Allocating “Risk Dollars” Back to Individual Cost Elements

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Abstract

Asymmetry of risks and opportunities for most WBS elements leads users of common estimating methods, such as "rolling up" (i.e., adding) most-likely costs of the various elements and labeling that sum the "point estimate," to underestimate actual program cost. Uncertainties in actual costs make it useful to model costs as random variables and to express program cost estimates in terms of percentiles of its probability distribution. After the point estimate of the program’s cost is determined by whatever method and definition are considered appropriate, it is sensible to establish a "management reserve" of additional funds to overcome unanticipated contingencies due to risks and other contingencies that may threaten to deplete the budget prior to program completion. Percentiles of the total-cost probability distribution can serve as guidelines for the size of an appropriate management reserve. If the point estimate falls at the 30th percentile level of the cost probability distribution, a prudent management reserve can be established by adding additional dollars to the point estimate in an amount that is required to bring the total amount of available dollars to the 50th, 70th, or even 80th percentile, depending on the criticality of the program. These additional dollars are often referred to as “risk dollars.”

Risk dollars in the management reserve pool, never very popular among funders, occasionally constitute a noticeably large percentage of the point-estimate-based candidate funding base. Even if that is not the case, funding organizations are typically reluctant to set aside large amounts of money for management reserve, believing that such pots of “slush funds” lead to sloth, waste, inefficiency, and generally slack management. It is therefore necessary to provide logical justification for such requests by displaying in a defensible way an allocation of the requested risk dollars among the various cost elements. This presentation suggests a mathematical procedure that allows the analyst to allocate risk dollars among program elements in a manner that is logically justifiable and consistent with the original goals of the cost-estimating task. Because a WBS element’s “need” for risk dollars arises out of the asymmetry of the uncertainty in the cost of that element, a quantitative definition of “need” must be the logical basis of the risk-dollar computation. In general, the more risk there is in an element’s cost, the more risk dollars will be needed to cover a reasonable probability (e.g., 0.70) of being able to complete that element of the program. Correlation between risks must also be taken into account to avoid double-billing for correlated risks or insufficient coverage of isolated risks.
Contents

• What Are “Risk Dollars”?  
  – What is Your “Point” Estimate?  
  – What Level of Confidence Do You Need?

• Why Allocate Risk Dollars?  
  – The Political Reason  
  – The Project-Management Reason

• How Should We Allocate Risk Dollars?  
  – The Difference between Uncertainty and Risk  
  – How Many Risk Dollars Does Each WBS Element Need?

• Summary
• **What Are “Risk Dollars”?**
  – What is Your “Point” Estimate?
  – What Level of Confidence Do You Need?

• **Why Allocate Risk Dollars?**
  – The Political Reason
  – The Project-Management Reason

• **How Should We Allocate Risk Dollars?**
  – The Difference between Uncertainty and Risk
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• **Summary**
The Term “Point” Estimate Must be Formally Defined

• A Necessity if the “Point” Estimate is to Serve as a Basis to which “Risk Dollars” will be Appended
• By “Point” Estimate, Do You Mean the …
  – … “Most Likely” Cost? (“Mode”)
  – … 50th-Percentile Cost? (“Median”)
  – … Expected Cost? (“Mean”)
  – … the “Roll-Up” of Most Likely Costs of Each WBS Element?
  – … Something Else?
• When Estimating Costs of Complex Hardware and/or Software Systems, These Numbers are Almost Always Different (Especially the “Something Else”)
• To Illustrate the Ideas, This Discussion Will Consider the “Point” Estimate to be the Roll-Up (i.e., “Sum”) of the WBS-Element Most Likely Costs
The Roll-Up “Point Estimate” in Pictures

**WBS-ELEMENT TRIANGULAR COST DISTRIBUTIONS**

**MERGE WBS-ELEMENT COST DISTRIBUTIONS INTO TOTAL-COST NORMAL DISTRIBUTION**

Note: The roll-up of WBS element most likely costs is not equal to the most likely total cost.

* When the Number of WBS Elements is “Large”
When WBS Elements Are Few...

**Note:** The roll-up of WBS element most likely costs is **still not** equal to the most likely total cost.
“Risk Dollars”

• Amount of Additional Dollars (beyond the Point Estimate) Required to Fund Program at an Appropriate Level of Confidence
  – If Point Estimate is the Roll-up of Elements’ Most Likely Costs, Lots of Risk Dollars Will Be Needed to Reach 50% Confidence Level and Even More to Reach 80% Level
  – If Point Estimate is the Most Likely Total Cost, Some Additional Risk Dollars Will Usually Be Required to Reach 50% Confidence Level and Some More Will be Needed to Reach 80% Level
  – If Point Estimate is the 50th-percentile Cost, Additional Risk Dollars Will Be Required to Reach 80% Confidence Level
  – If Point Estimate is the Expected Cost, Additional Risk Dollars Will Be Required to Reach 80% Level
  – Point Estimates Can be Selected for other Characteristics

• Sometimes Called …
  – Management Reserve
  – (Sneeringly) “Slush Fund”
• What Are “Risk Dollars”?  
  – What is Your “Point” Estimate?  
  – What Level of Confidence Do You Need?  

• Why Allocate Risk Dollars?  
  – The Political Reason  
  – The Project-Management Reason  

• How Should We Allocate Risk Dollars?  
  – The Difference between Uncertainty and Risk  
  – How Many Risk Dollars Does Each WBS Element Need?  

• Summary
Why Allocate?

• Your Request to Funding Authority
  - “Our Point Estimate is $ΩM, but We Also Foresee a Need for $ΘM as Management Reserve”

• Common Responses from Funders
  - “What? Don’t You Know How Much Your Program is Going to Cost?” – “Do You Even Know How You are Going to Manage the Program?”
  - “That’s a Rather Large Slush Fund - What Are You Going to Do With It?”

• Your Answer
  - “We are Pushing the State of the Art in a Number of Technology and Software Areas and There are Several Other Risk Issues Due to the Innovative Nature of This Program. I’ll Show You How We Plan to Use Our Management Reserve to Manage the Various Risk Issues and Make Our Program Executable.”
How Will the Risk Dollars Actually Be Spent?

