Relating Tornado and Variance Analysis with Allocated RI$K Dollars

ACEIT Users Workshop
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Abstract

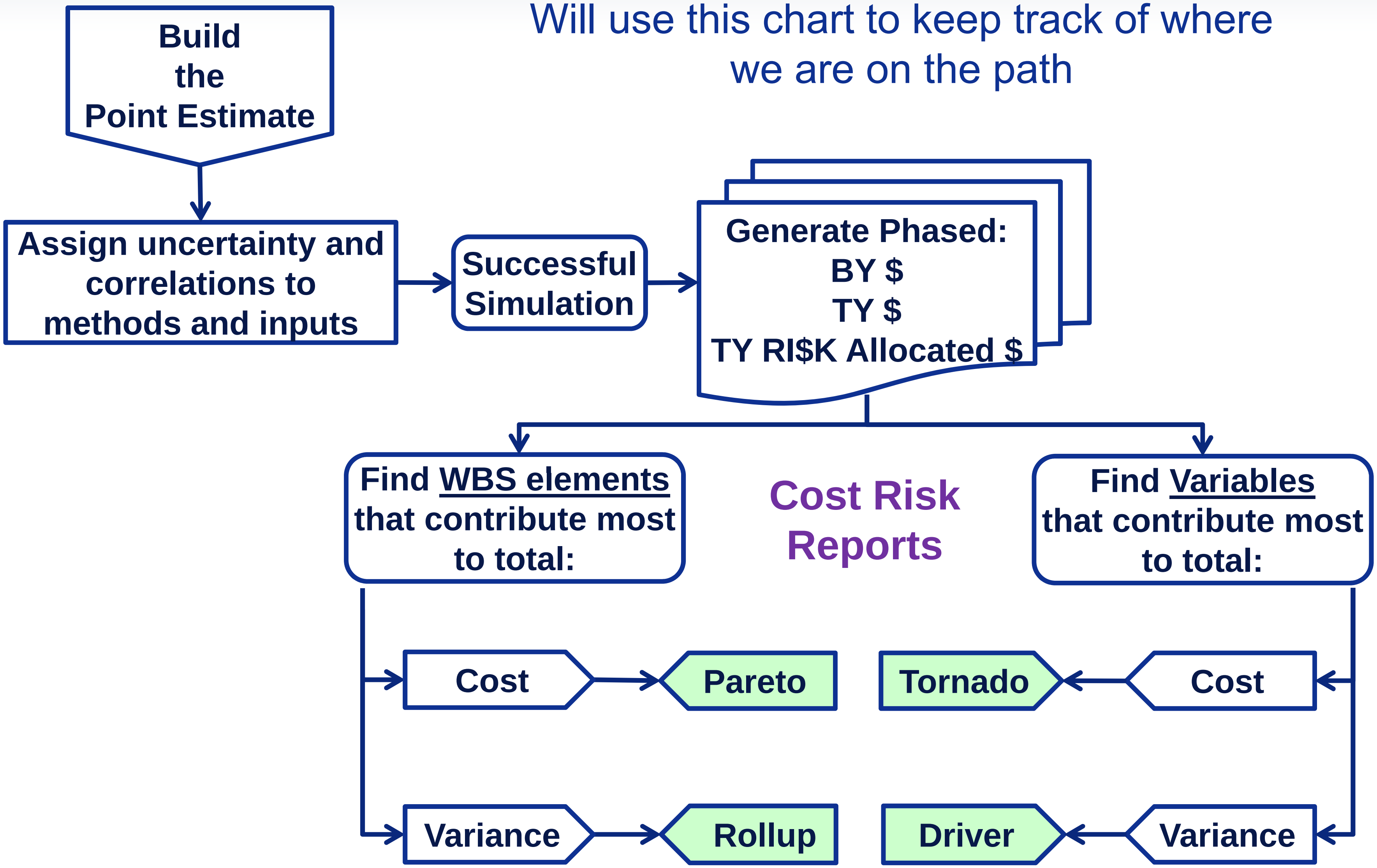
This presentation will explore two well known, but frequently misunderstood POST RI$K charts: Tornado and Variance Analysis. It will address common questions such as "What does this report tell me?" And "What is the connection between these reports and my risk dollars at a particular confidence level?" POST report options will be explained for each chart so you can get the information you need to bring clarity and understanding to your RI$K analysis results and provide decision makers with critical "cost risk driver" information.

Outline

- **Typical steps in an uncertainty analysis**
- **ACE Model Overview**
  - WBS, methods, variables, uncertainty
  - ACE RI$K Reports
    - RI$K Statistics, Correlation, RI$K Allocation
- **POST Charts**
  - Pareto, Tornado, Variance Analysis
  - Exploit these charts to find cost and variance drivers
  - Relationship to RI$K allocation results
- **Summary**

The Path To Cost Risk Reports

Will use this chart to keep track of where we are on the path



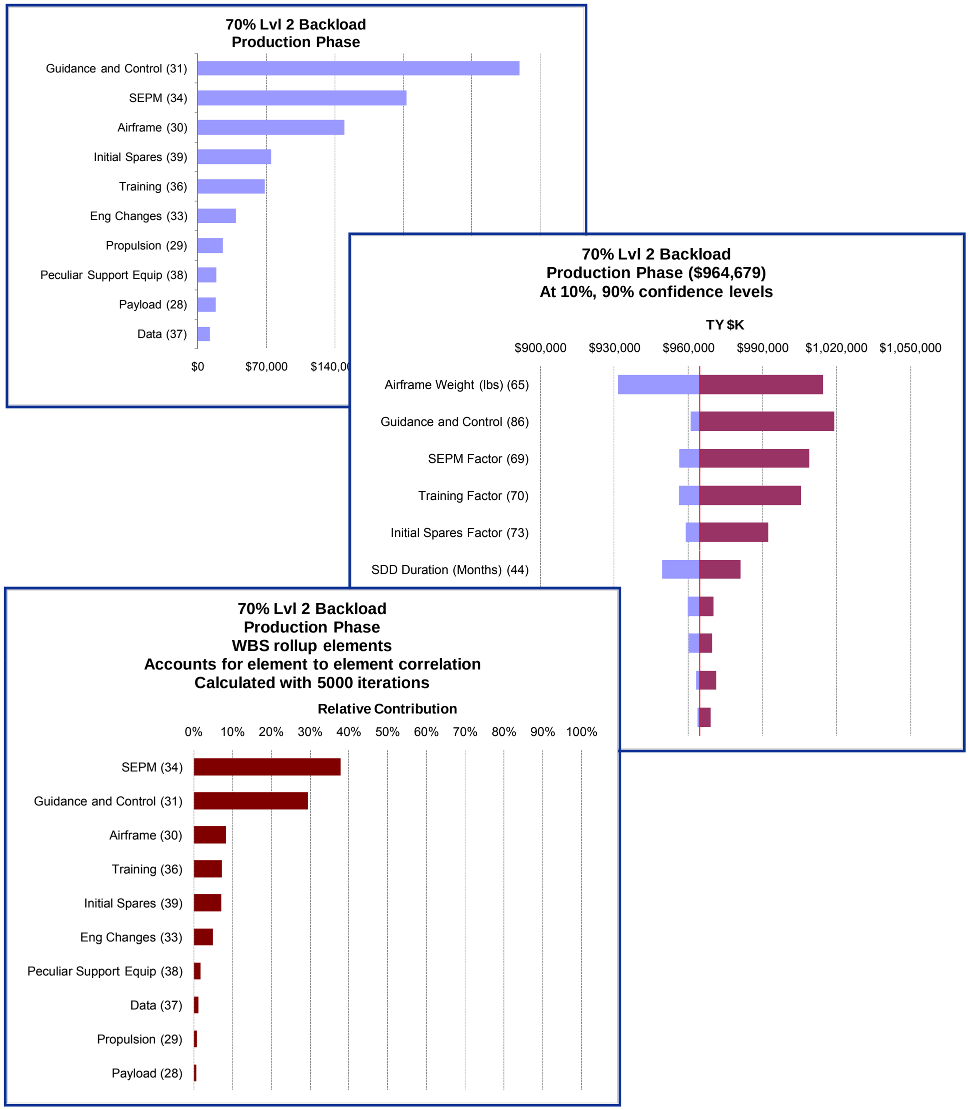
Defining Cost and Uncertainty Drivers

- **Different opinions on what a cost driver is:**
  - The WBS element that contributes the most to the total
  - The variable (labor rate, weight, etc) that has the most influence on total cost
- **SCEA's "Body of Knowledge" defines:**
  - **Cost Passenger**: WBS elements with the highest dollar value
  - **Cost Driver**: those design decisions and requirements, especially at a system level, that truly drive or influence cost
  - By extension, we can use the same definitions to describe a variance passenger (WBS element) and variance driver (input)
- **ACEIT has the tools to help you find the elements that contribute most to cost and uncertainty in your model!**

Tools to Help You Find Cost and Uncertainty Contributors

- **Pareto Chart:** identifies WBS elements that contribute most to the target row *total*
- **Tornado/Spider Chart:** identifies the uncertain variables that most influence the target row *total*
- **Variance Analysis (Rollup):** identifies *WBS elements* that contribute most to the target row *uncertainty*
- **Variance Analysis (Driver- not shown** but similar in appearance to RollUp**):** identifies the defined distributions that contribute most to the target row *uncertainty*

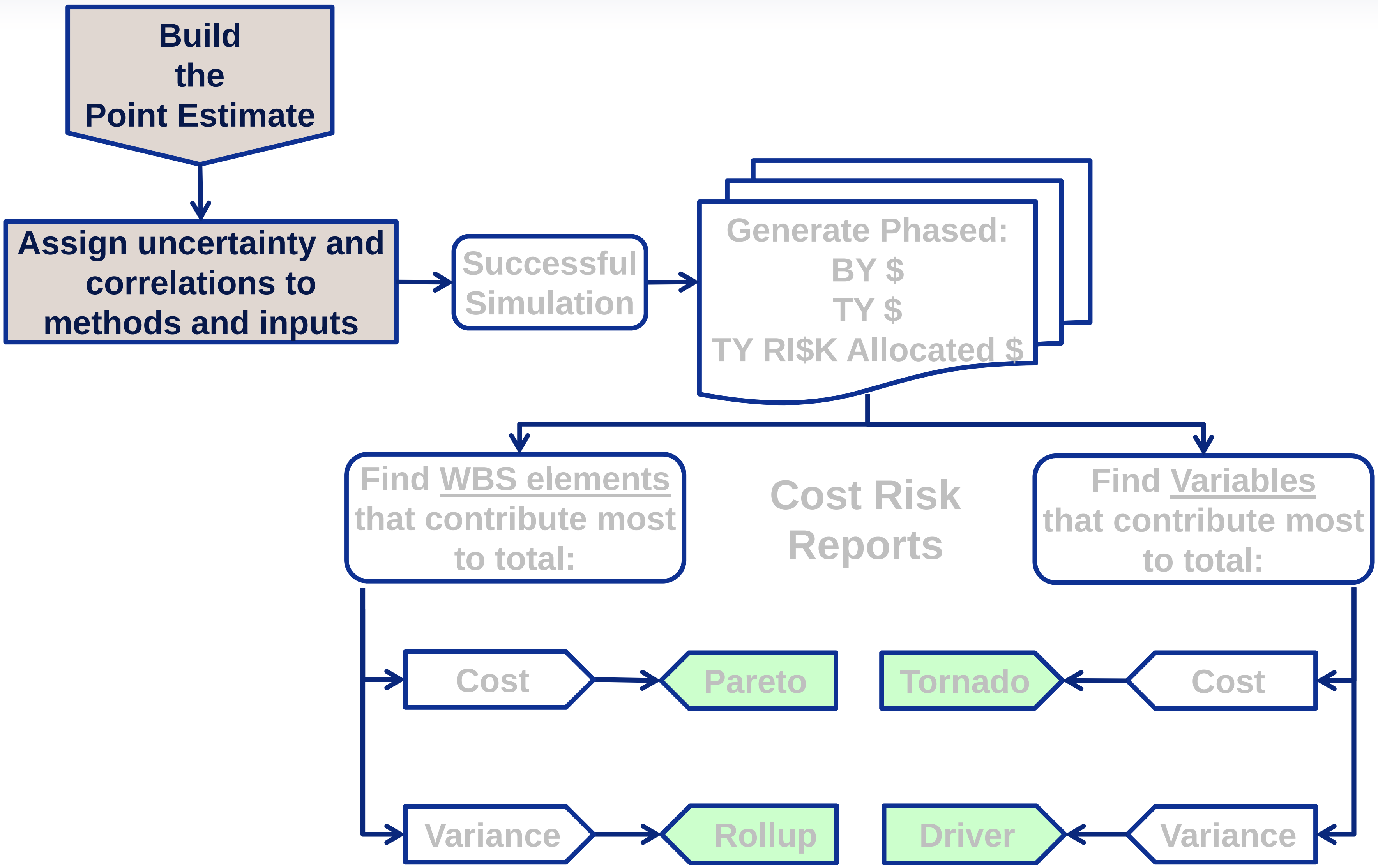
Note that ACE is the only tool to provide an option to account for applied correlation when performing variance analysis (other tools call it "sensitivity analysis")



Finding Cost and Uncertainty Contributors

- **The analyst is responsible for finding the key cost and uncertainty drivers**
- **But, when searching for the cost and uncertainty contributors…**
  - Is the analysis influenced by the type of dollars reported (ie. BY vs TY)?
  - Is the analysis influenced by the RI$K allocation choices we make, such as the
    - WBS level we choose to allocate from
    - confidence level

