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Moment One, Please

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ICEAA Conference, June 2017

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Agenda

- **Overview of CAAG Risk Process & Correlation**
- Comparison to Language in Joint Cost Schedule Risk and Uncertainty Handbook (CSRUH), Naval Center for Cost Analysis
- Impact on Mean when using Functionally Correlated Models (CAAG Example)

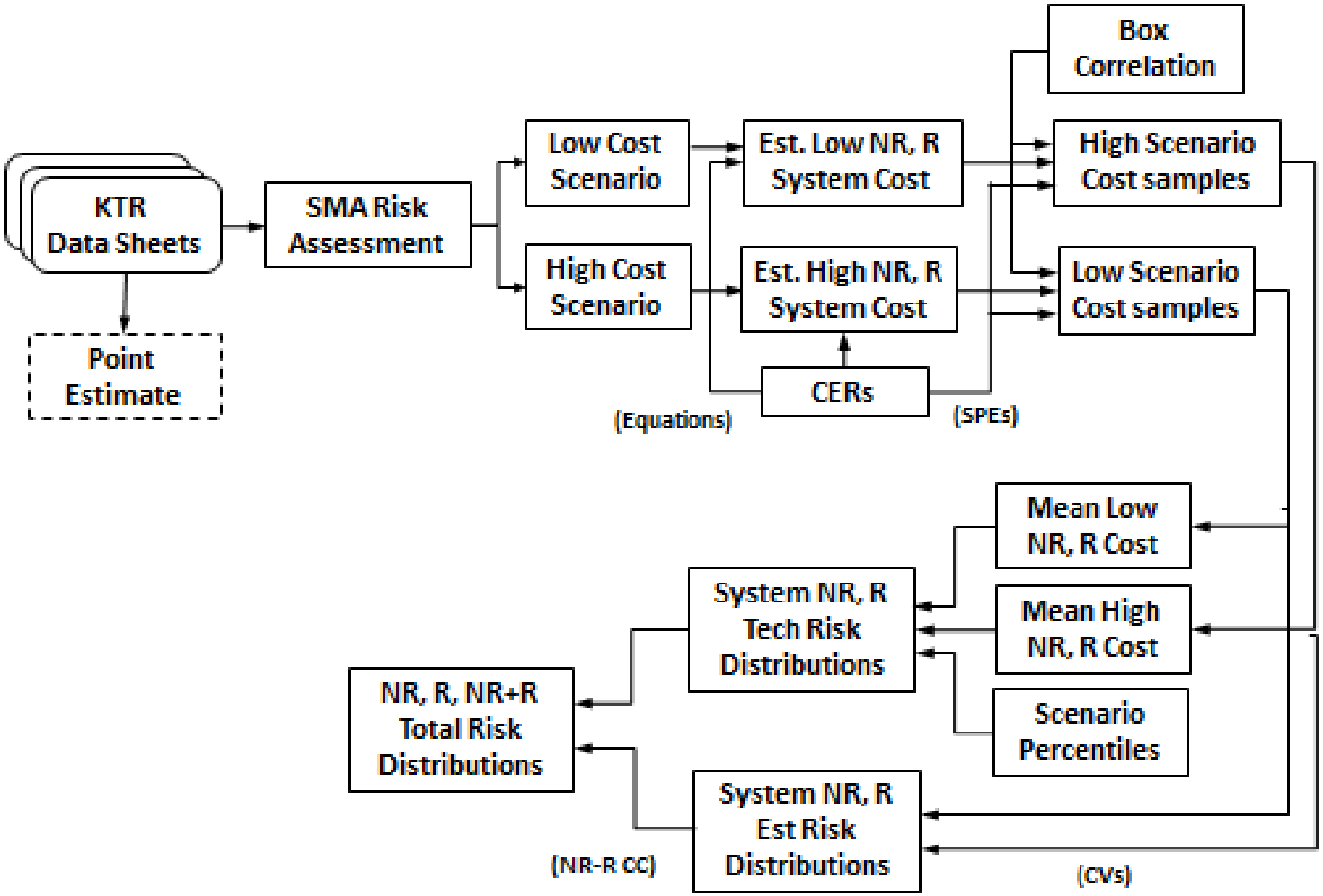
CAAG Risk Process

- NRO Cost & Acquisition Analysis Group (CAAG) previously briefed its risk process at ICEAA
  - A Comparison of Risk Analysis Methods Employed by the NRO CAAG [1]
- Primary Focus Areas
  1. Defining and modeling scenarios
     - Technical assessments should be incorporated in a manner consistent with SE/TAD's formulation and assumptions
     - SE/TAD guidance is to provide subsystem-level scenarios
       - High recurring
       - High nonrecurring