- Not the Way You Think
  - After All, They’re Risk Dollars
  - They’ll Be Spent on Risks that Turn Out to Be Critical
- All the Risk Dollars Must be Retained by the Program Manager Until Specific Need Materializes – That’s Why it’s Called “Management Reserve”
- Then Why are We Doing the Allocation Now?
  - We’re Not Really Allocating the Money Now
  - We’re Merely Proposing that Some (or All) WBS Elements May Need Extra Money in Proportion to Their Riskiness
  - We are Making that Extra Money Part of our Cost Estimate
  - “The Race Is Not to the Swift, nor the Battle to the Strong, ...” *(Ecclesiastes, 9:11)*, but That’s the Way to Bet
• What Are “Risk Dollars”?  
  – What is Your “Point” Estimate?  
  – What Level of Confidence Do You Need?  

• Why Allocate Risk Dollars?  
  – The Political Reason  
  – The Project-Management Reason  

• **How Should We Allocate Risk Dollars?**  
  – The Difference between Uncertainty and Risk  
  – How Many Risk Dollars Does Each WBS Element Need?  

• Summary
“Roll-Up” Issues Impact Risk-Dollar Allocation Method

• Mathematical Facts
  – Most-Likely Project-Element Costs Do Not Sum to Most Likely Total Project Cost
  – $n$th Percentiles of Project-Element Costs Do Not Sum to $n$th Percentile of Total Project Cost
  – If Project-Element Costs are Correlated, the Correlations Must be Taken into Account when Summing Element Costs (usually by Monte Carlo) to Obtain the Distribution of Total Project Cost

• These Mathematical Facts Guarantee that There is no Simple Way (or even a Unique Right Way) to Allocate Risk Dollars Back to the WBS Elements
To Allocate the Risk Dollars …

• Calculate Total Amount of Risk Dollars Required
  – $^{50\text{th}}\text{Risk} = 50\text{th}-\text{percentile Total Cost, Minus Roll-Up;}$ or …
  – $^{80\text{th}}\text{Risk} = 80\text{th}-\text{percentile Total Cost, Minus Roll-Up}$
  – Of Course, Other Percentiles (70th, 90th, etc.) May Be Considered Appropriate for a Project, as Well as Other Definitions of the Point Estimate

• Allocation of Risk Dollars to Project Elements Must Put Risk Dollars Where They are “Needed”

• We Must Define an Element’s “Need” in Order to Determine How Many Risk Dollars are “Needed”
  – Need\textunderscore j = Dollar “Need” of Project-element j (to Be Defined Precisely Later)
  – Corr\textunderscore ij = Correlation Between Risk-dollar Requirements of Project Elements i and j
1. Those WBS Elements Having More Cost Risk Shall be Allocated More Risk Dollars, Relative to their Point Estimates

2. Inter-Element Correlation Shall be Taken into Account when Calculating an Element’s Risk-Dollar Allocation
   - Correlated Elements Shall “Share” Risk Dollars
   - Risk Dollars Shall not be “Double-Allocated”

3. The Risk-Dollar Allocation Shall Not Result in a WBS-Element’s Estimate Being Reduced Below its Point Estimate
   - This Means that Risk Dollars Shall Not be Subtracted from a Point Estimate
   - Therefore the Fewest Possible Number of Risk Dollars Allocated to any WBS Element will be Zero
Impact: No Element’s Estimate is Reduced Below its Point Estimate

• “The Risk-Dollar Allocation Shall Not Result in a WBS-Element’s Estimate Being Reduced Below its Point Estimate” Even if …
  – The Point Estimate Exceeds the 50th Percentile Estimate
  – The Point Estimate Exceeds the 80th Percentile Estimate
Example: System X WBS-Element
Triangular Cost Distributions

1. Antenna
2. Electronics
3. Platform
4. Facilities*
5. Power Distribution
6. Computers
7. Environmental Control
8. Communications
9. Software

* Vertical scale (probability density) different in this graph only.
<table>
<thead>
<tr>
<th>WBS Element</th>
<th>L</th>
<th>M</th>
<th>H</th>
<th>Mean**</th>
<th>Sigma</th>
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<tr>
<td>1. Antenna</td>
<td>191</td>
<td>380</td>
<td>1151</td>
<td>574</td>
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<td>2. Electronics</td>
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<td>192</td>
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<td>143</td>
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<td>4. Facilities</td>
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<td>18</td>
<td>27</td>
<td>18</td>
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<td>5. Power Distribution</td>
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<td>154</td>
<td>465</td>
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<td>6. Computers</td>
<td>30</td>
<td>58</td>
<td>86</td>
<td>58</td>
<td>11.43</td>
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<td>7. Environmental Control</td>
<td>11</td>
<td>22</td>
<td>66</td>
<td>33</td>
<td>11.88</td>
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<td>8. Communications</td>
<td>58</td>
<td>120</td>
<td>182</td>
<td>120</td>
<td>25.31</td>
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<tr>
<td>9. Software</td>
<td>120</td>
<td>230</td>
<td>691</td>
<td>347</td>
<td>123.68</td>
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<td><strong>SUMS</strong></td>
<td></td>
<td></td>
<td></td>
<td>1250*</td>
<td>1756**</td>
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* Point Estimate (Not the Same as the Most Likely Total Cost)
** “Mean” = “Expected Cost” (Note: Sum of WBS-Element Means is Equal to the Total-Cost Mean.)
### System X Inter-Element Correlations

#### Correlation Matrix

<table>
<thead>
<tr>
<th>WBS Element</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
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<td>0.50</td>
<td>0.50</td>
<td>0.60</td>
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<td>0.60</td>
<td>0.50</td>
<td>0.50</td>
<td>0.70</td>
<td>0.70</td>
</tr>
<tr>
<td>3</td>
<td>1.00</td>
<td>0.70</td>
<td>0.60</td>
<td>0.70</td>
<td>0.70</td>
<td>0.50</td>
<td>0.70</td>
<td>0.50</td>
<td>0.70</td>
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<tr>
<td>4</td>
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<td>0.40</td>
<td>0.40</td>
<td>0.50</td>
<td>0.30</td>
<td>0.60</td>
<td>0.30</td>
<td>0.60</td>
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<tr>
<td>5</td>
<td>1.00</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.70</td>
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<td>6</td>
<td>1.00</td>
<td>0.40</td>
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<td>0.80</td>
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<td>7</td>
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<td></td>
<td></td>
<td></td>
<td>1.00</td>
</tr>
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</table>
Computation of Total Cost Standard Deviation ($\sigma_T$)

Use the WBS-Element “Sigma” Values and the Inter-Element Correlations to Compute $\sigma_T$:

$$\sigma_T = \sqrt{\sum_{j=1}^{n} \sigma_j^2 + 2 \sum_{j=2}^{n} \sum_{i=1}^{j-1} \rho_{ij} \sigma_i \sigma_j} = 491.78$$
System X Total-Cost Percentiles (as Output by Crystal Ball®)

