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Cost Risk Analysis Made "Simple"

Alfred Smith, Dr. Shu-Ping Hu

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Outline

- **Setting the Stage: Overview of DoD Risk Guidance**
- **Six Step Cost Risk Analysis Approach**
  - **Focus on cost risk, configuration risk and correlation**
- **Demonstrate that Crystal Ball, @RISK, FRisk and ACE RI$K risk tools <u>give the same results</u> for the same problem (including correlation application).**
- **Concluding Observations**

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Setting the Stage

Cost Risk Analysis Publications

- **Risk Management Policies from DoD 5000.4-M Cost Analysis Guidance and Procedures**
  http://acc.dau.mil/simplify/ev.php?ID=6388_201&ID2=DO_TOPIC
- **Department of the Army Cost Analysis Manual May 2002**
  http://www.ceac.army.mil/ce/default.asp
- **(Air Force) Cost Analysis Guidance And Procedures 1 October 1997**
  http://www.saffm.hq.af.mil/afcaa/
- **NASA Cost Estimating Handbook 2002**
  http://www.jsc.nasa.gov/bu2/NCEH/
  http://www.jsc.nasa.gov/bu2/conferences/NCAS2004/index.htm
- **FAA Life Cycle Cost Estimating Handbook v2 03 Jun 2002**
  http://www.faa.gov/asd/ia-or/lccehb.htm
- **Parametric Estimating Initiative (PEI) Parametric Estimating Handbook Spring 1999**
  http://www.ispa-cost.org/PEIWeb/newbook.htm

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Common Cost Risk Analyst Observations

Analysts want…

- **Clear guidance on how to conduct cost risk analysis**
- **Standard expectations for quality and completeness**
- **Consistent approaches for:**
  - Interpreting the point estimate CER (mean?, median? mode?, other?)
  - Sensitivity analysis vs. stochastic analysis?
  - Selecting a distribution and its bounds? Are there defaults?
  - Defining dispersion and/or correlation
  - Adjusting risk for schedule/technical concerns?
  - Planned growth (i.e., weight, power, operational profile, etc margins).
  - Risk allocation
  - BY vs. TY presentation

Analysts want to improve the quality of their risk adjusted cost estimates in a more productive/repeatable way.

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Six Step Cost Risk Analysis Approach

Definitions and Sources of Cost Risk and Cost Uncertainty

- **Risk stems from a *known* probability distribution**
  - Cost estimating methodology risk
  - Cost factors such as inflation, labor rates, labor rate burdens, etc
  - Configuration risk (variation in the technical inputs)
  - Schedule and technical risk
  - Correlation between risk distributions

- **Uncertainty stems from an *unknown* probability distribution**
  - Potential for massive requirements changes
  - Budget Perturbations, Congressional actions
  - Re-work, and re-test phenomena
  - Contractual arrangements (contract type, prime/sub relationships, etc)
  - Potential for disaster (labor troubles, shuttle loss, satellite “falls over”, war, etc)
  - Probability that if a discrete event occurs it will invoke a project cost
  - **NOT** the subject of this presentation

Cost Risk Analysis Approach

Step 1: Create the Point Estimate

Step 2: Specify Risk

- a.) CERs & Cost Throughputs **(Cost Risk)**
- b.) Technical Inputs **(Configuration Risk)**
- c.) **Schedule/Technical** Considerations
- d.) **Measure** correlation in the model
  Apply additional correlation as required
- e.) **Review** assumptions for consistency

Step 3: Run the Simulation

Step 4: View & Interpret Results

Step 5: Allocate Risk

Step 6: Create BY/TY Charts

Step 1: The Point Estimate

WBS/CES Description	Appro	Unique ID	BASELINE	Phasing	Equation / Throughput	Fiscal Year	Units
Payload (P/L) Non Recu	SFCDC	*Payload	$ 42,071 *				
Payload IA&T	SFCDC		$ 7,641 *				
Integration, Assembly, Te	SFCDC		$ 6,595 *	BE	850.764 + 0.159 * PLPME	1992	$K
Software Integration	SFCDC		$ 1,046 *	BE	.28*PLSW		
Payload PME NR	SFCDC	PLPME	$ 34,430 *				
PL Software	SFCDC	PLSW	$ 3,735 *	BE	SWPPM$*(0.682+0.00006*Loc^1.32)		
Pointing Subsystem	SFCDC		$ 25,480 *				
Scan Mirror	SFCDC		$ 1,249 *	BE	70.215 * ScanMirrorStrWt^0.830	1992	$K
Gimbal	SFCDC		$ 19,041 *				
Gimbal Structure	SFCDC		$ 3,257 *	BE	70.215 * GimbalStrWt^0.830	1992	$K
Motor Drive Electro	SFCDC		$ 892 *	BE	416.033+23.754*MotorDrvPcdWt	1992	$K
LOS Computer	SFCDC		$ 7,785 *	BE	256.878*LosCompDeWt	1992	$K
IMU electronics	SFCDC		$ 7,108 *	BE	256.878*IMUElecDeWt	1992	$K
Payload Reference Be	SFCDC		$ 5,190 *	BE	70.215 * BenchStrWt^0.830	1992	$K
Thermal Control Subsyste	SFCDC		$ 5,215 *				
Active	SFCDC		$ 2,631 *	BE	205.155*TCSActiveThWt^0.635	1992	$K
Passive	SFCDC		$ 2,584 *	BE	205.155*TCPassThWt^0.635	1992	$K
***INPUT VARIABLES**		*IN_VAR					
Monthly Software developmer	SFCDC	SWPPM$	$ 21 *		20	2001	$K
Software for payload SLOC		Loc	80,000 *		80000		
Scann Mirror weight		ScanMirrorStrWt	23 *		23		
Gimbal structure weight		GimbalStrWt	73 *		73		
Gimbl Drive motor weight		MotorDrvPcdWt	11 *		11		
Los Computer weight		LosCompDeWt	23 *		23		
IMU weight		IMUElecDeWt	21 *		21		
Sensor Optical bench weight		BenchStrWt	128 *		128		
Payload active thermal contro		TCSActiveThWt	36 *		36		
Payload passive thermal contr		TCPassThWt	35 *		35		

Elements of a Point Estimate:

- R&D, Procurement, and O&S
- Software, Hardware & Personnel
- Inherent levels of indenture
- Combination of methods:
  - Engineering build-ups
  - Linear/non-linear CERs
  - Pass-throughs, etc.
- CERs derived from historical data
- CERs (Judgmental)
- Inflation, learning, fee/overhead
- Phased & non-phased variables
- BY & TY phased results

Decision Required: Define what should be addressed in a **risk analysis** (vs. sensitivity analysis).

Step 2.a: Cost Estimating Risk: Picking a Distribution Shape and Bounds

Objective Distribution Selection

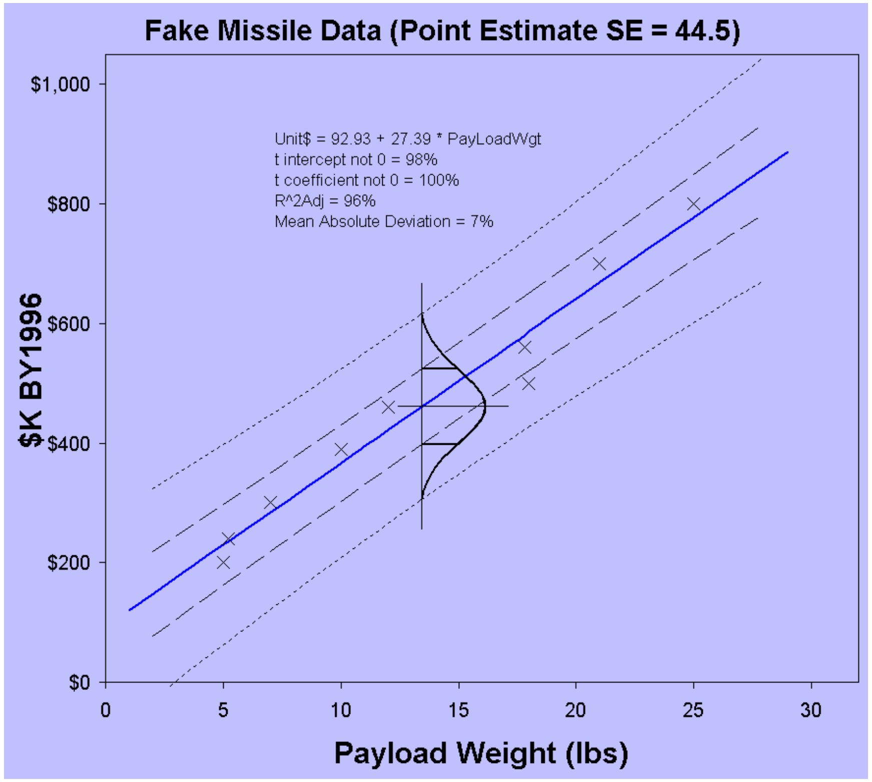
- OLS CERs – produce the “**mean**” (also the mode/median), error is **normally** distributed.
- Log Space OLS CERs - produce the “**median**”, error is **log-normal** in unit space.
- MUPE CERs usually produce the “**mean**”, where error is **normally** distributed.

Subjective Distribution Selection

- Analysts will often declare that risk will be non-symmetrical about the CER result.
- Risk on non-parametric CERs (analogy, build-up, through-puts) are almost always subjective.
- Log-normal, weibull, or beta are popular to avoid a sharp peakness around the mode with at least some probability of a large overrun.

Bounds

- Statistical analysis (objective)
- Expert Opinion (subjective)



Suggestion:
- Publish the objective distribution shape for each regression technique.
- Define how to interpret the CER (mean or median).
- Provide guidance on what to pick if there is a basis to depart from the objective shapes.

