How to Capture Discrete Cost Risks in Your Project Cost Model

presentation for

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BACKGROUND

- Spring/summer 2007 a NASA ICE required a discrete, scenario-based risk approach
- Aerospace tasked with scenario-based ICE
  - Developed cost-risk distribution from 5X5 risk matrix using Excel random number generator
- NASA Constellation program utilizing 5X5 risk matrix (Tecolote & Aerospace)
- Tecolote tasked with replicating Aerospace approach
  - Validated simulation approach with the Excel random number generator approach
  - Expanded capability to include correlated uncertainty on probability of occurrence and on cost consequences and permit discrete risk events to be correlated

5x5 Risk Matrix Identification Summary

Definitions From Risk Management Guide for DoD Acquisition

- Consequence[1]
  - 1 Minimal or no impact
  - 2 Additional resources < 5%
  - 3 Additional resources = 5-7%
  - 4 Additional resources = 7-10%
  - 5 Additional resources > 10%
  - OPP (opportunities) Potential cost savings (added to matrix)

Consequence	Likelihood 1	2	3	4	5
5	2	1	1	1	1
4	0	0	0	1	2
3	0	0	0	0	0
2	1	3	3	7	2
1	0	1	0	0	0
OPP	0	1	3	0	0

1) Percent additional resources taken as percent of major WBS element (i.e. Spacecraft, Payload, etc.)

- Level Likelihood of Occurrence[2]
  - 1 Remote (10%)
  - 2 Unlikely (30%)
  - 3 Likely (50%)
  - 4 Highly likely (70%)
  - 5 Near certainty (90%)

Total Risks =	30
High =	9
Medium =	12
Low =	5
Opportunities =	4

2) As taken from "Risk Management Guide for DoD Acquisition", Sixth Edition, August 2006., pg. 12

Different organizations may use different definitions, but most require quantification of likelihoods and consequences

5x5 Matrix Cost Risk Conversion

General Process Overview

Identify Discrete Risks

Risk #1
Risk #2
Risk #3
…

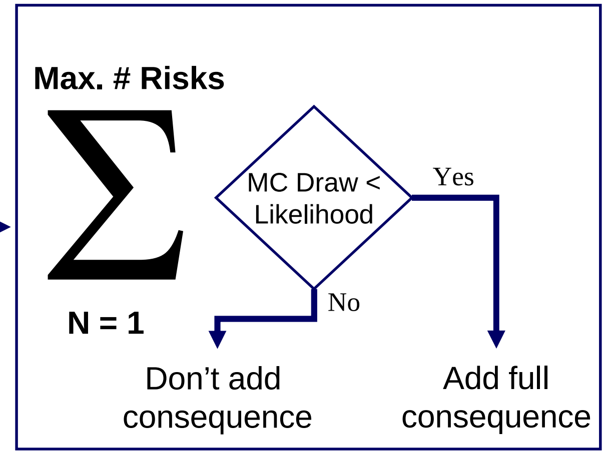
Estimate Consequence

- WBS, Months delay, Phase of Delay
- WBS % Increase in NRE, RE or both
- Convert both to $

Estimate Likelihood

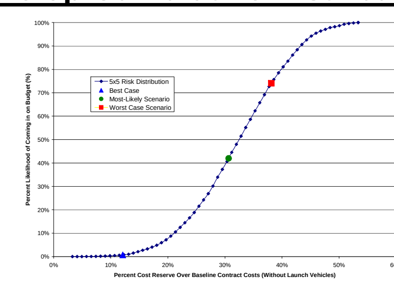
- Remote, Unlikely, Likely, Very Likely, Near Certainty

Consequence					
5	M	H	H	H	H
4	L	M	H	H	H
3	L	M	M	H	H
2	L	L	M	M	H
1	L	L	L	L	M
	1	2	3	4	5
	Likelihood				



Run appropriate # of iterations

Develop Cumulative Distribution



Rule populated a probability density function that ended up looking very normally distributed at 10,000 iterations

OUTLINE

- Discrete risk definition & show how the simulation approach with Excel random number approach was validated
- Commercial Simulation Tools
- Two model approach:
  - First model combines project element discrete risk events
  - Second model combines project element totals
- Variations on How to Model Discrete Risk Events
  - Correlated uncertainty on probability of occurrence
  - Correlated uncertainty on cost consequence/opportunity
  - Correlation of the risk events
- Impact of applying correlated uncertainty and correlating risk events on the project element total
- Impact of applying correlation when combining project element totals
- How to include the total discrete cost-risk distribution in the project estimate

Discrete Risk

- Defined as: if risk event A occurs, there is a cost consequence or opportunity. The probability of A occurring is x%
- If there are only a few such risk events, treat as discrete what-if cases (event cost impact is either "in" or "out" of the point estimate)
  - Point estimate often taken to be the full impact (when there are few)
- If there are "many" such risk events, model using the Bernoulli distribution (also known as the yes/no distribution)
  - Point estimate often taken to be the expected value (when there are many)
  - Model should allow user to adjust the risk events to be correlated
  - Model should capture correlated uncertainty associated with the cost consequence or opportunity and/or the probability of occurrence
  - Variance can be calculated by summing P*(1-P)*PE^2 for each element (P= probability of occurrence, PE= point estimate) when probability of occurrence and cost uncertainty and risk event correlation ignored

