Exploring Uncertainty and Risk

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Agenda

- Is it ‘Uncertainty’ or ‘Risk’?
- Types of Uncertainty – what we know and what we don’t
  - Known Unknowns
  - Unknown Unknowns
- Compounding of Uncertainties
- Frequency (Likelihood or Probability) and Consequence
- A Simple Way to Quantify Uncertainty
- Contingency and Management Reserves
- Bias
- Summary
- Q&A
- Backup

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Is it Uncertainty or Risk?

- The terms ‘Uncertainty’ and ‘Risk’ are frequently used interchangeably
- ‘Risk’ is the often and commonly used term
  - *<u>However</u>*, it is often inappropriately used in conversation
- ‘Uncertainty’ is more precise in referring to program unknowns
- Uncertainty can impact a baseline assessment in different ways:
  - Risk has a negative or pessimistic implication in terms of outcome
  - However, unspecified factors may also result in a positive or optimistic outcome
  - The net result is based on the interplay between the unknowns of the project
  - (‘Optimism’ is conceived as optimal and efficient; whereas ‘Pessimism’ conveys status quo or repeating the same errors)

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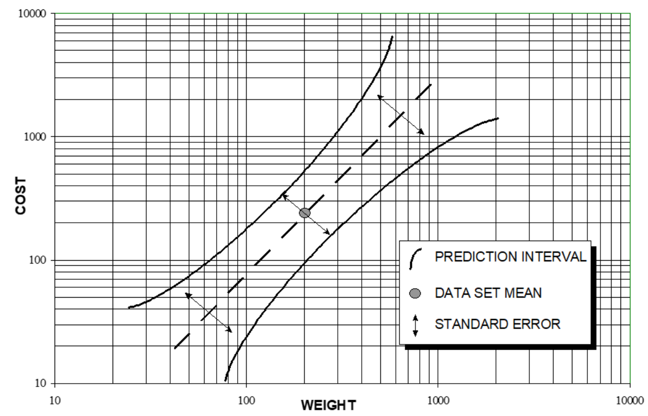
Types of Uncertainty – what do we know and what we don't (1 of 5)

- Events creating uncertainty are frequently referred to as being of two types:
  - "Known Unknowns"
  - "Unknown Unknowns"
- Both should be considered, but often aren't
- "It's always more uncertain than you think, even taking into account that it is more uncertain than you think" – Dr. Smart

Types of Uncertainty – what do we know and what we don't (2 of 5)

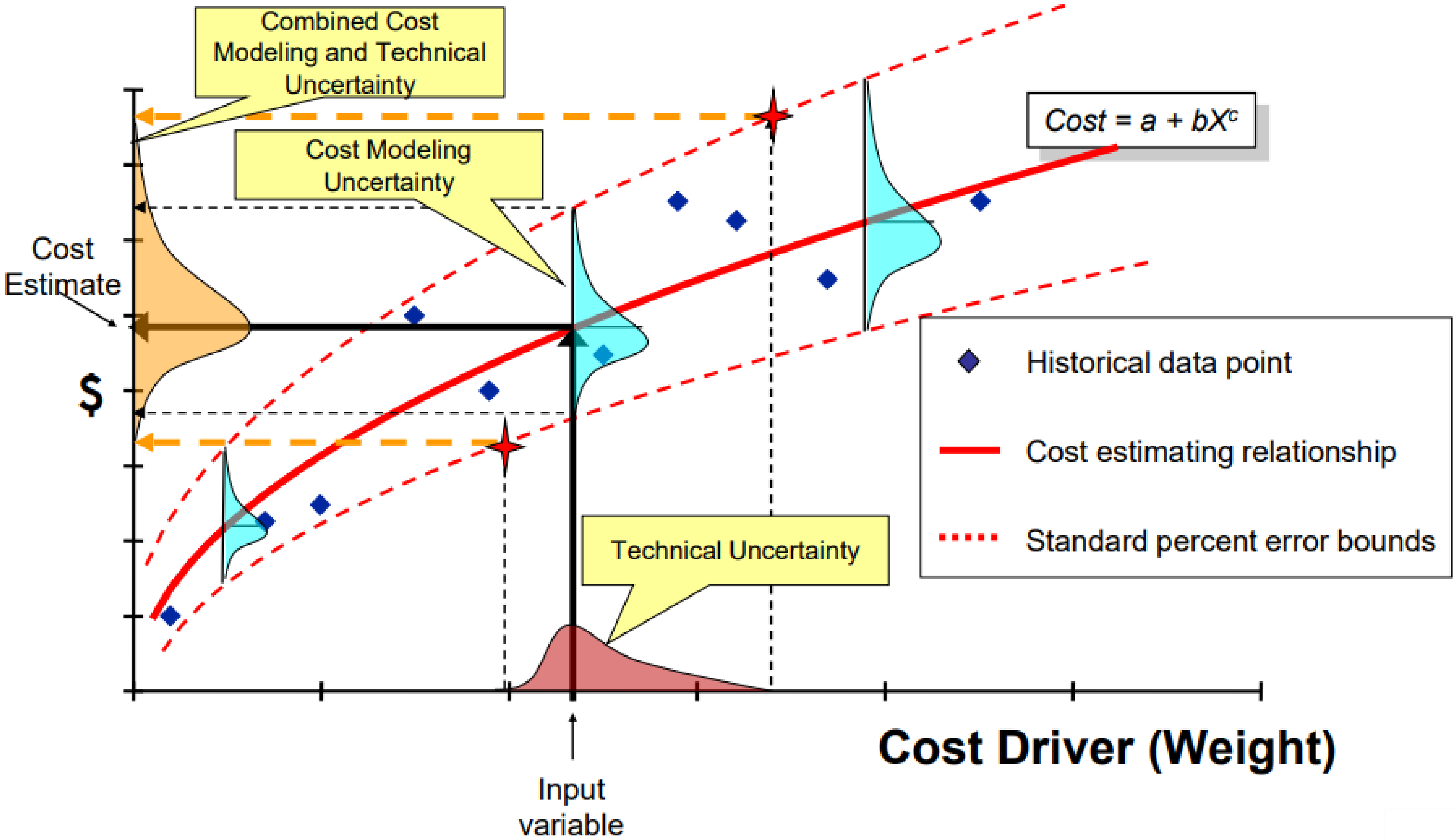
"Known Unknowns"

