The Society of Cost Estimating and Analysis

NORTHROP GRUMMAN

What Percentile Are We At Now (And Where Are We Going?)

"Are We Really at the 50th Percentile?"

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Outline

- Motivation
- Coverage
- Cost Realism
- Evidence of Understatement
- Mathematical Difficulties Presented by Estimation of the Variance
- Sources Of Understatement of the Mean and the Variance
  - Resulting in understating of the 80th percentile
- Last Thoughts and Conclusion

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Motivation

- Cost growth has never been acceptable, but it has been tolerated
- Today's political climate and economic conditions have made cost growth much more damaging than ever before - it has become intolerable
- Many agencies, corporations and offices seek solutions to cost growth. These solutions take the form of:
  - More attention to the basics of cost estimation, documentation and BOEs
  - More attention to risk analysis
  - Calls for estimates and funding at higher percentiles
  - Calls for bids to be
    - Submitted at higher percentiles
    - Structured for better protection of ROS at higher percentiles
- This begs the question: What percentile are we now operating at, and what does that say about our quest for
  - Better cost estimates
  - Determination of higher percentiles?
- We hope it goes without saying that if we don't know where we are, we can't get to where we wish to be
  - But we said it anyway!
- Our cost estimates and risk analyses need significant scrutiny
  - Errors of understatement are far too pervasive to take them at face value
  - We hope that we can convince the reader that one cannot simply trust "any old" cost estimate, risk analysis or S-curve
  - *Doing the same thing (or even more of it) and expecting a different outcome is madness*

Focus of this Paper

- In prior papers we examined:
  - Aspects of cost realism that dealt mostly with the technical solution[1]
  - Common errors in the set up and execution of risk models[2]
  - Historical evidence for Cost Estimating Risk[3] … the bias and variability inherent in our cost estimates
  - Broad challenges in cost estimating and risk analysis[4]
- This paper will not dwell on:
  - Schedule and technical risks, except in passing, for completeness
  - Errors of risk analysis execution covered in the earlier paper except as they relate
  - Historical analysis except where it can frame the problem or suggest the size of the challenge
  - General problems in cost estimating except where they have a known impact on understatement
- In this paper we will:
  - Dwell on cost estimating risk as manifested in cost estimation and risk analysis
  - Discuss what twenty years of risk analysis and independent cost estimation have taught us about typical errors and how they contribute to understating middle and higher percentiles

1. *Two Timely Topics: Independence and Cost Realism, R. L. Coleman, J. R. Summerville, S. S. Gupta,* ASC/Industry Cost/Schedule Workshop, Oct 04, SCEA/ISPA 2005
2. *Taking a Second Look: The Potential Pitfalls of Popular Risk Methodologies, E. R. Druker, R. L. Coleman, C. J. Leonetti, P. J. Braxton,* ISPA/SCEA 2007, NASA Project Management Challenge 2008
3. *Analysis and Implementation of Cost Estimating Risk in the Ballistic Missile Defense Organization (BMDO) Risk Model, A Study of Distribution,* J. R. Summerville, H. F. Chelson, R. L. Coleman, D. M. Snead, ISPA/SCEA1999
4. *Hilbert's Problems for Cost Estimating*, P. J. Braxton, R. L. Coleman, ISPA/SCEA 2007

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Cost Realism – What We Are Charged With?

- "'Cost realism' means that the costs in an offeror's proposal—
  (1) Are realistic for the work to be performed;
  (2) Reflect a clear understanding of the requirements; and
  (3) Are consistent with the various elements of the offeror's technical proposal."[5]
- *"The probable cost should reflect the SEB's (selection evaluation board) best estimate of the cost of any contract which might result from that offeror's proposal, including any recommended additions or reductions in personnel, equipment, or materials. To the extent that the recommended additions or reductions reflect a lack of understanding of the requirements of the RFP (request for proposal), that lack of understanding should be reflected in the scoring of the Mission Suitability factor, subfactors, and elements."*[6]

5. FAR 2.101
6. *Competitive Negotiation: The Source Selection Process,* Nash, R.C., and J. Cibinic, Jr., National Law Center, Government Contracts Program, The George Washington University, Washington, D.C., 1993