<table>
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<tr>
<th>Percentile</th>
<th>Cost</th>
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<td>0%</td>
<td>683.59</td>
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<td>5%</td>
<td>1,040.36</td>
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<tr>
<td>10%</td>
<td>1,151.05</td>
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<td>15%</td>
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<td>20%</td>
<td>1,300.93</td>
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<td>25%</td>
<td>1,369.69</td>
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<td>30%</td>
<td>1,439.55</td>
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<td>35%</td>
<td>1,504.28</td>
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<tr>
<td>40%</td>
<td>1,565.28</td>
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<tr>
<td>45%</td>
<td>1,628.48</td>
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<tr>
<td>50%</td>
<td>1,698.05</td>
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<tr>
<td>55%</td>
<td>1,770.74</td>
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<tr>
<td>60%</td>
<td>1,843.17</td>
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<tr>
<td>65%</td>
<td>1,914.46</td>
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<tr>
<td>70%</td>
<td>1,992.61</td>
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<td>75%</td>
<td>2,083.55</td>
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<tr>
<td>80%</td>
<td>2,183.27</td>
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<tr>
<td>85%</td>
<td>2,296.40</td>
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<td>90%</td>
<td>2,434.42</td>
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<td>95%</td>
<td>2,633.74</td>
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<td>100%</td>
<td>3,309.18</td>
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Monte Carlo Statistics

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<tr>
<th>Statistics</th>
<th>Value</th>
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<tr>
<td>Trials</td>
<td>10000</td>
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<tr>
<td>Mean</td>
<td>1,749.95</td>
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<tr>
<td>Median</td>
<td>1,698.05</td>
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<tr>
<td>Std Dev</td>
<td>487.83</td>
</tr>
<tr>
<td>Range Min</td>
<td>683.59</td>
</tr>
<tr>
<td>Range Max</td>
<td>3,309.18</td>
</tr>
<tr>
<td>Range Width</td>
<td>2,625.59</td>
</tr>
</tbody>
</table>
Risk-Dollar Definition

Notes:
1. Addition of risk dollars increases confidence that total estimate (point estimate plus risk dollars) is sufficient to execute program.
2. Point estimate may also be chosen to be the 50th Percentile ("Median"), Expected Cost ("Mean"), or Most Likely Cost ("Mode"), as well as the "Roll-Up" Estimate.
• Impact of Risk on Cost is Modeled as “Uncertainty” in Cost
• Uncertainty in Cost Means That Cost Distributions Range Over Wide Intervals
  – More Uncertainty Means a Wider Range
  – Less Uncertainty Means a Narrower Range
• Sigma (σ), or Standard Deviation, the Statistical Measure of Range of Cost Distribution, Is Universal Measure of Uncertainty
• Question: Is σ a Good Measure of Risk?
How Does $\sigma$ Measure Uncertainty?

- $\sigma^2$ is the Mean (i.e., “Average”) Squared Distance from the Mean of the Distribution

\[ \sigma^2 = \int_{-\infty}^{\infty} (x - \mu)^2 f(x)dx \quad \text{where} \]

\[ \mu = \text{Mean (“Expected Value”)} \text{ of Distribution} \]
\[ f(x) = \text{Probability Density Function} \]

- If Inter-Element Correlations are Zero

\[ \sigma_{TOTAL}^2 = \sigma_1^2 + \sigma_2^2 + \ldots + \sigma_n^2 = \sum_{k=1}^{n} \sigma_k^2 \]

- If $\rho_{ij} = \text{Correlation Between Project Elements } i \text{ and } j$

\[ \sigma_{TOTAL}^2 = \sum_{k=1}^{n} \sigma_k^2 + 2 \sum_{j=2}^{n} \sum_{i=1}^{j-1} \rho_{ij} \sigma_i \sigma_j \]
• Larger $\sigma$ Implies More Uncertainty, Which in Turn May Imply Greater Need for Risk Dollars

• Consider the Following Algebraic Rearrangement of the Total-Cost $\sigma$ Value:

$$\sigma_{TOTAL}^2 = \sum_{k=1}^{n} \sigma_k^2 + 2 \sum_{j=2}^{n} \sum_{i=1}^{j-1} \rho_{ij} \sigma_i \sigma_j$$

$$= \sum_{k=1}^{n} \rho_{kk} \sigma_k^2 + \left( \sum_{j=2}^{n} \sum_{i=1}^{j-1} \rho_{ij} \sigma_i \sigma_j + \sum_{j=2}^{n} \sum_{i=1}^{j-1} \rho_{ji} \sigma_j \sigma_i \right)$$

• Let’s See What the Algebraic Rearrangement Means in the Case of $n = 4$ WBS Elements
\[ \sigma_{TOTAL}^2 = \sum_{k=1}^{4} \sigma_k^2 + 2 \sum_{j=2}^{4} \sum_{i=1}^{j-1} \rho_{ij} \sigma_i \sigma_j \]

\[ = \sum_{k=1}^{4} \rho_{kk} \sigma_k^2 + \left( \sum_{j=2}^{4} \sum_{i=1}^{j-1} \rho_{ij} \sigma_i \sigma_j + \sum_{j=2}^{4} \sum_{i=1}^{j-1} \rho_{ji} \sigma_j \sigma_i \right) \]

\[ = \rho_{11} \sigma_1 \sigma_1 + \rho_{22} \sigma_2 \sigma_2 + \rho_{33} \sigma_3 \sigma_3 + \rho_{44} \sigma_4 \sigma_4 \]

\[ + \left( \sum_{i=1}^{2-1} \rho_{i2} \sigma_i \sigma_2 + \sum_{i=1}^{3-1} \rho_{i3} \sigma_i \sigma_3 + \sum_{i=1}^{4-1} \rho_{i4} \sigma_i \sigma_4 \right) \]

\[ + \left( \sum_{i=1}^{2-1} \rho_{2i} \sigma_2 \sigma_i + \sum_{i=1}^{3-1} \rho_{3i} \sigma_3 \sigma_i + \sum_{i=1}^{4-1} \rho_{4i} \sigma_4 \sigma_i \right) \]

\[ = \rho_{11} \sigma_1 \sigma_1 + \rho_{22} \sigma_2 \sigma_2 + \rho_{33} \sigma_3 \sigma_3 + \rho_{44} \sigma_4 \sigma_4 \]

\[ + \left( \sum_{i=1}^{1} \rho_{i2} \sigma_i \sigma_2 + \sum_{i=1}^{2} \rho_{i3} \sigma_i \sigma_3 + \sum_{i=1}^{3} \rho_{i4} \sigma_i \sigma_4 \right) \]

