risk and uncertainty analysis in cost estimates. In addition, a risk cube tracks all of the known risks/issues within a program and assigns them a likelihood and consequence. It has been proven that risks, regardless of if they are programmatic, technical, or schedule defined, will have an effect on the overall program cost. This paper investigates the linkage between identified program risks with their cost outcomes and suggests a way to elicit more accurate consequences that can then be allocated appropriately into the cost estimate.

Section 2: Introduction

ACAT III and below programs do not always have a team of cost analysts fully dedicated to themselves, but program managers and decision makers still need to be able to get quick and accurate feedback. They may need to know the impact of newly identified program risks or if updates to risk mitigation plans actually reduce the risk consequence level on the risk matrix. . DoD guidance instructs program managers to include risk and uncertainty analysis in cost estimates, but to do this accurately the Program Office Estimate (POE) should at a bare minimum include risks identified in the program risk matrix. In addition to the POE needing to use the risk matrix as an input, you may notice at the same time the risk matrix requires the POE to determine risk consequences based on the risk definitions in Figure 1.

Consequence (x)

Level	Technical Performance *	Schedule	Cost
1	Minimal or no consequence to technical performance	Minimal or no impact To schedule	Minimal or no impact
2	Minor reduction in technical performance or supportability, can be tolerated with little or no impact on program ; same approach retained	Additional activities required, able to meet key dates. Slip < 1 month from baseline.	Budget increase or unit production cost increases ≤ (1% of Budget)
3	Moderate reduction in technical performance or supportability with limited impact on program objectives; workarounds available	Additional activities required, able to recover key dates, slip < 2 month of critical path, subsystem slip > 1 month from baseline	Budget increase or unit production cost increase ≤ (5% of Budget)
4	Significant degradation in technical performance or major shortfall in supportability; may jeopardize program success; workarounds may not be available or may have negative consequences	Program critical path affected, all schedule float associated with key milestone exhausted. Slip < 6 months from baseline	Budget increase or unit production cost increase ≤ (10% of Budget)
5	Severe degradation in technical performance; Cannot meet KPP or Key technical/supportability threshold; will jeopardize program success; no workarounds available	Cannot meet key program milestones. Slip > 6 months from baseline	Exceeds APBA threshold ≥ (10% of Budget)

Figure 1 – Consequence definitions

As the POE and risk matrix are dependent on each other, it is imperative that the cost analyst train the Integrated Product Teams (IPT) to effectively identify and quantify risk consequences in order to make sure we are not just accurately reporting risks in the program risk cubes but also in the POEs. Humans typically lack precision/accuracy with understanding risk and this is exacerbated when those risks are thought to be improbable or unlikely to happen (famous last words of program managers). According to a paper published in a 2013 study: “They select extreme outcome values, typically above the top value of the distribution.” Within the paper, a study is detailed where specific information about the battery life of 100 laptop computers was given to participants. Of the one hundred computers, forty of the batteries lasted 2.5 hours, 25 batteries lasted 3 hours, 20 batteries lasted 2 hours, 10 batteries lasted 1.5 hours, and five batteries last 3.5 hours. The study then asked participants to complete the statement –

"It is improbable/unlikely that the battery will last ______ hours."

60% of participants answered 4 hours despite the fact that 0 of the 100 batteries lasted that long. The same kind of result occurred in a variety of similar experiments, thereby suggesting that things deemed improbable or unlikely are frequently interpreted as having close to a 0% chance of occurring.

Knowing that subject matter experts underestimate risk is nothing new and neither is suggesting it should be used to quantify risk in cost estimates; in fact, the subject is covered in the risk module of the Cost Estimating Body of Knowledge (CEBoK) *Module 9 Cost and Schedule Risk Analysis.* In that module, it specifically mentions that:

> *"Given what the risk cube relies on, it is the case that this method almost always understates risk. First, SMEs familiar with a program (or even worse, working on the program) will tend to be biased low in both their probabilities and cost impacts."*

This paper attempts to outline a process that will hopefully help the team and decision makers better understand the cost impacts of risks and thus better quantify the consequences. This will not only allow the team to more accurately identify risk but also gives the cost analysts better data to use in the program office estimate risk analysis.

