A FULLY INTEGRATED RISK AND COST MODEL FOR COMPLEX AEROSPACE SYSTEMS

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Summary
Introduction to SpaceWorks
The EEG utilizes advanced modeling techniques, state-of-the-art software tools, expert market forecasts, and a knowledgeable technical staff to help our clients with:

- Strategic insight into the global aerospace industry
- Flight and ground systems life-cycle cost estimating (non-recurring and recurring)
- Programmatic risk assessment
- Reliability quantification, uncertainty, and fault prevention/tolerance strategies
- Top-level safety evaluation and probability quantification (loss of crew, expected casualty rate)
- Operations assessment including high-fidelity discrete event simulation
- Technology investment cost-to-benefit assessments
- Market size and demand estimation
- Financial analysis (net present value, break-even point, return on investment, etc.)
- Rapid integrated assessment of cost and risk in the early design phase
Integrated Risk and Cost Model (I-RaCM): Introduction and Tools Overview
Motivation for an Integrated Risk and Cost Model

Traditional early design process does not fully consider cost and risk concurrently with system performance.

Reasons why designing to cost and risk is challenging at the conceptual level:
- Very large trade space with limited time to evaluate options
- Difficult to quantify affordability, reliability, and other “ilities”
- Fear of reporting figures that exceed the available budget

The Integrated Risk and Cost Model (I-RaCM) is a collection of tools in ModelCenter to synchronously evaluate life-cycle cost and reliability.

Benefits of I-RaCM to the conceptual designer include:
- Complete cost picture
- Ability to combine new and existing tools
- Improved analytical consistency
- Ability to interface with other design disciplines
- Efficiency and automation
- Investigation of uncertainty
- Optimization
I-RaCM: Integrated Risk and Cost Model

Legend:
- <Function>
- <Preferred Tool>
- \( \text{Current} \)
- \( \text{Future} \)

Data Handling and Integration
PHX Integration ModelCenter

Output Visualization and Exploration
Stack 'em

Development and Production Cost
NAFCOM
SEER-H

Facilities and Operations Cost
Facilities and Ground Ops Analysis (FGOA)

Reliability
Event Sequence Diagrams
Fault Trees

Technology Cost
Technology Cost Estimator (TCE)

Business Case Evaluation
Cost and Business Analysis Module (CABAM)
Nodal Economic Space Commerce (NESC) Tool

Operations Scheduling and Simulation
Descartes Discrete Event Simulation In Arena

Risk / Reliability and Consequences
Probabilistic Risk Assessment

Availability and Performability
Stochastic Petri Nets
I-RaCM Tools

**Technology Cost Estimator (TCE)**

**Function:** Estimate early (pre-TRL 6) technology development costs

**Platform:** MS Excel®

**Summary:** Relates a simple set of inputs to an underlying data set of historical technology development programs. Inputs include current TRL, length of the research activity, degree of funding availability, and extent of revolutionary innovation.

**Facilities and Ground Operations Analysis (FGOA) Tool**

**Function:** Estimate ground and infrastructure costs

**Platform:** MS Excel®

**Summary:** Outputs land, facilities, and equipment costs given definition of launch architecture. Based on NASA KSC Real Property database and other technical databases of GSE costs.

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Reliability_Calc

**Function:** Estimate reliability of the overall system or architecture

**Platform:** MS Excel®

**Summary:** Uses a Fault Tree Analysis (FTA) and Event Sequence Diagram (ESD) approach to quantify top-level reliability metrics such as Loss of Mission (LOM) and Loss of Crew (LOC). Features an automatic “wrapper generator” to facilitate integration with PHX ModelCenter®.

Descartes

**Function:** Calculate turn-around time, operations costs, number and specialties of personnel, and equipment needs

**Platform:** Windows Executable

**Summary:** Discrete event simulation built in Arena by Rockwell Automation. Inputs for the analysis model include descriptions of the basic vehicle concept of operations, mission models, and performance information.
SEER-H

Function: Estimate the costs of development, production, operations, and support for mechanical, electronic, structural, and hydraulic hardware elements

Platform: Windows Executable
Summary: Commercially available software developed by Galorath Corporation. Knowledge Bases are available to select appropriate cost analogies for each system component and to adjust variables defining mission, program, development, and production cost factors.

NASA Air Force Cost Model (NAFCOM)

Function: Estimate development and production costs for hardware, system engineering, integration, and program management

Platform: Windows Executable
Summary: Government-sponsored cost tool maintained by SAIC that uses cost estimating relationships derived from actual costs of various historical space systems.
SpaceWorks Software’s commercially available Remix “Wrapper Generator,” written in Java, automatically generates ModelCenter® wrappers for any saved NAFCOM or SEER-H file.

- Supports NAFCOM weight-based and multivariable CER methodologies, and can run NAFCOM models both with and without “risk.”
- Outputs hardware costs at subsystem and system level, and outputs project management/integration costs

**Integrating NAFCOM and SEER-H with PHX ModelCenter®**
Integrated Risk and Cost Model (I-RaCM) Example Instance
Example Integrated Model Outputs:
Lunar Architecture Case Study
### Lunar Exploration Architecture for Case Study

- **4 crew**
- **First Lunar Landing in 2018**
- **16 Missions over a 10 year period**
- **Maximum Lunar stay duration of 28 days**

Lunar architecture elements and cost/reliability results have been generated using publicly available data.
The Stack'em tool includes the capability to optimize development and production expenditures to fit an available budget (coordinate pattern search algorithm)

Constraints on start year for individual elements and campaign mission dates must be met

Cost/reliability results have been generated using publicly available data
A chart of cost by category is available to help assess cost-schedule risk.

Other categories, such as technology development, may be added as desired.

Contributors to life cycle cost are represented including:
- Pre-phase A costs
- Development cost phasing
- Production schedule
- Test program definition
- Sustaining engineering costs

The inventory chart shows a queue of produced units of each element at any given time in the life of the program.

Fractional units can be produced in a given year, accounting for non-whole numbers in the inventory chart.

Constraints may be set by the user within Stack'em, limiting the total number of units which may be held in inventory.
Cost/reliability results have been generated using publicly available data.
Cost risk can be further investigated when the I-RaCM tools are run probabilistically.

Output cost distributions of each element are depicted in a single chart, allowing for comparisons of their relative magnitude, uncertainty, and skewness.

For each element, points near the mean of the distribution appear as a darker blue, while the tails of the distribution are lighter in color, and orange horizontal lines in the bars represent a particular user-specified percentile of the distribution (the 70th percentile in this case).

Histograms of each element’s cost and overall program cost are also provided.

When I-RaCM is integrated with a performance analysis, these distributions may represent the response of cost to uncertainty in technical parameters (e.g. mass, engine thrust)
Summary
I-RaCM enables consideration of cost and risk during conceptual design
- Integrates with performance disciplines to enable full trade space exploration
- Conduct probabilistic analysis to assess uncertainty associated with cost and reliability results
- Cost as independent variable (CAIV) studies and optimization
- Evaluate schedule impacts
- Perform technology injection trades
- Optimize to multiple competing criteria
- Perform sensitivity studies and parametric sweeps

I-RaCM is a continuing development, evolving to include more analysis tools and visualization capability

Remix allows for NAFCOM and SEER-H, industry standard cost estimation tools, to be easily integrated within ModelCenter®

I-RaCM and ModelCenter® data collection and visualization features facilitate decision-making based on cost and risk