Uncertainty With Uncertainty

PDR JCL Observations & Research

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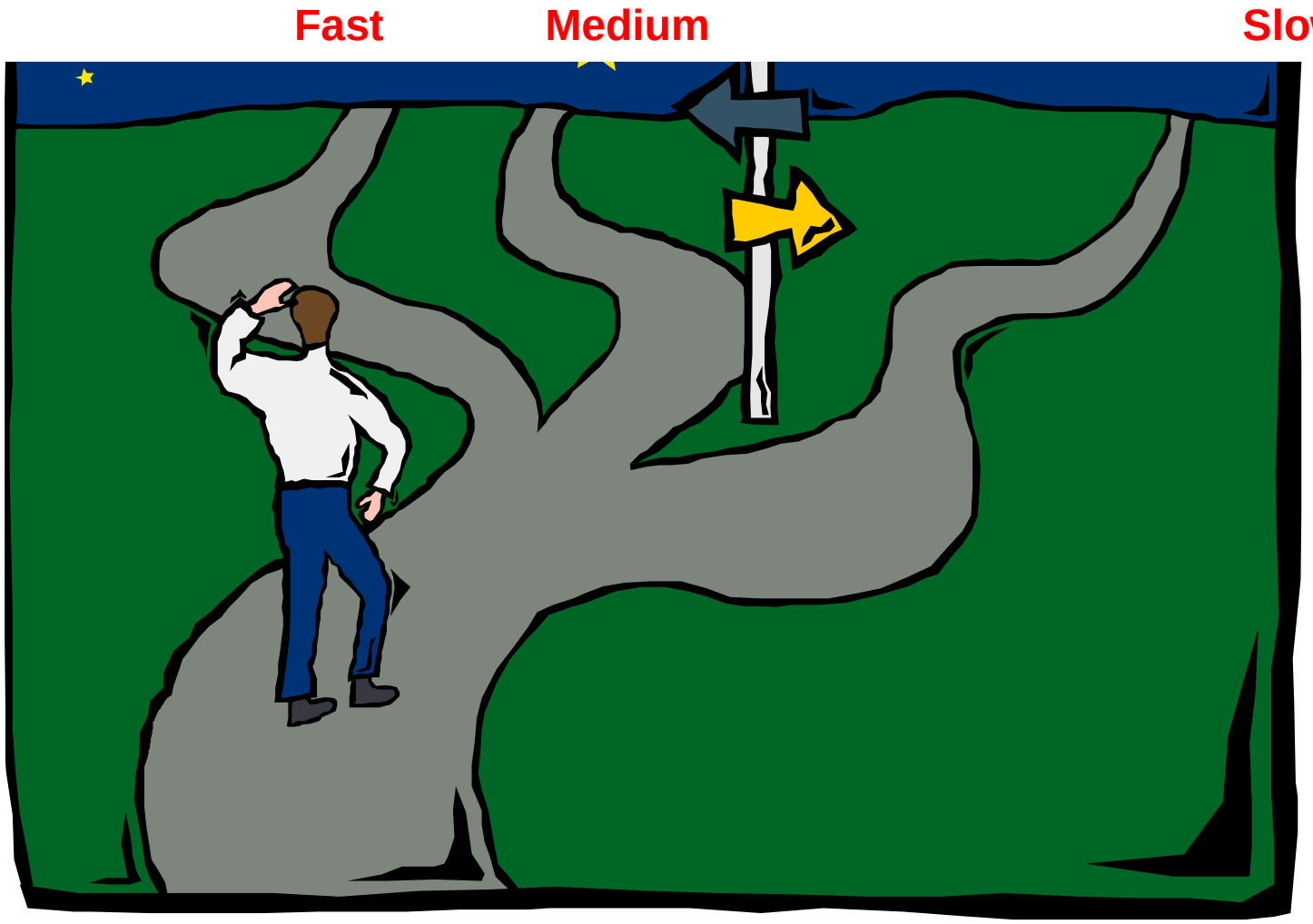
NASA Cost Symposium

August 2014

Two Tons in ¼ Ton Truck
Or an Hour's Presentation in 30 Minutes…

Three Options



Analysis Schedule
Health Checks

Analysis Schedule DCMA Health Check

- **Acumen changed their scoring methods**
  - After notification about questionable DCMA scores

DCMA Ribbon Analyzer															
1. Logic	2. Leads	3. Lags	4. FS Relations	5. Hard Constraint	6. High Float	7. Negative Float	8. High Duration	9. Invalid Dates	10. Resources	11. Missed Activities	12. Critical Path Test	13. CPLI	14. BEI	Score	
N/A	N/A	N/A	N/A	N/A	0 0%	0 0%	0 0%	N/A	0 0%	0 0%	✓	N/A	N/A	90	Old Metric
N/A	N/A	N/A	N/A	N/A	0 0%	0 0%	0 0%	N/A	0 0%	0 0%	✓	N/A	N/A	0	Activity
N/A	N/A	N/A	N/A	N/A	N/A	0 0%	0 0%	0 0%	N/A	N/A	0 0%	0 0%	✓	N/A	0	100	New Metric
N/A	N/A	N/A	N/A	N/A	N/A	0 0%	0 0%	0 0%	N/A	N/A	0 0%	0 0%	✓	N/A	0	100	Activity

How Can this be True??

AS CHECKED BY ACUMEN FUSE

Analysis Schedule Health Checks
Obviously an Analysis Schedule Will Have High Duration Tasks

DCMA Ribbon Analyzer

1. Logic	2. Leads	3. Lags	4. FS Relations	5. Hard Constraint	6. High Float	7. Negative Float	8. High Duration	9. Invalid Dates	10. Resources	11. Missed Activities	12. Critical Path Test	13. CPLI	14. BEI	Score	
N/A	N/A	N/A	N/A	N/A	0 0%	0 0%	0 0%	N/A	0 0%	0 0%	✓	N/A	N/A	90	Metric
N/A	N/A	N/A	N/A	N/A	0 0%	0 0%	0 0%	N/A	0 0%	0 0%	✓	N/A	N/A	0	Activity

GAO - Partial Health Check

Milestone Ratio	No Dependencies	Lags	Leads	Open Start	Open Finish	Summaries with Dependencies	Merge Hotspot	Soft Constraints	Hard Constraints	High Duration	Critical	Critical LOE	Critical High Duration	High Float	Negative Float	Actual Start in the Future	Actual Finish in the Future	BEI	Score	
1:10 0.1	1 0%	16 1%	0 0%	0 0%	0 0%	0 0%	126 15%	114 13%	0 0%	508 65%	63 5%	0 0%	16 42%	69 8%	0 0%	0 0%	0 0%	N/A	96	Metric
1:10 0.1	1 0%	16 1%	0 0%	0 0%	0 0%	0 0%	126 15%	114 13%	0 0%	508 65%	63 5%	0 0%	16 42%	69 8%	0 0%	0 0%	0 0%	N/A	46	Activity
1:10 0.1	1 0%	16 1%	0 0%	0 0%	0 0%	0 0%	126 15%	114 13%	0 0%		63 5%	0 0%	16 42%	69 8%	0 0%	0 0%	0 0%	N/A	74	
1:10 0.1	1 0%	16 1%	0 0%	0 0%	0 0%	0 0%		114 13%	0 0%		63 5%	0 0%	16 42%	69 8%	0 0%	0 0%	0 0%	N/A	84	
1:10 0.1	1 0%	16 1%	0 0%	0 0%	0 0%	0 0%			0 0%		63 5%	0 0%	16 42%	69 8%	0 0%	0 0%	0 0%	N/A	92	

AS CHECKED BY ACUMEN FUSE

Analysis Schedule Health Checks

- **STAT score**

Schedule Health Check

Overall Project Health Status Indicator: G

Project Name: GSDO Analysis Schedule BL IMS 01_13 v9

Schedule Status

Description	Current
Current Start (Note: earliest activity Early Start Date)	10/3/2011
Current Finish (Note: latest activity Early Finish Date)	3/14/2018
Approximate Remaining Work Days	1044
Is this schedule externally linked to other schedules?	N
Status Date	1/9/2014

Task and Milestone Count

(Note: These counts exclude summary ta

Description	Count	% of Total
Total Tasks and Milestones	885	
Completed Tasks and Milestones	20	2%
To Go Tasks and Milestones	865	98%

Integrity Indicators *(Note: These counts exclude summary and started/completed tasks)*

Tasks and Milestones Without Predecessors	0	0%	G
Tasks and Milestones Without Successors	18	2%	G
To Go Tasks with No Finish Ties	0	0%	G
To Go Tasks with No Start Ties	0	0%	G
Summaries with Logic Ties (see note below)	0	0%	G
Out of Sequence Relationships	0	0%	G
Tasks and Milestones Needing Updates	0	0%	G
Actuals after Status Date	0	0%	G
Tasks marked as Milestones (Note: having a duration of > 0)	0	0%	G
Tasks With Estimated Duration	0	0%	G
Manual Tasks (includes summary tasks - see note below)	0	0%	G

Note: *The summaries with logic ties and manual tasks numbers are calculated as a percentage of tasks and m*

Constraints

Total Constraints (Note: other than ASAP including deadlines)	110	13%	
Start No Earlier Than	110	13%	Y
Start No Later Than	0	0%	G
Finish No Earlier Than	0	0%	G
Finish No Later Than	0	0%	G
Must Start On	0	0%	G
Must Finish On	0	0%	G
As Late As Possible	0	0%	G
Deadlines	0	0%	G

Additional Schedule Information

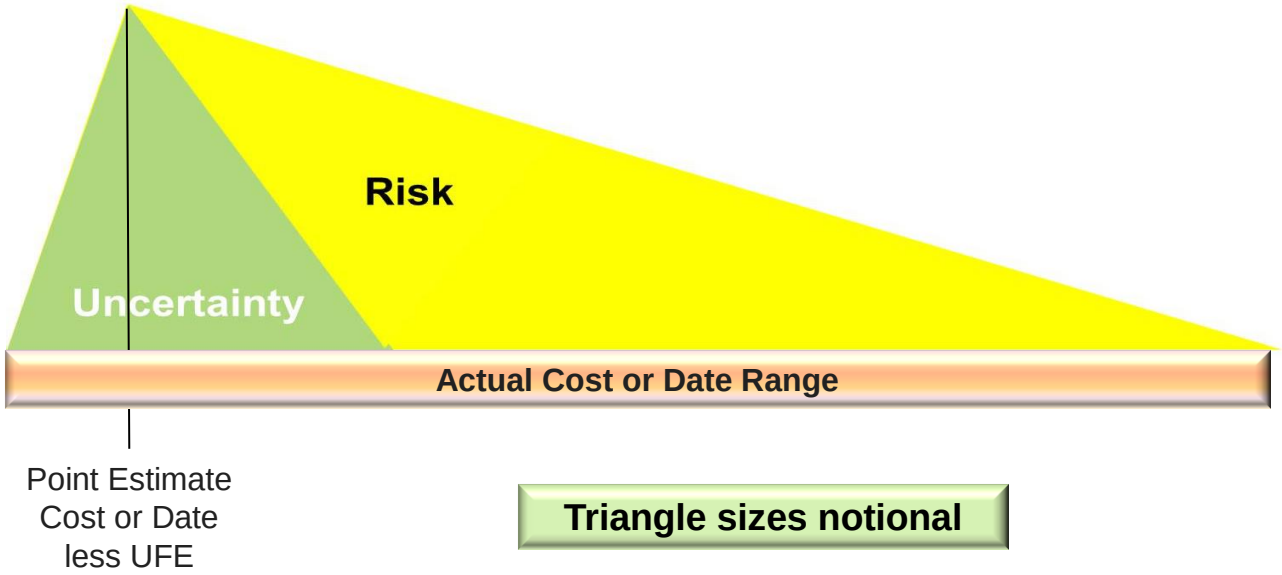
Recurring Tasks	0	0%
Schedule traceable to WBS (Y/N)	Y	
Realistic Critical Path(s) (Y/N)	Y	
Schedule Baselined Tasks	0	0%
Tasks With Resources	0	0%
Tasks and Milestones with 10 days or less Total Float	103	12%
Tasks with Total Float > 25% of remaining duration	298	34%
Total Tasks (Including summary tasks)	1199	

Uncertainty
What Is It, and How Much Should I Use?