Section 3: Suggested Risk Process & Example

At each Risk Working Group (RWG) it is imperative that a cost analyst be present to make a quorum and assist in the risk categorization process. These RWGs should take place on a recurring basis to not only status existing risks but to step though the process shown in Figure 2 for new risks. This is key in the process to ensure that the major program risks are identified in a timely matter. The risk management process already under estimates total program risks because it leaves out "unknown-unknowns" and "trivial" risks – so it is imperative that known risks are properly identified and quantified.

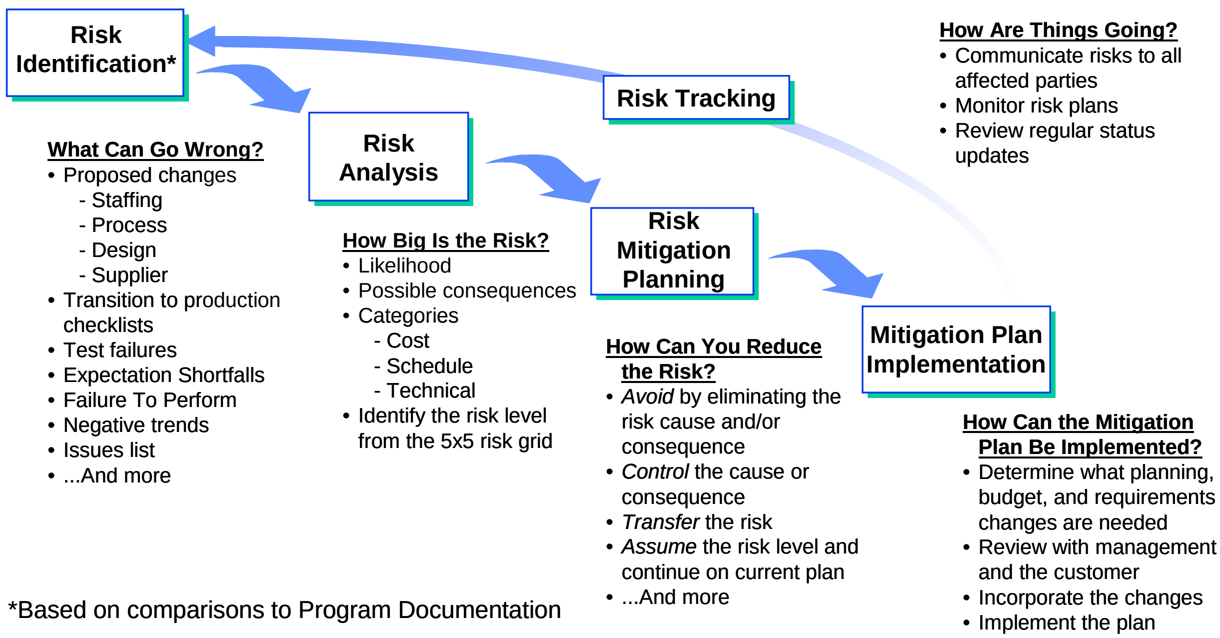


Figure 2 Risk Identification Process

After risks are identified, the quantification process begins. This involves assigning/reviewing a likelihood and consequence to each risk and updating if there are any changes to the risk mitigation plan. Normally the likelihood is listed on a scale of 1-5 with those likelihoods defined as: Not Likely, Low Likelihood, Likely, Highly Likely, or Near Certainty with the respective probabilities of occurrences ranging respectively from 10%-90%. To ensure that the IPT team truly understands the impact of their assessment of the likelihood/consequence, this paper recommends using the "Step-Wise Approach to Elicit Triangular Distributions" suggested in the 2013 ICEAA presentation by Marc Greenberg.

To start the process begin by ensuring that each risk is clearly defined. This includes making sure each risk has a unique title and a clearly understandable statement that describes the root cause. A more detailed description of the risk is then included and a consequence description of what happens if the risk is realized. Next, the cost analyst should look into the POE and decide which WBS elements will be effected by that particular risk and note the baseline cost from the elements.