       } Highly correlated NR and R scenarios
       - Low recurring
       - Low nonrecurring

       } Highly correlated NR and R scenarios
  2. Incorporating functional correlation
     - It does affect the mean, not just the S-curve (variance or spread)

CAAG Risk Process



Applied (Explicit) Correlation

Cost Risk

- Box-level correlation coefficients are applied using the ruleset to the right

Technical Risk

- CAAG applies correlation on both cost uncertainty and technical distributions at SS level
  - Cost uncertainty distributions are correlated based on the measured correlation from the output of low/high scenarios
  - Technical distribution correlation coefficients are applied using following ruleset

Box-Level Pairing	Default Correlation
Box A REC to Box A NR	0.3
Box A REC to Box B NR	0.2
Box A REC to Box B REC	0.2
Box A NR to Box B NR	0.4
Box A NR to Box B Incidental NR	0.2

Distribution Pairing	Default Correlation
HW NR to HW NR	0.6
HW NR to HW REC	0.2
HW REC to HW REC	0.6
FSW to FSW/HW	0.15

Functional (Implicit) Correlation

- Most NRO CAAG cost estimates are built up from unit-level cost estimates of the form

$$\$R = f(wt, qty, tech) + \varepsilon_{\$R}$$
$$\$NR = f(\$R, newness) + \varepsilon_{\$NR}$$
$$\$SEPM = f(\$NR + \$R, qty, type) + \varepsilon_{\$SEPM}$$

- Functional correlation
  - $R has estimating uncertainty, $\varepsilon_{\$R}$, and is an input to $NR, which also has estimating uncertainty, $\varepsilon_{\$NR}$
  - Both $R and $NR have estimating uncertainty and are inputs to $SEPM
- Risk modeling changes variance (2nd moment) **and** mean estimate (1st moment) of functionally correlated items
  - $\mu_{\$SEPM}$ of $SEPM is a function of $\varepsilon_{\$R}$, $\varepsilon_{\$NR}$, $\varepsilon_{\$SEPM}$, and correlation among these errors

Functional Correlation Example

- Correlation between costs that results from a risk process that has one cost random variable as an input to another cost (the correct way to model cost-to-cost CERs)
- You can't "input" functional correlation in a matrix
- Functional correlation is more important than correlation coefficients in the correlation matrix
  - It affects the mean, not just the variance (spread)
  - Need to determine realistic applied correlation values
  - Green boxes show functionally correlated SEPM mean cost as applied correlation changes

	Point est	SE	Mean (no correlation except functional)	Mean (ρ = 0.3)	Mean (ρ = 0.5)	Mean (ρ = 0.7)
Unit 1	100	40%	100.0	100.0	100.0	100.0
Unit 2	100	40%	100.0	100.0	100.0	100.0
SEPM = (Unit1+Unit 2)*0.3	60	40%	60.0	62.9	64.9	66.7
Change in SEPM mean cost:				+5%	+8%	+11%

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2014 Joint Cost Schedule Risk and Uncertainty Handbook (CSRUH) [2]

- Multi-Agency effort to describe acceptable analytical techniques to model uncertainty in a cost estimate
  - Led by Naval Center for Cost Analysis (NCCA)
  - Significant contributions from NAVAIR, SPAWAR, NAVSEA, MARCORSYSCOM, NCCA, MDA, NELO, AFCAA, ODASA-CE, Army TACOM, and NASA.
- Well-defined processes and principles for our industry
  - No single tool or method advocated
  - Comprehensive summary of today's "state of the practice"
- CAAG's risk processes and principles are consistent with CSRUH

CSRUH Functional Correlation

- Elements are functionally correlated if they are related to other WBS elements through the model algebra
- Functional correlation applied on top of functionally related uncertain WBS elements will impact the parent mean and spread
  - Uncertainty that is defined on a variable or assigned to a CER will be inherited by any relationship that uses them in its equation
- Functional correlation can exist between:
  - CER inputs if these inputs are in fact a function of each other
  - CERs if the CERs share one or more common input variables
  - **Two or more CERs if one CER is related to other CERs (for instance through a factor relationship)**
  - A CER result and the uncertainty of its input(s)