\[ + \left( \sum_{i=1}^{1} \rho_{2i} \sigma_2 \sigma_i + \sum_{i=1}^{2} \rho_{3i} \sigma_3 \sigma_i + \sum_{i=1}^{3} \rho_{4i} \sigma_4 \sigma_i \right) \]
Total Cost Standard Deviation for \( n = 4 \) WBS Elements, Chart 2 of 3

\[
\sigma^2_{\text{TOTAL}} = \sum_{k=1}^{4} \sigma_k^2 + 2 \sum_{j=2}^{4} \sum_{i=1}^{j-1} \rho_{ij} \sigma_i \sigma_j
\]

\[
= \rho_{11} \sigma_1 \sigma_1 + \rho_{22} \sigma_2 \sigma_2 + \rho_{33} \sigma_3 \sigma_3 + \rho_{44} \sigma_4 \sigma_4
\]

\[
+ \left( \sum_{i=1}^{1} \rho_{i2} \sigma_1 \sigma_2 + \sum_{i=1}^{2} \rho_{i3} \sigma_1 \sigma_3 + \sum_{i=1}^{3} \rho_{i4} \sigma_1 \sigma_4 \right)
\]

\[
+ \left( \sum_{i=1}^{1} \rho_{2i} \sigma_2 \sigma_i + \sum_{i=1}^{2} \rho_{3i} \sigma_3 \sigma_i + \sum_{i=1}^{3} \rho_{4i} \sigma_4 \sigma_i \right)
\]

\[
= \rho_{11} \sigma_1 \sigma_1 + \rho_{22} \sigma_2 \sigma_2 + \rho_{33} \sigma_3 \sigma_3 + \rho_{44} \sigma_4 \sigma_4
\]

\[
+ \left( \rho_{12} \sigma_1 \sigma_2 + \rho_{13} \sigma_1 \sigma_3 + \rho_{23} \sigma_2 \sigma_3 + \rho_{14} \sigma_1 \sigma_4 + \rho_{24} \sigma_2 \sigma_4 + \rho_{34} \sigma_3 \sigma_4 \right)
\]

\[
+ \left( \rho_{21} \sigma_2 \sigma_1 + \rho_{31} \sigma_3 \sigma_1 + \rho_{32} \sigma_3 \sigma_2 + \rho_{41} \sigma_4 \sigma_1 + \rho_{42} \sigma_4 \sigma_2 + \rho_{43} \sigma_4 \sigma_3 \right)
\]

\[
= ( \rho_{11} \sigma_1 \sigma_1 + \rho_{21} \sigma_2 \sigma_1 + \rho_{31} \sigma_3 \sigma_1 + \rho_{41} \sigma_4 \sigma_1 )
\]

\[
+ ( \rho_{12} \sigma_1 \sigma_2 + \rho_{22} \sigma_2 \sigma_2 + \rho_{32} \sigma_3 \sigma_2 + \rho_{42} \sigma_4 \sigma_2 )
\]

\[
+ ( \rho_{13} \sigma_1 \sigma_3 + \rho_{23} \sigma_2 \sigma_3 + \rho_{33} \sigma_3 \sigma_3 + \rho_{43} \sigma_4 \sigma_3 )
\]

\[
+ ( \rho_{14} \sigma_1 \sigma_4 + \rho_{24} \sigma_2 \sigma_4 + \rho_{34} \sigma_3 \sigma_4 + \rho_{44} \sigma_4 \sigma_4 )
\]
Total Cost Standard Deviation for \( n = 4 \) WBS Elements, Chart 3 of 3

\[
\sigma^2_{TOTAL} = \sum_{k=1}^{4} \sigma_k^2 + 2 \sum_{j=2}^{4} \sum_{i=1}^{j-1} \rho_{ij} \sigma_i \sigma_j
\]

\[
= (\rho_{11} \sigma_1 \sigma_1 + \rho_{21} \sigma_2 \sigma_1 + \rho_{31} \sigma_3 \sigma_1 + \rho_{41} \sigma_4 \sigma_1 )
\]

\[
+ (\rho_{12} \sigma_1 \sigma_2 + \rho_{22} \sigma_2 \sigma_2 + \rho_{32} \sigma_3 \sigma_2 + \rho_{42} \sigma_4 \sigma_2 )
\]

\[
+ (\rho_{13} \sigma_1 \sigma_3 + \rho_{23} \sigma_2 \sigma_3 + \rho_{33} \sigma_3 \sigma_3 + \rho_{43} \sigma_4 \sigma_3 )
\]

\[
+ (\rho_{14} \sigma_1 \sigma_4 + \rho_{24} \sigma_2 \sigma_4 + \rho_{34} \sigma_3 \sigma_4 + \rho_{44} \sigma_4 \sigma_4 )
\]

\[
= \sum_{i=1}^{4} \rho_{i1} \sigma_i \sigma_1 + \sum_{i=1}^{4} \rho_{i2} \sigma_i \sigma_2 + \sum_{i=1}^{4} \rho_{i3} \sigma_i \sigma_3 + \sum_{i=1}^{4} \rho_{i4} \sigma_i \sigma_4
\]

\[
= \sum_{j=1}^{4} \left( \sum_{i=1}^{4} \rho_{ij} \sigma_i \sigma_j \right) = \sum_{j=1}^{4} \sum_{i=1}^{4} \rho_{ij} \sigma_i \sigma_j
\]
Try This: Use $\sigma$ Values to Allocate Risk Dollars Based on Uncertainty

- Consider the Following $n$-Element Version of the Representation of the Total-Cost $\sigma^2$ Value, the 4-Element Version of which Appears on the Previous Chart:

$$\sigma_{TOTAL}^2 = \sum_{j=1}^{n} \sum_{i=1}^{n} \rho_{ij} \sigma_i \sigma_j$$

- The Portion of the Total-Cost $\sigma^2$ Value that is Associated, either Directly or via Correlation, with WBS Element $k$ is Given by the Following Expression:

$$\sigma_{ASSOC(k)}^2 = \sum_{i=1}^{n} \rho_{ik} \sigma_i \sigma_k$$
σ-Based Allocation Formula

• Uncertainty Base  \(= \sigma^2_{TOTAL} = \sum_{j=1}^{n} \sum_{i=1}^{n} \rho_{ij} \sigma_i \sigma_j\)

