SEER-Space in the 21st Century

Dec 12, 2018
Topics

- Galorath Background
- SEER-Space
Galorath Background

- Galorath Incorporated has invested more than three decades developing solutions to help government and commercial organizations plan and manage complex projects.
- Introduced SEER commercial software in 1988
- Activities include:
  - SEER parametric tool development and support
  - SEER implementation services
  - SEER product training
  - Professional cost analysis / management consulting services
  - Custom parametric tool development
- SEER solutions combine an intuitive interface, extensive project-applicable Knowledge Bases, sophisticated project-modeling technologies, and rich reporting features to expedite the planning process and keep projects on track.
- Worldwide clients in:
  - Defense / aerospace
  - Manufacturing
  - Finance, insurance, consulting
estimate

estimate • analyze • plan • control

SEER-Space

© 2018 Copyright Galorath Incorporated
What is SEER-Space?

• A system/subsystem level model that estimates spacecraft projects

• Allows early life cycle estimation of space programs when little information is known
  • NASA:  Pre-phase A
  • DoD:  Before Milestone A

• Covers Science, Military, and Commercial domains

• Data spans from nanosats to large telescope observatories

• Driven by WBS, can model different space project types:
  • Full mission with Bus and Payload
  • Payload only
What is SEER-Space?

• Quick and comprehensive ROM estimate in one model
• Includes cost drivers which are known to be good predictors of space project costs, both **quantitative** and **qualitative**
  • Balances the art and science of cost modeling
• Evaluate cost impact of:
  • Technical Inputs
  • Procurement strategy
  • Heritage
  • Technology Readiness Level
  • Organizational relationships and management structure
What is SEER-Space?

• Knowledge Bases
  • Industry derived scope of technical parameters
  • Preliminary estimate

• Capture different layers of system level effort at Mission/System, Bus, and Payload levels
  • Program Management
  • Systems Engineering
  • Mission Assurance
  • Integration, Assembly, and Test

• Account for customer furnished hardware and contributions to the project, domestic or international
### Comparison to Other Parametric Model Archetypes

<table>
<thead>
<tr>
<th></th>
<th>SEER-Space</th>
<th>System Level Parametric</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level of detail</strong></td>
<td>Bus Subsystems + Instruments</td>
<td>Varies, Flight System + Instruments</td>
</tr>
<tr>
<td><strong>Work Breakdown Structure</strong></td>
<td>NASA: WBS Elements 1-11</td>
<td>Specific to WBS element, Multiple models required to account for all WBS elements</td>
</tr>
<tr>
<td></td>
<td>DOD MIL-STD-881D: WBS Elements 1.1-1.5</td>
<td></td>
</tr>
<tr>
<td><strong>Applicability to Space Missions</strong></td>
<td>Dedicated to space domain, Programmatic and qualitative parameters specific to space (Classification level, TRL, Destination, Landers, Rovers, Probes, etc...)</td>
<td>Dedicated to space domain, Programmatic and qualitative parameters specific to space, if any</td>
</tr>
<tr>
<td><strong>Database</strong></td>
<td>NASA CADRe database, commercial public data, industry and contractor data sources, and additional internal research</td>
<td>Industry or organization-specific database</td>
</tr>
<tr>
<td><strong>CER derivations</strong></td>
<td>SME influenced regression analysis including cross-validation</td>
<td>Limited SME derivation, Regression analysis, Unique cost drivers</td>
</tr>
</tbody>
</table>
## Comparison to Other Parametric Model Archetypes

<table>
<thead>
<tr>
<th></th>
<th><strong>SEER-Space</strong></th>
<th><strong>Component Level Parametric</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level of detail</strong></td>
<td>Bus Subsystems + Instruments</td>
<td>MEL, BOM, or equivalent</td>
</tr>
</tbody>
</table>
| **Work Breakdown Structure** | NASA: WBS Elements 1-11  
DOD MIL-STD-881D: WBS Elements 1.1-1.5 | WBS Hardware Elements, NASA: WBS Elements 1-3,5,6,10  
DOD MIL-STD-881D: WBS Elements 1.1,1.2 |
| **Applicability to Space Missions** | Dedicated to space domain, Programmatic and qualitative parameters specific to space,  
(Classification level, TRL, Destination, Landers, Rovers, Probes, etc...) | More generic knowledge and input parameters that are applicable to both space and non-space projects |
| **Database**            | NASA CADRe database, commercial public data, industry and contractor data sources, and additional internal research | Various data sources                                      |
| **CER derivations**     | SME influenced regression analysis including cross-validation                | Various including SME derived                             |
Work Breakdown Structure

