

Estimating Cost Uncertainty when only Baseline Cost is Available

A Typical Problem

It is always better to have upper and lower bound projections of the cost of a project. In most companies the project team estimates from the lowest level of the Work Breakdown Structure, the bottom, and rolls consecutively higher levels up to the top. This is the most accurate estimate, as compared to analogy methods and cost estimation relationships, especially when the team performing the estimate is the same team performing the actual work.

For small projects and in small companies, there is usually only a single point estimate made, the baseline. A single estimate cannot account for either cost escalation or cost savings. A cumulative probability distribution of cost would produce cost percentiles and provide a much better, quantitative method to handle cost risk.

Cost Uncertainty Estimating Methods

Pure cost estimation uncertainty occurs when variations result even when configuration items remain constant. These uncertainties result from errors in historical data, cost estimating relationships, specifications, analogies, extrapolations, or differences among analysts and their procedures. Such errors usually amount to only 5%¹. Most cost uncertainty is due to changes in a configuration item due to changes in requirements, technology, specifications, performance characteristics, interfaces, operational-deployment-support concepts, et al - all of these are non-cost parameters. It is generally accepted that the biggest risk in most projects is technology risk.

It is difficult to get many project teams to provide more than the baseline cost. However, all projects must provide a risk plan that includes identification, analysis, prioritization, and management. One way to evaluate cost uncertainty is to tie it to the risk assessment. When key team members assess the risk and when the same players are responsible for the baseline cost estimate, it is possible to project reasonably accurate cost inflation/deflation.

Both NASA and the USAF use risk analysis to quantitatively assess cost uncertainty.

USAF Methodology

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). It is a qualitative evaluation of subsystem risk relative to select criteria, see Table 1².

R.L. Abramson and S. A. Book (also of Aerospace Corp.) took the MRCM and outlined a procedure for developing a cost estimate of a subsystem incorporating the influence of risk on cost. Both the Risk Driver Criteria weights and Intensity Level weights are determined quantitatively through pair wise comparisons (the Analytical Hierarchy Process, AHP³) applied to the MRCM⁴.

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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

Table 1 Maxwell Risk Criteria Matrix

Using the AHP permits scaling independent of the other criteria and without having to make an arbitrary determination of whether this scale is linear, logarithmic, exponential, or another scale. The subsystem expert’s judgments determine the mathematical scale.

Once the MRCM levels are quantitatively addressed, the procedure for estimating cost uncertainty is briefly as follows. The subsystem (assembly, subassembly, or entire program) is rated against each risk driver category with respect to where the subsystem falls within each category risk level. A weighted score is obtained by summing across all risk-driver categories. This score is divided by the reference point score to obtain a ratio. The ratio is applied to the baseline to determine a high-end cost estimate. The same procedure may be applied to obtain a low-end estimate. Then the three points – Baseline, low (Optimistic), and high (Pessimistic) cost Estimates - are used in a Beta or Triangular Distribution to develop the cumulative probability for cost.

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The advantage of this procedure is that when assessments are unbiased and performed in a consistent manner, exact quantitative weights are unimportant - only the *ratios*, Optimistic-to-Baseline, and Pessimistic-to-Baseline, are used. Using the same personnel to develop both the baseline costs as well as the risk rankings ensures consistency as much as possible.

Example of Three Point Method Based on Risk Evaluation

A risk assessment (performed by the key subproject engineers, program manager, and systems engineer) on a project determined that Technology Status, Complexity, Interaction Dependencies, and Reliability were most important. Table 2 illustrates the use of AHP in a pair wise comparison among these four parameters. Raw Rankings are converted into Normalized Rankings by 1) dividing each column entry by the sum of all entries in a column, 2) averaging the normalized entries across each row to form the column labeled “weights”, 3) performing a sum check on the weights column to assure the sum of the weights equals one. Thus Technology Status was deemed the most important and Reliability least important.