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Evidence of Understatement

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Evidence of Understatement

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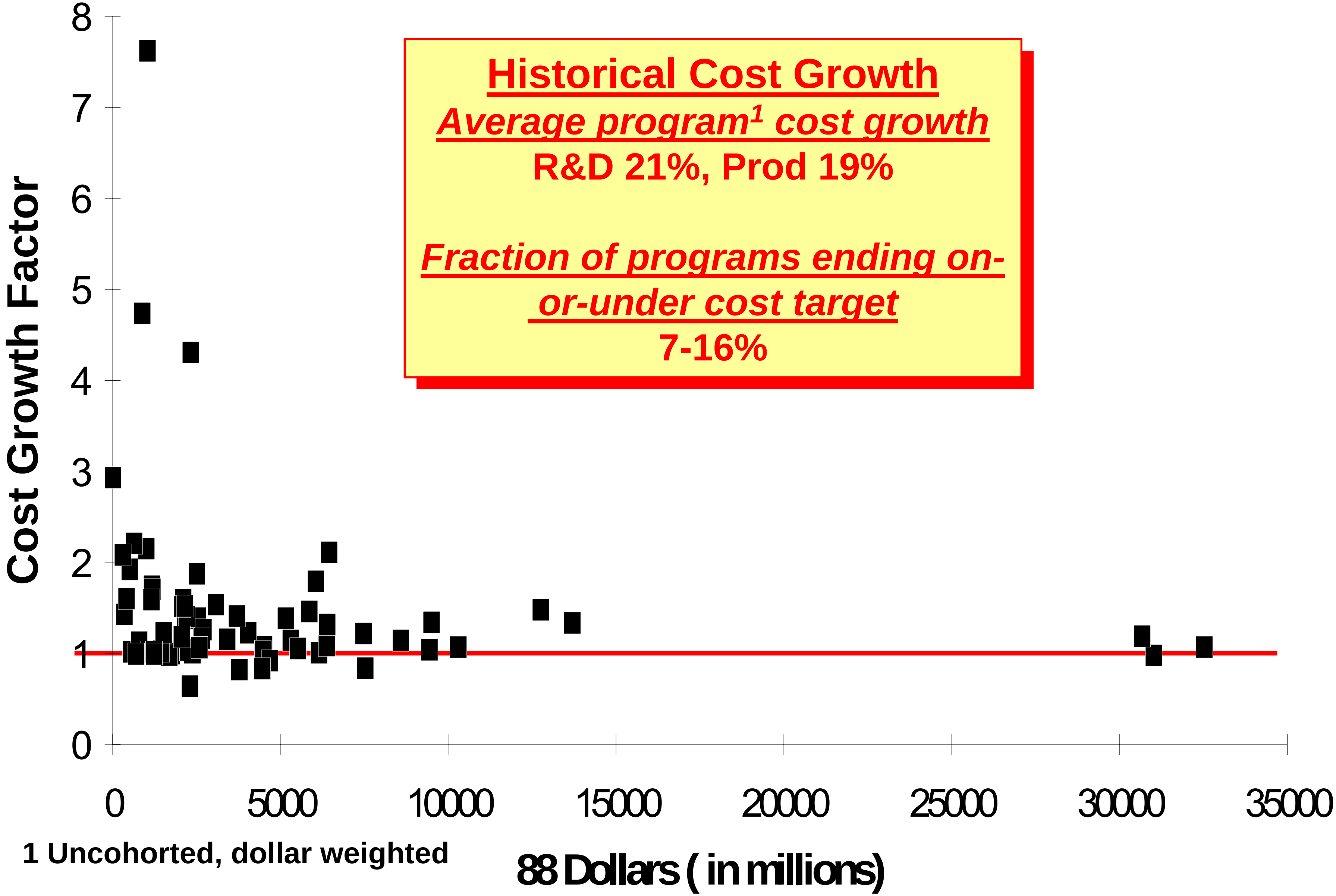
So, How Are We Doing? Are We at the 50th Percentile now?



1 Uncohorted, dollar weighted

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Discussion – Aren't We at the 50th?

