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# Galorath –A Technical Solutions Provider

AN ESOP Company
Dedicated to quality (ISO 9001:2008 certified)

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ISO 9001:2008
REGISTERED FIRM
Certificate no A11351

SEER® by GALORATH

# Topics

- Overview of Galorath Inc.
- Overview of SEER Models
- SEER-Space
- Demo of SEER-Space

# Galorath Background

GALORATH

- 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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# An Overview of SEER Models

SEER® by GALORATH

# SEER Suite of Applications

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- Different products for different domains/disciplines

SEER-SEM – software/application development, maintenance, integration and testing

SEER-H – system, hardware and electronics development, production and support

SEER-IT – IT infrastructure, services and operations

SEER-MFG – hardware manufacturing and assembly

SEER-SYS – Systems Engineering

SEER-Space – New!

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# SEER-Space

SEER by GALORATH

# Why SEER-Space?

- SEER-Space (Version 1) is NASA centric in terms of the data behind the model
  - However, it is applicable to non-NASA space missions as well
    - Space projects all use the same Physics
    - Same Aerospace Engineering processes
    - Same systems, subsystems and components
    - Similar institutions and contractors
- And SEER-Space includes cost drivers which are known to be good predictors of space project costs, both quantitative variables and some that are qualitative
  - Balances the art and science of cost modeling
- SEER-Space can be used in very early conceptual stages of the project life cycle
  - But is also applicable through mid life cycle (PDR to CDR)
  - Early utility is further supported by SEER-Space Knowledge Bases

# Differentiation of SEER-Space From SEER-H/SEM SEM

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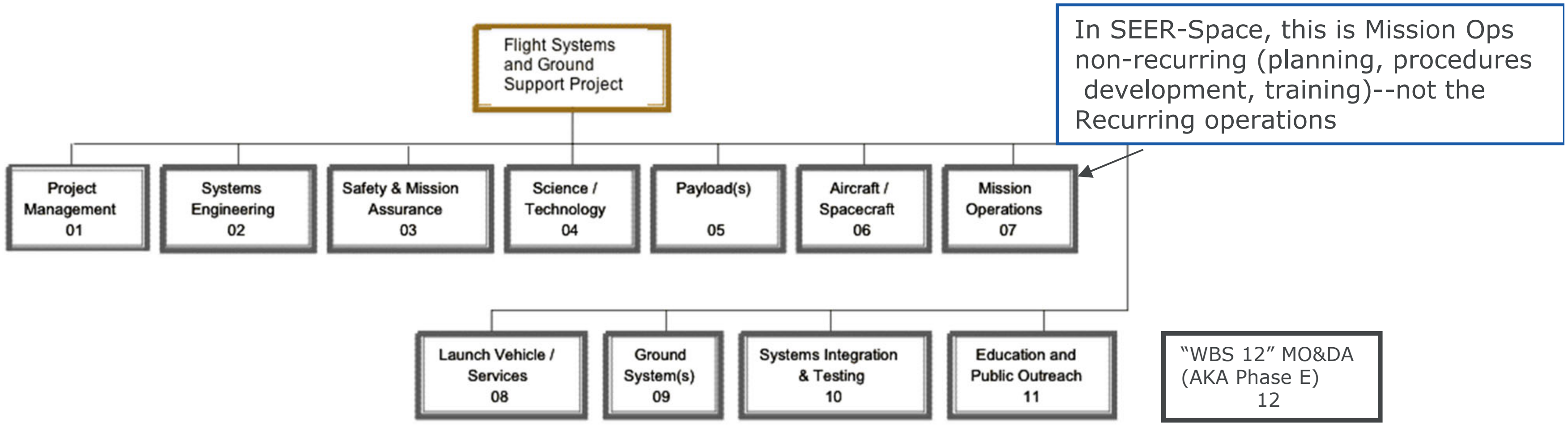
| | SEER-H and SEM | SEER-Space |
|---|---|---|
| Level of detail | MEL level (or close) | Bus subsystems + instruments |
| Work Breakdown Structure | NASA WBS Elements 1 through 6 + 10 (NR + Production) | NASA WBS Elements 1-11 (NR + Production + Operations) and DOD MIL-STD-881D |
| Applicability to Space Missions | More generic Kbases and input parameters that are applicable to both Space and Non-Space Projects | NASA Class A, B, C and D Standards, Technology Readiness Levels effects, Earth Orbital and Deep Space missions (including Orbiters, Flybys, Landers, and Rovers) |
| Database | Various data sources + SME derived CERs | Recent missions drawn from the NASA CADRe database as well as additional data sources and extensive research by Galorath analysts |
| CER derivations | Various including SME derived | Regression analysis including cross-validation |