Create the RI$K Model



AFCAA CRUH Missile Model

WBS

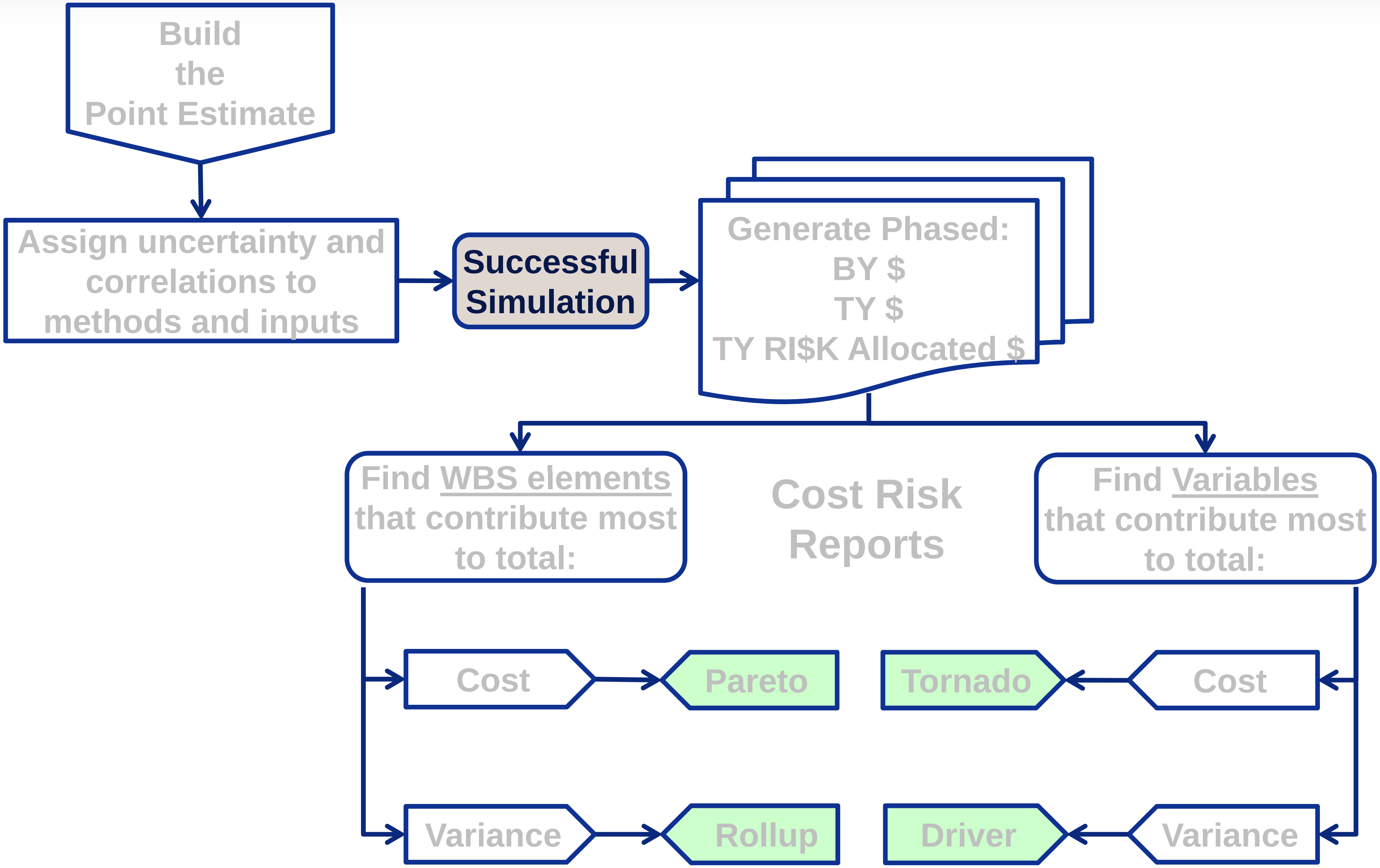
- Σ Missile System
  - Σ Sys Dev and Demo
    - Σ Air Vehicle
      - Design & Dev
      - Prototypes
      - Software
    - SEPM
    - Sys Test & Eval
    - Training
    - Data
    - Support Equip
  -
  - Σ Production Phase
    - Σ Air Vehicle
      - Payload
      - Propulsion
      - Airframe
      - Guidance and Control
      - IAT&C
    - Eng Changes
    - SEPM
    - Sys Test & Eval
    - Training
    - Data
    - Peculiar Support Equip
    - Initial Spares

Target for analysis in this presentation

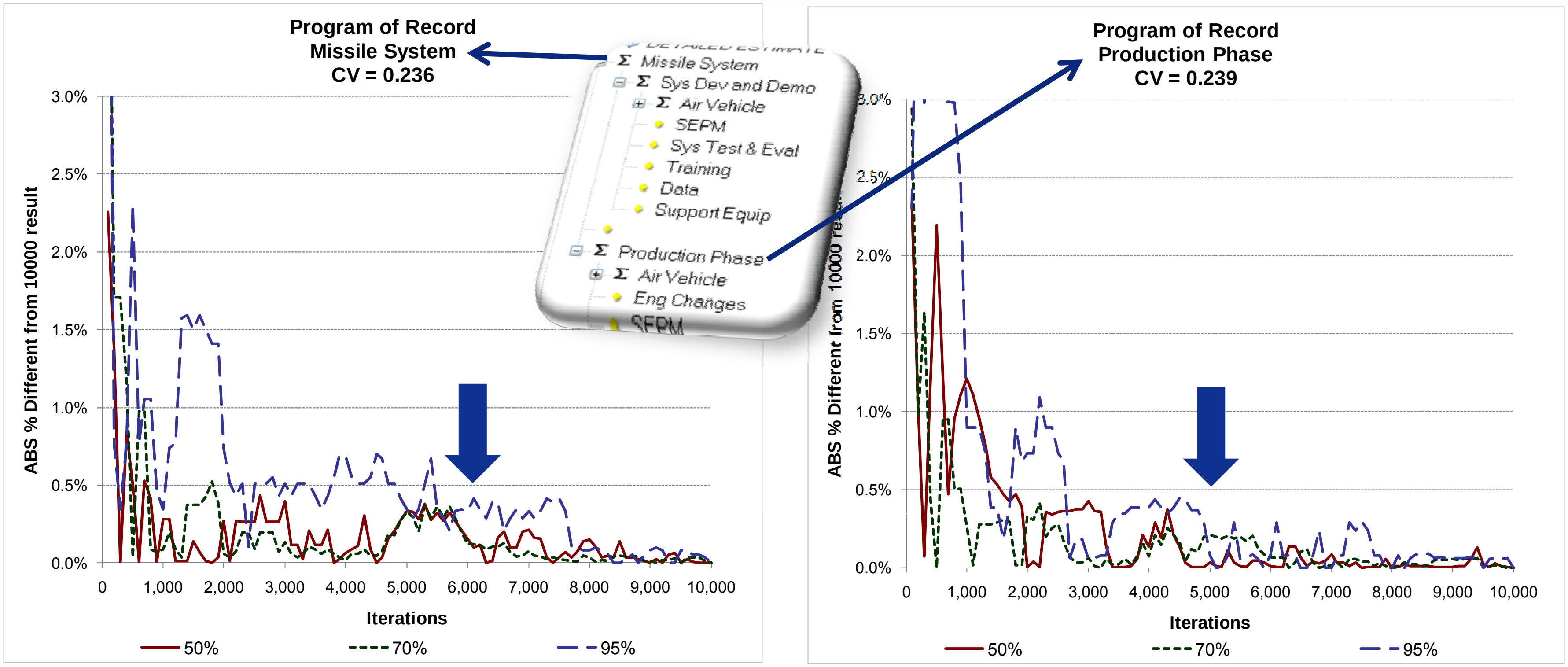
Inputs

- DEVELOPMENT VARIABLES
- Start Sys Dev and Demo (SDD)
- SDD Duration (Months)
- End of SDD
- Protoype Quantity
- Development Learning Slope
- Step Increase over Prod Cost
- SW Manmonths
- SW Labor Rate ($/month)
- SEPM Headcount
- SEPM Labor Rate ($/mo)
- Sys Test Eval Factor
- Training Factor
- Data Factor
- Support Equip Factor
-
- PRODUCTION VARIABLES
- Production Start Date
- Production Quantity
- Production Stop Date
- Production Learning Slope
- Warhead Weight (lbs)
- Motor Weight (lbs)
- Airframe Weight (lbs)
- IATC Hrs/Unit
- Manuf Labor Rate
- Eng Changes Factor
- SEPM Factor
- Training Factor
- Data Factor
- PSE Factor
- Initial Spares Factor

Successful Simulation



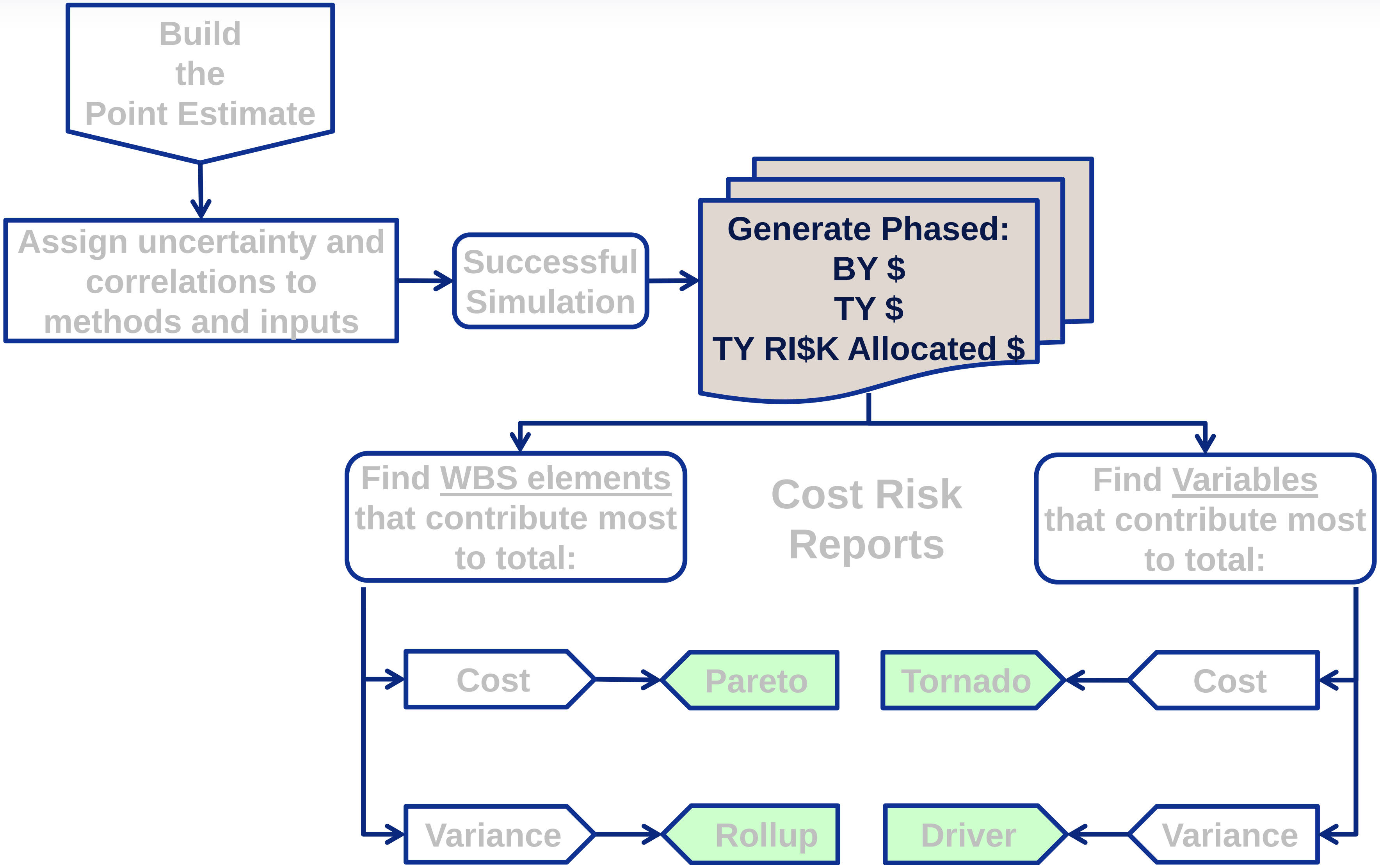
Once Model is Complete, Determine Iterations Required



- **POST Convergence Chart will yield a different result depending on the target!**
- **5,000 iterations appears to be adequate[1] to evaluate the Production Phase**
  - If convergence is not achieved, need to re-run the analysis using > 10k iterations (see backup slide)
- **Must reassess if model changes**

[1]How Many Iterations Are Enough?, Alfred Smith, Tecolote Research, Joint SCEA/ISPA Annual Conference, June 2008

Generate Reports



Risk Statistics

- Also available in the inputs results viewer (IRV)

	WBS/CES	Point Estimate	Mean	Std Dev	CV	5.0% Level	10.0% Level	15.0% Level	20.0 Leve
14	Missile System	$ 718,557 (13%)	$ 979,884	$ 243,945	0.249	$ 640,927	$ 690,594	$ 731,888	$ 767
15	Sys Dev and Demo	$ 170,002 (27%)	$ 226,409	$ 84,160	0.372	$ 125,405	$ 139,752	$ 150,444	$ 158
16	Air Vehicle	$ 115,178 (32%)	$ 147,406	$ 56,890	0.386	$ 79,525	$ 89,349	$ 96,010	$ 102
17	Design & Dev	$ 26,506 (25%)	$ 31,920	$ 6,901	0.216	$ 22,019	$ 23,523	$ 24,676	$ 25
18	Prototypes	$ 10,328 (20%)	$ 15,942	$ 6,323	0.397	$ 7,321	$ 8,621	$ 9,504	$ 10
19	Software	$ 78,344 (40%)	$ 99,545	$ 52,443	0.527	$ 39,324	$ 47,294	$ 52,849	$ 58

