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Comparing Crystal Ball With ACEIT

2004 Crystal Ball User Conference
18 June 2004

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- **Background**
- **Objective**
- **Simulation settings**
- **Run risk analysis on three case studies**
- **Compare the risk results among ACE, Crystal Ball, and @Risk**
- **Evaluate the sample correlation coefficients generated by the simulation tools**
- **Conclusions**

- **Cost analysts develop cost point estimates through a systematic process of defining work breakdown structure (WBS), specifying cost estimating relationships (CER) and the application of risk**
 - Cost estimating risk, schedule/technical risk, and configuration risk
- **Many users develop Excel based cost estimating models and use Crystal Ball for running risk analyses. Many other military cost analysts use ACE to do the work.**
- **Do different tools generate different results based upon the “same” specifications?**



- **What are the risk tools and which should I choose?**
- **ACE RI\$K, Crystal Ball, @Risk, and FRisk are compared.**
- **Three case studies examined:**
 - Two are published, simple and analytically solved case studies (Reference 1 and 2).
 - Third example is based upon a more “realistic” cost model (Reference 3).
- **If handled properly, the simulation tools all give similar total cost distribution results.**



■ Number of Iterations

- Use 10000 as the number of iterations

■ Simulation Methods: Monte Carlo vs. Latin Hypercube

- Use 10000 LHC intervals in ACE and @Risk
- Use 5000 LHC intervals in CB

■ Random seeds

- Crystal Ball allows users to specify the initial seed value under “Run Preferences.”
- Choose 3320 as the initial seed for all simulation models

■ Distribution Truncation

- ACE truncates distributions at zero by default
- CB and @Risk default to sample the entire range of the distribution, which may include negative numbers



- Six throughputs and five factor equations defined in the model
- Five of the WBS elements are estimated as a factor of the Prime Mission Product (PMP). No risk applied to the factors.
- PMP and factor equations constitute about 70% of the total cost.
- Correlations are not specified.
- STE has an additive risk term, which is modeled separately (as a reserve item).