Discrete Risk Can be Modeled in Excel

	A	B	C	D	E	F	G	H	I
14	Expected Value	$ 275.98		GS1	GS2	GS3	GS4	GS7	GS8
15	Average	$ 278.55	Consequence	$ 4.09	$ 4.09	$ 3.41	$ 1.22	$ 4.37	$ 8.1
16			Likelihood	0.5	0.7	0.7	0.3	0.3	0
17	Iteration	Sum							
18	1	$ 306.21		$ -	$ 4.09	$ 3.41	$ -	$ -	$ 8.1
19	2	$ 264.37		$ 4.09	$ 4.09	$ 3.41	$ 1.22	$ -	$ 8.1
20	3	$ 217.80		$ 4.09	$ -	$ -	$ 1.22	$ -	$ 8.1
21	4	$ 230.17		$ -	$ -	$ 3.41	$ 1.22	$ -	$ -
10014	9997	$ 357.24		$ -	$ 4.09	$ 3.41	$ -	$ -	$ -
10015	9998	$ 291.84		$ 4.09	$ -	$ 3.41	$ -	$ 4.37	$ 8.1
10016	9999	$ 254.16		$ 4.09	$ -	$ -	$ -	$ -	$ -
10017	10000	$ 345.23		$ -	$ 4.09	$ 3.41	$ -	$ -	$ 8.1

- Making creative use of Excel functions, it is possible to model discrete risk events
- Assumes:
  - No uncertainty on probability of occurrence or cost consequence
  - Discrete risk events are not correlated

Validation

- So, when the probability of occurrence is fixed with no uncertainty on the cost consequence and the risk events are not correlated: we have an equivalence with the simulation model to the Excel model
  - Includes all identified discrete risk events spread across 5 project elements
  - Includes both cost consequences (+$) and cost opportunity events (-$)
  - The uncertainty result for the five project elements are added together

- Simulation model matches the mean and standard deviation of the random number generator Excel model

From Spreadsheet Tool		ACE Using 10k Iterations	
mean =	278.69	279.03	0.12%
stdev =	60.25	60.26	0.01%

Commercial Tools

- Crystal Ball, @Risk and ACEIT provide ability to assign discrete distributions to a cost
- Also allows user to assign correlated uncertainty to the probability of occurrence and cost consequence
- Can apply correlation across the risk events
- Need to have “tiered” models in order to adjust correlation at parent levels in the model
- While any of the tools could be used, this presentation is based upon an ACEIT solution

The Two Model Approach

Ground System

Σ TOTAL FOR DISCRETE RISKS

- Total for Discrete Risk Item 1
- Total for Discrete Risk Item 2
- Total for Discrete Risk Item 3
- Total for Discrete Risk Item 4
- Total for Discrete Risk Item 5
- Total for Discrete Risk Item 6
- Total for Discrete Risk Item 7
- Total for Discrete Risk Item 8
- Total for Discrete Risk Item 9
- Total for Discrete Risk Item 10
- Total for Discrete Risk Item 11
- Total for Discrete Risk Item 12
- Total for Discrete Risk Item 13

- Model 1 sums 1-50 discrete risk events
  - If less than 3-5, should consider what-if analysis instead (i.e. the cost is either in or out regardless of probability of occurrence)
  - If more than few, then the process defined in this presentation is appropriate
  - Allow correlated uncertainty on the % and/or $
  - Allow $ to be phased (spread over various FY)
  - Allow discrete risk events to be correlated

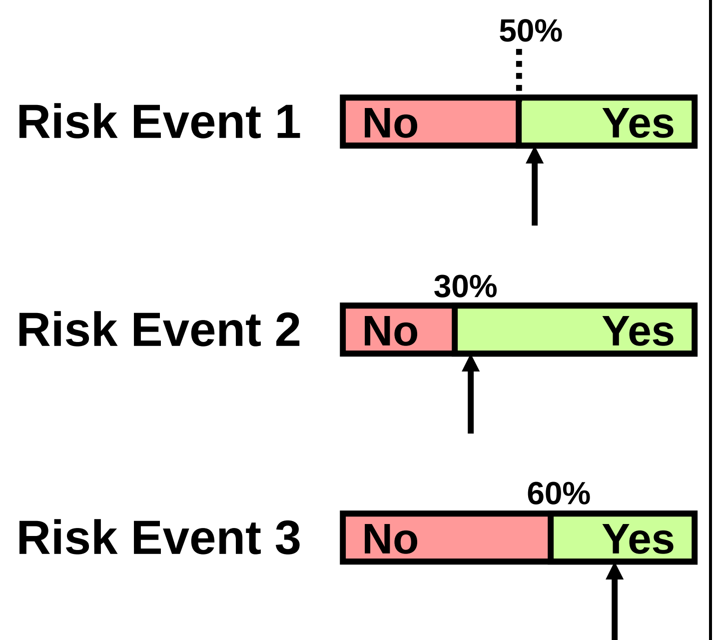
Σ Total

- Ground System
- Spacecraft
- Payload
- Program Management
- Launch Vehicle

- Second model combines the results from across multiple project elements
  - Allows user to adjust correlation across project elements

Variations on Modeling Discrete Risk

Probability of Occurrence:	**Fixed**
Uniform Draw:	**Independent**



- No/Yes boundaries are the likelihoods of the risk events occurring and are the most likely values
- Arrows represent one draw from a uniform distribution across 3 risk events under 4 different conditions
- Blue bars identify the bounds of a triangular distribution where the mode is the expert's opinion for the probability that the cost consequence/opportunity will occur. The simulation will draw from this distribution to define the yes/no boundary as it changes for each iteration.