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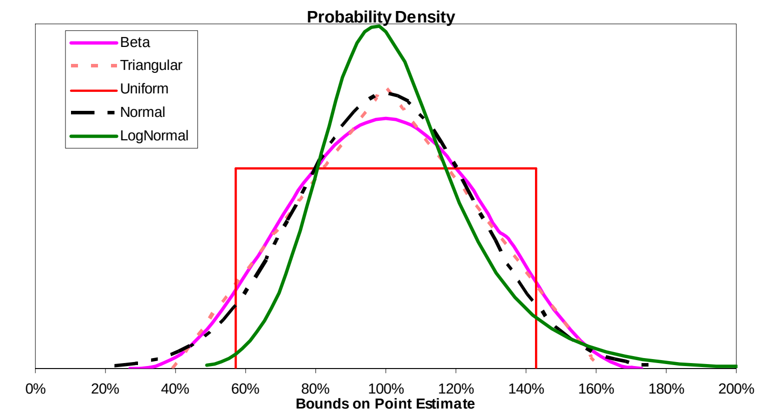
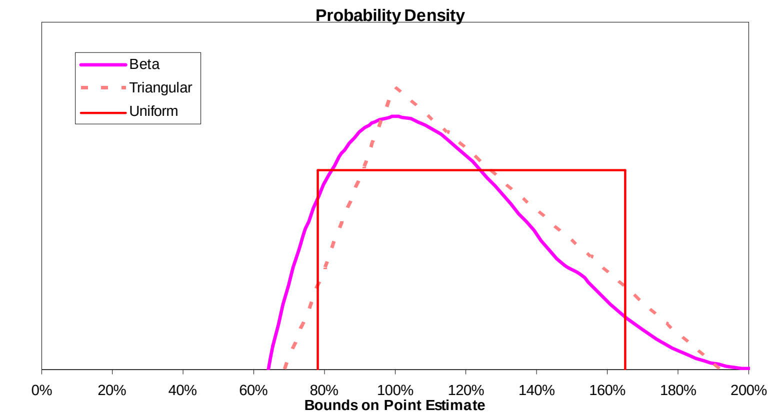
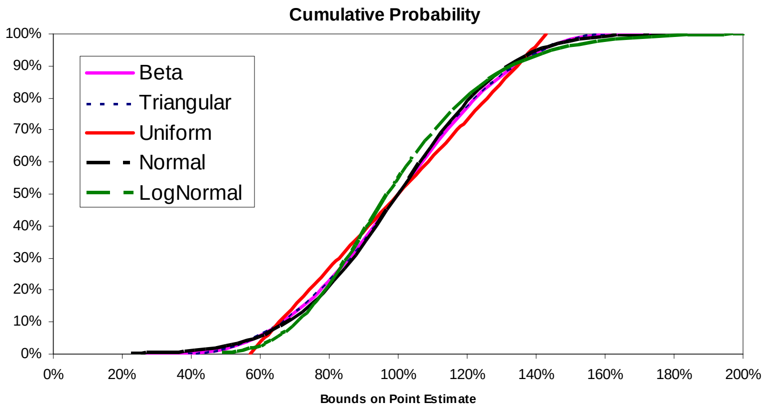
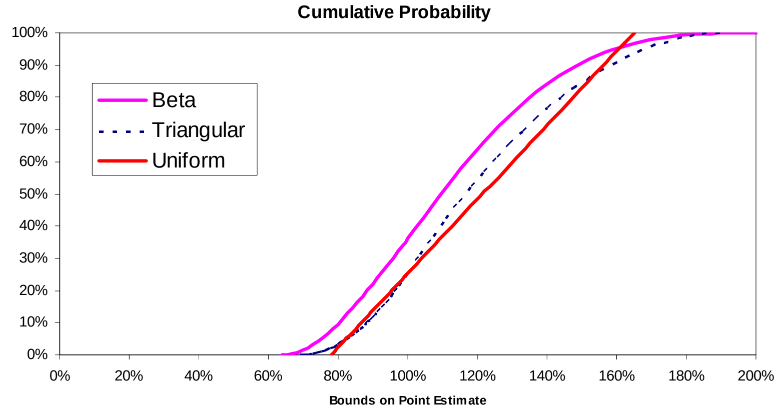
Step 2.a: Define “Standard” Distribution Shapes and Bounds









- **Plots compare different distribution shapes based on similar dispersion**

Suggestion:
- Publish “standard” distribution shapes and bounds.
- Develop tables for different distribution shapes by commodity.

Step 2.b: Configuration Risk

- **Focus is now on the inputs (risk or sensitivity analysis?)**
- **Frequent sources of cost risk: learning slope, lines of code count, weight, composite labor rates, etc. assumptions**
- **Modeling considerations:**
  - Do CER inputs represent design goals or include allowable margin?
  - Do CER inputs represent the mode/mean/median (normal error) or median (log-normal error) or some other percentile value?
  - Are only discrete sets of CER inputs permissible (i.e. is it inappropriate to model them with continuous risk distributions)?
  - Can CER inputs be functionally linked? For instance, can airframe weight be estimated from the engine weight?

Suggestion: Publish “default” input variable interpretation, distribution shapes, and bounds based upon commodity type.

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Step 2.c: Schedule/Technical Considerations

- Difficult to isolate schedule from technical cost impacts. Many approaches assess the impact together.
- Compare the project you are estimating to the CER source data.
- CERs, estimating methods, analogy and expert opinion estimating processes are influenced by past, real projects.
- Estimating methods capture some "nominal" schedule/technical cost impact (contributes to OLS error term?).
- Realistically assess the degree to which the schedule and technical considerations compare to the CER source.
- Subjective assessment.

Decision Required:

Develop a default method for adjusting risk distributions to capture schedule and technical considerations:

- Parametric approach - penalty factor, additional distribution, etc
- Employ schedule and EVM experts to explicitly model the schedule risk.

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Step 2.d: Correlation

- **Modeling considerations often overlooked when trying to assess the correlation *already present* in the cost model**
  - Functional relationships between the input variables.
  - Functional relationships between WBS elements.
  - More than one CER sharing same risk-adjusted input variable. (Most common: learning slope).
  - Same CER used in multiple places in the cost model.
  - Same phased buy quantity applied to multiple cost elements.
- ***Measure* to determine if more correlation is required.**

Measure Correlation Present in The Cost Model

	WBS/CES	Row 14: Integr ation,	Row 15: Softw are	Row 17: PL Softw	Row 19: Scan Mirror	Row 21: Gimba l	Row 22: Motor Drive	Row 23: LOS Compu	Row 24: IMU electr	Row 25: Payloa d	Row 27: Active	Row 28: Passiv e
14	Integration, Assembly, Test an	1.00	0.07	0.08	0.05	0.11	0.04	0.24	0.23	0.16	0.03	0.08
15	Software Integration		1.00	0.90	0.02	0.04	-0.07	-0.01	0.00	0.00	-0.03	0.01
17	PL Software			1.00	0.01	0.01	-0.03	0.00	-0.01	-0.00	-0.03	0.00
19	Scan Mirror				1.00	-0.02	0.01	0.05	0.03	0.03	0.02	-0.03
21	Gimbal Structure					1.00	0.01	0.01	-0.01	0.03	0.04	-0.03
22	Motor Drive Electronics							-0.02	0.10	-0.01	0.03	-0.06
23	LOS Computer							1.00	0.02	0.04	-0.08	0.02
24	IMU electronics								1.00	-0.00	-0.03	-0.05
25	Payload Reference Ben									1.00	0.00	-0.04
27	Active										1.00	-0.00
28	Passive											1.00

Point Estimate	Mean	Std Dev	CoV
$ 42,071 (29%)	$ 48,673	$ 10,826	0.22

Measured Pearson product moment correlation

	WBS/CES	Row 14: Integr ation,	Row 15: Softw are	Row 17: PL Softw	Row 19: Scan Mirror	Row 21: Gimba l	Row 22: Motor Drive	Row 23: LOS Comp	Row 24: IMU electr	Row 25: Paylo ad	Row 27: Active	Row 28: Passiv e
14	Integration, Assembly, Test and	1.00	0.38	0.31	0.32	0.35	0.32	0.47	0.45	0.38	0.35	0.35
15	Software Integration		1.00	0.91	0.23	0.24	0.23	0.26	0.24	0.24	0.26	0.25
17	PL Software			1.00	0.18	0.20	0.18	0.20	0.19	0.19	0.20	0.20
19	Scan Mirror				1.00	0.20	0.21	0.23	0.22	0.20	0.22	0.20
21	Gimbal Structure					1.00	0.20	0.23	0.22	0.21	0.22	0.20
22	Motor Drive Electronics						1.00	0.23	0.21	0.22	0.22	0.21
23	LOS Computer							1.00	0.22	0.23	0.22	0.22
24	IMU electronics								1.00	0.23	0.23	0.22
25	Payload Reference Bench									1.00	0.22	0.23
27	Active										1.00	0.23
28	Passive											1.00

Point Estimate	Mean	Std Dev	CoV
$ 42,071 (36%)	$ 48,955	$ 15,793	0.32

Correlation after layering an additional 20% across all elements

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Unintentional Correlation?

	WBS/CES Description	BASELINE	Unique ID	Equation / Throughput	Curve Slope	Distribution Form	Low or Low %	High or High %	Spread	Skew
44	Procurement	$ 56,633 (26%) *	Proc$							
45	Manufacturing	$ 41,543 (30%) *	Manuf$							
46	Non Recurring	$ 506 (23%) *		500		Uniform	80%	200%		
47	Recurring	$ 41,037 (30%) *								
48	Missile	$ 23,607 (37%) *		64.59 * Wgt ^ 0.7649	AntSlp	LogNormal	87.29%	114.56%		
49	Antenna	$ 15,156 (29%) *	Ant$	0.3808 * Aper ^ 1.244	AntSlp	LogNormal	85.5%	116.9%		
50	Integration	$ 2,273 (26%) *		0.15*Ant$		Beta			Medium	Right
51	SE/PM	$ 10,024 (37%) *		0.2413 * Manuf$		Normal	54.2%	145.8%		
52	Other	$ 5,065 (10%) *		5000		Triangular	100%	200%		
57										
59	Antenna Lrning Slope	90.0 (37%) *	AntSlp	90		Uniform	85	100		

Same risk adjusted slope variable for missile/antenna.

	WBS/CES	Row 37: Total	Row 44: Procu	Row 45: Manu	Row 47: Recu	Row 48: Missile	Row 49: Anten	Row 50: Integr	Row 51: SE/PM	80.0% Level
37	Total	1.00	0.90	0.90	0.90	0.68	0.88	0.79	0.68	$ 177,979.07
44	Procurement		1.00	0.97	0.97	0.83	0.88	0.79	0.80	$ 91,714.58
45	Manufacturing			1.00	1.00	0.85	0.91	0.81	0.66	$ 67,666.46
47	Recurring				1.00	0.85	0.91	0.81	0.66	$ 66,884.04
48	Missile					1.00	0.56	0.48	0.56	$ 35,638.72
49	Antenna						1.00	0.87	0.60	$ 28,166.22
50	Integration							1.00	0.54	$ 4,798.61
51	SE/PM								1.00	$ 17,645.23

- **Much worry over possible *underestimated* correlation**
- **No apparent concern over possible *excessive* correlation**

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Removing Unintentional Correlation

	WBS/CES Description	BASELINE	Unique ID	Equation / Throughput	Curve Slope	Distribution Form	Low or Low %	High or High %	Spread	Skew
44	Procurement	$ 56,633 (18%) *	Proc$							
45	Manufacturing	$ 41,543 (21%) *	Manuf$							
46	Non Recurring	$ 506 (23%) *		500		Uniform	80%	200%		
47	Recurring	$ 41,037 (22%) *								
48	Missile	$ 23,607 (37%) *		64.59 * Wgt ^ 0.7649	MissSlp	LogNormal	87.29%	114.56%		
49	Antenna	$ 15,156 (29%) *	Ant$	0.3808 * Aper ^ 1.244	AntSlp	LogNormal	85.5%	116.9%		
50	Integration	$ 2,273 (26%) *		0.15*Ant$		Beta			Medium	Right
51	SE/PM	$ 10,024 (34%) *		0.2413 * Manuf$		Normal	54.2%	145.8%		
52	Other	$ 5,065 (10%) *		5000		Triangular	100%	200%		
57										
59	Antenna Lrning Slope	90.0 (37%) *	AntSlp	90		Uniform	85	100		
60	Missile Lrning Slope	90.0 (37%) *	MissSlp	90		Uniform	85	100		

Need separate slope variable for the missile.

