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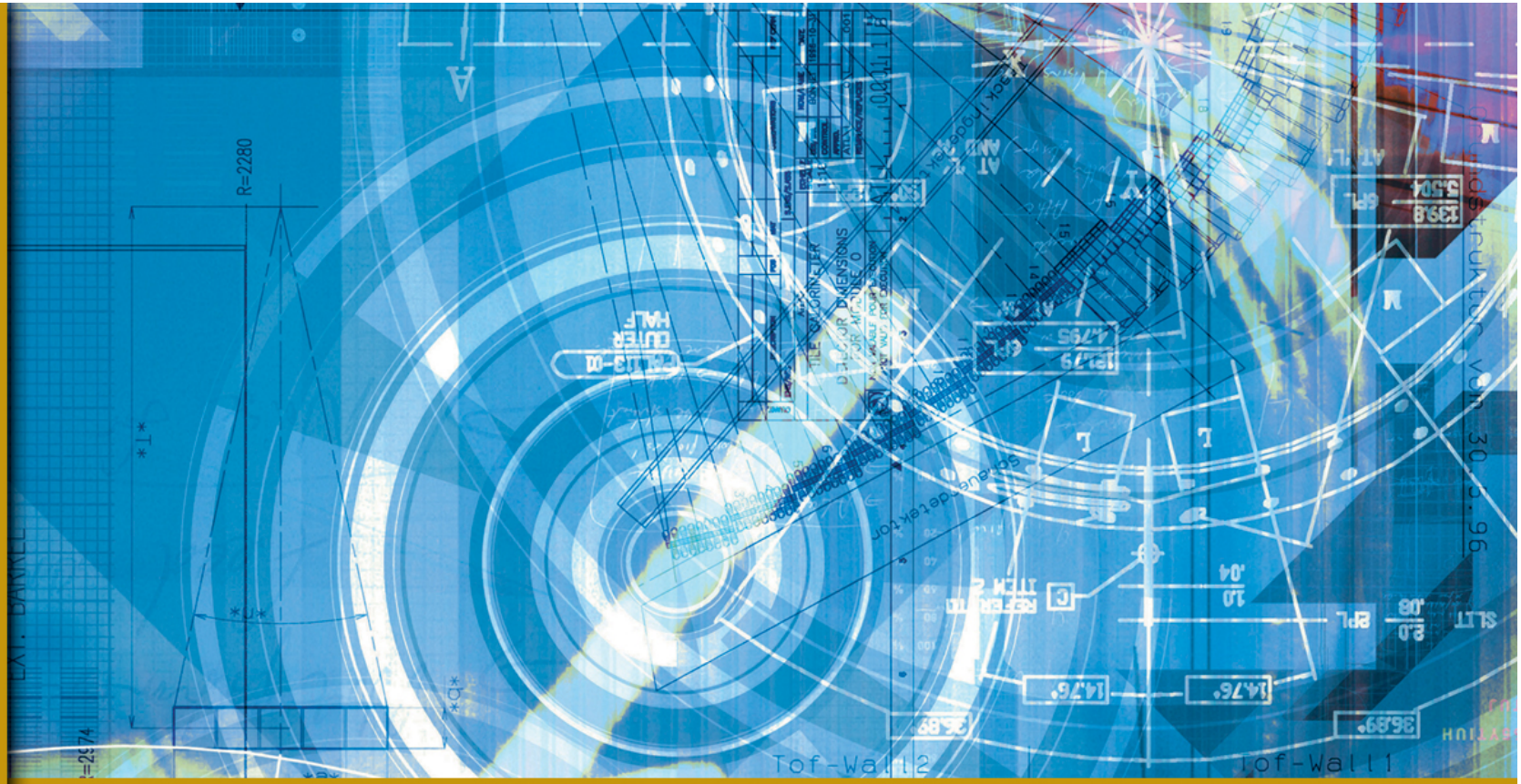

# Budgeting to the Mean

# ISPA/SCEA - June 2011


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# Summary / Abstract

**Decision makers (and policy) often require cost estimators and analysts to move to a higher confidence level on the S-Curve to ensure enough budget is requested so that a program does not overrun its budget target. Although the request to budget at a higher confidence level is a pragmatic attempt to avoid overruns (underbudgeting), there are other factors to consider besides simply "moving to the right" on an S-Curve; such as ensuring a cost estimate captures all relevant uncertainty and acknowledging acquisition changes that will impact a program after a budget has been set. With all of these factors to consider, the simply stated conclusion of this analysis is that the decision to pay for the project should be based on the risk adjusted expected value (mean) of a program. If an analyst believes in the completeness of their underlying cost model, it is rational to purchase the project for the risk adjusted expected value (mean) since the mean is the probability weighted, statistical norm or average. This analysis examines the rationale for advocating budgeting to the risk-adjusted mean, and compares this methodology and its results against budgeting above or below the expected value (mean). In addition, this discussion will also explore some of the misconceptions of confidence level terminology.**

# Outline

- Introduction
- What is a Cost Estimate?
- Is My Cost Estimate "Right"?
- The Estimate S-Curve
- Which Percentile Should I Recommend?
- Summary
- References

# Introduction: The Problem

- Decision makers (and policy) often require cost estimators and analysts to report costs at a particular confidence level on an S-Curve, such as the 80%, to ensure enough budget is requested so that a program does not overrun its budget target
- Although the request to budget at a higher confidence level is a pragmatic attempt to avoid overruns (caused by underbudgeting), there are other factors to consider besides simply "moving to the right" on an S-Curve
  - Ensuring a cost estimate captures all relevant uncertainty
  - Acknowledging acquisition changes that will impact a program after a budget has been set

# *What Is a Cost Estimate?*

# What Is a Cost Estimate?

- **Cost Analysis**
  - **The accumulation and analysis of actual costs, statistical data, and other information on current and completed contracts or groups of contracts or programs. Cost analysis also includes the manipulation of cost data, comparisons and analyses of these data, and cost extrapolations of data for future projections of cost.**
- **Cost Estimating**
  - **The art of approximating the probable cost or value of something, based on information available at the time.**

**Cost Estimate**

- **Anticipated costs associated with a project or program alternative (usually representing the entire life cycle)**

**Source: The Society of Cost Estimating and Analysis (SCEA)**

# Importance of Cost Estimates… In Establishing Budgets

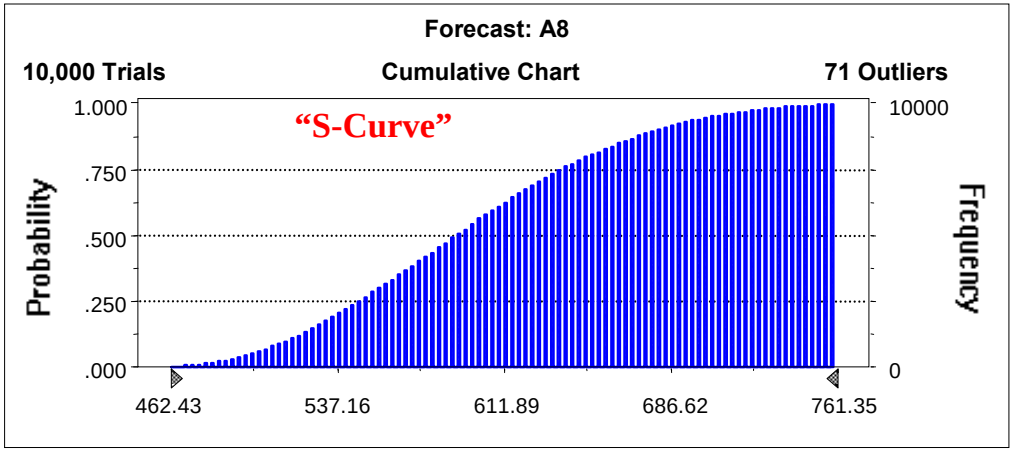
- **A competent estimate is the key foundation of a good budget!**
- **A program's approved cost estimate is often used to create the budget spending plan. This plan outlines how and at what rate the program funding will be spent over time.**
- **Because resources are not infinite, budgeting requires a delicate balancing act to ensure that the rate of spending closely mirrors available resources and funding.**
  - **And because cost estimates are based on assumptions that certain tasks will happen at specific times, it is imperative that funding be available when needed so as to not disrupt the program schedule.**
- **For a government agency, reliable estimates help in assessing the reasonableness of a contractor's proposals and program budgets.**
- **Credible cost estimates also help program offices justify budgets to the Congress, Office of Management and Budget (OMB), Government Accountability Office (GAO), department secretaries, and others.**
- **Cost estimates are often used to help determine how budget cuts may hinder a program's progress or effectiveness.**

