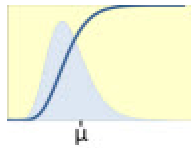
Joint
Cost Schedule Risk and Uncertainty
Handbook

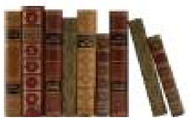
24 April 2013

https://www.ncca.navy.mil/tools/tools.cfm



Intent is to make CSRUH and associated support files available from this web site

S-Curve Tool for Risk and Uncertainty Analysis



Collaborative Cost Research Library System

The Naval Center for Cost Analysis maintains a Collaborative Cost Research Library containing a host of cost analysis related publications

NCCA Inflation Indices

The Naval Center for Cost Analysis generates inflation rates and indices for the Navy and Marine Corps appropriations and cost elements.

JCARD

Joint Cost Analysis Research & Database Working Group

Web information system that aids in improving efficiency, credibility and capability of cost analysis within the DoD community through the use of shared resources, data, knowledge and expertise.

Operating and Support Cost Analysis Model

OSCAM

System Dynamics simulation tool provides rapid cost estimation and analysis of high cost capital assets and their subsystems.

Manpower Cost Estimating Tool for Enhanced Online Reporting

DISCOUNT

NCCA Discount Rate Calculator - 2013

The NCCA 2013 Discount Calculator is a new Excel-based tool for use by analysts to help facilitate the use of discount factors published by the Office of Management and Budget (OMB) that are required for use in Department of the Navy economic analyses.

Background and Purpose

- **Background**
  - AFCAA Cost Risk and Uncertainty Handbook released in 2007. Chapter 14 of the GAO Cost Estimating and Assessment Guide, released in 2009, is consistent with the AFCAA CRUH.
  - NCCA initiated a task Sep 2012 to update the AFCAA CRUH to capture the latest concepts and to place more emphasis on capturing schedule uncertainty and the risk register in cost risk assessments
- **Purpose:**
  - The Cost Schedule Risk and Uncertainty Handbook (CSRUH) is to describe acceptable analytical techniques to model uncertainty in a cost estimate in order to calculate and report the cost risk.
  - Define and present simple, well-defined cost risk and uncertainty processes that are repeatable, defendable and easily understood.
  - Facilitate inter and intra-service buy-in

Government Led Effort

- The task leads were Duncan Thomas, Technical Director NCCA and John Fitch, NCCA.
- Significant contributions were made by: Steve VanDrew NAVAIR, Mike Koscielski SPAWAR, Dane Cooper NAVSEA, Kyle Ratliff MARCORSYSCOM, Janet Vacca-LeBoeuf NELO, Ranae Woods AFCAA, Dave Henningsen ODASA-CE, Trevor Vanatta Army TACOM, and Charles Hunt NASA.
- Numerous other Government employees and support contractors also participated in detailed reviews of handbook drafts and/or participated in the Peer Reviews. All provided valuable comments and guidance.
- Alfred Smith and Jeff McDowell were the principle authors with Dr Shu-Ping Hu as the principle author of Appendix A.

Introducing CISM and FICSM

- **CISM**: Cost Informed by Schedule Method
  - ***Spreadsheet*** *based* cost uncertainty model that has some level of duration uncertainty built into it
  - CISM model is the focus of the handbook
- **FICSM**: Fully Integrated Cost Schedule Method
  - Typically a ***cost loaded schedule*** *model* with cost and schedule risk and uncertainty addressed
  - FICSM is gaining popularity. It is introduced in this handbook as a concept for future consideration and study.

Agenda

- Compare Joint CSRUH to the AFCAA CRUH
- Applying the Cost Informed by Schedule Method (CISM)
- Finish and Evaluate the CISM Model
- Correlation, convergence, interpreting results
- Allocating and Phasing Risk Dollars
- Reports: For Technical Review, For Decision Makers
- Alternate Methods: eSBM, Method of Moments, Outputs based
- Fully Integrated Cost and Schedule Method (FISCM) - Introduction
- Future Work

Comparing Joint CSRUH to AFCAA CRUH (1 of 3)

AFCAA CRUH (2007)	Joint CSRUH (2013)
Cost Risk and Uncertainty Methods	
Inputs stressed throughout	**CISM** (Inputs: emphasis on duration uncertainty)
Outputs, FRISK, SBM	**FICSM**, eSBM, Method of Moments, Outputs
Sources of Uncertainty	
	More emphasis on schedule and risk register
	Added: sources of risk
Point Estimate	
Based on CARD	Based on realistic, documented program definition
Finish PE First	Perform PE and Uncertainty in Parallel
	Introduce schedule driven methods
	PEs = Point Estimate for the schedule
Uncertainty Distributions	
	Guidance on histograms, bin count
Lognormal, Normal, Triangular, Beta, Uniform	Added Log-t, Student-t, and BetaPERT
	Descriptive Statistics, more definitions
Weibull mentioned in a table	Poisson, Weibull, Exponential (Introduced for O&S)

Comparing Joint CSRUH to AFCAA CRUH (2 of 3)

AFCAA CRUH (2007)	Joint CSRUH (2013)
Objective Uncertainty	
Statistical Analysis, Regression	Statistical Analysis, Regression
	Distribution Fitting
	Significant update to Appendix A mathematics
Subjective Uncertainty	
Expert Opinion treated as 15/85	Expert Opinion treated as 15/85
	Expanded Elicitation Guidance
Adjust for Skew (Triangular only)	Adjust for Skew (Triangular, Uniform, BetaPERT)
Default Table	Table of Last Resort (same as AFCAA CRUH)
New or Significantly Revised Material	
	NCCA SAR Growth Study, AFCAA CRUAMM
	Best Practices including spreadsheet layout
Truncate at zero	Truncate at zero reinforced
	Capturing the Risk Register, Sunk costs, Inflation
Technical/Schedule Adjustment (removed)	CER Adjustment factors
	Calibrated CERs, Significant re-write of CIC guidance
	Detailed example to measure correlation
	Tool independent utilities included: - adjust for skew, correlation, s-curve, convergence

CRUAMM: Cost Risk Uncertainty and Analysis Metrics Manual

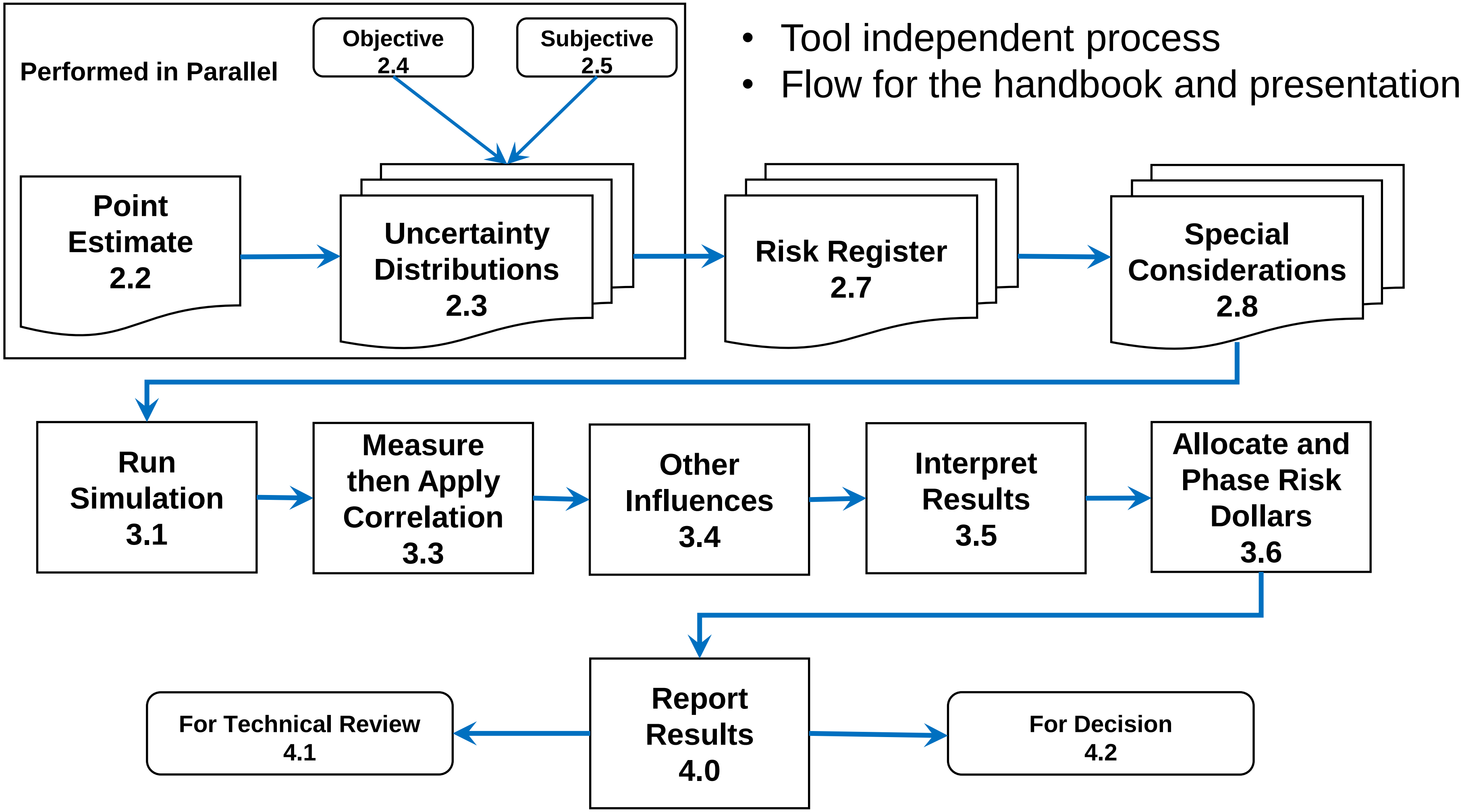
Comparing Joint CSRUH to AFCAA CRUH (3 of 3)

AFCAA CRUH (2007)	Joint CSRUH (2013)
Correlation	
Measure first	Emphasized measure first (including examples)
	Stress application where needed only
Implicit and Explicit	Functional and Applied
Default based on number of elements	Default 0.3 (based on 2012 MDA Cost Handbook)
Allocation	
Based on Standard Deviation - Fully Defined	Several methods fully defined, worked examples:
Needs - Introduced	- Std Dev, Std Dev adj for corr, Needs
	More detail on phased allocation
Reporting	
	Charts for technical review
	- distinction between cost contributor and driver
	- cost and uncertainty driver chart guidance
Charts for Decision Makers	Charts for decision makers
Appendix A - Terminology and Detail	
	Completely re-organized
Definitions	More definitions, including Nunn-McCurdy Breach
	Descriptive statistics and distribution math
	Goodness-of-fit statistics
	Three allocation methods compared
Appendix B - Fully Integrated Cost and Schedule Method	
	All new material.

BUILDING THE CISM MODEL

CISM Model Development Flow

- Tool independent process
- Flow for the handbook and presentation



5.0 Alternatives to CISM   6.0 Portfolio Considerations

The Point Estimate

- The point estimate (PE) can be based on:
  - **Program of Record**: requirement documents
  - **Technical Baseline**: technical assessment
  - **What-If Case**: specific case study
- Cost & schedule WBS should be same, but:
  - **Cost Point Estimate** (PE) will be derived from an approved WBS structure (MIL-STD-881C)
  - **Schedule Point Estimate** (PE_s) is an integrated, network of activities to support the events, accomplishments, and criteria of the project plan

Example Model WBS

Built in Crystal Ball, @Risk and ACE

Estimate WBS	EMD Variables	Production Variables

Estimate WBS

- Missile System
  - Engineering and Manufacturing Development
    - Air Vehicle
      - Design & Development
      - Prototypes
    - Software
    - System Engineering
    - Program Management
    - System Test and Evaluation
    - Training
    - Data
    - Peculiar Support Equipment
  - Production & Deployment
    - Air Vehicle
      - Airframe
      - Propulsion
      - Guidance
      - Payload
      - Air Vehicle IAT&C
    - System Engineering
    - Program Management
    - System Test and Evaluation
    - Training
    - Data
    - Peculiar Support Equipment
    - Initial Spares and Repair Parts

Risk Register 1 Impact →

Risk Register 1 Impact →

EMD Variables

- INPUT VARIABLES
- DEVELOPMENT

EMD Date and Duration

- EMD Date and Duration
- EMD Planned Start Date
- EMD Start Delay (Months) ← Drives EMD Schedule
- EMD Modeled Start Date
- EMD Duration (Months) ← Drives EMD Schedule
  - EMD Duration (Months)
  - EMD RR Dur Incr Due to SW (Months)
- EMD End Date

EMD Qty and Variables

- EMD Qty and Variables
- EMD Design & Dev Cost Per Month
- EMD Protoype Quantity
- EMD Prototype Learning Slope
- EMD Step Increase over Production Cost
- EMD SW Effort (Mths)
  - EMD SW Effort (Third Party Tool)
  - RR #1 Add to SW Person Months
- EMD SW Labor Rate ($/month)
- EMD Sys Eng Annual Cost
- EMD PM Annual Cost
- EMD Sys Test Eval Factor

Production Variables

- PRODUCTION

Production Dates

- Production Dates
- Production Start Date
- Production Start GFY
- Production End GFY (Obligation)
- Production End Date (Performance, not obliga
- Production Duration (Months)

Production CERs

- Production CERs
- Production Qty
- Airframe First Unit Cost
- Airframe Learning Slope
- Ariframe Rate Slope
- Propulsion First Unit Cost
- Propulsion Learning Slope
- Propulsion Rate Slope
- Guidance First Unit Cost
  - Guidance First Unit Cost CER
  - Guidance RR#2 Add to First Unit Cost ← Risk Register 2 Impact
- Guidance Learning Slope
- Guidance Rate Slope
- Payload First Unit Cost
- Payload Adjustment Factor
- Payload Learning Slope
- Payload Rate Slope

Guidance Risk Register (RR #2)

- Guidance Risk Register (RR #2) ← Risk Register 2 Variables
- Prod RR2 Potential Guidance Cost Incr
- Prod RR2 Probability Prototype Problem
- Prod RR2 Guidance