	WBS/CES	Row 37: Total	Row 44: Procu	Row 45: Manuf	Row 47: Recur	Row 48: Missile	Row 49: Anten	Row 50: Integr	Row 51: SE/PM	80.0% Level
37	Total	1.00	0.86	0.85	0.85	0.33	0.82	0.73	0.61	$ 173,903.81
44	Procurement		1.00	0.96	0.96	0.59	0.75	0.68	0.77	$ 87,848.49
45	Manufacturing			1.00	1.00	0.62	0.78	0.71	0.58	$ 64,449.32
47	Recurring				1.00	0.62	0.78	0.71	0.58	$ 63,686.82
48	Missile					1.00	0.00	-0.01	0.36	$ 35,457.46
49	Antenna						1.00	0.87	0.46	$ 28,166.22
50	Integration							1.00	0.42	$ 4,798.61
51	SE/PM								1.00	$ 17,298.13

- Missile/ Antenna correlation now 0.
- Rec cost is now 5% less.

Decisions Required:

Define Correlation Strength

- Strong (.9?)
- Moderate (.6?)
- Weak (.2?)

When to apply?

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Step 2.e Review for Consistency

WBS/CES Description	Unique ID	BASELINE	Equation / Throughput	Distributi on Form	Spread	LogNor mal	Low or Low %	High or High %	Grouping	Group Strength
Payload (P/L) Non Recurring	*Payload	$ 42,071 (36%) *								
Payload IA&T		$ 7,641 (43%) *								
Integration, Assembly, Test ar		$ 6,595 (44%) *	850.764 + 0.159 * PLPME	Normal			35.3%	164.7%	CER	.4472
Software Integration		$ 1,046 (40%) *	.28*PLSW	Normal	Low				CER	.4472
Payload PME NR	PLPME	$ 34,430 (35%) *								
PL Software	PLSW	$ 3,735 (38%) *	SWPPM$*(0.682+0.00006*Loc^1.32)	LogNormal		.25			CER	.4472
Pointing Subsystem		$ 25,480 (36%) *								
Scan Mirror		$ 1,249 (45%) *	70.215 * ScanMirrorStrWt^0.830	Normal			37.4%	162.6%	CER	.4472
Gimbal		$ 19,041 (36%) *								
Gimbal Structure		$ 3,257 (45%) *	70.215 * GimbalStrWt^0.830	Normal			39%	161%	CER	.4472
Motor Drive Electronics		$ 892 (46%) *	416.033+23.754*MotorDrvPcdWt	Normal			25.1%	174.9%	CER	.4472
LOS Computer		$ 7,785 (42%) *	256.878*LosCompDeWt	Normal			5.7%	194.3%	CER	.4472
IMU electronics		$ 7,108 (42%) *	256.878*IMUElecDeWt	Normal			5%	195%	CER	.4472
Payload Reference Bench		$ 5,190 (45%) *	70.215 * BenchStrWt^0.830	Normal			40.6%	159.4%	CER	.4472
Thermal Control Subsystem (T		$ 5,215 (44%) *								
Active		$ 2,631 (45%) *	205.155*TCSActiveThWt^0.635	Normal			35.8%	164.2%	CER	.4472
Passive		$ 2,584 (45%) *	205.155*TCPassThWt^0.635	Normal			35.7%	164.3%	CER	.4472
***INPUT VARIABLES**	*IN_VAR									
Monthly Software development cos	SWPPM$	$ 21 *	20							
Software for payload SLOC	Loc	80,000 (32%) *	80000	Triangular			90%	130%	Inputs	0.4472
Scann Mirror weight	ScanMirrorStrWt	23 (32%) *	23	Triangular			90%	130%	Inputs	0.4472
Gimbal structure weight	GimbalStrWt	73 (32%) *	73	Triangular			90%	130%	Inputs	0.4472
Gimbl Drive motor weight	MotorDrvPcdWt	11 (32%) *	11	Triangular			90%	130%	Inputs	0.4472
Los Computer weight	LosCompDeWt	23 (32%) *	23	Triangular			90%	130%	Inputs	0.4472
IMU weight	IMUElecDeWt	21 (32%) *	21	Triangular			90%	130%	Inputs	0.4472
Sensor Optical bench weight	BenchStrWt	128 (32%) *	128	Triangular			90%	130%	Inputs	0.4472
Payload active thermal control wgt	TCSActiveThWt									
Payload passive thermal control we	TCPassThWt									

Bounds expressed as % of point estimate are:

- Easier to understand
- Scale with changes to the point estimate
- Provides a consistent basis for comparison

Step 3: Run the Simulation

- **Simulation tool results are influenced by:**
  - Interpretation of point estimate
  - Truncation assumption
  - Number of iterations
  - If using Latin Hypercube [LHC], the number of partitions
  - Random seed

- **When the above assumptions are consistent (as far as possible), ACE, Crystal Ball, @Risk and FRisk all produce similar results.**

Decision Required:
- Identify acceptable risk simulation tools
- Provide guidance on how they should be applied

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Step 4: View and Interpret Results

WBS/CES	Point Estimate	Mean	Std Dev	CoV	5.0% Level	10.0% Level	50.0% Level	90.0% Level	95.0% Level
Payload (P/L) Non Recurring	$ 42,071 (35%)	$ 49,068	$ 17,493	0.36	$ 22,111	$ 26,437	$ 47,830	$ 70,960	$ 78,692
Payload IA&T	$ 7,641 (43%)	$ 9,350	$ 5,372	0.57	$ 2,241	$ 3,250	$ 8,534	$ 16,434	$ 18,946
Integration, Assembly, Test an	$ 6,595 (44%)	$ 8,126	$ 5,113	0.63	$ 1,325	$ 2,316	$ 7,339	$ 15,016	$ 17,155
Software Integration	$ 1,046 (41%)	$ 1,224	$ 478	0.39	$ 601	$ 708	$ 1,143	$ 1,841	$ 2,095
Payload PME NR	$ 34,430 (35%)	$ 39,718	$ 12,975	0.33	$ 18,868	$ 22,420	$ 39,297	$ 56,580	$ 61,649
PL Software	$ 3,735 (38%)	$ 4,317	$ 1,371	0.32	$ 2,457	$ 2,726	$ 4,161	$ 6,061	$ 6,935
Pointing Subsystem	$ 25,480 (37%)	$ 29,764	$ 11,158	0.37	$ 12,340	$ 15,083	$ 29,528	$ 44,450	$ 49,257

- **Risk analysis will give context to the point estimate**
- **CoV (Stdev/Mean), confidence of the point estimate (PEcl) and quartile range are useful measures of the overall risk in the cost model.**
- **Observations in DoD Estimates:**
  - Estimates rich in parametric CERs: 15%<CoV<45%, and 5%<PEcl<30%
  - Estimates rich in build-up methods: 5%<CoV<15%, and 30%<PEcl<45%

Suggestion: Identify reasonable, commodity-based metrics the analyst can use to assess the completeness and possibly the quality of the risk analysis as it is being developed. **NASA has done so with the CRL concept.**

Step 5: Allocate Risk

- **Confidence level results *do not add***
  - Mathematicians are quite happy with this result, budget folks are not.
- **Results must:**
  - Be phased in both BY (constant year) and TY$ (real dollars?)
  - Add up
- **Significant issues must be resolved to define a phased, risk allocation method with consistent BY and TY results (where TY inflation rates are developed from assumed spend profiles)**
- **Phasing assumptions will have *<u>significant impact</u>* on TY results.**

Decision Required:

- Choose the “standard” risk allocation approach, including how the cost risk dollars should be phased.
- Cost models should be flexible enough to phase the risk dollars consistent with the program managers risk mitigation plans.

Allocated Risk Report

ACE 6.1 - [NASA USCM7 Simple Example Jul04.acw - BY Phased Costs (FY2003 $K, Time Ph...

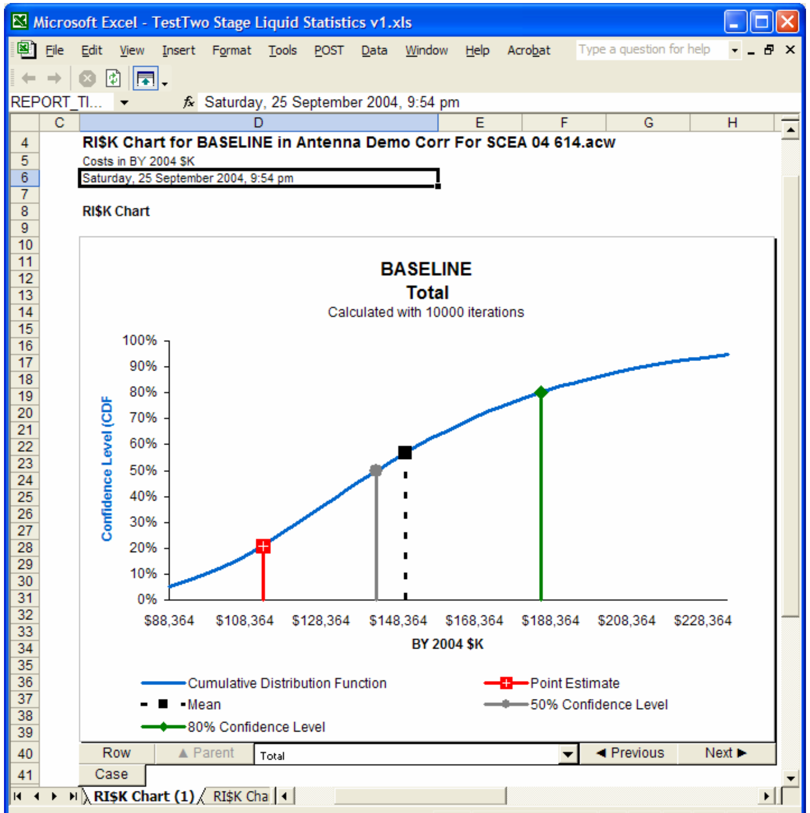
File Edit Workscreen Calc Tools Window Help

