

***NORTHROP GRUMMAN***

DEFINING THE FUTURE

# Hilbert's Problems for Cost Estimating

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# Hilbert's Problems for Cost Estimating

- **Body of knowledge**
- **Community of practice**
- **Analyst paradox**
- **Integrity**
- **Double analogy**
- **Theoretical probabilistic underpinnings**
- **Standardization of CERs**
- **Thought experiments**
- **“Grand unified theory” of learning curves**
- **“Grand unified theory” of estimate at complete (EAC)**
- **Physics-based estimating**
- **Emerging technology**
- **Assumption of skewness**
- **Meta-cost estimating**
- **Data rights management**
- **Epistemology of cost models**
- **Blended cost models**
- **“Self-fulfilling prophecy”**
- **The assumption of skewness in risk**
- **Portfolio management**
- **Impact of incentives on contract cost**
- **Uncertain partnership with cost management**

# Outline

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- **The Original Hilbert's Problems**
- **Hilbert's Problems for Cost Estimating**
  - Introduction
  - Groupings
  - Enumeration
  - Interactions
- **Next Steps**

# The *Original* Hilbert's Problems

- **International Congress of Mathematicians at the Sorbonne in Paris in 1900**
- **German mathematician David Hilbert boldly put forth a list of 23 theretofore unsolved problems in mathematics**
  - Subsequently became quite influential in 20th-century research efforts
  - Though problems were not new *per se*, Hilbert distilled and focused attention on them
  - Though many were solved, some remain unsolved to this day
    - Most famously, the Riemann Hypothesis
- **Hilbert's Problems came at a time where the whole of known mathematics was quickly exceeding the ken of any one individual, however brilliant**
  - Henri Poincaré, in the early 20<sup>th</sup> century, is said to be the last person to understand all known mathematics

# Hilbert's Problems for Cost Estimating

- **Similar list for 21st-century cost estimating and risk analysis**
  - OK, so we're seven years late ...
- **Some key differences:**
  - Because cost is an inherently but not purely analytical field, some of the problems take the form of broader issues to be addressed
  - Because cost is an interdisciplinary field, some of the problems may have been solved elsewhere (such as in the realm of probability and statistics) but the solution not yet fully "imported" into the cost world
- **Many of these problems could be entire papers – or groups of papers – in and of themselves**
- **These problems come at a time when many of our most valuable (Baby Boomer) analysts are nearing retirement**
  - It is hope that these problems will help engage the "next generation"
  - Cf. problem #1...

# Hilbert's Problems: Professional Identity

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- Defining the body of knowledge
- Aligning professional societies with the community of practice
- Solving the analyst paradox
  - Not enough trained analysts, but not enough intellectually-stimulating work to sustain the current pool
  - Addressing the black-box model death spiral
- Affirming the central role of integrity in cost estimating
  - Especially vis-à-vis independence, risk, and cost realism



# Professional Identity: Body of Knowledge

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- **Problem**: Cost estimating and analysis lacks a single unified definition of the body of knowledge
- **Present Situation**: Aspects of the body of knowledge are captured by various books, papers, and courses, as well as implicitly by experienced analysts
- **Work to Date**: Cost Programmed Review Of Fundamentals (CostPROF) (2002) was a good first attempt at encapsulating the body of knowledge
- **Future Research**: CostPROF Update effort current underway
  - Aims to produce unified CEBoK, including integrated glossary and bibliography
  - SCEA Certification Working Group ongoing
    - Ensure that CEBoK support certification as well as training
  - Public, “open-source” version of CEBoK – Wikipedia?!

