Back to the Big Easy: Revisiting Hilbert's Problems for Cost Estimating

Peter J. Braxton, Technomics, Inc.
Richard L. Coleman

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Abstract

At the 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, which subsequently became quite influential in 20th-century research efforts. At the Joint SCEA/ISPA Conference in New Orleans in June, 2007, the authors audaciously emulated Hilbert with a list of 21 problems for cost estimating and risk analysis. Because cost is an inherently but not purely analytical field, some of the problems took the form of broader issues to be addressed, and because cost is an interdisciplinary field, there's always a chance 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. This paper is a progress report of sorts, summarizing much of the research that has occurred in the intervening six years, and adding in a few new problems we neglected to include the first time because our proverbial headlights did not shine far enough down the cost estimating highway.

The original problems were grouped into four categories. The first, Professional Identity, comprised the **body of knowledge**, **community of practice**, **analyst paradox**, and **integrity** of the profession. Developments here include the merger of ISPA and SCEA to form ICEAA; the rebirth of CostPROF as CEBoK, and designation of the Body of Knowledge (BoK) Chair distinct from Training; the publishing of the GAO Cost Estimating and Assessment Guide; the establishment of the OSD CAPE by WSARA, subsuming the erstwhile Cost Analysis Improvement Group (CAIG); and the continued reinvigoration of the profession by bright young analysts as the Baby Boomers draw ever nearer to retirement.

The second category, Analytical Techniques, comprised **double analogy**, **theoretical probabilistic underpinnings**, **standardization of CERs**, **thought experiments**, **grand unified theories**, or GUTs, of **learning curve** and **estimates at completion (EACs)**, **physics-based estimating**, and estimating **emerging technology**. Developments here include numerous papers on risk, general-error regression models (GERM), serious concerns with the traditional Cumulative Average (CUMAV) learning curve formulation, progress-based EACs, and new trends in software and automated information systems (AIS), including enterprise resource planning (ERP). Other technological advances likely remain buried in the black world.

The third category, Cost Estimating Implementation, comprised **meta-cost estimating**, **data rights management**, **epistemology of cost models**, and **blended cost models**. There has been perhaps the least progress here, though developments such as XML-based CPRs, IMS-based cost models, and conflation of multiple probabilistic estimates show some promise.

The fourth category, Integration with Related Disciplines, comprised "**self-fulfilling prophecy**," **skewness in risk**, **portfolio management**, **contract incentives**, and the **uncertain partnership with cost management**. Developments here include the infamous 80th percentile of WSARA and its retraction, research into heteroskedastic regression models for the size effect, extensions of risk-based return on sales (ROS), and the Better Buying Power initiatives. A combination of the debt crisis, pending sequestration, and the end of the wars in Iraq and Afghanistan promises to spur renewed interest in portfolio management for the DoD.

While the original list of problems was surprisingly relevant and comprehensive, a few major areas were not anticipated. One is the emergence of joint cost and schedule risk analysis; the related interest of cost estimators in schedules, as evidenced by GAO's "sequel" Schedule Assessment Guide; and the coincident improvements in Monte Carlo simulation technology. Other key risk analysis areas include the enhanced scenario-based method (eSBM), the use of SME assessments, and data-based coefficients of variation (CVs) and correlations.

PBraxton@technomics.net, (703) 944-3114

Hilbert's Problems for Cost Estimating

Professional Identity
- Body of knowledge
- Community of practice
- Analyst paradox
- Integrity

Analytical Techniques
- 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

Cost Estimating Implementation
- Meta-cost estimating
- Data rights management
- Epistemology of cost models
- Blended cost models

Integration with Other Disciplines
- "Self-fulfilling prophecy"
- The assumption of skewness in risk
- Portfolio management
- Impact of incentives on contract cost
- Uncertain partnership with cost management

Hilbert's Problems Revis(it)ed

Professional Identity
- Body of knowledge
- Community of practice
- Analyst paradox
- Integrity

Cost Estimating Techniques
- Double analogy
- Standardization of CERs
- Thought experiments
- "Grand unified theory" of learning curves
- "Grand unified theory" of estimate at completion (EAC)
- Physics-based estimating
- Emerging technology