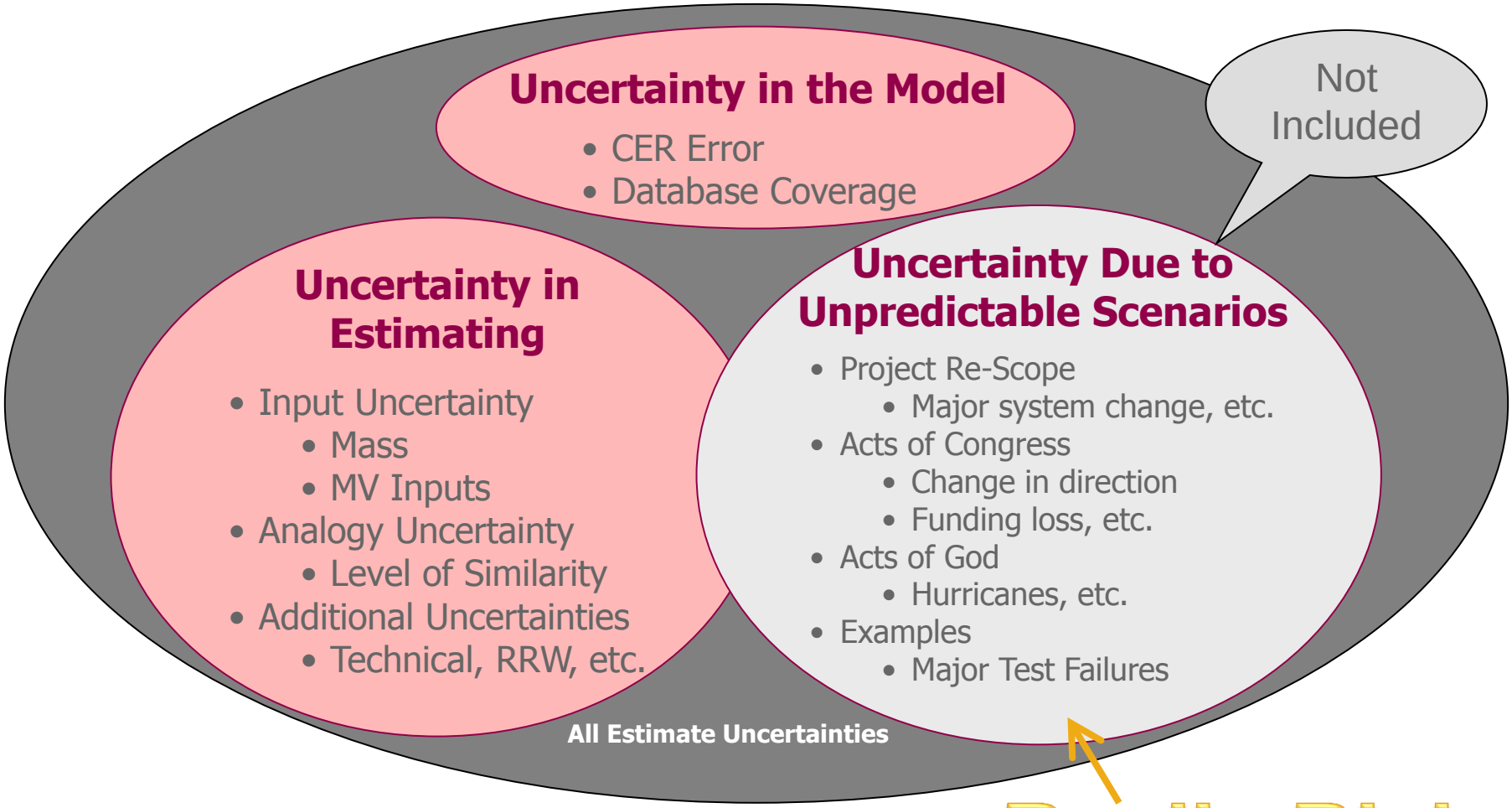
"Things should be made as simple as possible, but not any simpler."
Albert Einstein

Uncertainty Overview

- **Risks are discrete events, either they happen or they don't**
- **Uncertainty is error range around point value – margin of error**
  - Uncertainty: indefiniteness about outcome of situation includes both favorable and unfavorable events, due to following elements:
    1. Error
    2. Inaccuracy
    3. Bias
    4. Inadequate knowledge
- **Everyone agrees uncertainty must be included, but no one knows how much is needed**
  - Many opinions



Full Disclosure Example



30-50% of NASA's cost & schedule overruns due to external influences, yet we rarely account for them. Shouldn't we?

Typical Uncertainty Approach

- **We typically define arbitrary buckets**
  - Triangular distribution generally used
  - Each cost or schedule activity is subjectivity placed in a bucket

EXAMPLE Uncertainty Index	Low (10%)	Most Likely	High (90%)
1 – Very Pessimistic (Strong Potential to Beat Plan)	80	100	101
2 – Pessimistic (Potential to beat plan)	83	100	105
3 – Average (50-50)	88	100	112
4 – Slightly Optimistic	90	100	120
5 – Optimistic	95	100	130
6 – Very Optimistic	99.9	100	145

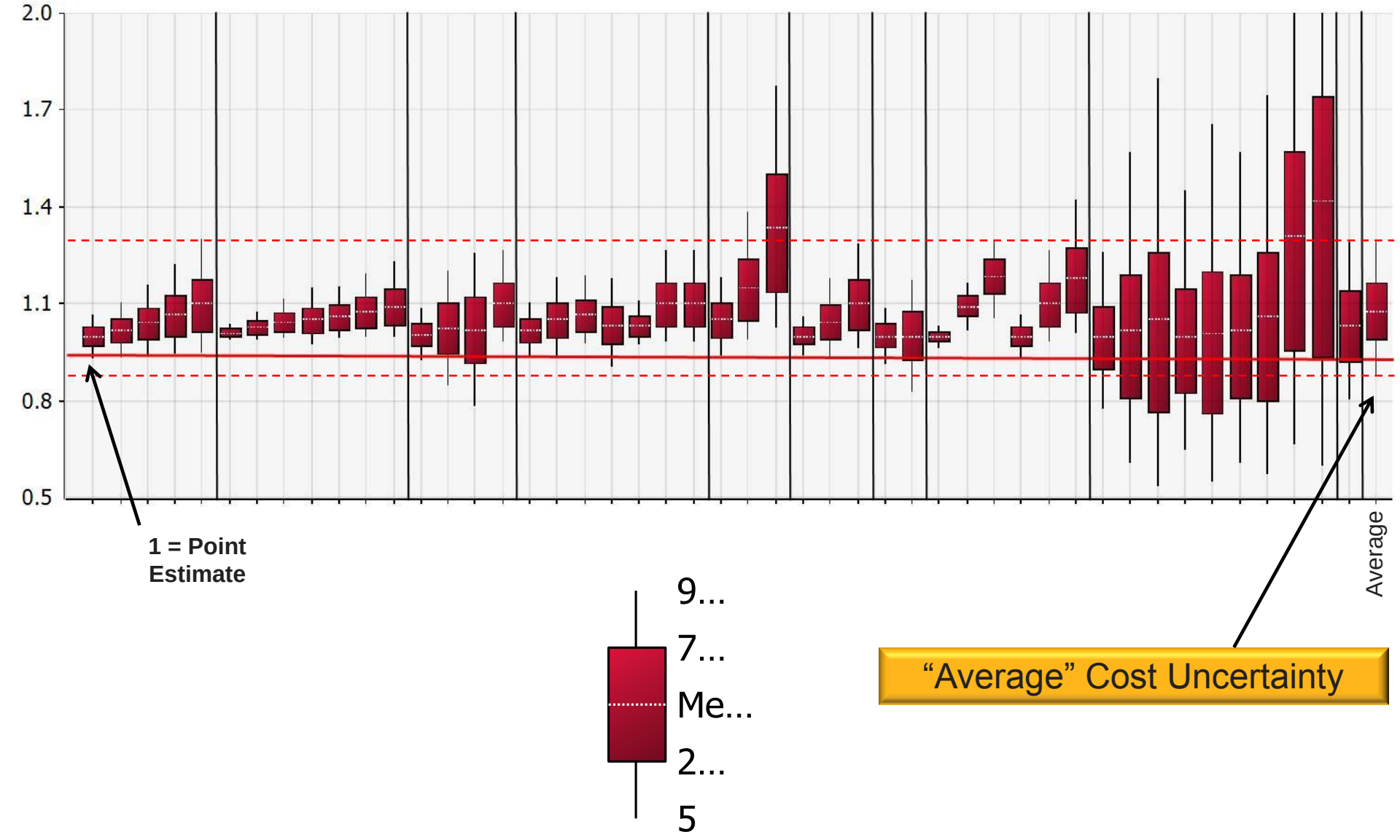
Most likely usually 100

Schedule Uncertainty Research

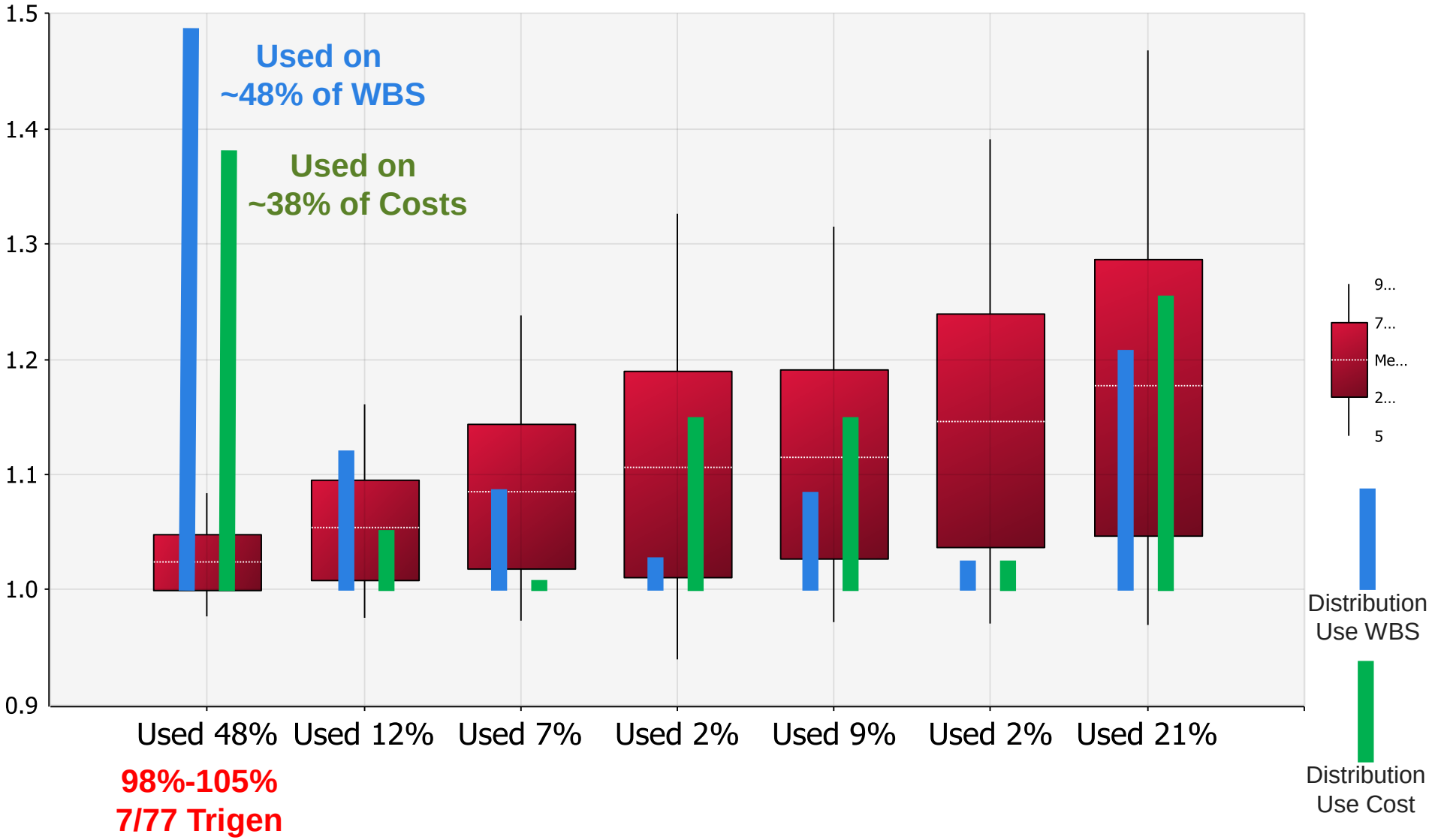
- **All available JCL uncertainty's reviewed**
- **Several trends emerged**
  - Uncertainty often not applied, or applied differently to activities with discrete risks
    - Due to concerns about double counting – IMO this is bogus, risks are not uncertainty
  - All activities not given uncertainty
    - Example LOE tasks are TD and schedule flex adds uncertainty
      - Problematic unless LOE tasks are hammocks
  - Activities subjectively grouped in multiple buckets according to expected uncertainty ranges
    - Historical "actual" uncertainty data lacking
    - *"-- it is virtually impossible to get historical data from a completed project at almost any level of detail except possibly the most aggregate." (Rand*)*
  - Most likely duration usually = plan