# Professional Identity: Community of Practice

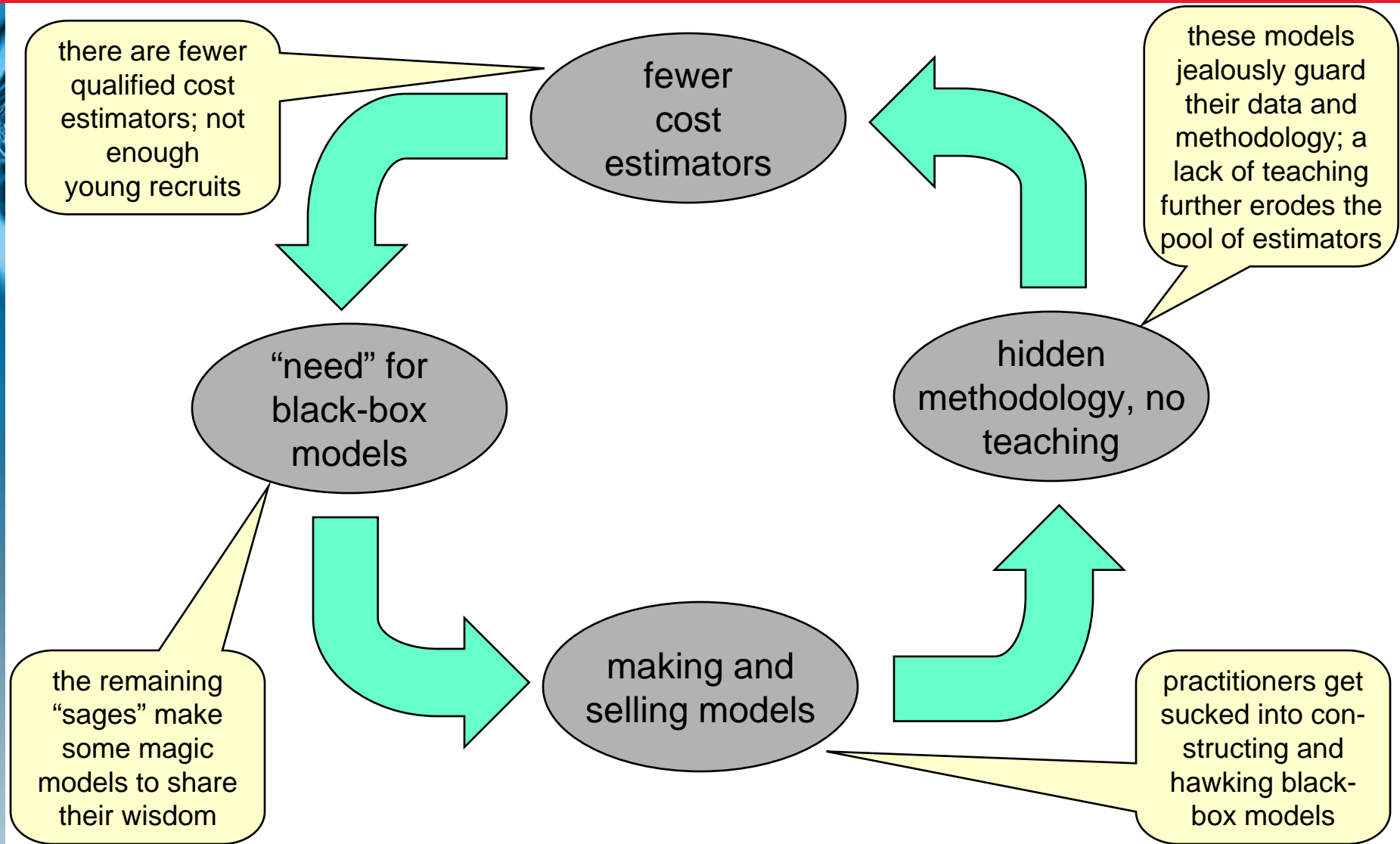
- **Problem:** Professional societies are not optimally aligned to support the cost estimating community of practice as a whole and are not taking full advantage of widely-available knowledge management and “social software” tools
- **Present Situation:** Cost community interaction is primarily limited to conferences and small groups
  - ISPA/SCEA, DoDCAS, SSCAG, etc.
  - Chapters, government cost groups, corporate CoPs, DAU/AFIT
  - Even when organizations are quite large, cost component is relatively small
  - At best, this balkanization is inefficient; at worst, it could undermine the entire community
  - Community is not very “electronic”; ~1-2 email discussions/year
- **Work to Date:** ISPA/SCEA Joint Committee formed
  - Initial focus on administrative efficiencies, Joint National Office
    - Greatly improved, database-driven SCEA website; elex distribution
  - “Content” efficiencies as well, joint conferences, journal, training
    - Working to make journals, conference proceedings available online to member
  - DAU’s Acquisition Community Connection (ACC)
- **Future Research:** Ideal end state seems single society with Parametric SIG
  - A la PMI, other SIGs possible
  - Centralized online community to enhance interaction and collaboration



# Professional Identity: Analyst Paradox

- **Problem**: Pool of trained analysts insufficient to support current market demand, yet not enough “cool” work to go around
- **Present Situation**: *De facto* caste system of a few graybeards and their acolytes, and an army of “worker bees”
  - Exacerbated by “Peter Principle,” as many top analysts get promoted to management positions
  - Analytical skills of many go undeveloped or atrophy
  - Cf. black-box model death spiral
  - Right “hump” of bimodal workforce is nearing retirement
- **Work to Date**: **Some successful “farm team” programs**
  - Navy interns, corporate college hires
  - Improved training (e.g., CostPROF), rigorous certification
- **Future Research**: **Bring breadth and diversity of workforce to bear on analytical problems**
  - End “hoarding” of methods development and research while making best use of talents
  - Separate analysts as a commodity from data and methods as a commodity

# Analyst Paradox: Black-Box Model Death Spiral



# Professional Identity: Integrity

- **Problem**: Integrity is the foundation for independence, intellectual honesty, and other characteristics vital to the profession
  - Inherent uncertainty in estimating makes integrity more, not less, important
- **Present Situation**: No explicit community-wide commitment to integrity – too important to take for granted
  - Natural pressures work to compromise independence
- **Work to Date**: Government agencies and corporations have ethics and compliance programs
  - Necessary but not sufficient focus (e.g., timecard reporting)
  - Shining individual examples, as well as bad apples
- **Future Research**: Incorporate integrity in membership, training, and certification
  - Estimators must be beholden to the truth, first and foremost