- We claim our costs are realistic
- We claim we estimate costs at the 50th percentile
  - This should mean we have 50% low and 50% high outcomes
- We have an unchanging cost growth pattern showing that about 12% (1 in 8) of our *estimates* are *high* and 88% are *low*
- The conclusions are inescapable
  - Our costs are not realistic
  - Our costs are at the 12th percentile, not the 50th percentile
  - This understatement will affect our computation of all percentiles, making our assertion of the value of the 80th percentile necessarily suspect
- We will now discuss how, in our opinion, based on our experience, we all got so far off the mark
- We will discuss determination of the mean and the variance and then categorize and illuminate the sources of their understatement

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Mathematical Difficulties Presented by Estimation of the Variance

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Estimating Variance

- Traditional cost estimating techniques have aimed to answer one, or both of the questions:
  - "On average, what will this program cost?"
  - "What is the 50th percentile confidence level for this estimate?"
- Recognizing the cost growth patterns seen on the preceding slides, there has been a recent push by all parties to answer a distinctly different (although related) question:
  - What are the potential range of outcomes for the cost of this system?
  - Which inevitably leads to the follow-on question:
    - "If I want to be x% sure I will complete my program at or under cost, what should I budget for this program?"
      - There is a trend of late to ask for the 70th or 80th percentile in government
      - Some parts of industry have been working at similar, higher percentiles for their internal reviews
- Answering this question requires a fundamentally different understanding of the potential costs of the system
  - The mean estimate is just a single point on the distribution of potential costs, and without additional knowledge, it is impossible to say at what percentile it falls
- To determine the distribution of costs, the variance of the estimate must be determined
  - Not to mention (but we will) that to determine the distribution requires the correct mean in the first place!

Estimating the Mean vs. the Variance

- Estimating variance is several degrees more difficult than estimating the mean
  - Among other issues, it is a second-order moment, thus less stable
- In general, mistakes in estimating the variance are far more difficult to spot
  - In general, the mean is preserved, but the variance (and thus CV) is decreased
  - This decreases the cost at the higher percentiles and increases the cost estimate at lower percentiles

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Estimating Variance

- Assessing variance around an estimate typically lies within the realm of risk analysis
- Risk analysis requires a far broader range of mathematical sophistication than traditional estimating
  - Estimating the mean generally requires (just in terms of math) a basic understanding of statistics
  - Estimating the variance requires sophisticated statistics, probability and often, even computer science knowledge
- Because of the large skill-set required to correctly perform risk analysis, it is at a far greater risk of being done incorrectly
  - It is also harder to spot errors in risk analysis because oftentimes all that is presented is an S-curve

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Sources Of Understatement of the Mean and the Variance

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Sources of Understatement

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- Sources of understatement of all percentiles are found in cost estimation and risk analysis (note 1)
  - These sources are grouped below in rough descending order of impact
  - Some affect measures of central tendency (the mean), understating *all* percentiles, and some affect measures of variability, understating *upper* percentiles (note 2)
  - Both cost estimating errors and risk analysis errors affect the mean and the variance
    - The distinction is somewhat arbitrary, but is customary, and so we will retain it
- In cost estimation, understatement occurs in the following ways
  1. Lack of basis in historical data, which gives free rein to optimism
  2. Errors, which seem “always to understate” (note 3)
  3. Omissions of elements of cost
  4. Systematic understatement of cost in non-linear CERs
- In risk analysis, understatement occurs in the following ways
  1. Omission of risks and elements of bias
  2. Omission of elements of variability
  3. Inadequate determination of cost relationships (too few CERs)
  4. Failure to include functional correlation
  5. Errors which seem “always to understate” (note 2)
  6. Omission of correlation of any type
  7. Insufficient data causing unrecognized wide(r) prediction intervals
  8. Systematic understatement of variability in non-linear CERs

Notes:
1.The authors assert that a cost estimate is incomplete until risk is accounted for, but in the usual parlance, a cost estimate does not include accounting for risks.
2. Understating variance overstates lower percentiles, but this is swamped by understatement of the mean and is not of much interest since “we always overrun”
3. We have used the usual nonjudgmental term “error” but observe that errors that systematically favor the erring party not truly errors – and find that in our, experience, errors of overstatement are rare.