*Rand, Impossible Certainty: Cost Risk Analysis for Air Force Systems, 2006

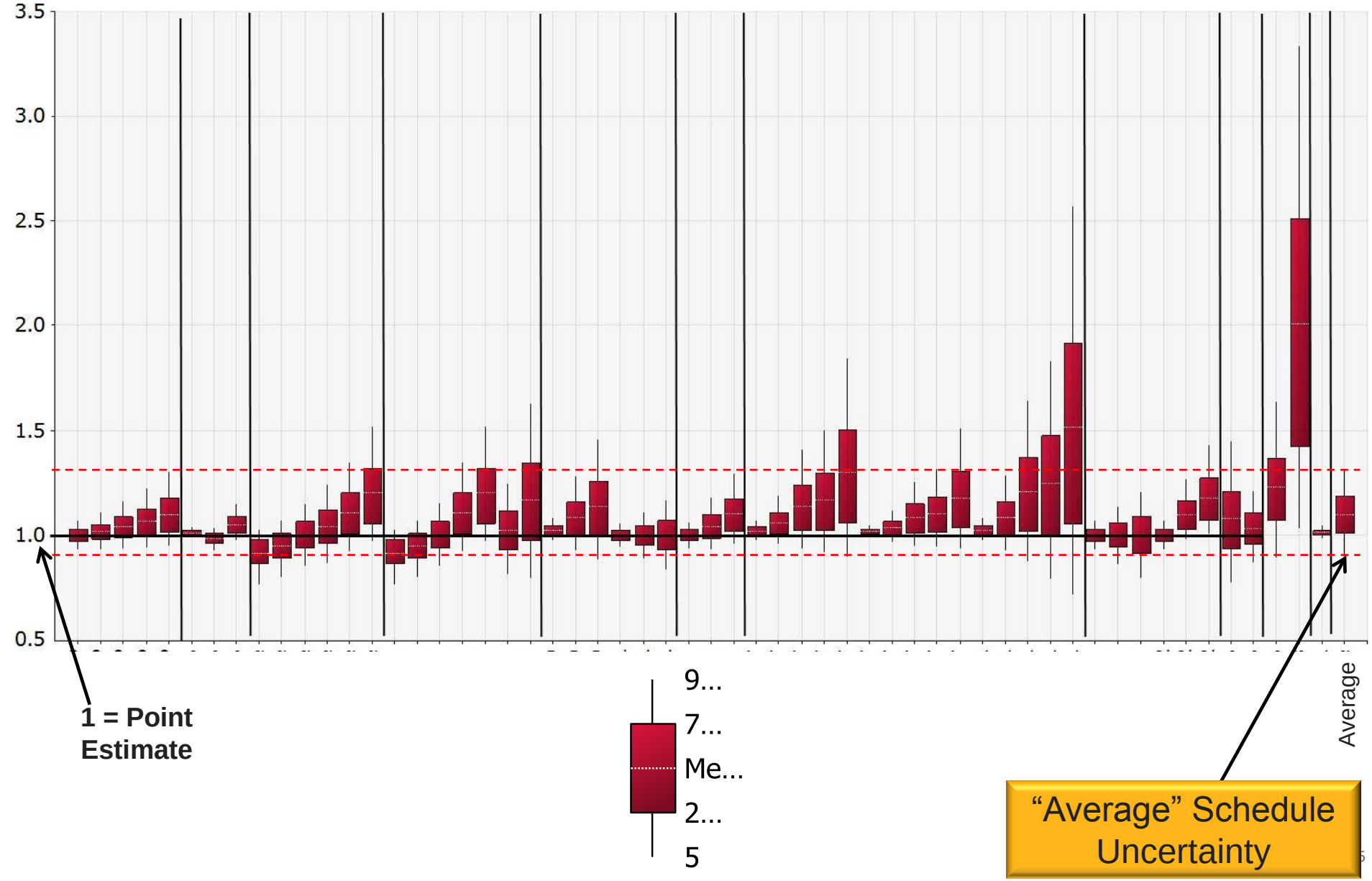
Cost Uncertainty Comparison



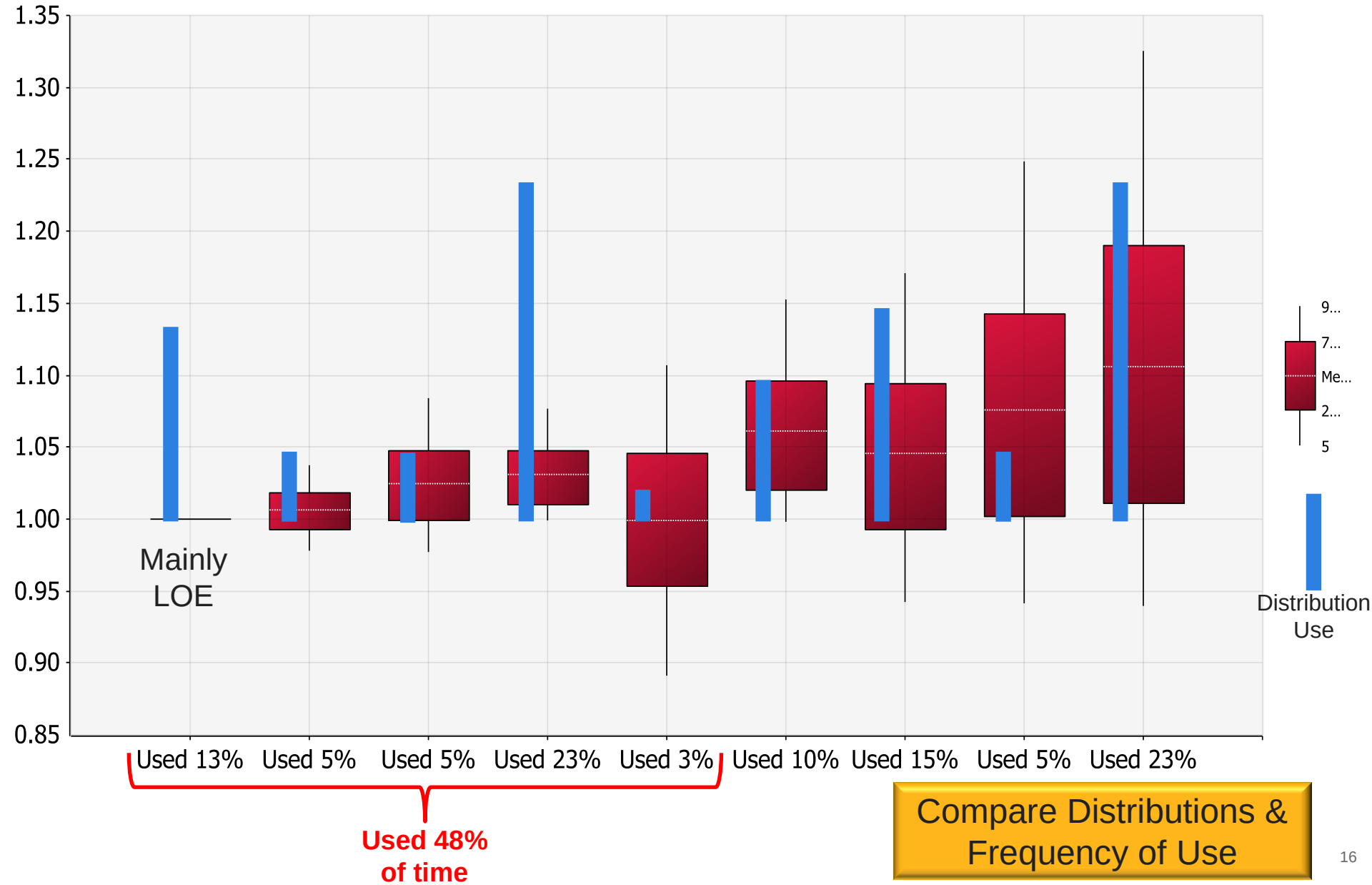
One Programs Cost Uncertainty Use



Schedule Uncertainty Comparison

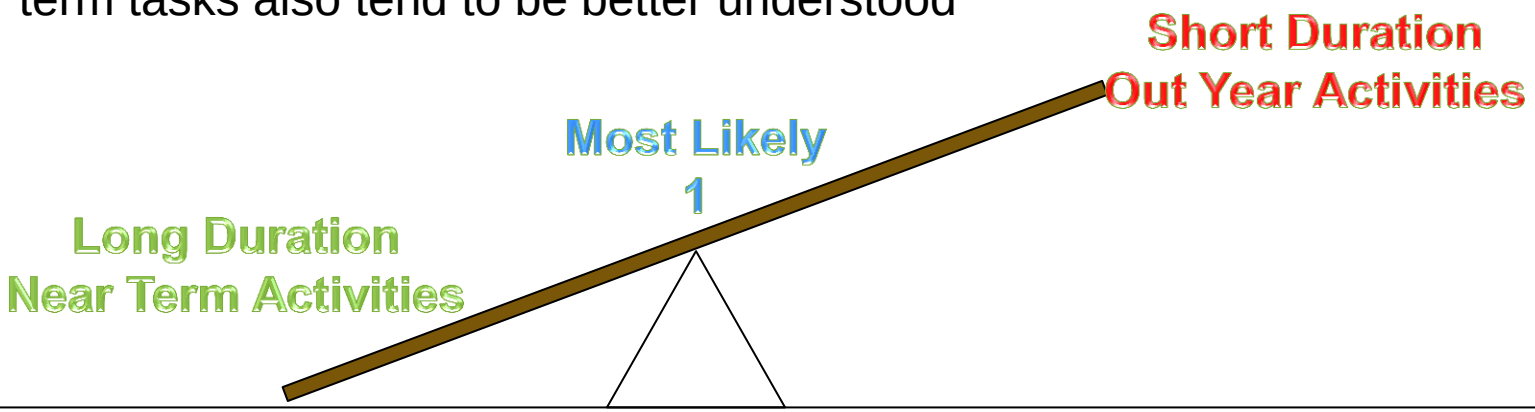


One Programs Schedule Uncertainty Use



Data Suggests

- **Longer schedule duration = lower expected variance**
  - Unlikely for a 2 year activity to double or triple
  - Likely for a 2 day task to double or triple
- **Near term tasks = lower expected variance**
  - Generally better understood
- **Inversely later task starts, the higher expected variance**
  - Out year tasks often not defined well, or compressed to meet imposed schedule
  - Consequently uncertainty at SDR should be more than PDR
- **Intuitively this makes sense**
  - Impacts to long duration projects have time to recover
  - Near term tasks also tend to be better understood



LOW UNCERTAINITY

HIGH UNCERTAINTY

Uncertainty Approach Schedule

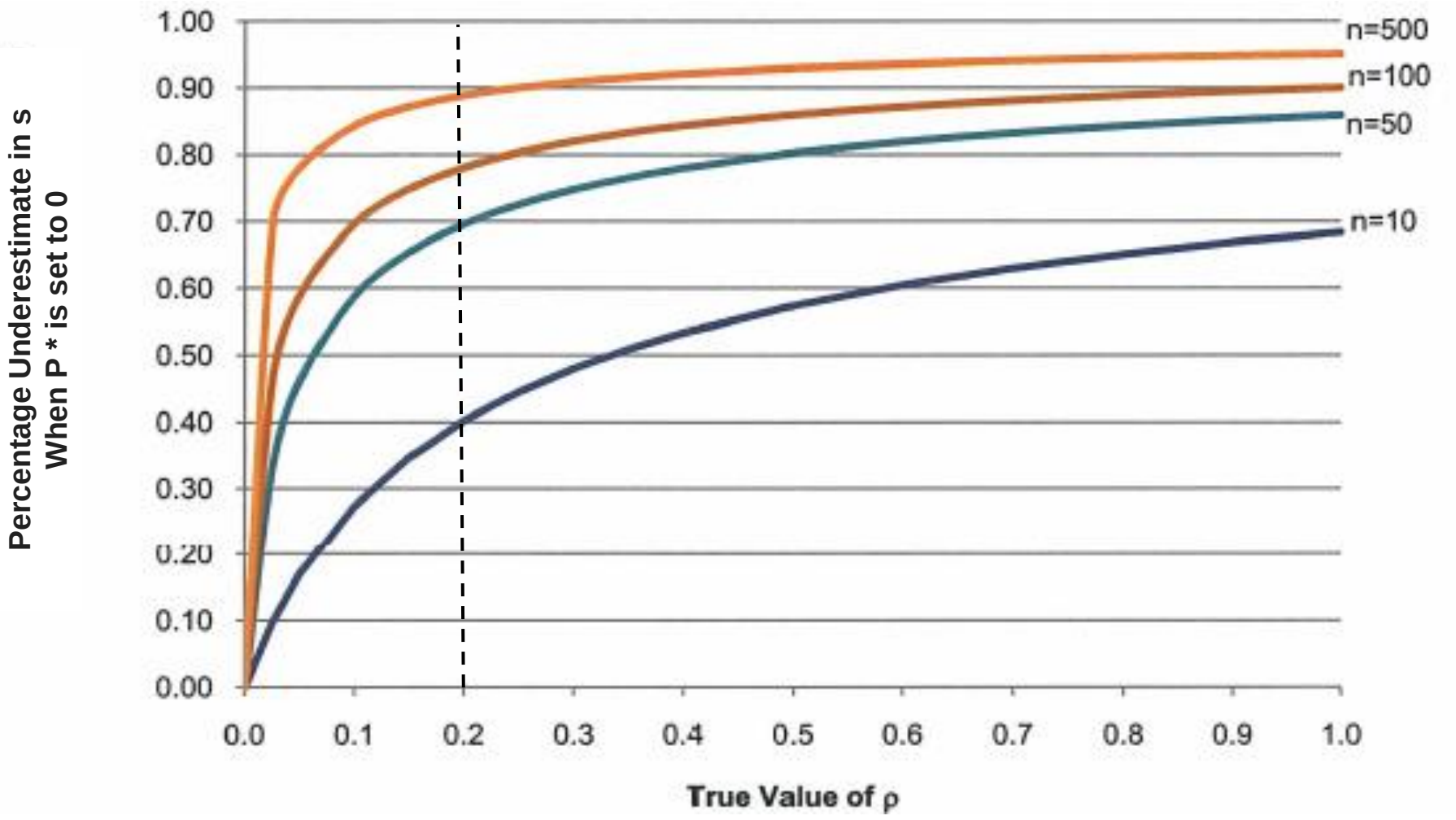
- 2012 Fred Kuo suggested
  - "that we may want to segregate uncertainty bounds by task duration range"
    - » Source: Developing Duration Uncertainty 2012 Cost Symposium
- 2013 SLS used this approach
- 2014 GSDO adopted approach, and developed table below

Planned Duration	Low	Most Likely	High
1-5 Days	90%	100%	200%
6-10 Days	90%	100%	150%
11-50 Days	90%	100%	115%
51 & up Days	85%	100%	110%
Out Year Activities	90%	100%	125%
High Risk Act	95%	100%	130%
High Risk (Command & Control)	95%	100%	140%

Correlation
How Much?

Dr. Book, Knee of Curve

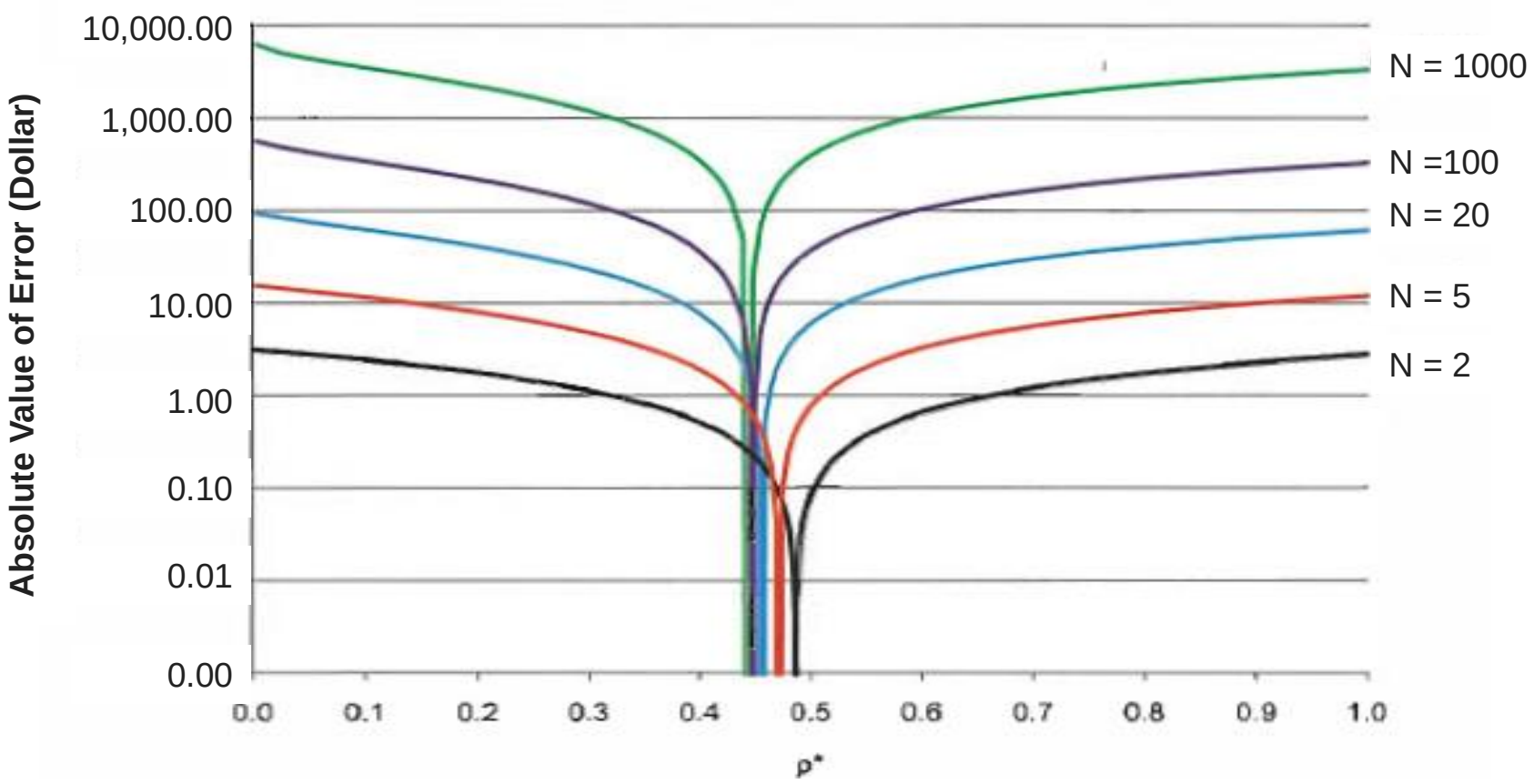
- **Dr. Book stressed importance of correlation**
  - Recommended that lacking data, 0.2 should be used