Cost Estimating Implementation
- Meta-cost estimating
- Data rights management
- Epistemology of cost models
- Blended cost models
- Use of Subject Matter Experts (SMEs)

Cost and Schedule Risk Analysis
- Theoretical probabilistic underpinnings
- "Self-fulfilling prophecy"
- The assumption of skewness in risk
- Joint cost and schedule risk
- Data-based CVs and correlations
- Top-level vs. detailed risk

Integration with Other Disciplines
- Portfolio management
- Impact of incentives on contract cost
- Uncertain partnership with cost management
- Sister disciplines: EVM, Schedule Analysis, RM, PM, Contract Mgt, SE

Legend
Green = new grouping or problem
Red = relocated problem

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Outline

- The Original Hilbert's Problems

- Revis(it)ing Hilbert's Problems for Cost Estimating

  - Continued progress on existing problems

  - New problems and groupings

- Next Steps

The *Original* Hilbert's Problems

- German mathematician David Hilbert boldly put forth a list of 23 theretofore unsolved problems in mathematics in 1900
  - 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 (#8)

- International Congress of Mathematicians at the Sorbonne in Paris
  - Hilbert discussed 10 of the problems on August 8th

- 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 20th century, is said to be "the *last* person to understand fully all of mathematics"

Hilbert's Problems for Cost Estimating

- Similar list for 21st-century cost estimating and risk analysis
  - Originally put forward at ISPA/SCEA 2007 New Orleans, the first of continual joint conferences

- 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 hoped that these problems will help engage the "next generation"

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Hilbert's Problems Updated

- Closed Problems – None!
  - Closest are first two, under Professional Identity
    - Body of Knowledge and Community of Practice
  - Significant progress on many
    - Cost Estimating is an applied field, not enough time for chin-stroking!
- New and Unanticipated Problems
  - Umberto Eco's antilibrary (NNT, *Black Swan*)
  - Most in the area of Cost and Schedule Risk Analysis, added as fifth grouping

Hilbert's Problems: Professional Identity

- Defining the <u>body of knowledge</u>

- Aligning professional societies with the <u>community of practice</u>

- Solving the <u>analyst paradox</u>
  - 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 <u>integrity</u> in cost estimating
  - Especially vis-à-vis independence, risk, and cost realism

Professional Identity: Body of Knowledge

- <u>Problem</u>: Cost estimating and analysis lacks a single unified definition of the body of knowledge

- <u>Previous Situation</u>: Aspects of the body of knowledge are captured by various books, papers, and courses, as well as implicitly by experienced analysts

- <u>Progress Made</u>: Cost Programmed Review Of Fundamentals (CostPROF) (2002) was a good first attempt at encapsulating the body of knowledge

- <u>Future Research</u>: 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?!

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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

