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The 3-Point Method Redux: Estimating Cost Uncertainty Given Only a Baseline Cost

Presented by:

Marc Greenberg
Strategic Investment Division (SID)
National Aeronautics and Space Administration

Outline

- **Review example by Robert L Abramson and Dr. Stephen Book**
  - ✓ 2007 paper: *Estimating Cost Uncertainty when only Baseline Cost is Available*
- **Present Notional Example of 3-Point Method**
  - ✓ **Risk Criteria Matrix**
    - Based upon 2007 Maxwell Risk Criteria Matrix
    - 6 *risk-driver* **categories** (6 columns) by 6 *intensity* **levels** (6 rows) = 36 descriptors
  - ✓ **Apply Analytic Hierarchy Process (AHP) to Risk-Driver Categories**
    - Pairwise comparison of risk-driver categories → weighted values of each category
  - ✓ **Develop Min, Most-Likely and Max Values (= Triangular Distribution)**
    - Five-step process
- **Describe how this presentation is similar & different from 2007 paper**
- **3-Point Method Demonstration (**if time permits**)**

R. L Abramson and Dr. Book Example

Estimating Cost Uncertainty when only Baseline Cost is Available (2007)

- Example provided in 2007 paper * entitled:
  - *Estimating Cost Uncertainty when only Baseline Cost is Available*
- F. D. Maxwell (Aerospace Corp.) developed a risk-driver matrix known at the USAF Space and Missile Systems Center (El Segundo, CA) as the **Maxwell Risk Criteria Matrix (MRCM)**
  - Using the MRCM, R.L. Abramson and S. A. Book (Aerospace Corp.) outlined a procedure for developing a cost estimate of a subsystem incorporating the influence of risk on cost.
  - Risk Driver Criteria weights and Intensity Level weights are determined quantitatively through pairwise comparisons (the Analytical Hierarchy Process, AHP) applied to the MRCM.

**** The paper can be downloaded at***
http://www.laserlightnetworks.com/Documents/Estimating%20Cost%20Uncertainty%20when%20Only%20Baseline%20Cost%20is%20Available.pdf

R. L Abramson and Dr. Book Example (cont'd)

RISK-DRIVER CATEGORY	INTENSITY LEVEL				
	Low	Medium Low	Medium	Medium High	High
1. Required Technical Advancement	Nothing new	Minor modifications only	Major modifications	State of the art	Beyond state of the art
2. Technology Status	Currently in use	Prototype exists	Under development	In design	Concept stage
3. Complexity	Simple	Somewhat complex	Moderately complex	Highly complex	Highly complex with uncertainties
4. Interaction/ Dependencies	Independent of other risk drivers	Dependent on one additional risk driver	Dependent on two additional risk drivers	Dependent on three additional risk drivers	Dependent on more than three additional risk drivers
5. Process Controls	Statistical process controls	Documented controls	Limited controls	Inadequate controls	No known controls
6. Manufacturing Precision	High	Adequate	Limited margins	Known but inadequate	Unknown
7. Reliability	Historically high	Average	Known limited problems	Serious problems of unknown scope	Infeasible
8. Producibility	Established	Demonstrated	Feasible	Known difficulties	Infeasible
9. Criticality to Mission	Nonessential	Minimum impact	Known alternatives available	Possible alternatives exist	"Show stopper"
10. Cost	Established	Known history or close analogies	Predicated by calibrated model	Out of range of experience	Unknown or unsupported estimate
11. Schedule	Demonstrated	Historical similarity	Validated Analyses	Inadequate analyses	Unknown or unsupported estimate

For the 2007 paper's example:

Project Baseline Cost is estimated = $7.55 M

From the MRCM to the left, four risk-driving categories were selected & ranked.