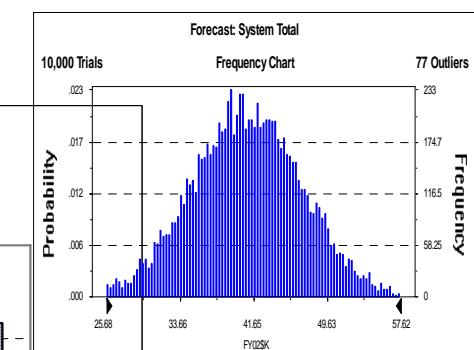
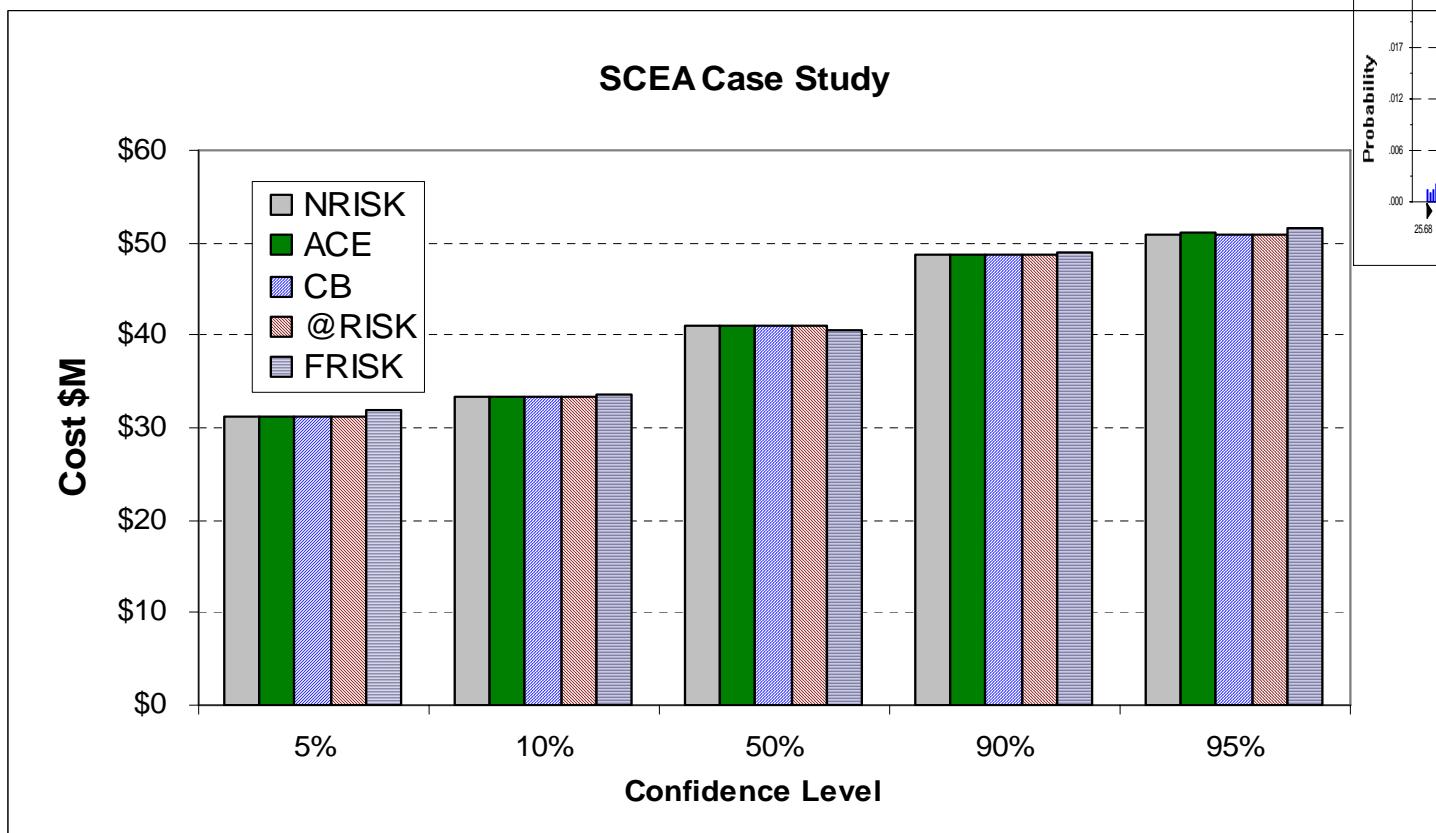
	Equation/ Throughput	Distrn	Lower	Point Estimate	Upper	Stdev	ACE Stdev	CB Stdev	@Risk Stdev
Electronic System									
PMP	12.50	Normal		12.500		2.569	2.570	2.569	2.569
SEPM	0.5*PMP			6.250		1.285	1.285	1.284	1.285
Sys Test & Evaluation				4.706		0.811	0.811	0.812	0.809
Sys Test & Eval	0.3125*PMP			3.906		0.803	0.803	0.803	0.803
Management Reserve	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 & Activation	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



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SCEA Training Manual Case Study – Risk Results

- All three tools produce very similar risk results. The differences of the percentiles across all simulation models are within half of a percent.
- The simulation results match the normal approximations very closely since normal distribution drives 70% of the total cost.



MCR Hand Calculator Case Study – Distribution Assumptions

- This model contains no CERs.
- Triangular distributions are assigned to nine throughput numbers.

	Point Estimate	Triangular Distribution			Mean	Standard Dev
		Lower	Mode	Upper		
System X	1,250	625		3,393	1,756	491.78
Antenna	380	191	380	1,151	574	207.62
Electronics	192	96	192	582	290	105.08
Structure	76	33	76	143	84	22.63
LV Adaptor	18	9	18	27	18	3.67
Power Distribution	154	77	154	465	232	83.86
ACS/RCS	58	30	58	86	58	11.43
Thermal Control	22	11	22	66	33	11.88
TT&C	120	58	120	182	120	25.31
Software	230	120	230	691	347	123.68