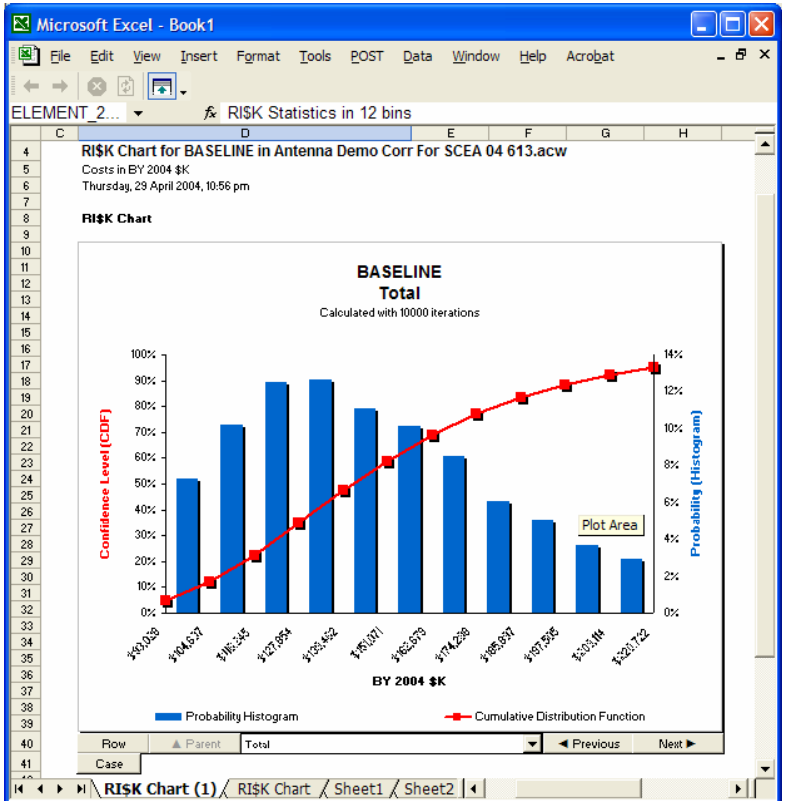
	Cost Element	Approp	Total	FY 2005	FY 2006	FY 2007	FY 2008
2	* Base Year of Calculation		2003				
3	* Time of Calculation		09:26:17				
4	* Date of Calculation		20Jul2004				
5	* System Inflation Table for Calcula		04, 29/APR/2004				
6	* Risk Iterations		10000				
7	* Risk Calculation Confidence Leve		70				
8	* Risk Allocation		2 WBS Elements>				
9	* Time ACE Session Last Saved		23:51:26				
10	* Date ACE Session Last Saved		19Jul2004				
11							
12	Payload (P/L) Non Recurring	SFCDC	$ 56,873 (~71%)	$ 37,152	$ 10,449	$ 8,849	$ 422
13	Payload IA&T	SFCDC	$ 11,175 (70%)		$ 4,537	$ 6,331	$ 307
14	Integration, Assembly, Test ar	SFCDC	$ 9,795 (70%)		$ 3,977	$ 5,543	$ 269
15	Software Integration	SFCDC	$ 1,381 (69%)		$ 561	$ 782	$ 38
16	Payload PME NR	SFCDC	$ 45,697 (70%)	$ 37,152	$ 5,912	$ 2,518	$ 115
17	PL Software	SFCDC	$ 4,755 (68%)	$ 2,495	$ 2,260		
18	Pointing Subsystem	SFCDC	$ 34,372 (68%)	$ 34,372			
19	Scan Mirror	SFCDC	$ 1,612 (66%)	$ 1,612			
20	Gimbal	SFCDC	$ 26,161 (66%)	$ 26,161			
21	Gimbal Structure	SFCDC	$ 4,040 (63%)	$ 4,040			
22	Motor Drive Electronics	SFCDC	$ 1,125 (63%)	$ 1,125			
23	LOS Computer	SFCDC	$ 10,963 (63%)	$ 10,963			
24	IMU electronics	SFCDC	$ 10,033 (64%)	$ 10,033			
25	Payload Reference Bench	SFCDC	$ 6,599 (66%)	$ 6,599			
26	Thermal Control Subsystem (T	SFCDC	$ 6,570 (68%)	$ 285	$ 3,652	$ 2,518	$ 115
27	Active	SFCDC	$ 3,325 (65%)	$ 144	$ 1,848	$ 1,274	$ 58
28	Passive	SFCDC	$ 3,245 (65%)	$ 141	$ 1,804	$ 1,244	$ 57

Ready NUM

- **In this example, risk funds managed from the 2nd level (70%)**
- **Total project dollars required are greater than 70% CL overall**
- **All numbers "add"**

Step 6: Charts and Tables





Decision Required:

- Identify the standard charts and their contents to be presented to management.
- Ensure consistent x and y-axis arrangements.
- Determine “if” a TY S-curve should be presented and if so, define the process to be used.

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Since 1973

Compare Cost Risk Tools

Compare Cost Risk Tool Results

- **What are the risk tools and which should I choose?**
- **ACE RI$K, Crystal Ball, @Risk and FRisk *results* are compared…. Not their usability or suitability.**
- **One case study examined (SCEA paper has three):**
  - Published, simple and analytically solved case studies (SCEA paper June 04, Reference 5).
  - Example is based upon a more "realistic" cost model (Reference 7).
- **If handled properly, *all tools produce similar total cost distribution results*.**

A "Realistic" Model

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	B	C	D	E	H	I	K	M	N	O	P	Q	R	S	T	U
4									1000 Iterations, Latin Hyper-Cube Comparison							
5									Standard Deviation			Mean			95th Perce	
6	VBS/CES Description	Unique ID	Eqn	FY	Low	High	Risk	Simulation	CB	ACE	ACE:CB	CB	ACE	ACE:CB	CB	ACE
7	Space System NR							$480,484.07	$187,627	$188,446	0.44%	$533,747	$533,537	-0.04%	$878,571	$875,281
8	Program Management/Systems Engine	PMSE	1.487*(PLNR+SCNR)^0.841	1992	46.80%	153.20%	1	$78,844.45	$50,241	$50,417	0.35%	$89,408	$89,430	0.03%	$184,204	$184,262
9	Payload (P/L) Non Recurring	PLNR						$125,388.99	$57,295	$55,684	-2.81%	$142,375	$142,118	-0.18%	$244,566	$242,655
10	Payload IA&T							$18,766.74	$14,536	$14,180	-2.45%	$22,752	$22,658	-0.41%	$50,100	$49,210
11	Integration, Assembly, Test and Checkout (IA		850.764 + 0.159 * PLPME	1992	35.30%	164.70%	1	$17,959.81		$14,060			$21,526			$47,863
12	Software Integration		.28*PLSW	2001	80%	120%	1	$806.93		$399			$1,132			$1,882
13	Payload PME NR	PLPME						$106,622.25	$45,801	$44,542	-2.75%	$119,623	$119,461	-0.14%	$202,048	$200,056
14	Optical Telescope Assembly (OTA)							$9,517.65	$3,945	$3,975	0.75%	$9,896	$9,882	-0.14%	$16,816	$16,872
15	Structure		70.215 * OTASTRWT^0.830	1992	41.90%	158.10%	1	$6,215.42		$2,985			$6,295			$11,655
16	Electrical		256.664*OTAELECTR^0.761	1992	14.60%	185.40%	1	$3,302.23		$2,039			$3,588			$7,279
17	Pointing Subsystem							$22,887.14	$8,846	$9,063	2.45%	$24,794	$24,793	-0.01%	$40,592	$40,863
18	Scan Mirror		70.215 * SCANMIRRORSTRWT^0.830	1992	37.40%	162.60%	1	$1,121.58	$566	$565	-0.25%	$1,144	$1,145	0.08%	$2,162	$2,154
19	Gimbal							$17,103.46	$7,732	$7,888	2.02%	$18,915	$18,919	0.02%	$32,702	$32,882
20	Gimbal Structure		70.215 * GIMBALSTRWT^0.830	1992	39%	161%	1	$2,925.20		$1,461			$2,982			$5,627
21	Motor Drive Electronics		416.033+23.754*MOTORDRVPCDWT	1992	25.10%	174.90%	1	$801.62		$432			$846			$1,600
22	LOS Computer		256.878*LOSCOMPTUDEWT	1992	5.70%	194.30%	1	$6,992.34		$4,835			$7,872			$16,812
23	IMU electronics		256.878*IMUPMATUDEWT	1992	5%	195%	1	$6,384.31		$4,447			$7,220			$15,465

Compare / USCM 7 CB / @RISK Correlations / USCM 7 @Risk / REPORT (4)

Microsoft Excel - 4 USCM7 CER Risk, CER Corr, Config Risk, Config Corr CrystalBall AtRisk Apr04.xls

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Type a question for help

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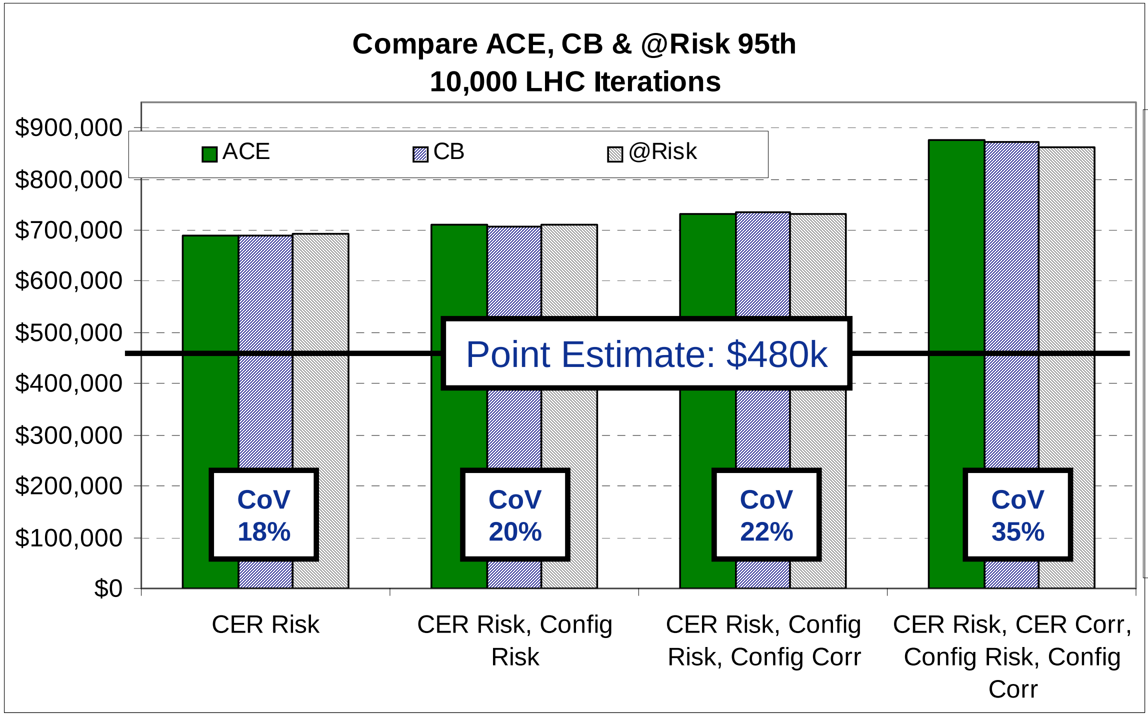
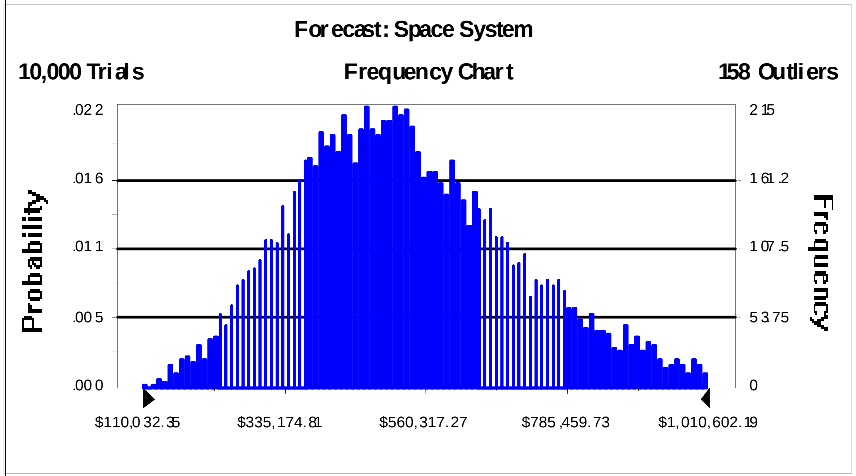
	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB
3			aPMSE	aIATC	aSoftInt	aOTStru	aOTElec	aScanM	aGimStru	aGimMDE	aGimLOSC	aGimIMU	aPayloadRel	aFPADel	aFPAAna	aSPAStru	aSPADigSig	aSPAPS	aPLSoft	aTCSAct	aTCSPass	aIATCSpace	aIATCSoft	aSpaceStrMec	aSpaceTCSAct	aSpaceTCSPass	aSpaceEPSPG	aSpaceEPSPS	aSpaceEPSPC	aSpaceEPSPC	aSpaceADCSAll
4	1	aPMSE	1.000	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.20
5	2	aIATC		1.000	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.20
6	3	aSoftInt			1.000	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.20
7	4	aOTStru				1.000	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.20
8	5	aOTElec					1.000	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.20
9	6	aScanM						1.000	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.20
10	7	aGimStru							1.000	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.20
11	8	aGimMDE								1.000	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.20
12	9	aGimLOSC									1.000	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.20
13	10	aGimIMU										1.000	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.20