Correlation Report

Production →

	WBS/CES	Row 28: Payload	Row 29: Propulsion	Row 30: Airframe	Row 31: Guidance and Control	Row 32: IAT&C	Row 33: Eng Changes	Row 34: SEPM
28	Payload	1.00	0.32	0.33	0.24	0.43	0.30	0.26
29	Propulsion		1.00	0.26	0.19	0.23	0.29	0.26
30	Airframe			1.00	0.19	0.26	0.40	0.36
31	Guidance and Co				1.00	0.13	0.57	0.50
32	IAT&C					1.00	0.20	0.19
33	Eng Changes						1.00	0.47
34	SEPM							1.00

Phased RI$K Allocation Report

- **Why do we produce a phased RI$K allocation report?**
  - RI$K Statistics report shows totals (not annual)
  - Specific confidence level results do not sum
- **RI$K Allocation report tabulates phased RI$K results at a user selected confidence level, and forces the annual results to sum**
  - Example below illustrates results when user selected 70% at the 2nd level in the WBS

	Cost Element	Approp	Total	FY 2010	FY 2011	FY 2012	FY 2013	FY 201
2	Total		$ 620,849 (~71%)	$ 1,299	$ 1,860	$ 6,788	$ 13,594	$ 23,'
3	RDT&E		$ 90,382 (70%)	$ 1,299	$ 1,860	$ 6,788	$ 13,594	$ 23,'
4	Concept Refinement		$ 1,318 (69%)	$ 1,296	$ 22			
5	Technology Development		$ 5,529 (70%)		$ 1,835	$ 3,694		
6	System Development and D		$ 83,535 (69%)	$ 3	$ 3	$ 3,094	$ 13,594	$ 23,'
7								
8	Procurement		$ 530,466 (70%)					
9	Manufacturing (Air Force)		$ 240,742 (68%)					

Compare Phased Results

PE

$531k

ACE 7.1a - [AUCHowToRiskExample12Jan09.aceit - BY Phased Costs (FY2009 $K, Time Phased, Case: Point Estimate, with Risk)]

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Point Estimate

	Cost Element	Approp	Total	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY
15	Total		$ 530,935 (30%)	$ 1,005	$ 1,437	$ 5,217	$ 10,124	$ 16,860	$ 25,319	$ 25,937	$ 22,003	$ 22,464	$
16	RDT&E		$ 67,470 (10%)	$ 1,005	$ 1,437	$ 5,217	$ 10,124	$ 16,860	$ 25,319	$ 7,509			
17	Concept Refinement		$ 1,020 (14%)	$ 1,003	$ 17								
18	Technology Development		$ 4,270 (15%)		$ 1,417	$ 2,853							
19	System Development and D		$ 62,180 (11%)	$ 2	$ 2	$ 2,364	$ 10,124	$ 16,860	$ 25,319	$ 7,509			
20													
21	Procurement		$ 463,465 (37%)							$ 18,428	$ 22,003	$ 22,464	$
22	Manufacturing (Air Force)		$ 218,803 (41%)							$ 2,438	$ 5,914	$ 4,129	

70%, 1st Lvl

$617k

ACE 7.1a - [AUCHowToRiskExample12Jan09.aceit - BY Phased (FY2009 $K, Time Phased, Case: Point Estimate, 70% CL allocated at Level 1)]

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70% Allocated from the 1st level

	Cost Element	Approp	Total	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2
15	Total		$ 617,044 (70%)	$ 1,292	$ 1,850	$ 6,749	$ 13,515	$ 22,978	$ 33,523	$ 31,956	$ 27,649	$ 27
16	RDT&E		$ 89,805 (69%)	$ 1,292	$ 1,850	$ 6,749	$ 13,515	$ 22,978	$ 33,523	$ 9,898		
17	Concept Refinement		$ 1,311 (68%)	$ 1,289	$ 22							
18	Technology Development		$ 5,499 (68%)		$ 1,825	$ 3,674						
19	System Development and D		$ 82,996 (68%)	$ 3	$ 3	$ 3,076	$ 13,515	$ 22,978	$ 33,523	$ 9,898		
20												
21	Procurement		$ 527,239 (68%)							$ 22,058	$ 27,649	$ 27
22	Manufacturing (Air Force)		$ 239,591 (66%)							$ 2,617	$ 8,103	$ 5
23												

70%, 2nd Lvl

$621k

ACE 7.1a - [AUCHowToRiskExample12Jan09.aceit - BY Phased (FY2009 $K, Time Phased, Case: Point Estimate, 70% CL allocated at Level 2)]

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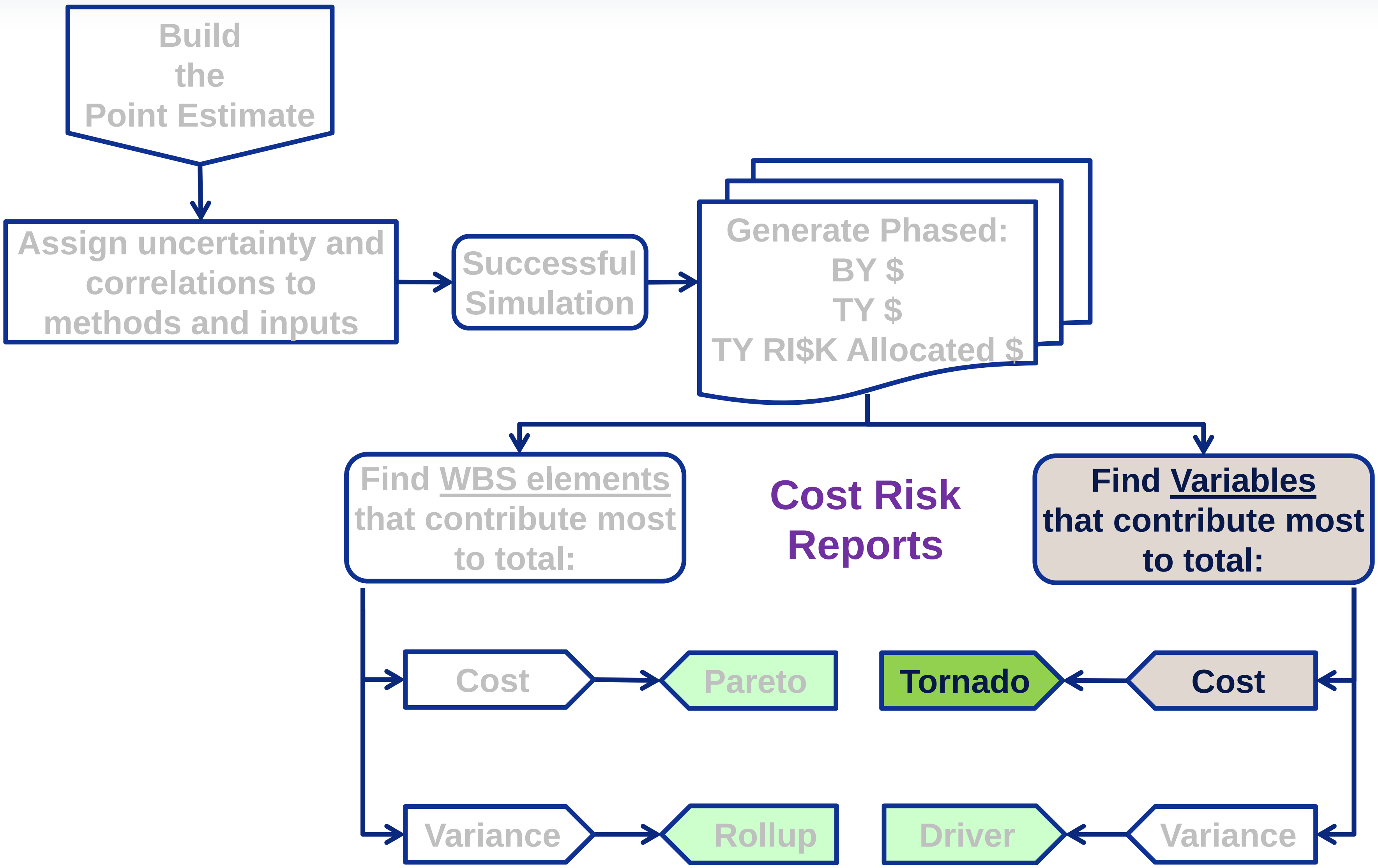
70% Allocated from the 2nd level

	Cost Element	Approp	Total	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY
2	Total		$ 620,849 (~71%)	$ 1,299	$ 1,860	$ 6,788	$ 13,594	$ 23,123	$ 33,744	$ 32,229	$ 27,888	$
3	RDT&E		$ 90,382 (70%)	$ 1,299	$ 1,860	$ 6,788	$ 13,594	$ 23,123	$ 33,744	$ 9,974		
4	Concept Refinement		$ 1,318 (69%)	$ 1,296	$ 22							
5	Technology Development		$ 5,529 (70%)		$ 1,835	$ 3,694						
6	System Development and D		$ 83,535 (69%)	$ 3	$ 3	$ 3,094	$ 13,594	$ 23,123	$ 33,744	$ 9,974		
7												
8	Procurement		$ 530,466 (70%)									
9	Manufacturing (Air Force)		$ 240,742 (68%)									$

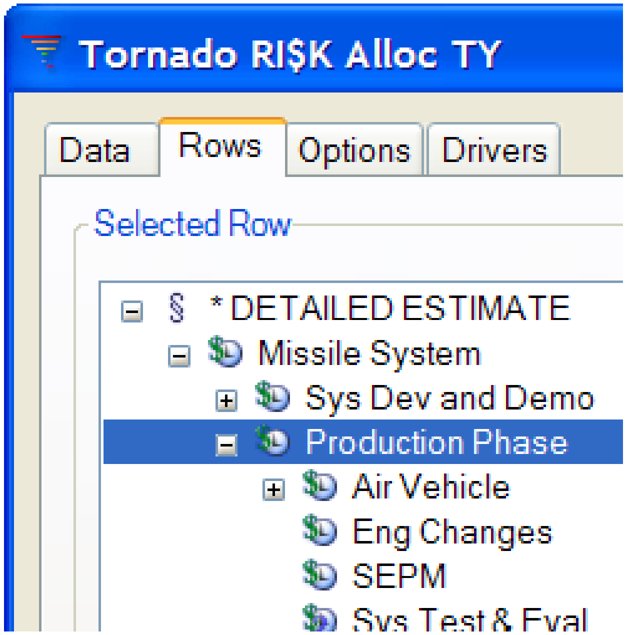
Allocating from further down the WBS causes Total to increase when % is above the mean!

Find Cost Drivers



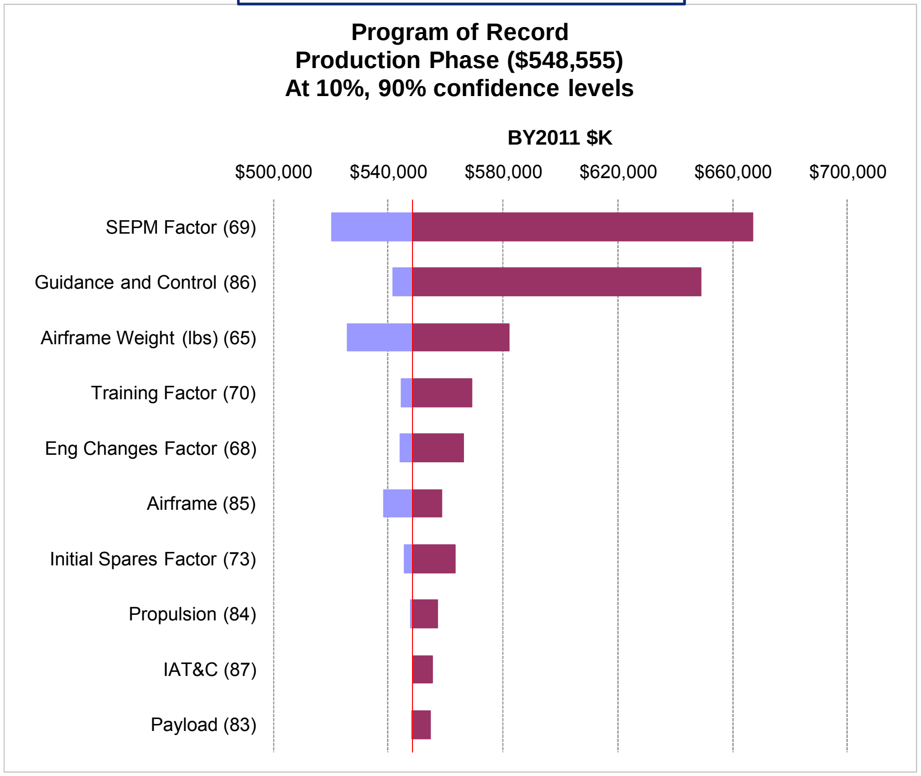
What Does A Tornado Chart Do For You?