MCR Hand Calculator Case Study

– Correlation Matrix

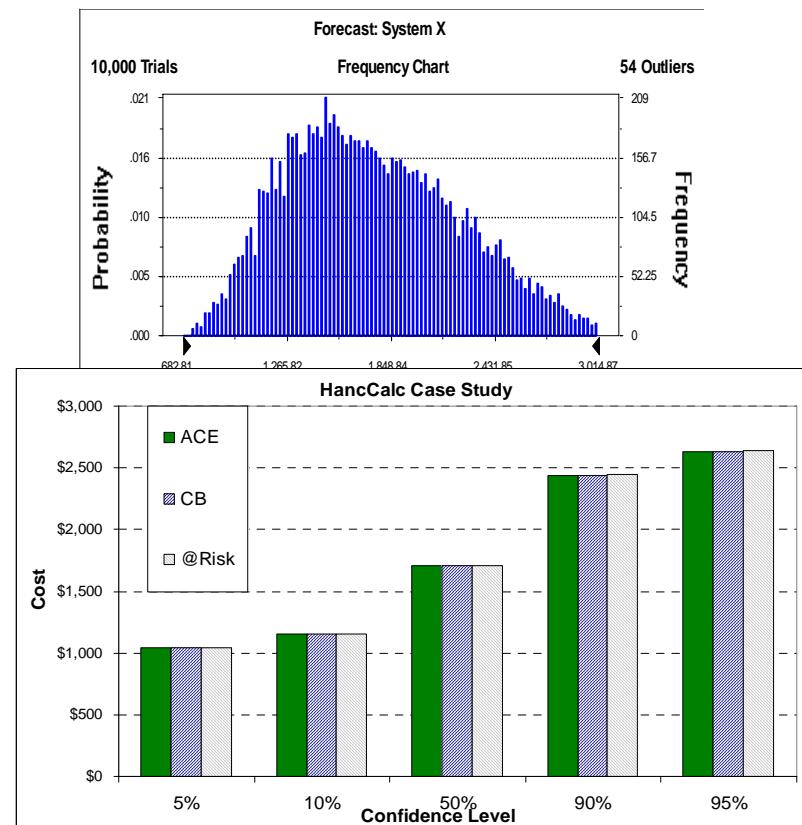
- The detailed correlation matrix is modeled in Crystal Ball and @Risk.
- ACE only allows user to select correlation vectors. During the simulation process, ACE will populate the remaining correlations with the cross product of their individual correlations.
- The column of software is chosen as a correlation group in ACE because its average sample correlation is larger than the others.

User-Defined Correlation Matrix									
Antenna	Electronics	Structure	LVAdaptor	PowDistr	ACSRCS	Thermal	TTC	Software	
Antenna	1.00	0.50	0.50	0.60	0.50	0.50	0.30	0.70	0.70
Electronics	0.50	1.00	0.40	0.50	0.50	0.60	0.50	0.50	0.70
Structure	0.50	0.40	1.00	0.70	0.60	0.70	0.70	0.50	0.70
LVAdaptor	0.60	0.50	0.70	1.00	0.40	0.40	0.50	0.30	0.60
PowDistr	0.50	0.50	0.60	0.40	1.00	0.50	0.50	0.50	0.70
ACSRCS	0.50	0.60	0.70	0.40	0.50	1.00	0.40	0.70	0.80
Thermal	0.30	0.50	0.70	0.50	0.50	0.40	1.00	0.50	0.70
TTC	0.70	0.50	0.50	0.30	0.50	0.70	0.50	1.00	0.80
Software	0.70	0.70	0.70	0.60	0.70	0.80	0.70	0.80	1.00
Average:	0.59	0.58	0.64	0.56	0.58	0.62	0.57	0.61	0.74