- Definition:
  - Events and factors that we know are uncertain and are likely to change
- Some examples:
  - Technical
    - Weight
    - Software Lines of Code (SLOC)
    - Number of Workstations
  - Cost Modeling variability in CERs
- Frequently occur, are almost universal
- Are quantitative and are objective
- Are the most addressed issues in performing an uncertainty analysis



Types of Uncertainty – what do we know and what we don't (3 of 5)

"Known Unknowns"



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Types of Uncertainty – what do we know and what we don't (4 of 5)

"Unknown Unknowns"

- Definition:
  - Events and factors that have irregularly impacted programs
- Some examples:
  - Labor strikes or disruptions
  - 'Acts of God' such as hurricanes or earthquakes
  - Pandemics
  - Impacts from other programs (Such as the Challenger disaster)
  - Terrorism
  - Cancelled programs usually aren't in the databases
- Occur infrequently and unpredictably, are almost always negative
- Are difficult to quantify at a detailed level and are subjective (qualitative) in terms of their likelihood and consequence
  - Best addressed in terms of their historical impact
  - Sometimes included in the CER Standard Error Bounds
- Are often overlooked in uncertainty analyses

Types of Uncertainty – what do we know and what we don't (5 of 5)

Compounding of Uncertainties (1 of 3)

- Interactive and multiplicative factors
  - Adding up the pieces from a lower level does not sum to the total uncertainty
  - The uncertainty of each of the WBS or CLIN items, even weighted, does not equal the unknown nature of the whole
  - This is due to the overlapping, interactive, and multiplicative nature of the factors within each of the elements contributing to the overall extent of uncertainty

Compounding of Uncertainties (2 of 3)

- Interactive and multiplicative factors (Cont)

1

EXAMPLE

For the six WBS elements on the right with a mix of triangular and lognormal distributions

2

FOUR LOGNORMAL AND TWO TRIANGULAR DISTRIBUTIONS

The parameters for these distributions are provided in the table on the right

All WBS elements are correlated at 0.6

3

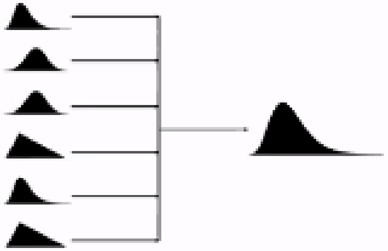
POINT ESTIMATES

The point estimates for each WBS element are $90, $50, $20, $40, $70, $30

The sum of these values is $300

What is the confidence level of the sum of the most likely values?

QUANTITATIVE RISK ANALYIS VS. SUMMING POINT ESTIMATES



WBS Element	Distribution	Mean	S.D.	L	M	H
1	LN	$109	$40			
2	LN	$62	$25			
3	LN	$24	$8			
4	Tri			$40	$40	$120
5	LN	$91	$40			
6	Tri			$30	$30	$120

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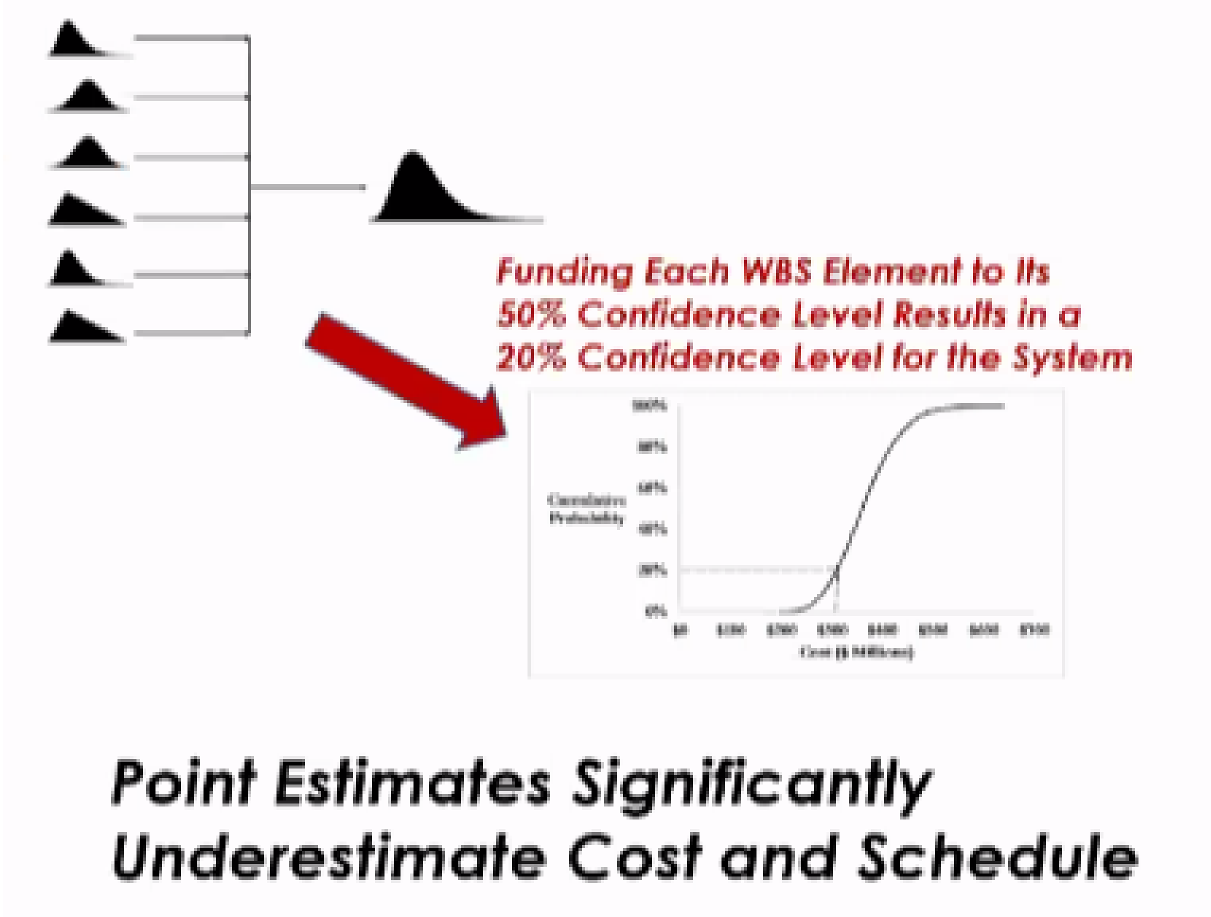
Compounding of Uncertainties (3 of 3)