Then, using pairwise comparison & AHP, weights were calculated for each category:

	Weight
Technology Status	0.458
Complexity	0.326
Dependencies	0.128
Reliability	0.088

R. L Abramson and Dr. Book Example (cont'd)

- **The next step was to create Intensity "look-up table"**

INTENSITY	RAW VALUE	NORMALIZED VALUE
Low	1	0.087
Medium-Low	1.5	0.130
Medium	2	0.174
Medium-High	3	0.261
High	4	0.348

- **Then, for the given Program, the SME assigns Intensities to each Risk-driver Category …**
  - *Example:* Baseline rated Complexity as Medium-High

- **This "intensity-level assignment" process by the SME is performed for 3 scenarios …**
  - Optimistic: e.g., Complexity Intensity = **Medium-Low** = 0.130
  - Baseline: e.g., Complexity Intensity = **Medium-High** = 0.261
  - Pessimistic: e.g., Technology Status = **High** (concept stage) = 0.348

ACTIVITY: Entire Program		WEIGHTS	Technology Status	Complexity	Interaction Dependencies	Reliability
Point Estimate	*Composite*		0.458	0.326	0.128	0.088
Optimistic	*0.174*	Intensity	0.174	0.13	0.348	0.087
		Score	*0.08*	*0.043*	*0.044*	*0.008*
Baseline	*0.206*	Intensity	0.174	0.261	0.087	0.348
		Score	*0.08*	*0.085*	*0.011*	*0.031*
Pessimistic	*0.289*	Intensity	0.348	0.261	0.261	0.13
		Score	*0.159*	*0.085*	*0.033*	*0.011*

These 4 weights are from AHP (refer to slide 4)

Intensity values selected from table above. Higher value implies higher risk / challenge.

- **Scores for each scenario are the "sum-product" of the AHP weights and intensities**

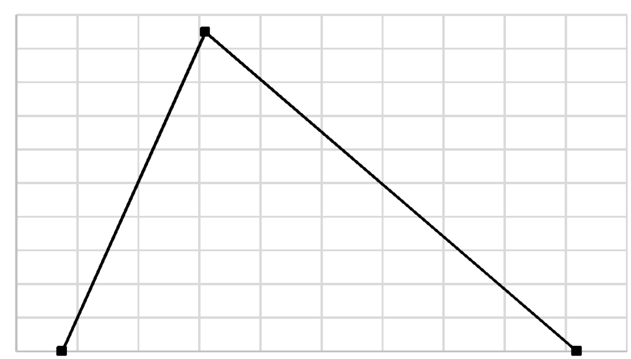
R. L Abramson and Dr. Book Example (cont'd)

- **(from previous slide) Calculated <u>composite values</u> for 3 scenarios:**
  - Optimistic = 0.174
  - Baseline = 0.206
  - Pessimistic = 0.289

- **Next step: Calculate composite value <u>ratios</u> relative to Baseline value:**
  - Optimistic / Baseline = 0.174 / 0.206 = **0.8447**
  - Pessimistic / Baseline = 0.289 / 0.206 = **1.4029**

- **The final step: apply these two ratios (of composite values) to Baseline cost ($7.55 M)**
  - Optimistic = Minimum = **$7.55 M** x **0.8447** **= $ 6.38 M**
  - Pessimistic = Maximum = **$7.55 M** x **1.4029** **= $10.59 M**

- **The 3-Point Method example produced a Triangular Distribution from a Baseline cost**
  - Minimum = **$ 6.38 M**
  - Most-Likely = **$ 7.55 M**
  - Maximum = **$10.59 M**



3-POINT METHOD

(NOTIONAL EXAMPLE)

Risk Criteria Matrix (6 x 6)

Combining elements of Maxwell Risk Criteria Matrix with Intensity Levels

6 Intensity Levels
Note: SME specifies each raw #

Intensity	Raw	Normalized
Low	0.5	0.0313
Medium-Low	1.5	0.0938
Medium	2	0.1250
Medium-High	3	0.1875
High	4	0.2500
Very High	5	0.3125

Each Normalized # = Raw # / Σ (Raw #'s)

6 Risk-Driver Categories

Intensity Scale:	Required Tech Advancemt	Technology Status	Design Complexity	Interaction/ Dependencies	Labor Skillset	Programmatic Experience
Low	Nothing new	Phase D: Sys Assembly, Integ & Test	Simple	Interaction of 2 key participants	Very high skill mix	Proven track record; extensive experience
Medium-Low	Minor modifications	Phase C: Final Design & Fab	Somewhat complex	Interaction of 3 key participants	High skill mix	Good amount of experience with similar efforts
Medium	Major modifications	Phase B: Prel Desn & Tech Completion	Moderately complex	Interaction of 4 key participants	Moderate-to-High skill mix	Moderate experience with similar efforts
Medium-High	State of the art	Phase A: Concept & Tech Development	Highly complex	Interaction of 5 key participants	Moderate skill mix	Moderate-Low experience with similar efforts
High	Beyond state of the art	Pre-Phase A: Concept Studies	Highly complex with some uncertainties	Interaction of 6 key participants	Low skill mix	Very limited experience with similar efforts
Very High	Far exceeds state of the art	Prior to Concept studies	Highly complex with many uncertainties	Interaction of more than 6 key participants	Very low skill	Virtually no experience with similar efforts