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Cost: Lack Of Basis In Historical Data

- This is the intellectually simplest and yet most pervasive problem in cost estimation
- Data is expensive and difficult to obtain, difficult to normalize and complicated to deal with, so it is routinely lacking
  - That said, the alibi of "insufficient" data is the first recourse of shoddy estimators in all endeavors, particularly in BOEs
  - "Not enough data" is always true, "no data" almost never is
- "Hope springs eternal" and consequently, lacking an historical basis, engineers, pricers, and cost estimators will virtually always underestimate
  - "Anecdotal actuals" are extremely vulnerable to flattering misremembering
  - Optimism guards us against the burden of having eaten the "forbidden fruit of the tree of knowledge" and thereby gaining the discouraging knowledge of our own mortality

  - We ask for conservatism in cost in vain because we are fighting the biologic imperative of self preservation to ask for conservatism
- Even *with* data, we find optimism and cherry picking to be pervasive, so it is unrealistic to hope for realism with *no* bridle on our optimism

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Cost: Errors Which Seem "Always To Understate"

- Virtually no Independent Cost Evaluation, Assessment or Estimate ever happens where there is not at least one, and often many, cases where data are available but misused
- Errors should be symmetric and thus introduce no bias, but experience and studies show that errors tend to understate cost
  - Cost Estimating Risk[7] has a mean of +8.7% in R&D and +3.1% in production with a standard deviation of 15%
- Errors include, but are not limited to:
  - Simple averages vice weighted averages which give undue weight to smaller data points
  - Adjusting analogies using simple ratios vice flatter slopes[8] which can over or understate
  - Ratios vice CERs, which amounts to missing the effect of the y intercept[9]
  - Cherry picking among single data points resulting in choosing the one that gives the hoped-for answer

7. *Analysis and Implementation of Cost Estimating Risk in the Ballistic Missile Defense Organization (BMDO) Risk Model, A Study of Distribution, J. R. Summerville, H. F. Chelson, R. L. Coleman, D. M. Snead*, ISPA/SCEA1999
8. *Analogies: Techniques for Adjusting Them, R. L. Coleman, J. R. Summerville, S. S. Gupta,* So. MD SCEA Chapter, Feb 2004, ASC/Industry Cost/Schedule Workshop, Apr 04, SCEA 2004, MORS 2004
9. *"To b or Not to b" The y-Intercept in Cost Estimation*, R. L. Coleman, J. R. Summerville, P. J. Braxton, B. L. Cullis, E. R. Druker, ISPA/SCEA 2007

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Cost: Omissions of Elements

- Virtually all Independent Cost Evaluations, Assessments and Estimates uncover at least one element of the WBS that is simply omitted
- Omissions are virtually unavoidable, but experience shows that they are not often a large percent
  - That said, even small omissions contribute to overruns
- Omissions seem to be more common in “Below-the-Line” elements
  - Perhaps because most proposal teams and program teams are heavy in engineers and domain experts and these teams are by nature focused on the object to be built and less interested in the mundane business of management and “less glamorous” pursuits such as contracting, subcontracting, procurement, EVM, RM, and other forms of administration
  - The failure to give due weight to such disciplines results in underrepresentation on the team and so underestimation (or omission) of the requirement
  - Some underrepresentation (Cost Estimators, Risk managers, EVM, to name a few) results in under dosage of the very medicine that could ameliorate the broader problem

Cost: Systematic Understatement In Non-linear CERs

- Non-linear CERs are not common in cost estimation but where they occur they result in understatement of the estimate
- Understatement has been treated extensively in the literature[10] but is still commonly missed
- Recent research indicates that improper use of power CERs results in much larger understatement of costs than previously thought[11]

10. *The Impact of Using Log-Error CERs Outside the Data Range and PING Factor,* Hu, S., SCEA 2005
11. *Don't Let the Financial Crisis Happen to You: Why estimates using power CERs are likely to experience cost growth,* Eric R. Druker, Richard L. Coleman, Peter J. Braxton, SCEA 2009

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Risk: Omission Of Risks And Elements Of Bias

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- Risk Management methods, notably the Risk Cube, must be calibrated[12] to allow adequate room for large risks
  - Allowable values must include room for at least the average for the commodity, and preferably at least one standard deviation more
  - Limiting values to the "tolerance for risk in the program" (which is a common practice) encourages understatement
- Any risk method that relies on enumeration is vulnerable to understatement
  - Some "obvious risks" are bound to drop through the cracks
  - The sum of a number of seemingly inconsequential risks is probably as big as the biggest risk
  - "Unknown unknowns" is a catchphrase for risks that we are unable to imagine or cannot quite believe possible
    - The sinking of the *Mary Rose*, the *Vasa* and the *Titanic*; the Black Plague, the Spanish Influenza of 1917 and the SARS virus; the German drives through the Ardennes in 1939 and 1944, the attack on Pearl Harbor, the Kamikaze, and the attacks of 9/11; and the tsunami in Indonesia and Hurricane Katrina are examples across many disciplines and all ages
- Any risk methodology that relies on experts to score or enumerate is vulnerable to understatement
  - Experts who know the program are likely to be advocates
  - Experts who don't know the program are likely to miss things
- Risk Management, which is a discipline conducted "by engineers for engineers", is prone to focus narrowly on technical issues, to the detriment of:
  - Cost-on-cost WBS elements, such as PM
  - Business risks such as changing rates and business rates
  - Program-wide risks
  - Mathematical subtleties, which matter greatly in risk analysis
- The Scenario Based Method[13] is particularly prone to understatement
  - Only one risk scenario is costed, making *direct* determination of variability impossible
  - The choice of the scenario can understate or overstate, and since the choice of the scenario is discretionary, it is particularly vulnerable to the same optimism that affected the estimate it is designed to correct