• Fraction of Risk Dollars to be Allocated to Element \(k\) Should Therefore be:

\[
\frac{\sigma^2_{ASSOC(k)}}{\sigma^2_{TOTAL}} = \frac{\sum_{i=1}^{n} \rho_{ik} \sigma_i \sigma_k}{\sum_{j=1}^{n} \sum_{i=1}^{n} \rho_{ij} \sigma_i \sigma_j} = \frac{Uncertainty\ Portion\ for\ k}{Uncertainty\ Base}
\]

• Amount of Risk Dollars to be Allocated to Element \(k\) is Therefore

\[
\frac{\sum_{i=1}^{n} \rho_{ik} \sigma_i \sigma_k}{\sum_{j=1}^{n} \sum_{i=1}^{n} \rho_{ij} \sigma_i \sigma_j} \times \text{Total Amount of Risk Dollars}
\]
Now for the Bad News

• Unfortunately, This Clever Procedure is No Good*
• \( \sigma \) as a Measure of Uncertainty Cannot Distinguish Between High-End “Risk” and Low-End Uncertainty

Both Distributions Have the Same \( \sigma \) Value, but the One on the Left (with the High-End Risk) Needs Lots of Risk Dollars to Reach its 50th Percentile and Even More to Reach its 80th Percentile
• The One on the Right is More than Fully Funded to its 80th Percentile by its Point Estimate (PE)

*Of course, that won’t stop people from using it!
This Problem with $\sigma$ is Not New

  - “Full variance considers extremely high and extremely low underreported receipts or overstated expenses equally undesirable. Semi-variance, on the other hand, measures deviations from the mean for observations below or above the mean.” (page 198)
  - “We extend the semi-variance estimators described above to a covariance context and develop a semi-variance based correlation coefficient between a pair of a selected half of X and a selected half of Y ....” (page 199)
  - “…This result is critically dependent on investor utility being a function of the standard deviation (or variance) of returns. But why should risk be defined in such a way? Introspection would suggest that investors are primarily concerned about losing money, not making money. To take this behavioral consideration into account, …we found the minimal semi-standard deviation of returns.” (pages 2-3)
Let’s Look at the “Need” of WBS Element $k$ for Risk Dollars

- Calculated “Need” of Any WBS Element is Based on its Probability of Overrunning its Point Estimate (which here is its “Most Likely Cost” = Mode)
- An Element that Has Preponderance of Probability Below its Point Estimate (such as the distribution on the left) Has Little or No Need
- Proposed Definition of “Need” of Project Element $k$ at the 80th Percentile Level
  - $\text{Need}_k = 80\text{th Percentile Cost Minus Point Estimate}$
  - $\text{Need}_k = 0$ If Point Estimate Exceeds 80th Percentile Cost

\[ \text{Need}_k = 0 \] 
\[ \text{Need}_k >> 0 \]
Need-Based Allocation Formula

• Total Need Base (Analogue of Total-Cost $\sigma^2$)
  
  \[ \text{Need Base} = \sum_{i=1}^{n} \sum_{j=1}^{n} \rho_{ij} \text{Need}_i \text{Need}_j \]

• Need “Portion” for Project Element $k$ (Analogue of Portion of Total-Cost $\sigma^2$ that is Associated with Element $k$)
  
  \[ \sum_{i=1}^{n} \rho_{ik} \text{Need}_i \text{Need}_k \]

• Risk Dollars Allocated to Project Element $k$
  
  \[ = ( \sum_{i=1}^{n} \rho_{ik} \text{Need}_i \text{Need}_k \div \text{Base} ) \times \text{Risk Dollars} \]
  
  \[ = \text{A percentage of total risk dollars} \]

• Now We Have to Calculate the “Need” of Each WBS Element
Triangular Cost Distribution

- Probability Density Function
- Three Parameters $L, M, H$ Completely Specify Distribution
- Mean, Median, Mode, Sigma, All Percentiles can be Expressed in Terms of $L, M, and H$
Expected Value and Percentiles of Triangular Distributions

• Expected Value \( \frac{L + M + H}{3} \)

• \( p^{th} \) Percentile = \( T_p \)

\[ T_p = \text{Dollar Value at which } P\{\text{Cost } \leq T_p\} = p \]

\[ = L + \sqrt{p(M - L)(H - L)} \quad \text{if } p \leq \frac{M - L}{H - L} \]

\[ = H - \sqrt{(1 - p)(H - L)(H - M)} \quad \text{if } p \geq \frac{M - L}{H - L} \]
Example: 50th and 80th Percentiles of Usual Triangular Distributions

- WBS Elements that May Very Well “Need” Risk Dollars at Both the 50th and 80th Percentile Levels Have Triangular Distributions Shaped Like This:

- Distributions Like This Have $M-L < (.50)(H-L)$ and, of course, $M-L < (.80)(H-L)$. Therefore …

- 50th Percentile = $T_{.50} = H - \sqrt{(.50)(H - L)(H - M)}$
- 80th Percentile = $T_{.80} = H - \sqrt{(.20)(H - L)(H - M)}$
WBS-Element “Need” Calculated for the Case $M-L < (.50)(H-L)$

- **At the 50th-Percentile Level …**
  - “Need” > 0 Always if the Most Likely Cost is Taken as the Point Estimate
  - “Need” = 50th-Percentile Element Cost, Minus Most Likely Element Cost
  - “Need” = $H - \sqrt{(0.50)(H-L)(H-M)} - M$

- **At the 80th-Percentile Level …**
  - Again, “Need” > 0 Always in this Situation
  - “Need” = 80th-Percentile Element Cost, Minus Most Likely Element Cost
  - “Need” = $H - \sqrt{(0.20)(H-L)(H-M)} - M$
Example: 50th and 80th Percentiles of Other Triangular Distributions

- WBS Elements that Probably Don’t “Need” Risk Dollars at the 50th, but Might or Might Not “Need” Them at the 80th Percentile Level, Have Triangular Distributions Shaped Like This:

- If Distributions Like This Have $M-L > (.80)(H-L)$, 80th Percentile = $T_{.80} = L + \sqrt{(.80)(M-L)(H-L)}$

- If Distributions Like This Have $M-L < (.80)(H-L)$, 80th Percentile = $T_{.80} = H - \sqrt{(.20)(H-L)(H-M)}$
• At the 80th-Percentile Level
  – Need = 80th-Percentile Element Cost, Minus Most Likely Element Cost
  – “Need” = \( L + \sqrt{(0.80)(M - L)(H - L)} - M \)
  – If “Need” < 0, We Set Need = 0
  – If “Need” > 0, We Use that Positive Number as the Need of the Element