**Source: GAO** Cost Estimating and Assessment Guide

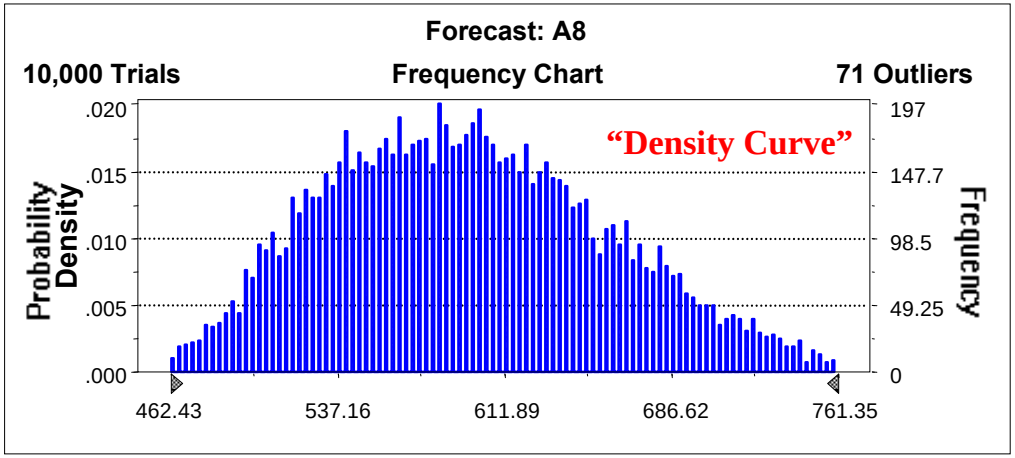
# What A Cost Estimate Looks Like

- **Often erroneously considered to be a single value that represents program cost/schedule, when it really is a probability distribution of cost and schedule values**

| Percentile | Value |
|---|---|
| 10% | 516.81 |
| 20% | 538.98 |
| 30% | 557.85 |
| 40% | 575.48 |
| 50% | 592.72 |
| 60% | 609.70 |
| 70% | 629.19 |
| 80% | 650.97 |
| 90% | 683.01 |




| Statistics | Value |
|---|---|
| Trials | 10,000 |
| Mean | 596.40 |
| Median | 592.72 |
| Mode | --- |
| Standard Deviation | 63.18 |
| Range Minimum | 450.19 |
| Range Maximum | 796.68 |



# *Is My Cost Estimate "Right"?*

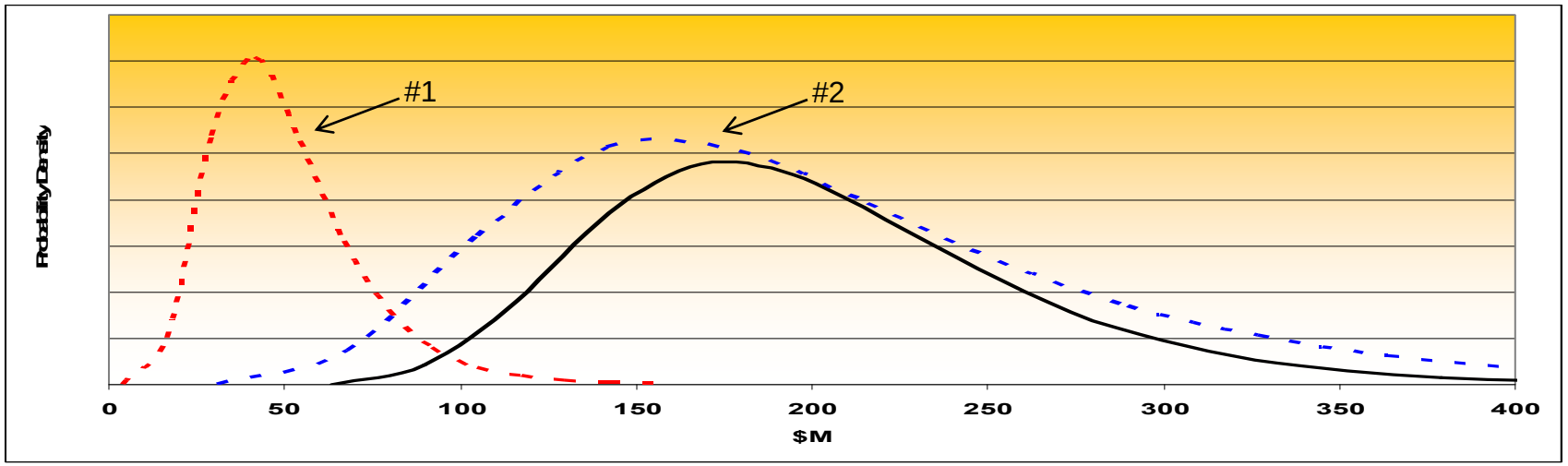
# Is My Cost Estimate "Right"?

- **NO!**
  - **The statistical chances of getting the estimate exactly "right" are infinitesimal**
- **The cost distribution is a representation of the approximation of the probable cost or value of something, based on information available at the time**
  - **A blend of Objective and Subjective components…for example…**
- **Objective**
  - **WBS Structure**
  - **Mathematical / statistical summing**
  - **Inflation Indices**
- **Both Objective and Subjective**
  - **Uncertainty modeling**
  - **Technical baseline changes**
  - **Acquisition life cycle changes**
- **Instead of asking, "Is My Cost Estimate "Right"?, the analyst should be asking another question…**