- Previous 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

- Progress Made: 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
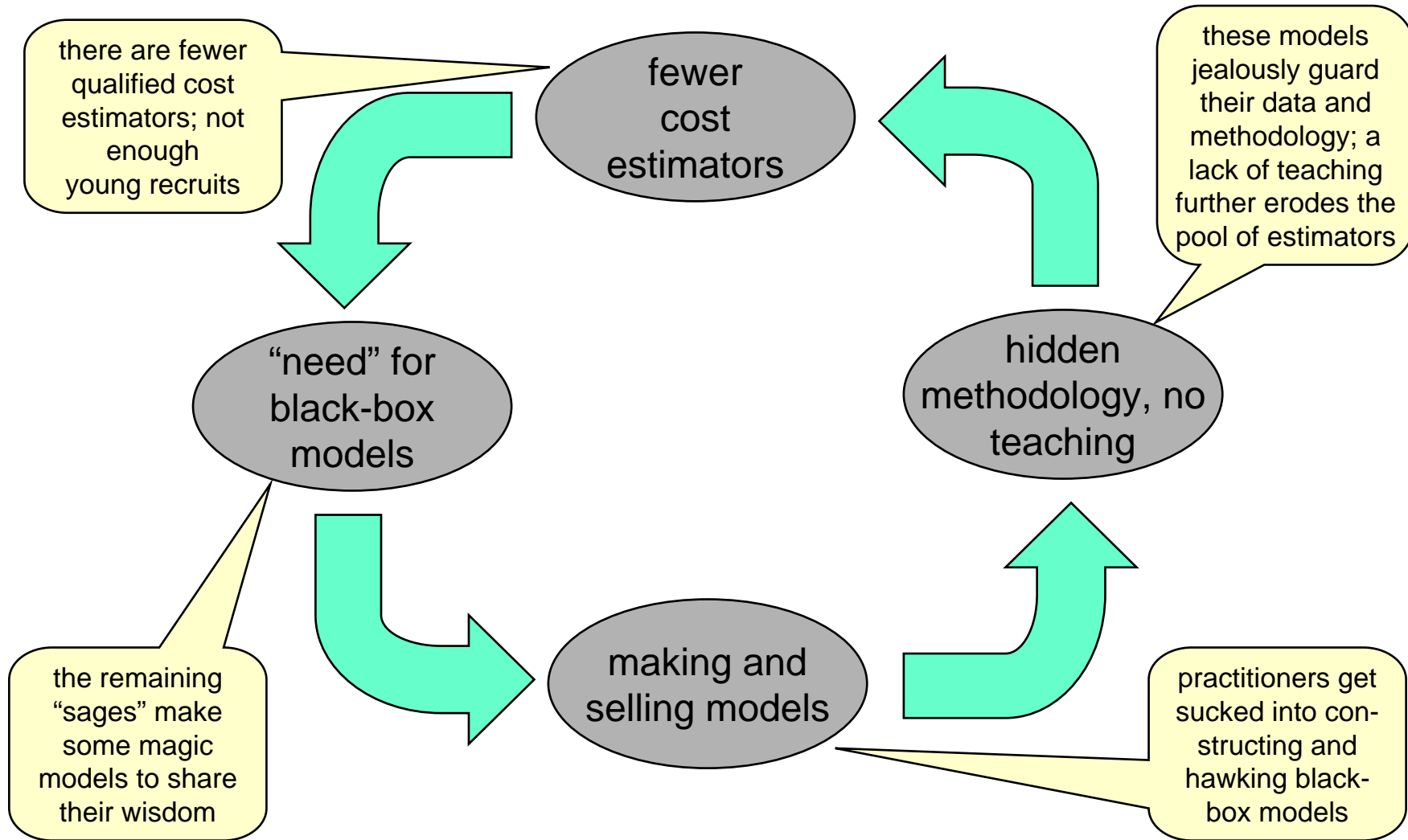 - Centralized online community to enhance interaction and collaboration

Professional Identity: Analyst Paradox

- <u>Problem</u>: Pool of trained analysts insufficient to support current market demand, yet not enough "cool" work to go around

- <u>Previous Situation</u>: *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

- <u>Progress Made</u>: Some successful "farm team" programs
  - Navy interns, corporate college hires
  - Improved training (e.g., CostPROF), rigorous certification

- <u>Future Research</u>: 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

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Black-Box Model Death Spiral

there are fewer qualified cost estimators; not enough young recruits

fewer cost estimators

these models jealously guard their data and methodology; a lack of teaching further erodes the pool of estimators

"need" for black-box models

hidden methodology, no teaching

the remaining "sages" make some magic models to share their wisdom

making and selling models

practitioners get sucked into con-structing and hawking black-box models

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Professional Identity: Integrity

- <u>Problem</u>: 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
- <u>Previous Situation</u>: No explicit community-wide commitment to integrity – too important to take for granted
  - Natural pressures work to compromise independence
- <u>Progress Made</u>: 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
- <u>Future Research</u>: Incorporate integrity in membership, training, and certification
  - Estimators must be beholden to the truth, first and foremost