12. *Making Risk Management Tools More Credible - Calibrating the Risk Cube*, J. R. Summerville, R. L. Coleman, M. E. Dameron, SCEA 2006, DoDCAS 2007
13. *A Scenario-Based Method (SBM) for Cost Risk Analysis*, Paul Garvey, DoDCAS 2008

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Risk: Omission Of Elements Of Variability

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- Many risk methodologies omit the variability in the initial cost estimate
  - As previously cited, cost estimating errors contribute a variability of at least 15% which is less than the contribution of what are classically called risks, which contribute[14] as much as 40%, but still substantial
- Even unbiased, well-informed experts are prone to understate extreme values
  - This reduces variance and deflates higher percentiles
- Many risk analyses assess at a low level of the WBS and fall victim of the "square root of n problem"[15]
  - The coefficient of variation of the sum of independent random variables deflates proportionately with the square root of the number of variables (WBS elements)
  - Failure to take this into account, coupled with overly tight variances at the lower level, will shrink total variability to a ridiculous extent
- Understating variability of CERs and statistics[16]
  - Omitting variability altogether
  - Using SEEs instead of Confidence Intervals
  - Using Confidence Intervals instead of Prediction Intervals
  - Modeling variability as a Normal instead of a Student's t in Confidence or Prediction Intervals
  - A last component of this problem, error beyond the Student's t, will be treated separately
- Many analysts unintentionally deflate variability when substituting triangles for normals and log normals
  - In the triangular-for-normal substitution, a factor of $\sqrt{6}$ is needed to derive endpoints from standard deviations (see b/u)
  - With the correct substitution, there is little-to-no error

14. *NAVAIR Cost Growth Study*, R. L. Coleman, M.E. Dameron, C.L. Pullen, J.R. Summerville, D.M. Snead, 34th DoDCAS and ISPA/SCEA 2001
15. *Taking a Second Look: The Potential Pitfalls of Popular Risk Methodologies*, E. R. Druker, R. L. Coleman, C. J. Leonetti, P. J. Braxton, ISPA/SCEA 2007, NASA Project Management Challenge 2008
16. *Taking the Next Step: Turning CER-Based Estimates into Risk Distributions*, Christina M. Kanick, Eric R. Druker, Richard L. Coleman, Matthew M. Cain, Peter J. Braxton, SCEA 2008

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Risk: Inadequate Determination Of Cost Relationships

- CERs reduce the variance of the ultimate cost estimate by explaining variability in terms of independent variables
  - The percent of variation explained is equal to r^2
  - Failure to determine and use CERs will leave otherwise explainable variance in our estimates because if we use CERs, we can reduce the variability by a percent equal to r^2
    - This effect can overstate variance by as much as double in individual CERs
- Use of analogies and buildups in place of averages would seem to avoid this issue, but this is illusory; the variability is not avoided, it is simply unrecognized
  - If we take this route, we understate variability
- There is an effect on cost but the error is hopefully symmetric
  - All other things being equal, adjusted analogies understate below and overstate above the analogy point[17]
  - Apart for miniaturization, most new products are larger than their predecessors, so this error may tend to raise costs

17. *Analogies: Techniques for Adjusting Them*, R. L. Coleman, J. R. Summerville, S. S. Gupta, So. MD SCEA Chapter, Feb 2004, ASC/Industry Cost/Schedule Workshop, Apr 04, SCEA 2004, MORS 2004