User Interface to Project Element Level Discrete Model

GS CALCULATE Clear

	Cost	Probability	Risk Events
Low Interpretation	0	0	
High Interpretation	100	100	
Correlation Between	0%	0%	0%

Iterations	10000

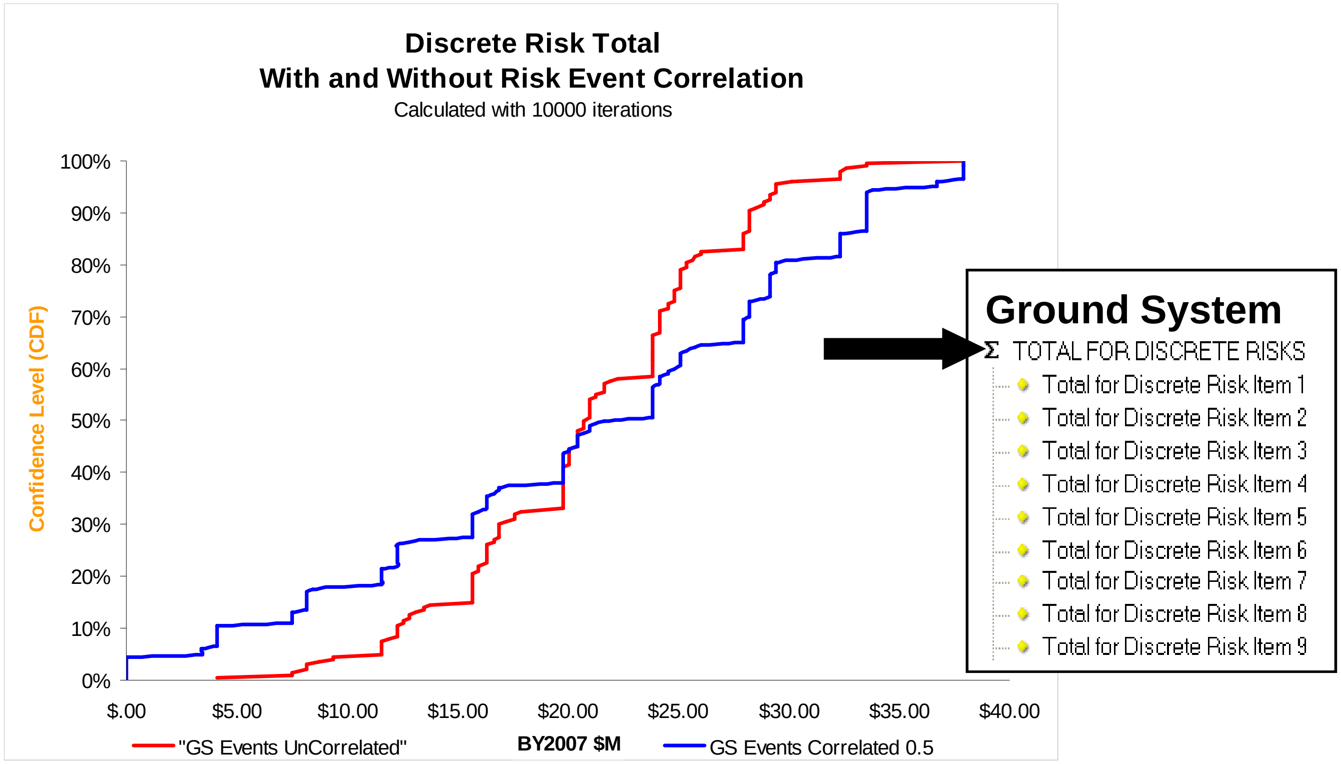
Ground System

- Σ TOTAL FOR DISCRETE RISKS
  - Total for Discrete Risk Item 1
  - Total for Discrete Risk Item 2
  - Total for Discrete Risk Item 3
  - Total for Discrete Risk Item 4
  - Total for Discrete Risk Item 5

	Probability of Occurrence			Cost Consequence		Most Likely Cost Consequence, BY 2007 $M					
	Low (value)	Likely (value)	High (value)	Low (% of PE)	High (% of PE)	Total	2007	2008	2009	2010	201
Risk Event 1	**50**	**50**	**50**	**100**	**100**	**$4.09**	$0.00	$0.00	**$4.09**	$0.00	$
Risk Event 2	**70**	**70**	**70**	**100**	**100**	**$4.09**	$0.00	$0.00	**$4.09**	$0.00	$
Risk Event 3	**70**	**70**	**70**	**100**	**100**	**$3.41**	$0.00	$0.00	**$3.41**	$0.00	$
Risk Event 4	**30**	**30**	**30**	**100**	**100**	**$1.22**	$0.00	$0.00	**$1.22**	$0.00	$
Risk Event 5	**30**	**30**	**30**	**100**	**100**	**$4.37**	$0.00	$0.00	**$4.37**	$0.00	$