Compare / USCM 7 CB / @RISK Correlations / USCM 7 @Risk / REPORT (4)

USCM 7 Comparison

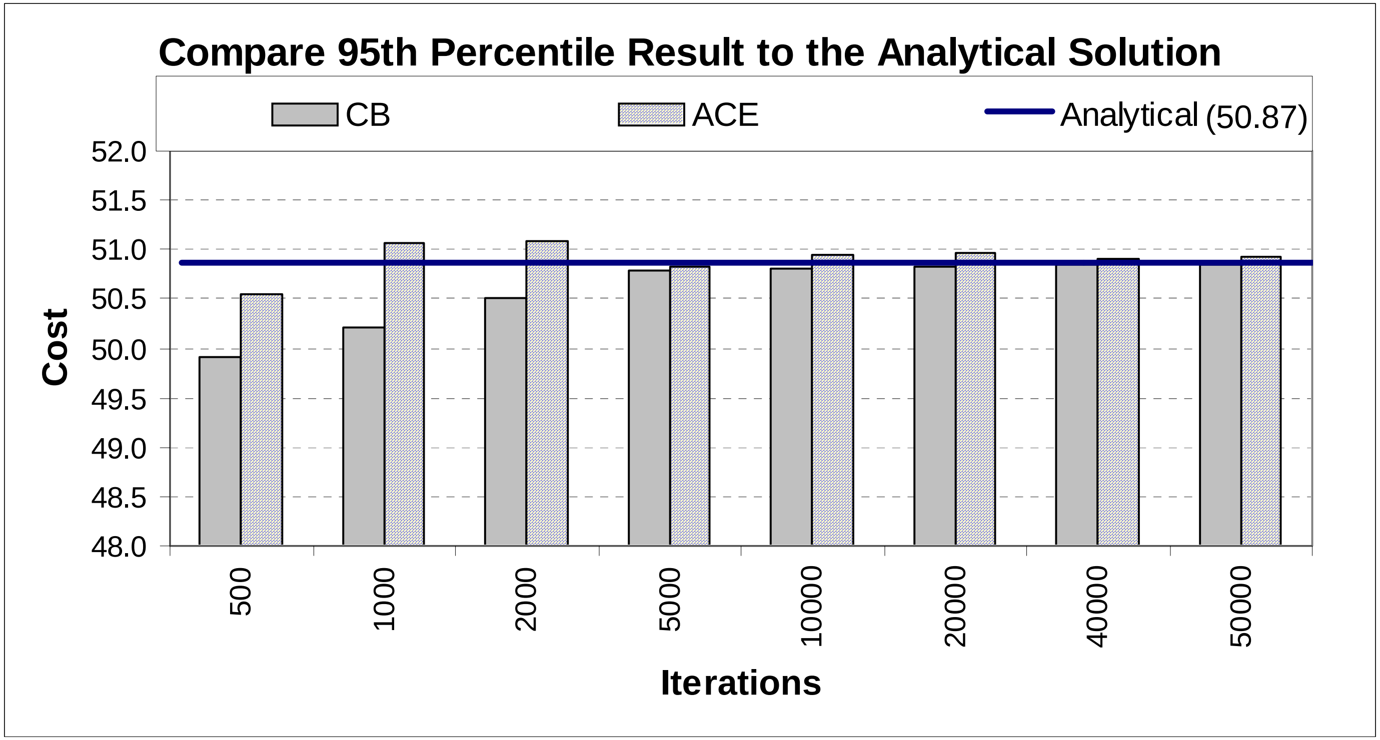




- More than 30 linear, non-linear, throughput CERs and 30 input values
- Compared total cost result at the 95th percentile based upon a systematic layering of correlation assumptions
- All three tools produce remarkably similar results.

How Many Iterations Required?

- Use Latin Hypercube and maximize the number of partitions. (Crystal Ball default is 500 and max is 5000, ACE and @Risk use the same number of partitions as iterations).
- DO NOT conclude from the chart that ACE stabilizes with fewer iterations than Crystal Ball. Simply changing seed values (or LHC partition in Crystal Ball) can cause the results to “flip/flop”.
- Both tools stabilize near 5000 iterations for this model.



Comparing Risk Tools

- **If you are consistent with:**
  - How to interpret the point estimate
  - Number of iterations.
  - If using Latin Hypercube [LHC], the number of partitions.
  - Inflation, learning, and other modeled adjustments.
  - How functional correlations are modeled
  - Distribution shape and bound assumptions.
  - Truncation assumptions.
- **If you follow the tool developer's recommendation for inputting correlation:**

ACE, Crystal Ball and @Risk will give similar results.

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Benefits of Clear Guidance

- **Default positions would establish a minimum expectation for estimates – not a cookbook**
- **No need to "over specify" the guidance**
- **Advanced analysts will still develop sophisticated models to deal with exceptional circumstances**
- **Establishing a "standard process" will:**
  - Focus attention on "building" the estimate rather than defining "how" to build it.
  - Enable more risk analysis practitioners to "do" cost risk analysis ***with confidence***.

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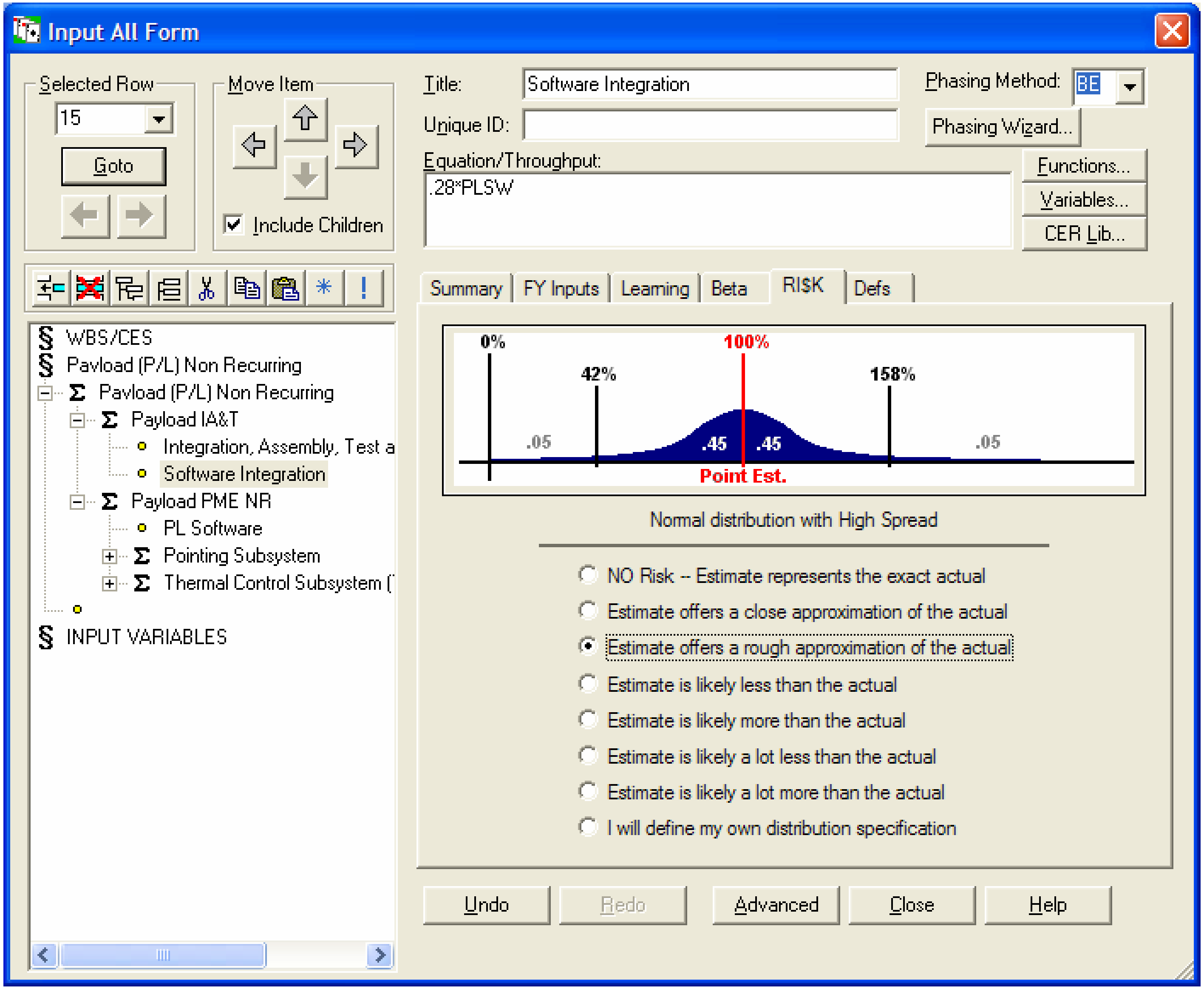
BACKUP SLIDES

Step 2.a: Use Basic or Advanced ACE Wizards to set Shapes and Bounds



Step 2a: ACE Spreadsheet Interface Also Available

WBS/CES Description	Unique ID	BASELINE	Equation / Throughput	Distribution Form	Spread	LogNormal	Low or Low %	High or High %
Payload (P/L) Non Recurring	*Payload	$ 42,071 (36%) *						
Payload IA&T		$ 7,641 (43%) *						
Integration, Assembly, Test ar		$ 6,595 (44%) *	850.764 + 0.159 * PLPME	Normal			35.3%	164.7%
Software Integration		$ 1,046 (40%) *	.28*PLSW	Normal	Low			
Payload PME NR	PLPME	$ 34,430 (35%) *						
PL Software	PLSW	$ 3,735 (38%) *	SWPPM$*(0.682+0.00006*Loc^1.32)	LogNormal		.25		
Pointing Subsystem		$ 25,480 (36%) *						
Scan Mirror		$ 1,249 (45%) *	70.215 * ScanMirrorStrWt^0.830				4%	162.6%
Gimbal		$ 19,041 (36%) *						
Gimbal Structure		$ 3,257 (45%) *	70.215 * GimbalStrWt^0.830				3%	161%
Motor Drive Electronics		$ 892 (46%) *	416.033+23.754*MotorDrvPcdWt				1%	174.9%
LOS Computer		$ 7,785 (42%) *	256.878*LosCompDeWt				.7%	194.3%
IMU electronics		$ 7,108 (42%) *	256.878*IMUElecDeWt	Normal			5%	195%
Payload Reference Bench		$ 5,190 (45%) *	70.215 * BenchStrWt^0.830	Normal			40.6%	159.4%
Thermal Control Subsystem (T		$ 5,215 (44%) *						
Active		$ 2,631 (45%) *	205.155*TCSActiveThWt^0.635	Normal			35.8%	164.2%
Passive		$ 2,584 (45%) *	205.155*TCPassThWt^0.635	Normal			35.7%	164.3%