- **Select the row to analyze (target row)**
- **POST identifies all elements that influence the target row result and lists them on the Drivers tab**
- **Use the Drivers tab to focus on those elements of interest**
- **A low and high what-if is calculated for each driver**
  - 200 drivers means 400 what-if cases, be selective
- **The Tornado chart plots identifies those drivers that have the most influence on the target row**

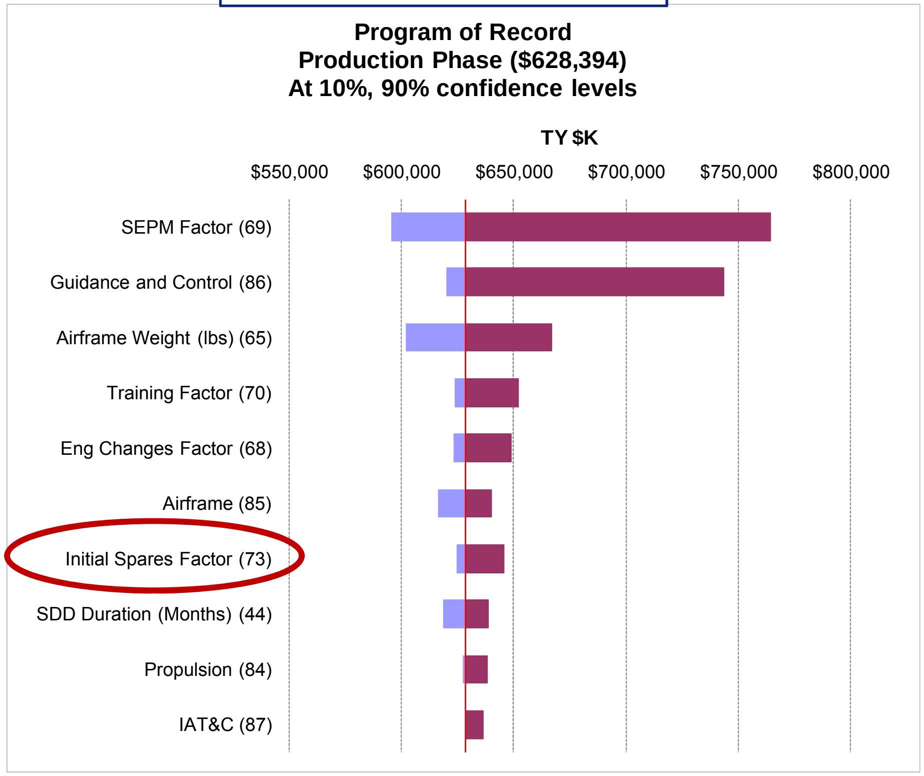


Tornado Based on What? BY vs TY

Not Recommended



Better



- **Tornado based on:**
  - 10/90 bounds of inputs that influence the Production Phase
  - BY dollars - does not account for time phasing of dollars
- **Same Tornado in TY$**
  - A better choice, accounts for phasing
  - SDD Duration variable shows up because it drives Production start, BY$ not affected by start, but TY is!

A Word of Caution on Tornado Charts

- **Assessing extreme bounds (10/90%) can lead to very extreme results depending on modeling methods**
  - Useful for identifying which variables have the potential to be most harmful
  - Fixed +/- 5% can give PM guidance on what elements have the biggest impact for a small change, that is give him/her goals he/she can achieve
- **Be wary of "Fixed range" testing. Every driver, even those that are not uncertain (e.g., a units conversion) will be tested unless the user excludes them**
- **Tornado charts assess one variable at a time**
  - Can underestimate the true impact if other variables should move with the tested one
  - Building functional relationships between variables will address this problem
  - If specific combinations of variables are of interest, they should be examined as specific what-if cases

What about a Tornado based on a RI$K Allocated Case?

- **Create a RI$K allocated case based upon the percentile you plan to use as the basis for your budget**
- **Run the Tornado and select the RI$K Allocated case**
- **Caution: After the report is generated, check the table below the chart to ensure there is a result for each low and high tested**

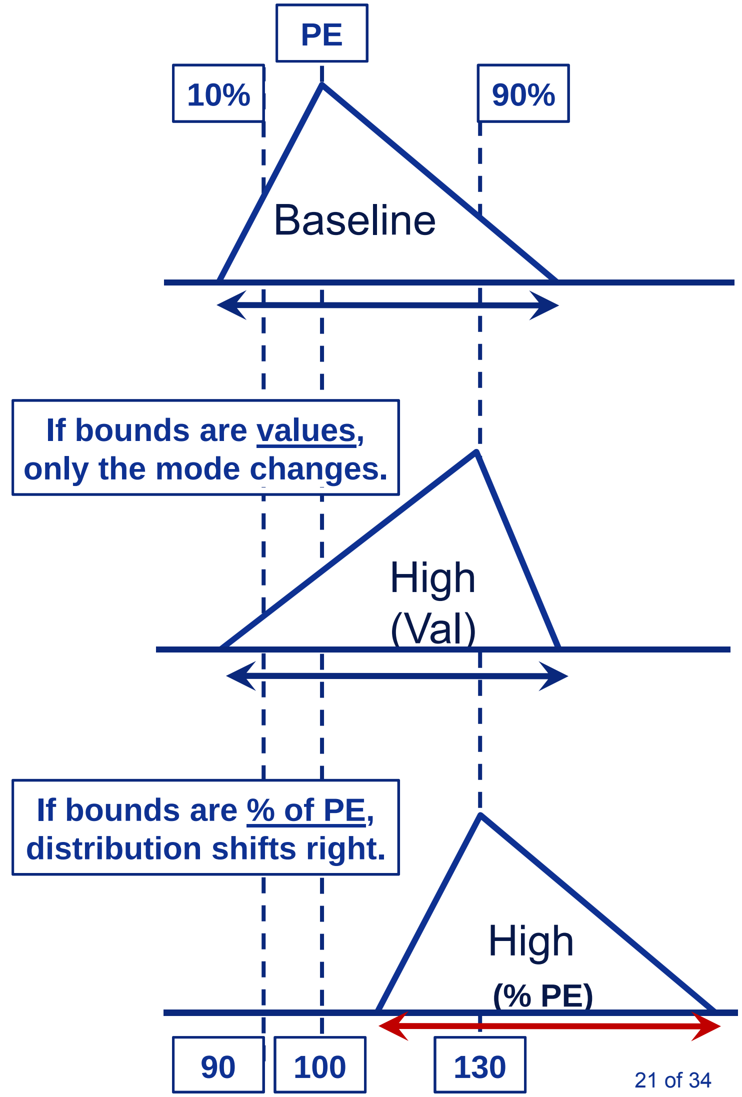
		Target Row Results			Risk Range Inputs		
Drivers (exlcuding Rollup, Zer	Row	Delta	5%	95%	Point Estimate	5%	95%
Airframe Weight (lbs) (65)	65	$106,311	$918,788	$1,025,099	369.7010	231.1232	471.3310
Guidance and Control (86)	86	$69,394	$951,153	$1,020,547	1.20	0.95	1.38
SEPM Factor (69)	69	$62,752	$945,847	$1,008,600	0.421	0.115	0.623
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Warhead Weight (lbs) (63)	63	$1,581	$958,408	$959,989	18.578	11.304	24.000
IATC Hrs/Unit (66)	66	$241	$958,533	$958,292	142.004	102.999	157.002
SDD Duration (Months) (44)	44			$974,725	64.846	52.293	71.997
Motor Weight (lbs) (64)	64				238	190	272

Low and high not calculated because the inputs exceed absolute value bounds used in model

Impact of Percent of PE vs Absolute Value Distribution Bounds

- **A variable is tested by generating a low and high override and running the model**
- **To obtain RI$K allocated results, each low and high must be run with RI$K**
- **Consider how the Tornado high is the processed for a triangular distribution**
  - **Top** is the Baseline distribution
  - **Middle** is the distribution applied to the Tornado high if bounds are values
  - **Bottom** is the distribution applied to the Tornado high if bounds are % of PE
    - covers a completely different range
  - Analysts should review how uncertainty is defined for each element appearing on the Tornado to ensure the test is realistic

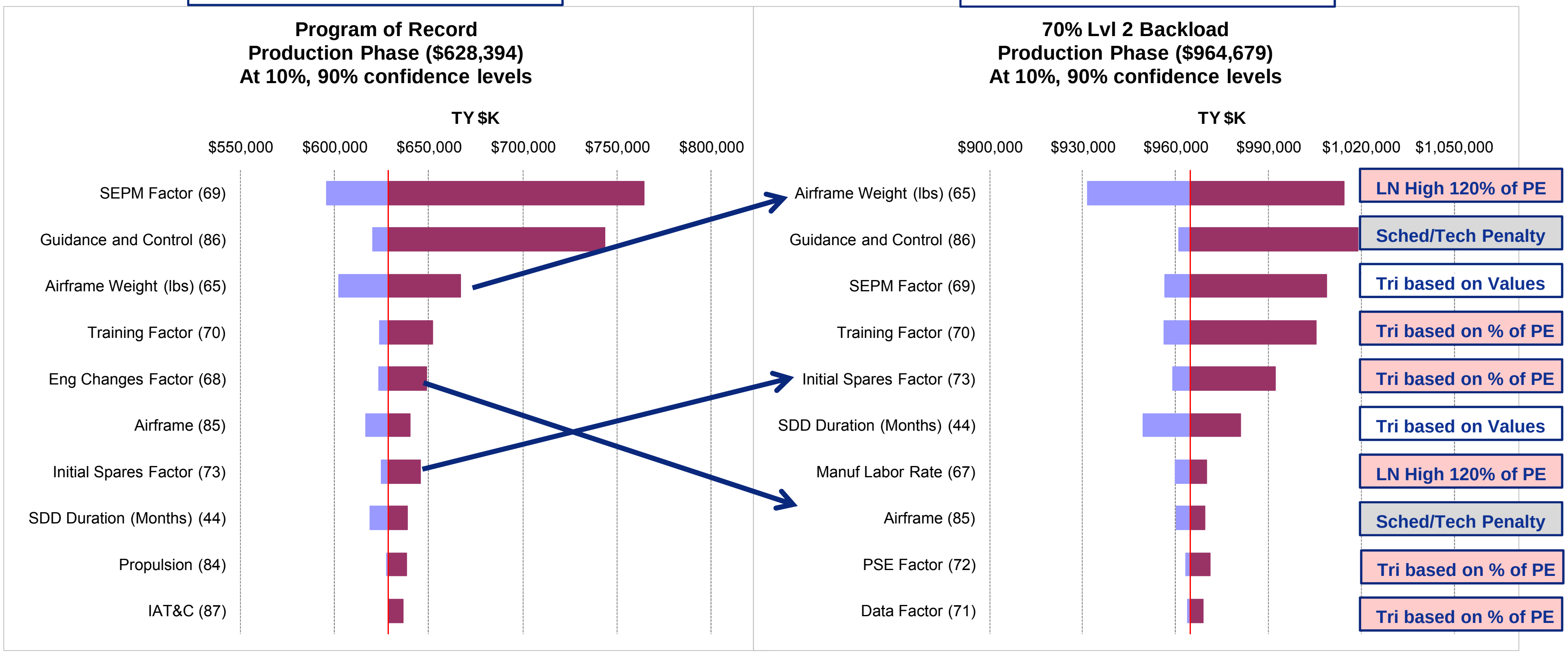
Distribution bound modeling method has a big impact on processing the Tornado bounds



Tornado: TY vs TY RI$K Allocated

Not Recommended

Recommended



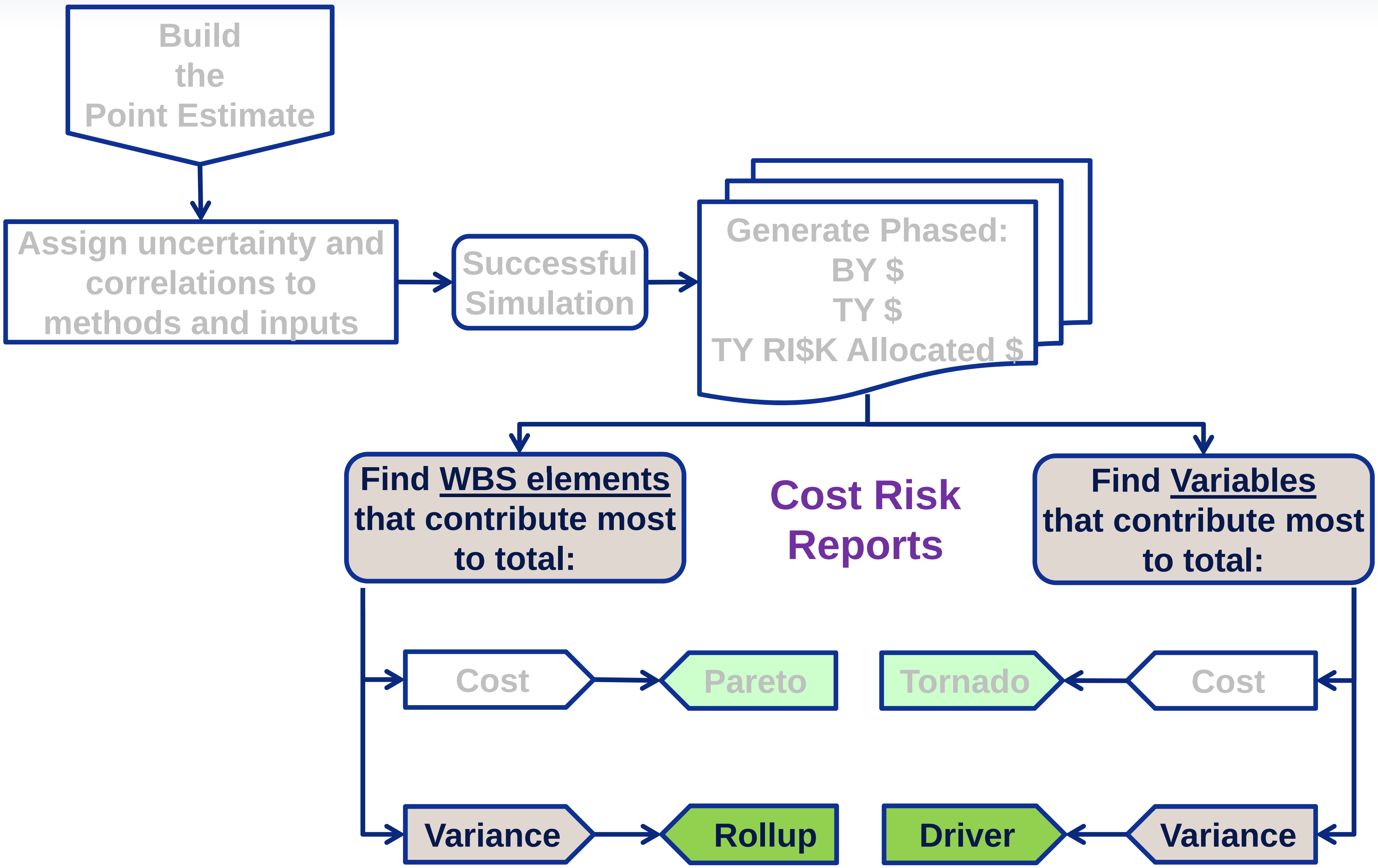
- **Based on Point Estimate in TY$**
- **Several significant differences when compared to Tornado based upon RI$K allocated result**

