Early Cost Risk and Confidence Determination with Minimal Project Information

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Introduction - Purpose

- **The purpose of this presentation is to introduce a unique perspective on cost risk, confidence intervals, element correlations, and the relationship between them**
  - **"Risk-based"**
  - **Statistically valid and consistent**

- **Allows for assessing an estimate's cost risk for consideration of varying confidence level and WBS element correlation with minimum additional project information**
  - **Can be used by proposal teams and management for a quick assessment of cost risk and confidence level early in the project definition stage; supports determination of project strategies**
  - **May also support budgeting studies for initial determination of budget and risk/reserve positioning**

Introduction - Uniqueness

- Literature review showed this model to perhaps be a unique perspective
  - Some earlier work* made progress at modeling the %-error behavior for types of programs based on characterization of historical data

- Here we are suggesting a model <u>not</u> using real historical cost data; it is purely an observation of the behavior of the statistics relative to the application of correlation factors and confidence levels

- As such it is not considered proprietary and is presented to the ICEAA and costing and statistics community for comment and consideration
  - Suggested as a complimentary method for assessing budget bounds or program cost risk potential
  - Note: the model does not improve the accuracy of the “most likely” estimate; but helps characterizes the current state upside cost risk
    - Improves the accuracy of the <u>initial</u> estimate range or PDF-shape

*** *A Macro-Stochastic Model for Improving the Accuracy of Department of Defense LCCE's* – Ryan, Kabban, Jacques, & Ritschel (2013); Journal of Cost Analysis and Parametrics, 6:1, 43-74, DOI: 10.1080/1941658X.2013.767073**

Agenda

- Model Definition & Key Assumptions
- Example Applications
- Model Sensitivities
- Thoughts on Benefits
- Discussion on Correlation & Correlation Determination Process
- Summary & Conclusion
- Future Work

Model Description

- ***Model Details***

Total Cost: $C = \sum_{k=1}^{n} C_i$ **, C_i is individual cost item. N is # of total cost items** **(1)**

Variance of C: $Var(C) = \sum_{k=1}^{n} Var(C_i) + 2\rho \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \sqrt{Var(C_i)\ Var(C_j)}$

$$= n\sigma^2 + n(n-1)\rho\sigma^2$$

$$= n\sigma^2(1 + (n-1)\rho)$$ **(2)**

Ref.: Correlation Tutorial – Ray Covert , MCR, and Tim Anderson, Aerospace Corp (2004); presented at Cost Drivers Learning Event, Nov 2 2005 by NASA, Assoc. of Cost Engineers, and The Aerospace Corporation

Where σ is the standard deviation of each individual cost item, ρ is the correlation between any two cost items. C is the total cost (as a random variable). σ_c is the standard deviation of the C

Standard deviation of total cost (σ_c)

