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SEER-Space in the 21st Century

Dec 12, 2018

SEER by GALORATH

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Topics

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- 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

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SEER-Space

SEER by GALORATH

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?

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- 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

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

Comparison to Other Parametric Model Archetypes

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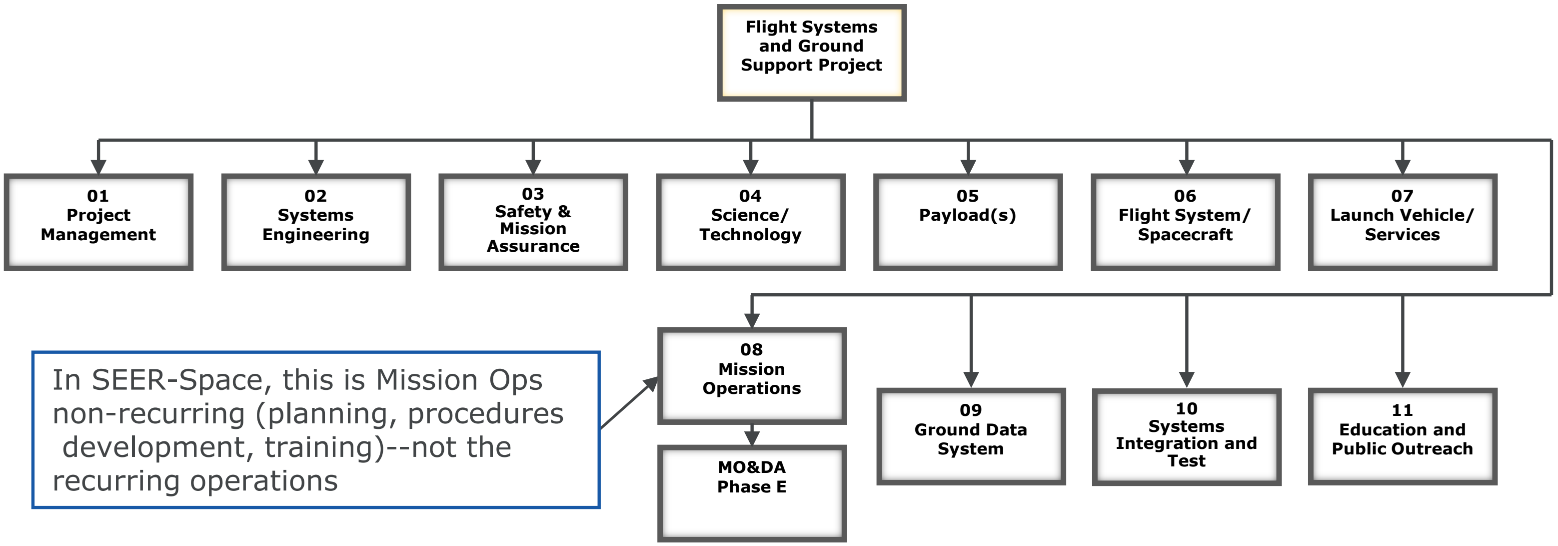
	SEER-Space	Component Level Parametric
Level of detail	Bus Subsystems + Instruments	MEL, BOM, or equivalent
Work Breakdown Structure	NASA: WBS Elements 1-11 DOD MIL-STD-881D: WBS Elements 1.1-1.5	WBS Hardware Elements, NASA: WBS Elements 1-3,5,6,10 DOD MIL-STD-881D: WBS Elements 1.1,1.2
Applicability 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)

Knowledge Bases

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- 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