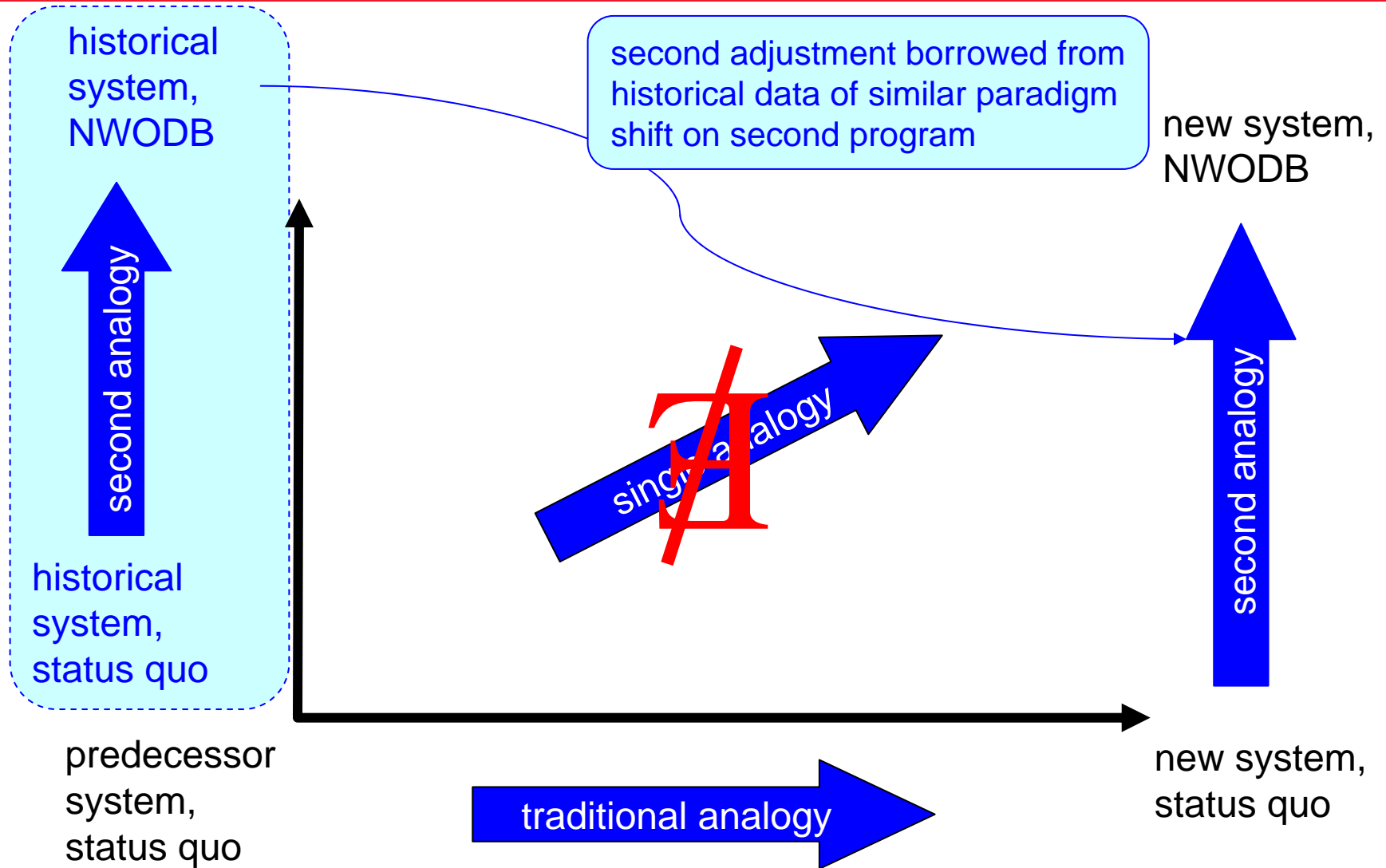
# Hilbert's Problems: Analytical Techniques

- Defining the double analogy estimating technique
- Developing the theoretical probabilistic underpinnings for risk analysis associated with cost estimating
  - Especially addressing the difficulties associated with the fact that our data come from “experiments” that are neither controlled nor repeatable
- Standardization of CERs
  - Developing “open” standards together with documentation requirements
  - Recent controversy on regression methods
  - Adjusting analogies and the role of the y-intercept
- Using thought experiments in conjunction with systematic data analysis to test theoretical constructs
  - Develop better mental models without overindulging the need to explain
- Development of a “grand unified theory” of learning curves
- Development of a “grand unified theory” of estimate at complete (EAC)
- Physics-based estimating, modeling and simulation, and chaos
- Development of techniques for estimating emerging technology
- Re-examining the assumption of skewness

# Analytical Techniques: Double Analogy

- **Problem:** (Single) analogies are often poorly applied in estimating
  - One driving problem is need to account for “paradigm shifts”
- **Present Situation:** Attempts to account for new ways of doing business (NWODB) stretch the credibility of a single analogy
  - Departure from historical data results in estimate with weak or no basis
- **Work to Date:** “Adjusting Analogies” (Coleman, Summerville, Gupta) laid groundwork for more systematic and rigorous treatment of analogy estimates
- **Future Research:** Describe a standard approach for the double-analogy technique
  - Compound traditional analogy adjustment (e.g., weight based) with a second paradigm-shift adjustment from a second historical program
    - Illustrated on next slide
  - Examine implications for risk analysis
  - Cost estimating according to Ecclesiastes: “There’s nothing new under the sun”