MCR Hand Calculator Case Study – Risk Results

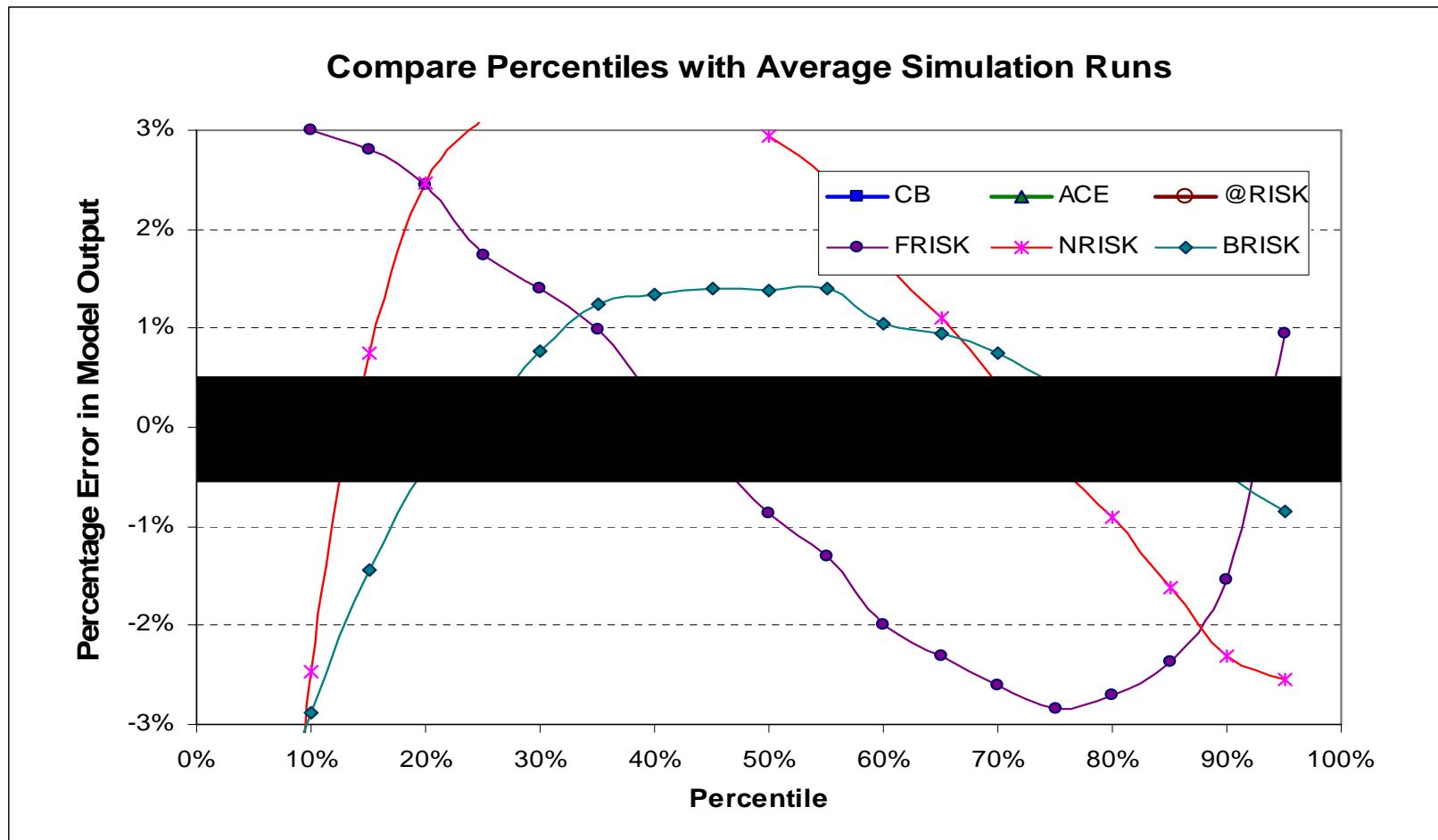
- The risk results by all simulation tools match one another very closely.
- Based upon the histogram, the total cost distribution is not normal.
- Three popular analytic solutions: Normal, Log-normal (FRISK), and Beta approximation methods. Solutions by beta approximation compared better to the simulation models than normal or log-normal methods.

	Stdev	5%	10%	50%	90%	95%
ACE	487.2	1,043	1,156	1,708	2,438	2,630
CB	486.1	1,044	1,157	1,704	2,441	2,626
@Risk	489.9	1,039	1,150	1,705	2,448	2,640
Normal	491.8	947	1,126	1,756	2,386	2,565
FRISK	491.8	1,076	1,189	1,691	2,405	2,657
Beta	491.8	994	1,121	1,729	2,431	2,610





MCR Hand Calculator Case Study – Percentile Comparison



Note: The comparison baseline is the average of the three simulation models.