Low
Medium
High

Beta - Beta
LogNormal - Log Normal
None - None
Normal - Normal
Triangular - Triangular
Uniform - Uniform
Weibull - Weibull

- **Point estimate reflects "median" for lognormal, "mode" for all others.**
- **Right click to choose distribution and "default" spread/skew**
- **Define upper/lower bounds in terms of % of point estimate at specific confidence levels (may enter absolute values if desired)**
- **Bracketed numbers in Baseline column reports point estimate confidence level**

ACE Correlation Wizard

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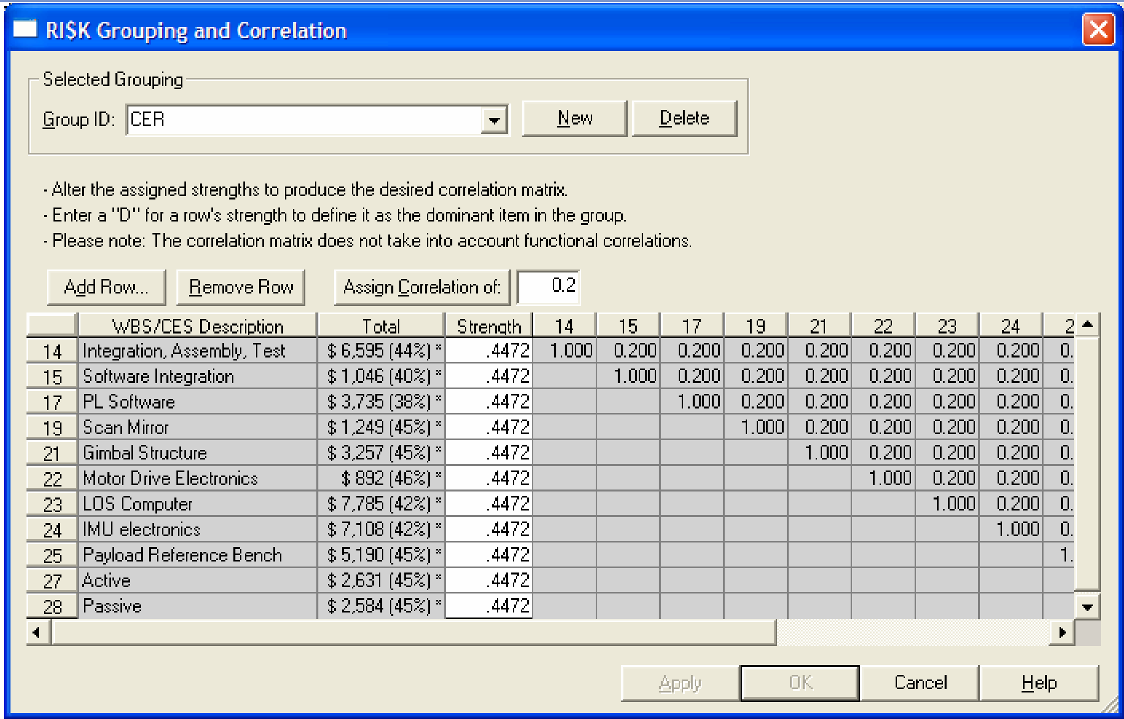
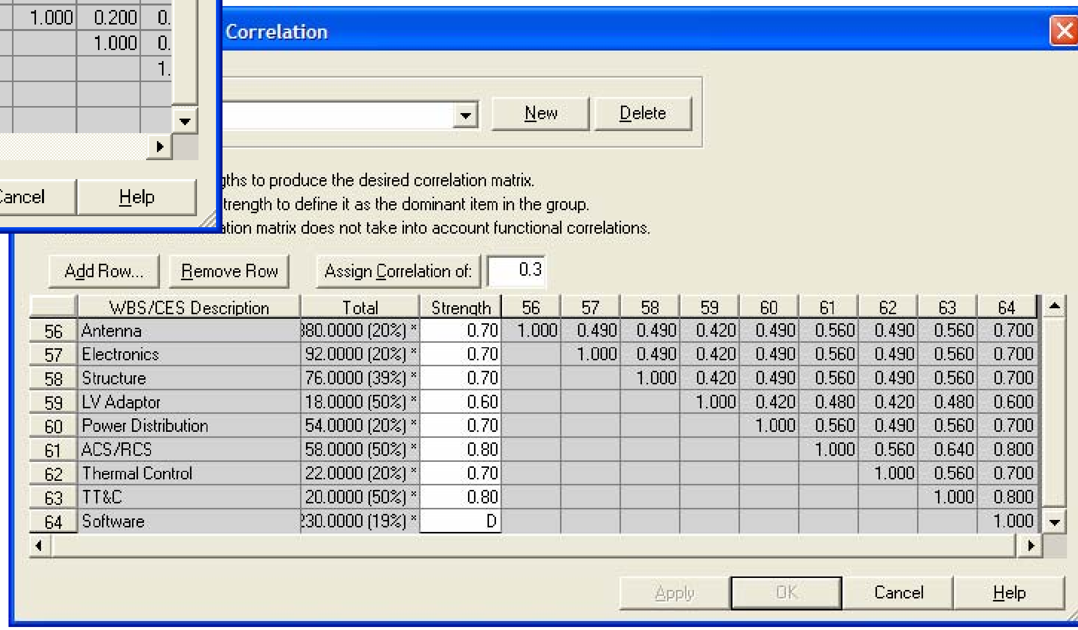


	WBS/CES Description	Total	Strength	14	15	17	19	21	22	23	24	2
14	Integration, Assembly, Test	$ 6,595 (44%) *	.4472	1.000	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.
15	Software Integration	$ 1,046 (40%) *	.4472		1.000	0.200	0.200	0.200	0.200	0.200	0.200	0.
17	PL Software	$ 3,735 (38%) *	.4472			1.000	0.200	0.200	0.200	0.200	0.200	0.
19	Scan Mirror	$ 1,249 (45%) *	.4472				1.000	0.200	0.200	0.200	0.200	0.
21	Gimbal Structure	$ 3,257 (45%) *	.4472					1.000	0.200	0.200	0.200	0.
22	Motor Drive Electronics	$ 892 (46%) *	.4472						1.000	0.200	0.200	0.
23	LOS Computer	$ 7,785 (42%) *	.4472							1.000	0.200	0.
24	IMU electronics	$ 7,108 (42%) *	.4472								1.000	0.
25	Payload Reference Bench	$ 5,190 (45%) *	.4472									1.
27	Active	$ 2,631 (45%) *	.4472									
28	Passive	$ 2,584 (45%) *	.4472									

Ability to force the same correlation across all selected WBS elements



	WBS/CES Description	Total	Strength	56	57	58	59	60	61	62	63	64
56	Antenna	380.0000 (20%) *	0.70	1.000	0.490	0.490	0.420	0.490	0.560	0.490	0.560	0.700
57	Electronics	92.0000 (20%) *	0.70		1.000	0.490	0.420	0.490	0.560	0.490	0.560	0.700
58	Structure	76.0000 (39%) *	0.70			1.000	0.420	0.490	0.560	0.490	0.560	0.700
59	LV Adaptor	18.0000 (50%) *	0.60				1.000	0.420	0.480	0.420	0.480	0.600
60	Power Distribution	54.0000 (20%) *	0.70					1.000	0.560	0.490	0.560	0.700
61	ACS/RCS	58.0000 (50%) *	0.80						1.000	0.560	0.640	0.800
62	Thermal Control	22.0000 (20%) *	0.70							1.000	0.560	0.700
63	TT&C	20.0000 (50%) *	0.80								1.000	0.800
64	Software	230.0000 (19%) *	D									1.000

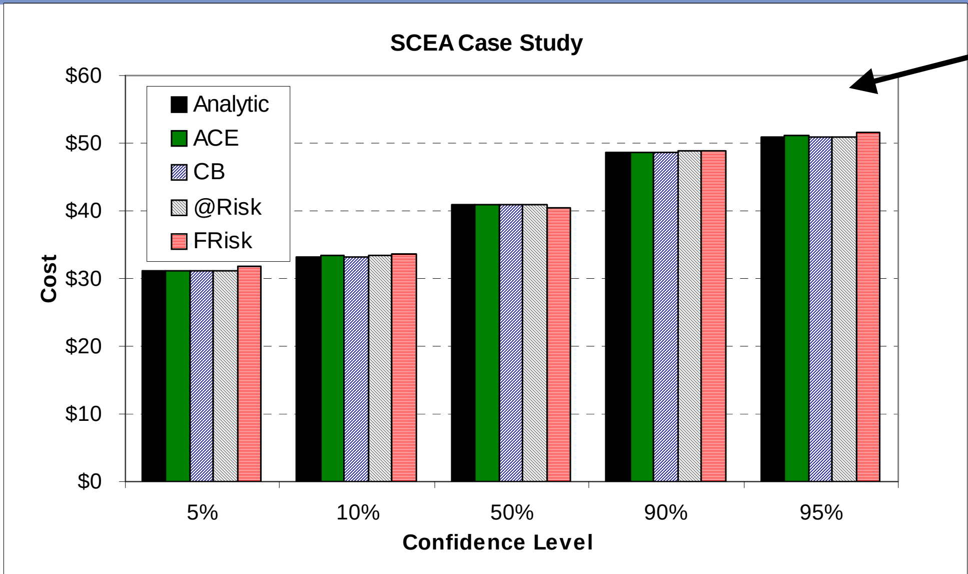
Ability to generate the entire matrix from a single column of the desired matrix

ACE Government sponsors not motivated to fund more detailed approach, but not against it