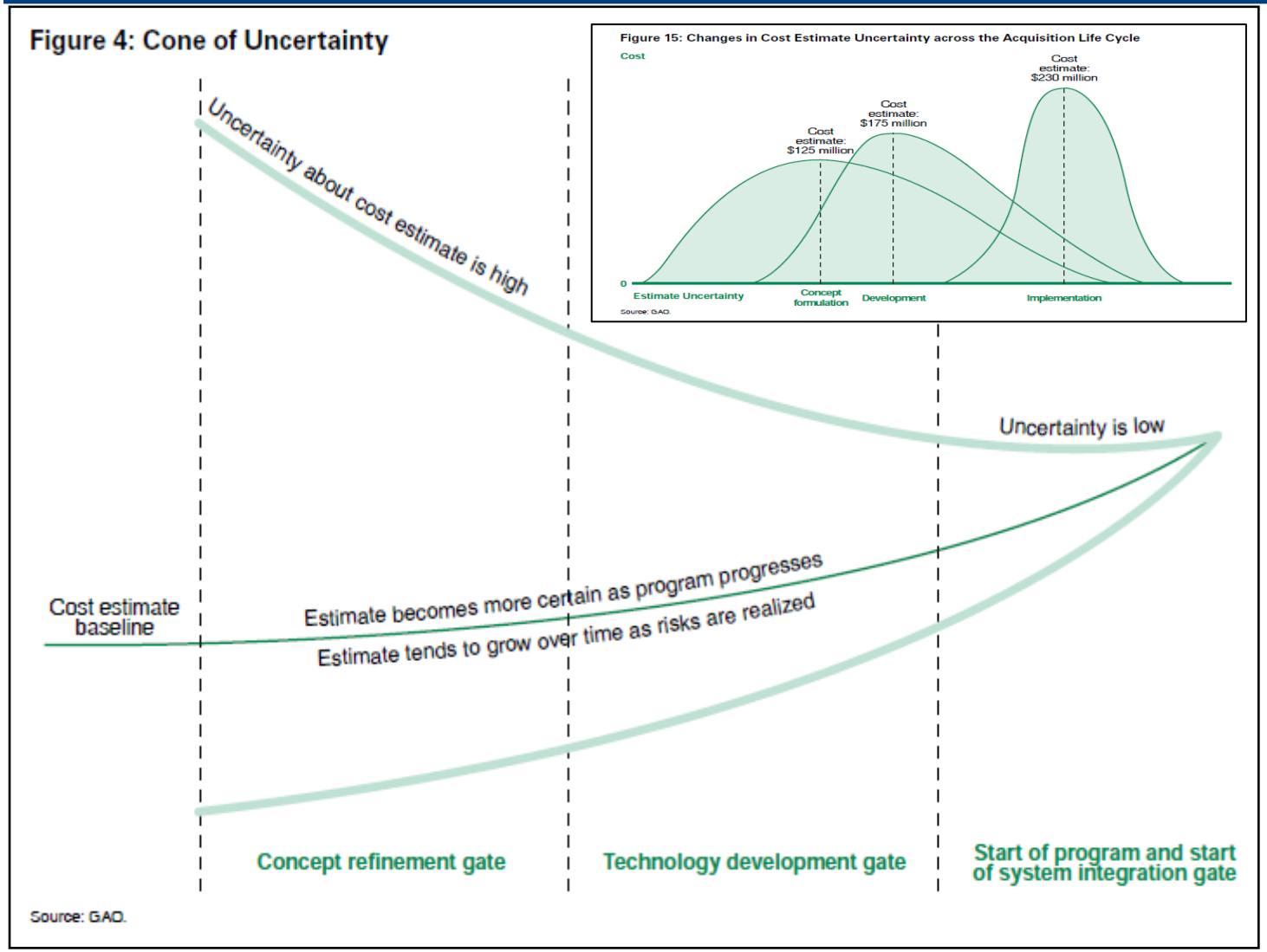
# Is My Cost Estimate a Reasonable Representation of the Actual Program?

- This is the question all analysts should ask themselves EVERY time they are asked to provide a cost estimate
  - Really applies to the Cost Estimate and Cost Model that generates it

- Two schools of thought
  - 1) Due to changes that occur over the acquisition life cycle, the entire cost distribution (usually) marches to the right over time
  - 2) A complete and thorough analysis of the program and its acquisition environment can enable an analyst, even early in the program, to capture "sufficient" program uncertainty
- Truth about how an estimate changes over time is probably a combination of both



# Cost Estimate Uncertainty



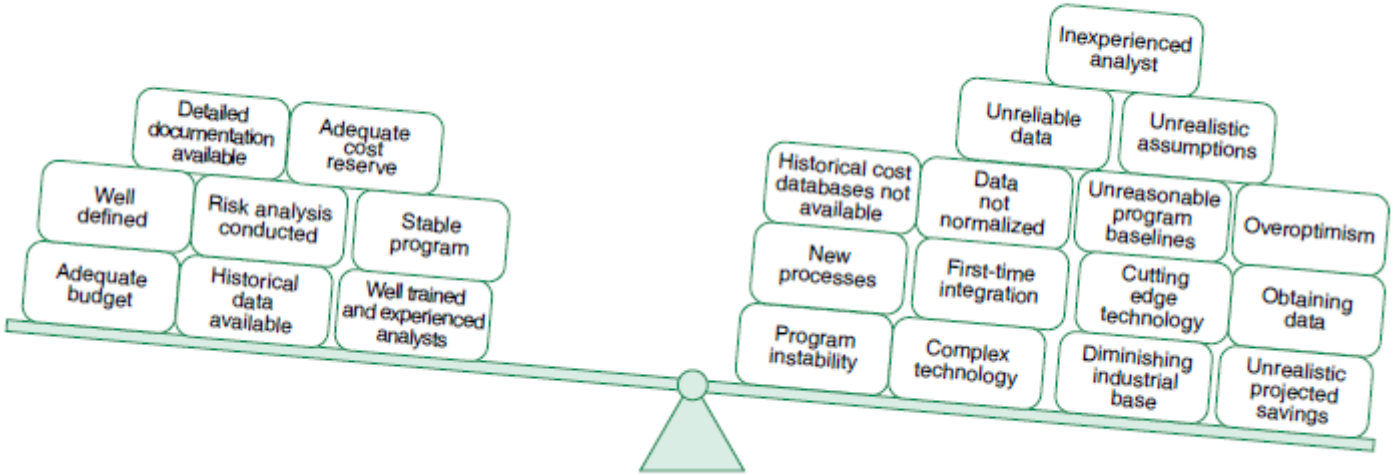

Source: GAO Cost Estimating and Assessment Guide

- **It is important to continually update estimates with actual costs, so that management has the best information available for making informed decisions**
- **Narrow risk ranges should be viewed as suspect, because more cost estimates tend to overrun than under run**

# Challenges of a Good Cost Estimate

- Developing a good cost estimate requires
  - stable program requirements
  - access to detailed documentation and historical data
  - well-trained and experienced cost analysts
  - risk and uncertainty analysis
  - the identification of a range of confidence levels
  - adequate contingency and management reserves