- **Based on RI$K Alloc Case in TY$**
  - Same percentile used to estimate budget
  - In this case, used 70% conf lvl, allocated from the 2nd level in the WBS, back loaded
  - Must examine where uncertainty modeled as % of PE (in this case, plausible to accept)

Tornado Recommendations

- **Run both the Point Estimate in TY$ and the RI$K Allocated case in TY$**
- **Note differences and use results to influence your identification of cost drivers**
- **For this model:**
  - Must use TY$ report to ensure methods driven by schedule elements are properly assessed (ie SDD duration)
  - Airframe is the top cost driver if we think the uncertainty will scale with the point estimate
  - Our model of Schedule/Technical penalty for Guidance and Control is the second most important regardless of which Tornado is used (even BY$)
  - 10/90 bounds to define the Tornado analysis is a common standard, but worthy of debate (vs 80/20 or some other combination)

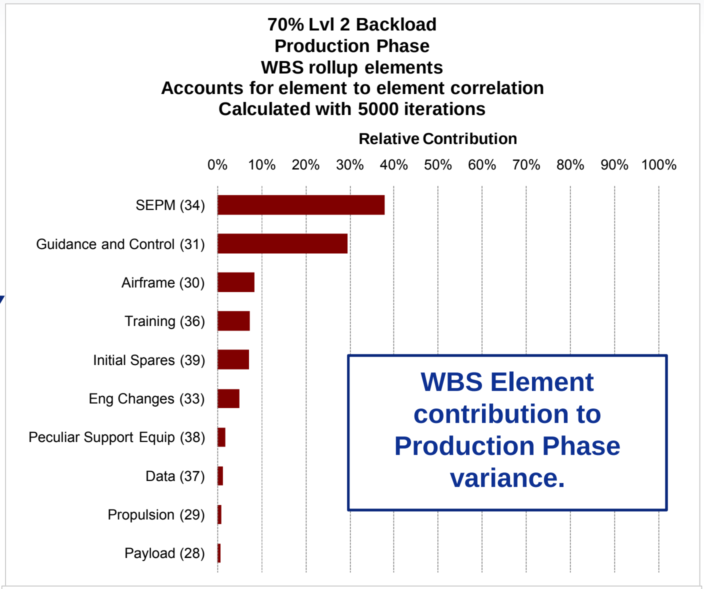
Find Uncertainty Drivers

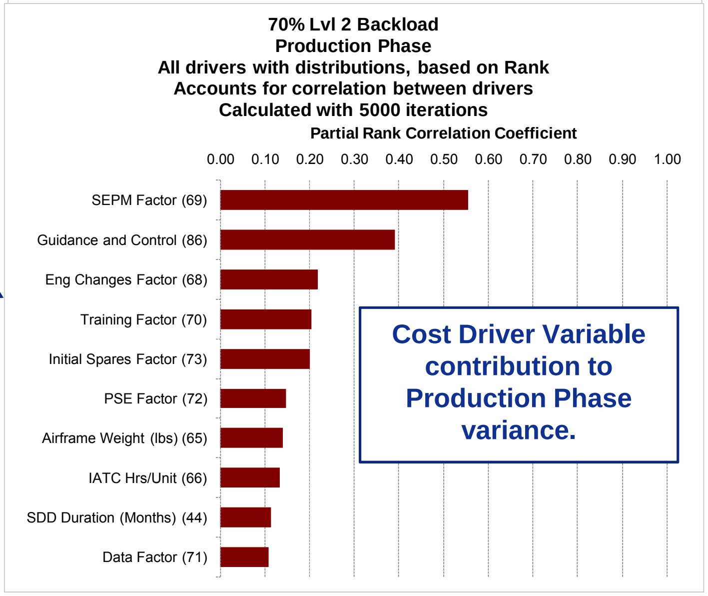


Finding the Uncertainty Drivers

- **Pareto Chart:** identifies WBS elements that contribute most to the target row *total*
- **Tornado/Spider Chart:** identifies the uncertain variables that most influence the target row *total*
- **Variance Analysis (Rollup):** identifies WBS elements that contribute most to the target row *uncertainty*
- **Variance Analysis (Driver):** identifies the defined distributions that contribute most to the target row *uncertainty*

Note that ACE is the only tool to provide an option to account for applied correlation when performing variance analysis (other tools call it "sensitivity analysis")

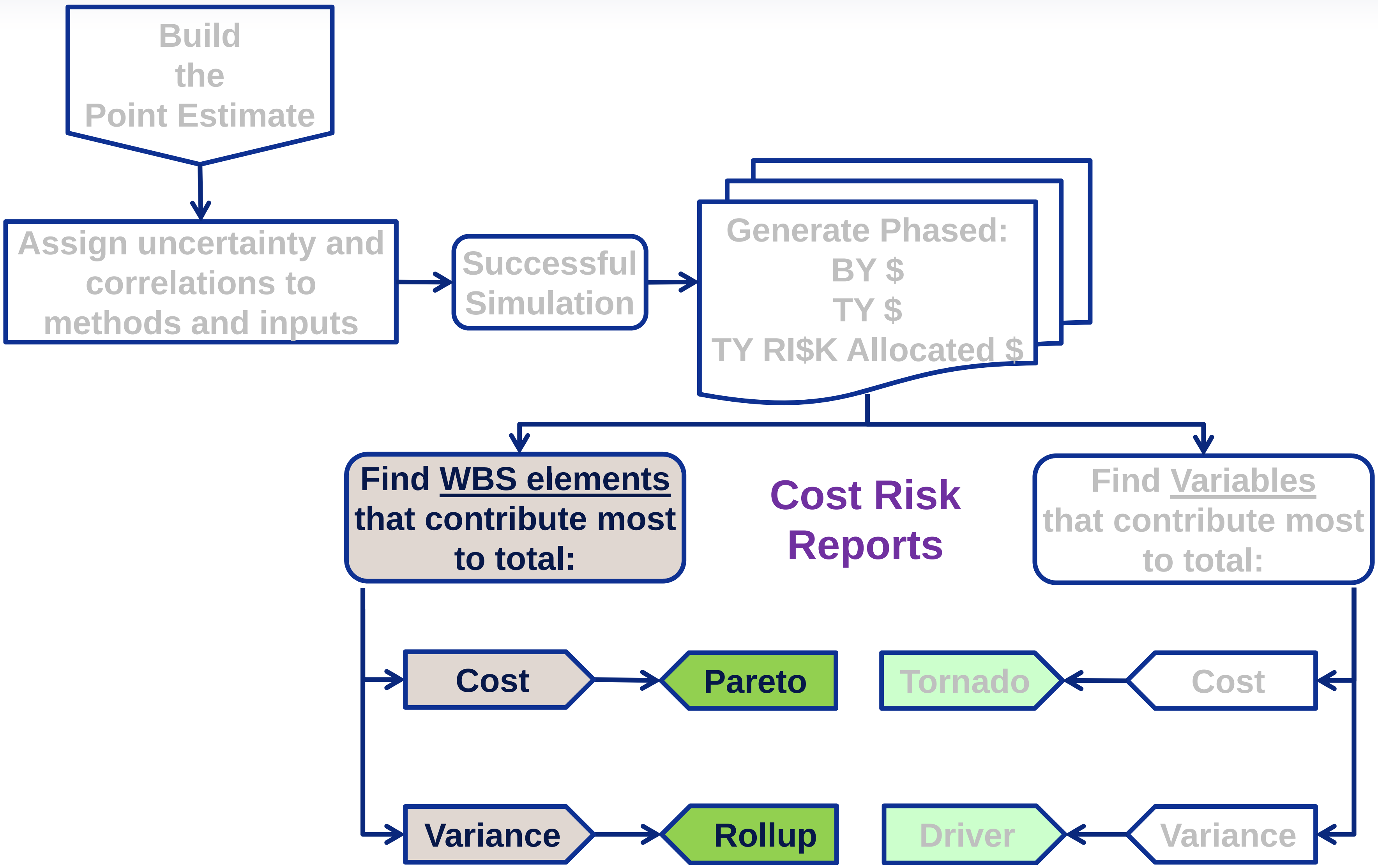




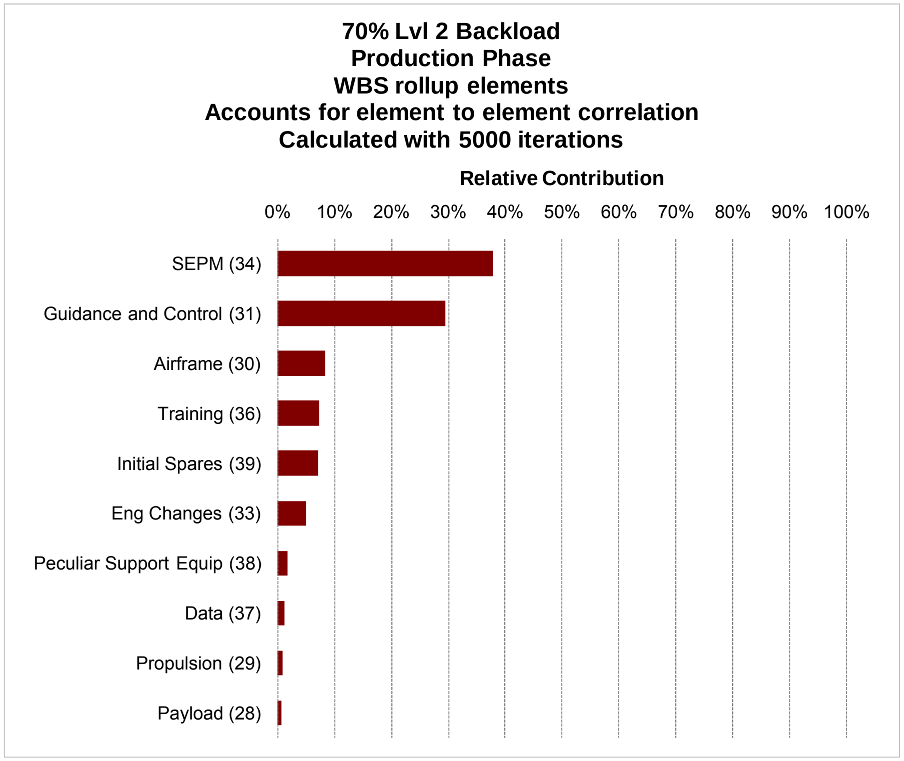
Finding Key Contributors to Total Uncertainty

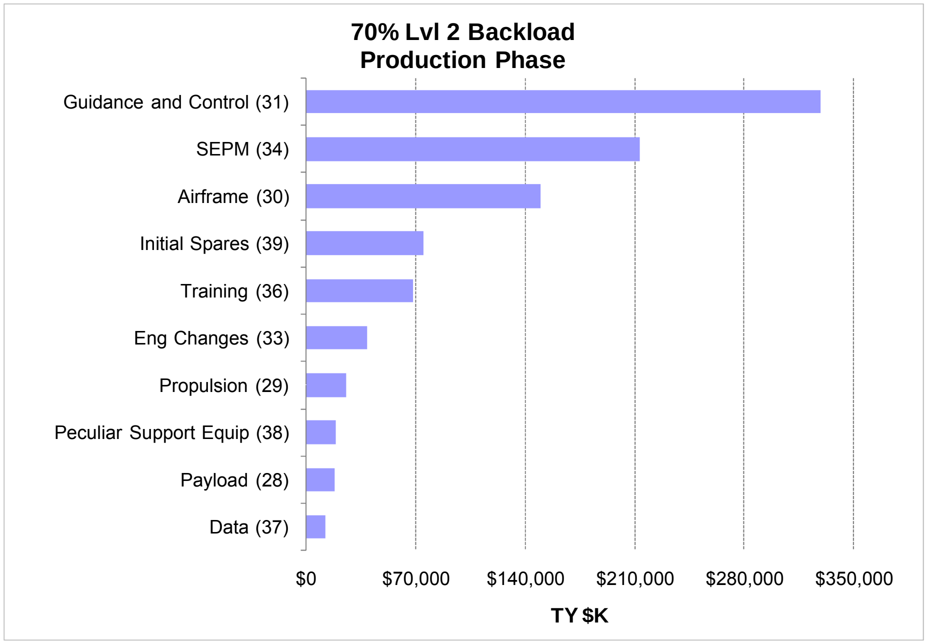
- **Uncertainty distributions are assigned to:**
  - cost method uncertainty
  - cost method inputs
- **The objective of a "Variance Analysis" is to find the most important contributors to the Total uncertainty**
- **POST allows you to quickly examine different types:**
  - **WBS Rollup**: Find <u>WBS elements</u> that contribute the most to total uncertainty (cost passengers)
  - **All Drivers**: Find <u>distributions</u> anywhere in the model (methods or inputs) that contribute the most to total uncertainty
  - **Some Drivers**: Consider a <u>specific subset of distributions</u> in the model
    - For instance, examine only those distributions assigned to input variables (cost drivers)
    - Similar to a Tornado analysis targeting input variables (thus can be a source of further confusion)