# Double Analogy: Illustration





# Analytical Techniques: Theoretical Probabilistic Underpinnings

- **Problem**: Cost estimating relies on statistical analysis of data produced under “messy” real-world conditions
  - In contrast to the controlled, repeatable experiments typical of scientific data analysis
- **Present Situation**: Application of traditional regression techniques to sparse, uncontrolled data sets
  - Even social science can rely on larger data sets and some manner of control
- **Work to Date**: *The Lady Tasting Tea* gives an excellent perspective on the 20<sup>th</sup>-century statistical revolution in science
  - “Ship Enterprise Costs...” (Summerville, Coleman, et al.) embodies best-in-breed analysis independent of an underlying probability theory
  - “Bootstrap Bounds...” (Book, et al.) examines implications of particular assumption of multiplicative errors
- **Future Research**: Develop a testable probability theory underpinning the data sets and analysis typical of cost estimating
  - Address questions like: Are we estimating the instance or the mean?
  - This is a daunting problem – even Kolmogorov was unable to reinvent his probability axioms before his death

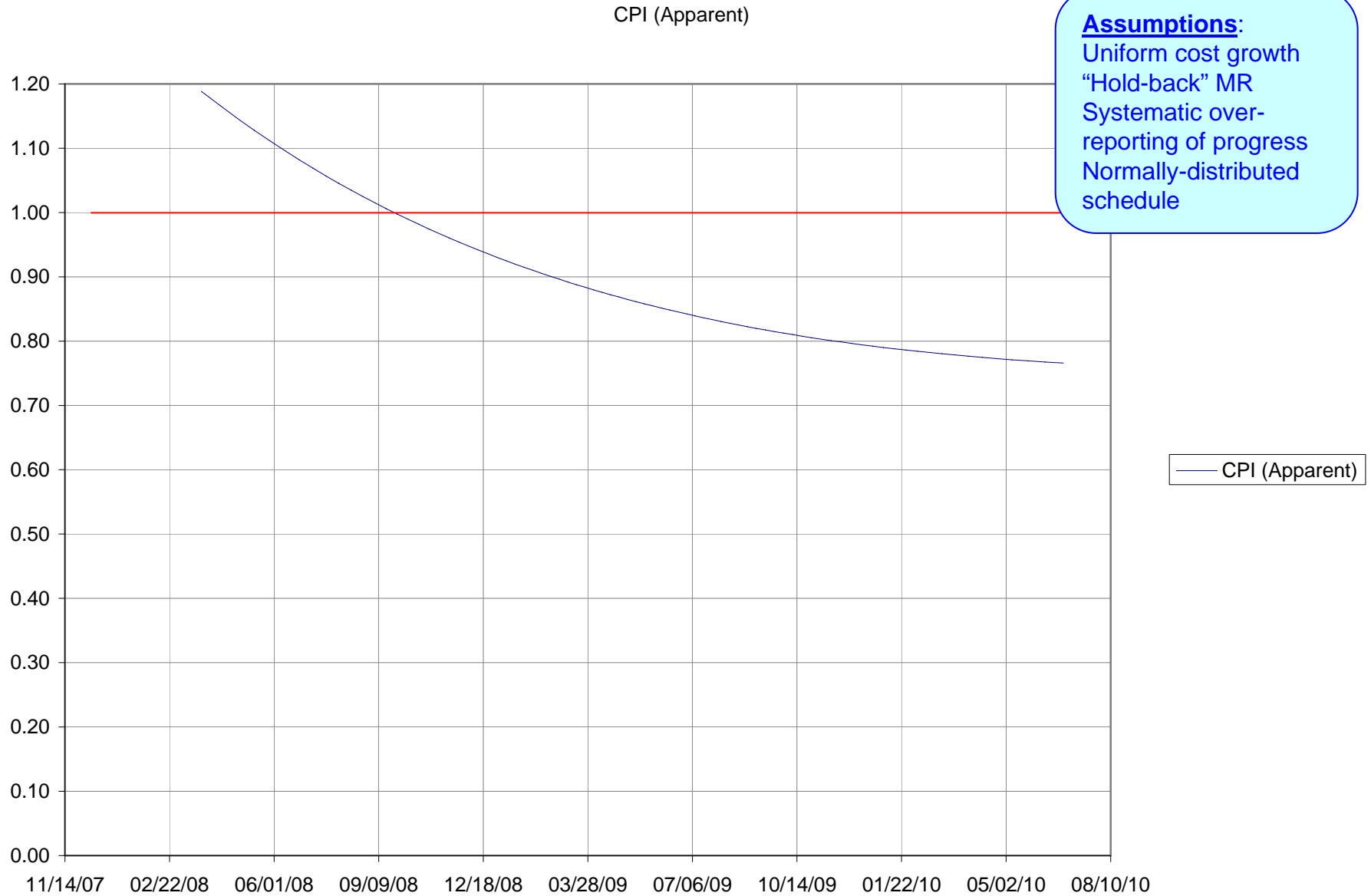
# Analytical Techniques: CER Standardization

