Why Can’t We All Get Along? II (The Sequel)

Larry Wolfarth
Email: lawrence.wolfarth@nasa.gov
Cell: 571-216-2224
Office: 202-358-0065

Presentation to 2013 NASA Cost Symposium
August 27, 2013
Special Thanks

- Dr. Neal Hulkower (ret.)
- Ray Covert
- John Neatrour
- Nate Menton
- Jo Gunderson
- Joe Hamaker

Justin Van Genderen ad, based on Stanley Kubrick’s “2001: A Space Odyssey” film
http://laughingsquid.com/2001-a-space-odyssey-themed-ads-for-hal-9000-pan-am/

“At PanAm, the sky is no longer the limit....”
A Brain Challenge…

The Out-Shuffle, 4 cards

1 2 3 4

1 2 3 4

1 2 3 4

The In-Shuffle, 4 cards

x 1 2 3 4

1 3 1 4 2

2 4 3 2 1

3 2 4 1 3

4 1 2 3 4

Cards in Deck | Number of out- and in-shuffles required to restore original order
---|---
4 | 2 4
8 | 3 6
12 | 10 12
52 | ? 8
54 | ? ?


Focus was on reconciliation of multiple cost estimates

Context:
- Project estimates are often “flawed”
- Search for “truth”

The authors are veterans of many Independent Cost Estimates (ICEs) and Very Few Program Office Estimates (POEs) by Choice!
1961: NASA Administrator Jim Webb asked to provide Congress and President Kennedy with a manned moon project
- Webb had been briefed on a $10 billion project
- He prudently decided to quote a $20 to $40 billion range

1983: O’Keefe Sullivan from MSFC… named lead estimator for Space Station
- Sullivan estimate was $11.8 to $14 billion (1984 $)
- NASA Administrator Jim Beggs, under pressure to propose something affordable, committed to Congress in September of 1983 to build the Station for $8 billion
- NASA pushed ahead with Station Phase B
- In the fall of 1987 the Critical Evaluation Task Force was organized to narrow the options
  - Bill Rutlege led team of NASA estimators (Bill Hicks, Richard Whitlock, Tom LaCroix and Dave Bates)
  - The new Station baseline design was estimated at $14 billion, which was submitted to OMB

Beyond Political Considerations: Cost Estimates Are Based on Models...

... and models are imperfect representations of a future reality

Why We Should Expect Problems (Theoretical)

“‘Four’ is cloned from ‘Two’, and has the mentality of an overly-curious child. Unfortunately since he is a clone-of-a-clone, his IQ is considerably lower than that of his predecessors, since the personality defects are more pronounced when a clone is cloned (The analogy from the movie refers to how a copy of a copy may not be as ‘sharp’ as the original).” http://en.wikipedia.org/wiki/Multiplicity_(film)
Findings (2006)

- Why do cost estimates differ?
  - Different Motives
  - Different Methodologies
  - Time Lag
  - Lingering Vagueness
  - Different Ground Rules and Assumptions

- Estimate reconciliation is a process of understanding what drives the differences*

*Not the differences *per se*
Summary (2006)

- Any cost estimate is a prediction and predictions are always precisely wrong!
- There are any number of reasons why cost estimates differ
- Recognize that reconciliation means identifying the valid reasons for the differences, not unnaturally forcing two estimates closer to each other
- Use relevant history as a source of sanity checks

- The Program/Project office estimate (POE) represents more of a policy as to how much management is willing to pay and what the head count will be
- The ICE is more likely to represent how much the program or project actually could cost
What’s Changed at NASA in Cost Estimating Since 2006?

Evolution of Confidence Level Analysis at NASA

Project Estimates (Advocacy)

- 2002 and before
  - Primarily Bottoms up Point Estimates and Cost Confidence Levels

- 2003 - 2007
  - Formalized Cost Confidence Level Policy (2006)

- 2/2007
  - JCL Policy Established

- 1/2009
  - Cost-Loaded Schedule Requirement Established

- 5/2009
  - Refined Requirements for KDP-C Established

- 12/2009
  - Add KDP-B Confidence Levels for cost & schedule ranges

- 11/2010
  - NPR 7120.5E Effective

- 8/2012
  - Assessment of Project JCLs
  - KDP-B cost & schedule probabilistic ranges

“Independent” Estimates (Non-Advocacy)

A Change in Perspective

2006

What’s the right cost estimate?