Example Model Introduces Duration Into a Typical Cost Model

WBS Description	Estimate Method	Duration Sensitive
Missile System		
Engineering and Manufacturing Development		
Air Vehicle		
Design & Development	**[DurationBased]** EMD_DesignDevPerMth*EMD_Duration	Direct
Prototypes	**[Factor for T1]** EMD_Prod * ProdToEMDStepUpFact * Learning	Time Independent
Software	**[Analogy]** ThirdPartyToolSWManMonths * SWLaborRate$	Time Independent
System Engineering	**[Build-up]** EMD_SEFTE * EMD_SELabRate$ * EMD_Duration	Direct
Program Management	**[Build-up]** EMD_PMFTE * EMD_PMLabRate$ * EMD_Duration	Direct
System Test and Evaluation	**[Factor]** EMD_Trng_Fac * EMD_Proto$	Time Independent
Training	**[Factor]** EMD_Trng_Fac * EMD_AV$	Indirect
Data	**[Factor]** EMD_Data_Fac * EMD_AV$	Indirect
Peculiar Support Equipment	**[Factor]** EMD_SptEquip_Fac * EMD_Proto$	Time Independent
Production & Deployment		
Air Vehicle		
Airframe*	**[Parametric CER: TRIAD]** 25.62 + 2.101 * AirFrameWt ^ 0.5541	Learning Rate
Propulsion*	**[Parametric CER: OLS Loglinear]** 1.618 * MotorWt ^ 0.6848	Learning Rate
Guidance*	**[Throughput]** 100	Learning Rate
Payload*	**[Parametric CER: OLS Linear] (**30.15 + 1.049 * WarheadWt) * AdjustFactor	Learning Rate
Air Vehicle IAT&C*	**[Third Party Tool]** IACO_HsPerUnit * MfgLaborRate$	Learning Rate
System Engineering	**[Build-up]** Prod_SEFTE * Prod_SELabRate$ * Prod_Duration	Direct
Program Management	**[Build-up]** Prod_PMFTE * Prod_PMLabRate$ * Prod_Duration	Direct
System Test and Evaluation	**[Throughput]** $1,250 per year	Direct
Training	**[Factor]** Trng_Fac * AV_Prod$	Indirect
Data	**[Factor]** Data_Fac * AV_Prod$	Indirect
Peculiar Support Equipment	**[Throughput]** $7,634.27	Time Independent
Initial Spares and Repair Parts	**[Factor]** InitSpares_Fac * AV_Prod$	Indirect

Duration Sensitive

* = CER to estimate the first unit cost for a rate affected unit learning curve

Basic Distribution Shapes

DISTRIBUTION	TYPICAL APPLICATION	KNOWLEDGE OF MODE	NUMBER OF PARAMETERS REQUIRED	RECOMMENDED PARAMETERS
Lognormal	**Default** when no better info. Probability skewed right. Replicate another model result. Power OLS CER uncertainty.	Mean or median known better than the mode	2	**Median, high** (some tools have a 3rd parameter: "Location". By default, it is zero. Used to "slide" the lognormal left or right (even into negative region)
Log-t	Log-t when < 30 data points		3	**Add Degrees of Freedom**
Triangular	Expert opinion. Finite min/max. Probability reduces towards endpoints. Skew possible. Labor rates, labor rate adjustments, factor methods	Good idea	3	**Low, mode, and high**
BetaPert	Like triangular, but mode is 4 times more important than min or max.	Very good idea	3	**Low, mode, and high**
Beta	Like triangular, but min/max region known better than mode.	Not sure	4	**Min, low, high, and max**
Normal	Equal chance low/high. Unbounded in either direction Linear OLS CER uncertainty.	Good idea, but unbounded in either direction	2	**Mean/Median/Mode and high value**
Student's-t	t when < 30 data points		3	**Add Degrees of Freedom**
Uniform	Equal chance over uncertainty range. Finite min/max.	No idea	2	**Low and High** (some tools require min and max)

Note: *Low/high* are defined with an associated percentile
Min/Max are the absolute lower/upper bound (also known as the 0/100)

Example Model Makes Use of All Recommended Distributions

- Recommend uncertainties organized on a single sheet
- Recommended format facilitates validation

					Distribution Parameters					
* INPUT VARIABLES	Forecast	Distribution Form	Point Estimate is:	Uncertainty	Min	Low	High	Max	Percentile	Percentile
* EMD Qty and Variables										
EMD Design & Dev Cost Per Mont	200.0000	Lognormal	Median	1.3378	1.189					
EMD Protoype Quantity										
EMD Prototype T1	$678.47									
EMD Step Increase over Productio	1.800	Triangular	Mode	1.8		1.5	2.5		9	79
EMD Prototype Learning Slope										
EMD SW Effort (Mths)	2,100.00									
EMD SW Effort	2,100.00	LogNormal	Median	1.00			1.50			80
RR #1 Add to SW Person Month										
EMD SW Labor Rate ($/month)	15.0000	Uniform	Undefined	1.00	0.95			1.3		100
EMD Sys Eng Annual Cost	3,500.00	Triangular	Mode	1.00		0.90	1.50		5	75
EMD PM Annual Cost	3,000.00	Triangular	Mode	1.00		0.90	1.30		8	78
EMD Sys Test Eval Factor	0.6000	Triangular	Mode	1.00		0.90	1.70		4	74
EMD Training Factor	0.0600	Triangular	Mode	1.00		0.95	1.30		4	74
EMD Data Factor	0.0800	Triangular	Mode	1.00		0.95	1.30		4	74
EMD Support Equipment Factor	0.2500	Triangular	Mode	1.00		0.90	1.70		4	74

Prototype uncertainty Inherited from Production

Operating and Support Probability Distributions

- **Poisson distribution**
  - Discrete distribution that requires only the mean of the distribution
  - Used to define the number of failures in a specified time when the average number of failures is small
  - Also used to estimate testing, inventory levels, and computing reliability
  - Commonly used to simulate the number of failures per year by specifying with the inverse of the mean time between failure

- **Exponential distribution**
  - a continuous distribution that can be used to estimate the time between failures.
  - Specified using the mean time between failures

- **Weibull distribution**
  - A continuous distribution defined by location, scale and shape parameters
  - Identical to Exponential when shape = 1; identical to Rayleigh when shape = 2
  - Used to estimate the time between failures when failure rate is decreasing (beginning of service) and when failure rate is increasing (end of service)

Objective and Subjective Uncertainty

- Use **objective**, data-driven uncertainty, such as:
  - Parametric equations through regression analysis
  - **Fit distributions to historical data or CER residuals**
  - **NCCA SAR Growth Study or AFCAA CRUAMM**

- **Subjective** uncertainty if necessary.
  In absence of compelling evidence to do otherwise:
  - Use lognormal distribution as the default **(data driven)**
    - **CRUAMM found 60% of measured uncertainty distribution were lognormal**
  - Treat expert opinion as the 70 percent interval (15/85)
  - Adjust the 15/85 interpretation to maintain expert's skew when using triangular, **uniform or betaPERT** distributions

- CSRUH also provides a **Table of Last Resort**

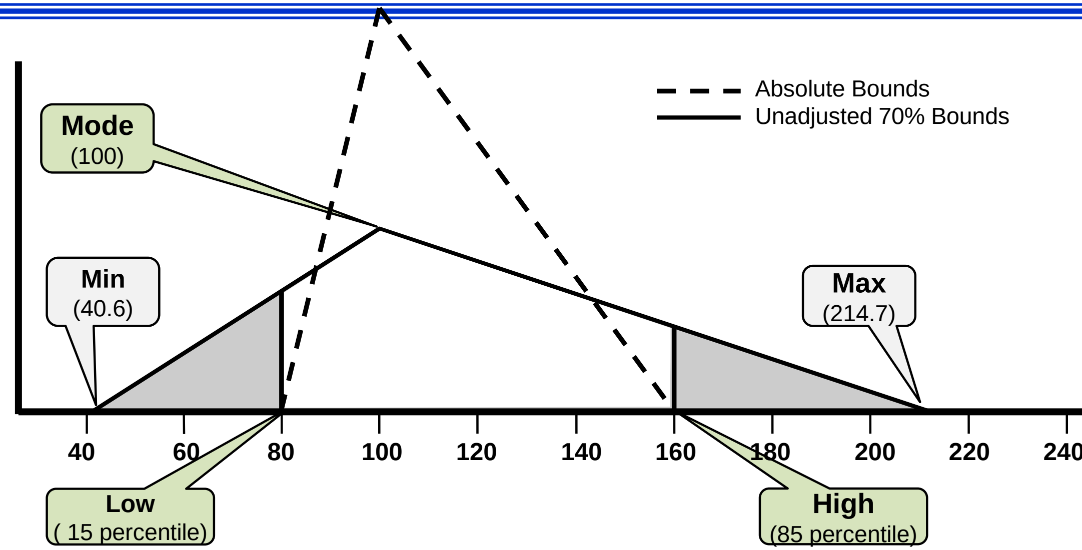
NCCA SAR Growth Study
AFCAA CRUAMM

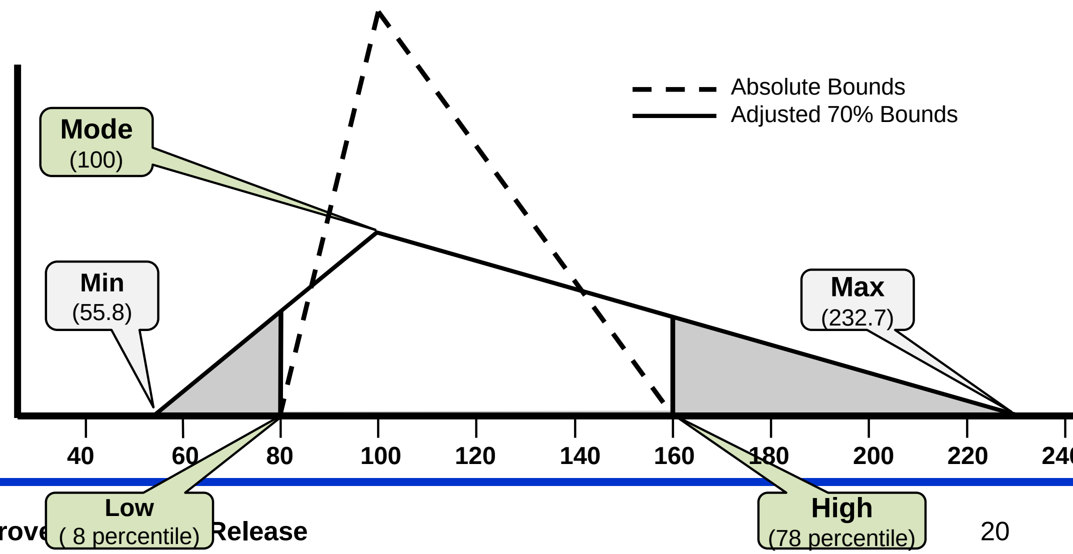
- **NCCA SAR Growth Study**
  - CSRUH contains two tables: mean cost growth factor (CGF), and the CVs that go with them
  - Stratified by commodity, phase, service, and milestone
  - Available from the NCCA Tools website

- **AFCAA CRUAMM** (Cost Risk and Uncertainty Metrics Manual)
  - Thousands of fitted distributions to cost, cost drivers, factors and CER residuals
  - Stratified by commodity, phase and WBS element
  - Public domain volume available from AFCAA

Interpreting the Expert's Opinion

- Dotted line represents the triangular distribution if the expert bounds are treated as absolute
- Top image illustrates what the distribution would look like before adjusting for skew
- Bottom image shows the distribution adjusted for skew
- Similar effects if you choose **betaPERT or uniform** distributions





Delivered Utility Used to Calculate Example Model Adjustments for Skew

- Recommend uncertainties organized on a single sheet
- Recommended format facilitates validation

					Distribution Parameters					
*** INPUT VARIABLES**	**Forecast**	**Distribution Form**	**Point Estimate is:**	**Uncertainty**	**Min**	**Low**	**High**	**Max**	**Percentile**	**Percentile**
*** EMD Qty and Variables**										
EMD Design & Dev Cost Per Mont	200.0000	Lognormal	Median	1.3378	1.189					
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EMD Support Equipment Factor	0.2500	Triangular	Mode	1.00		0.90	1.70		4	74

Subjective Bounds Adjusted for Skew

Table of Last Resort

- Table is from AFCAA CRUH
- Based on panel of industry experts observing that CV of 0.15, 0.25, 0.35 could be used to define low, med, high (0.45 for Space) uncertainty when nothing else is available
- Historical data, SAR Growth Study, CRUAMM, expert opinion are all better choices
- 15/85 bounds in this table **DO NOT** need to be adjusted for skew

Distribution	Point Estimate Position	Point Estimate and Probability	Mean*	CV*	15%	85%
Lognormal Low	Median	1.0 (50%)	1.0113	0.1509	0.8560	1.1682
Lognormal Med	Median	1.0 (50%)	1.0318	0.2541	0.7718	1.2958
Lognormal High	Median	1.0 (50%)	1.0632	0.3613	0.6957	1.4373
Lognormal Ehigh**	Median	1.0 (50%)	1.1067	0.4743	0.6273	1.5943
Normal Low	Mean	1.0 (50%)	1.0000	0.1501	0.8445	1.1555
Normal Med	Mean	1.0 (50%)	1.0000	0.2501	0.7409	1.2591
Normal High	Mean	1.0 (50%)	1.0024	0.3458	0.6400	1.3632
Normal EHigh	Mean	1.0 (50%)	1.0154	0.4258	0.5547	1.4703
Weibull Low	Mode	1.0 (25%)	1.1581	0.1794	0.9564	1.3695
Weibull Med	Mode	1.0 (20%)	1.3932	0.3324	0.9563	1.8547
Weibull High	Mode	1.0 (15%)	2.1037	0.5723	1.0000	3.2766
Triangle Low Left	Mode	1.0 (75%)	0.8775	0.1779	0.6953	1.0414
Triangle Low	Mode	1.0 (50%)	1.0000	0.1500	0.8338	1.1662
Triangle Low Right	Mode	1.0 (25%)	1.1225	0.1391	0.9586	1.3046
Triangle Med Left	Mode	1.0 (75%)	0.7959	0.3270	0.4923	1.0690
Triangle Med	Mode	1.0 (50%)	1.0000	0.2500	0.7230	1.2769
Triangle Med Right	Mode	1.0 (25%)	1.2041	0.2161	0.9310	1.5078
Triangle High Left*	Mode	1.0 (75%)	0.7454	0.4479	0.3467	1.1028
Triangle High	Mode	1.0 (50%)	1.0000	0.3501	0.6122	1.3878
Triangle High Right	Mode	1.0 (25%)	1.2858	0.2834	0.9034	1.7109
Triangle EHigh Left*	Mode	1.0 (75%)	0.7454	0.4960	0.3004	1.1501
Triangle EHigh	Mode	1.0 (50%)	1.0045	0.4439	0.5088	1.4998
Triangle EHigh Right	Mode	1.0 (25%)	1.3674	0.3426	0.8758	1.9140