# Work Breakdown Structure




- SEER-Space will estimate all 11 NASA WBS elements <u>plus</u> Phase E Mission Operations and Data Analysis (MO&DA) [aka Phase E operations cost] and DOD MIL-STD-881D
- The model allows for the accounting of hardware contributions made to a mission (from part level to whole instruments)
- Supports the analysis of different means of acquisition such as competed versus directed projects, prime contractor versus university-built, foreign contributions, and more.
- It can also assess heritage benefits (major modification vs minor modification) and Technology Readiness Level (TRL)

# SEER-Space Knowledge Bases

- SEER-Space knowledge bases allow you to create rough order of magnitude estimates with only a few high level inputs.
- SEER-Space offers five basic categories of knowledge bases
  - Applications
    - Project Rollup
    - Bus
    - Instrument
    - Telescope
    - Data Processing Unit
    - Cryocooler
  - Platform
  - Heritage
  - Standards
  - Organization

Parameters | Schedule | Economic Factors

| Spacecraft Bus: Structures and Mechanisms | Least | Likely | Most |
|---|---|---|---|
| **STRUCTURAL/MECHANICAL SUBSYSTEM ...** | | Yes | |
| Mass (kg) (SMS) | **1,000.00** | **1,000.00** | **1,000.00** |
| 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) | **25.00** | **25.00** | **25.00** |
| Thermal Control Type (TCS) | | Active | |
| New Development (TCS) | 50.00% | 60.00% | 70.00% |
| Technology Complexity (TCS) | Nom- | Nom | Nom+ |
| **COMMUNICATIONS, COMMAND & DATA H...** | | Yes | |
| Mass (kg) (CCDH) | **50.00** | **50.00** | **50.00** |
| Number of Bands (CCDH) | 2 | 3 | 4 |
| High Gain Antenna (CCDH) | | Yes | |
| Redundancy (CCDH) | | Partial | |
| New Development (CCDH) | 50.00% | 60.00% | 70.00% |
| Technology Complexity (CCDH) | Nom- | Nom | Nom+ |
| **GUIDANCE, NAVIGATION & CONTROL SU...** | | Yes | |
| Mass (kg) (GNC) | **100.00** | **100.00** | **100.00** |
| Control Mechanism (GNC) | | 3-Axis Controlled | |
| Redundancy (GNC) | | Partial | |
| Star Tracker (GNC) | | No | |
| New Development (GNC) | 50.00% | 60.00% | 70.00% |
| Technology Complexity (GNC) | Nom- | Nom | Nom+ |
| **ELECTRICAL POWER SUBSYSTEM (EPS)** | | Yes | |
| Mass (kg) (EPS) | **75.00** | **75.00** | **75.00** |
| Solar Array Type (EPS) | | Deployable | |
| Power (W) (EPS) | 0.00 | 0.00 | 0.00 |
| Total Radioisotopic Thermal Generators (E | 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) | 0.00 | 0.00 | 0.00 |
| Propulsion Type (RCS) | | Mono-Propellant | |
| New Development (RCS) | 50.00% | 60.00% | 70.00% |
| Technology Complexity (RCS) | Nom- | Nom | Nom+ |

# Instrument Application Kbases

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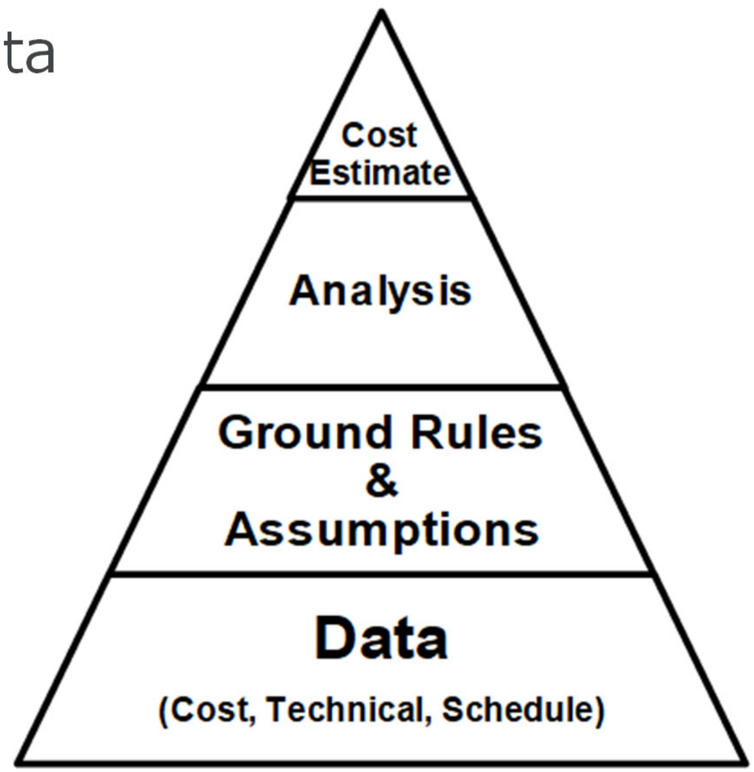
- ~Fields - General
- ~Optical - General
- ~Particle - General
- ~Radio - General
- ~Sample Acquisition - General
- ~Sample Analysis - General
- Calorimeter
- Camera - Multispectral Imager
- Camera - Spectral Imager
- Chemical Microscopy Scanner
- Gas Chromatograph
- Electric Field Sensor
- Compound Instrument- Multispectral Imager
- 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