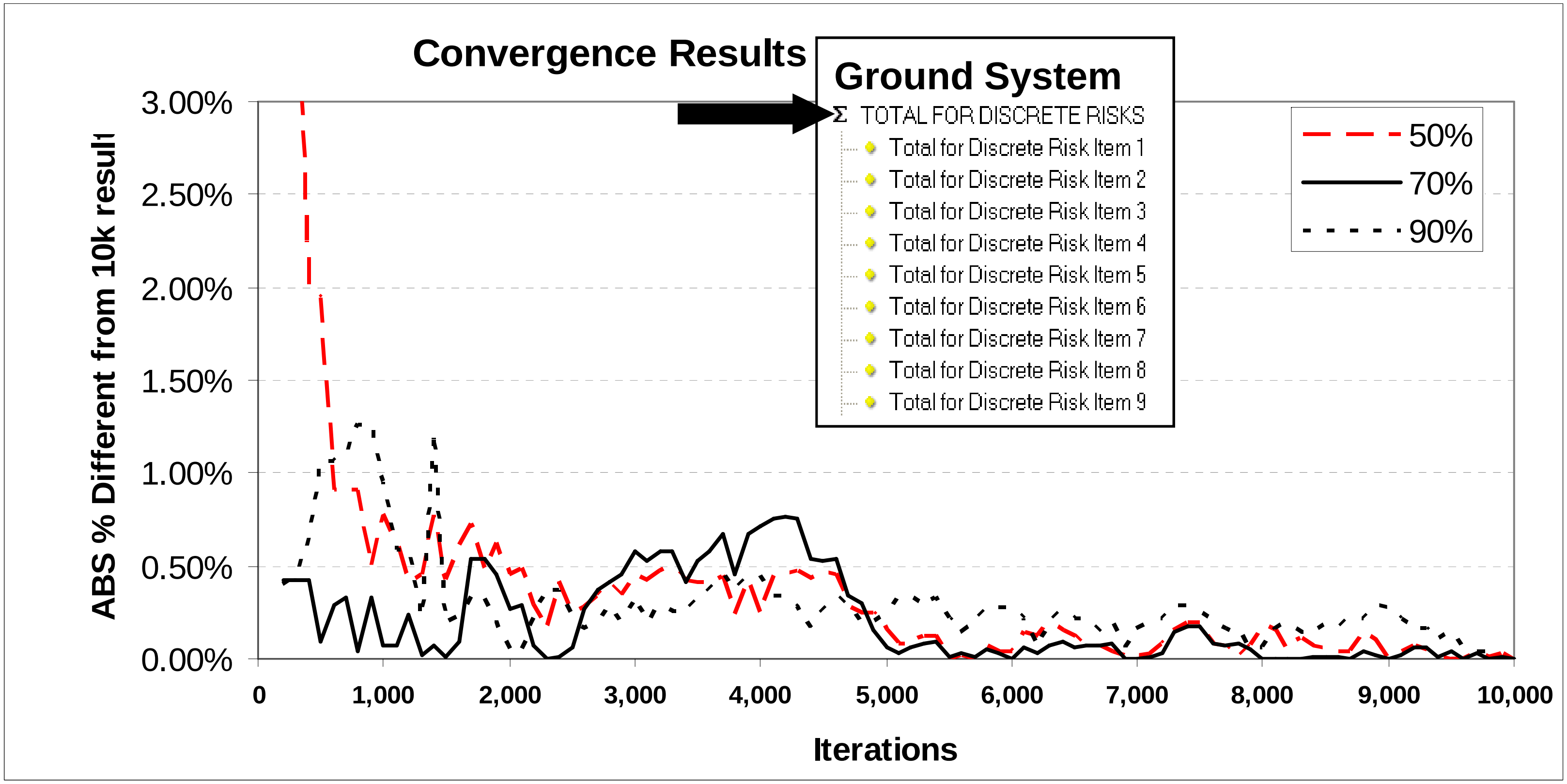
- User can assign cost consequence to appropriate year
- This example assigns no uncertainty to the probability or cost
- Correlation setting assigns correlation between probability and/or cost consequence uncertainties
- Separate input to assign correlation to risk events

S-Curve for One Project Element Discrete Total



- Sums 9 discrete risk events
- No uncertainty on probability of occurrence or cost
- Illustrates impact of correlating risk events at 0.5
- Given the "bumpy" nature of the S-Curve, exact rather than best fit methods should be considered when combining and correlating single project element S-curves to a total project level S-curve

How Many Iterations Required For Accurate Results at Project Element Level?