RAW RANKINGS	Technology Status	Complexity	Interaction/ Dependencies	Reliability
Technology Status	1.00	3.00	2.00	5.00
Complexity	0.33	1.00	4.00	5.00
Dependencies	0.50	0.25	1.00	1.00
Reliability	0.20	0.20	1.00	1.00

NORMALIZED RANKINGS	Technology Status	Complexity	Interaction/ Dependencies	Reliability	WEIGHTS
Technology Status	0.492	0.674	0.250	0.417	0.458
Complexity	0.164	0.225	0.500	0.417	0.326
Dependencies	0.246	0.056	0.125	0.083	0.128
Reliability	0.098	0.045	0.125	0.083	0.088

Table 2 Example of AHP Ranking Applied to Subset of MRCM

The Intensity Levels of Table 1 must also be pair ranked, and the results are as shown in Table 3. The scale is linear in the sense that a Medium value is twice as intense as a Low value, though for the following analysis this is unimportant as long as it does not change.

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

Table 3 AHP Applied to Intensity Levels of Table 1

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For simplicity, assume that the four risk drivers apply to the entire project, and the project Baseline Cost is estimated to be \$7.55 Million.

The risk categories with their associated weights are placed into Table 4 to provide scores for Optimistic, Pessimistic and Baseline estimates. Rather than placing “Low,” “Medium-Low,” “Medium,” etc., into the scoring matrix, the values from Table 3 are shown explicitly. For example, the Baseline estimate process rated Complexity as Medium High, while the Optimistic estimate rated it Medium Low.

ACTIVITY: Entire Program			Status	ty	Interaction Dependencies	Reliability
Point Estimate	Composite	WEIGHTS	0.458	0.326	0.128	0.088
Optimistic	0.174	Intensity	0.174	0.130	0.348	0.087
		Score	0.080	0.043	0.044	0.008
Baseline	0.206	Intensity	0.174	0.261	0.087	0.348
		Score	0.080	0.085	0.011	0.031
Pessimistic	0.289	Intensity	0.348	0.261	0.261	0.130
		Score	0.159	0.085	0.033	0.011

Table 4 Calculation of Baseline, Optimistic, Pessimistic Scores

The score at the intersection of a risk category and an estimate category is the product of the category weighting factor and intensity weight, and the composite score is the sum across a row.

Two ratios are then formed:

Optimistic/Baseline = 0.174/0.206 = 0.84, and
 Pessimistic/Baseline = 0.289/0.206 = 1.40.

Then a Triangular or Beta Distribution is calculated using:

Baseline = Mode = \$7.55 M
 Optimistic = Minimum = \$7.55 M x 0.84 = \$6.37 M
 Pessimistic = Maximum = \$7.55 M x 1.40 = \$10.58 M

Probability vs. Amount	
Percentile	\$M
25%	7.32
50%	7.80
75%	8.34
90%	8.83
95%	9.11
99.900%	9.98

Results for the Beta Distribution and its associated Cumulative Probability are shown as Figures 1 and 2, respectively, and the percentiles are in Table 5.

Table 5 Percentiles for Example Beta Distribution

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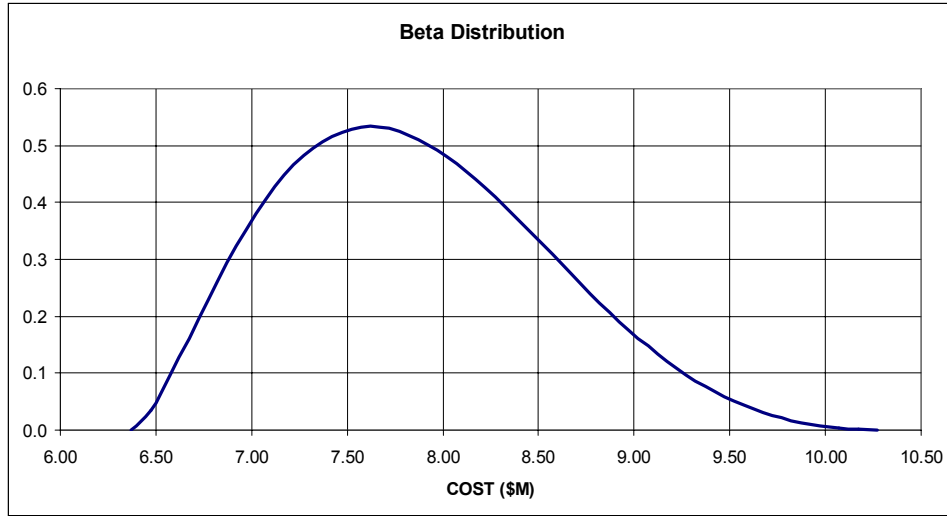