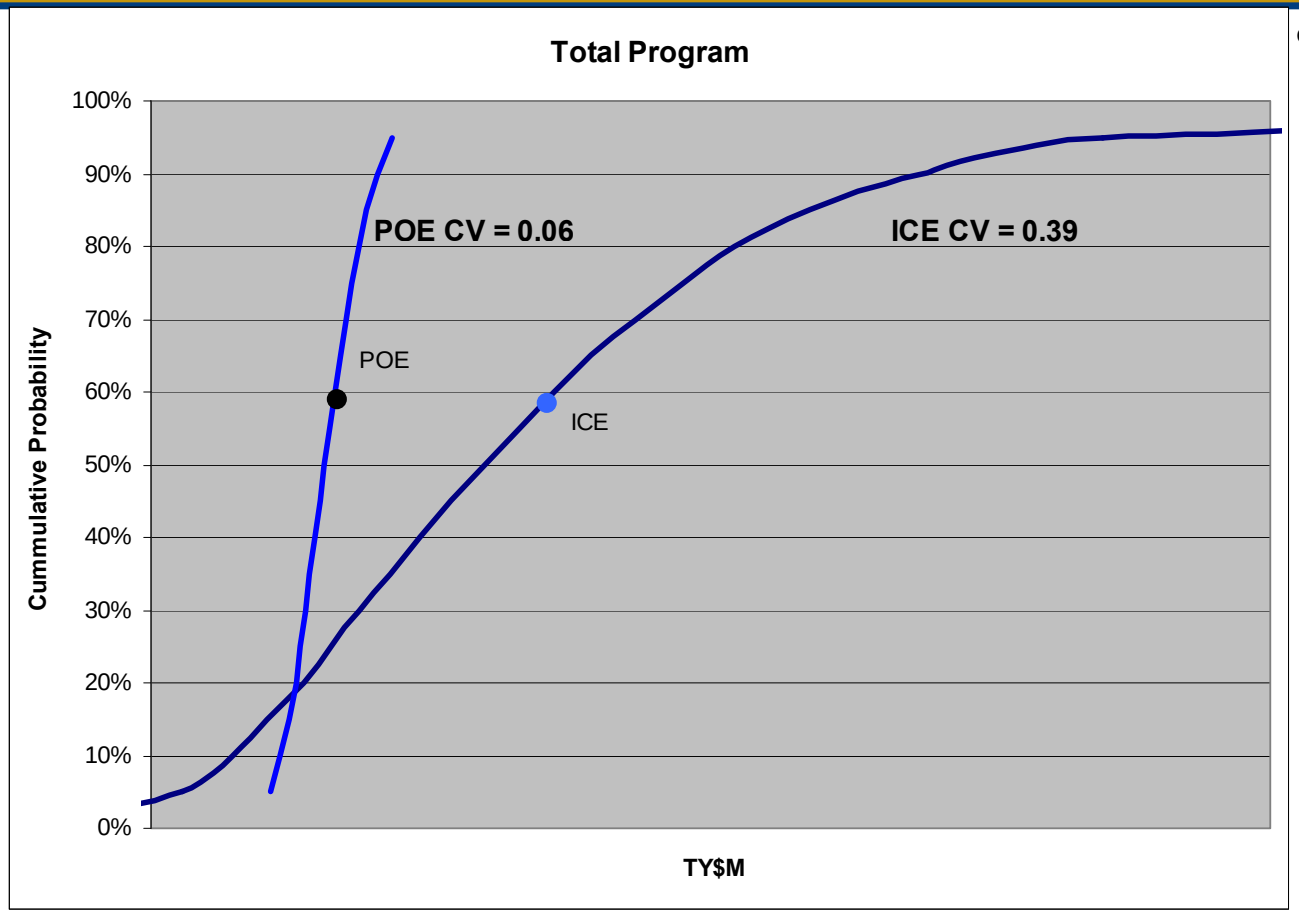
Figure 2: Challenges Cost Estimators Typically Face




Source: GAO.

**Even with the best of these circumstances, cost estimating is difficult**

# Phase A Program Example




- **PHASE A Program**
  - **POE did a decent job of capturing Cost and Schedule risk…**
  - **…but the POE missed the technical and programmatic risk of the proposed contractor solutions**

# *The Estimate S-Curve*

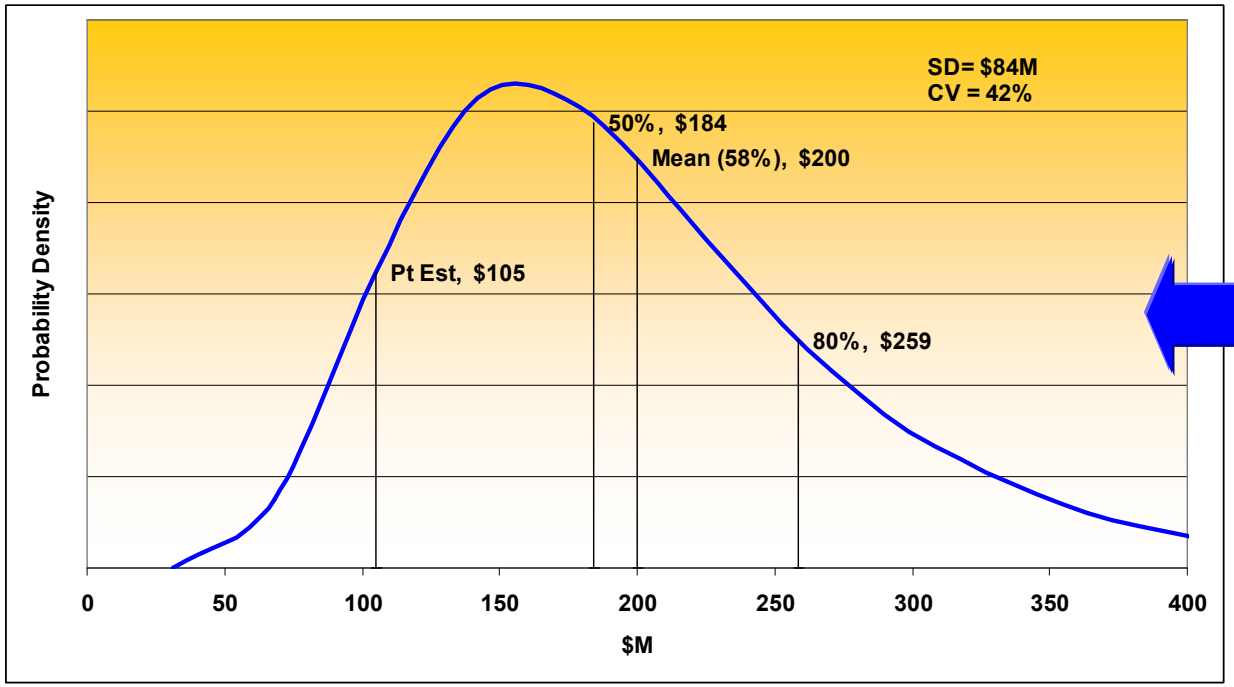
# Steps to Developing a Credible S-Curve

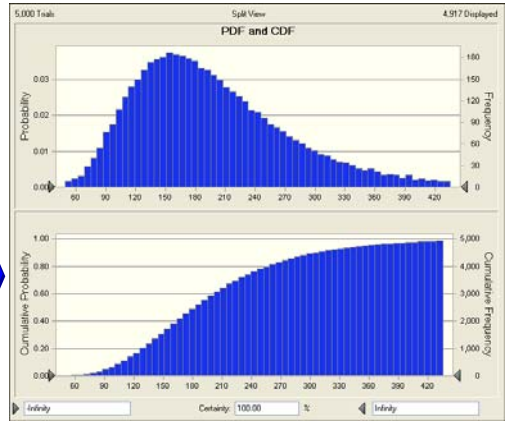
1. Determine the program cost drivers and associated risks
2. Develop probability distributions to model various types of uncertainty (for example, program, technical, external, organizational, program management including cost estimating and scheduling)
3. Account for correlation between cost elements to properly capture risk
4. Perform the uncertainty analysis using a Monte Carlo simulation or analytic model
5. Identify the probability level associated with the point estimate
6. Recommend sufficient contingency reserves to achieve levels of confidence acceptable to the organization
7. Allocate, phase, and convert a risk-adjusted cost estimate to then-year dollars and identify high-risk elements to help in risk mitigation efforts.