For each individual risk ask the IPT "What probability would you assign to a value that is very unlikely?" "What probability would you assign to a value that is extremely unlikely?" Using their choices, the analyst is then able to populate the probability chart in Figure 3.

1. What probability would you assign to a value that's "Very Unlikely"?
What probability would you assign to a value that's "Extremely Unlikely"?

Extremely Likely	Extremely Unlikely	Very Likely	Very Unlikely
95%	5%	75%	25%
96%	4%	80%	20%
97%	3%	85%	15%
98%	2%	90%	10%
99%	1%	95%	5%

Descriptor	Description	Probability
Absolutely Impossible	No possibility of occurrence	0%
Extremely Unlikely	Nearly impossible to occur	5%
Very Unlikely	Highly unlikely to occur; not common	20%
Somewhat Unlikely	Indifferent between "Very Unlikely" & "Even chance"	35%
Even Chance	50/50 chance of being higher or lower	50%
Somewhat Likely	Indifferent between "Very Likely" & "Even chance"	65%
Very Likely	Highly likely to occur; common occurrence	80%
Extremely Likely	Nearly certain to occur	95%
Absolutely Certain	100% Likelihood	100%

Figure 3 Likelihood scale development

In the case shown, the value of 5% was chosen for extremely unlikely and 20% for very unlikely. Somewhat unlikely is then calculated as the middle point between very unlikely and even chance and somewhat likely is the middle point between even chance and very likely. It should be noted that at this point these likelihoods do not need any association with the likelihood for the particular risk. The intent is to clearly define for the RWG what is meant by the ranges of probabilities.

Now the cost analyst should present the team with the value from the WBS associated with the risk. If that element is a point estimate (no risk included) we will assume that to be the "most-likely" value. If it already has a risk range around it that can also be pulled up to review.

We then step through this series of questions –

"What is the chance that the actual value could exceed the most-likely cost, M?"

"What is the lowest value, L?"

"What is the chance that the actual value could be less than L"

"What is the Highest value, H?"

"What is the chance that the actual value could be higher than H?"

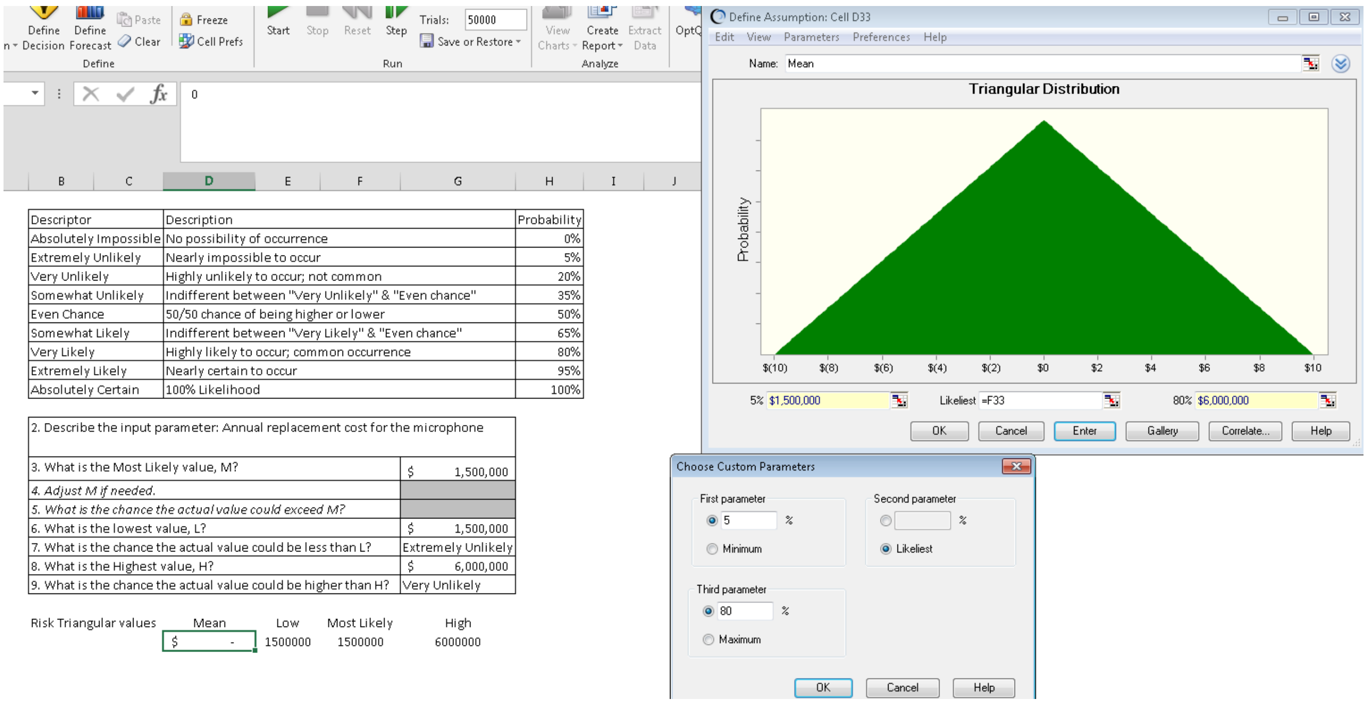
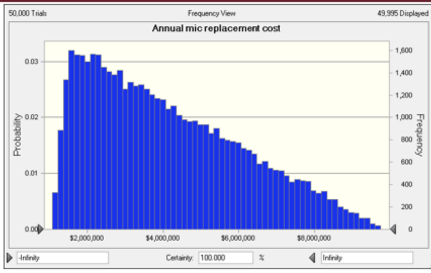