Figure 1 Beta Distribution for Example

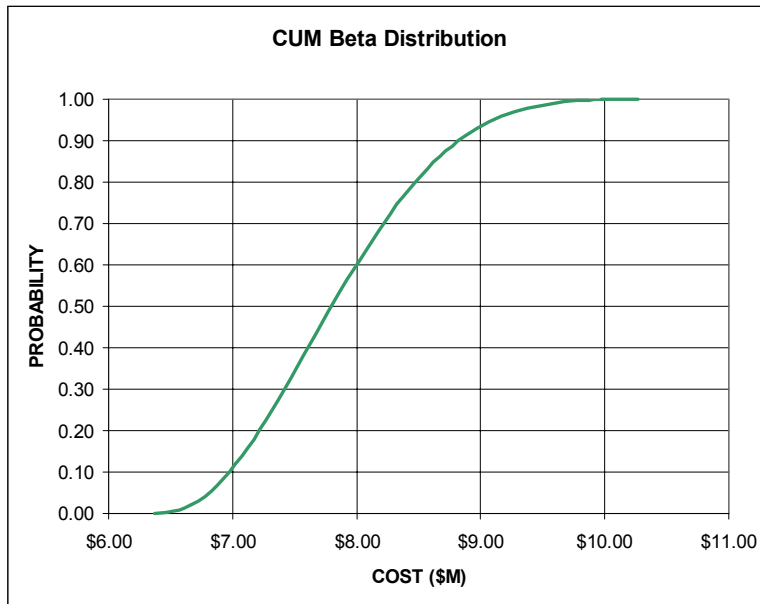


Figure 2 Cumulative Beta Probability for Example

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NASA Methodology

The three-point methodology of NASA is equivalent to that of the Air Force. NASA uses Risk Templates for the Risk Categories and follows the same procedures⁵ as above, which is called Relative Risk Weighting (RRW).

Additionally, NASA devised a Cost Readiness Level scheme⁶ similar to their Technology Readiness Level scheme, shown as Table 6. The percentage differences between the 25% vs. 50% percentiles and 75% vs. 50% percentiles are computed, and the larger of these two values compared to Table 6 to assess the CRL. For the previous example, these values are -6% and +7%, thus the CRL is 7. This scale may not be widely accepted as yet. Of interest is the points at which the accuracy estimates break between categories.

Cost Readiness Level (CRL)	Description fitness for use as cost information for a flight project	Percentage Accuracy
9	End of project actual cost	100%
8	Cost fit for very firm engineering decisions and very firm budget commitments	(+/- 5%)
7	Cost fit for firm engineering decisions and firm budget commitments	(+/- 15%)
6	Cost fit for PDR engineering decisions and PDR budget use	(+/- 25%)
5	Cost fit for preliminary engineering decisions and preliminary budget use	(+/- 35%)
4	Cost fit for very preliminary engineering decisions and very preliminary budget use	(+/- 45%)

Table 6 NASA Cost Readiness Levels

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Scenario Based Method

The Scenario Method uses well-defined sets of alternative technical and programmatic assumptions then defines resultant costs for each Scenario. The difference between the Baseline Scenario cost and any other Scenario cost measures cost increase or cost reduction. The advantage to this method is that the risk and cost of the risk are *directly related and traceable* in the sense that if a specific risk element is eliminated from consideration by program management, the overall program cost must be reduced by that element's associated cost. Different Scenarios may be hypothesized, analyzed, and evaluated for cost increase/decrease. This method does not use cost variables or assume probability distribution functions, and is a direct measure of cost risk.