Hilbert's Problems: Cost Techniques

- Defining the <u>double analogy</u> estimating technique

- <u>Standardization of CERs</u>

  - Developing "open" standards together with documentation requirements

  - Recent controversy on regression methods

  - Adjusting analogies and the role of the y-intercept

- Using <u>thought experiments</u> in conjunction with systematic data analysis to test theoretical constructs

  - Develop better mental models without overindulging the need to explain

- Development of a "<u>grand unified theory</u>" of learning curves

- Development of a "<u>grand unified theory</u>" of estimate at complete (EAC)

- <u>Physics-based estimating</u>, modeling and simulation, and chaos

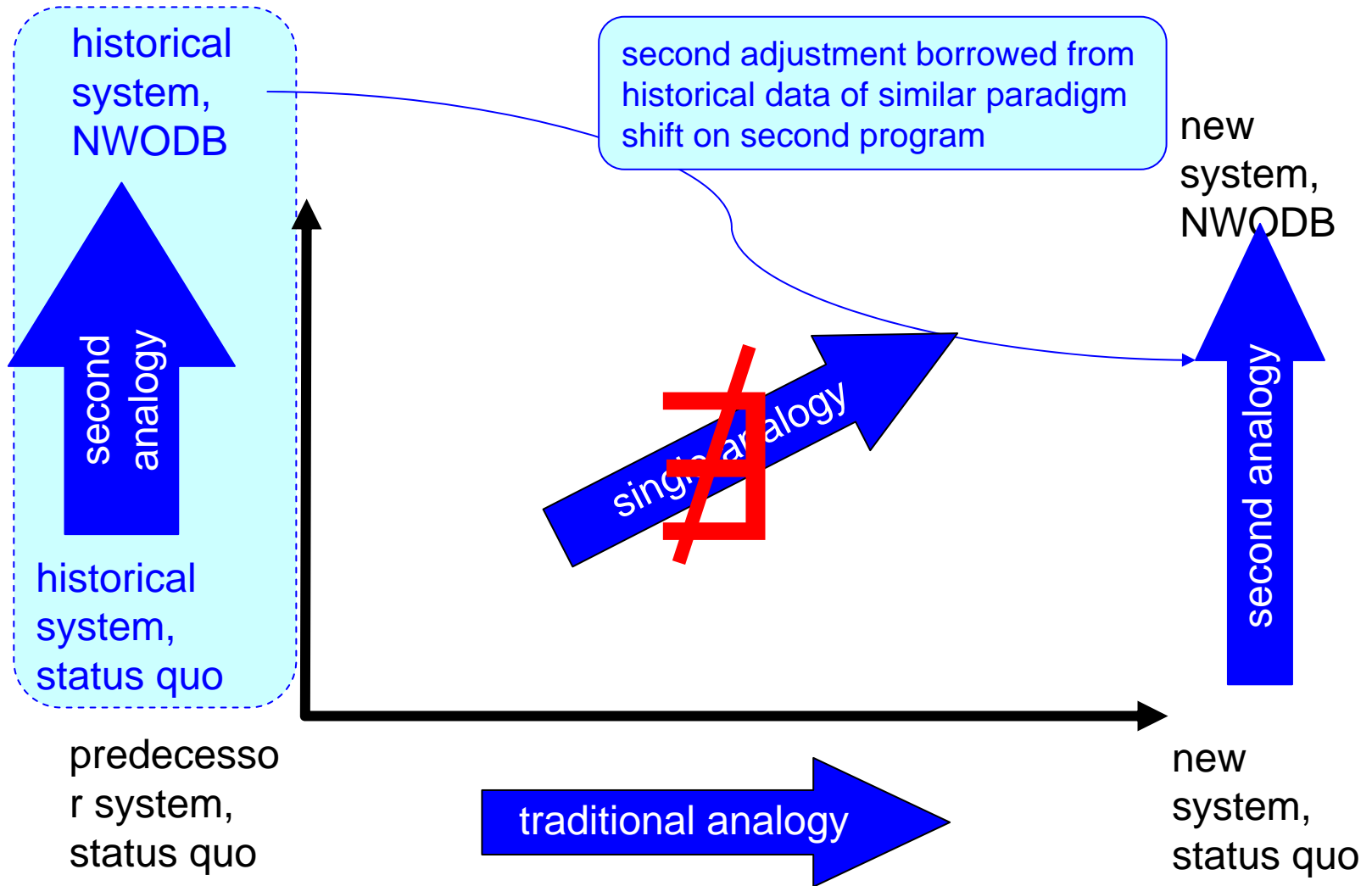- Development of techniques for estimating <u>emerging technology</u>