- Full Life Cycle Cost Estimate
- Estimate all NASA and DOD MIL-STD-881D WBS elements plus Phase E Mission Operations and Data Analysis (MO&DA)

In SEER-Space, this is Mission Ops non-recurring (planning, procedures development, training)--not the recurring operations
Knowledge Bases

- Knowledge Bases allow you to create rough order of magnitude estimates with only a few high level inputs

- 5 Knowledge Base Categories:
  - Applications
    - Rollup
  - Bus
  - Instrument
  - Telescope
  - Data Processing Unit
  - Cryocooler
  - Platform
  - Heritage
  - Standard
  - Organization
Payload Applications

- ~Fields - General
- ~Optical - General
- ~Particle - General
- ~Radio - General
- ~Sample Acquisition - General
- ~Sample Analysis - General
- Camera - Multispectral Imager
- Camera - Spectral Imager
- Compound Instrument - Multispectral Imager
- Cryocooler – ADR
- Cryocooler – Dewar
- Cryocooler – Mechanical
- Data Processing Unit – Integrated DPU
- Data Processing Unit – Multi-Instrument
- Electric Field Sensor
- Gas Chromatograph
- Langmuir Probe
- LASER - Altimeter
- LASER - LIDAR
- LASER - Optical Transceiver
- LASER - Spectrometer
- Magnetometer - Fluxgate
- Magnetometer - Search Coil
- Particle - Ion Trap Mass Spectrometer
- Particle - Quadrupole Mass Analyzer
- Particle - Sector Mass Spectrometer
- Particle - Time of Flight Mass Spectrometer
- Particle - Detector, Dust
- Particle - Detector, Energetic Particle
- Particle - Detector, Ion/Plasma
- RADAR - Scatterometer
- RADAR - Synthetic Aperture
- RADAR - Altimeter
- Radio - Antenna
- Radio - Receiver
- Radio - Transceiver
- Radiometer - IR
- Radiometer - Microwave
- Radiometer - UV/Visible
- Spectrograph - IR
- Spectrograph - UV/Visible
- Spectrograph - X Ray/Gamma Ray
- Spectrometer - IR
- Spectrometer - UV/Visible
- Spectrometer - X Ray/Gamma Ray
- Spectroradiometer
- Telescope – IR
- Telescope – Optical
- Telescope – UV
- Telescope – X-Ray
Data Collection

• Data are the foundation of cost estimates
• Researchers at Google found that simple models based on a lot of data are better than more elaborate models based on less data
• Need sound, quantitative data
  • Cost
  • Technical
  • Programmatic

Analysts spend the majority of their time developing techniques and honing tools, when the most important focus should be on the quality and quantity of data.
Data Normalization

- For some older missions adjusted to account for full-cost accounting, as applicable
- Split all costs into nonrecurring and recurring costs
- Normalized cost to a constant base year using latest NASA inflation guidance
- For multiple units, normalized recurring costs to a theoretical first unit cost
Data and CERs Included

• SEER-Space includes new cost estimating relationships for bus subsystems and instruments, including dedicated CERs for optical telescopes, cryocoolers, and data processing units
• Collected and normalized data from recent NASA CADRe files and other data sources
• Assumed that data for earth-orbiting and planetary missions can be used together for CER development
  • Account for with programmatic variable
• Bus subsystem CERs based on 80+ recent earth-orbiting and planetary missions
• Instrument CERs based on 400+ data points from recent earth-orbiting and planetary missions
CER Development Methodology

• The oldest method still in common use for developing power-form CERs is log-transformed ordinary least squares linear regression (LOLS)

• However this method has been criticized for many years for multiple reasons:
  • Transformation causes equation to be optimal for “log-dollars”
  • Result is biased (estimating the median vice the mean)