RAND Corporation describes three Scenarios in using this method⁷:

- Baseline: The normal course of execution of the program and normal risks expected to be encountered is the Baseline. It is a balanced picture of what will occur but neither overly optimistic nor pessimistic.
- Pessimistic: This does not mean worst possible case; rather, it incorporates selected risks beyond those included in the baseline scenario. It includes probable consequences due to the identified risks that the program manager would want to have budget for to guard against should the risks occur. The project team must identify the most critical risk subset that is most likely to occur, which involves modifying some of the technical and programmatic conditions that defined the Baseline Scenario.
- Optimistic: This means identifying potential opportunities for cost *savings* from enhancements, or cuts, or select actions. The project team must identify the subset that are most likely to occur and which involves modifying some of the technical and programmatic conditions that defined the Baseline Scenario.

The difference between the Pessimistic and Baseline estimates defines the Risk Reserve Budget required to guard against the risks over and above those of the Baseline Scenario. The Optimistic Scenario is many times simply ignored, but points out possible cost savings.

The Scenario Based Method does not generate confidence intervals. Garvey⁸ (MITRE) augmented the method to provide an option for using confidence intervals. He argued that the true cost falls within the interval bounded by the Baseline (a_1) and Pessimistic (b_1) Estimates, which is assumed to be *uniformly distributed* with probability α . Figure 3 shows the Uniform Distribution and relates it to Garvey's terms.

Note that for the Uniform Distribution, the cumulative probability that the cost will be at or below a certain amount X is:

$$\text{Cum Pr obability}(\text{Cost} \leq X) = (X - a)/(b - a),$$

which is easily calculated.

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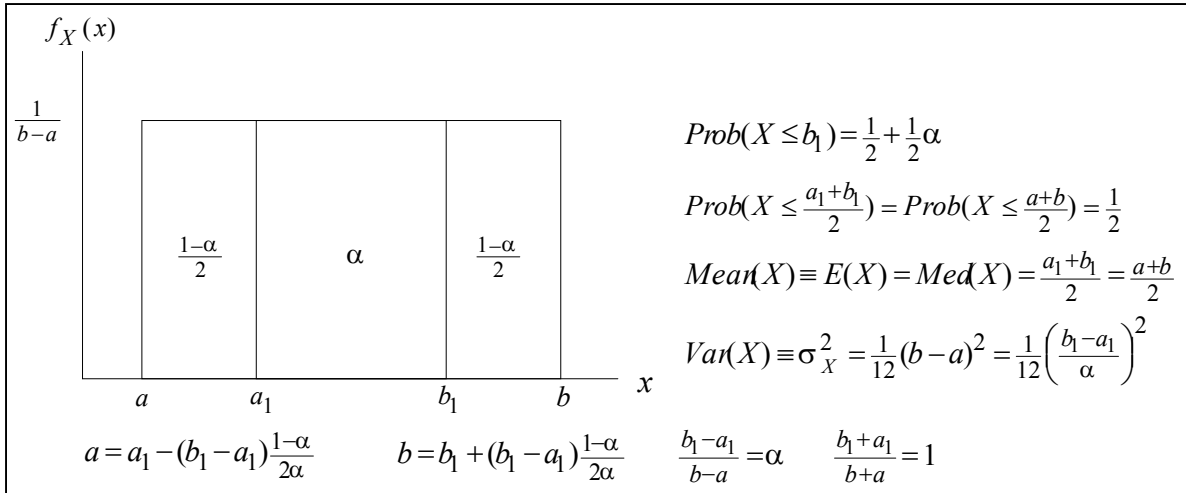
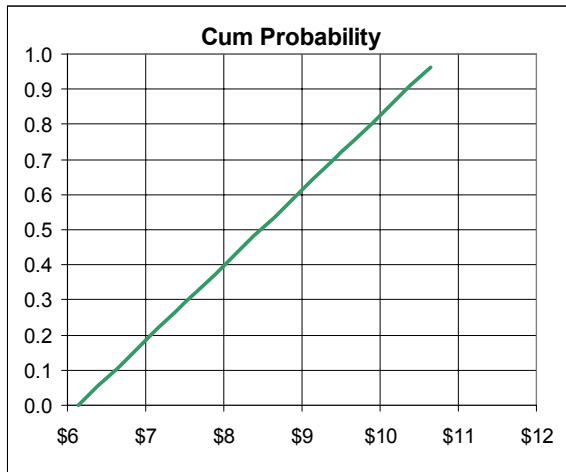