Impact of Functional Correlation

From CSRUH:

"Most estimates do contain many elements that are functionally related through linear and non-linear methods. This often causes uncertainty distributions to be multiplied, divided, exponentiated, etc. For this reason, correlation applied on functionally related uncertainty distributions will have an impact not only on the spread of the parent, but the mean as well. This is why applying functional relationships (rather than simply adding throughputs) within a model wherever possible is so important: it can have a significant impact on the mean of the ultimate uncertainty distribution."

"Applying the correlation to these five throughput uncertainties results in no impact on the mean. In a functionally correlated model, applying correlation on top of functional correlation will influence the mean a few percent." [3]

- 1% when applied correlation is at $\rho = 0.3$

"Further Research" from 1994 DoDCAS

- From ***An Overview of Correlation and Functional Dependencies in Cost Risk and Uncertainty Analysis*** *(R Coleman)* [4], the further research slide recommends:
  - *Collect a moderately large, "connected" set of data to observe and test actual correlations. Then,*
    - *Test functional dependency results*
    - *Test alternative methods, and compare fidelity and difficulty*

- 23 years later, we have an NRO CAAG example

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- **Impact on Mean when using Functionally Correlated Models (CAAG Example)**

Abstract (CAAG Example)

- Cost models constructed without statistical correlation, by design, underestimate the mean, unless they are simple sums
- Any model that uses a factor or other instances of functional correlation will miss the first moment (mean), not to mention others (variance, etc.), unless statistical correlation among the CERs is also applied
- An internal audit of 13 program estimates that use 83 CERs showed the mean non-recurring cost changes by as much as 16% when this correlation is applied

Dataset and Methods

Dataset

- Used “Retro ICEs” from 13 NRO Programs to calculate NR adder (to be used as a surrogate for functional correlation) at a box level
- Compared 983 HW items from the 13 programs

Methods

- Calculated the following for each box:
  - Recurring point estimate
  - Non-Recurring point estimate
  - Recurring risk-adjusted output (includes both mean variance)
  - Functionally correlated Non-Recurring risk-adjusted output
- Calculated % difference between NR point estimate and functionally correlated NR risk-adjusted output
  - Found averages across different NR CERs

Recommendations

- The creation of an “adder” for each NR CER adjusts the mean NR estimate so that functional correlation is incorporated into estimates where a risk engine is not available

- For NR CERs that **do not use** recurring cost as a base (ACS sensors, digital electronics), no adjustment needs to be made,
  - Functional correlation does not exist in these estimating relationships

- For NR CERs that **use** recurring cost as a base, adjustments up to 9.1% should be made to the mean

- Value of NR adder is a function of each CER’s
  - Standard Percent Error (SPE)
  - Applied correlation of R HW item to its functionally correlated NR HW item
  - Exponent of functionally correlated term in CER

Results

- Adders are implemented as a % increase over NR cost that has not been functionally correlated
  - Result will feed other parts of Estimate (SEITPM, ground, etc.)

CER Name	Avg.	Count
NR ACS Sensors 2013	0%	31
NR Antennas and Feeds 2013	1.9%	68
NR Digital Electronics 2013	0%	83
NR Misc Electronics 2013	9.1%	108
NR Optics 2013	5.0%	15
NR Positioners, Wheels and Deployment Drives 2013	2.1%	58
NR RF Equipment 2013	2.7%	161
NR Structures, Thermal, Propulsion 2013	1.3%	105
INR 2006	3.5%	369

References

- [1] A Comparison of Risk Analysis Methods Employed by the NRO CAAG, D Barkmeyer, C Massey, ICEAA Conference, June 2013
- [2] 2014 Joint CSRUH (Joint Cost Schedule Risk and Uncertainty Handbook), Naval Center for Cost Analysis, March 2014
- [3] Examination of Functional Correlation and Its Impact on Risk Analysis, A. Smith, Tecolote Research, Inc, SCEA/ISPA Conference, June 2007
- [4] An Overview of Correlation and Functional Dependencies in Cost Risk and Uncertainty Analysis, R. Coleman, 28th Annual DoD Cost Analysis Symposium, September 1994

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