Distribution	Point Estimate Position	Point Estimate and Probability	Mean*	CV*	15%	85%
Uniform Low Left	Mode	1.0 (75%)	0.8701	0.1724	0.6882	1.0520
Uniform Low	Mode	1.0 (50%)	1.0000	0.1500	0.8181	1.1819
Uniform Low Right	Mode	1.0 (25%)	1.1299	0.1328	0.9480	1.3118
Uniform Med Left	Mode	1.0 (75%)	0.7835	0.3191	0.4804	1.0866
Uniform Med	Mode	1.0 (50%)	1.0000	0.2500	0.6969	1.3031
Uniform Med Right	Mode	1.0 (25%)	1.2165	0.2055	0.9134	1.5196
Uniform High Left	Mode	1.0 (75%)	0.6969	0.5023	0.2726	1.1213
Uniform High	Mode	1.0 (50%)	1.0000	0.3500	0.5757	1.4243
Uniform High Right	Mode	1.0 (25%)	1.3031	0.2686	0.8788	1.7275
Uniform EHigh Left	Mode	1.0 (75%)	0.6949	0.5774	0.2085	1.1813
Uniform EHigh	Mode	1.0 (50%)	1.0000	0.4500	0.4544	1.5456
Uniform EHigh Righ	Mode	1.0 (25%)	1.3897	0.3238	0.8441	1.9353
Beta Low Left	Mode	1.0 (61%)	0.9393	0.1600	0.7750	1.0986
Beta Low	Mode	1.0 (50%)	1.0000	0.1502	0.8375	1.1625
Beta Low Right	Mode	1.0 (39%)	1.0607	0.1417	0.9014	1.2249
Beta Med Left	Mode	1.0 (63%)	0.8833	0.2827	0.6046	1.1517
Beta Med	Mode	1.0 (50%)	1.0000	0.2502	0.7255	1.2745
Beta Med Right	Mode	1.0 (37%)	1.1170	0.2240	0.8483	1.3957
Beta High Left	Mode	1.0 (66%)	0.8085	0.4191	0.4117	1.1862
Beta High	Mode	1.0 (50%)	1.0000	0.3501	0.6046	1.3955
Beta High Right	Mode	1.0 (33%)	1.2021	0.2912	0.8157	1.6061

** EHigh = Extreme High

* To match these paramaters, tools must be set to truncate the distribution at zero.

Create a Spreadsheet Layout That Simplifies Review

- Document the distribution shape and position of the point estimate in the distribution
- Define distribution parameters as a **percent of the point estimate** when uncertainty should scale with what-if cases
- Define distribution parameters **as values** when the uncertainty range should not change with what-if cases
- Show the low/high values with their percentiles (high/low interpretation)
- Identify the source of each uncertainty

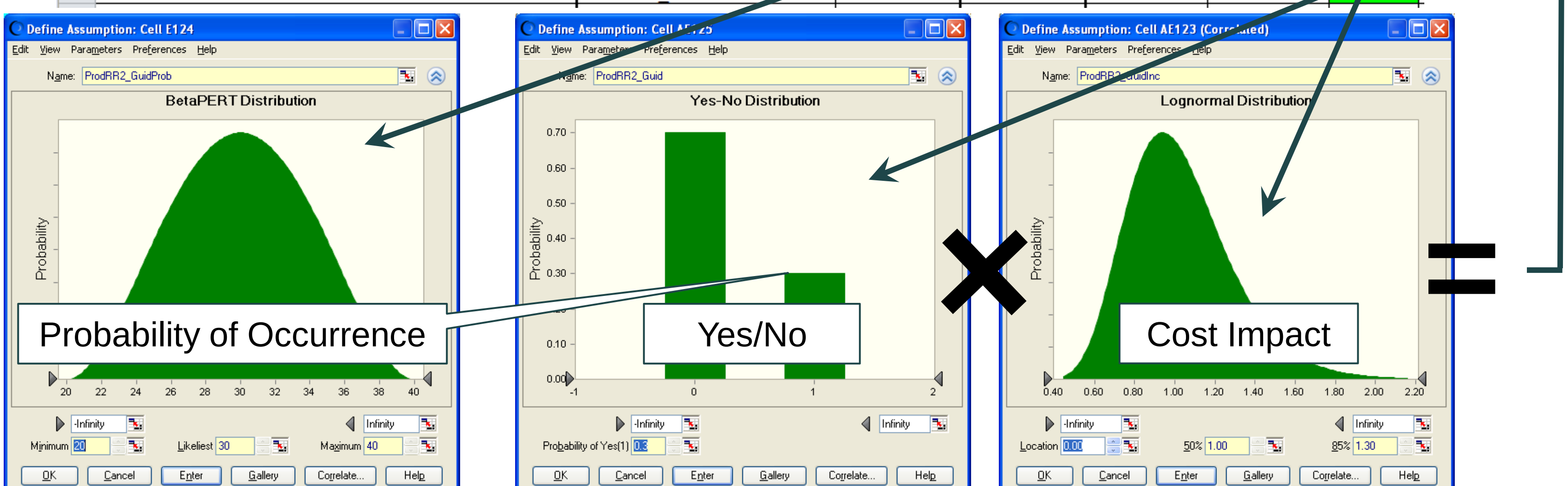
WBS Elements	Point Estimate	Cost Estimating Relationship	Form	PE Position	Std Dev	Low	Low Intrp	High	High Intrp	Comment
Airframe T1	$77.85	25.62 + 2.101 * AirFrameWt ^ 0.5541	Triangular	Mode = PE*85%		47.6%	0	167.7%	100	Fit Residual data
Propulsion T1	$78.56	1.618 * MotorWt ^ 0.6848	Log-t	Median				20.7%	90	Regression Result
Guidance and Control T1	$100.00	100	Triangular	Mode		85.0%	8	140.0%	78	Expert Opinion
Payload T1	$62.01	30.15 + 1.049 * WarheadWt * PayloadAdjustment	Student's-t	Mean				113.8%	90	Regression Result

Airframe Weight (lbs)	330.0	330	Uniform	Undefined		182.11	0	855.89	100	Fit to Data
Motor Weight (lbs)	290.0	290	Triangular	Mode		280.00	4	350.00	74	Expert Opinion
Warhead Weight (lbs)	25.0	25	Triangular	Mode		20.00	10	35.00	80	Expert Opinion

Build the Risk Register **Into the** Cost Uncertainty Model

Modeled as discrete events with uncertain probability of occurrence and consequence. Capture both risks (add cost) and opportunities (reduce cost). **Embed in estimate**.

	B	C	E	F	AC	AD	AE
46	* INPUT VARIABLES	Unique ID	Point Estimate	Forecast	Distribution Form	Point Estimate is:	Uncertainty
112	Guidance First Unit Cost	Guid_UC1	$100.00	$100.00			
113	Guidance First Unit Cost CER	Guid_UC1Raw	$100.00	$100.00	Triangular	Mode	1.00
114	Guidance RR#2 Add to First Unit Cost	GuideRR2_Add					
121							
122	* **Guidance Risk Register (RR #2)**						
123	Prod RR2 Potential Guidance Cost Incr	ProdRR2_GuidInc	50.0000	50.0000	LogNormal	Median	1.00
124	Prod RR2 Probability Prototype Problem	ProdRR2_GuidProb	30	30	BetaPERT	Median	
125	Prod RR2 Guidance	ProdRR2_Guid			Yes/No	N/A	



Do not double count uncertainty already captured in the CER or its drivers.

Special Considerations

- **Truncate** distributions at zero unless there is compelling evidence to do otherwise
- Ensure **sunk costs** are in correct units. Have a separate estimate for the **cost to go** and **scale the uncertainty** from the original estimate
- Apply uncertainty to **cost improvement curve methods** on the total. If uncertainty must be applied to T1 and Slope separate, consider applying high negative correlation
- **Adjustment Factors** may be necessary if your program is significantly different from the CER source data
- **Calibrating a CER** to go through an analogy may impact uncertainty assessment
- **Inflation**: no clear, widely accepted approach…..yet

FINISH AND EVALUATE CISM SIMULATION RESULTS

Correlation and Finishing the Model

- Functional vs. applied correlation
- Run the simulation before applying correlation
- Measure functional correlation already present
- Apply additional correlation **as required**

- Determine trials required (**convergence**)
- Review and interpret simulation results
- Allocate risk dollars in total and by year

Correlation

- Correlation is a measure of the **linear relationship** between random variables. Correlation does not prove a cause and effect relationship.
- Uncertain elements are **functionally correlated** if they are related through the model algebra.
- Applying correlation to child WBS elements **impacts the parent spread**.
- Correlation applied **on top of functionally** related uncertain WBS elements will **impact the parent mean and spread**.
- Build **a few large correlation matrices** rather than several small ones
  - Makes it easier to see where correlation should be applied
- Indiscriminately applying correlation can cause an **inconsistent matrix**. While tools will offer to “fix” the matrix, recommend you **fix it yourself.**
- **Do not leave matrix cells blank** (if you do, the tool may choose for you)
- **Measure correlation** across the WBS **first** (**utility provided**) and then apply **as necessary**

Measuring Functional Correlation in the WBS of the Example Model

- Training, Data and Initial Spares are estimated as a factor of Air Vehicle
  - **No need to add additional correlation across Training, Data and Initial Spares**
- Need to address correlation across Air Vehicle elements and those elements that are a function of duration
- **Default to apply is 0.3**, however table to left offers other alternatives

Strength	Positive	Negative
None	0.0	0.0
Weak	0.3	-0.3
Medium	0.5	-0.5
Strong	0.9	-0.9
Perfect	1.0	-1.0

MEASURED CORRELATION ACROSS PRODUCTION WBS ELEMENTS

	WBS/CES	Airframe	Propulsion	Guidance	Payload	IAT&C	Training	Data	Initial Spares	Sys Eng	PM	ST&E	PSE
Air Vehicle	Airframe	1.00					0.22	0.30	0.21				
	Propulsion		1.00				0.12	0.18	0.12				
	Guidance			1.00			0.28	0.40	0.27				
	Payload				1.00		0.13	0.15	0.13				
	IAT&C					1.00	0.33	0.42	0.30				
Factor of Air Vehicle	Training						1.00	0.36	0.25				
	Data							1.00	0.34				
	Initial Spares								1.00				
Function of Duration	Sys Eng									1.00			
	PM										1.00		
	ST&E											1.00	
	PSE												1.00

Consider Adding Correlation

Additional Correlation May Not Be Needed

Consider Adding Correlation

Functional Correlation Only

Applying Correlation to the Inputs of the Example Model

	EMD_MthsRaw	EMD RR1 SWIncDur	EMD RR1 SWIncMM	EMD SWLaborRate	EMD_SWMonthsRaw	DesignDevPerMonth	ProdToEMD_Step	Airframe_UC1	Prop_UC1	Guid_UC1Raw	Payload_UC1	PenaltyPayload	IATC_Hrs3rdPartyToo	MfgLaborRate	ProdRR2_GuidInc	EMD_AnnualSE	EMD_AnnualPM	EMD_STE_Fac	EMD_Trng_Fac	EMD_Data_Fac	EMD_SptEquip_Fac	ProdAnnualSE	ProdAnnualPM	ProdAnnualSTE	ProdPSE_TICost	ProdTrng_Fac	ProdData_Fac	ProdInitSpares_Fac	AirFrameWt	MotorWt	WarheadWt
EMD_MthsRaw	1.0	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3																
EMD RR1 SWIncDur		1.0	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3																
EMD RR1 SWIncMM			1.0	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3																
EMD SWLaborRate				1.0	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3																
EMD_SWMonthsRaw					1.0	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3																
DesignDevPerMonth						1.0	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3																
ProdToEMD_Step							1.0	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3																
Airframe_UC1								1.0	0.3	0.3	0.3	0.3	0.3	0.3	0.3																
Prop_UC1									1.0	0.3	0.3	0.3	0.3	0.3	0.3																
Guid_UC1Raw										1.0	0.3	0.3	0.3	0.3	0.3																
Payload_UC1											1.0	0.3	0.3	0.3	0.3																
PenaltyPayload												1.0	0.3	0.3	0.3																
IATC_Hrs3rdPartyTool													1.0	0.3	0.3																
MfgLaborRate														1.0	0.3																
ProdRR2_GuidInc															1.0																
EMD_AnnualSE																1.0	0.3														
EMD_AnnualPM																	1.0														
EMD_STE_Fac																		1.0													
EMD_Trng_Fac																			1.0												
EMD_Data_Fac																				1.0											
EMD_SptEquip_Fac																					1.0										
ProdAnnualSE																						1.0	0.3	0.3	0.3						
ProdAnnualPM																							1.0	0.3	0.3						
ProdAnnualSTE																								1.0	0.3						
ProdPSE_TICost																									1.0						
ProdTrng_Fac																										1.0					
ProdData_Fac																											1.0				
ProdInitSpares_Fac																												1.0			
AirFrameWt																													1.0	0.3	0.3
MotorWt																														1.0	0.3
WarheadWt																															1.0

Arrange all uncertain elements into meaningful Groups

What is the impact of filling these 351 cells?

What is the impact of filling these 71 cells?

Correlation should be applied where it makes sense, not just indiscriminately everywhere.