WBS Elements that Contribute Most to Total Uncertainty



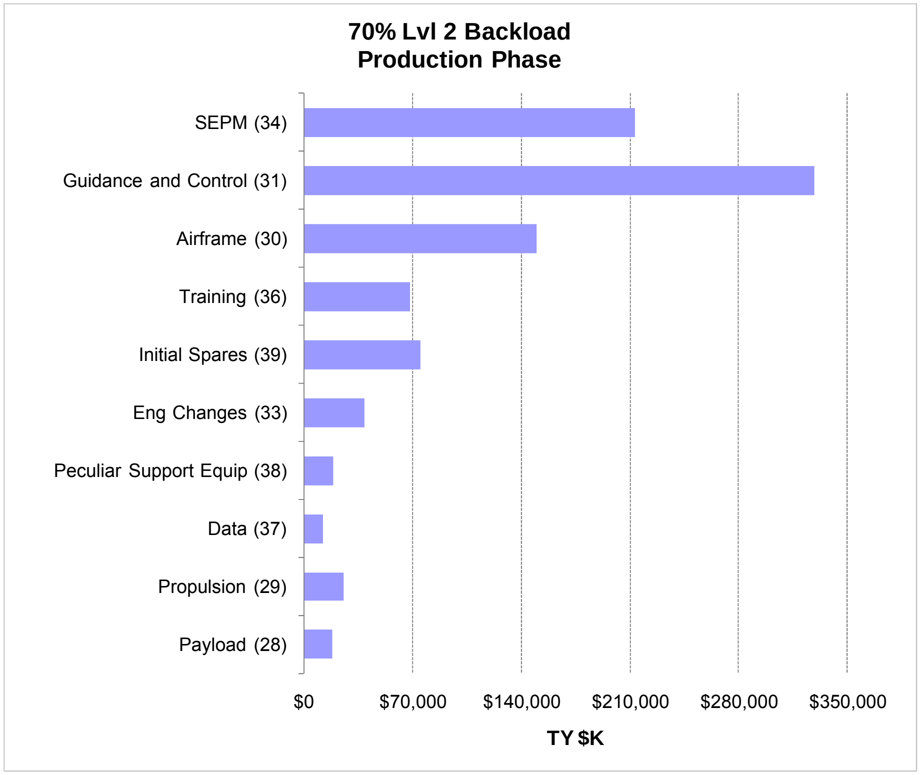
Compare WBS Rollup Variance Analysis with Pareto

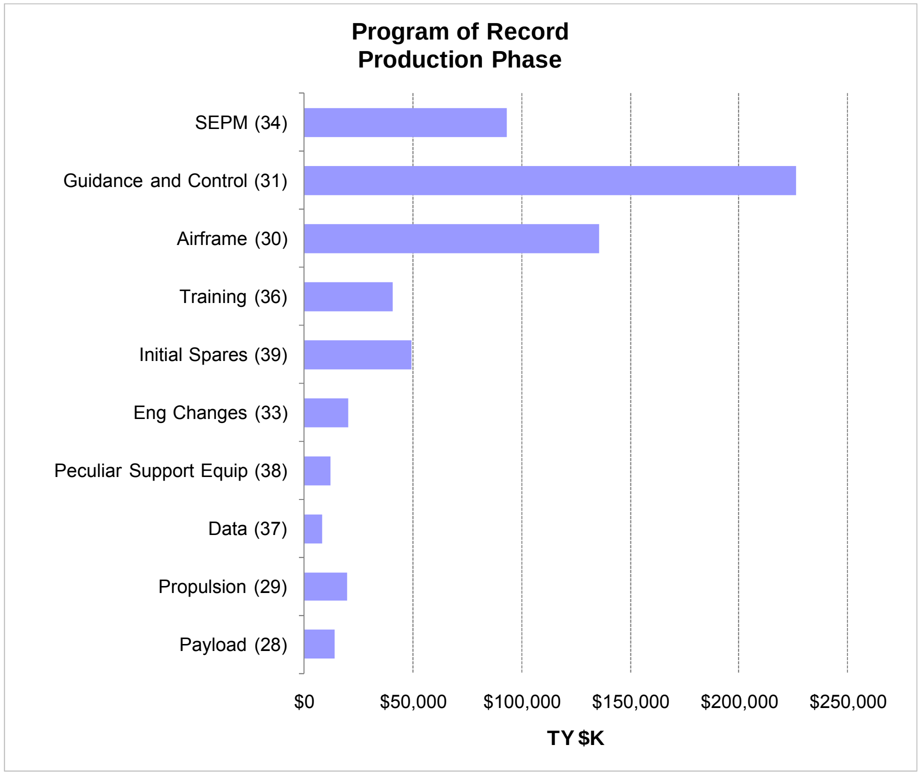




- **WBS Rollup (left) is not in same order as the Pareto (right)**
- **Can we make sense of this? Should there be a relationship?**

Use Pareto Reports to Derive RI$K Dollars by Element

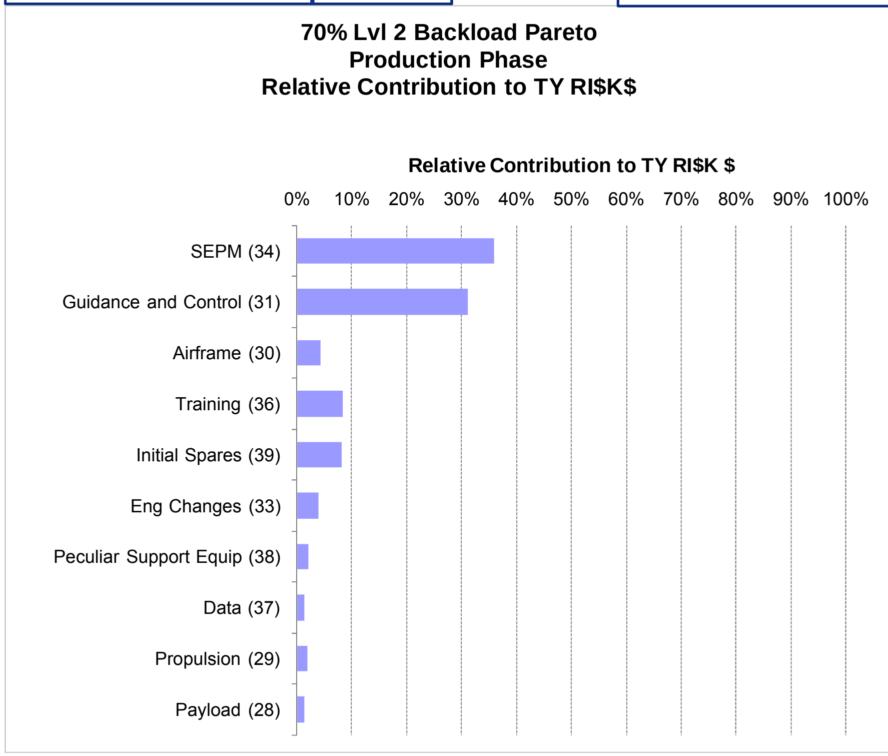


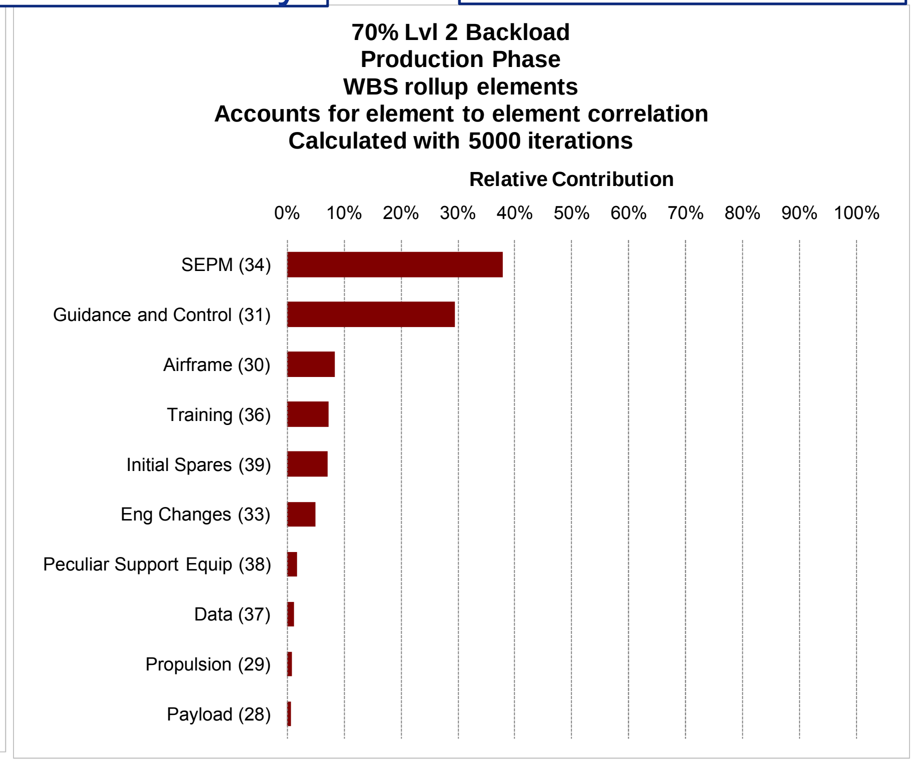


- **Create a Pareto RI$K Allocated (left) and Point Estimate (right), both in TY$**
- **Sort elements to same order as Rollup Variance chart to facilitate comparison**
- **Left-Right = RI$K $, use this to create a Pareto based upon % contribution**

Compare Rollup Variance to Pareto Based on Relative Contribution to RI$K $

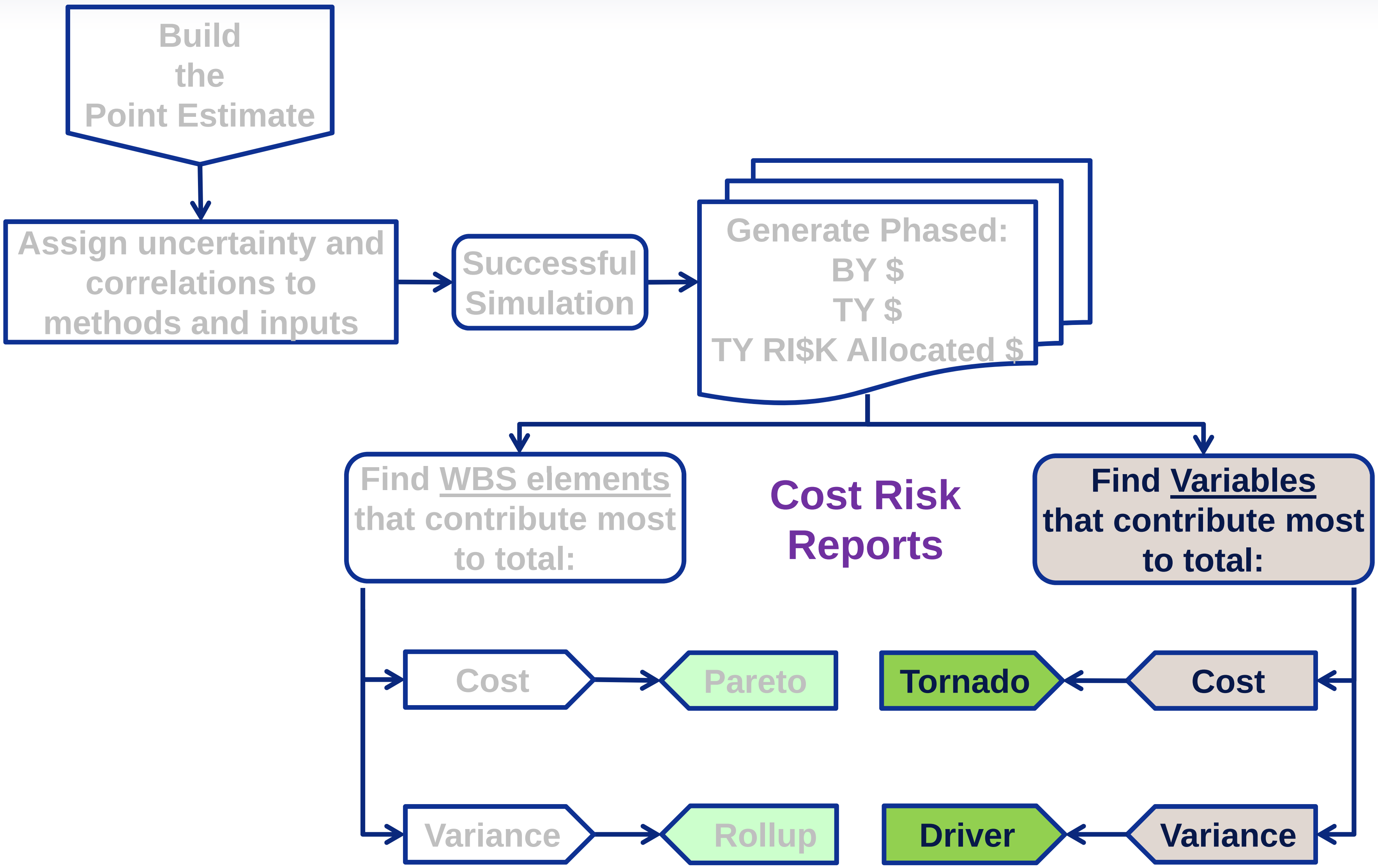
Easier to Explain | Both Tell The Same Story | Easier to Perform





- **General agreement, anomalies likely due to allocation process**
- **Rollup Variance Analysis identifies WBS elements that contribute most to RI$K Dollars**