- **Problem:** While the use of CERs as cost-predicting equations seems quite straightforward, universal “open” standards for CERs and supporting data and documentation are lacking
- **Present Situation:** Models, estimates, and organizations have idiosyncratic standards
  - Mild controversy following SCEA 2006 Best Paper Award illustrates lack of consensus in the community
- **Work to Date:** CostPROF Module 8 (Regression Analysis) sets forth basic criteria for evaluating CERs
  - Proponents of MUPE, IRLS, etc., have written papers detailing application of those approaches
  - “To b or not to b...” (Coleman, et al.) continues to bridges the gap between analogies, factors, and CERs
- **Future Research:** Develop comprehensive CER standards
  - Addressing analogy and build-up estimates as well as regression-based
  - Distinguish proper and improper application from matters of taste
  - Enable (auditable) evaluation of CERs and models even when data is proprietary
  - ISO/ANSI, or ISPA/SCEA?

# Analytical Techniques: Thought Experiments

- **Problem**: While cost estimating must always rest on analysis of historical data, too often this analysis proceeds without a mental model
- **Present Situation**: Analytical techniques tend to be applied by rote
  - Even when undertaken creatively, analysis can seem willy-nilly or unguided
- **Work to Date**: Contrast recent *Journal* article on predicting learning curve slope for aircraft and missiles with ship study
  - Former rife with regressions but less explanatory power than analysis that “deconstructed” the data using appropriate, testable, and well-accepted mental models (e.g., Markov chain)
  - Simple EVM EAC example illustrated on next slide
- **Future Research**: Balanced approach to data analysis and use of theoretical constructs
  - Thought experiments can quickly produce “perfect-world” results from hypothesis, which can then be tested using real data
  - Belief in “beautiful numbers” can co-exist with messy data!
  - Mind Ockham and Ptolemy
    - Seek simple (but not simplistic) models, and don’t cling to models when statistical evidence accrues against them

# Thought Experiments: EVM EAC Example



# Analytical Techniques: Assumption of Skewness (Log Normality)<sup>1</sup>

- **Problem:** Normality vs. log normality of cost/risk distributions remains unsettled
- **Present Situation:** Many studies have asserted the CGF distribution across many DoD programs to be distributed log-normally, e.g., Arena and Younossi<sup>2</sup>
  - Especially complicated by the fact that our data come from “experiments” that are neither controlled nor repeatable, and even worse, are assailed for impurities of the SAR data base
- **Work to Date:** A paper by Summerville and Coleman<sup>3</sup> presented a risk approach that recommended applying a normal distribution with a mean and standard deviation based on a weighted-average risk score based on several objective measures
- **Future Research:** Could it be possible that the log-normal distribution described in the Arena and Younossi paper is due to the risk scores from the Summerville and Coleman paper being distributed log-normally?
  - This would give the illusion of an underlying log-normal distribution when the actual distribution is normal with a mean and standard deviation dependent on the technical score
  - We’re not necessarily advocating dropping the umbrella log-normal assumption that is being used in many methods, especially when the technical score is unknown
  - We present this as a thought experiment that could be expanded on at a later date

<sup>1</sup> *Taking a Second Look: The Potential Pitfalls of Popular Risk Methodologies*, Druker, Coleman, Braxton, Leonetti, ISPA/SCEA 2007

<sup>2</sup> *Impossible Certainty: Cost Risk Analysis for Air Force Systems*, Arena, Younossi, et. al.. Santa Monica: RAND Corporation, 2006

<sup>3</sup> *Cost and Schedule Risk CE V*, Coleman, Summerville and Dameron, TASC Inc., June 2002

# Analytical Techniques: Learning Curve "GUT"

- **Problem:** Learning curve can often be the single biggest driver in acquisition cost, yet projected learning curves are often assumed with little basis
- **Present Situation:** Curves based on superficial analysis or industry standards are often applied
  - With lower quantities, it takes longer to establish the true curve of the current program, and the "shelf life" of such curves is short, without understanding disruptive effects
- **Work to Date:** Aforementioned aircraft/missiles and ships studies
  - Ships study systematically accounts for change orders and green labor, and produces a statistically-significant model for loss of learning based on interval (percent overlap)
- **Future Research:** Percent overlap approach offers promise for reliable learning curve predictions
  - Potential application to other commodities (UAVs, satellites)
  - Potential application *across* commodities



# Analytical Techniques: EAC “GUT”

- **Problem**: Develop a consistent statistically-significant method for arriving at estimates at complete (EACs)
- **Present Situation**: In-stride EACs rely on intuitive EVM formulae driven by performance indices, but these formulae seem to consistently underestimate, producing the so-called EAC “tail chase”
  - Previous thought experiment illustrates how systematic underestimation, “hold back” MR, and optimistic progress reporting shows *could* produce the tailchase
- **Work to Date**: Christensen, et al., have systematically examined various formulae and established thumb rules
  - “Do Not Sum...” (Book) proposed a risk-based roll-up of lower-level EACs
    - Reasonable approach, but lower-level EAC formulae still flawed
- **Future Research**: Two papers at this conference present a statistical progress-based EAC approach
  - Druker, Coleman, et al.
  - Early returns show that this approach is unbiased and has a low standard error