MCR Hand Calculator Case Study

- Sample Correlation Matrix (1/2)

- The internal ACE, CB, and @Risk results for all iterations were also extracted in order to calculate the actual correlations between the WBS elements.
- The sample correlation coefficients by these simulation models tend to underestimate the user-specified correlation coefficients on the average.

User-Defined Correlation Matrix									
	Antenna	Electronics	Structure	LVAdaptor	PowDistr	ACSRCS	Thermal	TTC	Software
Antenna	1.00	0.50	0.50	0.60	0.50	0.50	0.30	0.70	0.70
Electronics	0.50	1.00	0.40	0.50	0.50	0.60	0.50	0.50	0.70
Structure	0.50	0.40	1.00	0.70	0.60	0.70	0.70	0.50	0.70
LVAdaptor	0.60	0.50	0.70	1.00	0.40	0.40	0.50	0.30	0.60
PowDistr	0.50	0.50	0.60	0.40	1.00	0.50	0.50	0.50	0.70
ACSRCS	0.50	0.60	0.70	0.40	0.50	1.00	0.40	0.70	0.80
Thermal	0.30	0.50	0.70	0.50	0.50	0.40	1.00	0.50	0.70
TTC	0.70	0.50	0.50	0.30	0.50	0.70	0.50	1.00	0.80
Software	0.70	0.70	0.70	0.60	0.70	0.80	0.70	0.80	1.00

CB Internal Correlation Matrix									
	Antenna	Electronics	Structure	LVAdaptor	PowDistr	ACSRCS	Thermal	TTC	Software
Antenna	1.00	0.48	0.49	0.59	0.47	0.48	0.27	0.68	0.68
Electronics		1.00	0.39	0.49	0.47	0.58	0.47	0.50	0.69
Structure			1.00	0.70	0.59	0.69	0.69	0.50	0.69
LVAdaptor				1.00	0.37	0.39	0.48	0.30	0.59
PowDistr					1.00	0.48	0.48	0.48	0.67
ACSRCS						1.00	0.38	0.70	0.78
Thermal							1.00	0.49	0.69
TTC								1.00	0.79
Software									1.00

Initial Seed: 3320									
CB Internal vs. User-Defined Correlation Matrix in % Errors									
	Antenna	Electronics	Structure	LVAdaptor	PowDistr	ACSRCS	Thermal	TTC	Software
Antenna	0%	-5%	-2%	-2%	-7%	-4%	.9%	-2%	-3%
Electronics		0%	-2%	-2%	-6%	-3%	-6%	-1%	-1%
Structure			0%	-1%	-2%	-1%	-1%	0%	-1%
LVAdaptor				0%	-7%	-2%	-4%	1%	-2%
PowDistr					0%	-4%	-4%	-5%	-4%
ACSRCS						0%	-5%	0%	-2%
Thermal							0%	-3%	-2%
TTC								0%	-1%
Software									0%

MCR Hand Calculator Case Study

- Sample Correlation Matrix (2/2)

- CB would model the user-specified correlation coefficients much better when using different seeds. For example, CB underestimates the target numbers by about just 1% when using “20000” as the initial seed. “3320” appears to be a bad seed for CB.

User-Defined Correlation Matrix									
	Antenna	Electronics	Structure	LVAdaptor	PowDistr	ACSRCS	Thermal	TTC	Software
Antenna	1.00	0.50	0.50	0.60	0.50	0.50	0.30	0.70	0.70
Electronics	0.50	1.00	0.40	0.50	0.50	0.60	0.50	0.50	0.70
Structure	0.50	0.40	1.00	0.70	0.60	0.70	0.70	0.50	0.70
LVAdaptor	0.60	0.50	0.70	1.00	0.40	0.40	0.50	0.30	0.60
PowDistr	0.50	0.50	0.60	0.40	1.00	0.50	0.50	0.50	0.70
ACSRCS	0.50	0.60	0.70	0.40	0.50	1.00	0.40	0.70	0.80
Thermal	0.30	0.50	0.70	0.50	0.50	0.40	1.00	0.50	0.70
TTC	0.70	0.50	0.50	0.30	0.50	0.70	0.50	1.00	0.80
Software	0.70	0.70	0.70	0.60	0.70	0.80	0.70	0.80	1.00