• At the 50th-Percentile Level ...
  – It Must Be True that \( M - L > (0.50)(H - L) \), so We Apply the Following Formula ...
  – “Need” = \( L + \sqrt{(0.50)(M - L)(H - L)} - M \)
  – This Number is Always Negative in the Situation Described, so We Set Need = 0
“Need” Calculated in Cases when $M-L > (0.50)(H-L)$, but $M-L < (0.80)(H-L)$

- **At the 50th-Percentile Level …**
  - “Need” = 50th-Percentile Element Cost, Minus Most Likely Element Cost
  - “Need” = $L + \sqrt{(0.50)(M-L)(H-L)} - M$
  - This Number is Always Negative in the Situation Described
    Because $(0.50)(M-L)(H-L) > (0.50)^2(H-L)^2$ Means that $L + (0.50)(H-L) - M = (0.50)(H-L) - (M-L) < 0$
  - Therefore We Set Need = 0

- **At the 80th-Percentile Level**
  - “Need” = 80th-Percentile Element Cost, Minus Most Likely Element Cost
  - “Need” = $H - \sqrt{(0.20)(H-L)(H-M)} - M$
  - If “Need” < 0, We Set Need = 0
  - If “Need” > 0, We Use that Value as the Need of the Element
Total Amount of Risk Dollars Needed for 50% Confidence (says Crystal Ball®)

- $50^\text{th Risk}\$ = 50^\text{th}-\text{Percentile Total Cost, Minus “Roll-Up” Point Estimate}
- $50^\text{th Risk}\$ = 1698.05 - 1250.00 = 448.05$

Recall Output of Crystal Ball® Software:

<table>
<thead>
<tr>
<th>WBS Element</th>
<th>M (Mode)</th>
<th>Percentile</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>380.00</td>
<td>0%</td>
<td>683.59</td>
</tr>
<tr>
<td>#2</td>
<td>192.00</td>
<td>10%</td>
<td>1,151.05</td>
</tr>
<tr>
<td>#3</td>
<td>76.00</td>
<td>20%</td>
<td>1,300.93</td>
</tr>
<tr>
<td>#4</td>
<td>18.00</td>
<td>30%</td>
<td>1,439.55</td>
</tr>
<tr>
<td>#5</td>
<td>154.00</td>
<td>40%</td>
<td>1,565.28</td>
</tr>
<tr>
<td>#6</td>
<td>58.00</td>
<td>50%</td>
<td>1,698.05</td>
</tr>
<tr>
<td>#7</td>
<td>22.00</td>
<td>60%</td>
<td>1,843.17</td>
</tr>
<tr>
<td>#8</td>
<td>120.00</td>
<td>70%</td>
<td>1,992.61</td>
</tr>
<tr>
<td>#9</td>
<td>230.00</td>
<td>80%</td>
<td>2,183.27</td>
</tr>
<tr>
<td>Sum =</td>
<td>1250.00</td>
<td>90%</td>
<td>2,434.42</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100%</td>
<td>3,309.18</td>
</tr>
</tbody>
</table>
Allocation of System X Risk Dollars to WBS Elements at 50th Percentile

<table>
<thead>
<tr>
<th>WBS Element</th>
<th>Point Estimate</th>
<th>Allocation as % of Base</th>
<th>Allocation of Risk Dollars</th>
<th>50th Percentile Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>380.000</td>
<td>40.264%</td>
<td>180.402</td>
<td>560.402</td>
</tr>
<tr>
<td>#2</td>
<td>192.000</td>
<td>17.784%</td>
<td>79.680</td>
<td>271.680</td>
</tr>
<tr>
<td>#3</td>
<td>76.000</td>
<td>1.177%</td>
<td>5.273</td>
<td>81.273</td>
</tr>
<tr>
<td>#4</td>
<td>18.000</td>
<td>0.000%</td>
<td>0.000</td>
<td>18.000</td>
</tr>
<tr>
<td>#5</td>
<td>154.000</td>
<td>13.780%</td>
<td>61.740</td>
<td>215.740</td>
</tr>
<tr>
<td>#6</td>
<td>58.000</td>
<td>0.000%</td>
<td>0.000</td>
<td>58.000</td>
</tr>
<tr>
<td>#7</td>
<td>22.000</td>
<td>1.503%</td>
<td>6.733</td>
<td>28.733</td>
</tr>
<tr>
<td>#8</td>
<td>120.000</td>
<td>0.000%</td>
<td>0.000</td>
<td>120.000</td>
</tr>
<tr>
<td>#9</td>
<td>230.000</td>
<td>25.492%</td>
<td>114.218</td>
<td>344.218</td>
</tr>
<tr>
<td>Sums =</td>
<td>1250.000</td>
<td>100.000%</td>
<td>448.046</td>
<td>1698.046</td>
</tr>
</tbody>
</table>
Example: System X WBS-Element
Triangular Cost Distributions

1. Antenna
2. Electronics
3. Platform
4. Facilities*
5. Power Distribution
6. Computers
7. Environmental Control
8. Communications
9. Software

* Vertical scale (probability density) different in this graph only.
Total Amount of Risk Dollars Needed for 80% Confidence (says Crystal Ball®)

- $80^{\text{th Risk}} = 80^{\text{th-Percentile Total Cost, Minus “Roll-Up” Point Estimate}}$
- $80^{\text{th Risk}} = 2183.27 - 1250.00 = 933.27$
- Recall Output of Crystal Ball® Software:

<table>
<thead>
<tr>
<th>WBS Element</th>
<th>M (Mode)</th>
<th>Percentile</th>
<th>Cost</th>
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<tr>
<td>#1</td>
<td>380.00</td>
<td>0%</td>
<td>683.59</td>
</tr>
<tr>
<td>#2</td>
<td>192.00</td>
<td>10%</td>
<td>1,151.05</td>
</tr>
<tr>
<td>#3</td>
<td>76.00</td>
<td>20%</td>
<td>1,300.93</td>
</tr>
<tr>
<td>#4</td>
<td>18.00</td>
<td>30%</td>
<td>1,439.55</td>
</tr>
<tr>
<td>#5</td>
<td>154.00</td>
<td>40%</td>
<td>1,565.28</td>
</tr>
<tr>
<td>#6</td>
<td>58.00</td>
<td>50%</td>
<td>1,698.05</td>
</tr>
<tr>
<td>#7</td>
<td>22.00</td>
<td>60%</td>
<td>1,843.17</td>
</tr>
<tr>
<td>#8</td>
<td>120.00</td>
<td>70%</td>
<td>1,992.61</td>
</tr>
<tr>
<td>#9</td>
<td>230.00</td>
<td>80%</td>
<td>2,183.27</td>
</tr>
<tr>
<td>Sum =</td>
<td>1250.00</td>
<td>90%</td>
<td>2,434.42</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100%</td>
<td>3,309.18</td>
</tr>
</tbody>
</table>
### Allocation of System X Risk Dollars to WBS Elements at 80th Percentile