Impact to the WBS Correlation After Applying Inputs Correlation

MEASURED CORRELATION ACROSS PRODUCTION WBS ELEMENTS

	WBS/CES	Airframe	Propulsion	Guidance	Payload	IAT&C	Training	Data	Initial Spares	Sys Eng	PM	ST&E	PSE
Air Vehicle	Airframe	1.00					0.22	0.30	0.21				
	Propulsion		1.00				0.12	0.18	0.12				
	Guidance			1.00			0.28	0.40	0.27				
	Payload				1.00		0.13	0.15	0.13				
	IAT&C					1.00	0.33	0.42	0.30				
Factor of Air Vehicle	Training						1.00	0.36	0.25				
	Data							1.00	0.34				
	Initial Spares								1.00				
Function of Duration	Sys Eng									1.00			
	PM										1.00		
	ST&E											1.00	
	PSE												1.00

Consider Adding Correlation

Additional Correlation May Not Be Needed

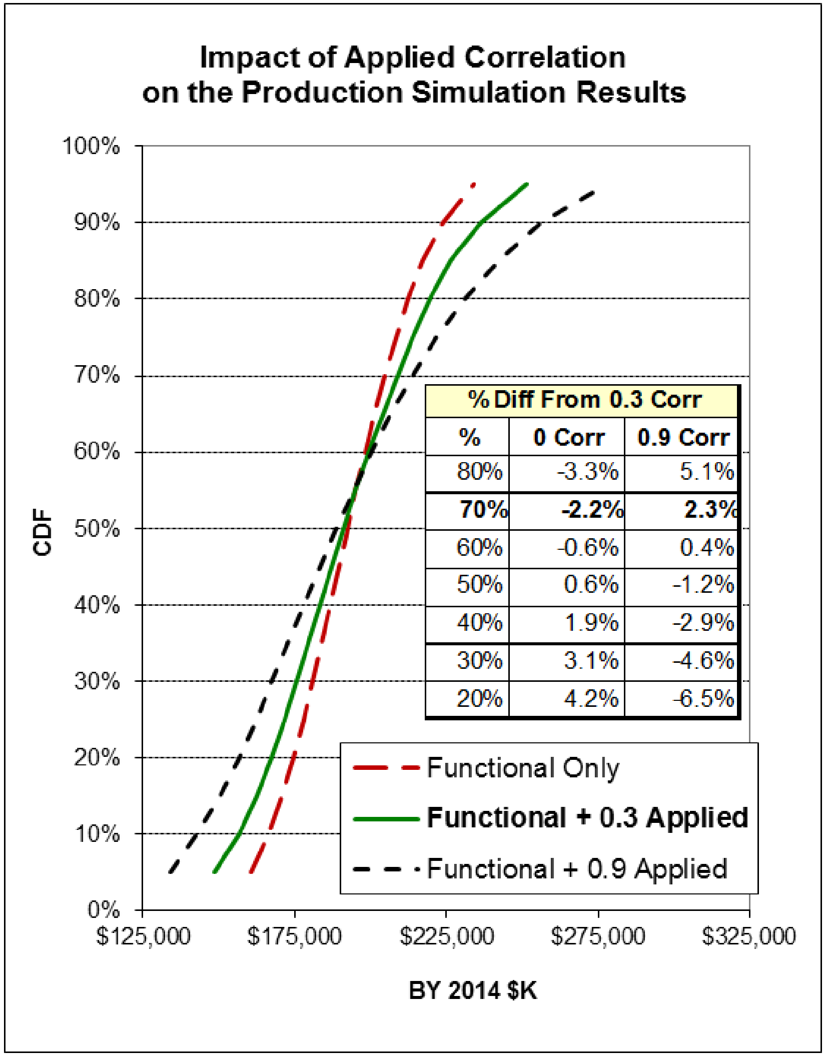
Consider Adding Correlation

Functional Correlation Only

	WBS	Airframe	Propulsion	Guidance	Payload	IAT&C	Training	Data	Initial Spares	Sys Eng	PM	ST&E	PSE
Air Vehicle	Airframe	1.00	0.28	0.21	0.34	0.27	0.40	0.50	0.39				
	Propulsion		1.00	0.22	0.34	0.28	0.35	0.44	0.34				
	Guidance			1.00	0.25	0.25	0.42	0.54	0.40				
	Payload				1.00	0.33	0.38	0.47	0.38				
	IAT&C					1.00	0.49	0.59	0.46				
Factor of Air Vehicle	Training						1.00	0.52	0.40				
	Data							1.00	0.50				
	Initial Spares								1.00				
Function of Duration	Sys Eng									1.00	0.30	0.30	0.32
	PM										1.00	0.31	0.31
	ST&E											1.00	0.30
	PSE												1.00

Note these increase even though none applied directly

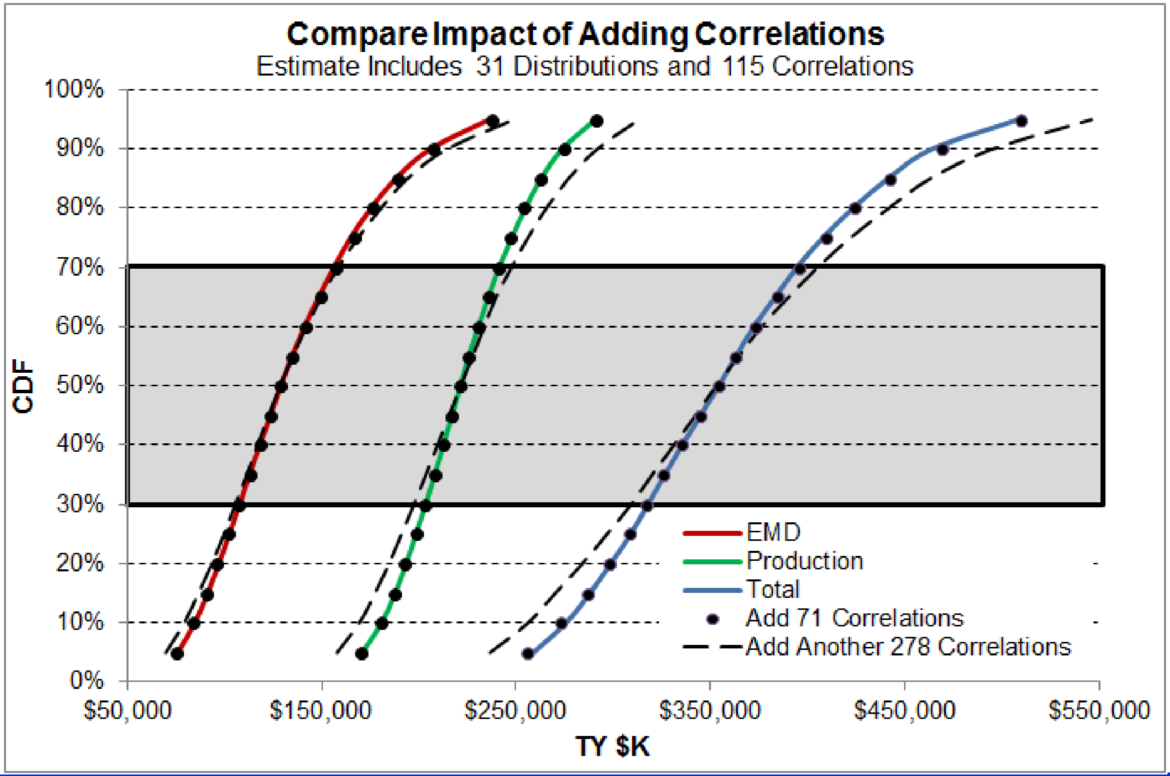
Functional Correlation Plus Applied Correlation



Impact of Adding Additional Correlation

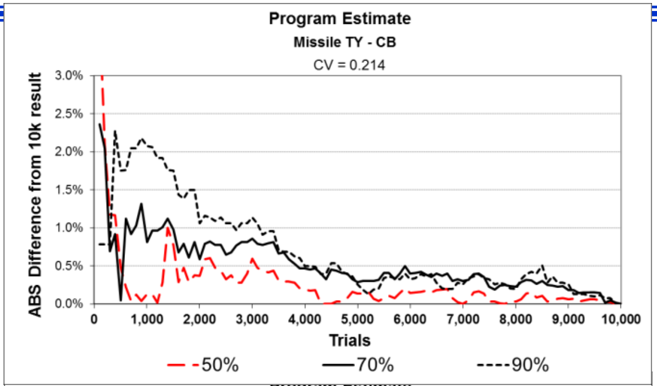
- Impact shown on EMD, Production and the Missile total
- No discernible impact when adding 71 more correlations, minimal impact between 30 and 70 percent when adding another 351 correlations
- Results specific to this model. Take care to investigate impact on yours!

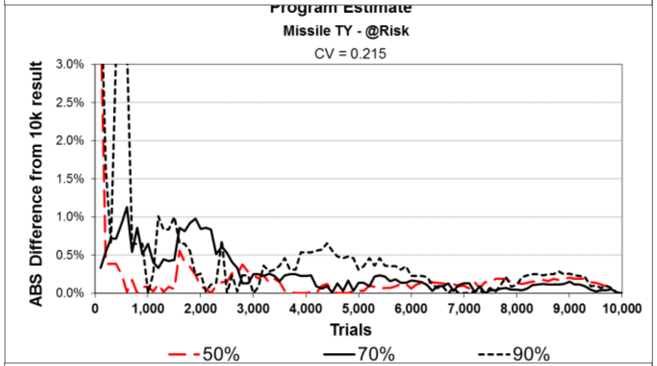
	Change to the Program Estimate					
	Estimate + 71 Corrrelations			Estimate + 351 Corrrelations		
	EMD	Prod	Total	EMD	Prod	Total
5%	-0.9%	-0.2%	-1.1%	-8.0%	-7.6%	-8.6%
10%	-1.1%	-0.2%	-0.8%	-6.5%	-6.3%	-7.1%
15%	-0.5%	-0.3%	-0.3%	-5.1%	-5.5%	-6.2%
20%	-0.8%	-0.2%	-0.2%	-3.8%	-4.6%	-4.9%
25%	-0.6%	-0.1%	-0.3%	-2.6%	-3.7%	-4.0%
30%	-0.3%	-0.2%	-0.2%	-2.0%	-3.0%	-2.7%
35%	0.1%	-0.1%	-0.2%	-1.2%	-2.2%	-2.0%
40%	0.2%	-0.1%	0.0%	-0.9%	-1.5%	-1.3%
45%	0.1%	-0.1%	0.1%	-0.8%	-0.6%	-0.7%
50%	0.2%	0.1%	-0.1%	-0.3%	0.1%	-0.4%
55%	0.3%	0.0%	0.0%	0.3%	0.9%	0.4%
60%	0.7%	0.0%	0.1%	0.6%	1.3%	1.0%
65%	0.5%	0.2%	0.2%	1.0%	1.7%	1.8%
70%	0.8%	0.0%	0.4%	1.4%	2.6%	2.7%
75%	1.0%	-0.2%	0.4%	2.3%	3.3%	3.5%
80%	0.3%	-0.2%	0.2%	2.9%	4.2%	4.3%
85%	0.6%	0.1%	0.3%	3.2%	5.4%	4.9%
90%	0.7%	0.5%	1.0%	4.2%	6.6%	6.7%
95%	0.8%	0.3%	0.3%	5.4%	7.7%	7.4%

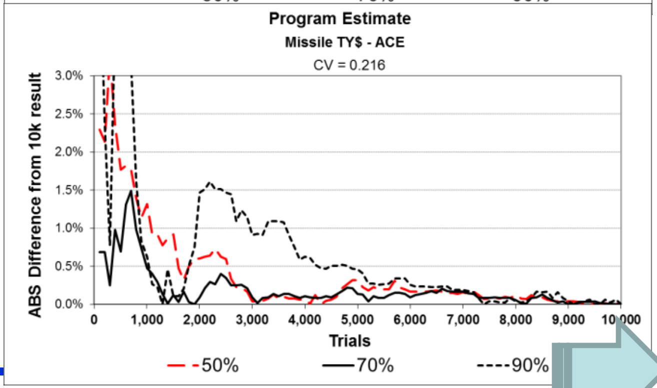


Trials Required For Stable Results

- Tool independent method to measure convergence (trials required for stable results)
- Images illustrate all tools show similar behavior
- When trials produce a result within 0.5% of the 10k trial result the model has converged
  - Changing random see will change results this much
- If lines never fall below 0.5%, it means 10k results are not enough
- Even if it takes no time to run 10k trials, perform this test to ensure model has converged
- **Excel utility provided**

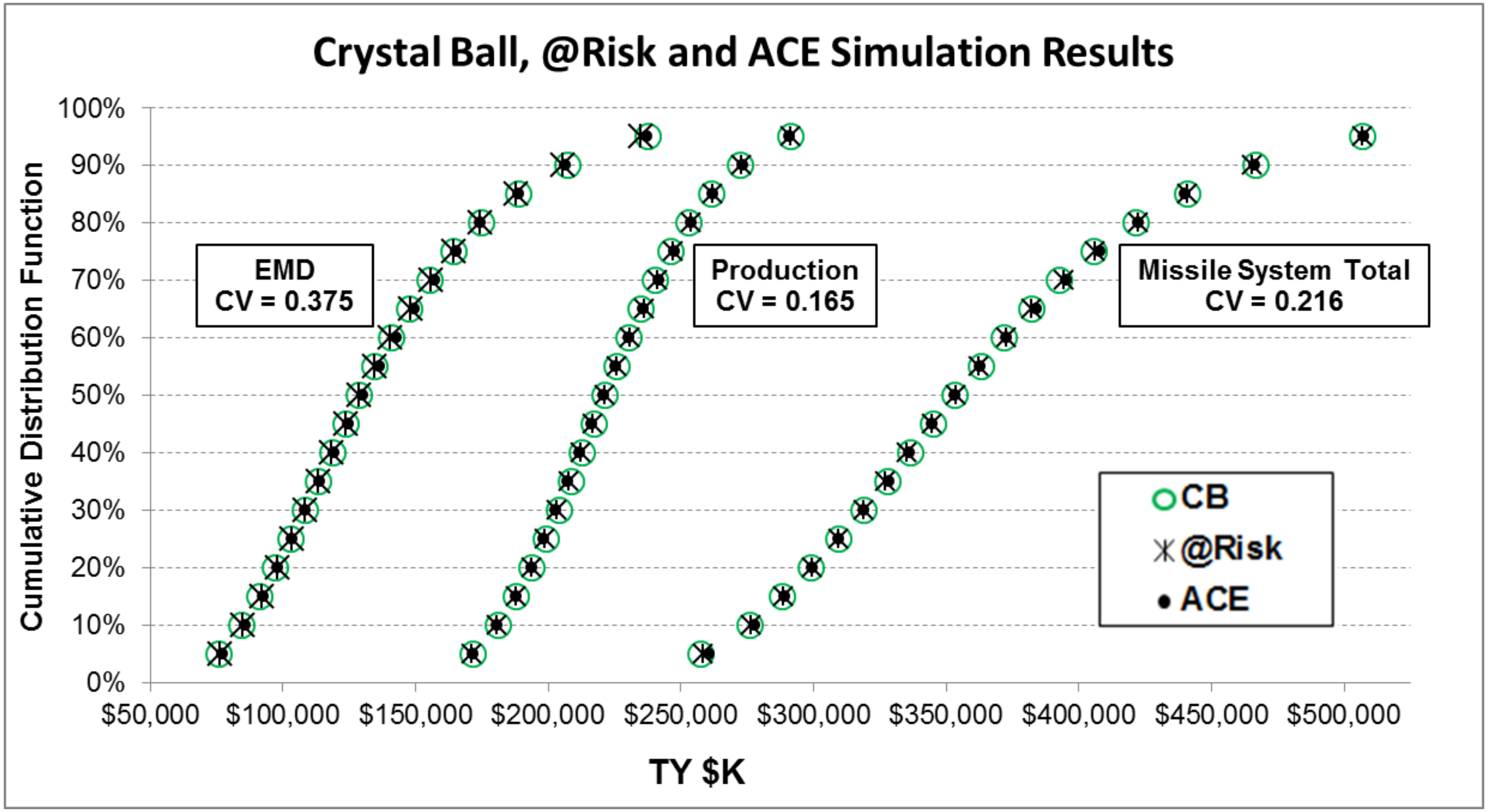






CISM Process is Tool Independent

- Same model created in three different tools deliver the same results
- EMD includes duration uncertainty, Production does not