Source Why Correlation Matters in Cost Estimating, Feb 1999

IDA Correlation

- **Institute of Defense Analysis (IDA)**
  - ***"Book has been taken out of context"***
  - ***"Default correlation values should be close to 0.5, rather than 0.2."***
    - » For cases where analysts have limited knowledge of correlation values we have shown inaccuracy minimized when value is set closer to 0.5



Source NASA Confidence Level Assessment Processes, May 2010

Eric Druker JCL in a Nutshell

- **When possible, data driven approaches should always be used to determine correlation between schedule task durations**
  - For example: historical schedule growth between satellite subsystems
- **If data driven approach is not feasible and schedule is of reasonable size, following guidelines should be used**

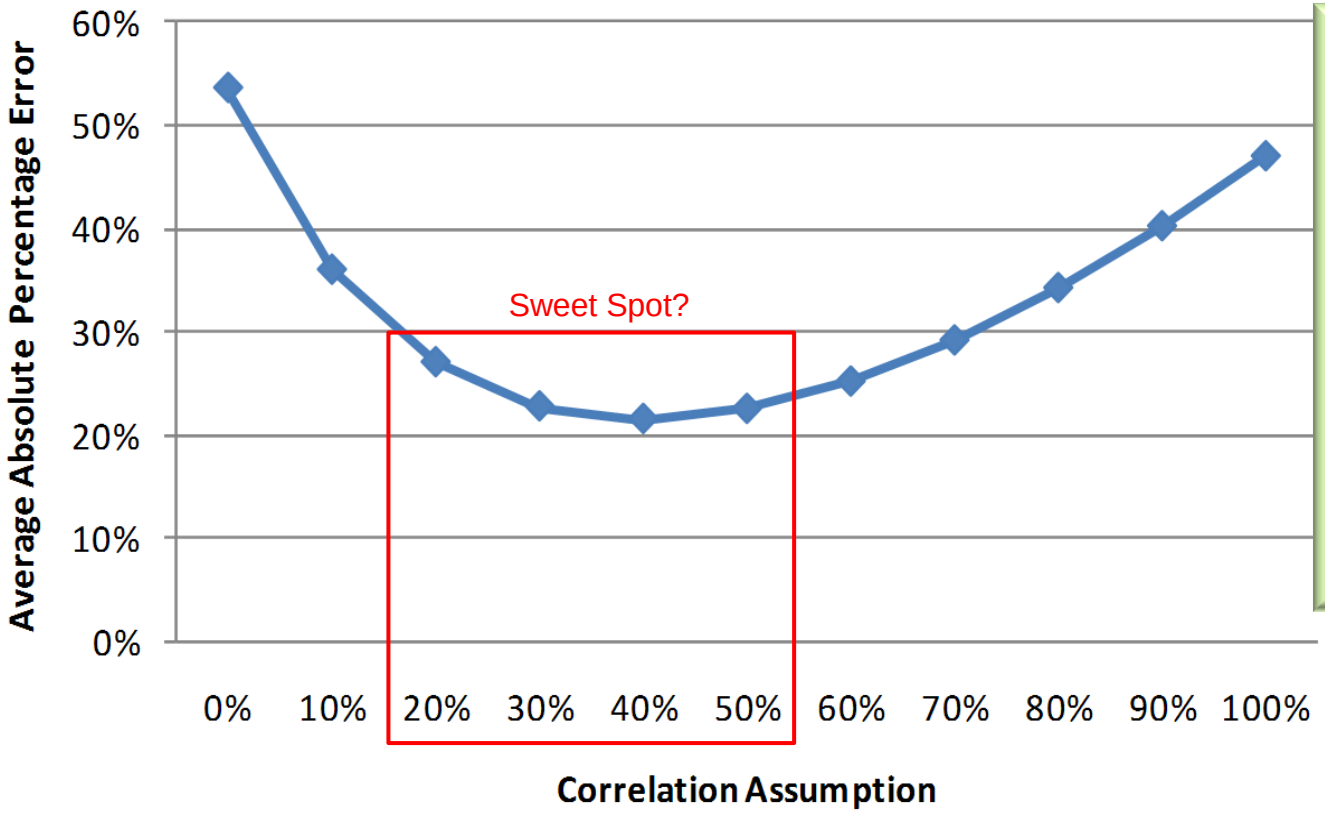
Correlation (including example basis for selection)*	ρ	Pic
Weak (different personnel working different component)	**0.25**	
Medium (same personnel working different component or different personnel working same component)	**0.50**	
Strong (same personnel working on same component)	**0.75**	

- **When data not available, or it is infeasible to directly assess correlation, it is recommended that correlation of 0.3 be injected between schedule distributions**
  1. This correlation is industry standard for cost risk analysis[4] to prevent sqrt(n) effect
     - » Mitigates ~30% of CV degradation
  2. Acts as knee in curve for schedule risk: Mitigates same % of schedule CV degradation for all serial networks (~30%), slightly less for all parallel networks (~15%)
     - » Simulation must be run to determine exact effect, likely to be 15% < x < 30%

Source SCEA 2010

MDA Correlation

- Robust approach to correlations would be to use value that results in least error
  - Assuming 0% correlation is wrong, and 100% is also wrong
  - Value of 40% minimizes sum of absolute errors over range of WBS sizes
- Graph denotes average absolute percentage error
  - Error reaches lowest level at 40%, but 30% and 50% provide similar accuracy



Empirical evidence to assign 20% correlation

Average correlation values for NAFCOM version 2004 was 20% for RDT&E costs

Correlation calculated by correlating residuals between CERs, as discussed in Aerospace Corporation's "Correlation Tutorial" (Covert and Anderson, 2005)

Source MDA Cost Handbook, 2012

What Is Correlation?

- **Correlation**
  - Measure of relationship strength between two or more variables
  - Closer to 1 = stronger relationship between variables
    - » if one variable increases other variable will increase
    - » if one variable decreases other variable will decrease
- **Effect of correlation**

Correlation Value	Percent Related
0.1	1%
0.2	4%
0.3	9%
0.4	16%
0.5	25%
0.6	36%
0.7	49%
0.8	64%
0.9	81%
1.0	100%

Sweet Spot

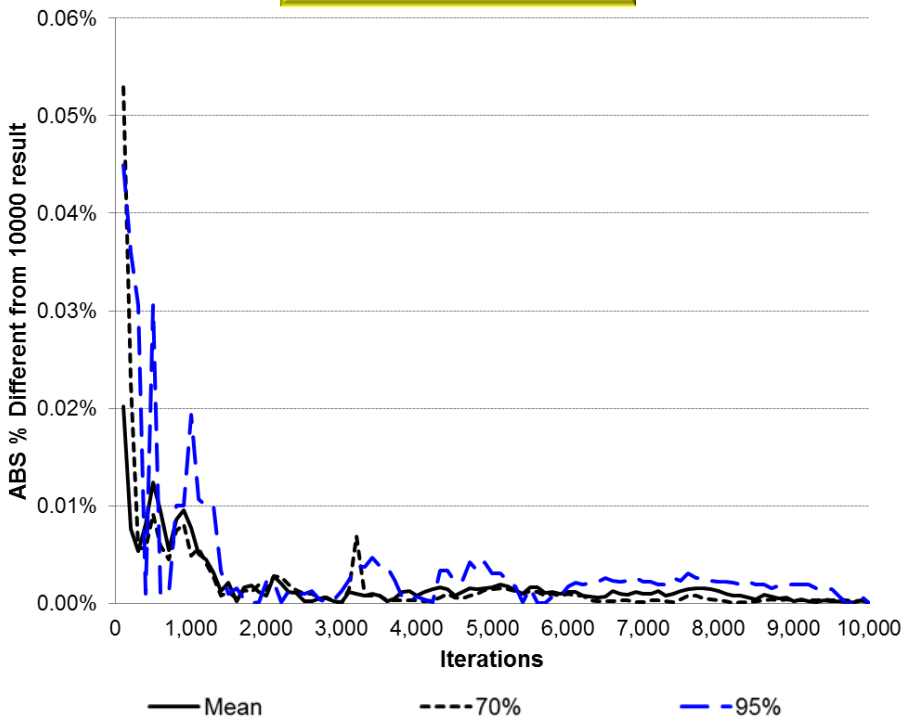
Need to clearly convey to stakeholders

JCL Iterations
How Many Are Needed?

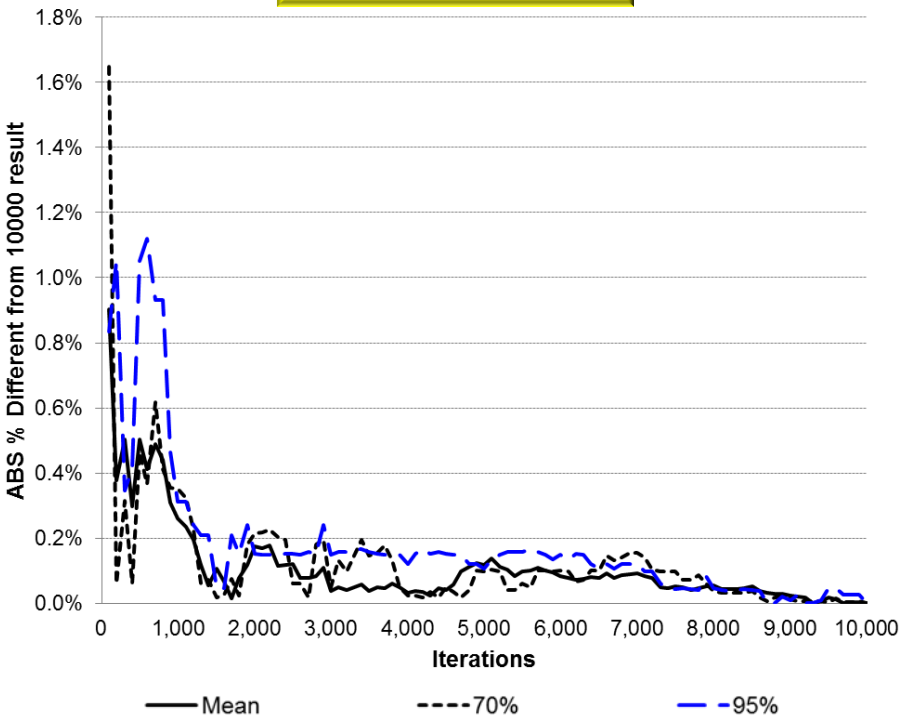
Convergence

- **Convergence checked on schedule and cost**
  - **Schedule convergence** @95% confidence of 0.01% reached after **1,000 iterations**
  - **Cost convergence** @95% confidence of 0.2% occurred after **2,000 iterations**

Finish Date

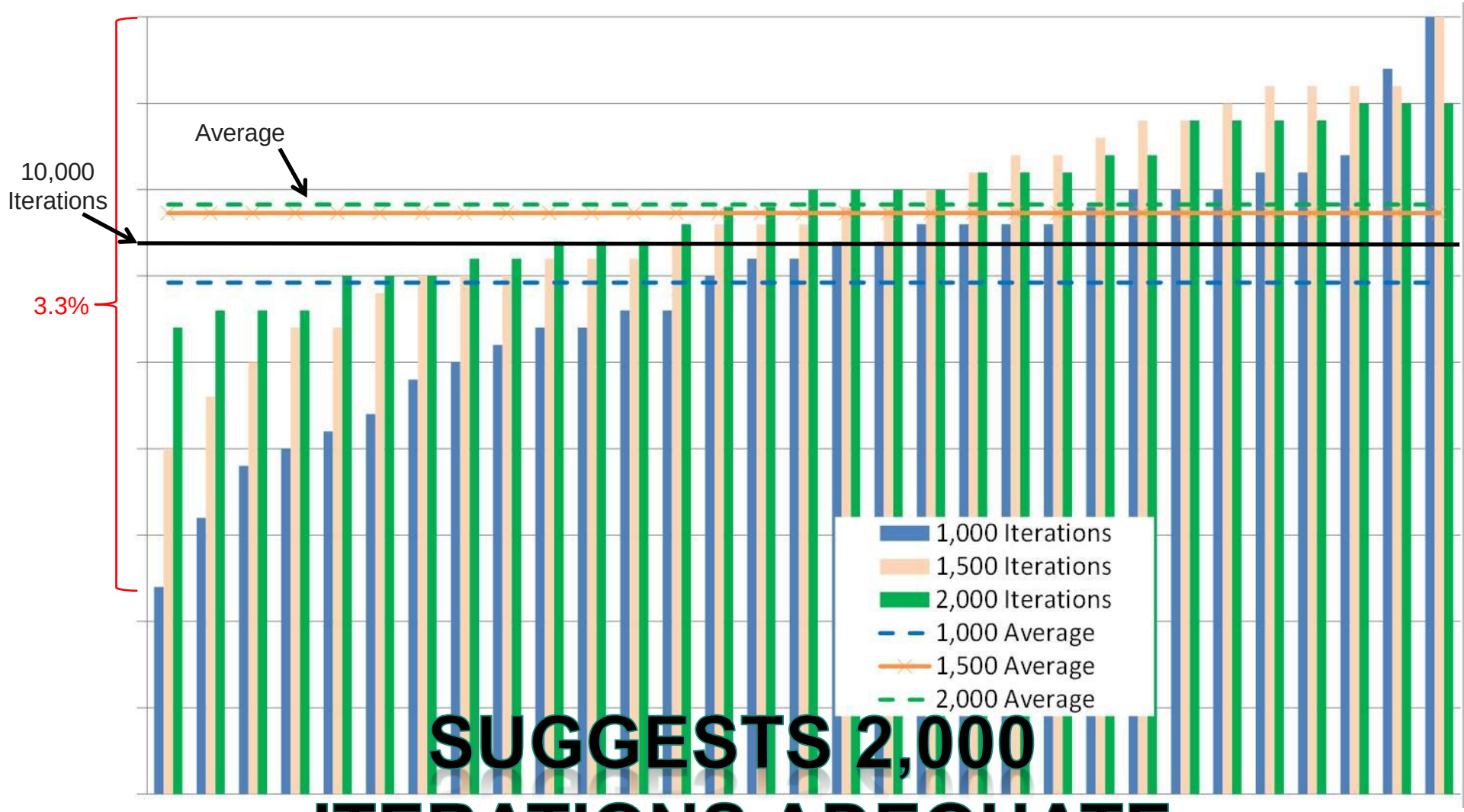


Total Cost



Number of Iterations Impact to JCL Result

- JCL Standard deviation decreased from 0.73% with 1,000 iterations to 0.40% with 2,000 iterations
- JCL variance was 3.3% between minimum & maximum values