Source: GAO Cost Estimating and Assessment Guide

# Now You Have a Probability Density

- **And by definition you also have an S-Curve (CDF) …what now?**




$$CDF = \int PDF$$

SD = Standard Deviation

CV = Coef of Variation% = SD /Mean

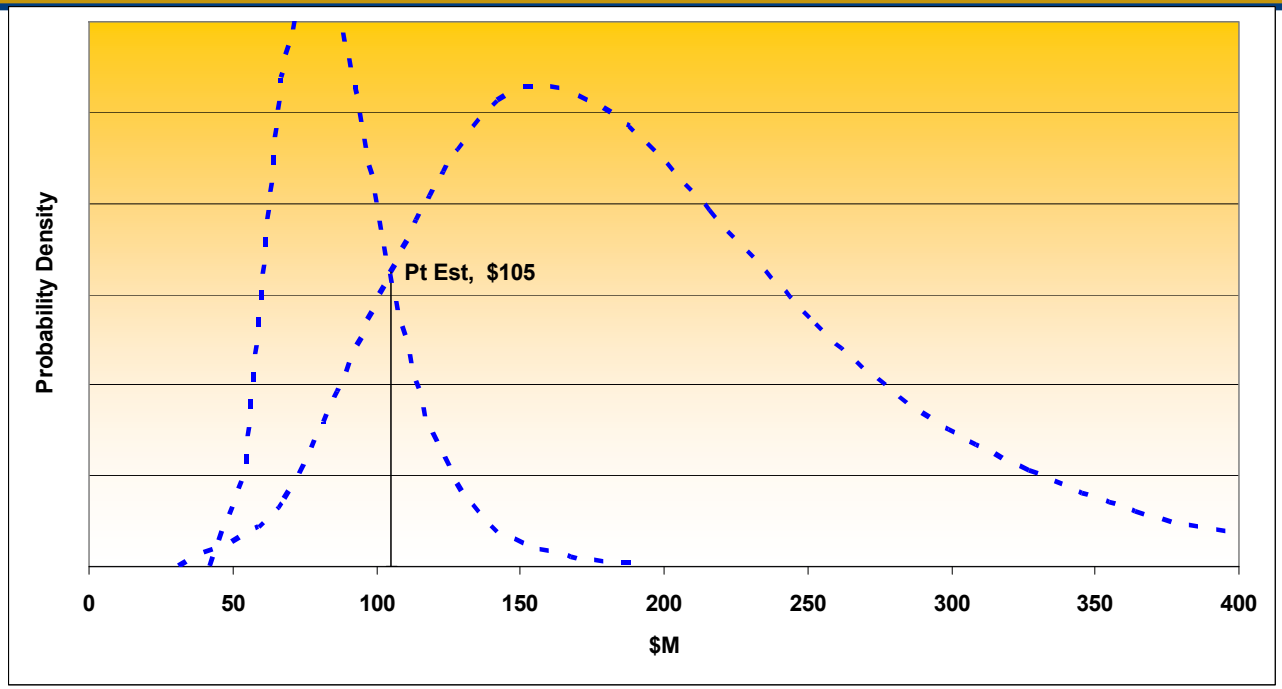
- **Program Managers (PM) make decision of where to budget and how to manage their program**
  - **We must provide the PM with as much information as possible for them to make an informed decision**
  - **Acquisition leaders need to understand that cost estimates are not deterministic, they are represented by a RANGE**

# Point Estimate, 50%, 80%, Mean?

- Management can use the S-Curve to choose a defensible level of cost estimation
- No specific confidence level is universally considered a "best practice"
  - Air Force Instruction (AFI) 63-101 & Guidance Memo (Mar 2010): (risk adjusted) Mean and 80%
  - Weapon Systems Acquisition Reform Act (WSARA) (2009): 80% or justification
  - Air Force Cost Analysis Agency (AFCAA): Risk Adjusted Mean
  - National Reconnaissance Office Cost Analysis Integration Group (NRO CAIG): Risk Adjusted Mean
  - National Aeronautics and Space Administration (NASA): 50% and 70% mentioned in policy
  - Space & Missile Systems Center Instruction (SMCI) 63-104: 80% or justification
- [Some] Experts agree that program cost estimates should be budgeted to at least the 50% confidence level, but budgeting to a higher level (for example,70% to 80%, or the mean) is now common practice
- How much contingency reserve should be allocated to a program beyond the 50 percent confidence level depends on the program cost growth an agency is willing to risk. Some organizations adopt other levels like the 70th or 80th percentile (refer to the S-Curve above) to:
  1. Reduce their anxiety about success within budget
  2. Make some provision for risks unknown at the time but likely to appear as the project progresses,
  3. Reduce the probability that they will have to explain overruns or re-baseline because they ran out of reserve budget.

Source: GAO Cost Estimating and Assessment Guide

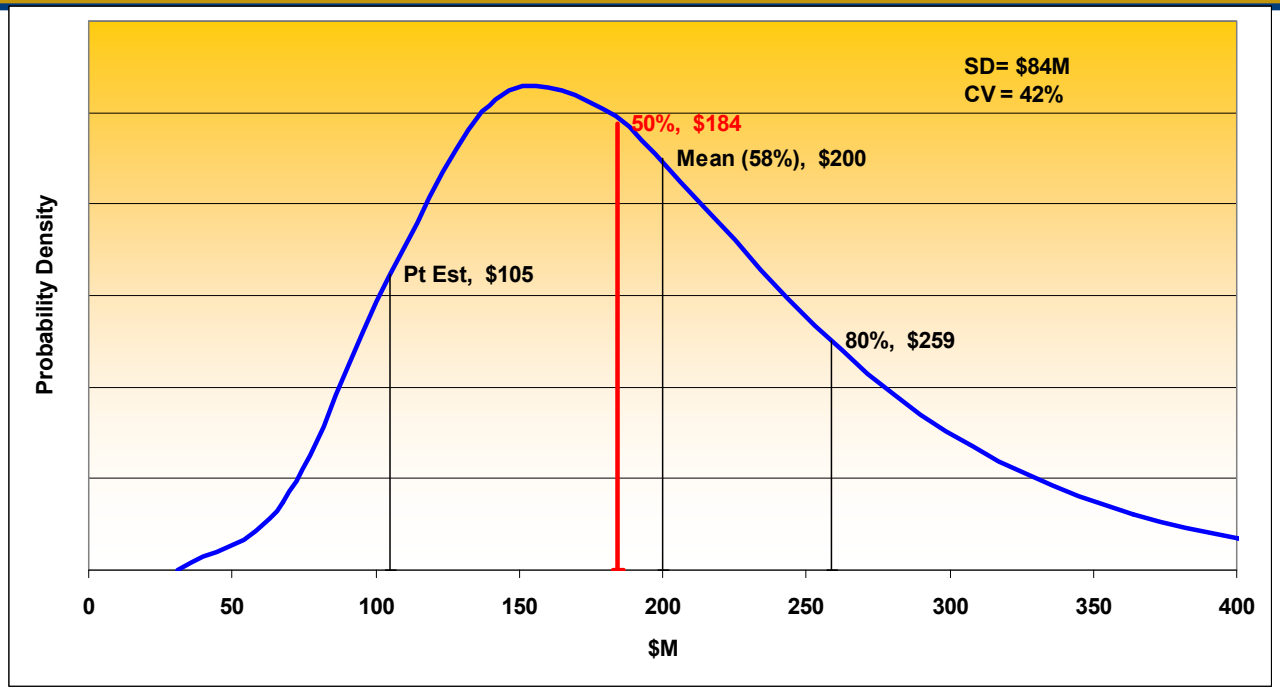
# Moving along the Percentile Scale: Point Estimate




- **Point Estimate = Raw Output of a Cost Model PRIOR to modeling any Risks**
- **A point estimate does not capture any uncertainty**
- **A point estimate does not tell us enough about the potential range of costs**
- **Any point on the PDF or S-Curve (CDF) can be understood only by relating it to the rest of the PDF or CDF**
  - **What is the Mean and Standard Deviation?**