Description of each risk-driver category by intensity level

Applying AHP to Risk-Driver Categories

SME Input: Pairwise comparison of risk-driver categories

Example 1: Pairwise comparison of Technology Advancement and Technology Status

Pair #1 — Pairwise Comparison wrt IMPACTS on Average Project Cost

Risk Factor	Risk Factor
Required Tech Advancemt	Technology Status
← LHS is More Important	RHS is More Important →

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Absolutely More Important		Very Strongly More Important		Strongly More Important		Slightly More Important		Equally Important		Slightly More Important		Strongly More Important		Very Strongly More Important		Absolutely More Important

Q1	Equal?	No	(If No, then answer Q2)
Q2	More Important?	Required Tech Advancemt	
Q3	Likert Score =	2.00	

Example 2: Pairwise comparison of Design Complexity and Labor Skillset

Pair #11 — Pairwise Comparison wrt IMPACTS on Average Project Cost

Risk Factor	Risk Factor
Design Complexity	Labor Skillset
← LHS is More Important	RHS is More Important →

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Absolutely More Important		Very Strongly More Important		Strongly More Important		Slightly More Important		Equally Important		Slightly More Important		Strongly More Important		Very Strongly More Important		Absolutely More Important

Q1	Equal?	No	(If No, then answer Q2)
Q2	More Important?	Design Complexity	
Q3	Likert Score =	2.50	

These paired values are the basis for weighting risk-driver categories.

Applying AHP to Risk-Driver Categories

Weighting risk-driver categories based upon pairwise values

Raw P/W Weighting	Required Tech Advancemt	Technology Status	Design Complexity	Interaction/ Dependencies	Labor Skillset	Programmatic Experience
Required Tech Advancemt	1	2	1	3 1/2	3 1/2	4
Technology Status	1/2	1	1	2 1/2	2	3
Design Complexity	1	1	1	3	2 1/2	3 1/2
Interaction/ Dependencies	2/7	2/5	1/3	1	1 1/7	4
Labor Skillset	2/7	1/2	2/5	7/8	1	3 1/2
Programmatic Experience	1/4	1/3	2/7	1/4	2/7	1
Sum	**3.321**	**5.233**	**4.019**	**11.120**	**10.436**	**19.000**

Example for calculating normalized values (as shown in matrix below):

- Raw value * of "*Technology Status* & *Required Tech Advancement*" pair = ½ = 0.5
- Normalized value of this pair = 0.5 / 3.321 = **0.151**

Normalized Matrix	Required Tech Advancemt	Technology Status	Design Complexity	Interaction/ Dependencies	Labor Skillset	Programmatic Experience	Weights	Product	Ratios
Required Tech Advancemt	0.301	0.382	0.249	0.315	0.335	0.211	0.2988	1.8901	6.3260
Technology Status	0.151	0.191	0.249	0.225	0.192	0.158	0.1941	1.2254	6.3119
Design Complexity	0.301	0.191	0.249	0.270	0.240	0.184	0.2391	1.5087	6.3104
Interaction/ Dependencies	0.086	0.076	0.083	0.090	0.110	0.211	0.1093	0.6830	6.2461
Labor Skillset	0.086	0.096	0.100	0.078	0.096	0.184	0.1066	0.6620	6.2130
Programmatic Experience	0.075	0.064	0.071	0.022	0.027	0.053	0.0521	0.3176	6.0968
Sum	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**CI**	**0.0501**
								CI/RI	**0.0557**

*** The SME believes that "Required Tech Advancement" is slightly more important than "Technology Status."**

Recap of Example (slides 7 – 9):
Intensity Levels & Weight per Risk Category

Referring to Slide 8: The following Intensity "look-up" table was created:

Intensity	Raw	Normalized
Low	0.5	0.0313
Medium-Low	1.5	0.0938
Medium	2	0.1250
Medium-High	3	0.1875
High	4	0.2500
Very High	5	0.3125