SUGGESTS 2,000 ITERATIONS ADEQUATE

Unknown Unknowns

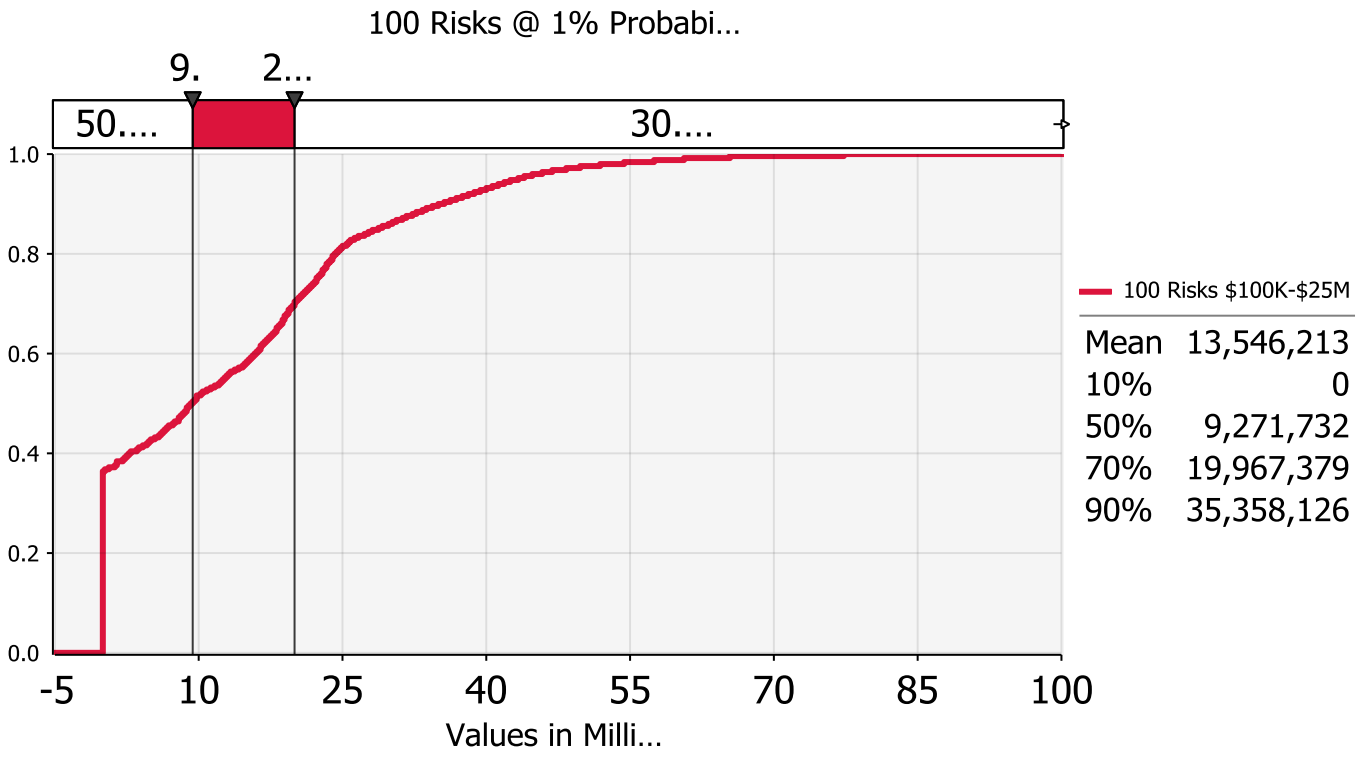
Unknown Unknowns

Ship carried Atlas first stage and Centaur upper stage for AEHF-2 and RBSP missions

Unknown Unknowns

But its only 1% probability of occurrence!

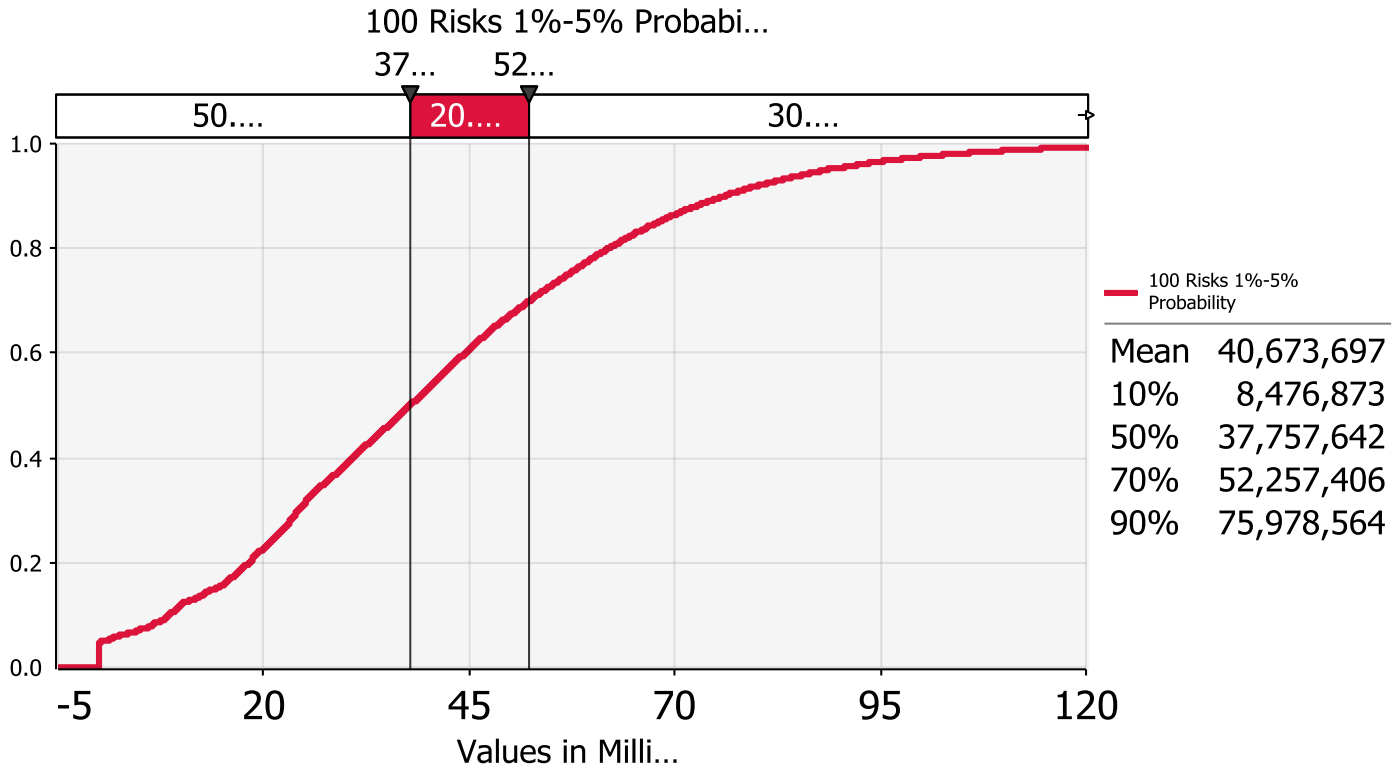
100 Risks each with 1% probability of occurrence & cost impact randomly spread between $100K & $25M



Unknown Unknowns

Probably more like 1%-5% probability of occurrence!

100 Risks each with 1-5% probability of occurrence & cost impact randomly spread between $100K & $25M



To get 70% JCL you need higher cost confidence level!

High Individual Cost and Schedule Confidence Required to Obtain 70% JCL

- **Assumes 0.6 Correlation**

Schedule Confidence Level \ Cost Confidence Level	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%	100%
15%	7%	9%	10%	12%	12%	12%	13%	13%	14%	14%	14%	15%	15%	15%	15%	15%	15%	15%
20%	9%	11%	13%	14%	15%	16%	17%	18%	18%	19%	19%	19%	19%	20%	20%	20%	20%	20%
25%	10%	13%	15%	17%	18%	20%	20%	22%	22%	24%	24%	24%	24%	25%	25%	25%	25%	25%
30%	12%	14%	17%	19%	21%	23%	24%	25%	27%	28%	28%	29%	29%	29%	29%	30%	30%	30%
35%	12%	15%	18%	21%	24%	25%	27%	28%	30%	31%	31%	32%	34%	34%	35%	35%	35%	35%
40%	12%	16%	20%	23%	25%	28%	30%	31%	33%	35%	36%	37%	38%	39%	40%	40%	40%	40%
45%	13%	17%	20%	24%	27%	30%	34%	34%	36%	38%	39%	41%	42%	43%	44%	45%	45%	45%
50%	13%	18%	22%	25%	28%	31%	34%	37%	39%	42%	44%	45%	46%	48%	49%	50%	50%	50%
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65%	14%	19%	24%	28%	31%	36%	39%	44%	47%	49%	53%	56%	58%	60%	62%	64%	65%	65%
70%	15%	19%	24%	29%	32%	37%	41%	45%	49%	52%	56%	58%	61%	63%	66%	68%	70%	70%
75%	15%	19%	24%	29%	34%	38%	42%	46%	50%	54%	58%	61%	64%	68%	71%	72%	74%	75%
80%	15%	20%	25%	29%	34%	39%	43%	48%	52%	56%	60%	63%	68%	71%	74%	77%	79%	80%
85%	15%	20%	25%	29%	35%	40%	44%	49%	53%	58%	62%	66%	71%	74%	77%	81%	83%	85%
90%	15%	20%	25%	30%	35%	40%	45%	50%	55%	59%	64%	68%	72%	77%	81%	84%	88%	90%
95%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	74%	79%	83%	88%	92%	95%
100%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%	100%

Chart by Kelli Mccoy

Coefficient of Variation (CV)

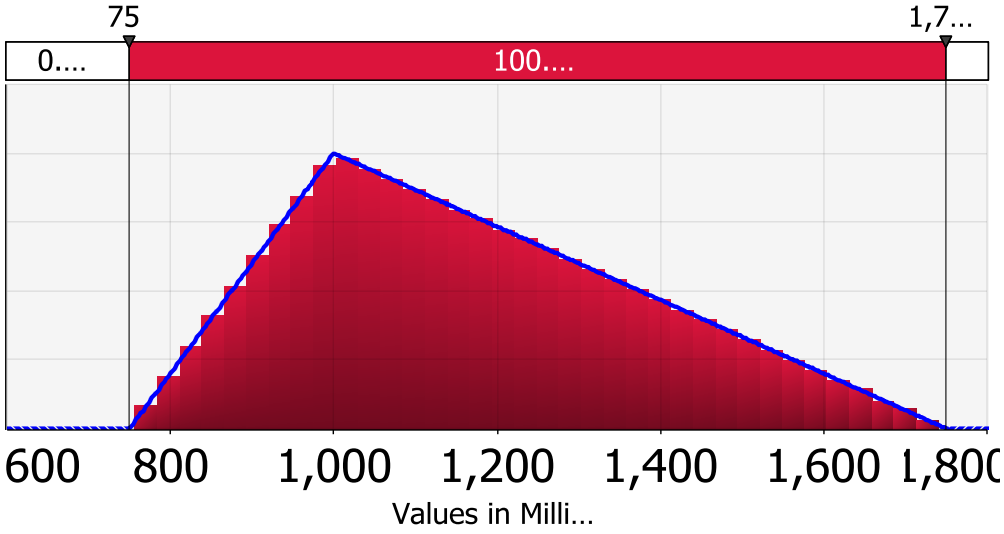
NASA 2008 Cost Estimating Handbook
Page 89

- **High CV values indicates a wider dispersion or a flatter s-curve.**
  - Often small CV of less than 0.15 is an indication of very optimistic ranges.
  - CVs near 0.15 are indicative of a program with low or modest risks.
  - CVs at 0.35 or above are indicative of a high risk program.
  - CVs larger than 0.35 may be an indication of unusually broad distributions. However, these rules-of-thumb are very commodity dependent and a function of where program is in life cycle.
    - For instance, a CV of 0.50 would not be unexpected for long range planning estimates.
    - Space programs, as another example, at an early stage of development often exhibit a CV of 0.40 or greater. Other observed metrics at the early stages of a project include:
      - 0.35-0.45 typical for space systems and software intensive projects
      - 0.25-0.35 typical for aircraft and similar complexity hardware
      - 0.10-0.20 typical for large electronic system procurements

Research Indicates these values “probably” derived from cost models during program formulation, and not applicable at PDR