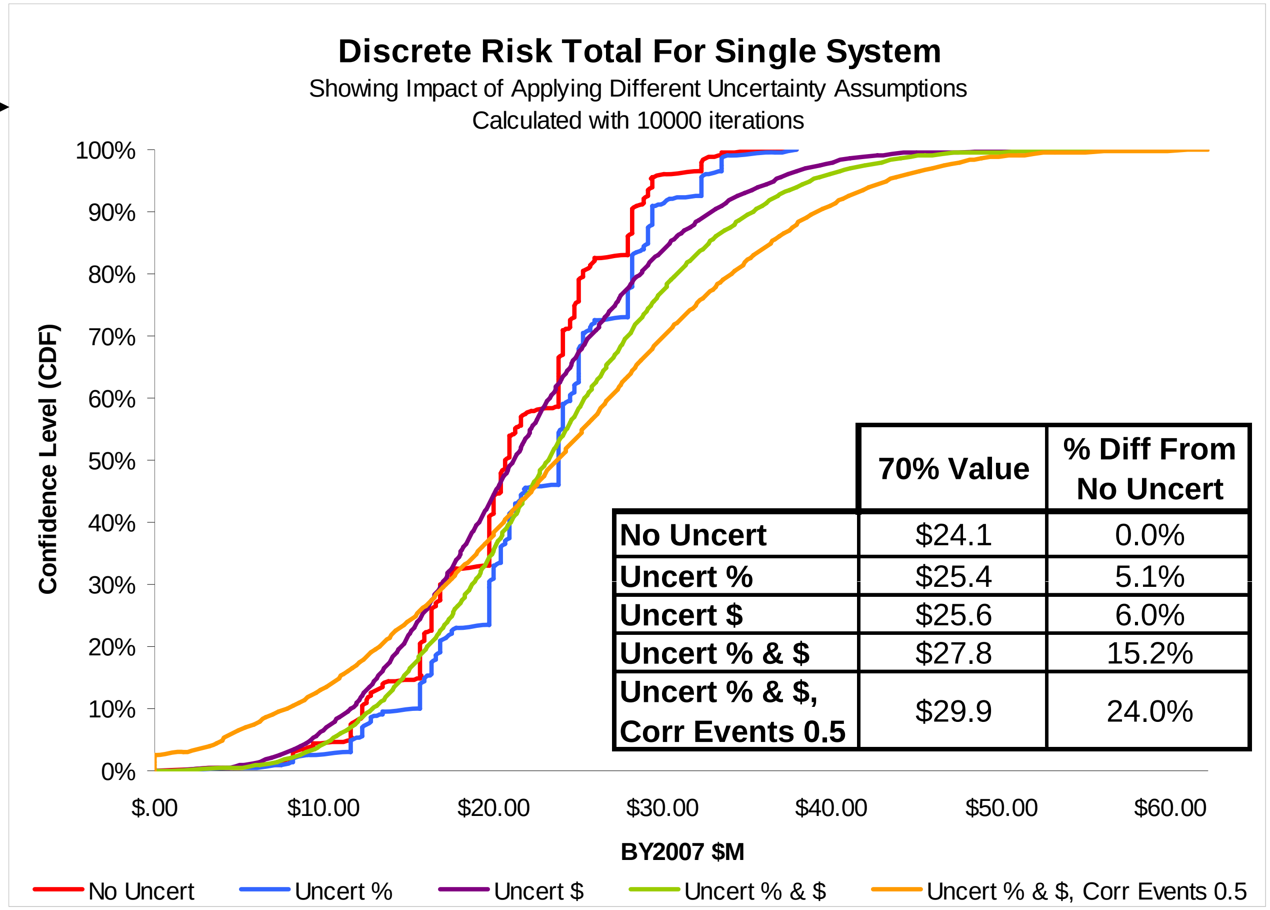
- Results from summing 50 discrete risk events, each with correlated uncertainty on probability and cost
- Even though 5k seems to be sufficient, 10k is used in the study

Impact of Adding Uncertainty

Ground System

Σ TOTAL FOR DISCRETE RISKS

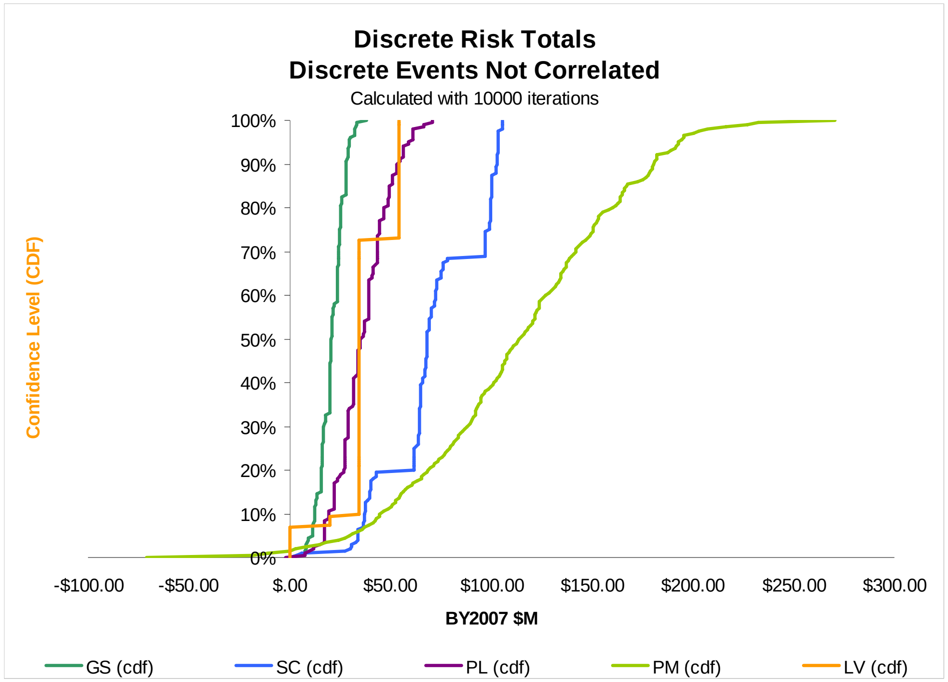
- Total for Discrete Risk Item 1
- Total for Discrete Risk Item 2
- Total for Discrete Risk Item 3
- Total for Discrete Risk Item 4
- Total for Discrete Risk Item 5
- Total for Discrete Risk Item 6
- Total for Discrete Risk Item 7
- Total for Discrete Risk Item 8
- Total for Discrete Risk Item 9
- Total for Discrete Risk Item 10
- Total for Discrete Risk Item 11
- Total for Discrete Risk Item 12
- Total for Discrete Risk Item 13
- Total for Discrete Risk Item 14
- Total for Discrete Risk Item 15
- Total for Discrete Risk Item 16
- Total for Discrete Risk Item 17
- Total for Discrete Risk Item 18
- Total for Discrete Risk Item 19
- Total for Discrete Risk Item 20