<table>
<thead>
<tr>
<th>WBS Element</th>
<th>Point Estimate</th>
<th>Allocation as % of Base</th>
<th>Allocation of Risk Dollars</th>
<th>80th Percentile Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>380.000</td>
<td>38.542%</td>
<td>359.706</td>
<td>739.706</td>
</tr>
<tr>
<td>#2</td>
<td>192.000</td>
<td>17.006%</td>
<td>158.712</td>
<td>350.712</td>
</tr>
<tr>
<td>#3</td>
<td>76.000</td>
<td>2.200%</td>
<td>20.529</td>
<td>96.529</td>
</tr>
<tr>
<td>#4</td>
<td>18.000</td>
<td>0.248%</td>
<td>2.311</td>
<td>20.311</td>
</tr>
<tr>
<td>#5</td>
<td>154.000</td>
<td>13.241%</td>
<td>123.571</td>
<td>277.571</td>
</tr>
<tr>
<td>#6</td>
<td>58.000</td>
<td>0.842%</td>
<td>7.861</td>
<td>65.861</td>
</tr>
<tr>
<td>#7</td>
<td>22.000</td>
<td>1.466%</td>
<td>13.679</td>
<td>35.679</td>
</tr>
<tr>
<td>#8</td>
<td>120.000</td>
<td>2.036%</td>
<td>18.999</td>
<td>138.999</td>
</tr>
<tr>
<td>#9</td>
<td>230.000</td>
<td>24.420%</td>
<td>227.904</td>
<td>457.904</td>
</tr>
<tr>
<td><strong>Sums =</strong></td>
<td><strong>1250.000</strong></td>
<td><strong>100.000%</strong></td>
<td><strong>933.272</strong></td>
<td><strong>2183.272</strong></td>
</tr>
</tbody>
</table>
Not So Fast! We’re Not Finished Yet

• Statistical Fact: Actual WBS-Element 50th Percentiles Do Not Sum to the 50th Percentile of Total Cost
• But Our (so-called) “50th Percentile Estimates” Really Do Sum to the 50th Percentile of Total Cost
• Why?
  – Because We Calculated the 50th Percentile of Total Cost First
  – Then We Divided the 50th Percentile Total-Cost Among the WBS Elements in Proportion to their Riskiness, with Inter-Element Correlations Taken into Account
• Therefore the Numbers You See Summing to the 50th Percentile of Total Cost are NOT the Actual 50th Percentiles of Each of the WBS Elements
• Same Assertions Hold True for 80th and All Other Cost Percentiles
Note: Actual Percentiles Represented by Term “50th Percentile Estimates”

<table>
<thead>
<tr>
<th>WBS Element</th>
<th>L</th>
<th>M = Point Estimate</th>
<th>H</th>
<th>&quot;50th Percentile Estimate&quot;</th>
<th>M-L</th>
<th>True Percentile of &quot;50th Percentile Estimate&quot;</th>
<th>Actual 50th Percentile Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>191.00</td>
<td>380.00</td>
<td>1151.00</td>
<td>560.402</td>
<td>0.197</td>
<td>52.87%</td>
<td>542.658</td>
</tr>
<tr>
<td>#2</td>
<td>96.00</td>
<td>192.00</td>
<td>582.00</td>
<td>271.680</td>
<td>0.198</td>
<td>49.19%</td>
<td>274.153</td>
</tr>
<tr>
<td>#3</td>
<td>33.00</td>
<td>76.00</td>
<td>143.00</td>
<td>81.273</td>
<td>0.391</td>
<td>48.30%</td>
<td>82.295</td>
</tr>
<tr>
<td>#4</td>
<td>9.00</td>
<td>18.00</td>
<td>27.00</td>
<td>18.000</td>
<td>0.500</td>
<td>50.00%</td>
<td>18.000</td>
</tr>
<tr>
<td>#5</td>
<td>77.00</td>
<td>154.00</td>
<td>465.00</td>
<td>215.740</td>
<td>0.198</td>
<td>48.51%</td>
<td>219.370</td>
</tr>
<tr>
<td>#6</td>
<td>30.00</td>
<td>58.00</td>
<td>86.00</td>
<td>58.000</td>
<td>0.500</td>
<td>50.00%</td>
<td>58.000</td>
</tr>
<tr>
<td>#7</td>
<td>11.00</td>
<td>22.00</td>
<td>66.00</td>
<td>28.733</td>
<td>0.200</td>
<td>42.61%</td>
<td>31.215</td>
</tr>
<tr>
<td>#8</td>
<td>58.00</td>
<td>120.00</td>
<td>182.00</td>
<td>120.000</td>
<td>0.500</td>
<td>50.00%</td>
<td>120.000</td>
</tr>
<tr>
<td>#9</td>
<td>120.00</td>
<td>230.00</td>
<td>691.00</td>
<td>344.218</td>
<td>0.193</td>
<td>54.31%</td>
<td>328.211</td>
</tr>
<tr>
<td>Sums =</td>
<td>450.00</td>
<td>910.00</td>
<td>1512.00</td>
<td>1698.046</td>
<td>p = .50</td>
<td>50.00%</td>
<td>1673.903</td>
</tr>
</tbody>
</table>

\[ p^{th} \text{ Percentile} \]

\[ p^{th} \text{ Percentile} = \begin{cases} 
L + \sqrt{p(M - L)(H - L)} & \text{if } p \leq \frac{M - L}{H - L} \\
H - \sqrt{(1 - p)(H - L)(H - M)} & \text{if } p \geq \frac{M - L}{H - L} 
\end{cases} \]
Note: Actual Percentiles Represented by “80th Percentile Estimates”