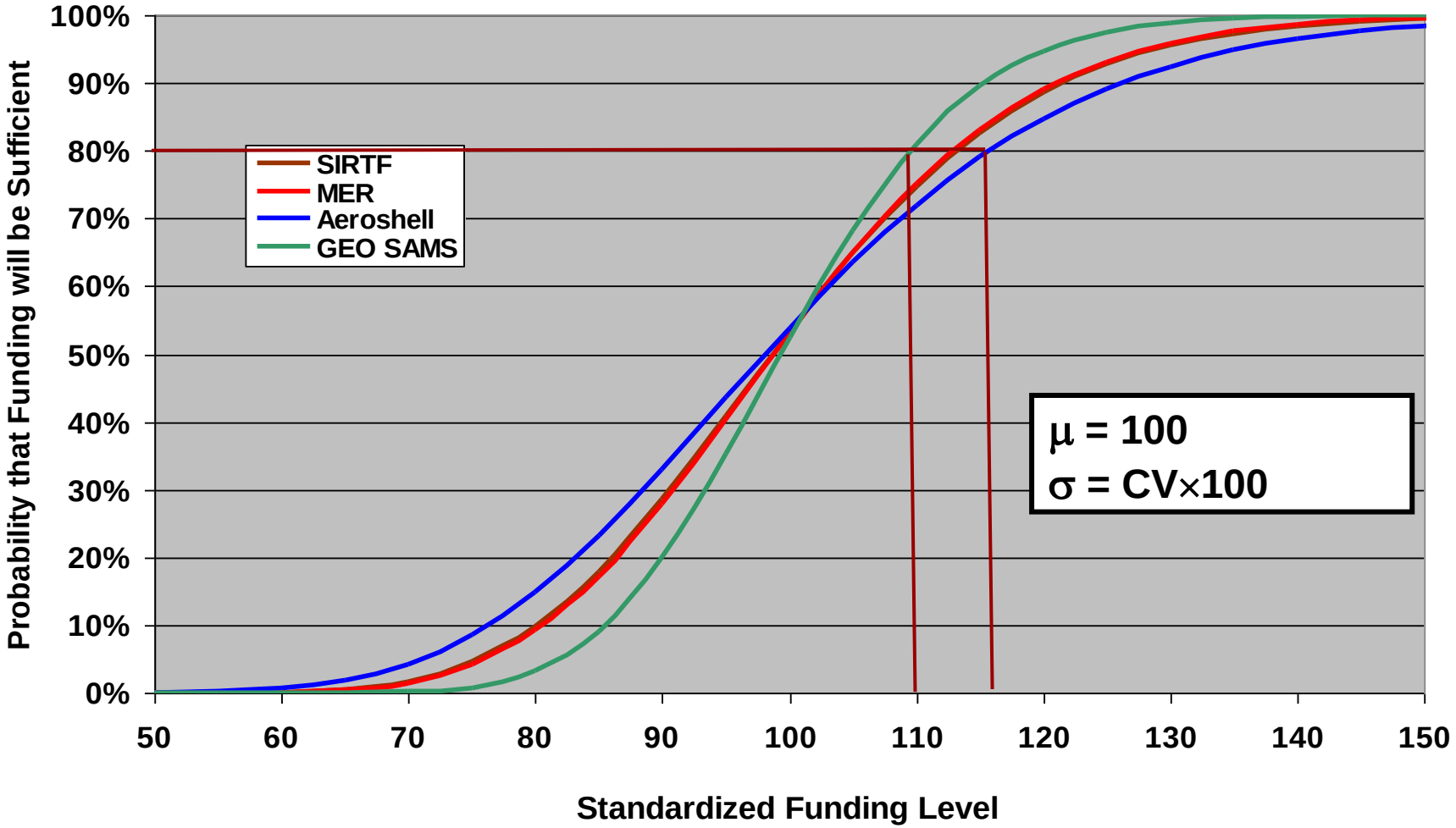
Complicating the Issue - CV Calculation

- **CV = standard deviation ÷ mean**
- **Values without uncertainty increase mean but don't change standard dev**
  - They must be deducted from mean value before performing calculation
- **For example**



  - Mean $1,167M ÷ standard deviation $212M = **18% CV**
  - However, project has $200M of sunk cost, so;
    - » Mean $1,167M – Sunk $200M = Mean $967M
  - Mean $967M ÷ standard deviation $212M = **22% CV – Correct value**
    - » **UFE will have same effect if not properly handled by model**

NASA S-Curves in "Standardized Lognormal"



Source The Meaning of S-Curves 2007 Dr. Book

Using the formula Mean – 80% ÷ Mean = ~CV values of 10% to 18%
Data suggests published CV values are not valid at PDR

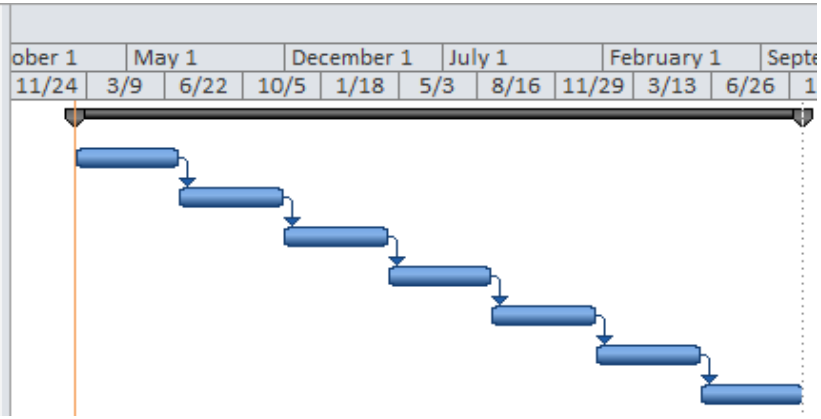
Summation vs Network Models

- **Cost models are pure summation**
  - Everything adds

	WBS/CES Description	Point Estimate	Equation / Throughput
1	*My Program Estimate		
2	Serial (CV=0.2)	700.000 *	
3	Item 1	100.000 *	100
4	Item 2	100.000 *	100
5	Item 3	100.000 *	100
6	Item 4	100.000 *	100
7	Item 5	100.000 *	100
8	Item 6	100.000 *	100
9	Item 7	100.000 *	100

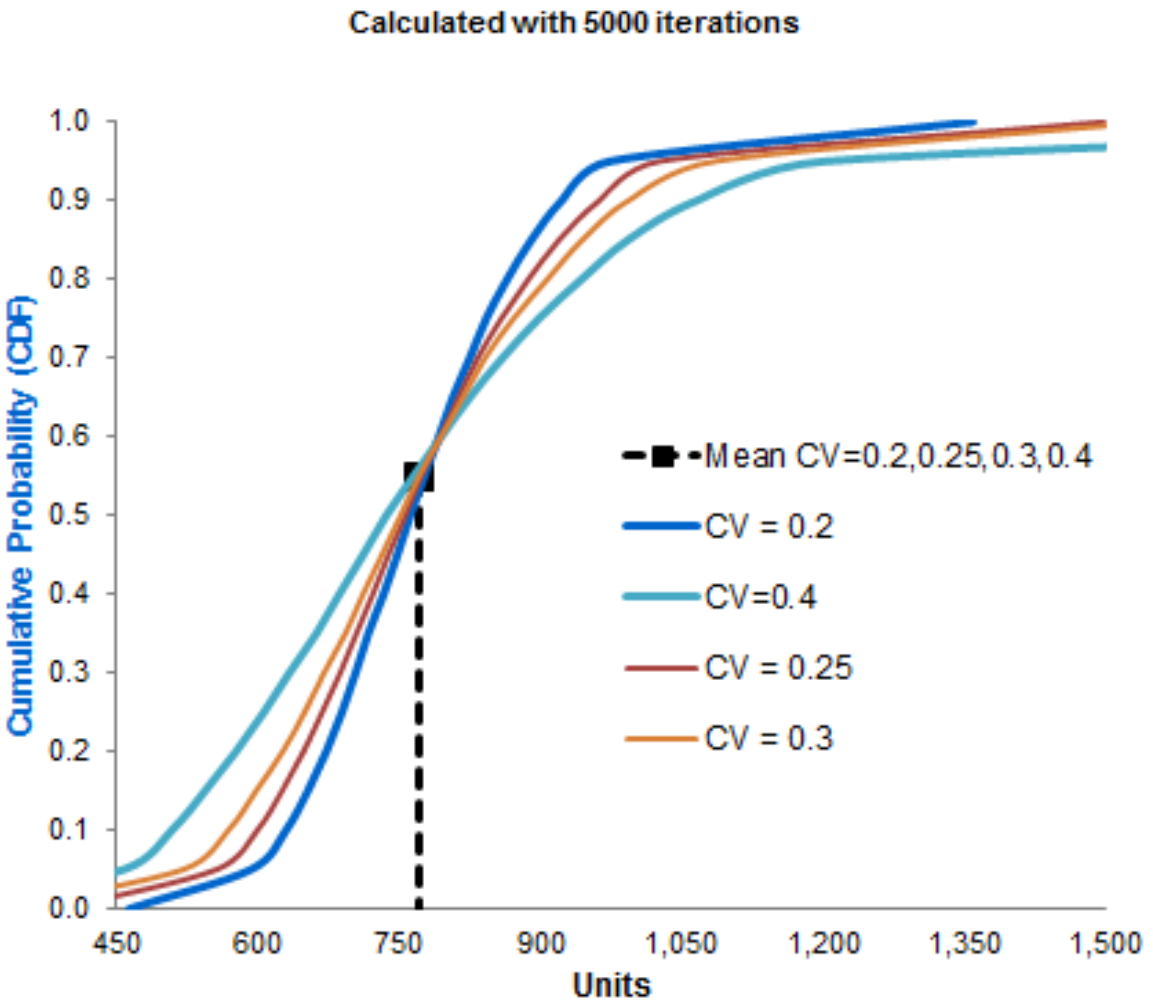
- **Schedule models are networks**
  - Logic drives how item are summed,
  - Max value of predecessors basis for addition
  - Fully serial schedule behaves like summation cost model

Name	Duration
Total Serial (CV=0.2)	700 days
Item 1	100 days
Item 2	100 days
Item 3	100 days
Item 4	100 days
Item 5	100 days
Item 6	100 days
Item 7	100 days



Effect of Correlation Changes to Summation Models

	Mean	Std Dev
CV = 0.2	770.0	116.2
CV = 0.25	770.0	144.5
CV = 0.3	770.0	172.8
CV = 0.4	770.1	230.2

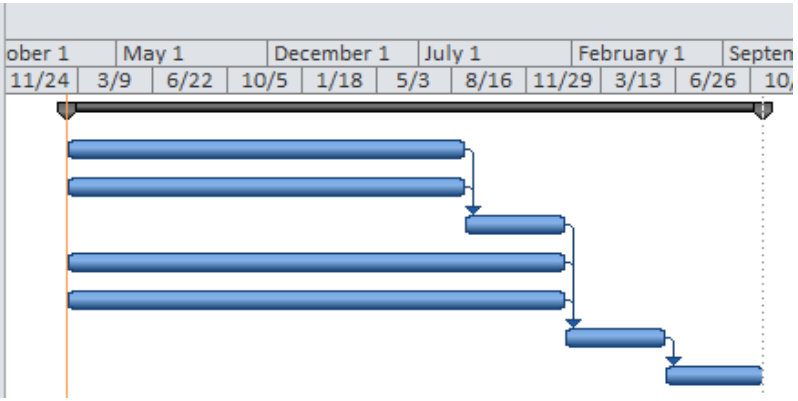


In Summation (Cost) Models, Mean stays steady as Uncertainty Increases
Rotates Around Mean

Network Models Have Complex Behavior

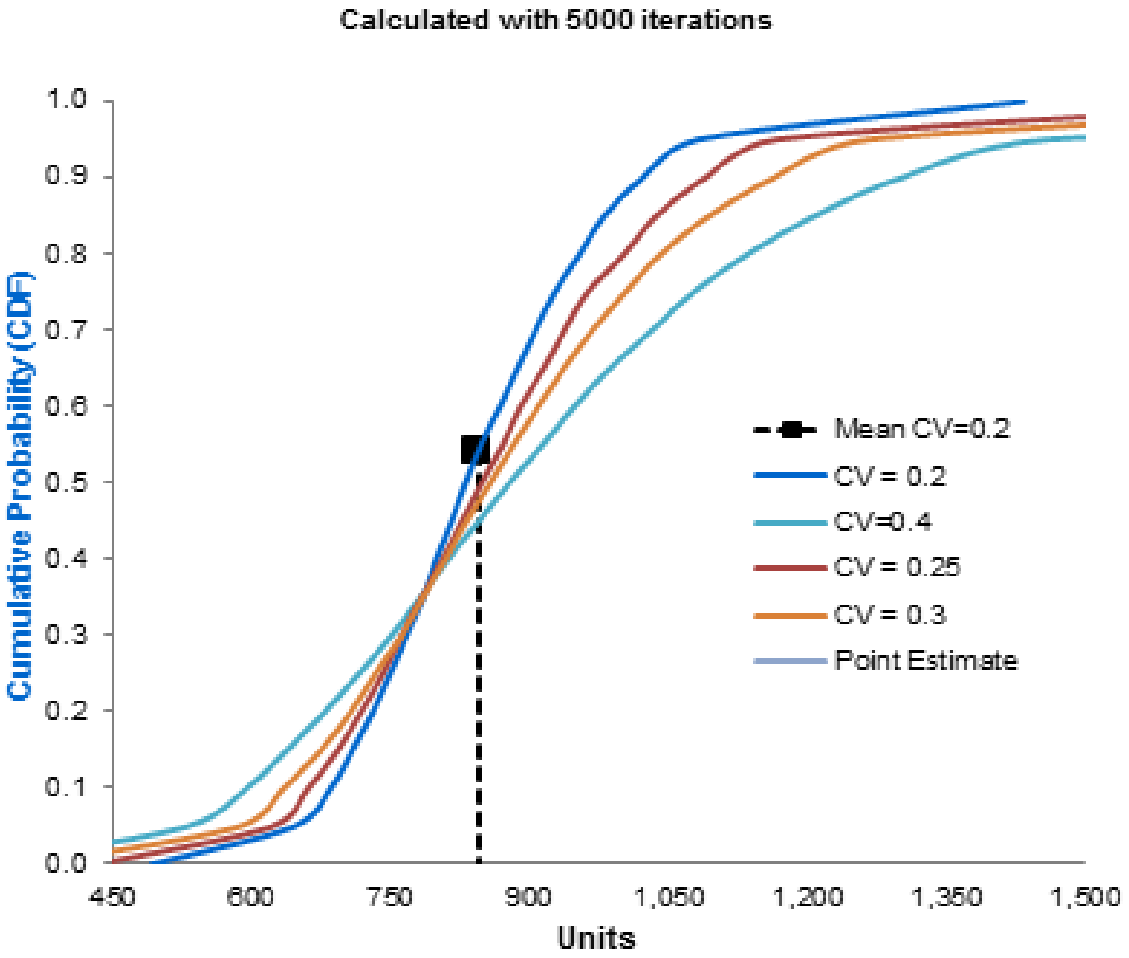
- Total (duration) is sum of longest path
- Parallel paths complicate calculations
- Probabilistic results have small variance on low end and wide variance on high end
- Descriptive statistics (e.g., mean, CV) don't behave similarly to summation models
- Due to merge bias, parallel tasks in schedule will cause deterministic schedule to be at low confidence level