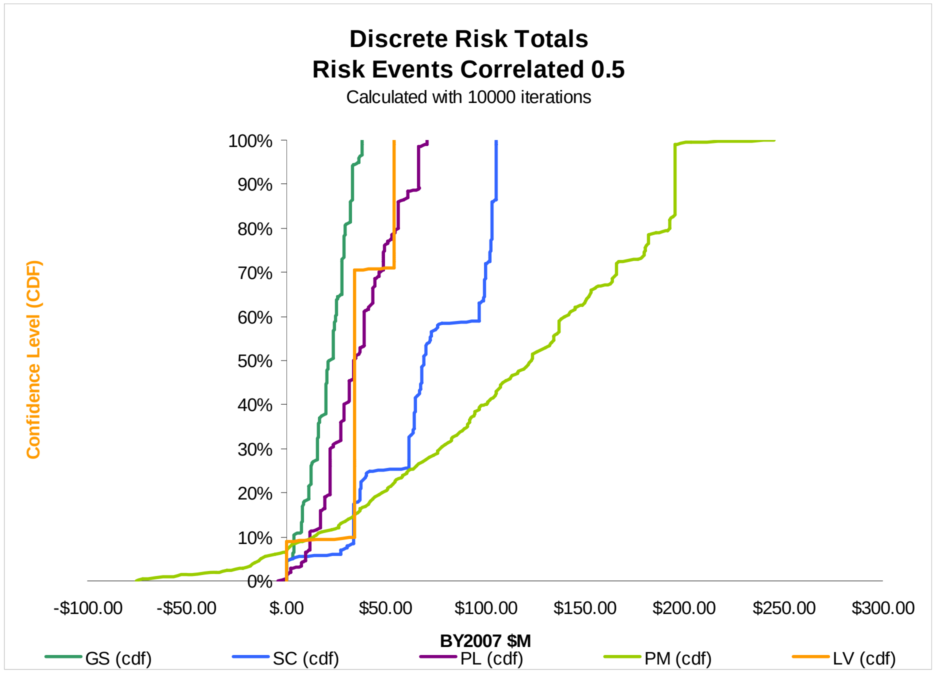


	70% Value	% Diff From No Uncert
No Uncert	$24.1	0.0%
Uncert %	$25.4	5.1%
Uncert $	$25.6	6.0%
Uncert % & $	$27.8	15.2%
Uncert % & $, Corr Events 0.5	$29.9	24.0%

- Adding correlated uncertainty to probability and/or cost increases variation
- Correlating the “risk events” together has a very significant impact