Parameters | Schedule | Economic Factors

Spacecraft Bus: Planetary Rover Flight System	Least	Likely	Most
STRUCTURAL/MECHANICAL SUBSYSTEM (SMS)		Yes	
Mass (kg) (SMS)	900.00	1,000.00	1,300.00
Number Of Deployables (SMS)	2	3	5
Deployable Complexity (SMS)	Hi+	VHi-	VHi
New Development (SMS)	50.00%	60.00%	70.00%
Technology Complexity (SMS)	Nom-	Nom	Nom+
THERMAL CONTROL SUBSYSTEM (TCS)		Yes	
Mass (kg) (TCS)	54.00	60.00	78.00
Thermal Control Type (TCS)		Active	
New Development (TCS)	35.00%	45.00%	55.00%
Technology Complexity (TCS)	Nom-	Nom	Nom+
COMMUNICATIONS, COMMAND & DATA HANDLING SUBSYSTEM (CCDH)		Yes	
Mass (kg) (CCDH)	67.50	75.00	97.50
Number of Bands (CCDH)	2	2	2
High Gain Antenna (CCDH)		Yes	
Redundancy (CCDH)		Full	
New Development (CCDH)	35.00%	45.00%	55.00%
Technology Complexity (CCDH)	Nom-	Nom	Nom+
GUIDANCE, NAVIGATION & CONTROL SUBSYSTEM (GNC)		Yes	
Mass (kg) (GNC)	27.00	30.00	39.00
Control Mechanism (GNC)		3-Axis Controlled	
Redundancy (GNC)		Full	
Star Tracker (GNC)		Yes	
New Development (GNC)	35.00%	45.00%	55.00%
Technology Complexity (GNC)	Nom-	Nom	Nom+
ELECTRICAL POWER SUBSYSTEM (EPS)		Yes	
Mass (kg) (EPS)	225.00	250.00	325.00
Solar Array Type (EPS)		Deployable	
Power (W) (EPS)	2,160.00	2,400.00	3,120.00
Total Radioisotopic Thermal Generators (EPS)	0	0	0
New Development (EPS)	50.00%	60.00%	70.00%
Technology Complexity (EPS)	Nom-	Nom	Nom+
REACTION CONTROL SUBSYSTEM (RCS)		Yes	
Mass (kg) (RCS)	135.00	150.00	195.00
Propulsion Type (RCS)		Bi-Propellant	
New Development (RCS)	35.00%	45.00%	55.00%
Technology Complexity (RCS)	Nom-	Nom	Nom+

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

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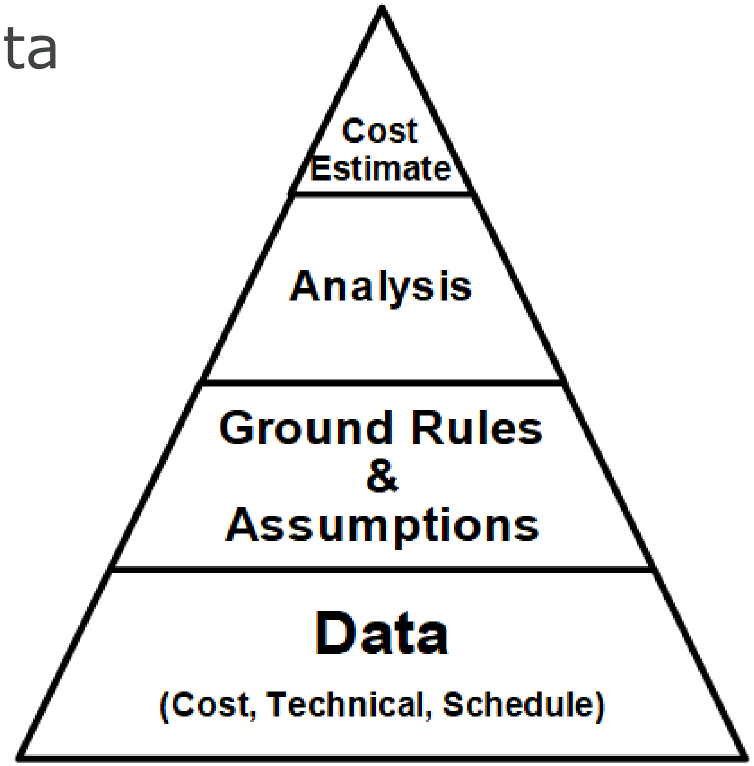
- Data are the foundation of cost estimates
- Researchers at Google found that simple models based on a lot of data are better than more elaborate models based on less data
- Need sound, quantitative data
  - Cost
  - Technical
  - Programmatic

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

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- 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

Model Form Application

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- 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

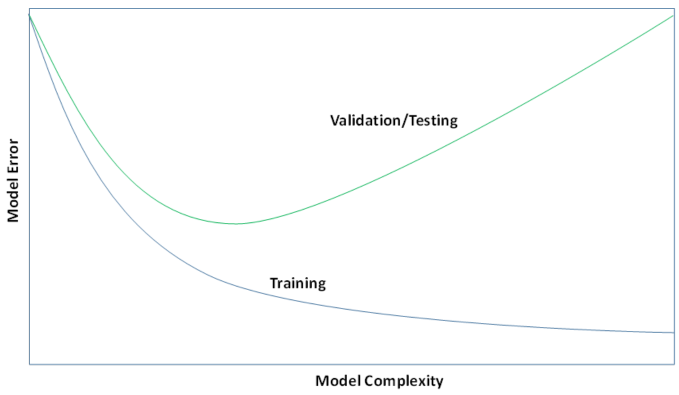
- The primary CER variable that we use is weight (aka mass)
- This is not a causative driver of cost, merely a scaling parameter
- Our models are not based on "cost drivers"
- However these parameters explains historical variation well and we typically have estimates of weight early in a program's lifecycle so we continue to use these parameters

Variable Selection (2)

- 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



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