Referring to Slide 11: Using pairwise comparison & AHP, the following weights were calculated for each risk category:

	Weight	
Required Tech Advancement	0.299	→ Biggest influence
Technology Status	0.194	
Design Complexity	0.239	
Interaction/Dependencies	0.109	
Labor Skillset	0.107	
Programmatic Experience	0.052	→ Smallest influence

These intensity levels & weighted values will be used for calculating the optimistic, baseline and pessimistic estimates (in slides 12 – 15)

Create Triangular Distribution from a Baseline Coefficient of Variation (CV) of a Spacecraft Instrument

Notional Project:
Electro-Nuclear Geosynchronous Observation Instrument (E-NGOI)

1. **Starting with discrete baseline value, select baseline intensity levels by category**
2. **Select intensity levels for each category for optimistic, most-likely & pessimistic scenarios**
3. **Calculate composite values per scenario**
4. **Calculate composite value ratios.**
5. **Apply composite value ratios to the Baseline value.** (Plot triangular distribution**).**
   - Assess resulting triangular distribution (realistic & credible?)
   - As-needed: Revisit inputs from step #2; revisit pairwise comparisons

One way to estimate discrete Baseline CV is from a CV dataset …

Develop Min, Most-Likely and Max Values

1. Starting w/baseline value, select baseline intensity levels by category

Project	Approx CV
Project A	0%
Project Y	1%
Project Z	1%
Project N	1%
Project O	1%
Project P	2%
Project Q	[illegible]
Project R	[illegible]
Projec[illegible]	[illegible]
Project[illegible]	[illegible]
Project[illegible]	[illegible]
Instrume[illegible]	7%
Instrume[illegible] B	8%
Instrument C	9%

Project	Approx CV
Rocket W	11%
Technology V	12%
Project T	12%
Mission TT	13%
Rocket R	[illegible]
Research T[illegible]	[illegible]
[illegible]	17%
[illegible]ent NN	17%
Instrument ZZ	17%
Mission Q	18%
Mission R	20%
Tech Demo D	23%
Mission LL	23%
Mission MM	25%

Project	Approx CV
Spacecraft TT	26%
Mission QQ	[illegible]
Instrument [illegible]	[illegible]
[illegible]	33%
[illegible]	33%
Tech Demo BB	34%
Mission ABC	40%
Tech Demo DE	45%
Mission DEF	46%
Project MNO	48%
Mission MO	56%
Mission NN	62%
Instrument XZ	62%
Rocket XXX	72%
Spacecraft MM	117%
Mean =	**23.3%**
Median =	**17.1%**

From notional CV dataset, use median CV (17.1%) as Baseline value

Using matrix (from slide 8), the median CV represents …

*Intensities based upon Median Value of Dataset **		Required Tech Advancemt	Technology Status	Design Complexity	Interaction/ Dependencies	Labor Skillset	Programmatic Experience
Presets (Must be complete prior to making selections)	Baseline Intensities	State of the art	Phase A: Concept & Tech Development	Highly complex	Interaction of 4 key participants	Moderate-to-High skill mix	Moderate experience with similar efforts
* These selections are unrelated to "E-NGOI"		**Medium-High**	**Medium-High**	**Medium-High**	**Medium**	**Medium**	**Medium**
	Baseline Intensities	0.188	0.188	0.188	0.125	0.125	0.125

Develop Min, Most-Likely and Max Values

2. Select intensity levels for each risk-driver category (for 3 scenarios);
3. Calculate composite values for each scenario

Composite Baseline Value:

= Sum Product of Baseline Intensities (from previous slide) and Risk-Factor Weights (slide 10)

Risk Factor Weights:	*0.299*	*0.194*	*0.239*	*0.109*	*0.109*	*0.052*	
	Required Tech Advancemt	Technology Status	Design Complexity	Interaction/ Dependencies	Labor Skillset	Programmatic Experience	Sum Product
Baseline Intensities	0.188	0.188	0.188	0.125	0.125	0.125	0.171

Using matrix (from slide 8), select Intensities for each risk-driver category by Scenario