Interpreting Results

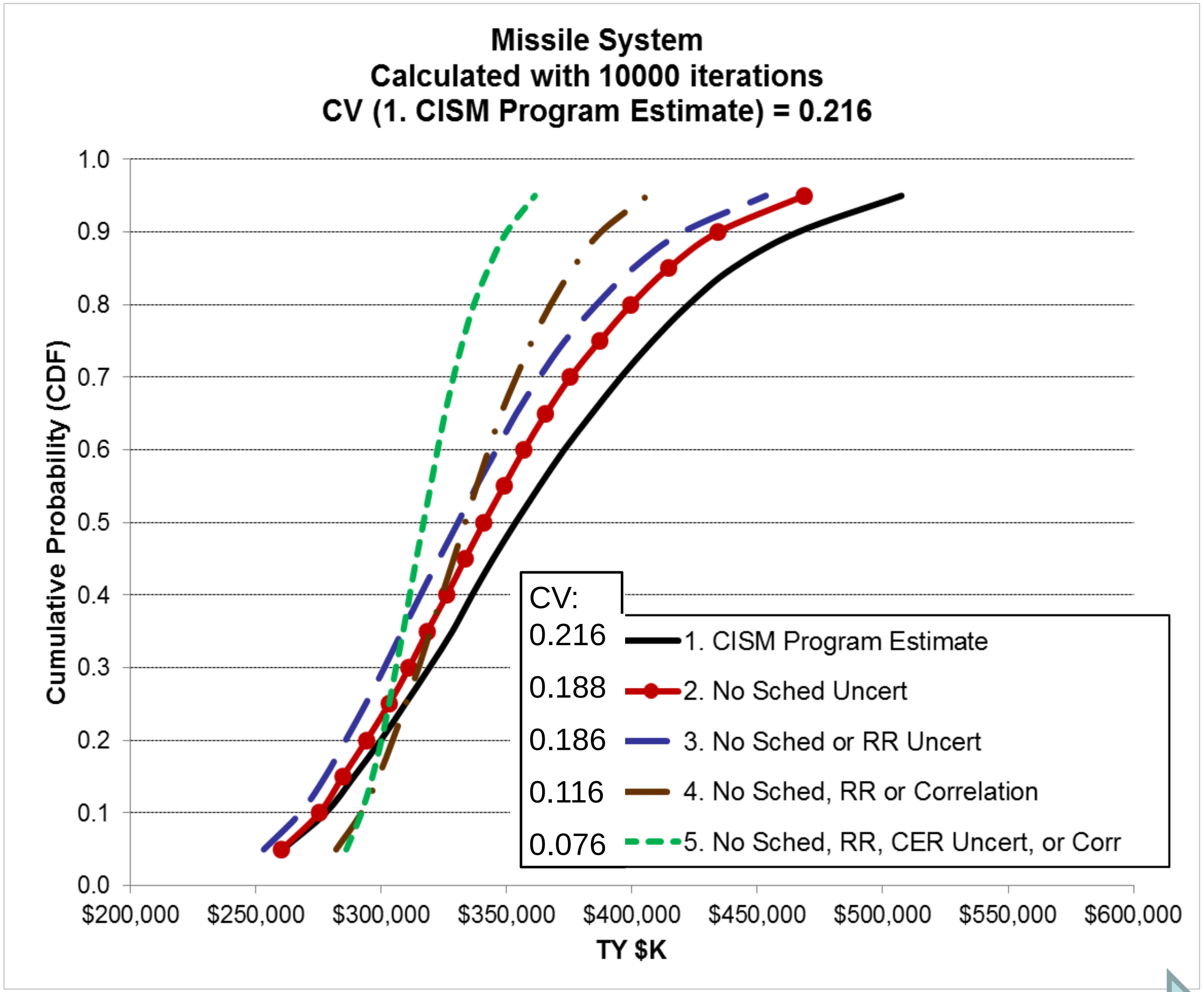
- CV (standard deviation/mean) is provided by all tools
- The higher the CV, the wider the dispersion and the flatter the s-curve
- **NCCA SAR Cost Growth Study and AFCAA CRUAMM provide benchmark CVs**
- Extremely large CVs may be an indication of unusually broad distributions or too much correlation.
- Often an extremely low CV is an indication of very optimistic uncertainty ranges, lack of functional relationships and/or a lack of correlation.
- **The NCCA S-Curve Tool is available to compare your S-Curve to historical CVs**

Interpreting Results

- Systematic application of uncertainty and correlation yields expected impact on the total S-Curve

- Impact of Risk Register (RR) is included in the illustration

- Note that the **addition of schedule uncertainty** to EMD (**CISM approach**) has significant impact on the total uncertainty



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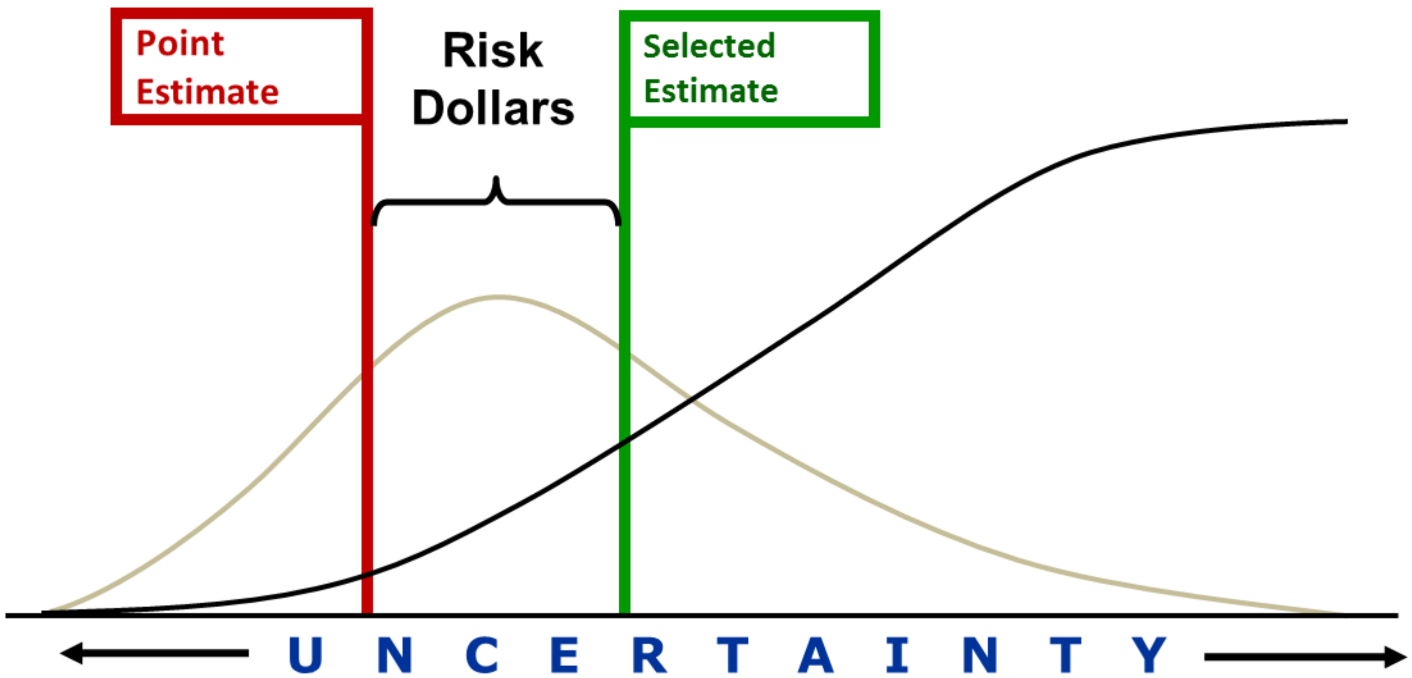
ALLOCATING RISK DOLLARS

Defining Risk Dollars

- **Risk dollars**: the difference between the point estimate and a selected estimate (e.g., budget)



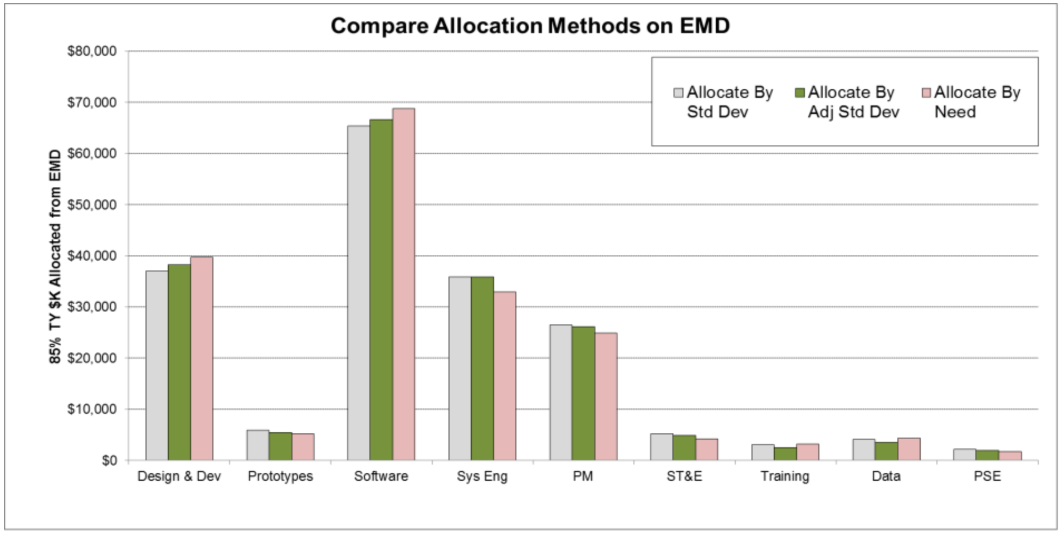
When is Allocation Required?

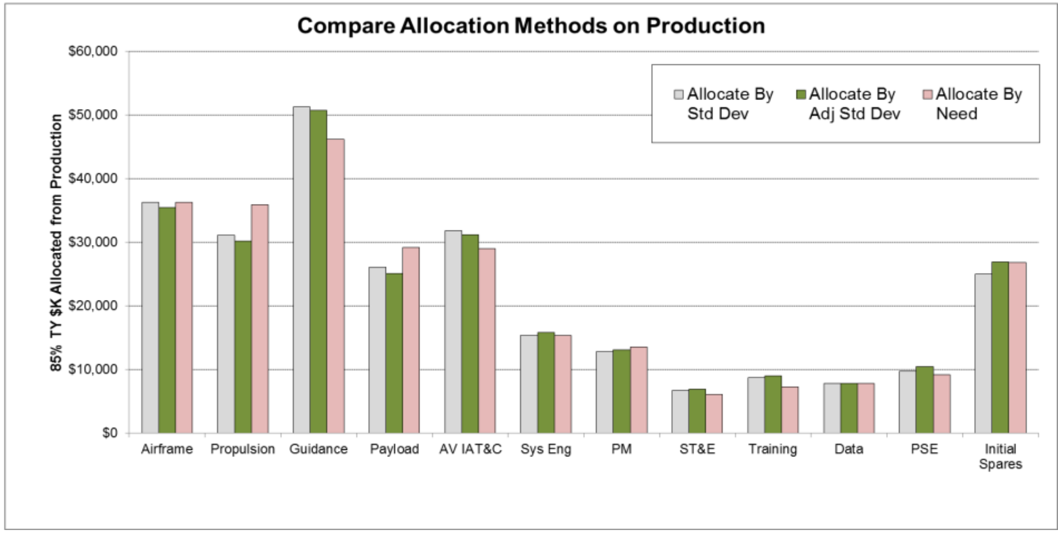
- The point estimate and the mean sum, however each element will **be at a different probability**
- Child elements at the **same probability** **do not sum to the parent**
- We are looking for a way to adjust child elements such that they do sum but remain close to the desired probability (see column 3)

	Elements Sum			**Elements Do Not Sum**					
Column	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
BY $2014	**Point Estimate**	**Mean**	**Allocated 58% From Level 2**	**All at 30%**	**Sum of Children**	**All at 60%**	**Sum of Children**	**All at 80%**	**Sum of Children**
Missile System	$246,836 (10%)	$325,183 (56%)	$328,430 (~58%)	$283,940	$254,462	$332,166	$331,032	$376,245	$407,615
Engineering and Manufacturing De	$83,539 (12%)	$130,683 (58%)	**$130,903 (58%)**	$101,840	$92,091	$132,976	$130,521	$162,083	$172,077
Air Vehicle	$14,944 (24%)	$28,615 (64%)	$27,172 (60%)	$16,668		$27,005		$39,533	
Design & Development	$12,000 (26%)	$24,380 (64%)	$22,814 (61%)	$12,990		$22,517		$34,725	
Prototypes	$2,944 (20%)	$4,235 (57%)	$4,357 (60%)	$3,284		$4,352		$5,412	
Software	$31,500 (33%)	$44,497 (59%)	$45,130 (60%)	$30,275		$45,072		$60,344	
System Engineering	$17,500 (9%)	$27,113 (56%)	$27,908 (60%)	$21,911		$27,907		$33,350	
Program Management	$15,000 (14%)	$20,528 (57%)	$20,963 (60%)	$17,201		$20,978		$24,762	
System Test and Evaluation	$1,766 (8%)	$3,654 (59%)	$3,699 (60%)	$2,612		$3,704		$4,866	
Training	$897 (16%)	$2,038 (64%)	$1,917 (61%)	$1,168		$1,900		$2,822	
Data	$1,196 (17%)	$2,714 (64%)	$2,565 (60%)	$1,559		$2,545		$3,775	
Peculiar Support Equipment	$736 (8%)	$1,524 (59%)	$1,550 (60%)	$1,091		$1,546		$2,021	

Compare Three Allocation Methods

- 3 methods defined in CSRUH
  - Adjust percentile based on standard deviation (simplest)
  - **Adjust percentile based on standard deviation adjusted for correlation**
  - Adjust point estimate based on "Need"
- **Chart illustrates the difference** between them for this model is very small
- Recommend simplest
- Different business rules can be injected (i.e., allocated result should not be less than PE)





Phasing Allocated Risk Dollars

- **Backload**: Use when near-term budget is set or there is little chance of consuming risk dollars early in the project
- **Frontload**: When greatest uncertainty is early in the project
- **Specific time**: time-phasing the risk dollars after a specific "risky" event, even to years beyond the current time-phased point estimate
- **Algorithm at Lowest Levels**: developing phasing methods that are influenced by the probability level requested
- **Prorate**: The analyst needs to make an effort to identify when the uncertainty will occur and choose one of the previous methods. When there is no evidence to do otherwise, prorating risk dollars across the point estimate phased result is recommended. **Prorate is a common approach for the Production estimate**.