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Analytical Techniques: Double Analogy

- <u>Problem</u>: (Single) analogies are often poorly applied in estimating
  - One driving problem is need to account for "paradigm shifts"
- <u>Previous Situation</u>: 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
- <u>Progress Made</u>: "Adjusting Analogies" (Coleman, Summerville, Gupta) laid groundwork for more systematic and rigorous treatment of analogy estimates
- <u>Future Research</u>: 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"

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Double Analogy: Illustration

historical system, NWODB

second adjustment borrowed from historical data of similar paradigm shift on second program

new system, NWODB

second analogy

single analogy

second analogy

historical system, status quo

predecessor system, status quo

traditional analogy

new system, status quo

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Cost 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

- Previous Situation: Models, estimates, and organizations have idiosyncratic standards
  - Mild controversy following SCEA 2006 Best Paper Award illustrates lack of consensus in the community

- Progress Made: 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 IPSA/SCEA?

Cost Techniques: Thought Experiments

- <u>Problem</u>: While cost estimating must always rest on analysis of historical data, too often this analysis proceeds without a mental model
- <u>Previous Situation</u>: Analytical techniques tend to be applied by rote
  - Even when undertaken creatively, analysis can seem willy-nilly or unguided
- <u>Progress Made</u>: 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
- <u>Future Research</u>: 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

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Cost Techniques: Learning Curve "GUT"

- <u>Problem</u>: Learning curve can often be the single biggest driver in acquisition cost, yet projected learning curves are often assumed with little basis

- <u>Previous Situation</u>: 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

- <u>Progress Made</u>: 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)

- <u>Future Research</u>: Percent overlap approach offers promise for reliable learning curve predictions
  - Potential application to other commodities (UAVs, satellites)
  - Potential application *across* commodities

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Cost Techniques: EAC "GUT"

- <u>Problem</u>: Develop a consistent statistically-significant method for arriving at estimates at complete (EACs)

- <u>Previous Situation</u>: 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

- <u>Progress Made</u>: 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

- <u>Future Research</u>: 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

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Cost Techniques: Physics-Based Estimating

- <u>Problem</u>: Developing physics-based cost estimates and understanding implications for uncertainty in modeling and simulation (M&S) designed for deterministic inputs

- <u>Previous Situation</u>: 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

- <u>Progress Made</u>: 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

- <u>Future Research</u>: 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

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Cost 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.
- Previous Situation: Result is estimating in a "data-poor" environment and trying to make subjective adjustments to account for new technology and/or NWODB
- Progress Made: 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 Implementation

- <u>Meta-cost estimating</u>
  - 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 <u>data rights management</u>
- Establishing the <u>epistemology of cost models</u>
  - Or how the analyst knows the model is operating as desired to produce the "right" answer
  - AKA verification and validation (V&V)
- Description of <u>blended cost models</u>
- Use of <u>subject matter experts (SMEs)</u>

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Implementation: Meta-Cost Estimating

- <u>Problem</u>: 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!
- <u>Previous Situation</u>: 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
- <u>Progress Made</u>: Rule of thumb: NR = Recurring
  - Meta-cost estimating analogue of Indirect = Direct
  - Challenge to keep Recurring from producing burn-out, NR from stagnating
- <u>Future Research</u>: 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]."