$$\sigma_c = \sqrt{Var(C)}$$ **(3)**

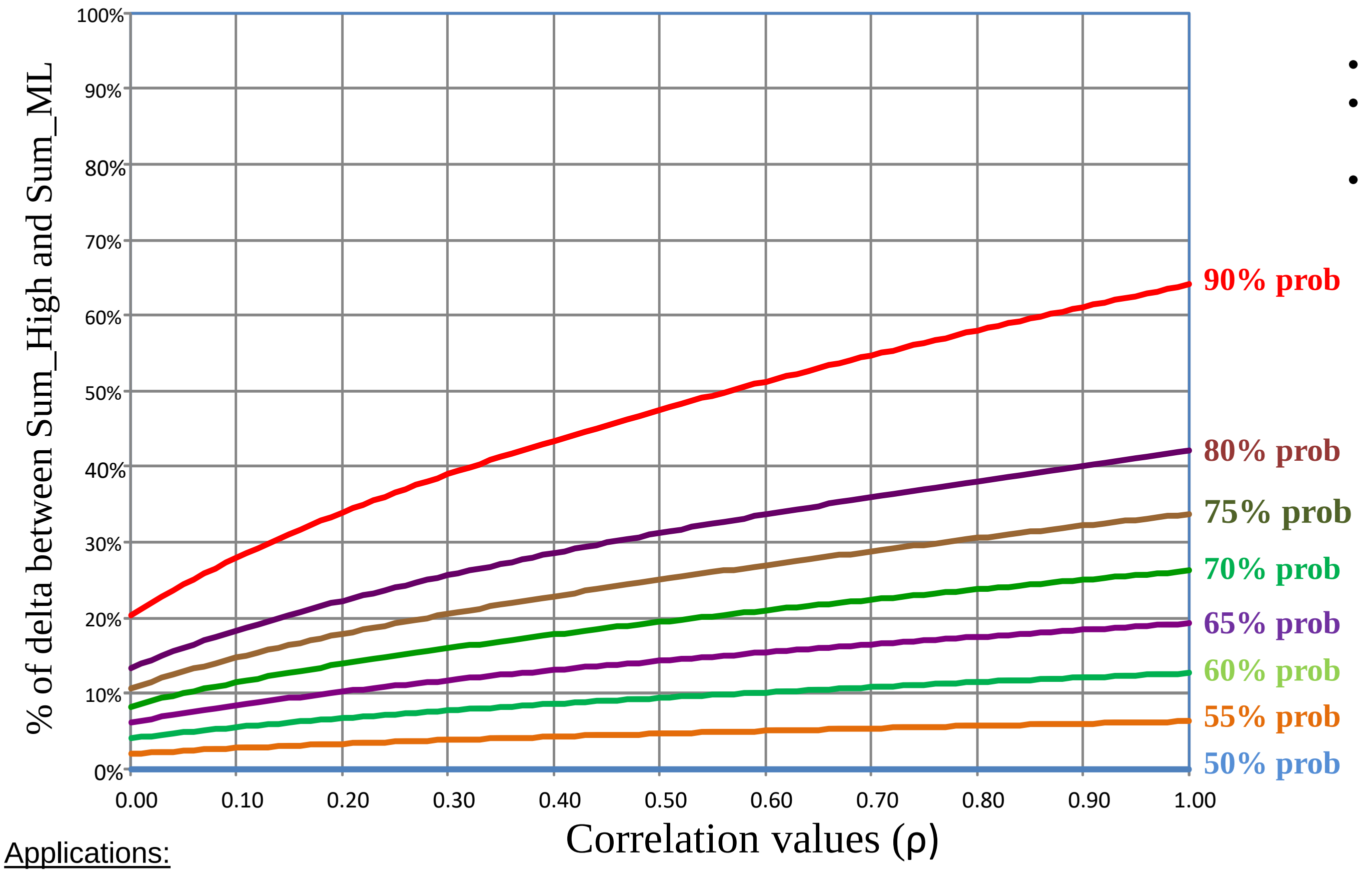
The Model definition: **% of delta between Sum_High and Sum_Most Likely as function of ρ (Perc_H_M)**

$$Perc\_H\_M = \frac{(Norm\ (P, \$Sum\_ML, \sigma_c) - \$Sum\_ML)}{\$Sum\_High - \$Sum\_ML}$$ **(4)**

In Eq., P is a probability on the cost S-curve. It is common that P is taken to be around 0.75 for cost proposal. $Norm\ (P, \$Sum\_ML, \sigma_c)$ **is the normal distribution percentile with probability P, and mean** $\$Sum\_ML$ **and standard deviation** σ_c

Figure X.1 graphically shows the relationships between correlation value ρ and Perc_H_M for the P values of 0.9, 0.8, 0.75, 0.7, 0.65, 0.55 and 0.5.

Figure X.1: % of Delta Cost as Function of Correlation (ρ) and Prob Level (P)



- This graph is for N=10 case.
- For N>10, all points at r=0 will cluster together toward Y-axis 0%
- For N<10, all curves will move toward horizontal lines

Applications:

Q1: For 10 risk item project, sum of most likely=200M, sum of high's = 250M. For correlation 0.5, what is 75% prob estimate of the cost?