- Interactive and multiplicative factors (Cont)



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Likelihood (Probability) and Consequence (1 of 3)

RISK: FREQUENCY VS. CONSEQUENCE

TWO DIMENSIONS OF RISK

Dimension 1: Likelihood of Occurrence

The frequency at which events occur is commonly referred to as the likelihood

Frequent event: cost growth and schedule delays in defense programs

Not-so frequent: catastrophic failure of a major system (e.g., Space Shuttle)

Rare: Extreme cost growth, pandemics, major wars

Dimension 2: Consequence

The impact of risks is often referred to as the consequence

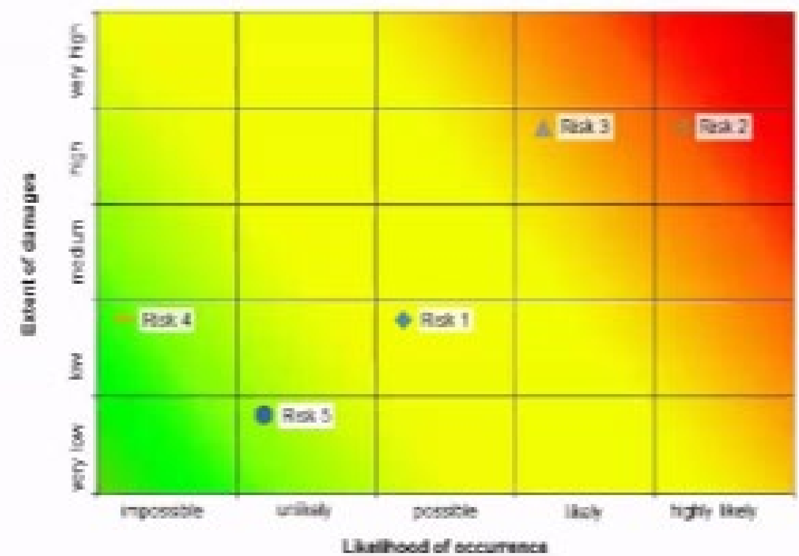
Low consequence: minor technical problem that shuts down a system for a day

High consequence: significant schedule delay that prevents fielding a critical system for years; large number of deaths due to a pandemic

Bias is to Focus on Frequency

Overwhelming tendency is to focus on likelihood rather than consequence

However, consequence is more important than likelihood



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Likelihood (Probability) and Consequence (2 of 3)

THE IMPORTANCE OF CONSEQUENCE

MORE IMPORTANT THAN FREQUENCY

		Actual: Exists	Actual: Does Not Exist
Belief	Exists	Good!	No Consequence
	Does Not Exist	Bad!	No Consequence

PASCAL'S WAGER

The seventeenth century mathematician Blaise Pascal argued that a rational person should bet on God's existence: belief has limited downside but unlimited upside, while unbelief has limited upside but unlimited downside, regardless of likelihood.

ARE YOU FEELING LUCKY, PUNK?

"I know what you're thinking: 'Did he fire six shots or only five?' Well, to tell you the truth, in all this excitement, I've kinda lost track myself. But being this is a .44 Magnum, the most powerful handgun in the world, and would blow your head clean off, you've got to ask yourself one question: 'Do I feel lucky?' Well, do you, punk?" Dirty Harry

STILL OVERLOOKED

Despite its importance, consequence is under weighted

Innate bias to be right

"Probability neglect" term is one example

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Likelihood (Probability) and Consequence (3 of 3)

Probability/ Likelihood		Negligible	Minor	Moderate	Serious	Critical
91% - 99%	Near Certainty					Very High
61% - 90%	Highly Likely				High	
41% - 60%	Likely			Medium		
11% - 40%	Low Likelyhood					
1% - 10%	Not Likely	Low				

Consequence/Impact

Probability/ Likelihood		Negligible	Minor	Moderate	Serious	Critical
91% - 99%	Near Certainty					High
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41% - 60%	Likely			Medium		
11% - 40%	Low Likelyhood					
1% - 10%	Not Likely	Low				

Consequence/Impact

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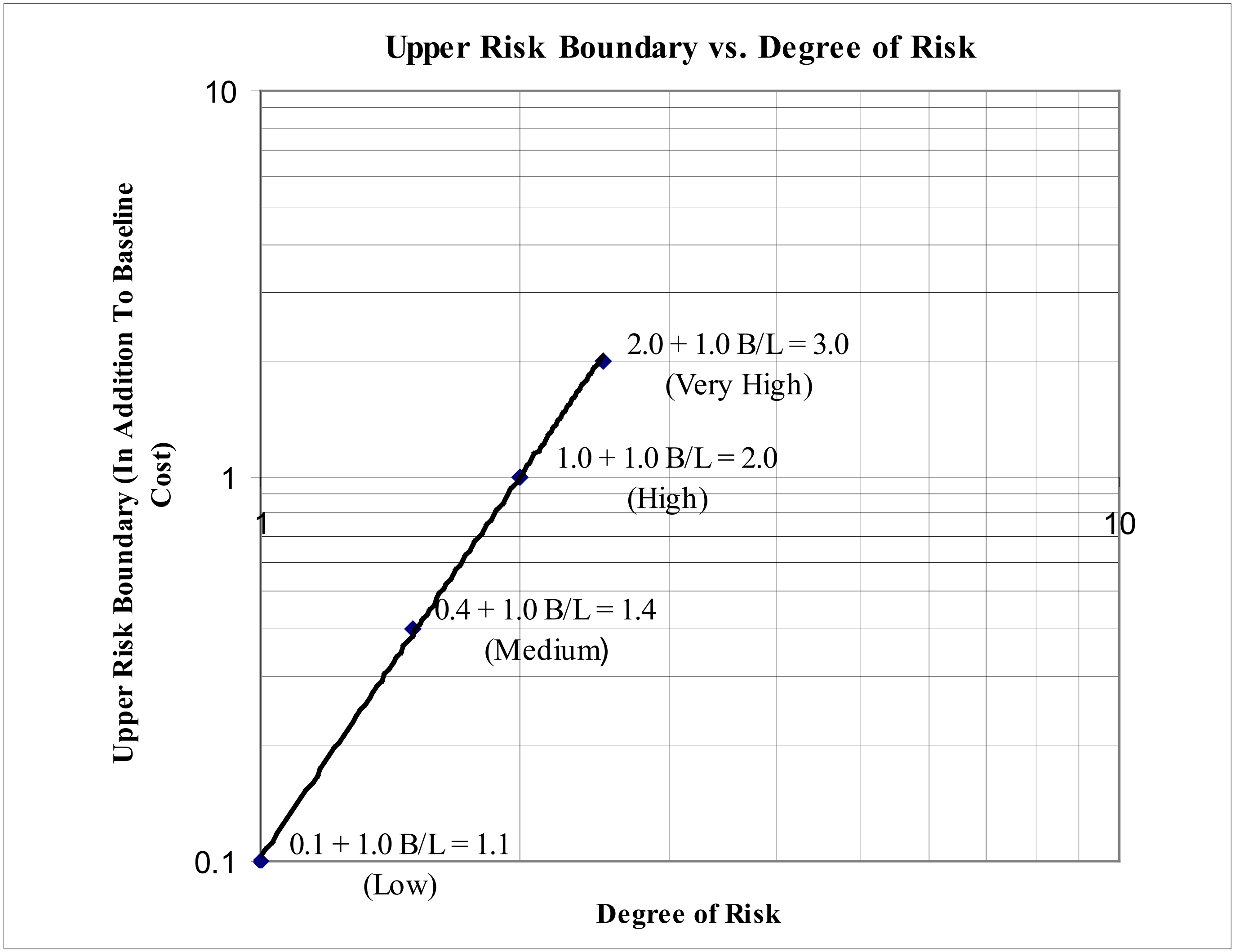
A Simple Way to Quantify Uncertainty (1 of 3)