2013

What’s the right estimated cost (range)?
Recent NASA Cost Growth History

Overall reduction in cost growth attributable to a combination of:

- Improved cost estimating, esp. introduction of cost ranges
- Improvements in Program Planning & Control (PP&C)
- Increased oversight
- Consistent policy and support for Unallocated Cost Expenditures (UFE), schedule reserves
But...


- Cost growth remains a significant challenge on some major missions.
- Remains difficult to predict which missions will experience cost growth and its magnitude.
- Is it RISK?
- Is it UNCERTAINTY?
Cost Estimates Available to NASA For PDR/KDP-C Program Analysis

2010:
- Project Office Baseline Cost Estimate
- Program Office, Center ICEs
- Mission Directorate ICA
- Project Office ICE
- IPAO-generated ICE

2013:
- Project Office Baseline Cost Estimate
- Program Office, Center ICEs
- Mission Directorate ICA
- Project Office ICE
- IPAO-generated ICE
- Project Office JCL results
- IPAO JCL review & analysis

How can estimates be combined to generate more robust cost estimates?
A Case Study: Identifying a Robust Cost Range (KDP B)

“Wisdom of the crowd”

- “the process of taking into account the collective opinion of a group of individuals rather than a single expert to answer a question”
- Statistician Frances Galton at a 1906 English country fair…
- Can we use the information in our multiple estimates to define better cost ranges?


<table>
<thead>
<tr>
<th>Estimate</th>
<th>JCL 50th Pct Cost</th>
<th>JCL 70th Pct Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project</td>
<td>99%</td>
<td>101%</td>
</tr>
<tr>
<td>A</td>
<td>103%</td>
<td>108%</td>
</tr>
<tr>
<td>B</td>
<td>95%</td>
<td>102%</td>
</tr>
<tr>
<td>C</td>
<td>90%</td>
<td>109%</td>
</tr>
<tr>
<td>Median</td>
<td>97%</td>
<td>105%</td>
</tr>
<tr>
<td>Median (excl. Project)</td>
<td>95%</td>
<td>108%</td>
</tr>
</tbody>
</table>
Need for New Approaches to Modeling Costs

- “What is wrong with space system cost models?” by Keller, Collopy, Componation* raises criticisms of cost models:
  - Parametric models only predict the past
  - They lack insight
    - Predictive power ($R^2$) not the same as explaining the relationship between design variables and cost
    - *Weight is not a cost driver*
  - Limited support for
    - Detailed design trades
    - Management, process trades

*http://dx.dol.org/10.1016/j.astro.2013.07.014
Need for New Approaches to Modeling Costs (cont)

- They encourage management, engineers to focus on process over engineering judgment
- They discourage our understanding cost growth as an endogenous process
  - Assembly, Integration & Test (AI&T)
  - UFE as good management strategy…but why?
  - Risk or uncertainty?

*http://dx.dol.org/10.1016/j.astro.2013.07.014
How Might We Model Cost?

- What if we regard final cost as the outcome of a complex, dynamic, non-linear feedback system?
- That means that outcomes are the result of the combination of:
  - Initial conditions
  - Strategies
  - Probabilities associated with manifestations of risks and uncertainties
- Some outcomes are “extreme”—abandoned projects, significant cost & schedule growth
The Shuffle Questions

There is a mathematical model

<table>
<thead>
<tr>
<th>Cards in Deck</th>
<th>Number of out-and in-shuffles required to restore original order</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>2 4</td>
</tr>
<tr>
<td>8</td>
<td>3 6</td>
</tr>
<tr>
<td>12</td>
<td>10 12</td>
</tr>
<tr>
<td>52</td>
<td>? 8</td>
</tr>
<tr>
<td>54</td>
<td>? ?</td>
</tr>
</tbody>
</table>