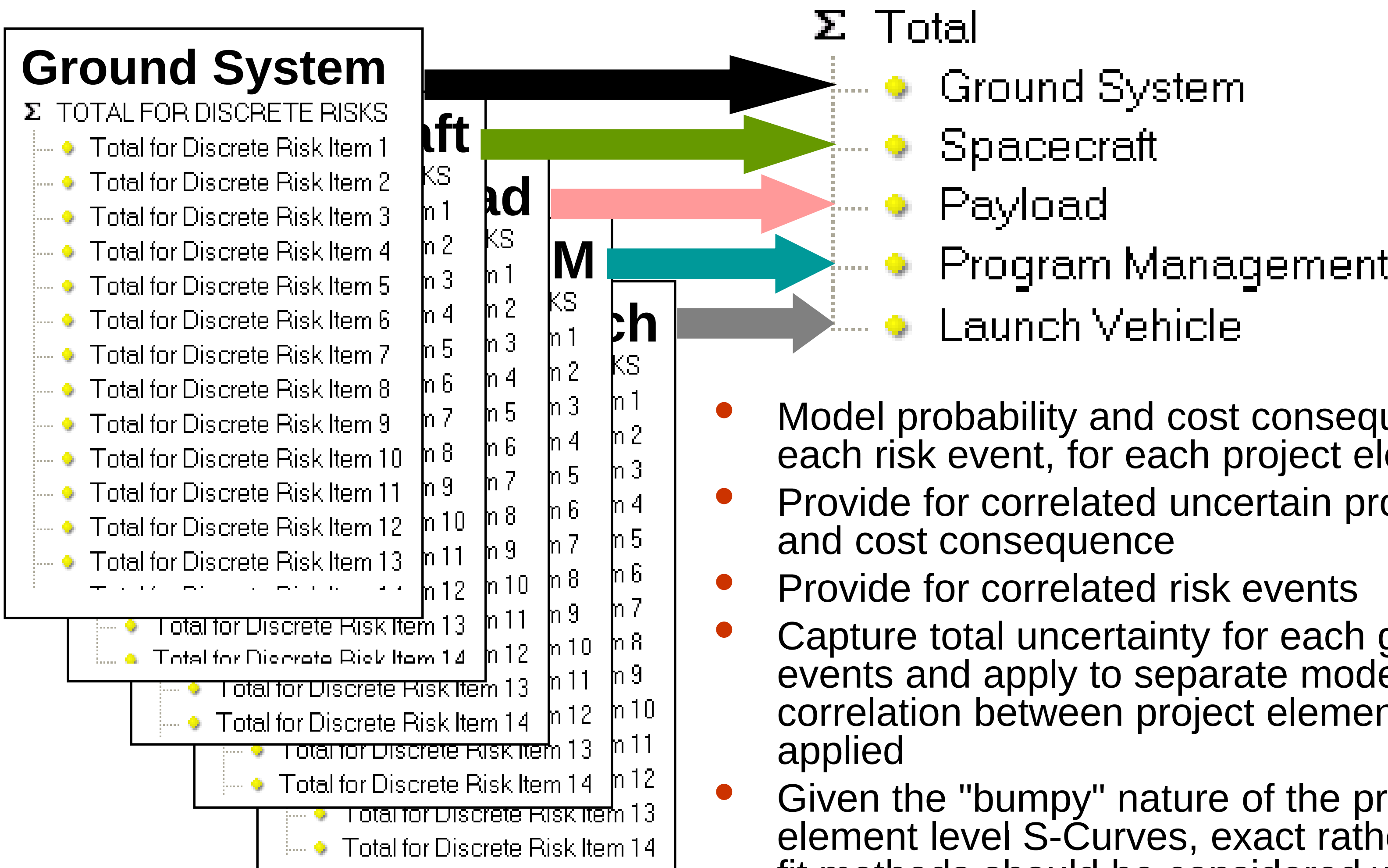
Impact of Correlating Risk Events On Discrete Totals





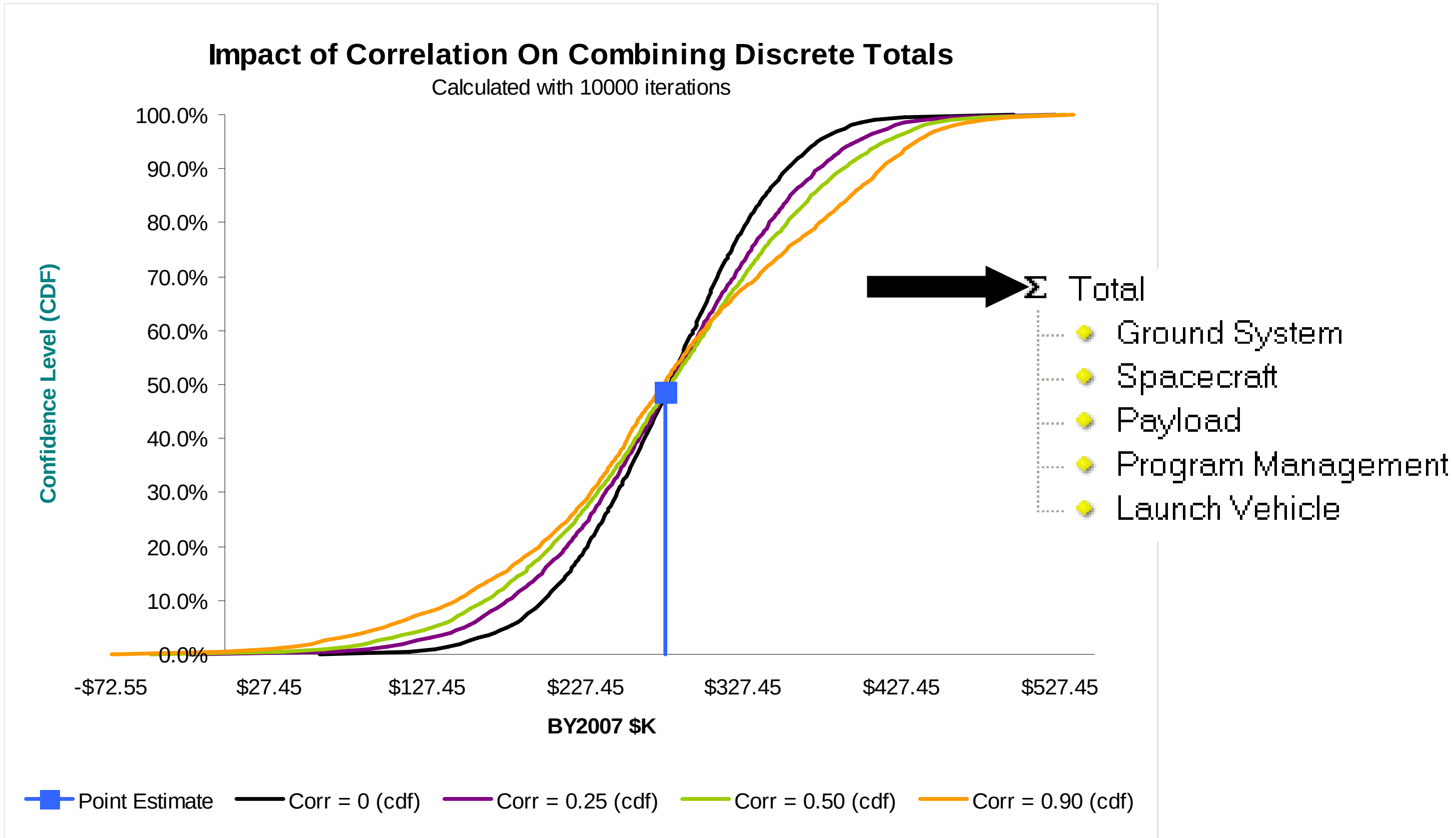
- Each Total is sum of 2 to 14 separate discrete risk events
- Given the "bumpy" nature of the S-Curve, exact rather than best fit methods should be considered when combining and correlating single project element S-curves to a total project level S-curve