- Upper boundaries can be exponentially extrapolated from the known and assumed upper distributions (notional or derived from heuristic conventional wisdom)
  - 1.1 for low (adds 10% to cost or resources)
  - 2.0 for high (doubles the cost or resources)

- The remaining upper boundaries of the distributions may be projected from these data points (See log log graph next page)
  - Low ‘risk’ = 1.1
  - Medium ‘risk’ = 1.4
  - High ‘risk’ = 2.0
  - Very high ‘risk’ = 3.0

A Simple Way to Quantify Uncertainty (2 of 3)



A Simple Way to Quantify Uncertainty (3 of 3)

- The resulting quantification of the uncertainty boundary distributions are summarized as:
  - Low uncertainty = .91 to 1.1 (91% to 110%)
  - Medium uncertainty = .91 to 1.4 (91% to 140%)
  - High uncertainty = .91 to 2.0 (91% to 200%)
  - Very high uncertainty = .91 to 3.0 (91% to 300%)
    - Lower boundary calculated as: 1.0/1.1 = .91 or 91%
- There is substantial and significant acceptance of these ranges
  - Results correlate with other studies
  - Findings are collaborated by Selected Acquisition Reports (SARs) data (see Backup)
  - Ranges are accepted and used by the Air Force Cost Analysis Agency (AFCAA)
  - Presented to the Office of the Secretary of Defense Cost Analysis Improvement group (OSD CAIG) without dissent

Contingency and Management Reserve (1 of 2)

- Are often incorrectly added to a cost estimate, proposal, or schedule
  - Primarily as protection against “Unknown Unknowns”
  - Sometimes called **“Undefined”** Risks
  - Interject subjectivity to an objective analysis

- These arbitrary contingencies are not allowable in Proposal Basis of Estimates (BOEs)
  - According to Federal Acquisition Regulations (FAR) 31.205-7

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Contingency and Management Reserve (2 of 2)

- How the Government approaches budgets, awards, and funding
  - The DoD will develop an Independent Cost Estimate (ICE) with uncertainty boundaries on major programs
  - The mean of this estimate establishes the requested project funding in the Presidents Budget (PB)
  - The contract is typically awarded at a lower confidence level (20% being typical)
    - This is especially the case with FFP type bids, as the contractor assumes the “risk” or, conversely, the reward should they perform in an innovative and efficient fashion
  - The difference between the PB and Award Value that the contracting agency retains is used to fund occurrences such as “Unknown Unknowns”, scope changes, ECPs, schedule delays, and/or overruns on a CP type contract
- “Withholds”
  - Are a published factor added bottom line to the ICE as a reserve against cutbacks resulting from unanticipated military actions, acts of congress, and other such activities
  - The percentage is dependent on the service, program type, and project phase

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Bias (1 of 2)

- Government Accountability Office (GAO) Report
  - “For the most part, **cost growth has not been caused by poor cost estimating** … **At times, estimates that were more realistic … were available** … **but they were not used**“.
- GAO testimony
  - ”… we found that **only 15 percent of the programs we assessed began development having demonstrated all their technologies mature**”.
- Defense Acquisition University (DAU)
  - “**Budgets may be** deliberately overstated or **deliberately understated** by a manager’s supervisor to reduce possible over consumption of resources.”
- “The Elusive Challenge of Estimating Costs”
  - “The GAO has found repeatedly … that **programs produce optimistic estimates in order to gain approval for funding**.”
- Another influence leading to over optimism is the need to win or continue the job by contractors and program managers

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Bias (2 of 2)
GIGO – It's a serious issue!

- Garbage-in and Garbage-out
  - Powerful Tools have the ability to provide great and insightful results
  - But be careful and make certain that you and your audience understand the domain/range of inputs by variable coupled with the uncertainty, risk, and assumptions, as well as any resultant relationships/correlation between variables that are driving the aggregated results.
  - Otherwise, the results are near meaningless, misleading, and potentially dangerous…

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Summary (Synopsis): Uncertainty, Risk, and Contingency (1 of 2)

Uncertainty:

In order to discuss Risk and Contingency, it is best to review "Uncertainty", as it relates to the other concepts. Almost every estimate, proposal, business transaction, scientific experiment and the like embodies elements of uncertainty. Uncertainty can impact an expected outcome in a positive, negative, or neutral fashion. There are usually multiple elements of uncertainty, both 'Known Unknowns', and 'Unknown Unknowns.' A 'Known Unknown' relates to conditions or factors that are recognized as being variables which may influence a result; whereas an 'Unknown Unknown' is a somewhat unusual occurrence (or occurrences) that cannot be predicted or is not recognized as a probable condition, but which could definitely alter the anticipated consequence. Risk is associated with 'Known Unknowns', and Contingencies most often with 'Unknown Unknowns.'