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Implementation: Data Rights Management

- Problem: Adding organizational barriers to data access chokes off an already data-poor environment
- Previous 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!
- Progress Made: 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 Models

- <u>Problem</u>: 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 methodolgies correct? (validation)
- <u>Previous Situation</u>: 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 mode scope and complexity
    - Murder boards (internal) and reconciliation (external) help
- <u>Progress Made</u>: Comparison of COTS models looks at end results
  - Techniques like Conditional Formatting help identify errors
- <u>Future Research</u>: 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. standarization of CERs

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Implementation: Blended Cost Models

- Problem: Need a (better) way to incorporate multiple estimating techniques on a *simultaneous and continuous* basis

- Previous 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

- Progress Made: 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

Implementation: Subject Matter Experts

- Problem: There is no systematic process for eliciting assessment from subject matter experts (SMEs) and quantifying the risk and uncertainty inherent in those assessments

- Previous Situation: Expert Opinion taught as method of last resort
  - Frequently used nonetheless, especially in risk analysis

- Progress Made: Research into elicitation, adjustment, and conflation of SME inputs
  - Elicitation (Goldberg)
  - "Teaching Pigs to Sing" (Braxton, Coleman)
- Future Research: Develop SME track records, commodity-specific SME training

Hilbert's Problems: Cost/Schedule Risk

- Developing the <u>theoretical probabilistic underpinnings</u> 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
- Addressing the question of <u>skewness in risk</u>
- Refuting the "<u>self-fulfilling prophecy</u>" of cost growth (Acquisition)
- Developing the practice of <u>joint cost and schedule</u> risk analysis
- Developing <u>data-based coefficients of variation (CVs) and correlations</u>
- Addressing issues with <u>top-level vs. detailed risk</u> analysis

Risk: Probabilistic Underpinnings

- <u>Problem</u>: 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
- <u>Previous Situation</u>: Application of traditional regression techniques to sparse, uncontrolled data sets
  - Even social science can rely on larger data sets and some manner of control
- <u>Progress Made</u>: *The Lady Tasting Tea* gives an excellent perspective on the 20th-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
- <u>Future Research</u>: 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

Risk: Self-Fulfilling Prophecy

- <u>Problem</u>: 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!"
- <u>Previous Situation</u>: Sufficient risk "wedges" and MRs are rare
  - IPTs try to "game" system by initially padding estimates
- <u>Progress Made</u>: Thought experiment on spending to budgeted percentile (50th) – see next slides
  - "Do not budget to 80th percentile…"
- <u>Future Research</u>: 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

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Risk: Assumption of Skewness

- Many studies have asserted the CGF distribution across many DoD programs to be distributed log-normally, e.g., Arena and Younossi
  - 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
- A paper by Summerville and Coleman 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
- 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

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Risk: Joint Cost and Schedule

- <u>Problem</u>: Cost risk analysis and schedule risk analysis have traditionally been conducted in a vacuum from each other (if at all!)
- <u>Previous Situation</u>: Cost risk analysis approaches are fairly robust in the community
  - The schedule (IMS) has traditionally been the province of the EVM community
- <u>Progress Made</u>: Attention to schedule risk and integration with cost
  - Schedule analysis and schedule risk analysis taught for many years
  - GAO Schedule Assessment Guide
  - JCL NASA
  - Resource-loaded schedule approach, Hulett, Druker
  - Top-level parametric approach, Michael Ross (ISPA 2012 Best Paper)
  - Advances in simulation (speed and correlation)
- <u>Future Research</u>: Data to support analyses

Risk: Data-Based CVs and Correlations

- <u>Problem</u>: Coefficients of variation (CVs) observed in LCCEs are often implausibly low, and correlation is often omitted, not handled properly, or not based on historical data
- <u>Previous Situation</u>: Low CVs not addressed, seat-of-the-pants injected correlation
  - S-curves not shown or not labeled, low CV issue not realized or swept under the rug
  - Steve Book's famous 0.2-0.3 injected correlation solution was proposed principally to solve low CV issues, not to solve correlation per se
    - Followed by a number of recommendations for minimum correlations, e.g., the GAO Cost Estimating and Assessment Guide
- <u>Progress Made</u>: Data-based benchmarks for CVs and risk bounds
  - NCCA SAR Study, S-Curve Tools (CVs)
  - AFCAA CRUAMM, NCCA CSRUAH (risk bounds, correlations)
  - GAO Cost Estimating and Assessment Guide (correlations)
- <u>Future Research</u>: Analysis of actual correlations in a single system is urgently needed
  - System, such as a ground combat vehicle, or aircraft, with a fairly large quantity, with unit (not lot) data and a WBS at least two levels deep (the more the better)
  - Analyze pairwise correlations throughout
  - Could be expanded to multiple systems with standard WBS