Modeling Approach



- Model probability and cost consequence for each risk event, for each project element
- Provide for correlated uncertain probability and cost consequence
- Provide for correlated risk events
- Capture total uncertainty for each group of risk events and apply to separate model where correlation between project elements can be applied
- Given the "bumpy" nature of the project element level S-Curves, exact rather than best fit methods should be considered when combining and correlating to a total project level S-curve

Impact of Correlation on Combining Discrete Totals



- Based on totals from five project elements with no uncertainty or risk event correlation
- Point estimate = sum of the expected values
- 0.25 correlation causes the 70% value to be 4% higher
- 0.50 correlation causes the 70% value to be 9% higher

Impact of Risk Event Correlation on Sum of Discrete Totals

	70%		Delta %
	Event Corr = 0	**Event Corr =0.5**	**Over Corr =0**
Project Elements Corr =0	$312.036	$328.348	5%
Cost Values for Corr = 0.25	$320.211	$342.519	7%
Cost Values for Corr = 0.50	$326.875	$355.752	9%
Cost Values for Corr = 0.90	$334.787	$375.415	12%

- Each of the project element risk events summed with and without 0.5 event correlation
- Chart shows 70% value when project element totals are summed and correlation between them adjusted

Σ Total
- Ground System
- Spacecraft
- Payload
- Program Management
- Launch Vehicle

How to Use Resulting Cost-Risk Distribution

ACE 7.1 - [7 Apr 08 ICE Update_NAFCOM.aceit - RI$K All Columns (BY2007$M)]

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26 | 7 Apr 08 Updated Project Risk Spread (Aero)

	WBS/CES Description	Equation / Throughput	RI$K Specification	Distribution Form	PE Position in Distribution
17	**WBS				
18	Total System				
19	Phase A Costs	[Cost Throughput]			
20	Phase B Costs	[Cost Throughput]			
21	SubTotal - Phase C/D				
22	Government Project Office				
23	PO (FTE+Travel)	8*(FTEs*CivilLR$-(.2*FTEs*CivilLR$)+.01*FTEs)	Form=Triangular, PE=Mode, Low*=90, High*=115,	Triangular	Mode
24	NASA Full Cost (21.78% on Lab$+Trvl$+Proc$)	.2178*(NASAToTCmt+Labor$_Travel$)	Form=Uniform, PE=Undefined, Low*=100, High*=110,	Uniform	Undefined
25	! NASA Procurement Total Committment	[Cost Throughput]			
27	7 Apr 08 Updated Project Risk Spread (Aero)	85.6	Form=CDF, PE=Mean, Ref=AeroCDF,	CDF	Mean
28	S/C Insurance	.1*(.9*T1$+.9*FUPROD)			
29	S/C&CommPyld NRE+FU (aka Non-Full Cost)	MutliYr2(@CERRISK$, Year_0% ,			
30	Follow On Production	MutliYr2(@RecProd$, Year_0% , Year_prior%, Year_2prior%,			
31	15% Fee on Total S/C + Ground	.15*(NonFullCost$+FUPROD+Grnd)			
32	Ground System				
33	Ground System Modifications	[Cost Throughput]	Form=Triangular, PE=Mode, Low*=100, High*=300,	Triangular	Mode
34	Launch Services	[Cost Throughput]	Form=Triangular, PE=Mode, Low*=100, Low%=10,	Triangular	Mode
35	Schedule Incentive	5	Form=Triangular, PE=Mode, Low*=70,	Triangular	Mode

NUM

Summary

- Discrete risks can be modeled with Bernoulli distributions
- Exploiting simulation tools allows analyst to:
  - Apply correlated uncertainty to probability and to cost consequence/opportunity
  - Cause discrete risk events to be correlated
- Combine the project element totals separately in order to assign correlation between them
- In our example:
  - Applying moderate correlated uncertainty increased the 70% value at the project element level by more than 25%
  - At the project level the impact was 5% to 12%