<table>
<thead>
<tr>
<th>WBS Element</th>
<th>L</th>
<th>M = Point Estimate</th>
<th>H</th>
<th>&quot;80th Percentile Estimate&quot;</th>
<th>M-L</th>
<th>Actual Percentile of &quot;80th Percentile Estimate&quot;</th>
<th>Actual 80th Percentile Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>191.00</td>
<td>380.00</td>
<td>1151.00</td>
<td>739.706</td>
<td>0.197</td>
<td>77.15%</td>
<td>766.251</td>
</tr>
<tr>
<td>#2</td>
<td>96.00</td>
<td>192.00</td>
<td>582.00</td>
<td>350.712</td>
<td>0.198</td>
<td>71.78%</td>
<td>387.300</td>
</tr>
<tr>
<td>#3</td>
<td>33.00</td>
<td>76.00</td>
<td>143.00</td>
<td>96.529</td>
<td>0.391</td>
<td>70.70%</td>
<td>104.607</td>
</tr>
<tr>
<td>#4</td>
<td>9.00</td>
<td>18.00</td>
<td>27.00</td>
<td>20.311</td>
<td>0.500</td>
<td>72.38%</td>
<td>21.308</td>
</tr>
<tr>
<td>#5</td>
<td>77.00</td>
<td>154.00</td>
<td>465.00</td>
<td>277.571</td>
<td>0.198</td>
<td>70.89%</td>
<td>309.650</td>
</tr>
<tr>
<td>#6</td>
<td>30.00</td>
<td>58.00</td>
<td>86.00</td>
<td>65.861</td>
<td>0.500</td>
<td>74.13%</td>
<td>68.291</td>
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<td>#7</td>
<td>11.00</td>
<td>22.00</td>
<td>66.00</td>
<td>35.679</td>
<td>0.200</td>
<td>62.01%</td>
<td>44.000</td>
</tr>
<tr>
<td>#8</td>
<td>58.00</td>
<td>120.00</td>
<td>182.00</td>
<td>138.999</td>
<td>0.500</td>
<td>75.95%</td>
<td>142.788</td>
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<tr>
<td>#9</td>
<td>120.00</td>
<td>230.00</td>
<td>691.00</td>
<td>457.904</td>
<td>0.193</td>
<td>79.36%</td>
<td>461.552</td>
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<tr>
<td>Sums</td>
<td>1250.00</td>
<td>2183.272</td>
<td>80.00%</td>
<td>2305.748</td>
<td></td>
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</table>
Recall Total-Cost Percentiles

- Output of Crystal Ball® Software:

<table>
<thead>
<tr>
<th>Percentile</th>
<th>Cost</th>
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</thead>
<tbody>
<tr>
<td>0%</td>
<td>683.59</td>
</tr>
<tr>
<td>10%</td>
<td>1,151.05</td>
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<td>20%</td>
<td>1,300.93</td>
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<td>30%</td>
<td>1,439.55</td>
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<tr>
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<td>1,565.28</td>
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<tr>
<td>50%</td>
<td>1,698.05</td>
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<tr>
<td>60%</td>
<td>1,843.17</td>
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<td>70%</td>
<td>1,992.61</td>
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<td>80%</td>
<td>2,183.27</td>
</tr>
<tr>
<td>90%</td>
<td>2,434.42</td>
</tr>
<tr>
<td>100%</td>
<td>3,309.18</td>
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</tbody>
</table>

1673.90 (48th)
2305.75 (85th)
Observations on the Risk-Dollar Allocation Process

• Under our Definition of “Need”, Percentage of Risk Dollars Allocated to Each WBS Element Depends on our Choice of “Point” Estimate of Total Cost
  – “Point” Estimate Can be Defined as
    • “Roll-Up of Element Most Likely Costs”
    • “Expected Cost”
    • “50th-Percentile Cost”
    • “Most Likely Total Cost”
    • (or Whatever)
  – An Element’s “Need” is Based on
    • Its Point Estimate (however that is defined)
    • Its Risk Characteristics (i.e, skewness of its cost distribution)
    • Correlation of its Risks with other WBS-Elements’ Risks

• Risk-Dollar Percentage Allocated to Each Project Element Also Depends on Level of Confidence (50th, 80th, etc.) Considered Appropriate for Management Reserve
Contents

• What Are “Risk Dollars”?  
  – What is Your “Point” Estimate?  
  – What Level of Confidence Do You Need?  

• Why Allocate Risk Dollars?  
  – The Political Reason  
  – The Project-Management Reason  

• How Should We Allocate Risk Dollars?  
  – The Difference between Uncertainty and Risk  
  – How Many Risk Dollars Does Each WBS Element Need?  

• Summary
Summary

• Allocation of Risk Dollars to WBS Elements Provides Supporting Justification for a Request for Management Reserve

• Before Deciding How to Allocate Dollars, Analysts Must …
  – … Assign WBS-Element Cost Probability Distributions
  – … Calculate Total-Cost Probability Distribution
  – … Agree upon Meaning of “Point Estimate” of Total Cost
  – … Agree upon Confidence Level Required for Risk Coverage
  – … Agree upon Specifications for Allocation Decision

• How Risk-Dollar Allocation Procedure Works
  – Define Dollar-Valued “Need” of Each WBS Element
  – Calculate Dollar-Valued “Need” of Each WBS Element, Taking into Account Inter-Element Correlations
  – Sum All “Needs” to Obtain Total “Need Base”
  – Allocate Risk Dollars to WBS Elements in Proportion to their Fractions of the Need Base
  – You Don’t Have to Worry About Someone in the Audience Noticing that Your 80th Percentile Estimates “Don’t Add Up”
Dr. Stephen A. Book is Chief Technical Officer of MCR, LLC, responsible for ensuring technical excellence of MCR’s products, services, and processes by encouraging process improvement, maintaining quality control, and training employees and customers in cost and schedule analysis and associated program-control disciplines. Dr. Book has given numerous technical and tutorial presentations on cost-risk analysis, CER development, and other statistical aspects of cost and economics to DoD, NASA, and EACE (European Aerospace Working Group on Cost Engineering) Cost Symposia, the AF/NASA/ESA Space Systems Cost Analysis Group (SSCAG), the U.S. Army Conference on Applied Statistics (ACAS), and professional societies such as the International Society of Parametric Analysts (ISPA), Society for Cost Estimating and Analysis (SCEA), Military Operations Research Society (MORS), U.K. Association of Cost Engineers (ACostE), and the American Institute of Aeronautics and Astronautics (AIAA). He was a principal contributor to several Air Force cost studies of national significance, including the DSP/FEWS/BSTS/AWS/Brilliant Eyes Sensor Integration Study (1992) and the ALS/Spacelifter/EELV Launch Options Study (1993) and has served on national panels as an independent reviewer of NASA programs. Dr. Book joined MCR in January 2001 after 21 years with The Aerospace Corporation, where he held the title “Distinguished Engineer” during 1996-2000 and the position of Director, Resource and Requirements Analysis Department, during 1989-1995. He is the current editor of ISPA’s *Journal of Parametrics* and the 2005 recipient of ISPA’s Freiman Award for Lifetime Achievement. Dr. Book earned his Ph.D. in mathematics, with concentration in probability and statistics, at the University of Oregon in 1970.