# Analytical Techniques: Physics-Based Estimating

- **Problem**: Developing physics-based cost estimates and understanding implications for uncertainty in modeling and simulation (M&S) designed for deterministic inputs
- **Present Situation**: CERs are usually driven by physical measures (e.g., weight), but these are usually understood to be proxies for “content” and/or “complexity”
  - True physics-based CERs are often attempted in O&S, incorporating reliability theory and other techniques
- **Work to Date**: Age and O&S (Grinnell, et al.), OPTEMPO and O&S (Cincotta, et al.)
  - Navy’s OSCAM attempts to use “systems dynamics” M&S for O&S cost modeling, but does not account for chaotic behavior that may occur due to CER uncertainty
- **Future Research**: Look for opportunities to expand and solidify physics-based estimating
  - Understand how chaotic behavior may be introduced in M&S where driving equations (e.g., CERs) have significant uncertainty
    - Cf. Theoretical probabilistic underpinnings, thought experiments

# Analytical Techniques: Emerging Technology

- **Problem**: Cost estimating and analysis relies on historical data but is constantly being asked to estimate “state of the art” systems
  - Transition from wired to wireless networks
  - Advanced materials, nanotechnology, etc.
- **Present Situation**: Result is estimating in a “data-poor” environment and trying to make subjective adjustments to account for new technology and/or NWODB
- **Work to Date**: Parametric trends based on or similar to Moore’s Law (time-driven)
  - “RAID Storage” (Blackburn, Converse, et al.)
  - Platform/requirements costing – historical trends for capabilities
- **Future Research**: Double analogy and parametric trend techniques hold promise
  - Estimators “embedded” with engineers on new technologies to accelerate the pace of data collection and methods development
  - Ironically, the further one is trying to estimate into the future, the further one has to go into the past for supporting data (mirror image!)

# Hilbert's Problems: Cost Estimating Implementation

- **Meta-cost estimating**
  - Taking our own medicine in estimating the cost of cost estimating
  - Especially as related to the recurring vs. non-recurring effort of cost estimating and analysis
    - Estimates vs. research
    - Configuring vs. coding
- **Development of guidelines for data rights management**
- **Establishing the epistemology of cost models**
  - Or how the analyst knows the model is operating as desired to produce the “right” answer
  - AKA verification and validation)
- **Description of blended cost models**

# Implementation: Meta-Cost Estimating

- **Problem: The cobbler's children have no shoes!**
  - Cost organizations have failed to proactively justify their LOE
    - Staff organizations, where LOE is determined by inertia; or
    - Program office organizations, where LOE is at the mercy of Program or Business Management
      - Sometimes cost isn't even in the BOEs!
- **Present Situation: Cost estimating organizations by and large fail to plan and manage the total scope of their effort in a systematic way**
  - Number and scope of estimates
  - Investments needed in data, methods development, research
- **Work to Date: Rule of thumb: NR = Recurring**
  - Meta-cost estimating analogue of Indirect = Direct
  - Challenge to keep Recurring from producing burn-out, NR from stagnating
- **Future Research: Greater discipline within cost estimating organizations**
  - Clarify fine line between coding and configuring models
  - Better "salesmanship" in justifying traditionally unpopular estimating effort to external customers
    - Decision makers, acquisition, program management, contracts, design engineering, et al.
  - CAIV for cost estimating: "We could do [xxx] if you gave us [yyy]."

# Implementation: Data Rights Management

- **Problem**: Adding organizational barriers to data access chokes off an already data-poor environment
- **Present Situation**: Organizations jealously guard their data
  - Somewhat understandable for industry
    - Consolidation has created even internal barriers to data!
    - “Proprietary” misused for “Private”
    - “Coopetition” necessitates NDAs and careful firewalls
  - Persistent within government as well
    - Unwillingness to share across multiple levels
    - Inability to share, even when government has paid for data!
- **Work to Date**: Data needs addressed on an ad-hoc basis
- **Future Research**: Develop community-wide data rights management plan
  - Thorny legal, contractual, and financial issues
  - Approaches to pooling data anonymously or at a sufficiently high level to enable cross-cutting analysis
    - COTS software often uses this approach



# Implementation: Epistemology of Cost Models

- **Problem:** How do you *know* your model is giving the “right” answer?
  - Are your computations correct? (verification)
    - Coleman’s Commandment: Commit no avoidable errors!
  - Are your methodologies correct? (validation)
- **Present Situation:** Presumably COTS and GOTS models undergo some sort of V&V
  - Widespread “homegrown” Excel models rarely undergo any formal testing
    - Small errors usually flushed out by an attentive team of sharp analysts
      - Can be perniciously elusive due to model scope and complexity
    - Murder boards (internal) and reconciliation (external) help
- **Work to Date:** Comparison of COTS models looks at end results
  - Techniques like Conditional Formatting help identify errors
- **Future Research:** Develop process and guidelines for V&V of models
  - Address at “cost estimating functionality” level
    - Inflation, time phasing, learning curve, factors, risk, etc.
  - Track records cross-check risk analysis V&V
  - Cf. standardization of CERs