CB Internal Correlation Matrix (Initial seed = 20K)									
	Antenna	Electronics	Structure	LVAdaptor	PowDistr	ACSRCS	Thermal	TTC	Software
Antenna	1.00	0.49	0.48	0.58	0.50	0.49	0.28	0.70	0.68
Electronics		1.00	0.39	0.50	0.51	0.59	0.49	0.49	0.69
Structure			1.00	0.70	0.60	0.70	0.70	0.49	0.68
LVAdaptor				1.00	0.41	0.41	0.50	0.30	0.58
PowDistr					1.00	0.50	0.50	0.50	0.70
ACSRCS						1.00	0.40	0.70	0.79
Thermal							1.00	0.48	0.69
TTC								1.00	0.79
Software									1.00

Initial Seed: 20000

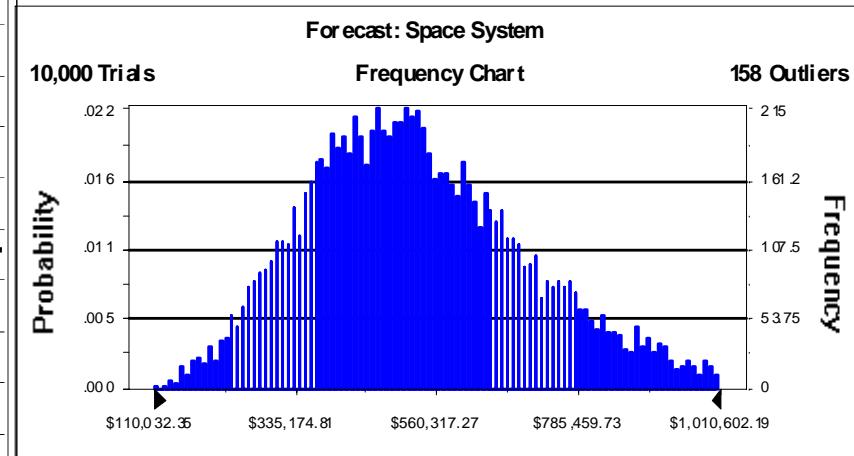
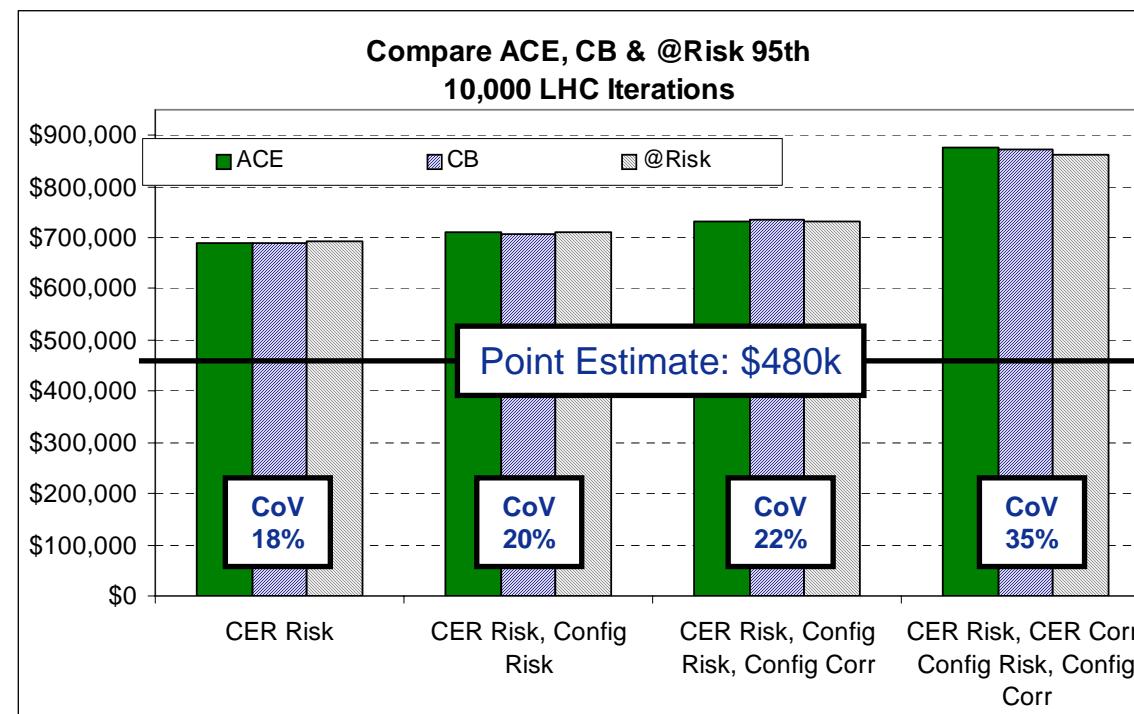
CB Internal vs. User-Defined Correlation Matrix in % Errors									
	Antenna	Electronics	Structure	LVAdaptor	PowDistr	ACSRCS	Thermal	TTC	Software
Antenna	0%	-2%	-5%	-4%	0%	-2%	-5%	-1%	-2%
Electronics		0%	-2%	-1%	2%	-1%	-2%	-2%	-1%
Structure			0%	0%	0%	0%	0%	-2%	-3%
LVAdaptor				0%	4%	1%	-1%	1%	-3%
PowDistr					0%	1%	0%	1%	0%
ACSRCS						0%	1%	-1%	-1%
Thermal							0%	-3%	-2%
TTC								0%	-2%
Software									0%