REPORTS

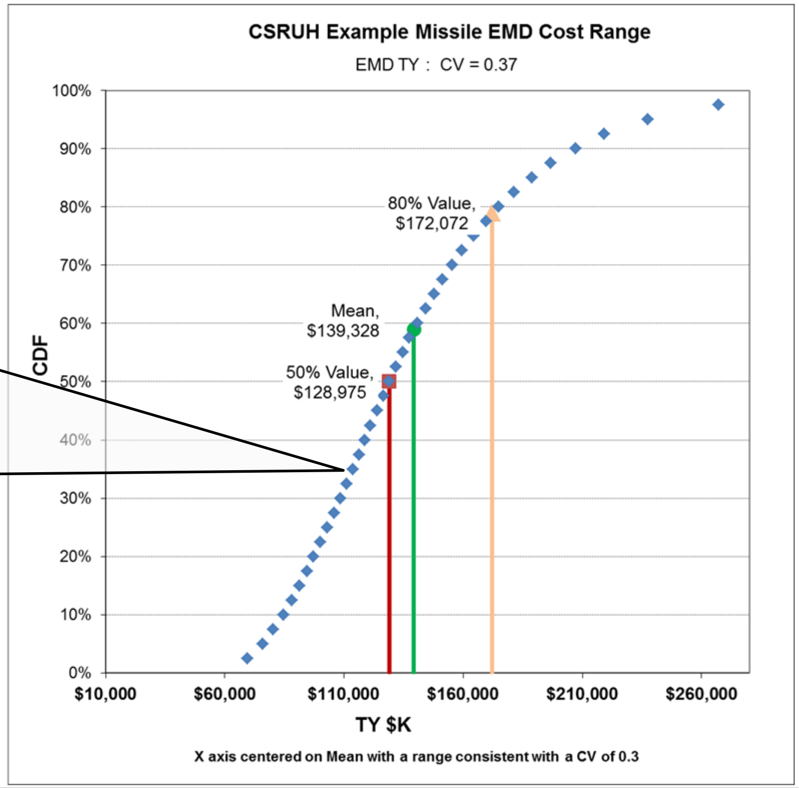
Typical Charts for Technical Review

- Distributions used in the estimate and their parameters
- S-curve showing multiple curves
- Scatter plot of cost vs. schedule (joint probability)
- Pareto chart to identify cost contributors
- Tornado and sensitivity charts to identify cost uncertainty contributors and drivers
- Charts intended for the subsequent decision maker review(s)

Sample Technical Review Charts

Charts for Decision Maker

The s-curve with markers for individual points of interest such as the mean or the 80%. budgets, CAPE estimates, or high and low scenarios.



Probability	TY K$
90%	$207,255
80%	$172,072
70%	$155,334
60%	$140,795
50%	$128,975
40%	$118,768
30%	$108,375
20%	$97,122
10%	$84,554

Show each 10% increment of probability and its corresponding value.

Cost Uncertainty Drivers

- SW Months
- Design Cost/Mth
- SW labor Rate
- EMD Duration

List major drivers, and scenarios in words and parameters that will resonate with the decision maker

Phased estimate by appropriation in TY$ at the selected cumulative probability

80% TY $K Allocated From EMD and Production.	**Risk Dollars are Phased Across the Point Estimate Schedule**									
	Total	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Missile System	$421,268	$26,682	$32,608	$34,455	$38,084	$34,393	$59,857	$66,456	$64,629	$64,106
Engineering and Manufacturing Development	$172,072	$26,682	$32,608	$34,455	$38,084	$34,393	$5,851			
Production & Deployment	$253,022						$54,831	$67,475	$65,622	$65,093

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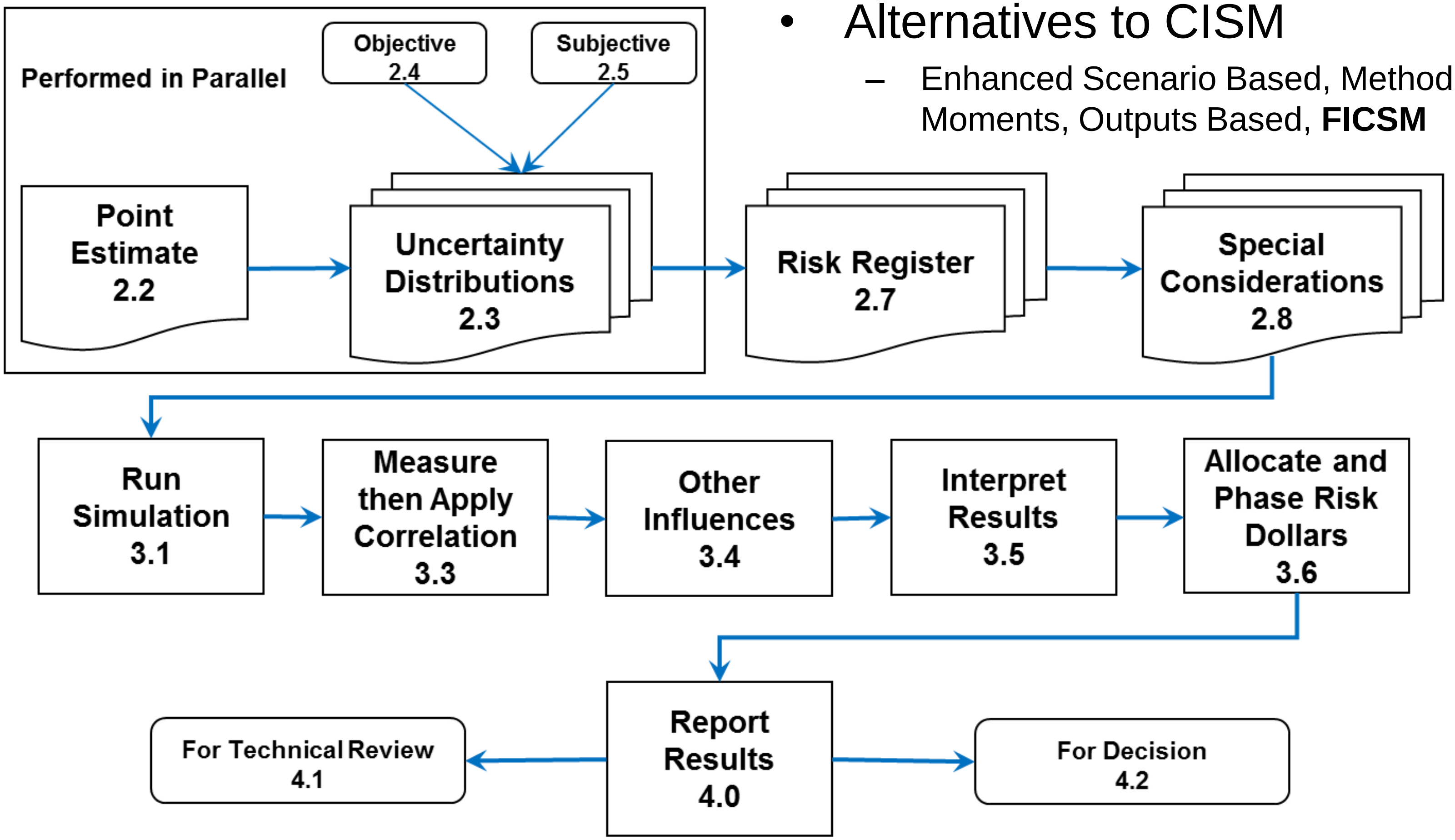
Recap

- Cost Informed by Schedule Method is a cost uncertainty model that has some level of duration uncertainty to influence cost simulation results.

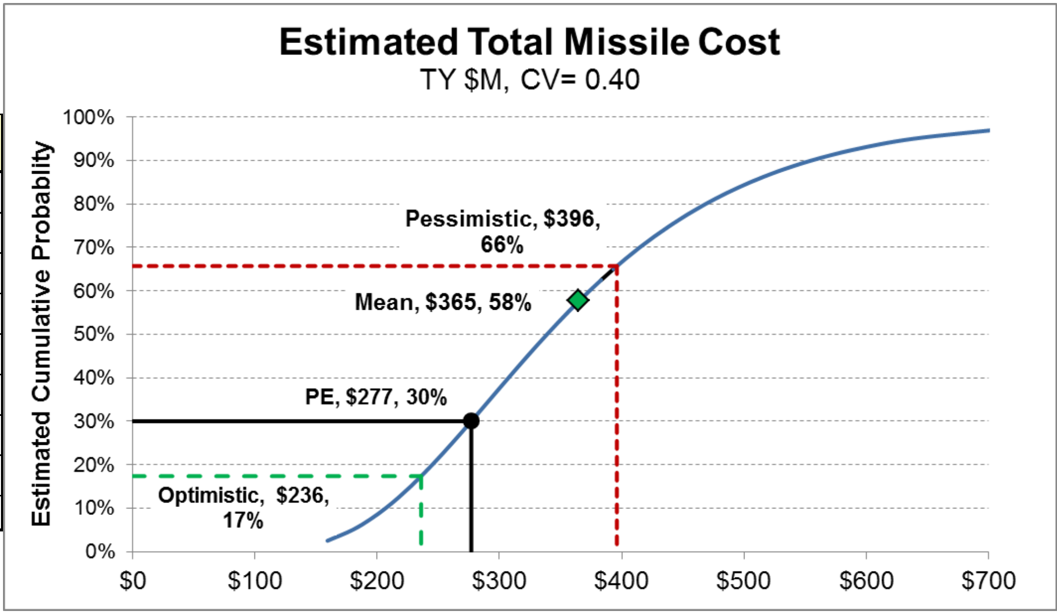
- Alternatives to CISM
  - Enhanced Scenario Based, Method of Moments, Outputs Based, **FICSM**



Alternatives to CISM:
Enhanced Scenario Based Method

- eSBM puts attention on the identification and quantification of what can go right and what can go wrong
- Using historical data for CV and expert opinion for the probability of the point estimate, a lognormal s-curve can be constructed

Cost Driver	Optimistic	Point Estimate	Pessimistic
EMD Duration (Months)	54	60	72
EMD RR1 Dururation Increase (Months)			24
EMD Software Effort (Person Months)	1,130	2,100	3,150
EMD RR1 Increase SW Effort (Person Months)			800
Prod RR#2 Incr to Guidance First Unit Cost			50
Prod Airframe Weight (lbs)	182	330	855
Prod Motor Weight (lbs)	280	290	350
Prod Warhead Weight (lbs)	20	25	35
Prod IAT&C First Unit Hrs (Third Party Tool)	240	450	675



Alternatives to CISM: Method of Moments

- An analytical method to estimate uncertainty
- Mean will sum and standard deviation can be calculated using the following formula (accounts for correlation)

$$TotalVariance = \sum_{k=1}^{n} \sigma_k^2 + 2\sum_{k=2}^{n}\sum_{j=1}^{k-1} \rho_{jk}\sigma_j\sigma_k$$

- The example below illustrates how well the simulation and method of moments (analytical) compare

Total is the sum		Parameters			Simulation		Analytical	
		Std Dev	Min	Max	Mean	Std Dev	Mean	Std Dev Adj For Corr
Total	**500**				**575.0**	**107.0**	**575.0**	**106.7**
Lognormal	100	40			100.0	40.0	100.0	55.1
Triangular	100		75	200	125.0	27.0	125.0	42.5
BetaPert	100		75	200	112.5	21.7	112.5	37.0
Normal	100	35			100.0	35.0	100.0	50.3
Uniform	100		75	200	137.5	36.1	137.5	51.4

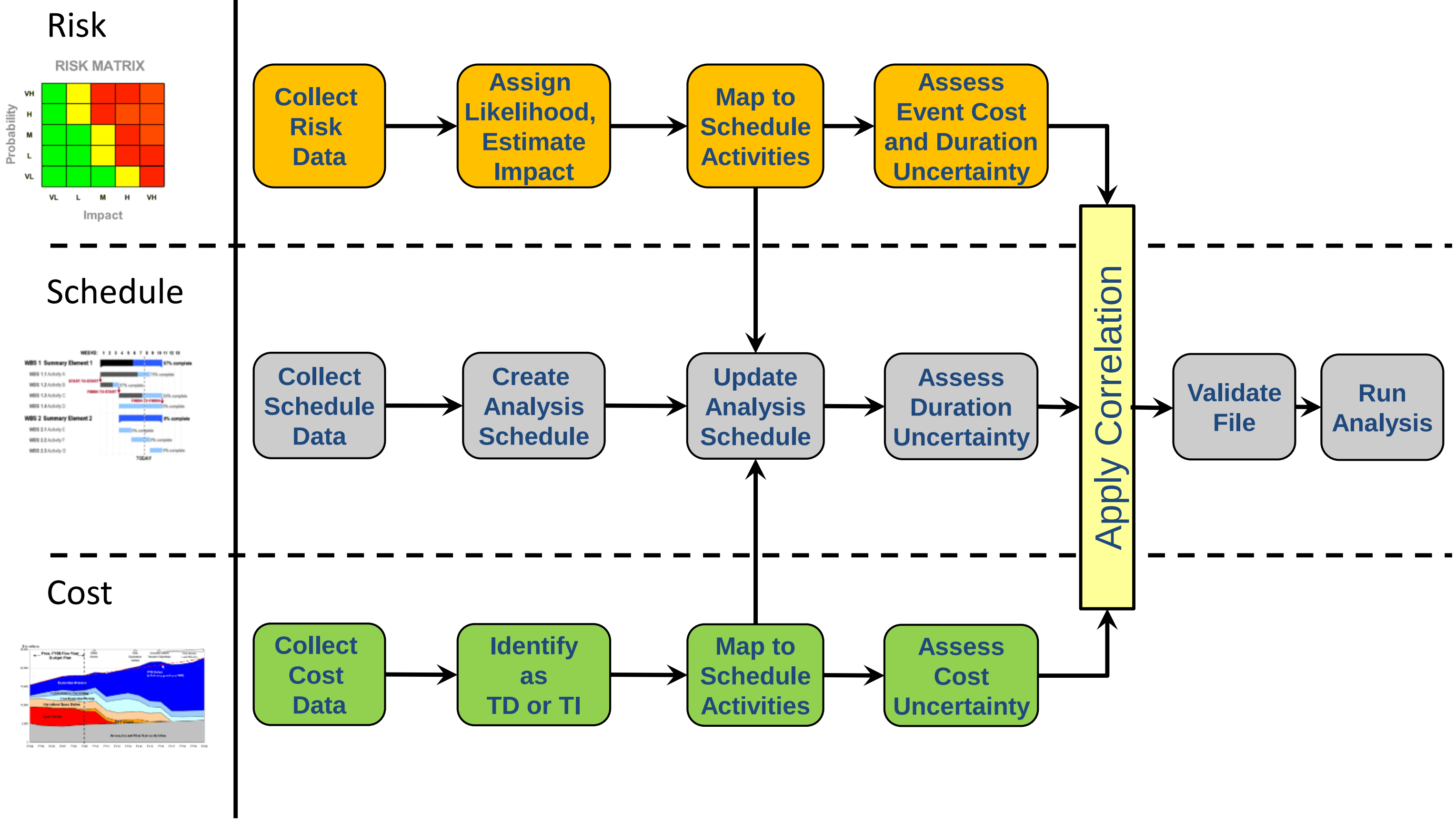
Alternatives to CISM: Outputs Based Simulation Method

- The outputs-based method applies uncertainty directly to the results (cost model outputs) rather than to the model's inputs.
- The analyst selects uncertainty distributions on the WBS outputs to address the combined uncertainty of the cost method and the cost method inputs.