A1: From graph, for P=75%, when r=0.5, y-axis value is about 25%. Therefore, 75% prob estimate of the cost is 200+(250-200)x25%= 212.5M

Q2: For 10 risk item project, sum of most likely =200M, sum of high's = 250M. When correlation changes from 0.2 to 0.5, how much higher is the cost value with 75% probability curve

A2. From 75% prob curve, when r changes from 0.2 to 0.5, y-axis value changes from about 18% to 25%, increasing by 7% which is 7% x (250M-200M) = 3.5M

Key Assumptions

Key Assumptions:

All cost items have the same standard deviation σ

Pair-wise correlation between any two cost item has the same value

High side estimates for all cost items have the same Standard Deviation distance from mean estimate

All cost items are subject to normal distributions, therefore, mean = median = mode (most likely)

Other Potential Helpful Applications

- Generate a quick ROM estimate of cost uncertainty and evaluation of correlation effects without Monte Carlo analysis

Examples: 1) What is 75% estimate of the cost uncertainty for r=0.5?

2) What is effect if r changes from 0.5 to 0.2?

3) How much mgmt reserve is needed to bring prob up?

- Quick check or cross-check for detailed Monte Carlo cost uncertainty simulation model
- Quick sensitivity examination for all model parameters involved
- Quick spot key drivers (key contributors)
- Sanity check for cost uncertainty results and trends

Model Sensitivity

- <u>Sensitivity to the real $ values</u>: No effect. The model output is normalized to % of delta $ values between Sum_Hign and Sum-Most likely. The exact $ values are normalized out.
- <u>Sensitivity to the distribution choice</u>: Not sensitive for the probability of 0.75 region, whether the distribution is Normal, Log-normal, Triangle or Weibull (or others)
- <u>Sensitivity to the N (# of WBS items being summed up)</u>: The smaller the N, the flatter the curve, therefore less affected by correlation values. The larger the N, the more the effect due to correlation. But when N>10, the effect change due to correlation is not significant.
- <u>Sensitivity to the upper value σ definition (i.e. whether the individual WBS High estimate is 2σ, 3σ or absolute upper bound (max):</u> The bigger the # of σ's the less sensitive the correlation effect in the neighborhood of probability of 0.75 or smaller.
- <u>Sensitivity to the lower side value σ definition (whether the individual WBS low estimate is 2σ, 3σ or absolute low</u> : Not sensitive at all.

  This represents the "Opportunity-side". We believe it needs to be addressed with different thinking and modeling approach than risk

Initial Thought About Benefits

- **Often, before we were "comfortable" in presenting and discussing cost risk, we needed to:**
  - **Define the project baseline details (non-recurring & recurring)**
  - **Define the estimate range(s) or cost risk of various project estimates uniquely, based on: scope, context, approach, TRL, perceived risk, individual WBS estimate uncertainties…**
  - **Decide if you believed them**
  - **Then perform a cost risk analysis (Monte Carlo or other) and decide if you can afford it (the baseline details and associated risk)**

- **New option – does not require a specific defined program baseline details**
  - **For a program: Most Likely, and High estimates**
  - **For budgeting: Budget target w/confidence level; initial correlation (based on knowledge or experience); how much cost risk is tolerable**

Budgeting Discussion

- **How about Customer budgeting?**
  - **Select a budget target, and an amount of reserve you are willing to spend (before you have to ask for more or get fired): "Most likely" and the "High Estimate"**
- **For example: Target ("I want to be at"): $750 with 75% confidence; assessed likely correlation of 0.5**
  - **Therefore, the "Delta cost" is 25% of the (High – ML)**
  - **Then, for a given ML, the cost risk dollars are:**

ML	H	"Cost Risk" Dollars to $750, 75% CL	"Cost Risk" Dollars High Estimate
$733.33	$800	$16.67	$66.67
$730.00	$810	$20.00	$80.00
$726.67	$820	$23.33	$93.33
$723.33	$830	$26.67	$106.67
$720.00	$840	$30.00	$120.00
$716.67	$850	$33.33	$133.33
$713.33	$860	$36.67	$146.67

  - **Would you be able to assess your realism and comfort level for a given baseline?**

Discussion on Correlation Group Thoughts

- Is high correlation good or bad (desirable or undesirable)? -It depends…on what?
  - Maybe on you, and what you're "good" at?
    - I might want high correlation among elements that I'm "good" at
    - I might want lower correlation among elements I'm less "good" at or have less control over; e.g. elements I put into the Supply Chain
  - Seems like it should consider schedule critical path, or how challenging the schedule is?
  - Correlation, as a measure of influence, affects negatives (risks) and positives (opportunities)

- Can we make decisions about an approach to correlation by design up front in the program planning?
  - With better understanding of "good" and "bad" correlations, proactively manage correlation related risks and opportunities to assist DTC and CAIV goals

- Note: the authors believe that examination of "cost opportunity" via correlation is a different analysis, and requires a different mindset. This discussion is contained to upside cost risk.