**A point estimate, by itself, provides no information about the underlying uncertainty**

# Moving along the Percentile Scale: 50%

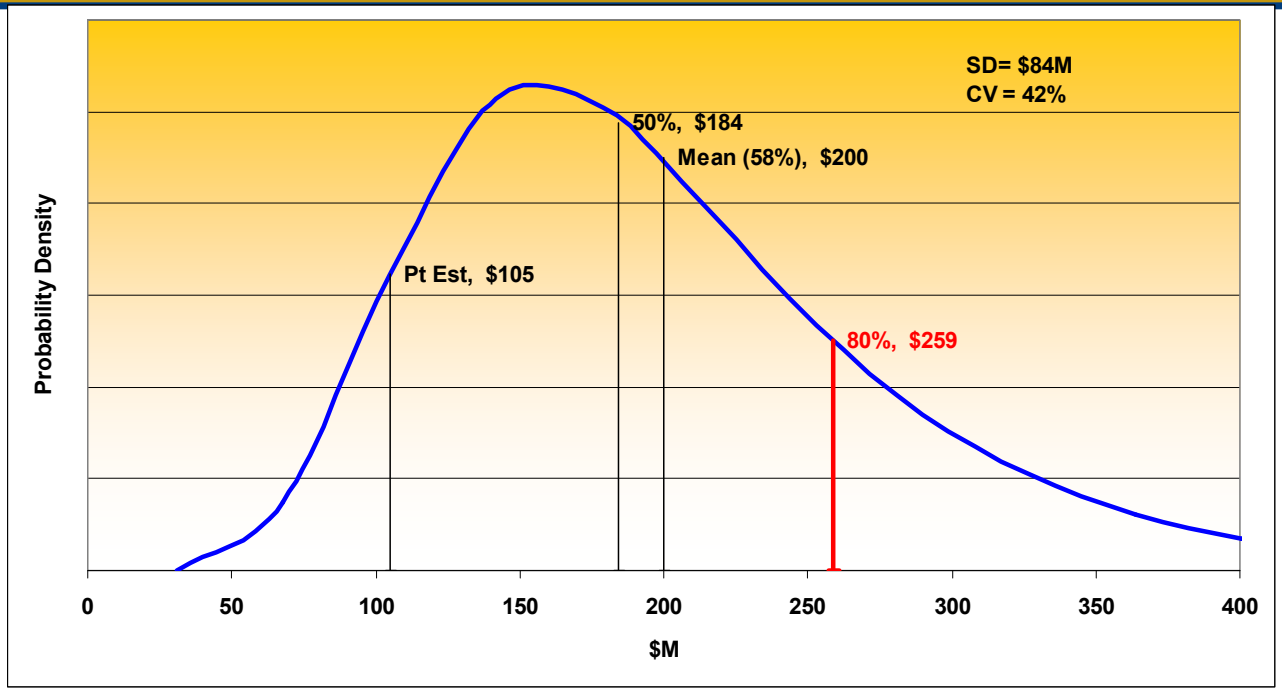



SD = Standard Deviation

CV = Coef of Variation%

- Better than budgeting to the Point Estimate; the Point Estimate will never materialize (it's usually too low)
- 50% probability of cost coming in at or below $184M
- 50% probability of cost coming in above $184M
- Remember, the major assumption underlying your estimate is that your model had "adequately" captured the program risks

# Moving along the Percentile Scale: 80%



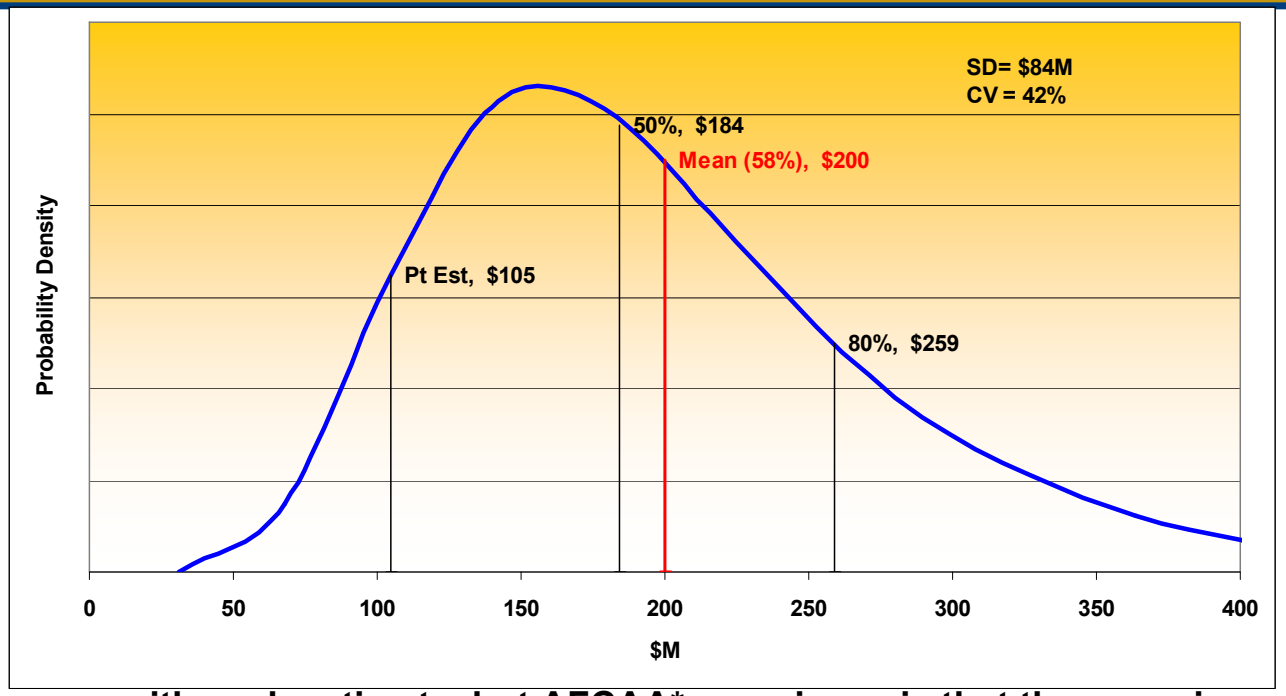

SD = Standard Deviation

CV = Coef of Variation%

- 80% probability of cost coming in at or below $259M
- 20% probability of cost exceeding $259M
- Budgeting individual programs at the 80% is inefficient from a portfolio standpoint (Anderson, Book, Covert, etc.)
- Research has shown that if individual programs were budgeted at the 80th percentile, the portfolio of programs was budgeted at a much higher, inefficient percentile (~95%). Not allowing for program portfolio success due to lack of adequate resources

# Moving along the Percentile Scale: Mean

**The Means Sum!**




- The mean's percentile changes with each estimate, but AFCAA* experience is that the mean is usually between 55%-65%
  - Jointly, the Coefficient of Variation (CV) should be "reasonable" (see AFCAA Cost Risk Handbook)
- In this example, 58% probability of cost coming in at or below $200M
- 42% probability of cost exceeding $200M
- Represents the probability weighted, statistical norm, average, or expected value
  - Mathematical/statistical measure, not subjective in relation to other projections along the S-Curve
  - Has Statistical Meaning