Figure 3 Uniform Distribution & Definitions for Cost Estimation Parameters

For $\alpha = 0.60,$ Cum Prob(Cost $\leq b_1$) = 0.80,
 $\alpha = 0.75,$ Cum Prob(Cost $\leq b_1$) = 0.875
 $\alpha = 0.90,$ Cum Prob(Cost $\leq b_1$) = 0.95.

For the previous example above, let $\alpha = 0.90$. The Baseline Estimate was $a_1 = \$6.37$ M, and the Pessimistic Estimate was $b_1 = \$10.58$ M. Therefore, $a = \$6.14$ M and $b = \$10.81$ M. The Cumulative Probability and Percentiles are as shown in Figure 4 and Table 7.



Percentile	Amount	
25%	\$7.26	
50%	\$8.39	Median
75%	\$9.51	
90%	\$10.19	
95%	\$10.41	

Table 7 Percentiles for Uniform Distribution for Example

Figure 4 Cumulative Uniform Probability for Example

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Here are several key points to this method:

- Monte Carlo simulation is *not* required for using the Scenario Based Method.
 - The Monte Carlo method captures a full range of potential cost outcomes that are driven by both *favorable and unfavorable* events.
- In the Scenario Based Method, outcomes of well-defined scenarios are captured that are driven by only *unfavorable* events (for the Pessimistic Scenario).
- Percentiles are calculated using simple algebra.
- Assuming a Uniform Distribution is a conservative approach.
- The amount of Risk Reserve Budget is well defined and since it is directly related to specific risk elements, the claim for it is well defined.
 - The process integrates risk reserve monies directly with the Work Breakdown Structure.

Conclusion

It is often difficult to come up with more than a Baseline, single point cost estimate when planning or starting a project. Yet nowadays the Baseline cost alone is simply insufficient - it does not thoroughly integrate cost with the risk plan and required reserve budget. This discussion showed how to quantitatively perform cost risk analysis using two methods. The first was a probabilistic method tied to a quantitative risk assessment and used a three-point estimate with an assumed distribution function to determine confidence intervals. The second method was deterministic, based on assuming different scenarios for risk then computing cost directly.

Either or both of these methods may be used for small projects with or without Monte Carlo simulation, which remains a Best Practice for Cost Risk estimation.

REFERENCES

¹ **FAA Life Cycle Cost Estimating Handbook, June 3, 2002**, p8-6

² R.L. Abramson and S. A. Book, "A Quantification Structure For Assessing Risk-Impact Drivers," briefing presented to the 24th Annual DoD Cost Symposium (Leesburg, VA, September 5-7, 1990)

³ Ernest Forman, **Decision by Objectives**, (book available at: www.mdm.gwu.edu/forman)

⁴ See Ref. 2

⁵ **NASA Cost Estimation Handbook 2004**, p.156

⁶ *Ibid.*, pp 105-107

⁷ Mark Arena, Obaid Younossi, et al, **Impossible Certainty: Cost Risk Analysis for Air Force Systems**, RAND Corporation, Project Air Force, 2006, Appendix F

⁸ Paul Garvey, "Cost Risk Analysis without Statistics!," MITRE Paper MP 050000001, February 2005, Presented as a seminar at the Huntsville Alabama Chapter of INCOSE on 15 Mar 2005.

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