Discussion on Correlation Determination

- **Obviously, the subject of correlation is very important to determining cost risk**

- **For initial top down estimating, we often use a common correlation value based on: recommended best practices, or knowledge & experience to select a value**

- **As we progress to a more refined estimate we have sometimes extracted values for the correlation matrix from IPT group discussions or "Delphi" approach to a none, low, med, high value**

- **What follows is an attempt to improve upon that**

An Application of the Model – Toward A Proactive Correlation Risk Management

Step 1. Identify all applicable correlation risk items relevant to your proposal from List Y1.

List Y1. A List of Generic "Correlation Risk" Drivers

1. **Common materials across WBS items (raw material or purchased items)**
2. **Common MFG process across WBS items**
3. **Common inspections/ checkouts across WBS items**
4. **Common vendors across WBS items**
5. **Common policy, procedures across WBS items**
6. **Work force skill mix/availability (internal and at suppliers)**
7. **Customer requirement changes / stability**
8. **Management system and decision making process**
9. **Schedule challenges or slack**
10. **Maturity and efficiency of Information Systems (CAD, ERP, PLM, etc)**
11. **Design features that may affect functionalities of multiple components or sub-systems**
12. **Critical path items**
13. **Long lead items**
14. **Parts obsolesce**
15. **Counterfeit parts probability**
16. **Cyber security reqmts and IT effectiveness**
17. **Labor Relations (possibility of strikes etc)**
18. **Low probability / high impact event influences**
    - **Natural disaster (earthquake, flood, hurricane, etc.)**
    - **Terror attack/ sabotage.**
    - **IT system failure/data or communication loss**

We have developed this table with the intent that it provides a comprehensive generic correlation risk items. If users find additional items that are not on the list, feel free to add them to the list.

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Correlation Determination

- **Assume you identified 5 highly relevant correlation risk items:**
  - **Common materials**
  - **Common MFG process**
  - **Common vendors**
  - **Common policy and procedures and**
  - **Workforce skill mix/availability**
- **Step 2. For each of the items you identified, assess "% of WBS items affected (0% to 100%)" and "Extent of the correlation effect"**

Correlation Risk Driver Drop Down Manul items)	% of WBS affected (0% to 100%)	Extent of the correlation effect (4- very significant (ρ = 1), , 3-Significant (ρ = 0.75), 2-Moderate (ρ = 0.50), 1-Minor (ρ = 0.25))
1. Common materials	50%	3
2. Common MFG process	33%	4
4. Common vendors	30%	2
5. Common policy, procedures	75%	3
7. Work force skill mix/availability (personnel changes, company disappears, security clearance, training requirement changes, etc.)	50%	3