# 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

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- SEER-Space includes new cost estimating relationships(CERs) for bus subsystems and instruments, including dedicated CERs for optical telescopes and data processing units
- Collected and normalized data from recent CADRe files
- Assumed that data for earth-orbiting and planetary missions can be used together for CER development – can include a dummy variable (aka binary/indicator variable) to account for the difference in the model
- Bus subsystem CERs based on ~50 recent earth-orbiting and planetary missions
- Instrument CERs based on ~150 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

- For SEER for 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:
  - AO or Directed
  - Earth Orbiting or Planetary
  - More than one sponsor
  - International Involvement
  - Extensive Testing
  - Number of Instruments
  - Number of Active Instruments
  - Design Life (Months)
- 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 – Mirror diameter is the primary driver, weight is not an independent variable
  - Bus subsystems:
    - Structures: number of deployables and deployable complexity
    - Thermal: type (passive/active)
    - CCDH: number of bands, high-gain antenna (yes/no), and level of redundancy
    - GNC: 3-axis (yes/no), level of redundancy, and start tracker (yes/no)
    - Power: deployable array (yes/no), maximum power
    - Reaction control: monopropellant (yes/no)

# 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

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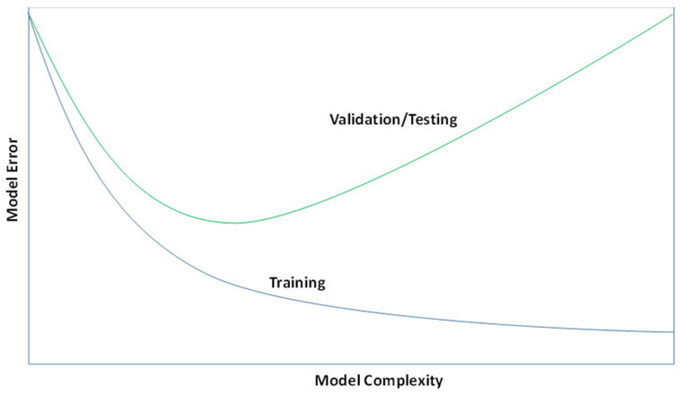
- All CERs were developed using cross-validation
  - In-sample standard errors will necessarily be lower than the generalization standard error
  - We can measure this as we develop the model by conducting n-fold cross-validation
  - N-fold cross validation involves splitting the data set into multiple 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



# Space Systems Cost Estimation Workshop

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- Space domain-focused workshop provides knowledge and skills necessary to estimate the cost, schedule and effort of space systems
- Students given overview of different methods of estimation being used today: including grass-roots and bottom-up estimates, analogy-based estimates, system level parametric models
- Led through a discussion of the differences between system level parametric models, such as the NASA Instrument Cost Model (NICM), and component level parametric models, such as SEER-H.
- Learn differences between modeling various spacecraft subsystems, how to model various instrument types and gain insights as to how to estimate new technology developments
- Familiarized with assessing cost, schedule, risk and how to build a defendable estimate
- Upon completion, will be able to produce a cost estimate for the full life cycle of a space mission project, from pre-concept through operations, taking into account the risks, uncertainty and cost drivers associated with space hardware development, acquisition and integration.

- Instructors don't just teach— extensively involved with SEER-H, NICM, PCEC, MOCET, Quickcost, SEER for Space Systems and other Space cost models.
- Instructors developed CERs with NASA and DoD and will augment training with "lessons learned" from their experience

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