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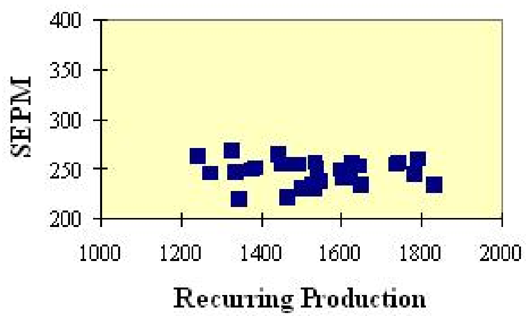
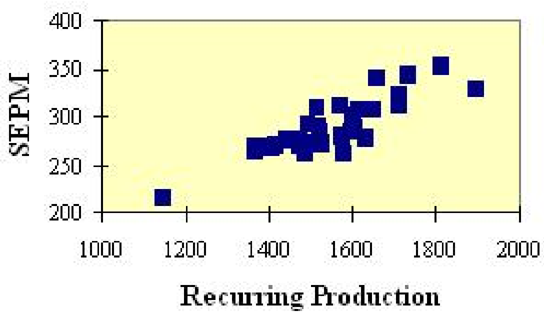
Risk: Failure To Include Functional Correlation

- It has been shown that functional correlation[18] adds substantially to cost and variation in elements which are derived as cost-on-cost
  - The rise in the mean is properly a cost estimating error, but is only detected in risk analysis and is customarily categorized as risk so we included here under risk
  - The rise in variance affects all percentiles away from the mean
  - The graphic shows that functional correlation causes a clear rise in the mean and variance of SEPM when estimated as a function of Recurring Production
  - Functional correlation, first described in the footnoted paper, is easily implemented by cell-referencing cost-on-cost CERs to their driving costs in the risk model



Without Functional Correlation



With Functional Correlation

18. *An Overview of Correlation and Functional Dependencies in Cost Risk and Uncertainty Analysis*, R. L. Coleman, S. S. Gupta, DoDCAS 1994

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Risk: Errors Which Seem "Always to Understate"

- Apart from the other enumerable problems in risk analyses there always seem to be errors that deflate variance and lower the mean
  - Independent assessment results in systematically higher probabilities for events than those assessed by advocates
    - This causes a rise in ultimate costs, so acts to understate the mean
    - Understating probabilities of risks in the Bernoulli case typically deflates variability because the variance of a Bernoulli ($cost^2 * p * (1-p)$) can be shown to be at its maximum at probability of $p = 0.5$
  - Proposal and Program teams believe that they can mitigate or "manage away" risks that in the end still manifest
    - This error deflates all percentiles and reduces assessed variance
  - Less commonly than probability understatement, there are cases of consequence understatement which understate all percentiles

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Risk: Omission of Correlation of Any Type

- It is well known that omitting positive correlation understates variance
  - Negative correlation is not common, but exists
    - One of the ways it can occur is when disparate data sources assign costs to different WBS elements, so while total costs may be similar, negative correlations arise between lower-level WBS items
    - This is not thought to be common enough to worry about
- Some risk analysts insert arbitrary small correlations throughout their estimate to inflate variance
  - This solution achieves higher variance but creates false phantom CERs among all cost elements[19] and so is distasteful to the authors
  - Just as effectively the analyst can insert an inflationary cost estimating variability, if it is not included, or another single risk with zero mean and achieve the same result with more traceability

19. *Relational Correlation, What to do when Functional Correlation is Impossible*, R.L. Coleman, J.R. Summerville, M.E. Dameron, C.L. Pullen, TASC, Inc., S. S. Gupta, IC CAIG, ISPA/SCEA 2001

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Risk: Insufficient Data Causing Unrecognized Wide(r) Prediction Intervals

- Prediction intervals for lower numbers of observations are correctly modeled as a Student's t distribution
  - The variance of the Student's t shrinks with the rise in degrees of freedom, which rise with the number of observations
    - Thus, more data allows us to estimate costs with tighter error bands
    - The limiting case of this arises at about 30 observations, at which point the prediction interval is normal and no further improvement can be had
    - This phenomenon occurs with simple averages as well as with regressions
- The punishment for insufficient data is thus greater uncertainty
- This problem is often unrecognized because prediction intervals are not modeled correctly[20]
  - Incorrect modeling conceals both the problem and the solution

20. *Taking the Next Step: Turning CER-Based Estimates into Risk Distributions*, Christina M. Kanick, Eric R. Druker, Richard L. Coleman, Matthew M. Cain, Peter J. Braxton, SCEA 2008