Figure 4 – Triangle distribution set-up

This approach now has given the team three data points with associated likelihoods that can be input into a risk simulation in either Crystal Ball or @Risk using a triangle distribution. The cost analyst can then run a Monte-Carlo simulation for that particular risk element and show the IPT the associated PDF, CDF, and risk percentiles such as the example shown in Figure 5.



First iteration results

Percentile	Forecast values
0%	$1,073,811
10%	$1,721,449
20%	$2,182,075
30%	$2,665,935
40%	$3,194,571
50%	$3,759,451
60%	$4,387,761
70%	$5,126,745
80%	$5,978,133
90%	$7,110,390
100%	$9,781,319

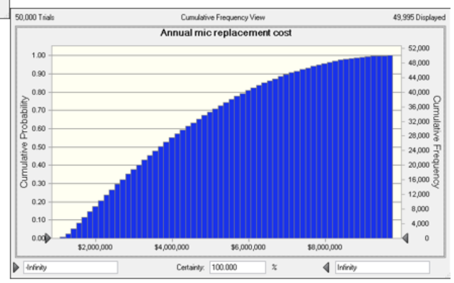


Figure 5 – First iteration results

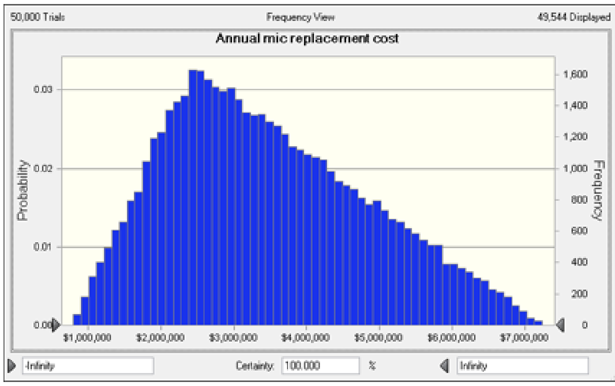
The team should then review and discuss the implications of those assumptions and ensure they are capturing the intent of the risk description. If not, the process should then be repeated and if need be the most likely value, M, may need to be adjusted in the risk scenario shown in Figure 6.