Risk:

Risk, due to semantics, is often thought of as having a negative impact, although it could also have a positive outcome. It is associated with known assumptions or factors that may not occur as predicted. Within a cost model, for instance, a recognized element of variability usually has a range of possibilities, both plus and minus from the baseline. Rates, Cost Estimating Relationships (CERs), Probable Weights, Software Lines of Code (SLOC), Schedules, and the like are some typical items that are frequently known to be inexact. Since it is acknowledged that the actual measurements of these items could likely be other than expected, a (ideally) objective or statistical measure of changeability can be applied separately to these constituents to aid when making decisions. These possible outcomes can be associated with different levels of confidence, both individually and collectively.

FAR 31.205-7

"Defined" vs "Undefined"

Contingency:

Contingency is usually added to a cost estimate, proposal, or schedule as a hedge against primarily 'Unknown Unknowns', or infrequent, uncommon, or unpredictable occurrences that cannot be known to impact a project with any certainty or in a determinable manner. Terrorist actions, inclement weather, labor strikes, airline accidents involving key personnel, and such events are usually not included in a bid, and when they are it is usually through the application of a subjective summary contingency factor. An example of such a factor is that when the Department of Defense (DoD) develops a budget, dollars (derived from a factor dependent on the service, program type, and project phase) are added to the budget. These are often referred to as 'withholds', although they are a contingency, and are needed in case of possible budget cutbacks resulting from unanticipated military action(s), acts of congress, and other such activities. Generally, subjective or arbitrary contingencies are not allowable in Basis of Estimates (BOEs) per Federal Acquisition Regulations (FARs).

Summary: Uncertainty, Risk, and Contingency (2 of 2)

- These are just a few common issues that often need attention or clarification
- There is much, much more!
- I am here to help talk over strategy, implementation, formula construction and outputs, etc.

Discussion and Questions?

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Exploring Uncertainty and Risk: Backup

April 2023

Objective

- To provide the audience with an enhanced understanding of uncertainty, general concepts, its application, and common issues.
- Benefit = You'll gain a fundamental working knowledge, but you will not become an 'expert'!

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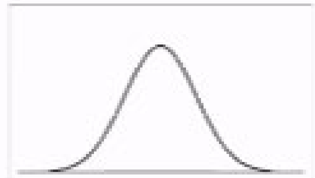
Uncertainty is a Shape

FOUR COMMONLY USED PROBABILITY DISTRIBUTIONS

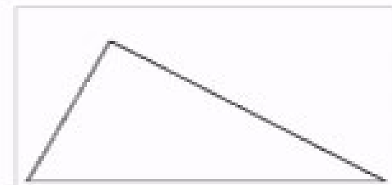
1 GAUSSIAN

The "Normal" distribution is commonly used but not applicable to cost and schedule (skew; fat tails)



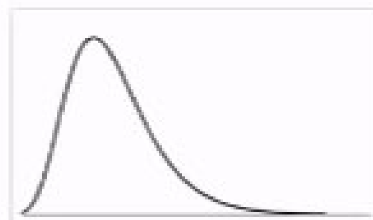
2 TRIANGULAR

Simple, but too simple
Has no tail
Can only model limited range



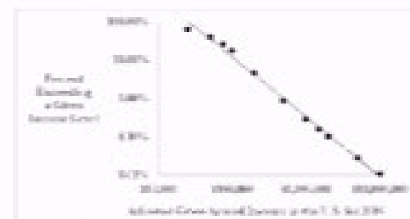
3 LOGNORMAL

Can model skew
Can model relatively fat tails
In-between thin tails and fat tails



4 PARETO

80/20 Rule
Used to model extreme risks
80% of outcomes are due to 20% of causes



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Ways To Approach Uncertainty (1 of 2)

- Bottom Up
  - Detailed or ‘Build-up’ approach
  - Add up all the factors and angles that can be considered
  - Tends to be subjective
  - Likelihood of omissions
  - Chance of double counting
  - Can’t see the forest for the trees
  - Doesn’t address interactive and multiplicative factors

Ways To Approach Uncertainty (2 of 2)

- Top Down
  - Addresses variability from an overarching holistic viewpoint
  - Looks at the total history rather than individual pieces
  - Statistically based - Objectively accounts for variation
  - Minimizes omissions and double counting
  - Has a greater tendency to include “Unknown unknowns”
  - Includes interactive and multiplicative factors
  - More accurate at representing variation around point estimates
  - Challenge: Requires significant amount of data

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S Curves and Confidence Levels (1 of 3)

- S Curve
  - Graphically represents the correlation between the cost or hours and the probability of achieving a particular outcome
  - Typically has cost or hours presented on the X axis, and probability (aka confidence level) on the Y axis

- Confidence Level (CL)
  - Exhibits the percent probability of achieving a particular outcome
    - A 20% CL means that there is a 20% chance executing a project for a particular number of dollars or hours, or for fewer resource expenditures
    - An 80% CL means a higher probability (80%) exits for accomplishing a task for a particular number of dollars or hours, or for fewer
    - A 50% CL indicates there is an equal chance of the outcome being greater or less
      - The mean is not necessarily the same as the 50% CL