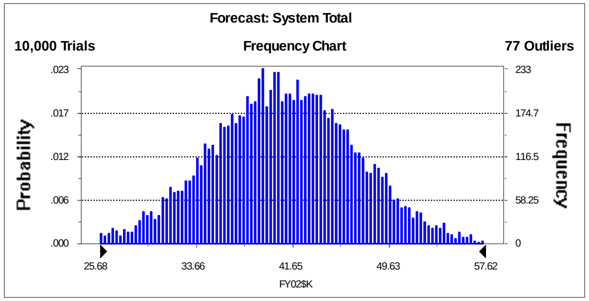
WBS	Equation/ Throughput	Distrn	Lower	Point Estimate	Upper	Analytic Stdev	ACE Stdev	CB Stdev	@Risk Stdev
Electronic System						6.015	6.013	6.026	5.998
PMP	12.50	Normal		12.500		2.569	2.570	2.569	2.569
SEPM	0.5*PMP			6.250		1.285	1.285	1.284	1.285
Sys Test & Evaluation				4.706		0.811	0.811	0.812	0.809
Sys Test & Eval	0.3125*PMP			3.906		0.803	0.803	0.803	0.803
Management Reser	0.80	Uniform	0.6	0.800	1.0	0.115	0.116	0.115	0.115
Data and Tech Orders	0.1*PMP			1.250		0.257	0.257	0.257	0.257
Site Survey & Activatio	6.60	Tiangular	5.1	6.600	12.1	1.505	1.505	1.505	1.505
Initial Spares	0.1*PMP			1.250		0.257	0.257	0.257	0.257
System Warranty	1.10	Uniform	0.9	1.100	1.3	0.115	0.116	0.115	0.115
Early Prototype Phase	1.50	Triangular	1.0	1.500	2.4	0.290	0.290	0.290	0.290
Operations Supt	1.20	Triangular	0.9	1.200	1.6	0.143	0.143	0.143	0.143
System Training	0.25*PMP			3.125		0.642	0.643	0.642	0.642

- **Combination of throughput and factor relationships**
- **No risk applied to the factors**
- **PMP drives about 70% of the model result, so 70% of the risk is modeled with a normal distribution making it reasonable that the total cost is likely to be normally distributed.**
- **Sys Test & Eval has an additive risk which is unusual in cost risk analysis. We generally assume the risk scales with the estimate.**

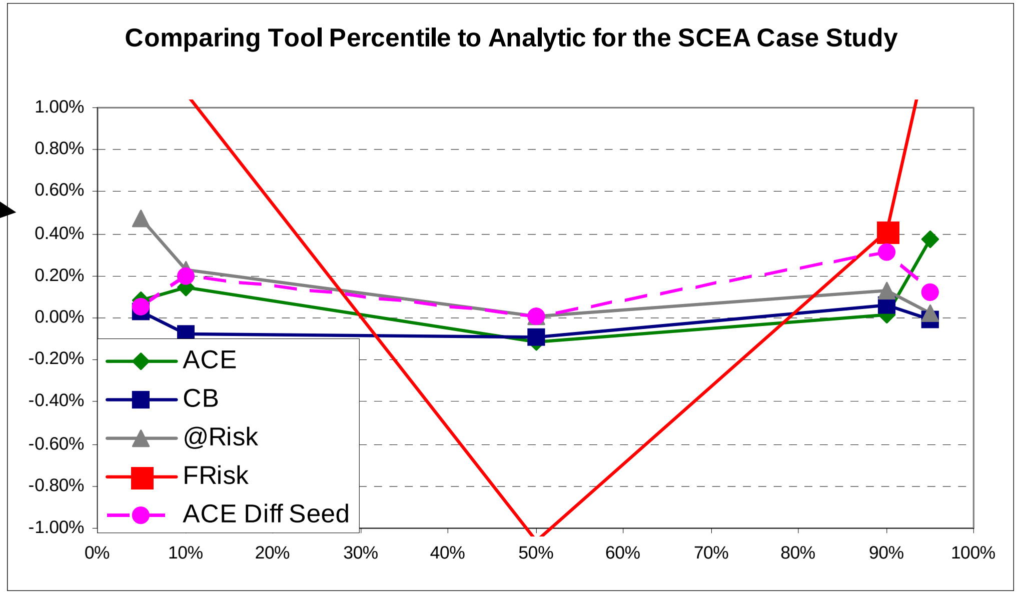
All Tools Perform Well



Use this scale if you wish to show that all models are not bad (FRisk is a little off because it assumes a log-normal distribution at the total level). Note that the simulation tool total result ***does*** appear “normal”.



- Use this scale if you wish to show there are in fact differences amongst the models.
- However, note that the scale is so magnified, that simply changing the initial seed value (ACE is shown, but all behave the same) noticeably changes the results!



Risk By Hand Calculator (Ref 5)

	Point Estimate	Mean	Distribution	Lower	Upper
System X	1250.000	**1,756.00**		625	3393
Antenna	380.00	574.00	Tiangular	191	1151
Electronics	192.00	290.00	Tiangular	96	582
Structure	76.00	84.00	Tiangular	33	143
LV Adaptor	18.00	18.00	Tiangular	9	27
Power Distribution	154.00	232.00	Tiangular	77	465
ACS/RCS	58.00	58.00	Tiangular	30	86
Thermal Control	22.00	33.00	Tiangular	11	66
TT&C	120.00	120.00	Tiangular	58	182
Software	230.00	347.00	Tiangular	120	691

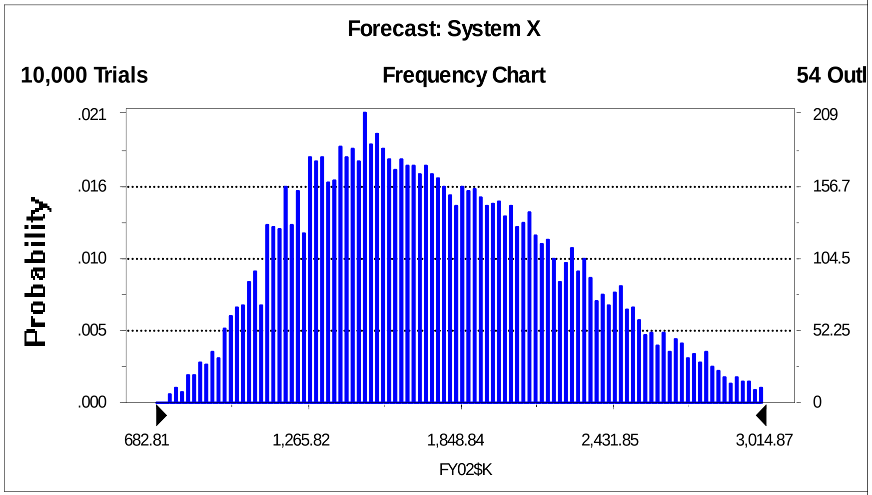
- No functional relationships.
- Triangular distributions only.
- No need to force tools to truncate distributions at “0”.

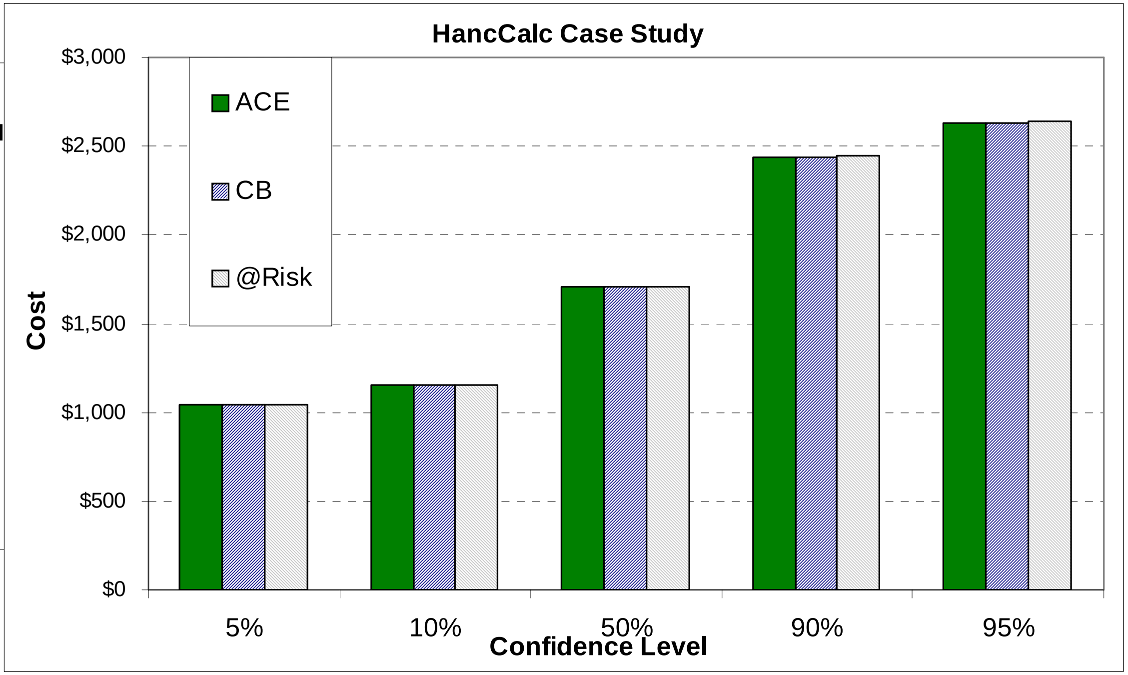
As Specified Correlation Matrix

	Antenna	Electronics	Structure	LVAdaptor	PowDistr	ACSRCS	Thermal	TTC	Software
Antenna	**1.0**	0.5	0.5	0.6	0.5	0.5	0.3	0.7	0.7
Electronics	0.5	**1.0**	0.4	0.5	0.5	0.6	0.5	0.5	0.7
Structure	0.5	0.4	**1.0**	0.7	0.6	0.7	0.7	0.5	0.7
LVAdaptor	0.6	0.5	0.7	**1.0**	0.4	0.4	0.5	0.3	0.6
PowDistr	0.5	0.5	0.6	0.4	**1.0**	0.5	0.5	0.5	0.7
ACSRCS	0.5	0.6	0.7	0.4	0.5	**1.0**	0.4	0.7	0.8
Thermal	0.3	0.5	0.7	0.5	0.5	0.4	**1.0**	0.5	0.7
TTC	0.7	0.5	0.5	0.3	0.5	0.7	0.5	**1.0**	0.8
Software	0.7	0.7	0.7	0.6	0.7	0.8	0.7	0.8	**1.0**
Average	0.59	0.58	0.64	0.56	0.58	0.62	0.57	0.61	0.74

- Detailed correlation matrix .
- Entered explicitly into CB & @Risk
- Pick column with highest average to enter into ACE.