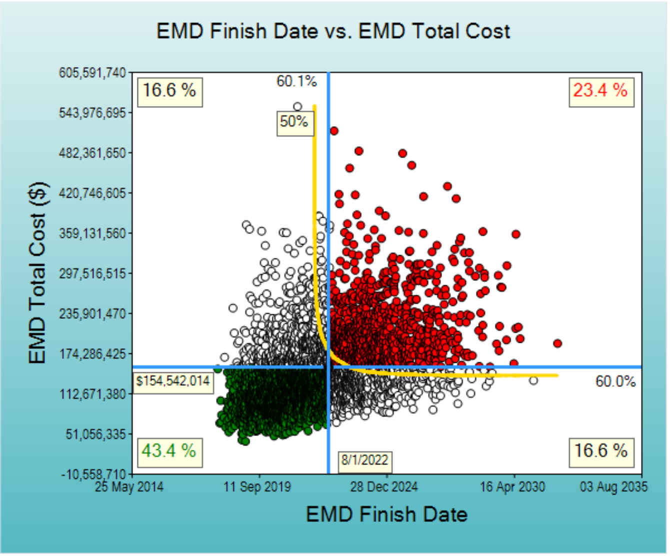
						Distribution Parameters					
DETAIL ESTIMATE based on PEs	**Point Estimate**	**Forecast BY 2014**	**Distribution Form**	**Point Estimate is:**	**Uncertainty**	**Min or 15%**	**Most Likely**	**Mean**	**Max or 85%**	**Std Dev**	**Source**
Missile System											
Engineering and Manufacturing De	$83,539	$83,539									
Air Vehicle	$14,944	$14,944									
Design & Development	$12,000	$12,000	Lognormal	Median	1			1.338		1.189	CRUAMM
Prototypes	$2,944	$2,944	Lognormal	Median	1			1.315		1.123	CRUAMM
Software	$31,500	$31,500	Lognormal	Median	1	**0.696**		1.063	**1.437**		**Last Resort Table**
System Engineering	$17,500	$17,500	Triangular	Mode	1	0.119	1.000		2.074		CRUAMM
Program Management	$15,000	$15,000	Triangular	Mode	1	**0.876**	1.000		**1.914**		**Last Resort Table**
System Test and Evaluation	$1,767	$1,767	Lognormal	Median	1			1.366		1.271	CRUAMM
Training	$897	$897	Lognormal	Median	1	**0.627**		1.107	**1.594**		**Last Resort Table**
Data	$1,196	$1,196	Lognormal	Median	1			1.904		3.086	CRUAMM
Peculiar Support Equipment	$736	$736	Triangular	Mode	1	**0.876**	1.000		**1.914**		**Last Resort Table**

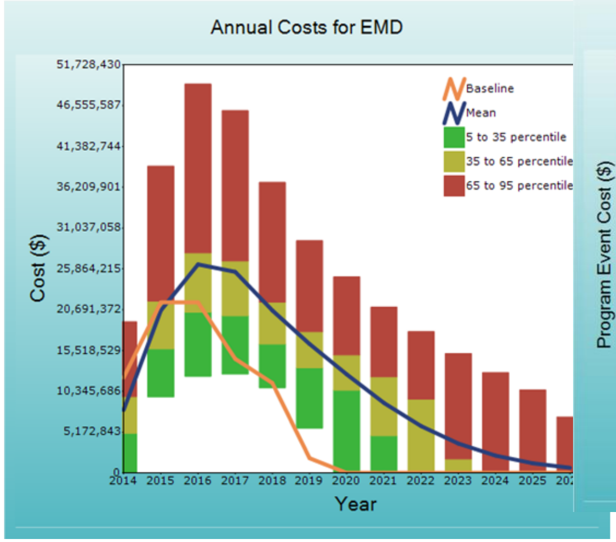
Alternatives to CISM:
The Fully Integrated Cost/Schedule Method

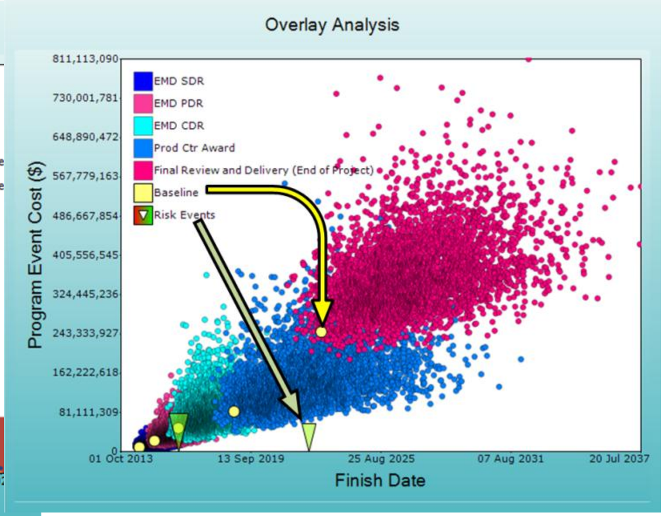
- A fully integrated cost and schedule (FICSM) model is a disciplined, systematic and repeatable process to integrate three critical pieces of information: cost uncertainty, schedule uncertainty, and the risk register.

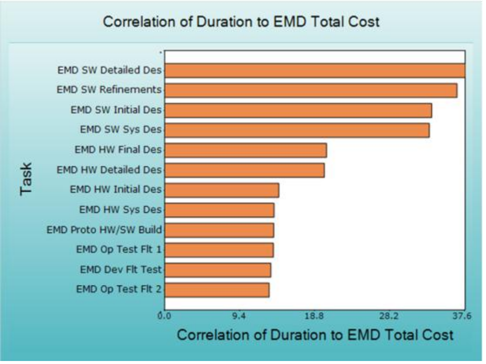


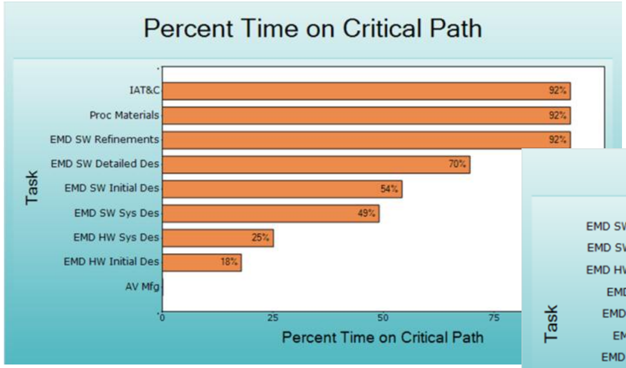
Typical FICSM Reports

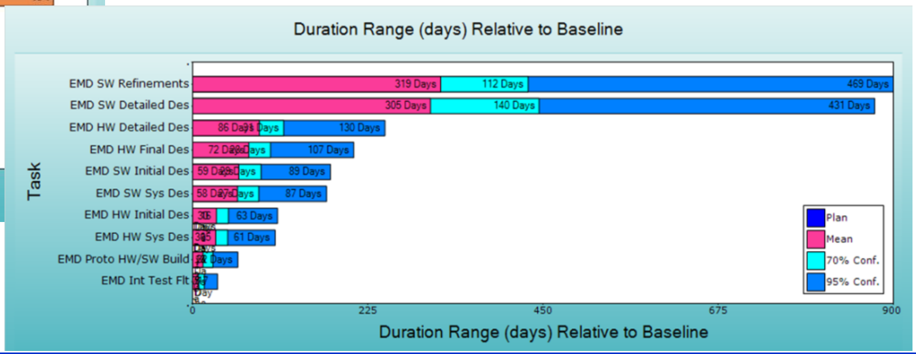












Obtaining the Joint CSRUH

- NCCA Website

https://www.ncca.navy.mil/tools/tools.cfm

- Contact

Duncan Thomas

SL, Technical Director

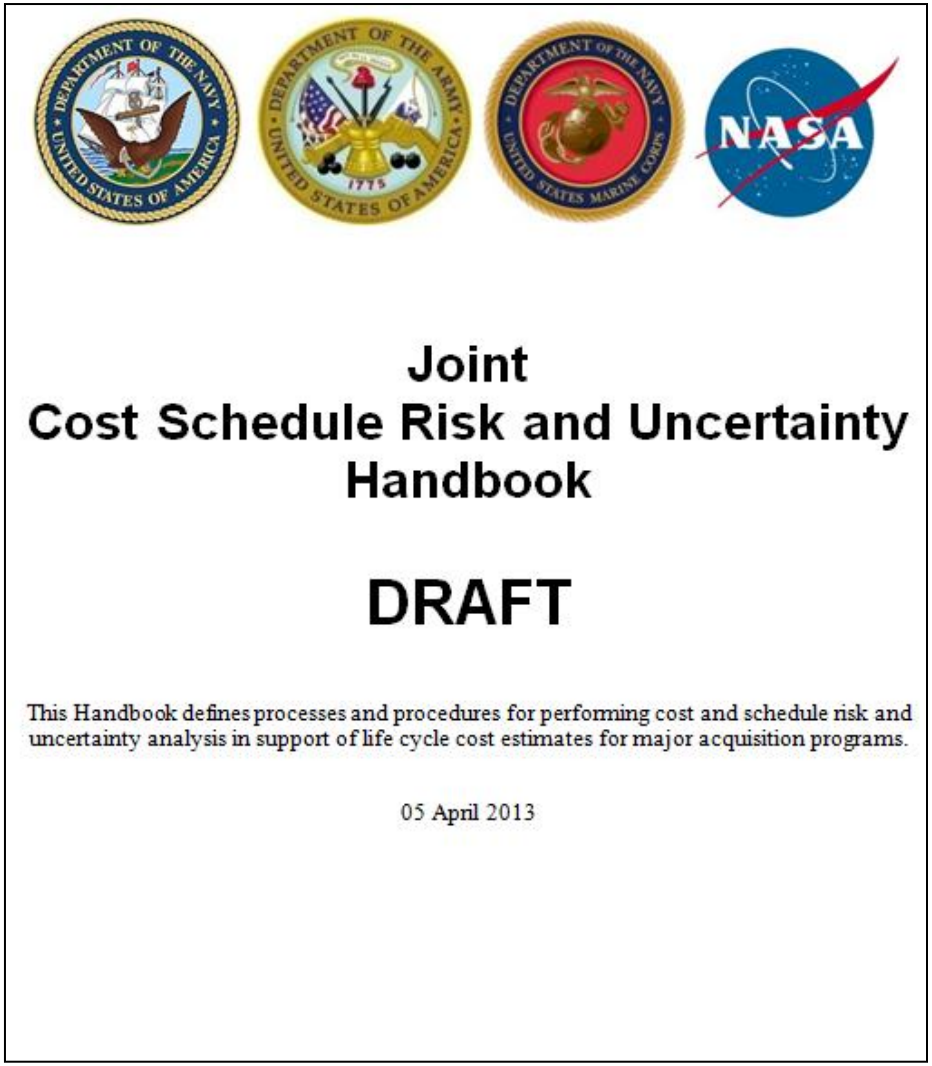
Naval Center for Cost Analysis

1000 Navy Pentagon

4C449, OASN (FM&C), NCCA

Washington, DC 20350-1000

703-604-3493



Joint
Cost Schedule Risk and Uncertainty Handbook

DRAFT

This Handbook defines processes and procedures for performing cost and schedule risk and uncertainty analysis in support of life cycle cost estimates for major acquisition programs.