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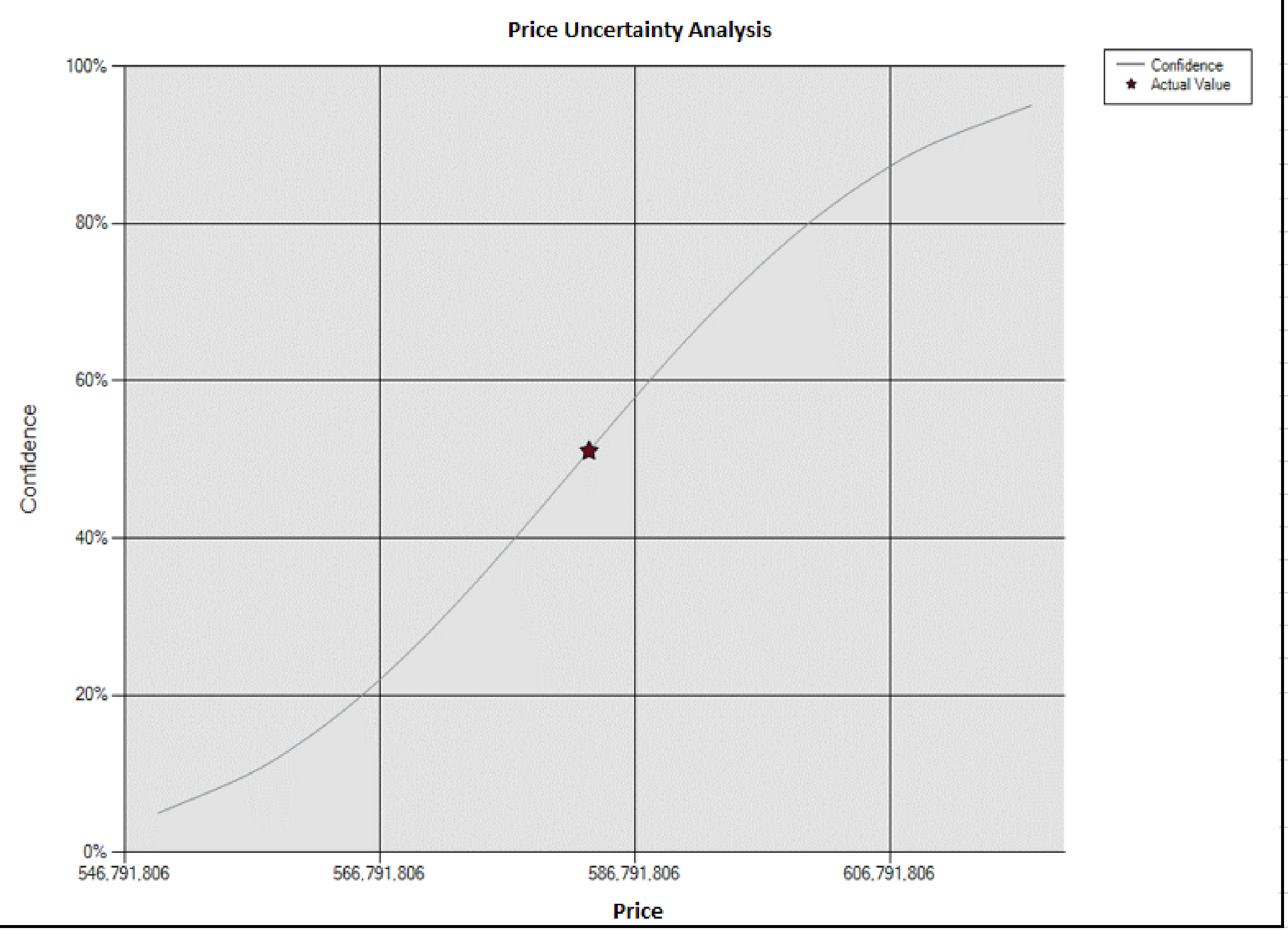
S Curves and Confidence Levels (2 of 3)

Typical TruePlanning Parametric PTW Output:

Confidence Level (C.L.)	Price - Summary	
5%	$	549,399,080
10%	$	556,569,597
15%	$	561,460,373
20%	**$**	**565,377,967**
25%	$	568,760,699
30%	$	571,815,786
35%	$	574,663,256
40%	$	577,374,654
45%	$	580,012,096
50%	$	582,619,370
55%	$	585,238,365
60%	$	587,911,729
65%	$	590,685,636
70%	$	593,627,072
75%	$	596,815,728
80%	$	600,386,556
85%	$	604,575,758
90%	$	609,888,381
95%	$	617,848,378
Point Estimate	**$**	**583,170,014**
Suggested PTW	**$**	**565,377,967**
Standard Deviation	$	20,815,086
Mean	$	582,990,606



S Curves and Confidence Levels (3 of 3)

- In the PTW
  - A lower CL is usually selected as the competitor reference point
    - Represents competitor contractor optimism and aggressive bidding
    - Conveys efficiency, innovation, and process improvements

- Historically in DoD Source Selections we find that
  - As low as a 20% CL can represent “Cost Realism” and a “Should Cost” position
  - Programs are funded or budgeted to the mean of the Internal ICEs or to the 50% CL as being the “Will Cost”
  - It is common for the program to be awarded to the contractor at a low CL, budgeted internally by the customer at the 50% CL, and the difference held back as a “Management Reserve”
    - Contingency for ECPs and when things go wrong
    - Can vary by contract type (CP versus FP – who carries the risk?)

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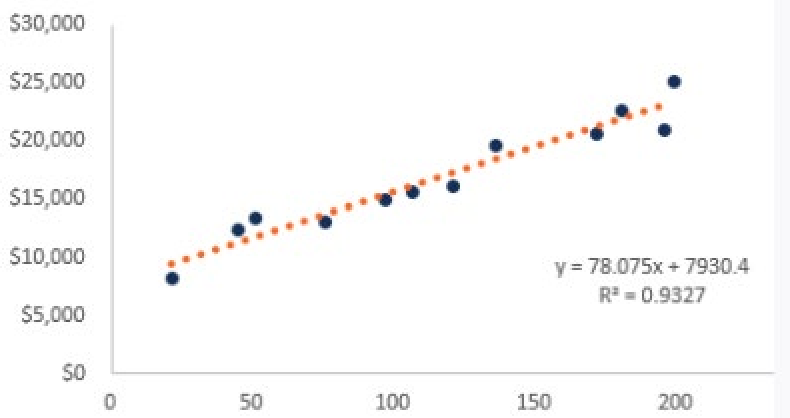
Regression and Metrics (1 of 4)

Regression Analysis

- Process of determining a CER and Best Fit Line
  - A set of statistical methods used for the estimation of relationships between a dependent variable and one or more independent variables
    - An independent variable is an input, assumption, or driver that is changed in order to assess its impact on a dependent variable
      - Cost = $ per pound (weight)
      - Weight = Independent variable [x]
      - Cost = Dependent variable [y]



Regression and Metrics (2 of 4)

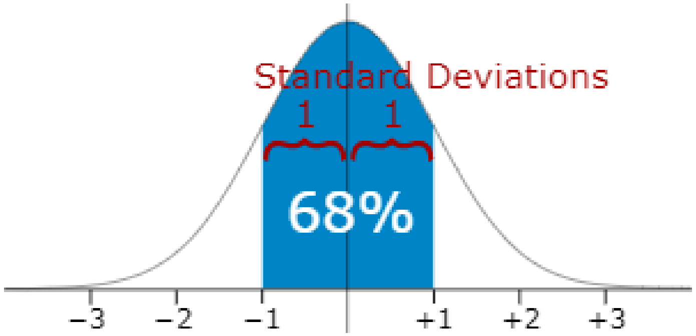
Metrics

- Mean = Sum of the terms/Number of terms
  - Arithmetic Mean = Average of all the datapoints
    - Mean of 2, 7, and 9 = (2+7+9)/3 = 6
  - Not the same as Median (middle value) or Mode (most frequent value)!