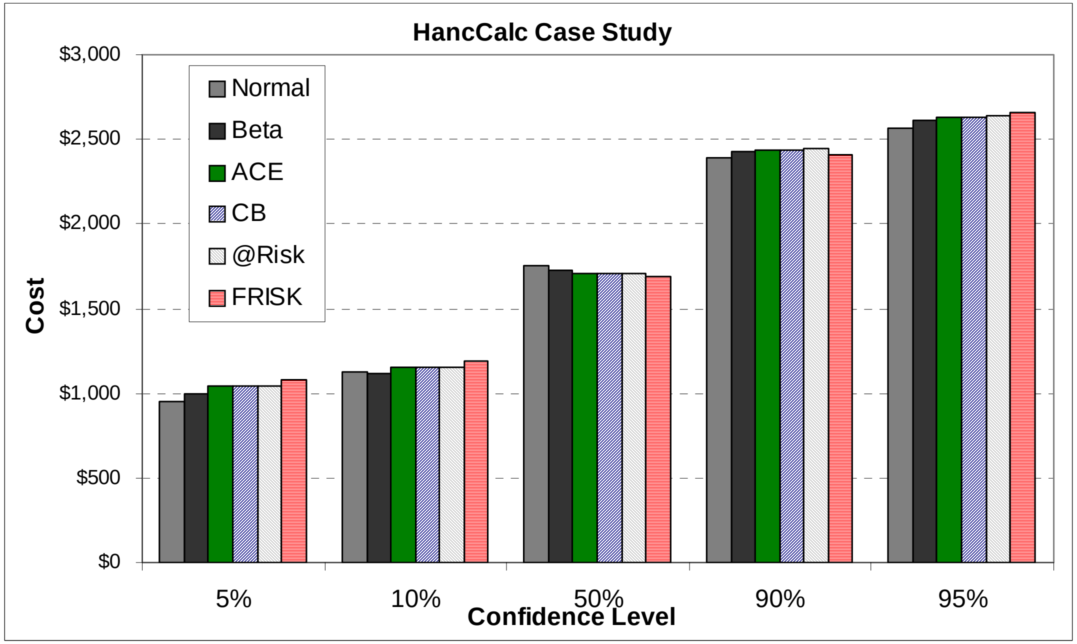
Simulation Total Cost Does Not Appear "Normal"

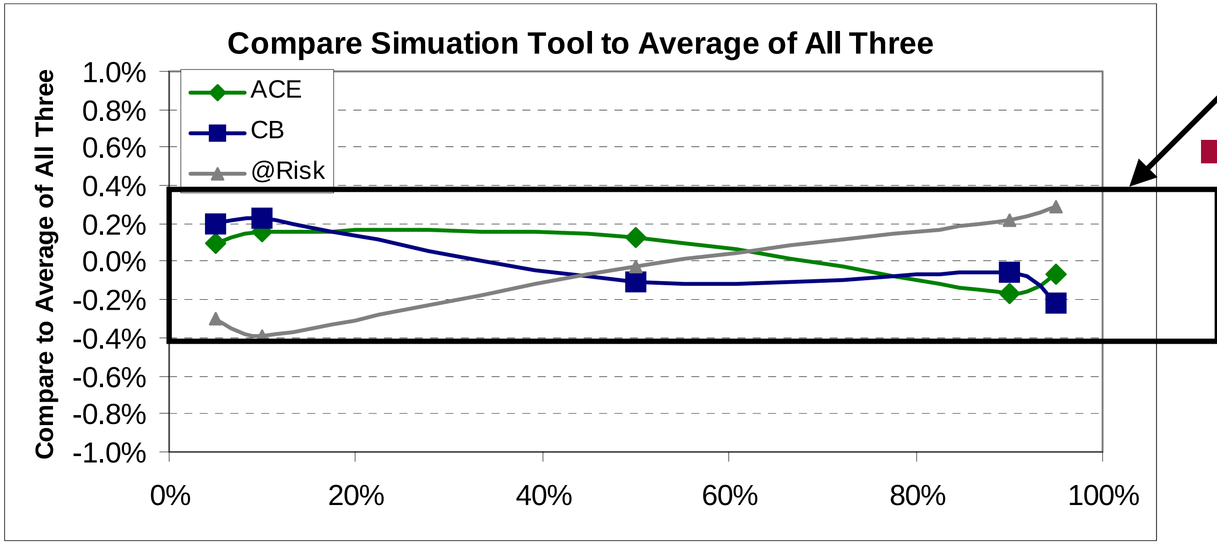




- **All simulation tools match each other. Had to use bar chart rather than "S" for comparisons, otherwise impossible to discern different tool result.**
- **All simulation tools suggest the total cost distribution is *not* "normal".**
- **Only nine elements and with correlation layered on top, suggests that the Central Limit Theorem may not be applicable.**
- **With this information, we were motivated to produce analytical results based on a beta distribution.**
- **FRisk will provide results based upon a Log-Normal assumption.**

Not Clear Which is "Right", Fortunately they are all the "*Same*"





- **Analytic based on beta distribution compares "better" to the simulation tools than "normal" or log normal (FRisk)**
- **All solutions likely well within the total cost estimate confidence**
- **Difference between simulation tools less than expected "noise" of the applications**
- **NOTE: Detailed correlation matrix was explicitly modeled in Crystal Ball and @Risk. This *did not* "improve" the result.**

Theoretical Basis for the ACE Correlation Method

- **Pearson's Product Moment Correlation v.s. Spearman's Rank Order Correlation**
- **ACE uses the Pearson's definition to model correlations in risk simulations.**

- **Lurie-Goldberg's Simulation Method[1] is summarized in the paper.**
- **ACE uses a modified Lurie-Goldberg algorithm to create a set of variables that match the user-supplied correlations.**

1. Simulating Correlated Random Variables; Philip M. Lurie and Matthew S. Goldberg; Institute for Defense Analyses; 32nd DODCAS; 2-5 February 1999

Differences between ACE and Lurie-Goldberg

- **ACE only allows the user to enter a single vector of correlation coefficients where the correlations are relative to the dominant cost driver in a particular "Group" of WBS elements. By doing this, the remaining members of the correlation matrix are "implied" (and therefore consistent) and the algorithm is simplified.**

- **ACE uses ranks during the simulation process to smooth out the resulting variables to make them suitable for the Latin-Hypercube (LH) simulation. Ranking in this context is for the purpose of <u>generating the LH draws</u> such that they closely resemble the original input distributions, and it should <u>not</u> be confused with <u>rank order correlation</u>.**

- **ACE does not iterate on the user supplied "Group Strengths" to achieve the desired correlations among the WBS elements. Nonetheless, in our test cases the user-defined group strengths match the desired correlations very closely, all within 0.5%.**

Pearson's Product Moment Correlation

$$r = \frac{\sum (X - \overline{X})(Y - \overline{Y})}{\sqrt{\sum (X - \overline{X})^2}\sqrt{\sum (Y - \overline{Y})^2}}$$

or

$$r = \frac{n\sum XY - \sum X \sum Y}{\sqrt{\left(n\sum X^2 - \left(\sum X\right)^2\right) * \left(n\sum Y^2 - \left(\sum Y\right)^2\right)}}$$

n = number of ordered pairs
σ = standard deviation
μ = mean
X = first variable of an ordered pair
Y = second variable of an ordered pair

General Steps for the ACE/RI$K Algorithm

- Generate n independent draws, Z1, Z2, …Zn, from a standard normal distribution.
- Construct n correlated standard normal random variables X1, X2, … Xn using Cholesky's pairwise factorization formula.

$$
\begin{aligned}
X_1 &= Z_1 \\
X_2 &= \rho_2 Z_1 + \sqrt{1-\rho_2^{\,2}}\; Z_2 \\
X_3 &= \rho_3 Z_1 + \sqrt{1-\rho_3^{\,2}}\; Z_3 \\
&\ldots \\
X_n &= \rho_n Z_1 + \sqrt{1-\rho_n^{\,2}}\; Z_n
\end{aligned}
$$

- Generate the corresponding uniform LH draws for the Xi variables consistent with the value of the normal cumulative probability for each of the Xi values.
- Invert the uniform draws by the user-defined marginal distribution Fi:

$$Y_i = F_i^{-1}(U_i)$$

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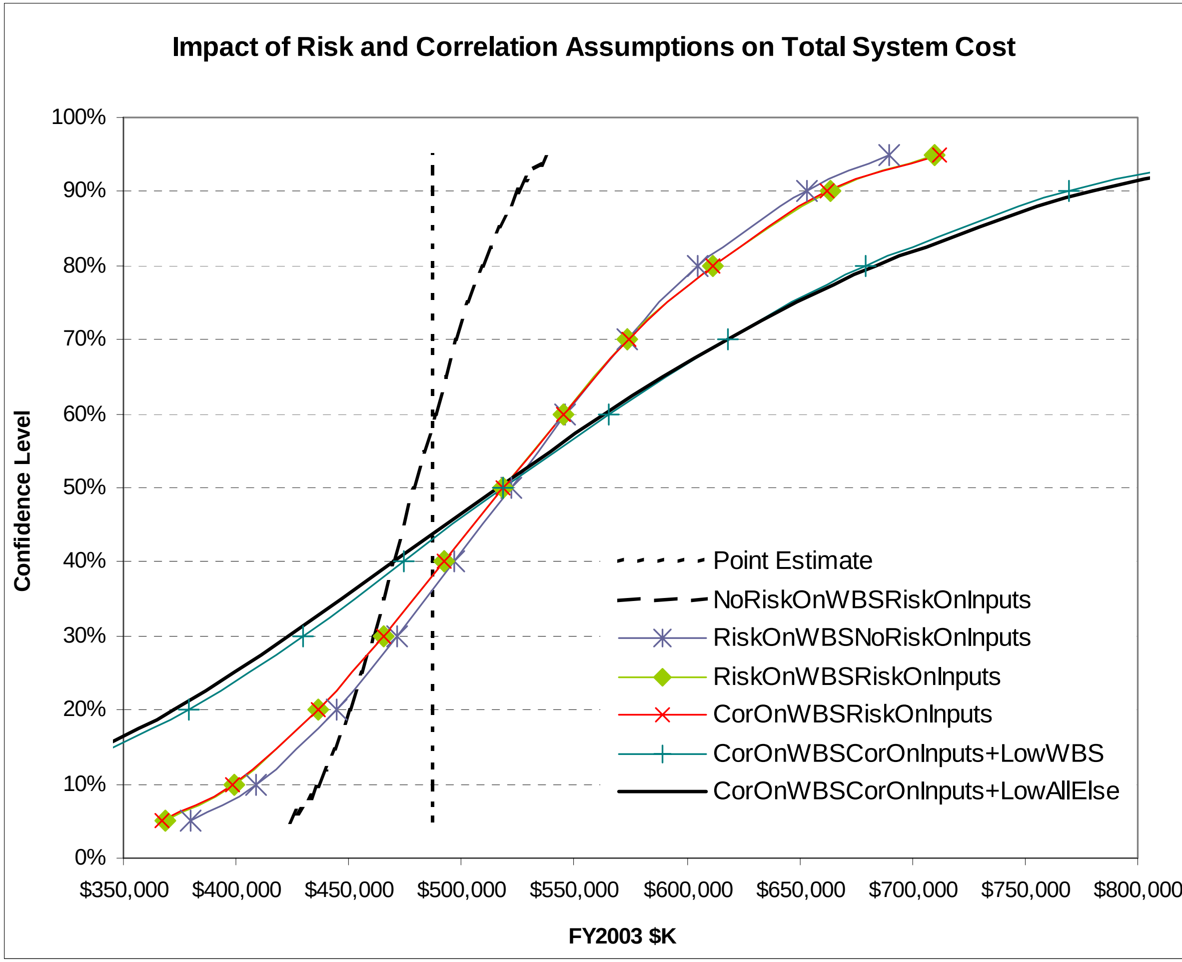
Impact on on Total Cost by Layering Risk Assumptions



In this model, the impact of correlating the Gimbal elements is insignificant. Applying 20% across all remaining WBS elements and inputs increases the cost result at 80% by 12%. The CoV of the final result is 35%.

Applying risk to the CERs and inputs in ACE, before layering correlation, captures most of the risk. Forcing an additional 20% correlation across all WBS elements (other than the Gimbal) does have a significant impact in this model.

Although the CoV of the final result is 35%, it might be excessive. To force even a 20% correlation across all elements is contrary to correlation studies on some datasets.