05 April 2013

Utilities and Files

- The following tool independent, Excel based utilities and files are delivered with CSRUH
- Files
  - CB, @Risk and ACE model
  - Excel file with handbook tables, charts and graphics
  - Excel file with example CER regression and curve fit results
- Utilities
  - Adjust for skew and table of last resort
  - Measure correlation
  - Measure convergence to determine number of trials required
  - Automate building an s-curve
  - Scatter plot to develop joint probability
  - Crystal Ball best fit utility to automate and report fits to data

Path Forward

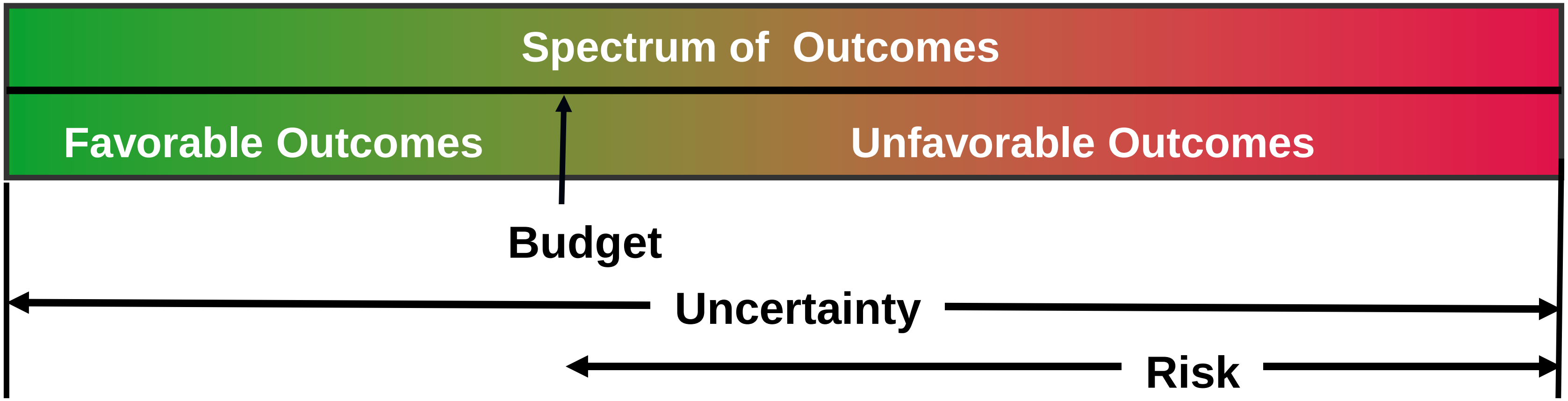
- Finalize your cover letter, and the acknowledgments
- Approve this presentation for ICEAA
- Many suggestions from the field for further research and guidance, worked examples on topics like:
  - Introducing duration and risk register into spreadsheet models
  - Defining, documenting and implementing a Risk Register
  - Distribution fitting, particularly on goodness-of-fit and fitting small samples
  - Defining and accounting for sunk costs
  - Measure and apply correlation,
  - Pooled regression learning curve
  - Application of uncertainty to cost benefit analysis and “should cost”
  - More reports and utilities
  - Building the analysis schedule as a basis for CISM and FICSM models
  - Exploring FICSM modeling more thoroughly

BACKUP

CSRUH Table Of Contents

Key Definitions

- **Risk** is the probability of a loss or injury.
- **Uncertainty** is the indefiniteness about the outcome of a situation



- **Risk Register** lists those events that may or may not happen, but if they do happen they will have a ***negative or positive*** impact on the cost or schedule or both

Excel Utility to Adjust for Skew

Enter title, low, mode, high and uncertainty captured

Utility calculates the low/high probability and min/max to preserve skew

Utility calculates the parameters for betaPERT if symmetrical, otherwise use solver

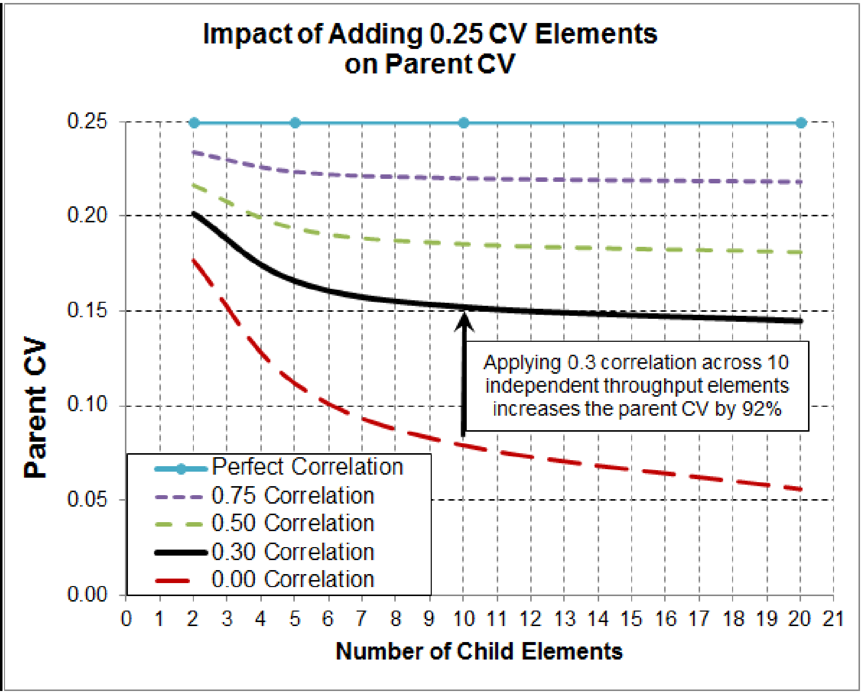
Template to Adjust Low and High Percentile for Skew					
Enter Case Title	Fig 2-17	EMD PM$	Motor Wgt	Warhead Wgt	**Comment or Formula**
Low	80	90	280	20	Input expert's low bound
Mode	100	100	290	25	Input expert's mode (most likely)
High	160	130	350	35	Input expert's high bound
Estimated uncertainty captured by expert	70%	70%	70%	70%	Default is 70%
Results for Triangular or Uniform Distributions					
mulative Probability Low	**8%**	**8%**	**4%**	**10%**	Round(Skew * (1 - UncertIncl),2)
nulative Probability High	**78%**	**78%**	**74%**	**80%**	UncertIncl + Adjusted Low Bound Interpretation
Min	**55.8**	**77.9**	**267.9**	**13.9**	(Mode-Skew * Max)/(1 - Skew)
Max	**232.7**	**166.3**	**422.7**	**47.1**	High+(High-Mode)*SQRT(UncertNotIncl)/(1-SQRT(UncertNotIncl))
Total uncertainty NOT captured by expert	0.30	0.30	0.30	0.30	1 - UncertIncl
Skew based upon inputs	0.25	0.25	0.14	0.33	(Mode-LowInp)/(HighInp-LowInp)
Revised Skew	0.25	0.25	0.14	0.33	(Mode-Min)/(Max-Min) i.e., CDF of Mode
Results for BetaPert					
Probability Low	**17%**	**17%**	**16%**	**16%**	BETADIST(LowInp, Alpha, Beta, Beta_Min, Beta_Max)
nulative Probability High	**87%**	**87%**	**86%**	**86%**	BETADIST(HighInp, Alpha, Beta, Beta_Min, Beta_Max)
Min	**49.6**	**74.8**	**262.2**	**12.8**	Mode-1/((1-2*BETAINV(UncertNotIncl/2,Alpha,Beta)))*(Mode-LowInp)
Max	**251.2**	**175.6**	**456.8**	**49.3**	Beta_Min + Lambda * (Mode - Beta_Min) / (Alpha - 1)
Total uncertainty NOT captured by expert	0.30	0.30	0.30	0.30	1-(HighPercentBeta-LowPercentBeta) **Red cell indicates solver required**
Beta skew based upon inputs	0.37	0.37	0.28	0.42	BETADIST(Mode, Alpha, Beta, LowInp, HighInp)
Beta skew after adjustment	0.37	0.37	0.28	0.42	BETADIST(Mode, Alpha, Beta, Beta_Min, Beta_Max)

Impact of Adding Additional Uncertain Elements

- Top table shows the parent CV decreasing as independent uncertain elements are broken into smaller elements with the same CV
- Bottom table shows impact of applying 0.3 correlation on parent CV
- Chart illustrates impact of various correlations. The more elements, the greater the impact of correlation on the parent.

0.00 Correlation	Sum Independent Distributions			Sum Independent Distributions			Sum Independent Distributions		
	Mean	Std Dev	CV	Mean	Std Dev	CV	Mean	Std Dev	CV
Total	1000	176.78	0.177	1000	111.80	0.112	1000	79.06	0.079
Element 1	500	125.00	0.250	200	50.00	0.250	100	25.00	0.250
Element 2	500	125.00	0.250	200	50.00	0.250	100	25.00	0.250
Element 3				200	50.00	0.250	100	25.00	0.250
Element 4				200	50.00	0.250	100	25.00	0.250
Element 5				200	50.00	0.250	100	25.00	0.250
Element 6							100	25.00	0.250
Element 7							100	25.00	0.250
Element 8							100	25.00	0.250
Element 9							100	25.00	0.250
Element 10							100	25.00	0.250

0.30 Correlation	Sum Correlated Distributions			Sum Correlated Distributions			Sum Correlated Distributions		
	Mean	Std Dev	CV	Mean	Std Dev	CV	Mean	Std Dev	CV
Total	1000	201.56	0.202	1000	165.83	0.166	1000	152.07	0.152
Element 1	500	142.522	% Increase	200	74.162	% Increase	100	48.09	% Increase
Element 2	500	142.522	in CV	200	74.162	in CV	100	48.09	in CV
Element 3			14%	200	74.162	48%	100	48.09	92%
Element 4				200	74.162		100	48.09	
Element 5				200	74.162		100	48.09	
Element 6							100	48.09	
Element 7							100	48.09	
Element 8							100	48.09	
Element 9							100	48.09	
Element 10							100	48.09	

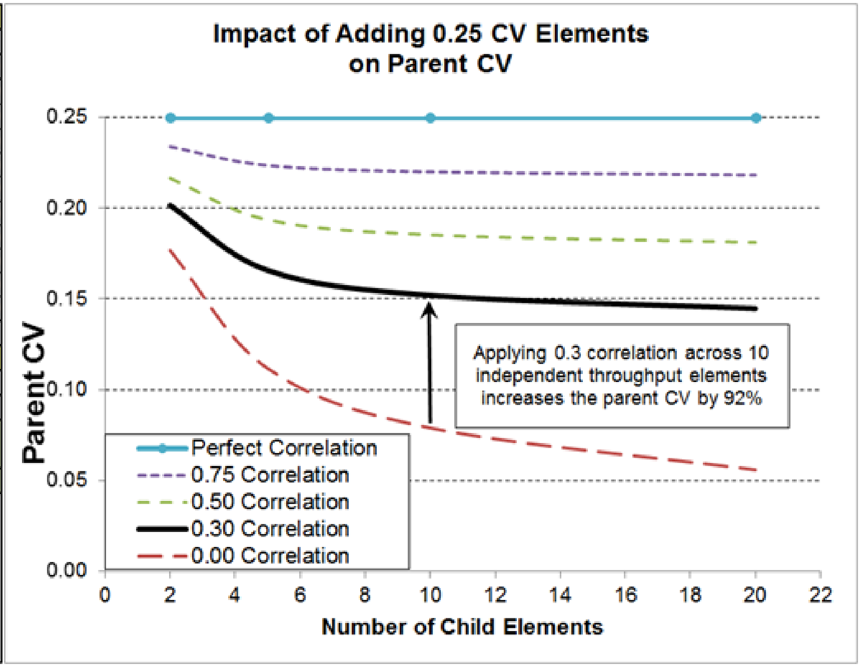


Impact of Adding Additional Uncertain Elements

- Top table shows the parent CV decreasing as additional independent uncertain elements are added
- Bottom table shows impact of applying 0.3 correlation on parent CV
- Chart illustrates impact of various correlations. The more elements, the greater the impact of correlation.

0.00 Correlation	Sum Independent Distributions			Sum Independent Distributions			Sum Independent Distributions		
	Mean	Std Dev	CV	Mean	Std Dev	CV	Mean	Std Dev	CV
Total	**200**	**35.36**	**0.177**	**500**	**55.90**	**0.112**	**1000**	**79.06**	**0.079**
Element 1	100	25.00	0.250	100	25.00	0.250	100	25.00	0.250
Element 2	100	25.00	0.250	100	25.00	0.250	100	25.00	0.250
Element 3				100	25.00	0.250	100	25.00	0.250
Element 4				100	25.00	0.250	100	25.00	0.250
Element 5				100	25.00	0.250	100	25.00	0.250
Element 6							100	25.00	0.250
Element 7							100	25.00	0.250
Element 8							100	25.00	0.250
Element 9							100	25.00	0.250
Element 10							100	25.00	0.250

0.30 Correlation	Sum Correlated Distributions			Sum Correlated Distributions			Sum Correlated Distributions		
	Mean	Std Dev	CV	Mean	Std Dev	CV	Mean	Std Dev	CV
Total	**200**	**40.31**	**0.202**	**500**	**82.92**	**0.166**	**1000**	**152.07**	**0.152**
Element 1	100	28.504	% Increase	100	37.081	% Increase	100	48.09	% Increase
Element 2	100	28.504	in CV	100	37.081	in CV	100	48.09	in CV
Element 3			14%	100	37.081	48%	100	48.09	92%
Element 4				100	37.081		100	48.09	
Element 5				100	37.081		100	48.09	
Element 6							100	48.09	
Element 7							100	48.09	
Element 8							100	48.09	
Element 9							100	48.09	
Element 10							100	48.09	



A Simple Allocation Process

(Not required if Mean is Selected)

- Select the level in the WBS from which risk dollars will be allocated (EMD and Production)
- Generate the simulation results in BY dollars for all levels in the WBS
- Sum the immediate subordinate probability results (2)
- Compute the difference between the sum of the children and the parent value (3)
- Using the standard deviation (4), prorate (6) the amount to allocate (3)
- Apply the adjustment (6) to the element percentile result (1) to develop the allocated result (7)
- Sum to parent levels

This process adjusts the percentile results directly, not the PE!

	Column	1	2	3	4	5	6	7	8	9
80% Allocated from EMD and Production BY 2014 $K		**Percentile Results**	**Sum of Child Percentiles**	**Amount To Allocate (1 - 2)**	**Std Dev**	**Stdev/ Sum(Stdev)**	**Child Adjustment (3 * 5)**	**Allocated Result (1 + 6)**	Point Estimate	Risk Dollars (1-8)
Missile System	MissileSys							$381,908	$246,836	$135,071
Engineering and Manufacturing Dev	EMD	**$163,168**	$170,462	-$7,294				$163,168	$83,539	$79,629
Air Vehicle	AV_EMD	$39,012	$39,507	-$2,831	20,400	0.3202	-$2,335.94	$36,676	$14,944	$21,732
Design & Development	DesignDev_EMD	$34,083			19,708	0.9288	-$2,629.13	$31,454	$12,000	$19,454
Prototypes	Proto_EMD	$5,424			1,510	0.0712	-$201.43	$5,222	$2,944	$2,278
Software	SW_EMD	$60,064			23,706	0.3721	-$2,714.49	$57,349	$31,500	$25,849
System Engineering	SysEng_EMD	$33,317			8,332	0.1308	-$954.08	$32,363	$17,500	$14,863
Program Management	PM_EMD	$24,677			5,433	0.0853	-$622.16	$24,055	$15,000	$9,055
System Test and Evaluation	STE_EMD	$4,852			1,686	0.0265	-$193.03	$4,659	$1,767	$2,892
Training	Trg_EMD	$2,794			1,472	0.0231	-$168.57	$2,626	$897	$1,729
Data	Data_EMD	$3,723			1,978	0.0310	-$226.46	$3,496	$1,196	$2,301
Peculiar Support Equipment	PSE_EMD	$2,023			695	0.0109	-$79.62	$1,944	$736	$1,207