A “Realistic” Model

	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 Percentile		
6	WBS/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 (IAT)		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 * OTANMIRRORSTRWT^0.820	1992	27.40%	162.60%	1	\$1121.50	\$4568	\$4558	-0.26%	\$1144	\$1145	0.08%	\$2,162	\$2,154		

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



- 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.



Conclusion (1/2)

Compare Risk Tools

■ If you are consistent with:

- Number of iterations
- Sample size of Latin Hypercube (LHC) if using LHC (the number of intervals)
- Inflation, learning, and other modeled adjustments
- How functional relationships are modeled
- Distribution assumptions for risk elements (cost estimating, schedule/technical, and configuration risks)
- Truncation assumptions

■ If you follow the tool developer's recommendation for entering correlation:

ACE, Crystal Ball, and @Risk will produce similar total cost distribution results.



Conclusion (2/2)

Evaluate Sample Correlations

- **Sample correlations (generated by simulation) appear to be less than the user-specified**
 - Hand Calculator Case Study (initial seed 3320)
 - CB underestimates by **2.9%**, @Risk 1.2%, and ACE 2%.
 - Hand Calculator Case Study (initial seed 20000)
 - CB underestimates by **1%**, @Risk 0.3%, and ACE 1.2% .
 - Is 3320 a “bad seed” for CB?
 - Hand Calculator Case Study (initial seed 2000)
 - CB underestimates by **1.3%**, @Risk 2.9%, and ACE 1.2% .
 - Is 2000 a “bad seed” for @Risk?
 - All simulation tools less sensitive to seed values when tighter dispersions used.
- **No evidence that Rank Order correlation (CB and @Risk) are detrimental to the studied cost risk analysis problems.**
- **Correlations generated by ACE, CB, and @Risk can be significantly smaller than user-specified between Lognormal distributions with broad dispersions. Worth further study.**



1. Garvey, Paul R, "Risk Analysis Case Study Page CE V – 80 SCEA Training Manual," MITRE Corporation, 2003 ISPA/SCEA International Conference, Orlando, FL, 17-20 June 2003.
2. Book, Stephen A., "Cost-Risk Computations by Hand Calculator," MCR Federal, Inc., 2002 SCEA National Conference, Phoenix (Scottsdale), AZ, 11-14 June 2002.
3. Smith, Alfred and Hu, Shu-Ping, "Impact of Correlating CER Risk Distributions Using a Real Cost Model," Tecolote Research, Inc., 2003 ISPA/SCEA International Conference, Orlando, FL, 17-20 June 2003 .
4. Garvey, Paul R, "Do Not Use Rank Correlation in Cost Risk Analysis," 32nd Annual DoD Cost Analysis Symposium, Williamsburg, VA, 2-5 February 1999.