Risk: Systematic Understatement Of Variability In Non-linear CERs

- Non-linear CERs are not common in cost estimation but where they occur they result in understatement of the variability of the cost estimate
- Understatement has been treated extensively in the literature[21], but is still commonly missed
- Recent research indicates that improper use of power CERs results in much larger understatement of variability than previously thought[21]

Note: This slide is a near duplicate of the one in "cost." The effect applies both places to such a large extent that it was thought worth repeating

21. *Don't Let the Financial Crisis Happen to You: Why estimates using power CERs are likely to experience cost growth,* Eric R. Druker, Richard L. Coleman, Peter J. Braxton, SCEA 2009

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The Effect of Underestimation: A Summary

Area	Source	Mean & 50th	Standard Deviation	80th
Cost	Lack Of Basis In Historical Data	Understate	-	Understate
	Errors Which Seem "Always To Understate"	Understate	-	Understate
	Omissions of Elements	Understate	-	Understate
	Systematic Understatement In Non-linear CERs	Understate	-	Understate
Risk	Omission Of Risks And Elements Of Bias	Understate	Understate	Understate
	Omission Of Elements Of Variability	-	Understate	Understate
	Inadequate Determination Of Cost Relationships	-	Overstate or Understate	Overstate or Understate
	Failure To Include Functional Correlation	Understate	Understate	Understate
	Errors Which Seem "Always To Understate"	Understate	Understate	Understate
	Omission Of Correlation Of Any Type	-	Understate	Understate
	Insufficient Data Causing Unrecognized Wide(r) Prediction Intervals	-	Understate	Understate
	Systematic Understatement In Non-linear CERs	-	Understate	Understate

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Last Thoughts and Conclusions

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Last Thoughts: Overreaction and Confusion?

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- It is widely understood that estimating at higher confidence levels will overtax budgets and thus reduce the number of systems we can acquire[22]
- We speculate that the press for higher confidence is partly motivated by reaction to the idea that we are at the 50th now, and that the cure is to go to the 80th
  - If we aren't really at the 50th now, perhaps just going to the true 50th is enough?
- We also speculate that the call for "higher confidence estimates" is really a call for tighter variance (narrower error bands)
  - Hearing a call for higher confidence, the statistician counsels a rise in the budget or the bid, when the decision maker may simply mean "do a better job on the cost estimate"
- Correcting the foregoing problems will help whether we wish to go to a higher confidence level or just to do a better job on the cost estimate

22. *The Percentile Problem: How Much is Enough?,* Cincotta, K, SCEA 2008

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Conclusions

- Many agencies, corporations, and organizations are now asking for more protection against cost growth
  - Cost estimation is getting more attention
  - Risk analysis is a growth business
- We speculate that the press for higher-confidence estimates is partly a conscious or unconscious reaction to pervasive understatement of cost estimates and risk-adjusted cost estimates
  - *"We always seem to overrun, so maybe if we budget at the (bogus) 80th, we will come in at-or-under half the time?"*
  - As an alternative, if we budget at the true 50th, perhaps that will be enough
- At the very least, we hope that we have made the case that one cannot just trust "any old" cost estimate, risk-adjusted estimate or s-curve
  - At best, we hope that illumination will lead to correction
- The most damaging effect, going forward, of continued understatement of percentiles could be a loss of faith in cost estimation and risk analysis and a reversion to the dark ages for both

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Backup

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Substituting a Triangular for a Normal: The √6 Factor

- For a triangle:

  Mean = 1/3 * (H+M+L)

  Variance = 1/18 * [(H-L)2 + (ML-L)(ML-H)]

  where L = Low, M = Most likely or Middle, H = High

- It is a straight-forward derivation from the formulas for the mean and variance to show that for any symmetric triangular distribution, one half the base is greater than the standard deviation by a factor of √6.
  - This is done by substituting, in the expression of the variance, the value of b (the half-base length) for the values of H-ML and ML-L, and 2b for the value of H-L. Then simply solve for the variance in terms of b.
- To approximate a normal, this factor of √6 is multiplied by the standard deviation of the normal to be emulated. This number is used as the half-base length.
  - By this means, end points are found that will produce a triangular distribution that emulates the underlying normal in mean and standard deviation.
- It should be noted that this triangular distribution differs from the underlying normal in all other moments, and at all percentiles other than the median and the two points corresponding to the standard deviation, but the difference is minor.

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