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Risk: Top-Level vs. Detailed Risk

- <u>Problem</u>: Analysts are often unable to explain to the satisfaction of decision-makers the results of the Monte Carlo simulation for risk analysis conducted on a complex LCCE
  - Community is divided between top-level methods like eSBM and improving detailed methods that require Monte Carlo
- <u>Previous Situation</u>: Easy to run Monte Carlo "without a license"
  - COTS tools such as Crystal Ball, @Risk, and ACE RI$K, easy to "turn the crank"
  - If inputs are not based on defensible data, and if the process is not implemented correctly, then the outputs are suspect
  - Focus on improving the inputs and process for Monte Carlo risk analysis; *or*
  - Implement a more intuitive top-level risk analysis (e.g., Paul Garvey's eSBM)
- <u>Progress Made</u>: eSBM can use historically based CVs and even percentiles
- <u>Future Research</u>: Continue to pursue both approaches
  - Output sanity checks, incl Nunn-McCurdy acid test (Jim Baratta)
  - Plot nominal Nunn-McCurdy breach (not all that uncommon). If it falls at an unreasonably high percentile (above the 99th, say), that is a clear indication that the CV of the estimate is too low

Hilbert's Problems: Related Disciplines

- Transcending budgeting and establishing the role of cost estimating in <u>portfolio management</u> (Budgeting)

- Determining statistically the <u>impact of incentives on contract cost</u> control, if any (Contracts)
  - Consider the application of game theory to government-contractor interactions

- Better defining the <u>uncertain partnership with cost management</u> (CAIV)

- Better integrating with the <u>sister disciplines</u> of Earned Value Management (EVM), Schedule Analysis, Risk Management (RM), Program Management (PM), Contract Management, and Systems Engineering (SE)

Integration: Portfolio Management

- <u>Problem</u>: Current politicized annual budget process, though intended to enhance fiduciary responsibility, makes no verifiable contribution thereto!

- <u>Previous Situation</u>: Cost and risk do not contribute significantly enough to budgeting
  - Little "bang-for-the-buck" in constant "churn" of budget

- <u>Progress Made</u>: Navy and Air Force portfolio management approaches/models
  - Consortium for Advanced Manufacturing – International (CAM-I) Cost Management Systems (CMS) Beyond Budgeting round table

- <u>Future Research</u>: 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

- <u>Problem</u>: Cost incentives in contracts have not been shown to reduce cost growth

- <u>Previous Situation</u>: 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.

- <u>Progress Made</u>: Risk-based ROS analysis

- <u>Future Research</u>: Historical contract analysis

Integration: Cost Management

- <u>Problem</u>: Cost estimating is needed to enable cost management but is often complicit in "cost fantasy"

- <u>Previous Situation</u>: CAIV not properly applied

- <u>Progress Made</u>: Erstwhile Navy cost participation in CAM-I CMS Target Costing working group

- <u>Future Research</u>: Historical study of sources of cost reduction
  - Do less
  - Do things better
  - Do things differently

Integration: Sister Disciplines

- <u>Problem</u>: Too often cost estimating operates in a vacuum from (potentially) related disciplines, or works only at arm's length, where things are "thrown over the fence," or is at odds with them

- <u>Previous Situation</u>: Traditional IPT roles, competing interests

- <u>Progress Made</u>: Interaction at conferences, through working groups, and on programs

- <u>Future Research</u>: Integration with Earned Value Management (EVM), Schedule Analysis, Risk Management (RM), Program Management (PM), Contract Management, and Systems Engineering (SE)

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

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Conclusions

- 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 past or future research that addresses one or more of these problems

PBraxton@technomics.net, (703) 944-3114