Cost Estimating of Space Science Missions

April 16, 2013

Robert E. Bitten, Eric M. Mahr and Robert C. Kellogg
NASA Program Division
Civil and Commercial Operations

Prepared for:
NASA Headquarters
300 East Street, SW
Washington, DC 20024

Authorized by: Civil and Commercial Operations

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Matthew J. Hart, Principal Director
Advanced Studies and Analysis
Directorate
NASA Programs Division
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Cost Estimating of Space Science Missions

Presentation to the NASA Advisory Council (NAC) Astrophysics Subcommittee

The Aerospace Corporation

16 April 2013
Agenda

• Background

• Cost Estimating Basics

• Probabilistic Cost/Schedule Estimating

• CATE Process

• Summary
Cost Evolution Throughout A Project’s Lifecycle

Goal of cost estimating is to forecast the final actual cost of system
An Example of Concept Growth: Substantial Differences Exist between Initial Concept and Final Implemented Configuration

<table>
<thead>
<tr>
<th>Programmatic</th>
<th>STEREO SDT*</th>
<th>STEREO Final</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schedule (months)</td>
<td>40</td>
<td>70</td>
</tr>
<tr>
<td>Launch Vehicle</td>
<td>Taurus</td>
<td>Delta II</td>
</tr>
</tbody>
</table>

**Technical**

<table>
<thead>
<tr>
<th>Mass (kg)</th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Satellite (wet)</td>
<td>211</td>
<td>630</td>
</tr>
<tr>
<td>Spacecraft (dry)</td>
<td>134</td>
<td>421</td>
</tr>
<tr>
<td>Payload</td>
<td>69</td>
<td>149</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Power (W)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Satellite (Orbit Average)</td>
<td>152</td>
<td>503</td>
</tr>
<tr>
<td>Payload (Orbit Average)</td>
<td>58</td>
<td>116</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Other</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Transponder Power (W)</td>
<td>20</td>
<td>60</td>
</tr>
<tr>
<td>Downlink Data Rate (kbps)</td>
<td>150</td>
<td>720</td>
</tr>
<tr>
<td>Data Storage (Gb)</td>
<td>1</td>
<td>8</td>
</tr>
</tbody>
</table>

* Science Definition Team (SDT)

Reference: “An Assessment Of The Inherent Optimism In Early Conceptual Designs And Its Effect On Cost And Schedule Growth”
Effect of Design Changes on Complexity, Cost & Schedule

- **System Cost as Function of Complexity**
  - $y = 11.523e^{0.7802x}$
  - $R^2 = 0.8832$

- **Schedule as Function of Complexity**
  - $y = 24.22e^{1.6479x}$
  - $R^2 = 0.6889$

**Complexity of System Increased Along with Development Cost and Schedule**

Note: Development cost does not include launch vehicle cost, or mission operations and data analysis (MO&DA).

Reference: “An Assessment Of The Inherent Optimism In Early Conceptual Designs And Its Effect On Cost And Schedule Growth”
Cost & Schedule from 20 Missions Show Significant Increase from Baseline Established at PDR

Over Half of Uncertainty for Mass & Power is Retired by PDR while 2/3rds of Cost & Schedule Uncertainty Remain

Payload Mass and Cost Increase from 20 Missions Significantly Greater than Spacecraft Mass & Cost Increase

Data Indicates Payload Resource has Greater Uncertainty than Spacecraft

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• A cost estimating relationship (CER) is a mathematical equation that uses regression techniques to establish a relationship between independent variables that are representative of the design, and cost as the dependent variable.

• CERs can be applied at the system level (e.g. spacecraft, instrument), subsystem level (e.g. attitude determination & control, optics) or component level (e.g., star tracker, CCD).

• All cost models, in their basic form, have some underlying CER defined.

*CERs are based on historical data.*
## Cost Estimation Methodology Examples

<table>
<thead>
<tr>
<th>Model</th>
<th>Developer</th>
<th>Spacecraft Estimating</th>
<th>Instrument Estimating</th>
</tr>
</thead>
<tbody>
<tr>
<td>NASA Instrument Cost Model (NICM)</td>
<td>JPL</td>
<td>N/A</td>
<td>X</td>
</tr>
<tr>
<td>Multivariable Instrument Cost Model (MICM)</td>
<td>GSFC</td>
<td>N/A</td>
<td>X</td>
</tr>
<tr>
<td>Space Based Optical Sensor Cost Model (SOSCM)</td>
<td>Aerospace</td>
<td>N/A</td>
<td>Optical Only</td>
</tr>
<tr>
<td>NASA/Air Force Cost Model (NAFCOM)</td>
<td>SAIC</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>PRICE H</td>
<td>PRICE Systems</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>SEER-H</td>
<td>Galorath</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Small Satellite Cost Model (SSCM)</td>
<td>Aerospace</td>
<td>Small Spacecraft</td>
<td>N/A</td>
</tr>
<tr>
<td>Adjusted Analogy</td>
<td>Aerospace</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Aerospace Method</td>
<td>Aerospace</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>
## Cost Database Characteristics