Name	Duration	Start	Finish	redecessor	Successors
Total Serial (CV=0.2)	**700 days**	**Fri 2/21/14**	**Thu 10/27/16**		
Item 1	400 days	Fri 2/21/14	Thu 9/3/15		4
Item 2	400 days	Fri 2/21/14	Thu 9/3/15		4
Item 3	100 days	Fri 9/4/15	Thu 1/21/16	2,3	7
Item 4	500 days	Fri 2/21/14	Thu 1/21/16		7
Item 5	500 days	Fri 2/21/14	Thu 1/21/16		7
Item 6	100 days	Fri 1/22/16	Thu 6/9/16	6,5,4	8
Item 7	100 days	Fri 6/10/16	Thu 10/27/16	7	



Effect of Correlation Changes to Network Models

	Mean	Std Dev
CV = 0.2	844.7	134.5
CV = 0.25	864.4	171.4
CV = 0.3	882.5	210.3
CV = 0.4	921.5	291.6



- **Schedule models behave differently**
  - Increasing uncertainty causes mean shift, instead of being constant
  - S-Curve rotation occurs below mean
  - Schedule model S-Curves have
    - » less variance on low end
    - » more variance on high end
  - CV alone does not inform variance (uncertainty) – must consider mean shift

In Network (Schedule) Models, Mean shifts as Uncertainty Increases Rotation Occurs Below the Mean

Schedule Models Produce Misleading CVs

- **Cost models are fundamentally different than schedule models**
  - Summation vs. logic networks
  - Summary costs are sums, summary schedule durations impacted by merge bias because of parallelism
  - Effects of increasing dispersion of input parameters in general:

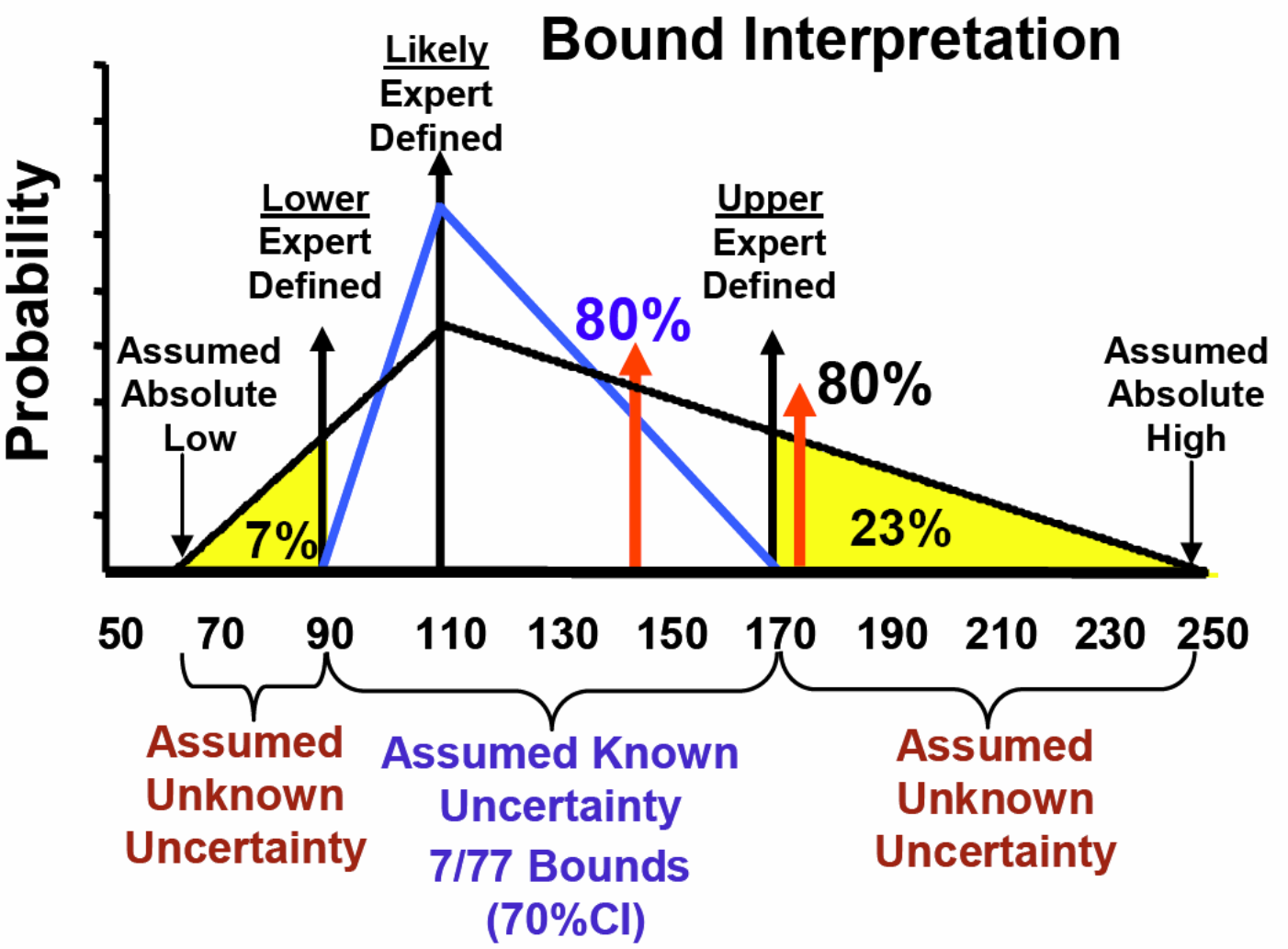
	Cost Model Output	Schedule Model Output
Mean	Stays constant	Shifts higher
Upper Bound	Grows due to high end of dispersion	Grows due to high end of dispersion
Lower bound	Reduces due to low end of dispersion	Limited reduction due to merge bias: Worst-case dominates result
CV	Good metric for dispersion	Noisy metric for dispersion – schedule result dispersion naturally restricted, but has mean shift instead

Mean shift more applicable metric than CV for schedules

BACKUP

Bounds Usually Set by Subject Matter Inputs

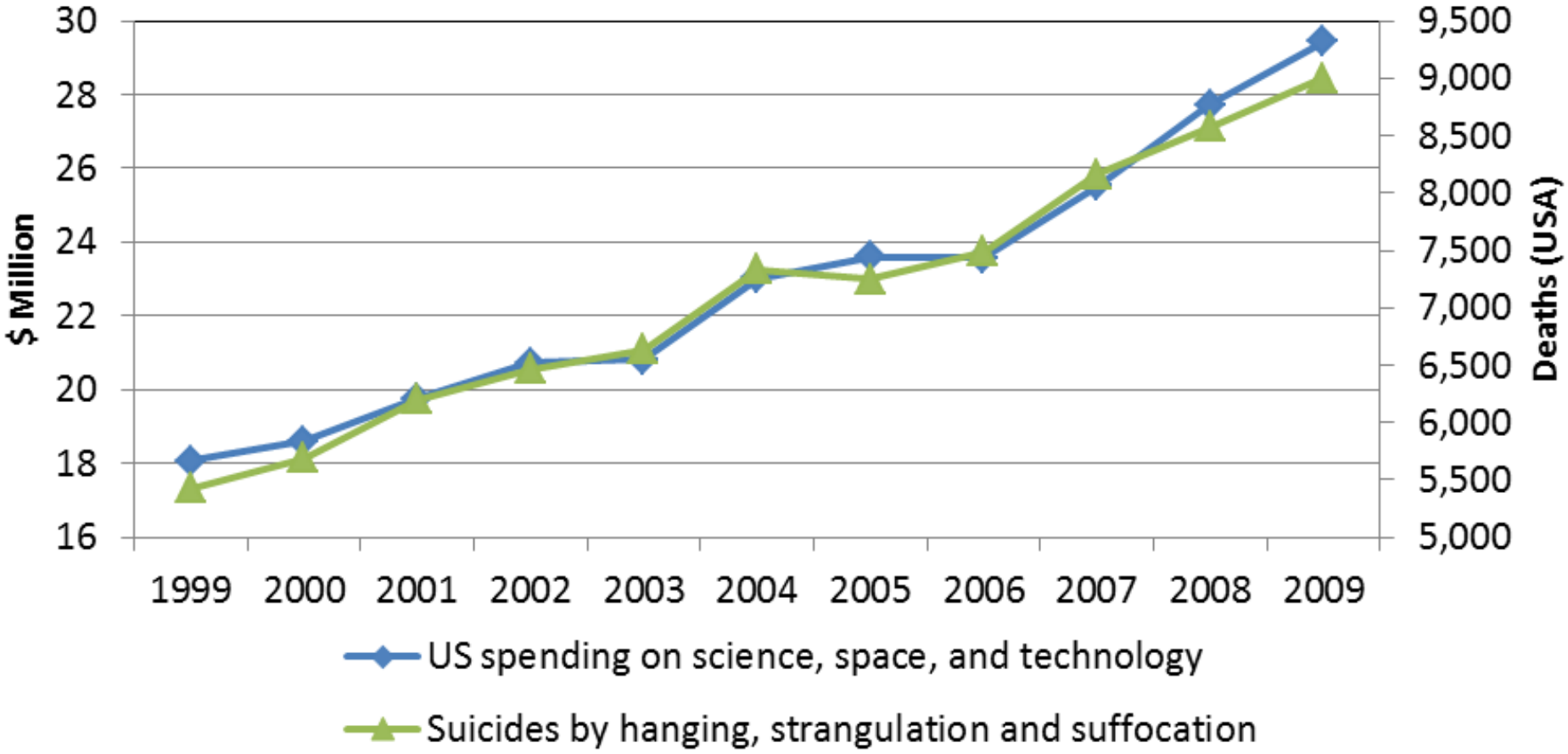
Bounds should usually be wider than they are set



Graphic from Air Force Cost Analysis Handbook

Correlation

- **NASA's budget must be cut to save lives!**
  - We are sure this will help since measured correlation is 0.992

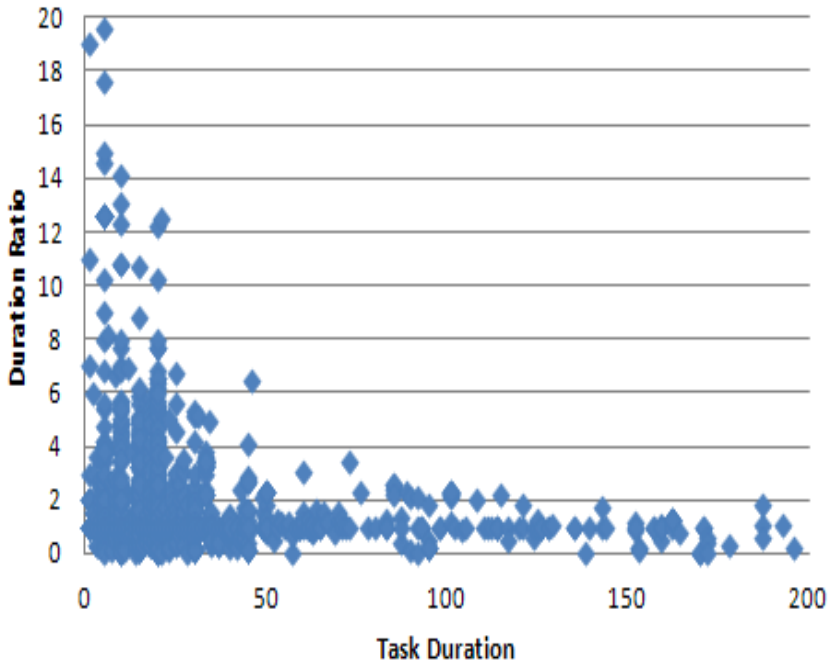


Correlation is not causation!