Regression and Metrics (3 of 4)

Metrics

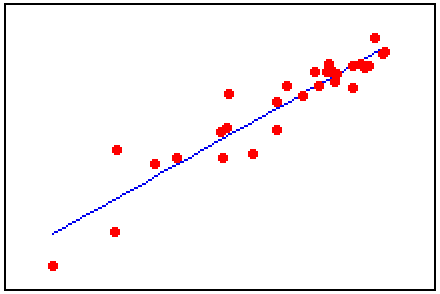
- Standard Deviation = A measure of how spread out the numbers are
  - It is the square root of the Variance, and the Variance is the average of the squared differences from the Mean
    - Variance = {[(6-2) x (6-2)] + [(6-7) x (6-7)] + [(6-9) x (6-9)])}/3 = 2
    - Standard Deviation = square root of 2 = ~ 1.415
    - Can be moderated by the sample size and values outside the standard deviation
  - Typically, we can expect about 68% of values to be within plus-or-minus 1 standard deviation from the mean

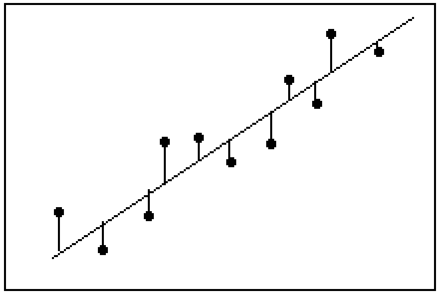


Regression and Metrics (4 of 4)

Metrics

- R–squared is a statistical measure of how close the data are to the fitted regression line
  - It is also known as the coefficient of determination, or the coefficient of multiple determination for multiple regression
  - Measures ‘Goodness of Fit’ (dispersion of data)
  - R-squared is between 0% and 100%
    - The closer it is to 100%, the less the data points deviate from the best fit line
  - Is not always useful dependent on the sample (bigger sample is best)





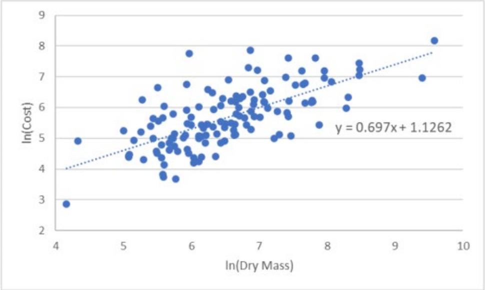
Formula

$$R^2 = 1 - \frac{RSS}{TSS}$$

R^2 = coefficient of determination
RSS = sum of squares of residuals
TSS = total sum of squares

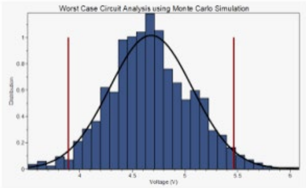
Outliers

- When doing regressions and creating CERs some points are far off of the “Best Fit” line
  - Poor R-squared

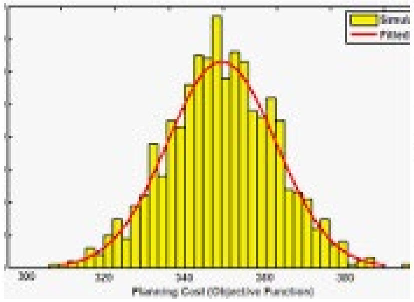


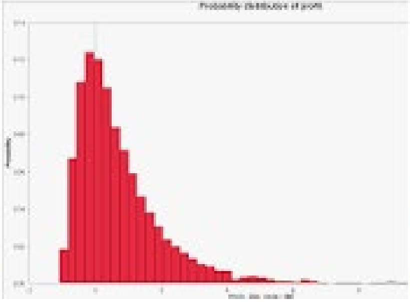
- Keep or exclude them? – tailoring
- Human nature and program/capture managers tend to be optimistic
  - Toss out sample data points outside of 2 or 3 times of the standard deviation?
  - We’re smarter now and know what we’re doing
- However, if it happened before it could reasonably be expected to reoccur (or something similar happening)
  - We won’t repeat the same mistakes – we’ll make new ones
- Realistically, they should almost always be included, IMHO

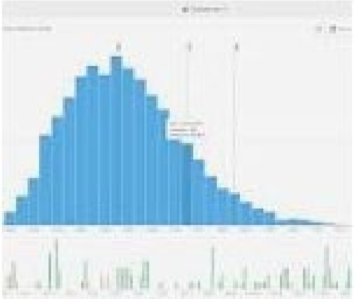
Monte Carlo Simulation



- A statistical method to predict the probability of different outcomes when a problem cannot be simply solved due to the interference or intervention of random variables being present
  - The simulation relies on the repetition of random samples to achieve numerical results.
  - It can be used to understand the effect of uncertainty and randomness in forecasting models
- Utilizes random picks of outcomes to determine the most likely result, and confidence levels and/or probability of alternative conclusions
  - Number of draws are often in the thousands
- Often similar techniques (such as Latin Hypercube) are often referred to as being a Monte Carlo Simulation







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Background on Monte Carlo Simulations (1 of 2)

- Monte Carlo Simulation/Method (in general) = probabilistic modeling tool:
  - User/Modeler define a domain/range of possible inputs
  - S/W Tool generates inputs randomly from a user selected probability distribution over the domain
  - Perform a deterministic computation on the inputs
  - Aggregate the results
- Wikipedia History Snippet:
  - The modern version of the Markov Chain Monte Carlo method was invented in the late 1940s by Stanislaw Ulam, while he was working on nuclear weapons projects at the Los Alamos National Laboratory…
  - Despite having most of the necessary data, such as the average distance a neutron would travel in a substance before it collided with an atomic nucleus, and how much energy the neutron was likely to give off following a collision, the Los Alamos physicists were unable to solve the problem using conventional, deterministic mathematical methods. Stanislaw Ulam had the idea of using random experiments.
  - Being secret, the work of von Neumann and Ulam required a code name. A colleague of von Neumann and Ulam, Nicholas Metropolis, suggested using the name Monte Carlo, which refers to the Monte Carlo Casino in Monaco where Ulam's uncle would borrow money from relatives to gamble.