* Source: AFCAA Cost Risk Handbook

# Moving along the Percentile Scale: What is the Mean?

- The mean is the probability-weighted average, or expected value.
- Let's look at a stylized example. We'll use the simplest of games, an equal probability binomial coin flip game.
  - Heads and you get a $1
  - Tails and you get $0
  - There is a 50% chance that the coin will be a heads, and the payoff to you is $1
  - There is a 50% chance that the coin will be a tails, and the payoff to you is $0
  - If you play for free, then over time this game is a guaranteed return of $0.50 to you
  - Your expected payoff is simply sum of the product of the probability weightings (50%, 50%) with the payoffs for the 2 states of the world (Heads=$1, Tails=$0)
  - **Expected Value = E(V) = (50% * $1) + (50% $0) = $0.50**

# Expected Value Drives the Decision, 1 of 3

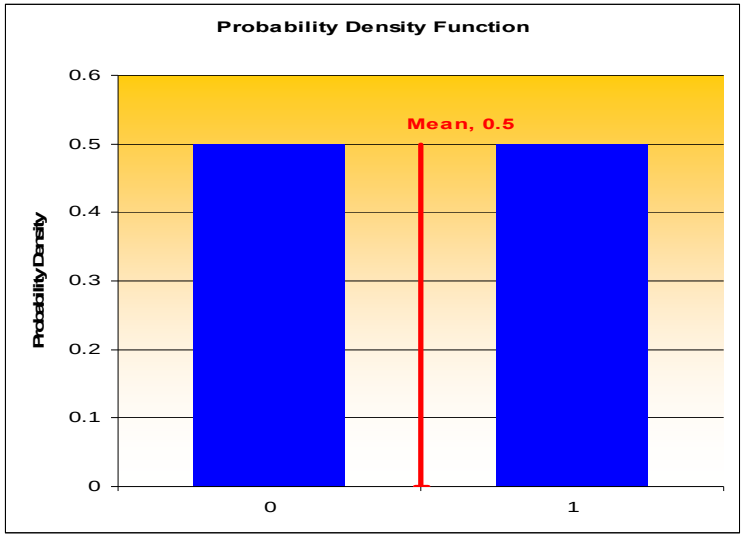
- Now, you have some alternatives. I'm not going to let you play for free. You have to put down one dollar deposit with me to play, and I'm going to charge you a fee. Alternatively, you can loan your dollar to the bank for a guaranteed rate of return.
  - What would be the maximum that you would pay me to play the game?
  - What return would you require from the bank that would make you indifferent between the game and the bank deposit?
  - The answer is the expected value
- Given the 2 (two) states of this example and your expectations for the payoffs of both, it is irrational to expect to earn more than $0.50 playing the game, you'd never pay more than $0.50 to play the game, and you'd require a $0.50 return from the bank to make you indifferent between the game and the deposit.
- Our simple 2 state model allows us to use the expected value to make logical decisions.

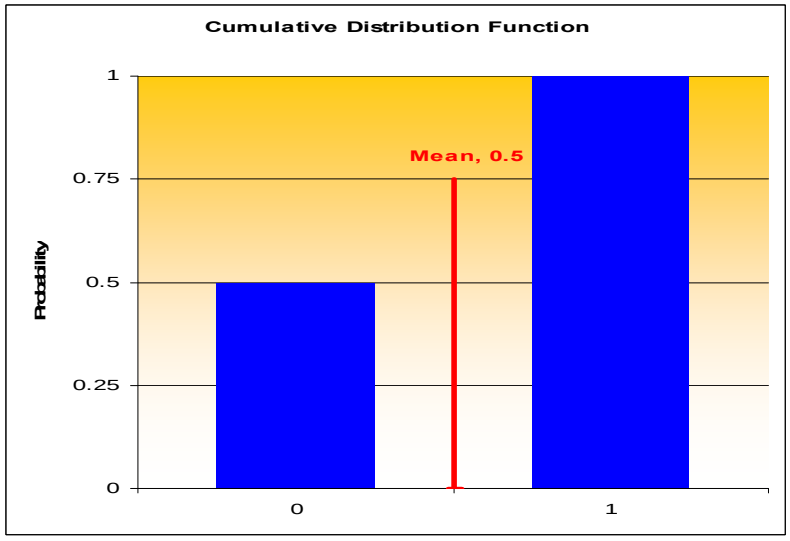
- Therefore, given the problem of predicting a payoff, or a cost, why would you ever expect any other value away from the mean?

# Expected Value Drives the Decision, 2 of 3

- $(V_{Heads})$ = \$1.00, $(V_{Tails})$ = \$0.00 — Value of Flipping Heads = $V_{Heads}$ ; Value of Flipping Tails = $V_{Tails}$
- p(Heads) = 50%, p(Tails) = 50% — Probability of Flipping Head = p(Heads) ; Probability of Flipping Tails = p(Tails)
- E(V) = [p(Heads) * $(V_{Heads})$] + [p(Tails) * $(V_{Tails})$] = \$0.50

**Rules: You don't play for free, you will have to pay me a fee. You have the choice of loaning me a dollar to play the game, or loaning your dollar to the bank for some return.**