Complexity as a cost driver

Figure 15 - SoS Functional Block Diagram

\[
SRL = IRL \times TRL
\]

\[
\begin{pmatrix}
SRL_1 \\
SRL_2 \\
SRL_3
\end{pmatrix} = \begin{pmatrix}
IRL_{11} & IRL_{12} & IRL_{13} \\
IRL_{12} & IRL_{22} & IRL_{23} \\
IRL_{13} & IRL_{23} & IRL_{33}
\end{pmatrix} \times \begin{pmatrix}
TRL_1 \\
TRL_2 \\
TRL_3
\end{pmatrix}
\]

Composite SRL = \( \frac{1}{n}(SRL_1/n + SRL_2/n + SRL_3/n) \)

= \( \frac{1}{n^2}(SRL_1 + SRL_2 + SRL_3) \)

Figure 9 - SRL Mathematical Approach
Summary

- Cost estimating has changed since 2006
  - Estimation is now probabilistic
  - Explicit consideration of schedule and risks
- Demands on cost estimating have also changed
  - JCL analysis
  - Search for the best estimate has been replaced by how to best support budget setting
- Multiple estimates can enhance budgeting
  - Estimate consensus may indicate its resilience
  - Diversity may suggest a range of cost outcomes are possible and a need for more UFE
- Still looking for parametric cost models that link design characteristics and cost
Future Research in Cost Growth

- Compare CADRes (all parts) and estimates for historical programs
  - CADRes – actual historical trends in lifecycle cost
  - Decision memoranda—available estimates
- Are our set of estimates capturing the range of possible outcomes?
- Does the distribution of estimates early on map to budget changes, etc.?
Future Challenges

Federal Budgets
- Increasing budgetary uncertainty—Congressional direction, sequestration
- Decline in Federal budgets, number of new starts

Products
- Fragmentation of the space market
  - New low end: “Reliable microsats”
  - Disappearing mid-range (Discovery, New Frontiers)

Clients
- Increasing number of clients—international, commercial
- Increasing reliance on foreign partnerships—payloads, collaborative missions

Competition
- New commercial providers—e.g., launch services, human transport
- Reliance on commercial partnerships to control cost and reduce risks

If the key to cost estimating is historical data, the cost community will be challenged to continue the record of success
Hamaker (2000): Voices from the Past

Names are NASA civil service individuals who formerly performed as cost analysts. Cost analyst is defined as a parametric or “grass roots” cost analyst, estimator or modeler. It does not include financial or program control analyst. The list also excludes contractor cost analysts, as well as current civil service cost analysts.

**MSFC**
- Bill Huber
- Terry Sharpe
- Bill Rutledge
- Walt Wood
- O’Keefe Sullivan
- Murray Castleman
- Bob Rutherford
- Herb Vaughan
- Dave Taylor
- Spencer Glasgow
- Jerry Wheeler
- Don Bishop
- Dick Klan
- Sam Sullins
- Bill Hicks
- Glenn Dodd
- Steve Creech
- Saroj Patel
- Jack Housley
- Rod Stewart

**KSC**
- Keith Smith
- Julie Martz
- Cary Thompson
- Allen Forney
- Lowell Smith
- George Mahoney
- Cynthia Fry
- Bill Powell

**JSC**
- Don Strope
- Mary Anne Gallager
- Jerry Gonzales

- Hum Mandell
- Gil Chisholm
- Richard Whitlock
- Howard Ashley
- Wayne Draper
- Wayne Whittington
- Howard Renfro
- Ralph Shombery
- Richard Fox
- Phil Shanahan
- Jim Wilcox

**GSFC**
- George Mosakowski
- Walter Feitshans
- Nick Talluto
- Chris Winewicz
- Joe Brown (C of F)

**LeRC**
- George Novack
- Marie Cassidy
- Chris Beins
- Tom LaCroix

**NASA HQ**
- Tom Campbell
- Mike Mann
- Frank Rosenburg
- Charlie Tulip
- Mal Peterson
- Jo Gunderson
- Dave Bates
- Kristen Erickson
- Logan Doane
- Lisa Guerra
- Andrew Hunter
- Tony Schoenfelder
- Tony Diamond
- Henry Hertzfeld