Uncertainty, Risk, and Assumptions…

- Building and Running the Model can be relatively easy, the difficult part is determining the variable domain/ranges and relationships amongst the moving parts!

- Therefore prior to beginning any Research, Analysis, or Modeling it is imperative to understand what question(s) is/are being asked!

- The uncertainty, risk, and assumptions you make in modeling your "at play" variables are key. This threesome is the cornerstone of applying critical thinking to complement your research and analysis activities directed to answering the correct series of questions!

- Uncertainty (n)
  - the quality or state of being uncertain
  - current state of knowledge is such that a) the order or nature of things is unknown, b) the consequences, extent, or magnitude of circumstances, conditions, or events in unpredictable

- Risk (n)
  - the possibility that something bad or unpleasant will happen
  - a probability or threat of damage, injury, liability, loss, or any other negative occurrence that is cause by external or internal vulnerabilities, and that may be avoided through preemptive action

- Assumption (v)
  - to think that something is true or probably true without knowing that it is true

- Sources
  - Merriam-Webster
  - BusinessDictionary.com

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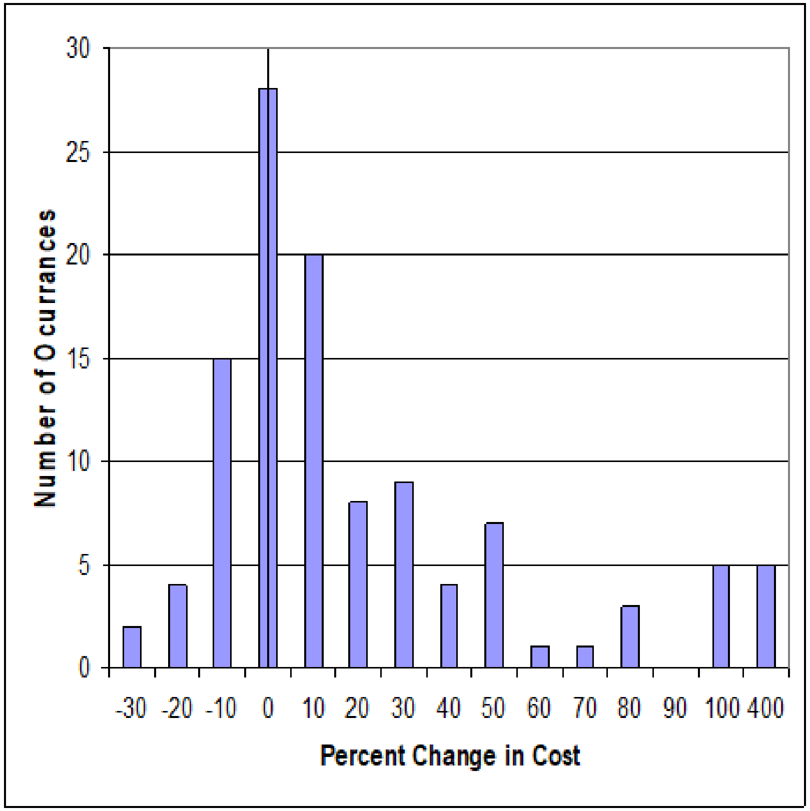
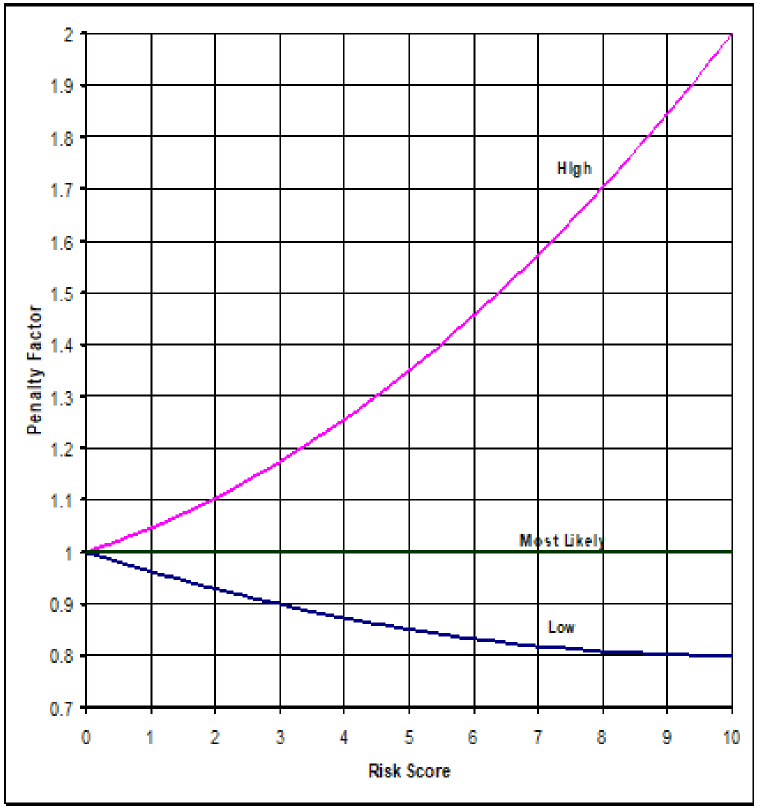
Selected Acquisition Report (SAR) Data



SAR Data Base Frequency Plot



TASC Plot of Polynomial Fits to SAR database

TASC = The Analytic Sciences Corporation

References

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- U. S. Air Force "Cost Risk and Uncertainty Analysis Handbook"
- Kurt Brunner "A Simple Approach to Assessing and Quantifying Technical, Schedule, and Configuration Risk in Cost Estimates", ISPA/SCEA Workshop September 2009
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- "The Elusive Challenge of Estimating Costs"; Molly Macauley and Prabirendra Chatterjee; 'Space News'; July 2007

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