Scenario Intensities:		Tech Advancemt	Technology Status	Design Complexity	Interaction/ Dependencies	Labor Skillset	Programmatic Experience
Optimistic Intensities	Must be lower vs ML on the Intensity Scale	Medium-High	Medium-High	Medium-High	Medium	Medium-Low	Medium-Low
Most Likely (ML) Intensities		Medium-High	Medium-High	High	Medium	Medium-Low	Medium
Pessimistic Intensities	Must be higher vs ML on the Intensity Scale	High	High	Very High	High	Medium	Medium-High

Calculate "Composite Value" for each Scenario

= Sum Product of Baseline Intensities (from previous slide) and Risk-Factor Weights (slide 10)

Risk Factor Weights:	*0.299*	*0.194*	*0.239*	*0.109*	*0.107*	*0.052*	
	Required Tech Advancemt	Technology Status	Design Complexity	Interaction/ Dependencies	Labor Skillset	Programmatic Experience	Sum Product
Optimistic Intensities	0.188	0.188	0.188	0.125	0.094	0.094	0.166
Most Likely Intensities	0.188	0.188	0.250	0.125	0.094	0.125	0.182
Pessimistic Intensities	0.250	0.250	0.313	0.250	0.125	0.188	0.248

Develop Min, Most-Likely and Max Values

4. Calculate composite score ratios
5. Apply composite score ratios to the Baseline value (plot triang dist'n)

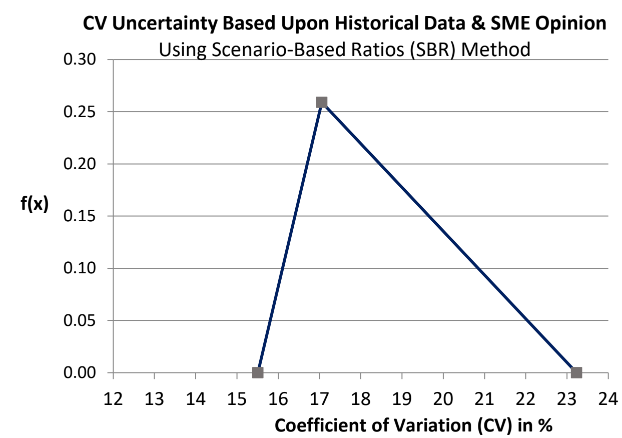
- **(from previous slide) Calculated <u>composite values</u> for 3 scenarios (for E-NGOI):**
  - Optimistic = 0.166
  - Most-Likely = 0.182
  - Pessimistic = 0.248

- **Next step: Calculate composite score <u>ratios</u> relative to Baseline score:**
  - Optimistic / Baseline = 0.166 / 0.171 = **0.9091**
  - Most-Likely / Baseline = 0.182 / 0.171 = **1.0658**
  - Pessimistic / Baseline = 0.248 / 0.171 = **1.3619**

Baseline Composite Value of 0.171 is based upon the median of the CV dataset

- **The final step: apply these 3 ratios (of composite scores) to Baseline CV = 17.1%**
  - Optimistic = Minimum = **17.1%** x **0.9091** **= 15.5%**
  - Most-Likely = Mode = **17.1%** x **1.0658** **= 18.2%**
  - Pessimistic = Maximum = **17.1%** x **1.3619** **= 23.2%**

- **The 3-Point Method example produced a Triangular Distribution from a Baseline cost:**
  - Minimum = **15.5%**
  - Most-Likely = **18.2%**
  - Maximum = **23.2%**



Similarities & Differences (vs. 2007 Paper)

- **Similarities**
  - Data requirement is one value (i.e., Baseline Coeff. of Variation, CV)
  - Select at least four risk-driver categories (from larger MRCM matrix)
  - Intensity "look-up" table (at least 5 intensity levels)
  - Application of pairwise comparison and AHP to calculate weights for each risk-driver category
  - Calculate composite value for each scenario
    - Optimistic, Most Likely and Pessimistic scenarios
    - Composite value = Sum product of weights and intensities
  - Calculate composite value ratios & apply to Baseline CV.
- **Differences**
  - Most-likely value not necessarily equal to Baseline value
  - Customized (some) risk-driver categories & descriptions
  - Reformatted matrix (e.g., intensity levels in rows, not columns)
    - "Automated" look-up of values in Excel with pull-downs, etc.
  - Evaluate output graphic of triangular distribution (seem reasonable?)

3-POINT METHOD DEMONSTRATION

(If Time Permits)