Derive an Average System Correlation Value Based on Knowledge and Rationale

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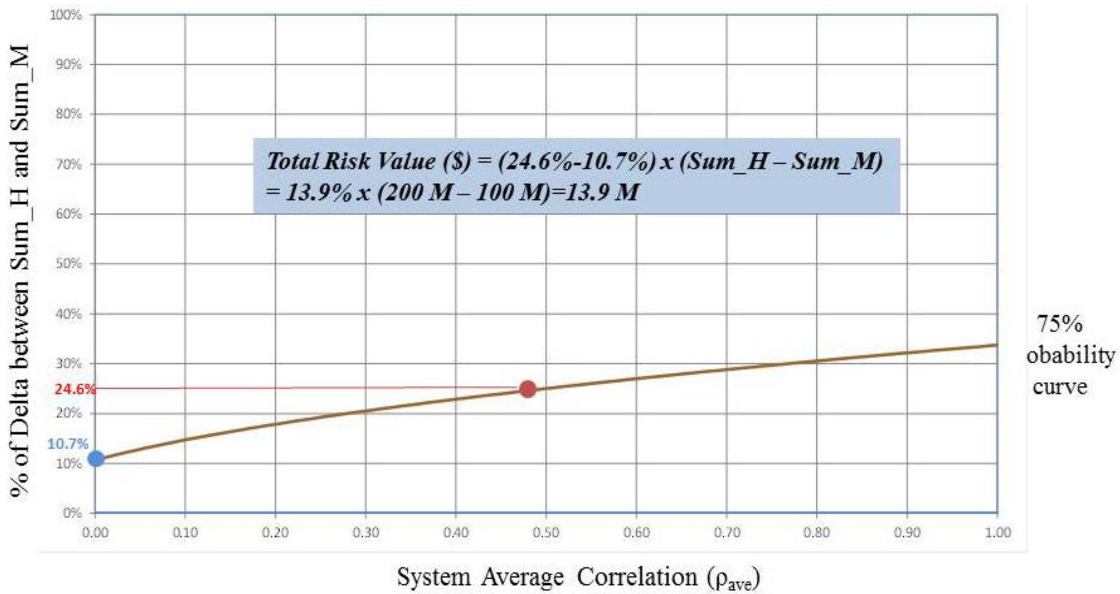
Step 3. Estimate the correlation values (ρ's) for each individual correlation item and the system overall correlation value (System Average Correlation ρ_{ave}). (hidden calc in Excel sheet)

Table Y3. System Average Correlation (ρ_{ave}) Derivation

Correlation Risk Driver Drop Down Manul items)	% of WBS affected (0% to 100%)	Extent of the correlation effect (4- very significant (ρ = 1), , 3-Significant (ρ = 0.75), 2-Moderate (ρ = 0.50), 1-Minor (ρ = 0.25))	Average Corre.	Square of Ave Correl	
1. Common materials	50%	3	0.167	0.02778	
2. Common MFG process	33%	4	0.084	0.00711	
4. Common vendors	30%	2	0.033	0.00111	
5. Common policy, procedures	75%	3	0.406	0.16504	
7. Work force skill mix/availability (personnel changes, company disappears, security clearance, training requirement changes, etc.)	50%	3	0.167	0.02778	
Total				**0.48**	**<---RSS of Individual Correlations used as ρ_{ave} for the system**

Estimate Total Correlation Risk $ Value

- **Step 4. Estimate Total Correlation Risk (TCR) $ Value**
- **This is the delta cost value between Correlation 0.48 and 0.**
  - **From Figure below, this is (24.6%-10.7%) = 13.9% of difference between Sum_High (Sum_H) and Sum_Most likely (Sum_M).**
  - **Here, Sum_High =$200M and Sum_M is $100M. So TCR value is ($200 Millions - $100 Millions) x 13.9% = $13.9 millions. This is also automatically computed by the EXCEL Tool.**



Total Cost Risk Value ($) as % of Delta Between Sum_H and Sum_M

Step 5. Estimate Individual Correlation Risk Item $ Values

- **From Step 4, we estimated that total cost risk value as $13.9M.**
- **We allocate this value to the 5 risk items identified based on their individual correlation values as the weights (see Table)**
- **The last column provides the individual correlation risk $ values. This is also the $ value for the return-on-investment (ROI) decision which will guide the management and design teams' decision for planning of mitigating the correlation risks.**

Correlation Risk Driver Drop Down Manul items)	% of WBS affected (0% to 100%)	Extent of the correlation effect (4- very significant (ρ = 1), , 3-Significant (ρ = 0.75), 2-Moderate (ρ = 0.50), 1-Minor (ρ = 0.25))	Average Corre.	Square of Ave Correl	Individual Risk Item $ (M) Value (Or ROI Break Even $)
1. Common materials	50%	3	0.167	0.02778	$2.7
2. Common MFG process	33%	4	0.084	0.00711	$1.4
4. Common vendors	30%	2	0.033	0.00111	$0.5
5. Common policy, procedures	75%	3	0.406	0.16504	$6.6
7. Work force skill mix/availability (personnel changes, company disappears, security clearance, training requirement changes, etc.)	50%	3	0.167	0.02778	$2.7
Total				**0.48**	**$13.9**