• Other methods such as Minimum Unbiased Percentage Error (MUPE) and Zero-bias Minimum Percent Error (ZMPE) have been recommended as alternatives to log-transformed linear regression

• However, statistical analysis of residuals for spacecraft CERs has shown that the best for the residuals is the lognormal distribution
CER Development Methodology (2)

- Developed a new CER method that has the advantages of log-transformed linear regression without the transformation issues
- Used solver to minimize a maximum likelihood equation that is optimal for lognormal residuals
- Similar to LOLS but unbiased
- No transformation required
- Also set logical constraints on the values for the coefficients
• For SEER-Space, we used the power equation for most subsystems and instruments
• In our experience power forms have worked well for other models, and they fitted the data well for this project so we used them extensively
• All CERs are multivariate
• In some cases when the cost of the system was low, we used linear equations (e.g., data processing units)
  • When the cost is low, it has a limited range as the lower bound is equal to zero
  • Log transformations compress the spread of the data, so low cost items are typically not nonlinear
Model Inputs

- All CERs include a set of programmatic parameters:
  - Competed or non-competed (sole source/directed)
  - Earth orbiting or planetary
  - Number of sponsors
  - International involvement
  - Qualification test scale/scope
  - Number of instruments
  - Number of active instruments
  - Design life duration

- The number of instruments and number of active instruments is not applied to the instrument CERs

- All instrument CERs except for the telescope CER include power as a driver
Model Inputs (2)

• In addition to the common factors, there are several CERs that include unique technical independent variables
  
  • Telescope
    • Primary mirror diameter is the primary driver, weight is not an independent variable
  
  • Bus subsystems:
    • Structures: number and type of deployables
    • Thermal: heat rejection (passive/active)
    • CCDH: number of communications bands (IEEE), high-gain antenna, and redundancy
    • GNC: degree of control (3-axis), redundancy, and star tracker (yes/no)
    • Power: fixed or deployable array, BOL maximum power
    • Reaction control: Propellant type
Variable Selection

- The primary CER variable that we use is weight (aka mass)
- This is not a causative driver of cost, merely a scaling parameter
- Our models are not based on “cost drivers”
- However these parameters explains historical variation well and we typically have estimates of weight early in a program’s lifecycle so we continue to use these parameters
Another controversial topic is the use of subjective parameters such as heritage (or its reciprocal, percent new design)

- The amount of new design is strongly correlated with the nonrecurring cost of a program
- Heritage is typically overrated early in a program’s lifecycle, can lead to underestimation
- The subjective nature can lead to misestimation when compared to the historical cost
- However, there is a need by customers to discern the impact of new design on cost, so we have made the decision to include new design as a parameter in SEER for Space
Cross Validation

- All CERs were developed using cross-validation
  - In-sample standard errors will necessarily be lower than the generalization standard error
  - We can measure this as we develop the model by conducting n-fold cross-validation
  - N-fold cross validation involves splitting the data set into multiple partitions (n-folds)
  - Train the model on n-1 of the partitions and test on the remainder
  - Repeat this process n times, once for each fold
  - Average the results
  - N-fold cross validation allows the validation error bounds to be calculated as a result of the CER development process
  - N-fold cross validation has the advantage in small data sets of saving more of the data for training
For more information, please contact us at:
Galorath Incorporated
Phone: +1-310-414-3222
E-mail: info@galorath.com
Web Site: www.galorath.com

Dan Galorath, CEO; galorath@Galorath.com
Bob Hunt, President Galorath Federal; bhunt@Galorath.com
Greg Wise, VP Galorath Federal; gwise@Galorath.com
Brian Glauser, VP Business Development; bglau@Galorath.com
Karen McRitchie, VP Product Development; kmcr@Galorath.com
Ian Brown, Director of Operations and Systems Analysis; ib@Galorath.com
Sam Sanchez, Technical Director-Electronics and Hardware ss@Galorath.com
Christian Smart, Chief Scientist; cs@Galorath.com
Joe Hamaker, Director of NASA Programs; jh@Galorath.com
Eric Sick, Cost Analyst; es@Galorath.com