**LaRC**
- Joe Twigg
- Ed Dean

**ARC**
- Chuck Jackson
- Sylvia Cox

**JPL**
- Bill Ruhland
- Stu Heller
- Helmut Partma
- Jerry Olivieri
- Jeff Smith
Why Can’t We All Just Get Along? (2006)

Because we’re really not supposed to!
Since 2006 What Has Changed Analytically for NASA Centers

**Schedule**
- New methods, tools for probabilistic schedule analysis (PSA)
- Joint Confidence Level (JCL) analysis: schedule + cost + risk

**Cost**
- Acceptance of cost estimates as probabilistic analysis (S-curves)
- Appearance of new datasets –
  - ‘Public’ datasets: CADRe (time series), NICM
  - Center-specific earned value (EV) and other ‘micro’ datasets

**ICEs**
- Fewer independent cost models
- IPAO uses project office products (ICEs, JCL)
- No requirement for project office ICE at KDP C
- Project office KDP-C effort now directed toward JCL analysis
NPR 7120.5 Revision E: Using Analytics to Ensure Sufficient Funding

- **Funding guidance**
  - Projects funded to at least 50\textsuperscript{th} percentile
  - HQ holds UFE to cover to 70\textsuperscript{th} percentile\(^*\)

- **Inherent uncertainty in estimated cost**
  - KDP B: cost ranges
  - KDP C: JCL-derived S-curve

- **Assessment of cost, schedule & risks**
  - Joint Confidence Level (KDP C) requirement

\(^*\)Other Federal agencies may fund to the 80\textsuperscript{th} percentile
One Strategy to Exploit Multiple Cost Estimates: “The Wisdom of the Crowd”*

- “the process of taking into account the collective opinion of a group of individuals rather than a single expert to answer a question”
- Statistician Frances Galton’s example based on his experiences at a 1906 English country fair...

Galton’s Example

- 800 people participated in a contest to estimate the weight of a slaughtered and dressed ox
- True weight: 1198 pounds
- Median guess: 1207 pounds (within 1%)
- Galton concluded that
  - The ‘mean’ of group observations appears to be an unbiased estimate
  - Crowds do not have to be uniform
  - The larger the crowd, the better
Limits on The Utility of ‘Crowd Estimation’ for Setting Budgets

Two challenges:

- Not enough data points to filter out ‘noise’
- Researchers are finding that crowd techniques are useful for determining ‘facts’; less effective at ‘prediction’
The El Farol Problem (Arthur, 1994): (Crowds and Predicting the Future)

W. Brian Arthur’s Problem

• Every Thursday night, a finite population (including Arthur) wants to go to Santa Fe’s El Farol Bar
• The El Farol is quite small, and it's no fun to go there if it's too crowded:
  • <60% = a good time
  • >60% = a bad time
• Everyone must decide by themselves late Thursday afternoon whether they will go to the bar or not.

“If I know the historical trend in El Farol attendance, do I go to the bar this Thursday or stay home?”
Brian Arthur’s observations:

• Even if there is perfect knowledge about past attendance, if everyone uses the same “pure strategy”, it is guaranteed to fail.
  
  • Example:
    
    • If attendance has increased for the last 3 weeks AND
    • Last week’s attendance > 55%, THEN
    • Skip El Farol this week
    • But if everyone shares the strategy,
      • Nobody goes to El Farol AND
      • The bar is not crowded (perfect)

• Successful prediction involves exact knowledge of:
  • Past performance
  • Strategies
  • Probabilities assigned to each
  • Fact that strategies, probabilities can change

• Success requires “mixed strategies”
  • Probability attached to pure strategy OR
  • Multiple pure strategies, each assigned a probability OR
  • BOTH
Budget Setting and ‘El Farol’

- Final cost, like attendance, are outcomes of a complex, dynamic, non-linear, feedback system.
- Outcomes are the result of initial conditions, strategies and the probabilities associated with their employment.
- While outcomes can vary wildly, they tend to fall within one or more relatively narrow ranges (‘attractors’).
- It is valuable for budgeting to understand:
  - How many ranges are possible
  - The characteristics of each