# Implementation: Blended Cost Models

- **Problem**: Need a (better) way to incorporate multiple estimating techniques on a *simultaneous and continuous* basis
- **Present Situation**: Cross-checks universally acclaimed but not as widely used
  - DAU technique transition through cost estimating life cycle generally accepted, but many estimators “stuck in a rut” with pet technique
- **Work to Date**: Estimates/model may evolve piecemeal throughout program life cycle
  - No up-front planning
  - No retention of earlier methods when supplanted by later (presumably more detailed) methods
- **Future Research**: Develop capability in both “homegrown” Excel and COTS/GOTS models
  - Needs to incorporate simultaneous estimates at different WBS levels

# Hilbert's Problems: Integration with Related Disciplines

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- Refuting the “self-fulfilling prophecy” of cost growth (Acquisition)
- Transcending budgeting and establishing the role of cost estimating in portfolio management (Budgeting)
- Determining statistically the impact of incentives on contract cost control, if any (Contracts)
  - Consider the application of game theory to government-contractor interactions
- Better defining the uncertain partnership with cost management (CAIV)

# Integration: Self-Fulfilling Prophecy

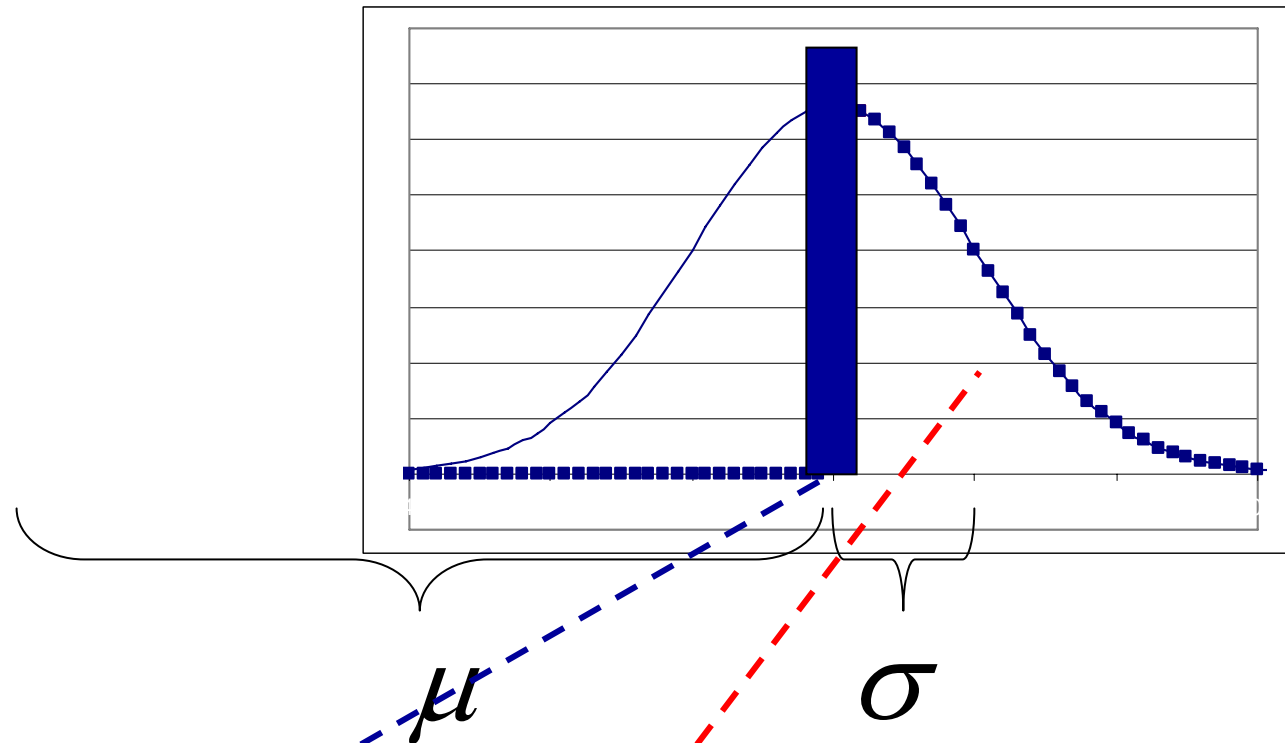
- **Problem:** Proper accounting for risk and use of management reserve (MR) are often circumvented by the claim of “self-fulfilling prophecy”
  - “If you budget it, they will spend it!”
- **Present Situation:** Sufficient risk “wedges” and MRs are rare
  - IPTs try to “game” system by initially padding estimates
- **Work to Date:** Thought experiment on spending to budgeted percentile (50<sup>th</sup>) – see next slides
  - “Do not budget to 80<sup>th</sup> percentile...”
- **Future Research:** Develop data-based theory of budgets, MR, and cost growth
  - Work with PM, EVM communities
  - Apply adequate risk to estimates as long as historical evidence of cost growth persists
  - Management approach to budgeting to maximize probability of success while minimizing wasteful spending
    - Budgeting to a high percentile risks inducing self-fulfilling prophecy and failing to fund needed programs
    - Budgeting to a low percentile minimizes self-fulfilling prophecy but requires larger MRs and efficient process for frequent requests for additional funding