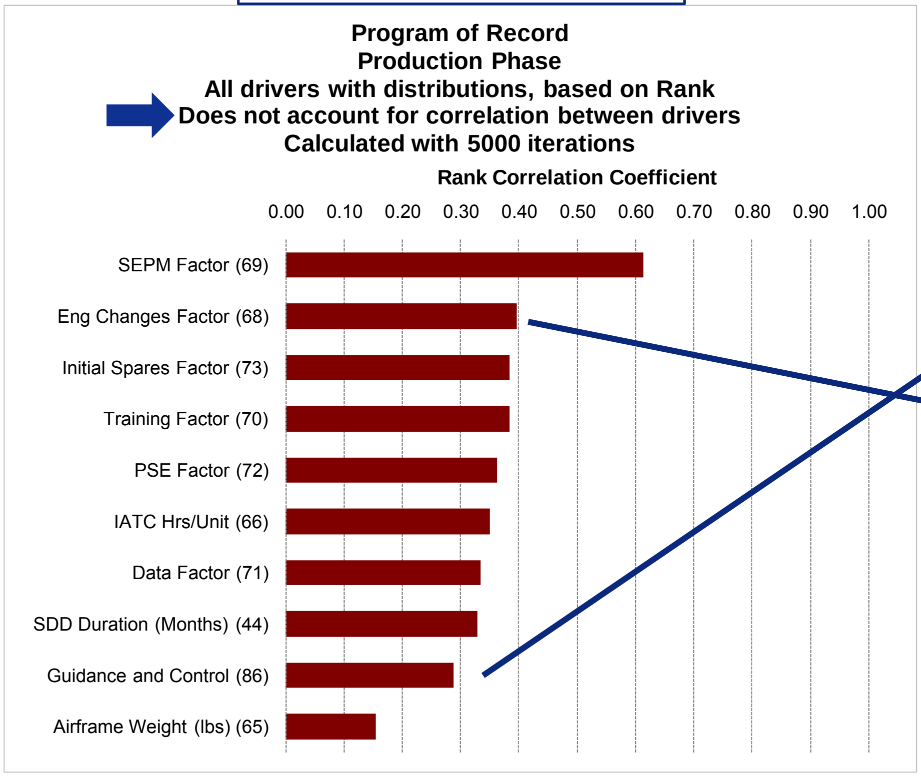
Variable Influence on Cost and Uncertainty



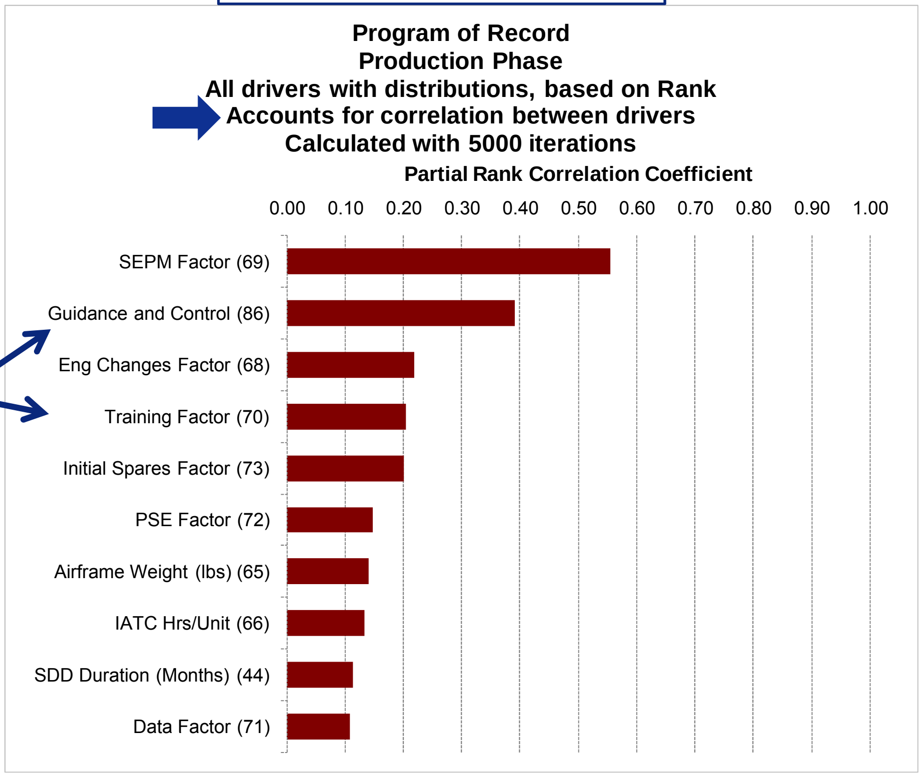
Approved for Public Release

Variance Analysis To Identify Cost Drivers That Contribute Most to Total Uncertainty

Not Recommended



Recommended



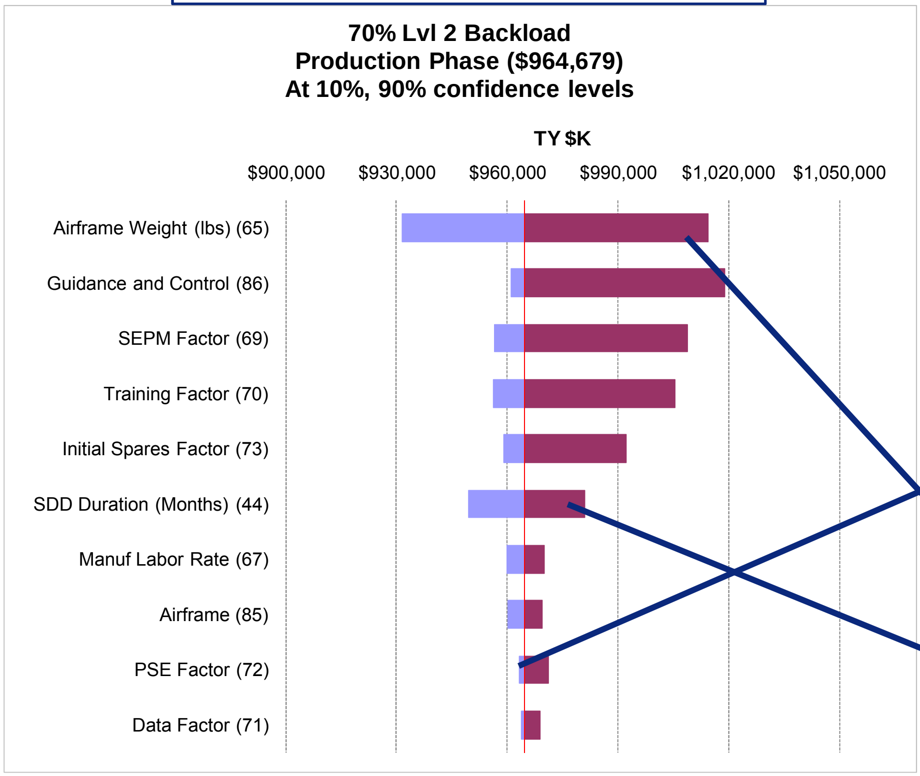
- **Without accounting for applied correlation, results can be misleading**
- **Variance analysis always performed on BY results (no choice given)**
- **PE & RI$K Allocated cases will yield identical results, meaning you need only run the PE case**

- **Accounting for applied correlation[1] between elements (only available in ACEIT)**
- **Note the significant changes to the results**

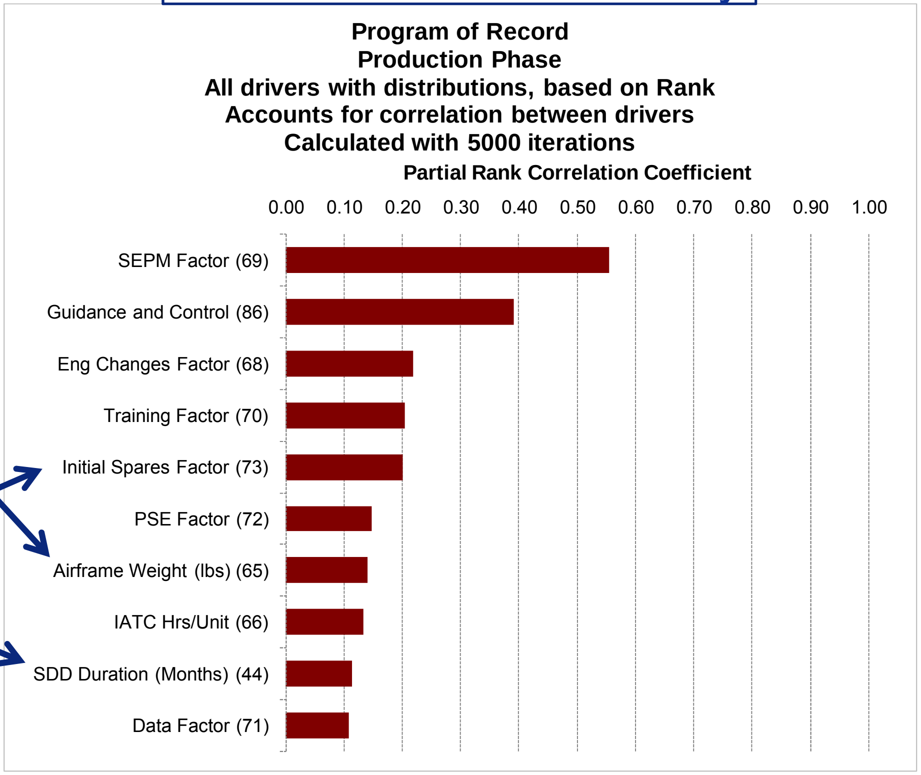
[1]Mishra, S., "Sensitivity Analysis with Correlated Inputs - An Environmental Risk Assessment Example", *1st Crystal Ball User Conference*, Denver, CO, 17-18 June 2004.

Influence on Cost is Not the Same as Influence on Uncertainty

Influence Total Cost



Influence Total Uncertainty



- **Tornado identifies variables that most <u>influence Total Cost</u>**
  - Performed on the RI$K Allocated case
- **Variance Analysis identifies variables that most <u>influence Total Uncertainty</u>**
  - Performed on the Point Estimate case

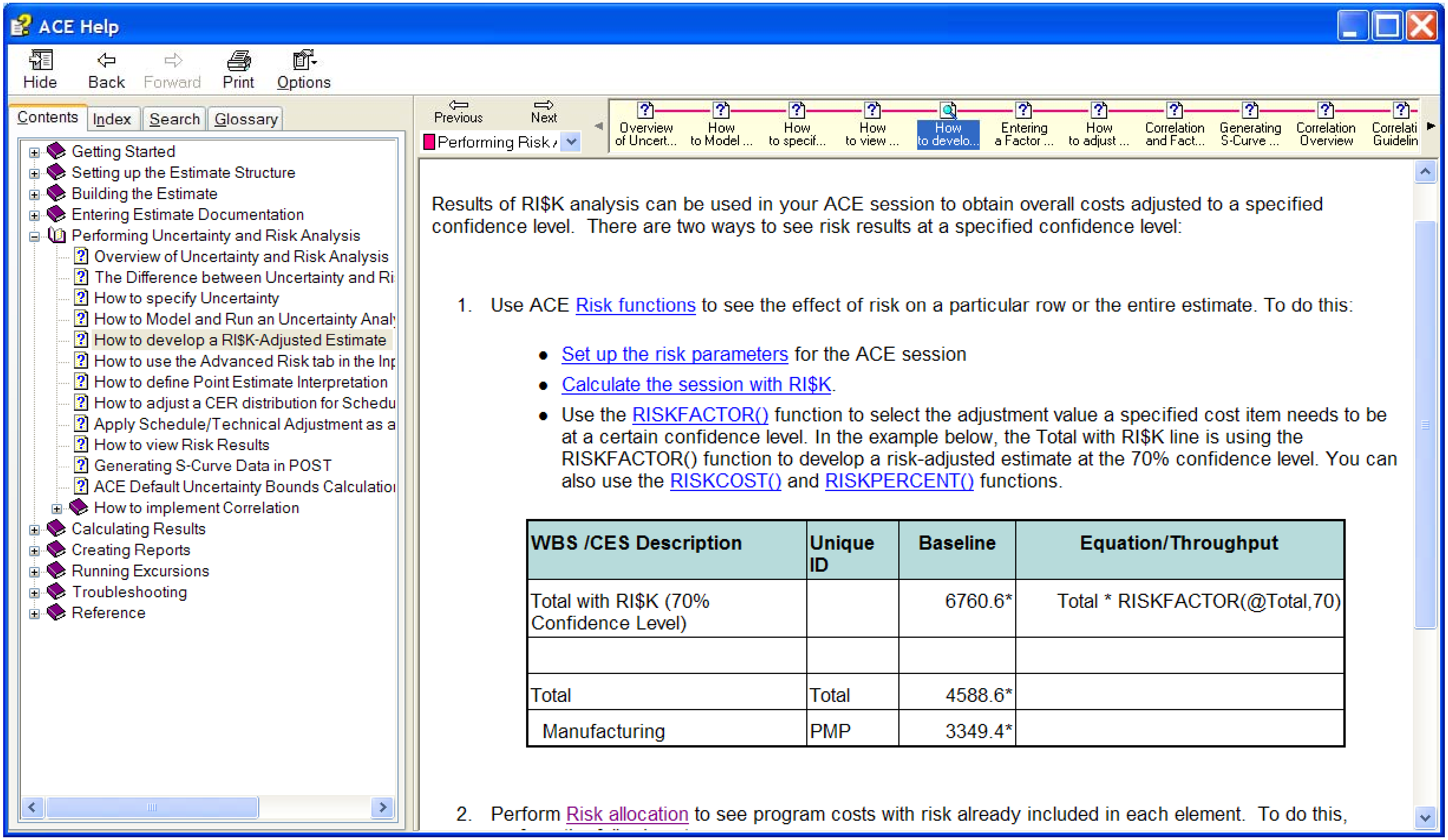
Summary

- **Use TY RI$K Allocated case when creating**
  - **Pareto**:
    - Find the WBS elements (cost passengers) that drive **total cost**
    - Can be used to identify top contributors to RI$K dollars
  - **Tornado**:
    - Find the variables (cost drivers) that drive **total cost**
    - 10/90 uncertainty bounds to identify cost drivers
- **Use any case when creating**
  - **Variance Analysis Rollup**:
    - Find WBS elements (cost passengers) that drive **total uncertainty**
    - Sorted based on variance, accounting for correlation
  - **Variance Analysis Non-rollup** :
    - Find variables (cost drivers) that drive **total uncertainty**
    - Sorted based on rank correlation, accounting for correlation
- **ACEIT contains all the reports you need to tell the risk story!**