<table>
<thead>
<tr>
<th>Database</th>
<th>Developer</th>
<th>Number of Spacecraft</th>
<th>Number of Instruments</th>
<th>Restrictions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost Analysis Data Requirement (CADRe)</td>
<td>NASA HQ</td>
<td>~100</td>
<td>From ~100 missions</td>
<td>NASA Cost Community</td>
</tr>
<tr>
<td>NASA/Air Force Cost Model (NAFCOM)</td>
<td>SAIC</td>
<td>&gt;100</td>
<td>&gt;350</td>
<td>NASA-Air Force Cost Community</td>
</tr>
<tr>
<td>NASA Instrument Cost Model (NICM)</td>
<td>JPL</td>
<td>N/A</td>
<td>160</td>
<td>NASA Cost Community</td>
</tr>
<tr>
<td>Small Satellite Database (SSDB)</td>
<td>Aerospace</td>
<td>~140</td>
<td>N/A</td>
<td>Aerospace Only</td>
</tr>
<tr>
<td>Aerospace Space-based Instrument Database</td>
<td>Aerospace</td>
<td>N/A</td>
<td>~600</td>
<td>Aerospace Only</td>
</tr>
</tbody>
</table>
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NPD 7120.5E Requires a New Way to Budget

Historically representative data

Percent Likelihood

Total Mission Cost ($M)

Life Cycle Cost Estimate
At KDP C = Agency Baseline Commitment

“New Way” Mission Budget

“New Way” Project Funding

“Old Way” Project Funding & Mission Budget

Note: UFE = Unallocated Future Expense as stated in NPD 7120.5E

Budgeting at the 70th Percentile should reduce historical overruns
Generic Cost/Schedule Risk Process Overview – Methodology Independent

Initial Cost Estimate Distributed over Baseline Schedule

- Project Management
- Systems Engineering
- Safety and Mission Assurance
- Science/Technology
- Payload(s)
- Flight System / Spacecraft
- Launch Vehicle/Services
- Mission Operations System (MOS)
- Ground Data System (GDS)
- System Integration, Assembly, Test & Check Out
- Education & Public Outreach

Develop Distributions for WBS Elements/Tasks

- Phase A
- Phase B
- Phase C
- Phase D
- Phase E

Combine WBS Element/Task Distributions into Total Project Cost/Schedule Distribution

Example Joint Cost/Schedule Distribution

Computed analytically or by using Monte Carlo simulation

Estimated Cost (FY08$M)

Cumulative Probability

$200 $250 $300 $350 $400 $450 $500 $550 $600
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Cost and Technical Evaluation (CATE) Background

• **CATE Process developed by NRC for Astro2010 Decadal Survey**
  – Previous Decadal Surveys significantly underestimated mission costs
  – US Congress required NRC to use an Independent CATE Contractor
  – Need to provide level treatment of projects of varying maturity
  – Realistic CATE estimates needed for future budget analysis & decisions
    • CATE estimates needed to reflect historical project growth
      – Not just analyze the specific proposed point design

• **CATE process is the same as NASA ICE range of estimates for KDP-B**
  – Begins with typical Independent Cost Estimate, ICE
  – Adds three types of cost threats, where appropriate:
    • Schedule, design (mass & power growth) and launch vehicle
Primary Tenets of Aerospace Cost Estimating

• **Use Multiple Methods**
  – *Ensures that no one model/database biases the estimate*
    • Industry Standard Methods
    • Aerospace Developed Models

• **Use Analogy Based Estimating**
  – *Ties cost to systems that have been built with known cost*
  – *Allows contractor specific performance to be addressed*
  – *Forces estimator and project to look at cost and complexity of new concepts with respect to previously built hardware*

• **Use Both System Level and Lower Level Approaches**
  – *Ensures that lower level approaches do not omit elements or under/overestimate overall cost relative to system level complexity*
CATE Cost Estimating Approach Overview

Estimate Instruments & Spacecraft
Multiple analogies and models

Estimate Other Elements
Based on historical data

Estimate Cost Reserves
Based on probabilistic cost risk analysis

Estimate Mass and Power Contingency Threat
Re-run estimate with Aerospace contingencies

Estimate Schedule Threat
Based on ISE results and project burn rates

Integrate Results & Level Across Concepts
Cross-check with CoBRA
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Summary

• Cost estimating methods attempt to predict cost of final configuration

• Cost estimating methods are based on actual costs of historical items

• Early project concepts are typically optimistic in complexity, schedule, and cost

• CATE process was developed to "level out" some of the initial optimism and provide a common process for all assessments
Back-up
Recent Aerospace Publications – Cost & Schedule Growth

- **Cost & Schedule Growth Research**
Recent Aerospace Publications - Methodology

- **Cost Analysis Methodology**
  - “An Assessment of Different Approaches for Conducting Joint Cost and Schedule Confidence Level Analyses” Robert Bitten, Robert Kellogg, Debra Emmons, NASA Cost Symposium, April 2009

- **Schedule Analysis Methodology**

- **Complexity Based Risk Assessment (CoBRA)**