# Self-Fulfilling Prophecy: Thought Experiment

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- **Thought experiment, to investigate ramifications of the “self-fulfilling prophecy”**
- **Suppose final costs are normally distributed and programs are budgeted to the mean**
  - Programs that would've come in under budget, spend all their budget (i.e., up to the mean)
  - This creates a hybrid distribution
    - 50% probability density all at the mean (discrete)
    - 50% probability density spread across the top (right) half of the bell curve (continuous)
- **For simplicity, assume programs are of uniform size and CV**
- **What mean cost growth does this imply (as a function of CV)?!**

# Self-Fulfilling Prophecy: Derivation



$$CV = \frac{\sigma}{\mu}$$

$$E(X) = \sum xp(x) + \int xp(x)dx = \mu(0.5) + \int_{\mu}^{\infty} \frac{x}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} dx$$

$$= \mu(0.5) + \mu \int_{\mu}^{\infty} \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} dx + \int_{\mu}^{\infty} \frac{(x-\mu)}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} dx$$



# Self-Fulfilling Prophecy: Derivation

$$= \mu - \frac{\sigma}{\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \Bigg|_{\mu}^{\infty} = \mu + \frac{\sigma}{\sqrt{2\pi}} = \mu \left( 1 + \frac{CV}{\sqrt{2\pi}} \right)$$

- **Since the denominator is about 2.5, a good rule of thumb is:**
  - Budgeting (and spending) to the mean causes **4% cost growth for every 10% of CV** of the underlying distribution
- **Derivation is easily corroborated with a Monte Carlo simulation**
- **Could be repeated for different percentiles**
  - Analytic solution not as clean, relies on computational approximations of normal distribution

# Integration: Portfolio Management

- **Problem**: Current politicized annual budget process, though intended to enhance fiduciary responsibility, makes no verifiable contribution thereto!
- **Present Situation**: Cost and risk do not contribute significantly enough to budgeting
  - Little “bang-for-the-buck” in constant “churn” of budget
- **Work to Date**: Navy and Air Force portfolio management approaches/models
  - Consortium for Advanced Manufacturing – International (CAM-I) Cost Management Systems (CMS) Beyond Budgeting round table
- **Future Research**: Encourage maximal use of cost and risk for responsible portfolio management within current system
  - Need both increased funding stability for flagship programs and increased agility for S&T / immediate-threat programs

# Integration: Contract Incentives

- **Problem**: Cost incentives in contracts have not been shown to reduce cost growth
- **Present Situation**: Contract “geometries” have a number of “moving parts,” the risk-based interaction amongst which is not well understood (especially by contracting officers!)
  - Target cost, fee pools, sharelines, etc.
  - Cost estimators by nature have a fatalistic view of the universe
  - Contracting officers, on the other hand, believe they can “carrot-and-stick” the contractor to “control” costs
- **Work to Date**: Risk-based ROS analysis
  - The *effect* piece: if this is the resultant cost, this will be the resultant fee and ROS under a given structure
- **Future Research**: Historical contract analysis
  - The *cause* piece: if this is the given structure, this will (or will not) be the resultant cost
  - Beware confusing correlation for causation
    - Costs didn’t grow *because* it was a Cost Plus contract, it was a Cost Plus contract because costs were likely to grow!

# Integration: Uncertain Partnership with Cost Management

- **Problem**: Cost estimating is needed to enable cost management but is often complicit in “cost fantasy”
  - “Cost consciousness” is well and good, but the better they understand your CERs / models, the more easily they can game them!
- **Present Situation**: CAIV not properly applied
  - Cannot make cost magically disappear
- **Work to Date**: Erstwhile Navy cost participation in CAM-I CMS Target Costing working group
  - “Recommendations for the Second Decade...” (Braxton, et al.)
- **Future Research**: Historical study of sources of cost reduction
  - Do less
  - Do things better
  - Do things differently
  - May be able to compute actual delta for cost reduction in full-rate production or O&S
    - Estimation required for cost avoidance to compare “as-is” to “as-would-have-been”

# Hilbert's Problems: Interactions

- **Individual problems have presented to highlight certain issues**
  - Clearly there is overlap and interaction amongst many of the problems
  - A few examples follow
- **Epistemology of cost models, standardization of CERs, theoretical probabilistic underpinnings**
  - Confidence in models rests on confidence in CERs, which begs for CERs to be evaluated against consistent criteria, which in turn requires a posited mathematical model
- **Standardization of CERs, data rights management, analyst paradox, meta-cost estimating**
  - Development of “open” standards for CERs would enable more effective and broad application of CERs while allaying fears of compromising proprietary data, which could enable more analysts to work on methods development and lead to a more careful consideration of estimating activities
- **Integrity and uncertain partnership with cost management**
  - Strengthened integrity will enable cost analysts to “play nice with others” without compromising their standards or misrepresenting the truth

# Conclusions

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- **We have presented each “Hilbert problem” (issue) with research to date and some ideas as to how resolution might be pursued**
- **While varied, they represent a personal list and are not intended to be comprehensive**
  - The authors welcome ideas and suggestions to round out and polish the list
  - As with Hilbert, the list may be “finalized” after the conference!
- **Ultimately, these problems are intended to spawn further research and study**
  - Please let us know of additional past or future research that addresses one or more of these problems