Source http://www.tylervigen.com/view_correlation?id=1597

Task Duration Vs Duration Ratio

- Relationship between task duration and duration ratio:
  - One would think that there might be a relationship between task duration and duration ratio because intuition suggests that it is more probable to overrun task of 1 day by 500% (to 5 days) than with tasks of 100 days (to 500 days).
  - Scattered plot between these two entities does seem to confirm a non-linear dependence. For example, when consider duration over 100 days, duration ratio is bounded by 0-2, as versus 0-20 for duration less than 100 days.
  - Correlation analysis showed that correlation coefficient is about -.065, which means that there is no linear dependence between these two entities.
  - Correlation coefficient is a poor metrics for non-linear dependence



- Analysis suggests that we may want to segregate uncertainty bounds by task duration range

Fred Kuo 2012 Developing Duration Uncertainty

Published Standards

American Society for Testing and Materials

ASTM E2516-06 Uncertainty

	Primary Characteristic	Secondary Characteristic	
	LEVEL OF PROJECT DEFINITION	ACCURACY RANGE	
ESTIMATE CLASS	Expressed as % of complete definition	Process Industry	Building and General Construction Industry
5	0% to 2%	-20% to -50% +30% to +100%	-20% to -30% +30% to +50%
4	1% to 15%	-15% to -30% +20% to +50%	-10% to -20% +20% to +30%
3	10% to 40%	-10% to -20% +10% to +30%	-5% to -15% +10% to +20%
2	30% to 70%	-5% to -15% +5% to +20%	-5% to -10% +5% to +15%
1	50% to 100%	-3% to -10% +3% to +15%	-3% to -5% +3% to +10%

Maturity Range

- http://www.astm.org/ABOUT/overview.html

Range Min 90%, Max 120%

Published Standards

AACE Recommended Practice 18R-97 Uncertainty

Association for the Advancement of Cost Engineering International

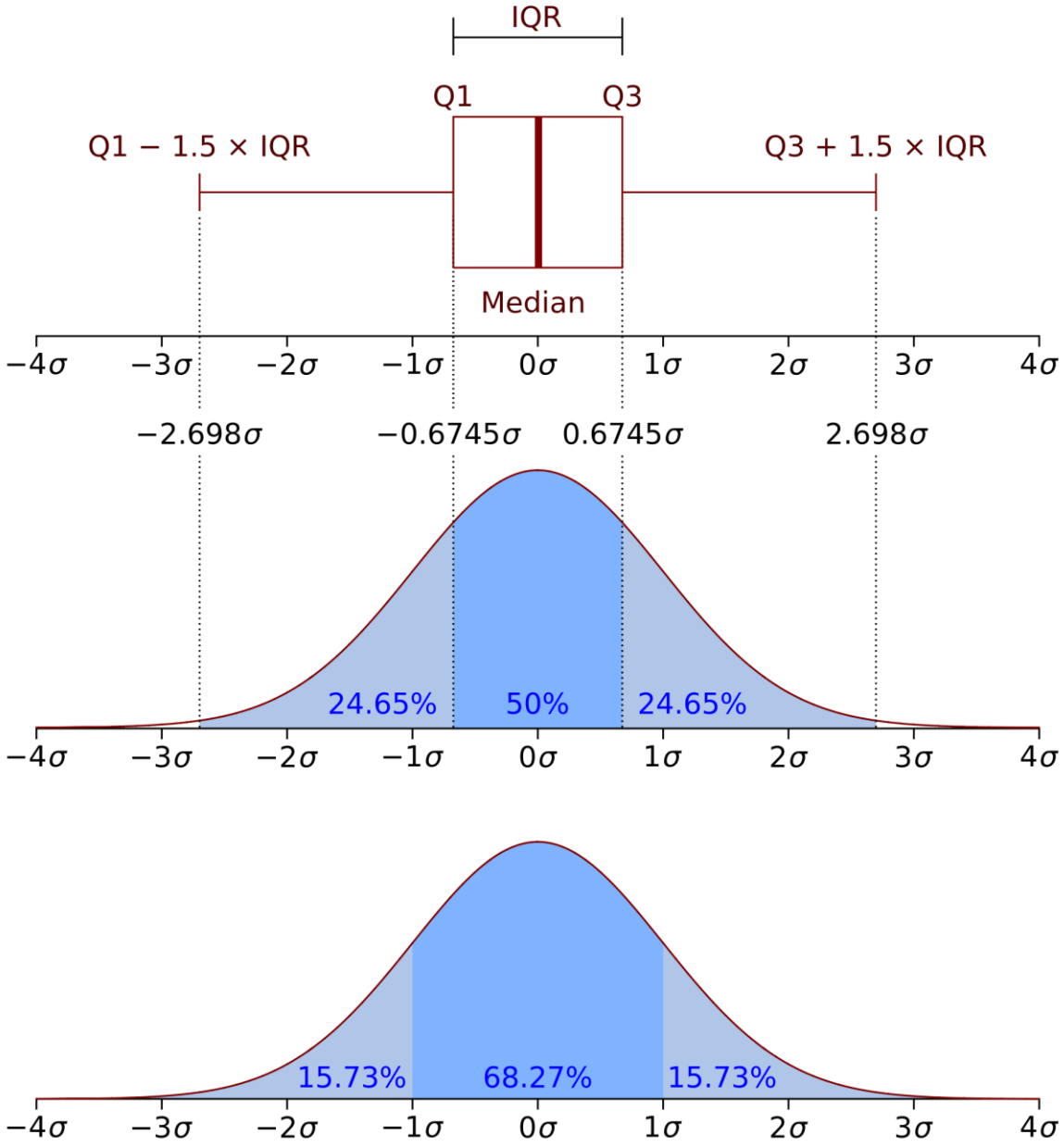
	Primary Characteristic	*Secondary Characteristic*			
ESTIMATE CLASS	**LEVEL OF PROJECT DEFINITION** Expressed as % of complete definition	**END USAGE** Typical purpose of estimate	**METHODOLOGY** Typical estimating method	**EXPECTED ACCURACY RANGE** Typical variation in low and high ranges [a]	**PREPARATION EFFORT** Typical degree of effort relative to least cost index of 1 [b]
Class 5	0% to 2%	Concept Screening	Capacity Factored, Parametric Models, Judgment, or Analogy	L: -20% to -50% H: +30% to +100%	1
Class 4	1% to 15%	Study or Feasibility	Equipment Factored or Parametric Models	L: -15% to -30% H: +20% to +50%	2 to 4
Class 3	10% to 40%	Budget, Authorization, or Control	Semi-Detailed Unit Costs with Assembly Level Line Items	L: -10% to -20% H: +10% to +30%	3 to 10
Class 2	30% to 70%	Control or Bid/ Tender	Detailed Unit Cost with Forced Detailed Take-Off	L: -5% to -15% H: +5% to +20%	4 to 20
Class 1	50% to 100%	Check Estimate or Bid/Tender	Detailed Unit Cost with Detailed Take-Off	L: -3% to -10% H: +3% to +15%	5 to 100

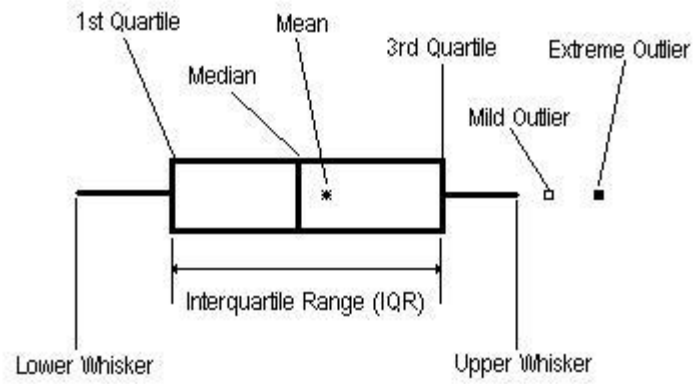
Maturity Range

- http://www.aacei.org/

Range Min 90%, Max 120%

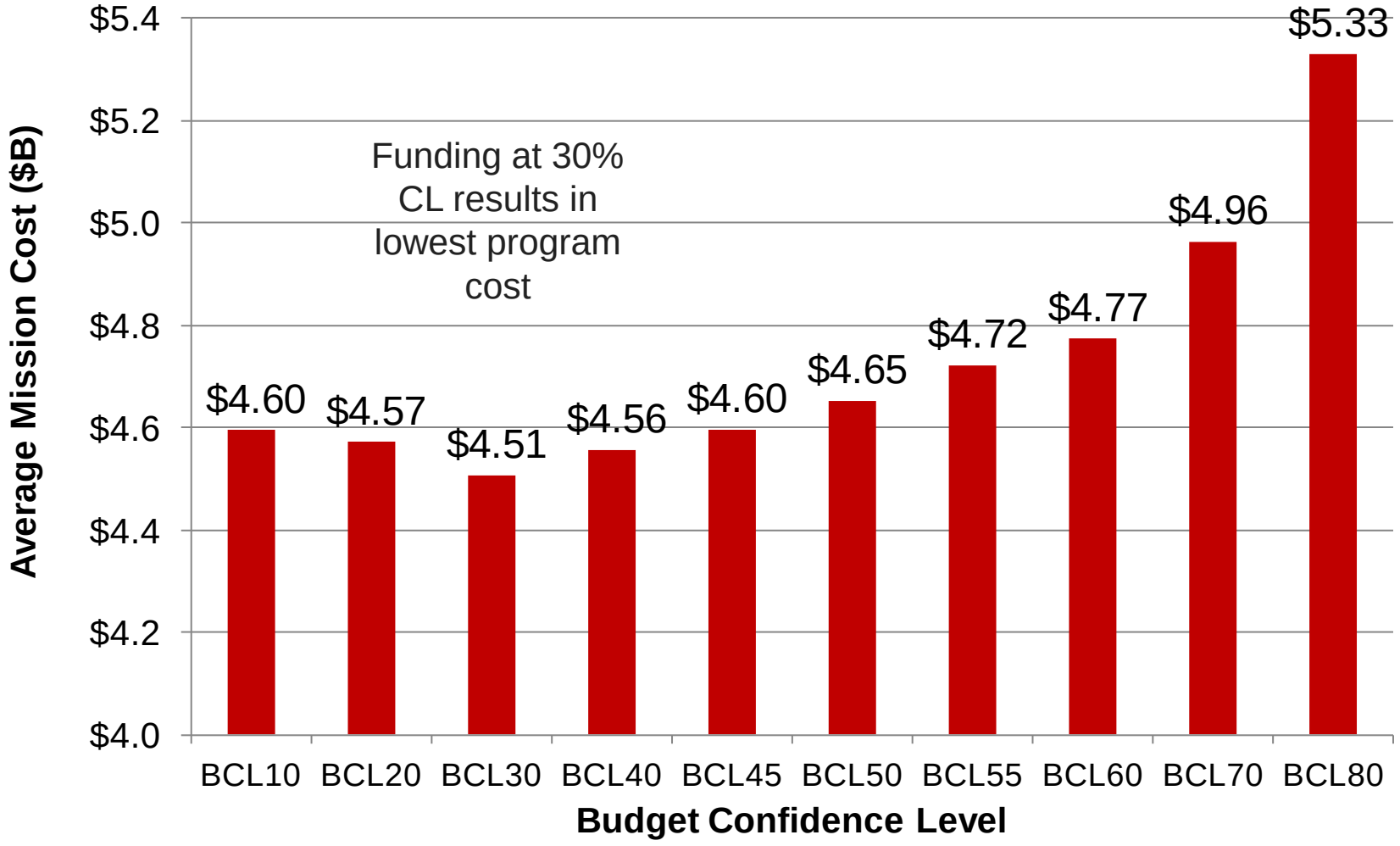
Using Box Plot Data





Whiskers extend to the furthest observations that are no more than 1.5 IQR from the edges of the box. Mild outliers are observations between 1.5 IQR and 3 IQR from the edges of the box. Extreme outliers are greater than 3 IQR from the edges of the box.

Effect of BCL – Average Cost



Results are Similar for BCL ≤ 50

Definitions

Courtesy of Charles Hunt HQ CAD

- **For the purposes of JCL, it is important to distinguish between discrete risk events and general uncertainty**
  - *Risk* - event not in project's baseline plan that is an undesirable outcome (discrete risk).
    - » Definition is similar to one that one would see in a risk matrix. Characterized by a probability of occurring and an expected impact if event did occur.
    - » Risks can also be opportunities if the outcome of the event is a positive outcome
  - *Uncertainty* - indefiniteness about project's plan. Represents fundamental inability to perfectly predict outcome of future events.
- **We don't know the answer**
  - In general, NASA projects don't know how to set the boundaries or distributions of "natural" variation of cost and schedules in project development due to lack of data.
  - Further, projects having difficulty distinguishing epistemic (discrete risks) in their risk registers from those that are included in natural uncertainty
- **Agency is currently researching this and has funded a research project on subject**
  - Four different contractors working on this project
  - Task goal is to create defendable uncertainty guidance for both cost and schedule inputs for projects and programs to use in their JCL analysis

Interim study results expected early December

How Much Uncertainty?

- **Everyone agrees that uncertainty should be included in a JCL**
  - However, no one knows ***how much*** uncertainty should be used
  - Examining historical data is one way to obtain uncertainty bounds
    - However, historical data includes actualized risk impacts on cost and schedule
    - Further cost uncertainty is often driven by schedule uncertainty
    - So how is uncertainty accurately included without double dipping?
    - *"-- it is virtually impossible to get historical data from a completed project at almost any level of detail except possibly the most aggregate." (Rand*)*
- **Questions?**
  - ***So how much uncertainty should be included?***
  - *Should the same uncertainty be applied to everything or should different categories be defined, each with different uncertainty bounds?*
    - LOE
      - FTE
      - WYE
    - ODC
    - GSE
    - CoF

*Rand, Impossible Certainty: Cost Risk Analysis for Air Force Systems, 2006

Uncertainty Defined

- **Uncertainty:** is the indefiniteness about the outcome of a situation. Every cost estimate at every WBS level has an uncertainty due to the following elements:

1. Error -

- Human Error - Incorrect assumptions, bad decisions, just plain mistakes, People make errors - always have, always will!
- Data error - data not valid for conditions under investigation, wrong data
- Model error - People make models

2. Inaccuracy -

- Even when everything is "correct" it is not possible to accurately predict the future because there are an infinite number of parameters that must be considered
- Predictions, whether from expert opinion or historical data will always be inaccurate even under the best of conditions

3. Bias -

- Bias - Sometimes inaccuracy (see #2) manifests itself as bias which can be determined based on historical data - e.g. people tend to underestimate maximum cost
- Human bias -
  - People, generally tend to be optimistic about things which they control: they will do it better than others therefore it will cost less and not take as long
  - People are also subject to pressures from "on-high" - e.g. it will be finished in 3 months, or it will not exceed $200M because the boss said so!

4. Inadequate knowledge -

- Sometimes there just isn't any information, all you can do is guess

Risks & Uncertainty

- **Risk - For the purpose of JCL, risk is the probability that an event will occur that has an adverse impact on program**
  - Categories of Risk -
    - i. Known Unknowns: Events that are likely to occur based on historical data
      - Technical Risks – Captured in ARM
        - Candidate technical risks – Captured in ARM
      - Cost Risks – Captured in Leans & Threats list
    - ii. Uncertainty: is the indefiniteness about the outcome of a situation.
      - Every cost estimate, at every WBS level, has uncertainty
    - iii. Unknown Unknown's*
      - Force Majeure: Events that are difficult to predict
        - Acts of nature - hurricanes, earthquakes, tsunamis, etc.
        - Program cancelation, rebase-lining, etc.
      - Events outside the realm of experience of the program
    - i. Excluded per ESD Direction
      - MPCV & SLS – Deliveries of components occur as planned

    Included in JCL
    Excluded from JCL

*Air Force Cost Risk and Uncertainty Analysis Handbook, 2007 excluding “uncontrollable events that can impact the cost of the program”