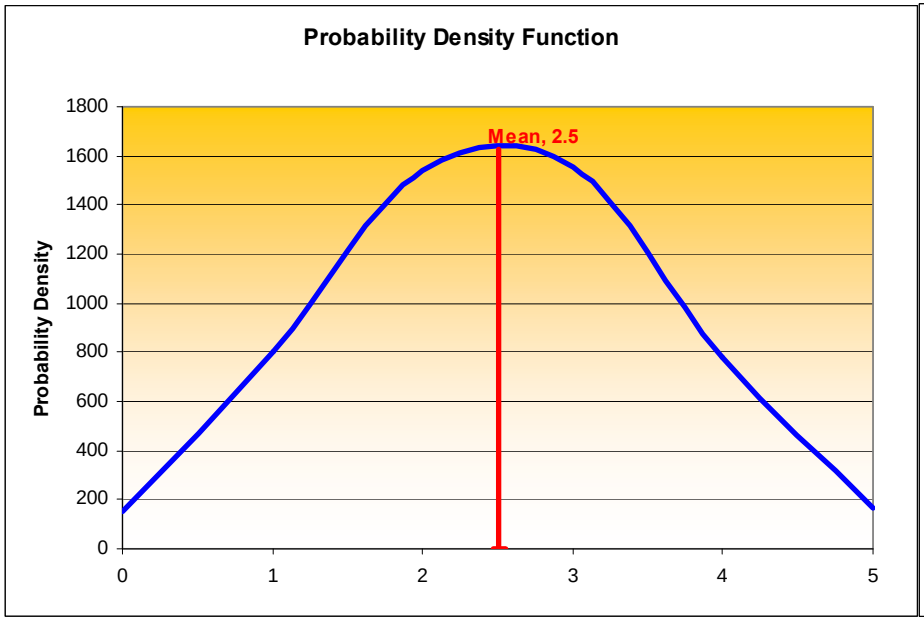

**Q: Should you play the game or loan your dollar to the bank?**

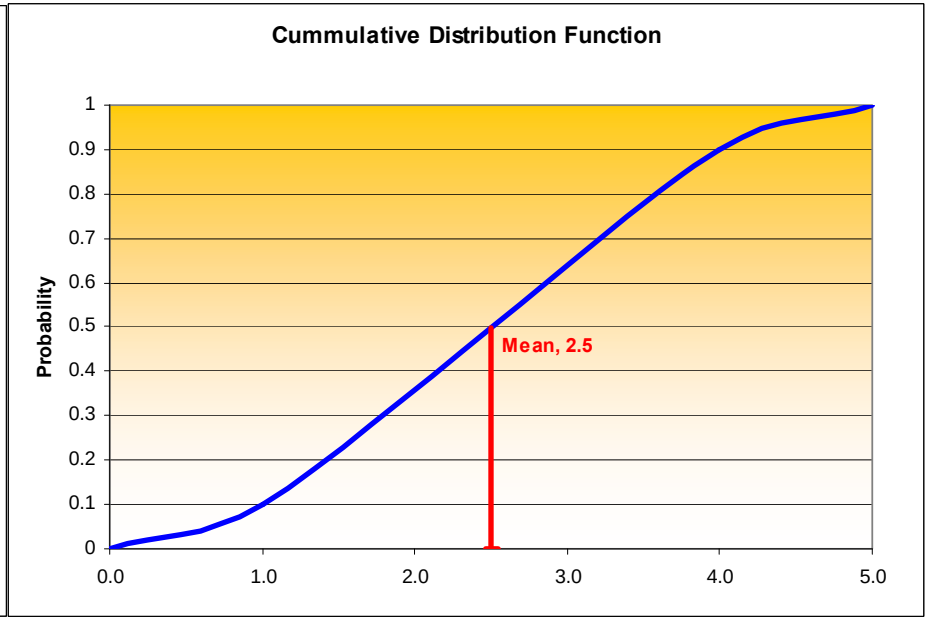
**Q: What would be the maximum fee that you would pay to play?**

**We base our Go/No Go decision to play the game (fund the program), and our valuation of the game (program cost), on the E(V)**

# Expected Value Drives the Decision, 3 of 3

- Our previous example is a simple Bernoulli distribution (heads/tails)
- Increasing the number of statistically summed distributions starts to reflect a familiar PDF and CDF (S-Curve)
  - Sum of 5 independent coin tosses




- **Process extends to cost models with dozen or hundreds of statistically summed elements**

# *Which Percentile Should I Recommend?*

# Summary of Advantages v. Disadvantages

| S-Curve Percentile Confidence Level | Advantages | Disadvantages |
|---|---|---|
| Point Estimate ("Baseline" Estimate) | ■Easy to understand<br>■Provides an easily repeatable and traceable point of reference | ■Does not take into account various Program risks<br>■Large likelihood that cost will be higher than the Point estimate; history shows the point estimate is usually at the 35% or below |
| 50% ("Median") | ■Easy to understand<br>■Same Chance of Over/Under Running | ■Same Chance of Over/Under Running<br>■If the true Risk of the program may not be adequately captured; large CV => large spread between percentile |
| 80% | ■"Possibly" reduces likelihood of overrunning; again, if your underlying model adequately captures risk<br>■Consistent with some policy/guidance | ■Creates unrealistic portfolio budgeting levels<br>■Self fulfilling prophecy of "high" program costs |
| Mean ("Expected" Value, typically 55%-65%) | ■Tied to a calculated Expected Value<br>■Intuitive mathematical "sense"; defines your distribution (along with the sigma)<br>■Value typically in the range between 55-65%; if the risk analysis and CV are adequate<br>■Consistent with some policy/guidance<br>■The Sum of the Mean is the Mean of the Sums! | ■Still chance of overrunning |

# Summary

- **Budget at The MEAN**
  - **Statistically the Sum of the Mean is the Mean of the Sum**
  - **Need to have spent time and effort adeqautely modeling program risks**
- **Program Managers make decision of where to draw the budget line and how to manage their program**
  - **We must provide the PM with as much value-adding information as possible for them to make an informed decision**
  - **Acquisition leaders need to understand that cost estimates are not deterministic, they are represented by a RANGE**
- **Some things to remember if you are asked to recommend a percentile level of funding…**
  - **Uncertainty Analysis and Risk Incorporation will never be "100%", but the Mean is the expected value, and also has mathematical attributes in relation to the rest of the data on the S Curve and "statistically" and "empirically" makes the most sense.**
  - **Cost growth can be mitigated only if we do our best to estimate the cost of the FINAL program rather than the BASELINE**
  - **The mean should make logical sense with respect to the rest of the CDF (S-Curve)**

# References


- AFI 63-101: "Acquisition and Sustainment Life Cycle Management, " April 17, 2009.
- Anderson, Timothy, MCR. "More Trouble With Estimating at the 80th Percentile," 43rd DoD Cost Analysis Symposium, Williamsburg, VA, February 2010.
- Book, Stephen, MCR. "Cost Risk as a Discriminator in Trade Studies", SCEA/ISPA, 2007
- Boulais, Ryan, et al. "Understanding Risk in the Budgeting Process from a Portfolio Point of View", 2010
- Brown, Bradford, Defense Acquisition University. "Weapon Systems Acquisition Reform Act of 2009 (Public Law 111-23)," 22 May 2009).
- Cincotta, Kevin, LMI. "The Percentile Problem: How Much Is Enough?", SCEA/ISPA 2008
- Covert, Raymond, The Aerospace Corporation. "Ten Common Things Wrong With Cost Risk Analysis," 2002.
- Garcia, Rick, MCR Federal. "S-Curves in Cost Estimating," February 2010.
- Government Accountability Office (GAO). "GAO Cost Estimating and Assessment Guide," March 2009.
- Guidance Memorandum to AFI 63-101: "Confidence Level Selection for Air Force Acquisition Programs, " March 17, 2010.
- Johnson, N.L. et al., "Distributions in Statistics," Ed. J. Wiley, Houghton M. Co., 1997
- NRO Cost Group, "NRO Cost Group Risk Process", 2003.
- Office of the Undersecretary of Defense (Comptroller) (USD(C)). "Department of Defense Financial Management Regulation, DoD 7000.14-R," Volume 1. 27 December 2008.
- Smart, Christian, MDA. "Here There Be Dragons: Considering the Right Tail in Risk Management", 2010.
- SMCI 63-104: "Software Acquisition Instruction, " May 26, 2009.
- Troge, Sam, USAF. "Space Radar Risk Metrics", 2006

# Acronym List

**AFCAA - Air Force Cost Analysis Agency**
**AFI - Air Force Instruction**
**CAIG - Cost Analysis Improvement Group**
**CDF - Cumulative Density Function**
**E(V) - Expected Value**
**GAO - Government Accountability Office**
**PDF - Probability Density Function**
**PM - Program Manager**
**NASA - National Aeronautics and Space Administration**
**NRO - National Reconnaissance Office**
**OMB - Office of Management and Budget**
**SCEA - Society of Cost Estimating and Analysis**
**SMCI - Space & Missile Systems Center Instruction**
**WBS - Work Breakdown Structure**
**WSARA - Weapon Systems Acquisition Reform Act**

# Confidence Level Terminology

- Mean – expected value
- Median – the statistically middle value in a range; the value at the 50th percentile
- Mode – the value in a range with most probability concentrated near it
- Skewed distribution – above 50% probability in one of the tails of the distribution
  - Positively skewed distribution: Mode < Median < Mean
- Risk – quantifiable likelihood of loss
  - Measure – standard deviation of cash flows
  - Metric – coefficient of variation (CV); sigma/E(V); (1/CV) $ cost per unit of risk
- Confidence Level – A statistical calculation measuring the degree of certainty about a correlation, result or forecast
  - Q: "How confident are you in your forecast of the actual program cost?"
  - A: "Given our model, I am 68% confident that the true cost estimate falls within +/- 1 standard deviation of our sample E(V)."
- Percentile – A value on a scale of 100 that indicates the percent of a distribution that is equal to or below it
  - Observation of output values from a Monte Carlo simulation
  - S-Curve at 80th percentile means that the 80% of the output values from the model are below, and 20% are above
- Valuation – Process of determining the expected value of an asset; E(V)
- Go/No Go decision to fund the project, and the valuation of the cost of that project, is based on the E(V)