Summary & Conclusion

- A unique perspective on the behavior of the statistics of correlation, confidence interval, and cost risk allows the generation of a stable, consistent, risk-based model for early stage assessment of cost risk

- Program specific baseline details are not required initially

- Model helps drive the discussion of correlation risks proactively to focus on CAIV/DTC as part of program definition
  - Can quickly evaluate the correlation effects on the dollar values proposed to support a proactive DTC planning and upfront risk mitigation considerations
  - Monitor program for correlation adjustments as definition matures and during execution to program advantage and proactively manage what you are good at
  - Justify aligning resources to manage "bad" correlations

- Model may have application to initial budgeting assessments or sizing

Future Work

- Further explore the business and program applications model
- Enhance development of table of correlation risk drivers, and allocation of total risk value to individual elements
- Evolve the model to accommodate variable σ across cost elements and probability of lower and upper bounds
- Develop approach to evaluation of “cost opportunity” and what beneficial correlation drivers can be encouraged
- Work with ICEAA community to determine overall benefits of these conclusions

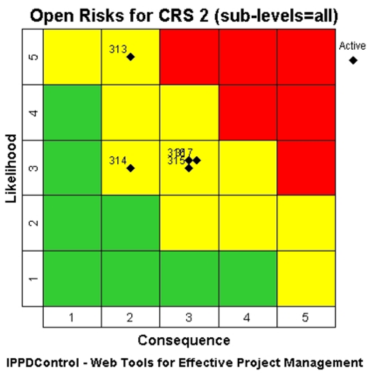
Backup

Initial Discussions of Cost Risk Usually Waited for Some Level of Baseline Detail Definition

WBS
11000 PM
11100 Program Management
11200 Chief Engineer, Quality, Mfg & Proc Integrators
11300 Business Management
11400 Travel
11500 ODC
12000 Reserved
13000 E-1
13100 Reserved
13200 Hardw are
13210 NRE
13220 Support to Procurements
13230 Support to In-house Fab / Assy
13240 Flight Support
13250 E-1 Project Integration
14000 E-2
14100 Reserved
14200 Hardw are
14210 NRE
14220 Support to Procurements
14230 Support to In-house Fab / Assy
14240 Test / Flight Support
14250 E-2 Project Integration
15000 SE
15100 Requirements Engineering
15200 Integration and Architecture
15210 SE Project Integration
15300 V&V
15400 Systems Analysis
15500 Design Review s
15600 Risk Management
15700 Mass Properties, Reliability & Supportability Engineering
15800 CM/DM
15900 SDRLs

Assessed WBS and scope for level of assessment

- Level A for Monte Carlo
- Level A+1 and A+2 for estimate uncertainty evaluation



	WBS 10000	WBS 20000	WBS 30000	WBS 40000	WBS 50000	WBS 60000
WBS 10000	1					
WBS 20000	0.00	1				
WBS 30000	0.25	0.25	1			
WBS 40000	0.85	0.00	0.25	1		
WBS 50000	0.25	0.85	0.25	0.00	1	
WBS 60000	0.20	0.20	0.25	0.50	0.50	1

Created WBS correlation coefficient matrix with program team

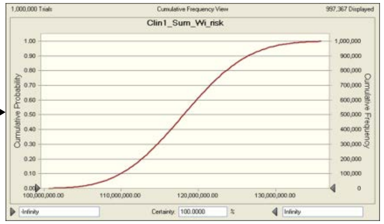
CODES	Upper	Lower	Descriptions
1A	1.02	0.9	[redacted]
1B	1.05	0.9	
1C	1.07	0.9	
1D	1.05	0.95	
2A	1.1	0.95	
2B	1.15	0.95	
2C	1.15	0.95	
2D	1.15	0.95	
2E	1.15	0.95	
3A	1.2	0.92	
3B	1.2	0.92	
3C	1.25	0.9	
3D	1.27	0.85	
3E	1.3	0.8	
3F	1.3	0.8	
3G	1.3	0.8	
4A	2	0.6	
4B	2	0.6	
0	1	1	(0) no variation used

Risk probabilities
Impact magnitudes

Bill of Material$_{WBS}$

Lo / ML / Hi

Labor$_{WBS}$



Monte Carlo Analysis

Applied Historical Estimate Uncertainty Factors