Descriptor	Description	Probability
Absolutely Impossible	No possibility of occurrence	0%
Extremely Unlikely	Nearly impossible to occur	5%
Very Unlikely	Highly unlikely to occur; not common	20%
Somewhat Unlikely	Indifferent between "Very Unlikely" & "Even chance"	35%
Even Chance	50/50 chance of being higher or lower	50%
Somewhat Likely	Indifferent between "Very Likely" & "Even chance"	65%
Very Likely	Highly likely to occur; common occurrence	80%
Extremely Likely	Nearly certain to occur	95%
Absolutely Certain	100% Likelihood	100%

2. Describe the input parameter: Annual replacement cost for the microphone	
3. What is the Most Likely value, M?	$ 1,500,000
4. Adjust M if needed.	$ 2,400,000
5. What is the chance the actual value could exceed M?	Even Chance
6. What is the lowest value, L?	$ 1,500,000
7. What is the chance the actual value could be less than L?	Extremely Unlikely
8. What is the Highest value, H?	$ 6,000,000
9. What is the chance the actual value could be higher than H?	Extremely Unlikely

Risk Triangular values	Expected Value	Low	Most Likely	High
	$ 3,288,367	$ 1,500,000	$ 2,400,000	$ 6,000,000

Figure 6 – Adjusted inputs



Percentile	Previous Forecast	New Forecast
0%	$1,073,811	$793,060
10%	$1,721,449	$1,807,416
20%	$2,182,075	$2,227,737
30%	$2,665,935	$2,566,498
40%	$3,194,571	$2,911,291
50%	$3,759,451	$3,284,497
60%	$4,387,761	$3,690,500
70%	$5,126,745	$4,162,424
80%	$5,978,133	$4,720,753
90%	$7,110,390	$5,457,797
100%	$9,781,319	$7,234,274

Second iteration results

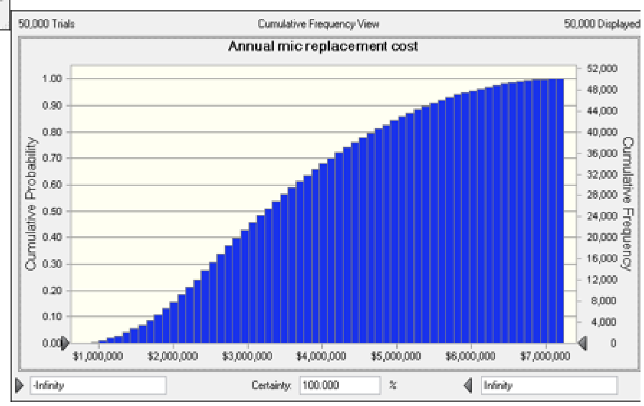


Figure 7 – New forecast

With the "New Forecast" the cost analyst can now help the team look at the cost impact of the risk in regards to unit price, total budget, procurement cost, etc. to determine the consequence of the risk more accurately. The analyst should also then take the risk distribution and include it in the POE. This concept can be taken further to look into sensitivity analysis to how certain risks effect the overall program cost or budget and can give decision maker a "worst-case" scenario of what happens if all known risks are realized. There is also potential for the process to be applied to the opportunity matrix in order to do should-cost analayis.

Section 5: Conclusion

As all DoD programs are required to report program risks via a risk matrix and have risk adjusted cost estimates prepared for milestone events, it makes sense to develop a process that can help fight the human nature to underestimate risk and cost. The cost analyst can play a large role during risk working groups to help the decision makers and program managers get quick feedback into new/updated program risks. If we work to train the IPTs to understand the cost consequences of the risks and better define what is meant by an "unlikely" scenario, we can get better inputs for our cost estimates as well. In the future, this concept can be applied to the opportunity matrix for should cost analysis.

Appendix A: Acronyms

CF	
DoD	Department of Defense
ICEAA	International Cost Estimating and Analysis Association
POE	Program Office Estimate
WBS	Work Breakdown Structure

Appendix B: References

Module 9 Cost and Schedule Risk Analysis, CEBoK 2009

A Step-Wise Approach to Elicit Triangular Distributions, Marc Greenberg, ICEAA conference 2013

Improbable outcomes: Infrequent or extraordinary?, Karl Teigan Cognition Volume 127, Issue 1, April 2013 pages 119-139