Backup

Use Help to Guide Risk Modeling

(Based on AFCAA CRUH)


ACE Help

Hide Back Forward Print Options

Contents Index Search Glossary

- Getting Started
- Setting up the Estimate Structure
- Building the Estimate
- Entering Estimate Documentation
- Performing Uncertainty and Risk Analysis
  - Overview of Uncertainty and Risk Analysis
  - The Difference between Uncertainty and Ri
  - How to specify Uncertainty
  - How to Model and Run an Uncertainty Anal
  - How to develop a RI$K-Adjusted Estimate
  - How to use the Advanced Risk tab in the Inp
  - How to define Point Estimate Interpretation
  - How to adjust a CER distribution for Schedu
  - Apply Schedule/Technical Adjustment as a
  - How to view Risk Results
  - Generating S-Curve Data in POST
  - ACE Default Uncertainty Bounds Calculatio
  - How to implement Correlation
- Calculating Results
- Creating Reports
- Running Excursions
- Troubleshooting
- Reference

Previous Next Performing Risk

Overview of Uncert... | How to Model ... | How to specif... | How to view ... | How to develo... | Entering a Factor ... | How to adjust ... | Correlation and Fact... | Generating S-Curve ... | Correlation Overview | Correlati Guidelin

Results of RI$K analysis can be used in your ACE session to obtain overall costs adjusted to a specified confidence level. There are two ways to see risk results at a specified confidence level:

1. Use ACE Risk functions to see the effect of risk on a particular row or the entire estimate. To do this:

   - Set up the risk parameters for the ACE session
   - Calculate the session with RI$K.
   - Use the RISKFACTOR() function to select the adjustment value a specified cost item needs to be at a certain confidence level. In the example below, the Total with RI$K line is using the RISKFACTOR() function to develop a risk-adjusted estimate at the 70% confidence level. You can also use the RISKCOST() and RISKPERCENT() functions.

WBS /CES Description	Unique ID	Baseline	Equation/Throughput
Total with RI$K (70% Confidence Level)		6760.6*	Total * RISKFACTOR(@Total,70)
Total	Total	4588.6*	
Manufacturing	PMP	3349.4*	

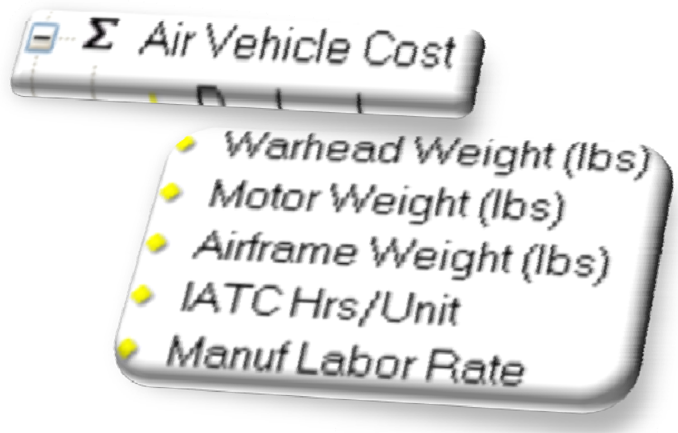
2. Perform Risk allocation to see program costs with risk already included in each element. To do this,

How Does RollUp Variance Analysis Work?

- **Two statistics sum in a simulation**
  - Mean
  - Variance
- **Total Variance** $= \sum_{k=1}^{n} \sigma_k^{\,2}$
  - Above formula only true if child elements are independent of each other (σ = standard deviation)
- **Total Variance** $= \sum_{k=1}^{n} \sigma_k^{\,2} + 2\sum_{k=2}^{n}\sum_{j=1}^{k-1} \rho_{jk}\sigma_j\sigma_k$
  - This formula accounts for correlation (ρ)
  - Reduces to first formula if all correlations are 0
- **POST measures the correlations first then uses the second formula to estimate the correlation adjusted variance for each child element**

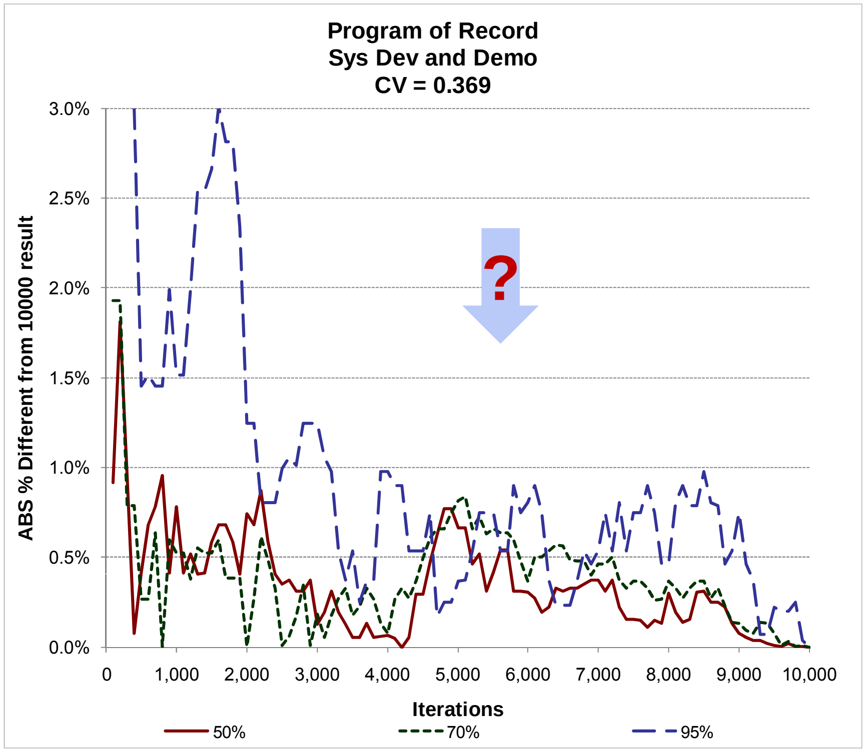
How Does Driver Variance Analysis Work?

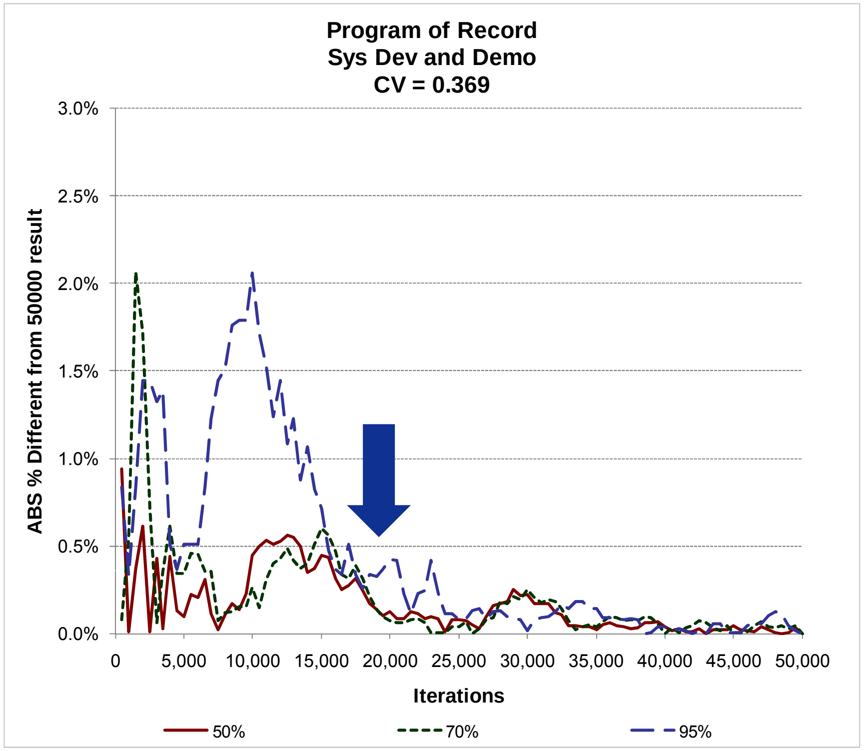
- **How does one measure the contribution of different input types (wgt, factors, rates, etc) on total cost variance?**
- **Solution: measure correlation**
  - Compare input distributions to target output distribution
  - Default is rank correlation by every tool



- **If correlations are applied to input distributions, most tools report that “results will be misleading”**
  - The message is almost always ignored
- **POST can account for applied correlation!**
  - the input with the largest partial correlation coefficient is the input with the largest contribution to total variance

What To Do If Target Does not Converge

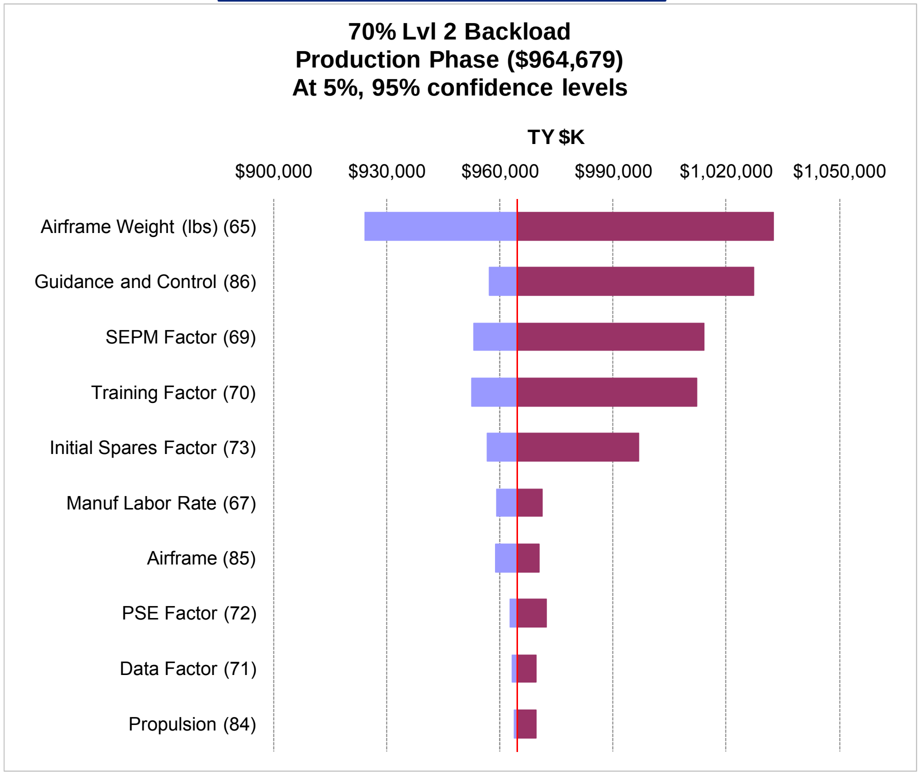




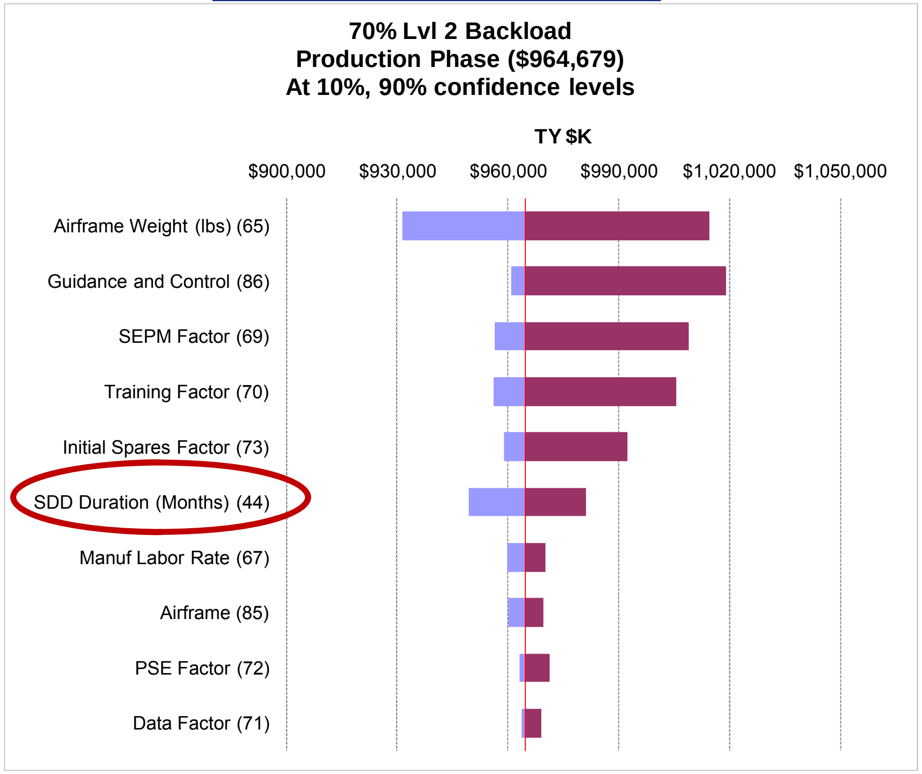
- **POST Convergence Chart, default settings, for SDD does not demonstrate convergence**
- **Need to change POST Convergence report option to more iterations (50k selected)**
- **SDD requires 20k (maybe 25k) to converge**
- **Must reassess all if model changes**

Tornado Settings: 10/90 or 5/95?

Not Recommended



Recommended



- **10/90 is the default setting**
- **Changing to 5/95 is an option, but not recommended as there is a greater chance that distribution bounds defined with absolute numbers will not process properly**
  - SDD Duration fails to show up in the 5/95 because the low/high were outside the defined bounds in the model