M&S at NASA

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Overview

• Constellation’s Discrete Event Simulation
  – DES?
  – Analysis

• NASA’s Modeling & Simulation Standard
  – Analysis/Results Focused
Discrete Event Simulation

• Definition:
  – Process & System Analysis, through time-based & resource constrained probabilistic simulation models, providing insight into operational system performance.

• “Competing” types of Analysis
  – Spreadsheets
  – Scheduling Software
  – Probabilistic Risk Assessment
Current End-to-End CxDES Process Flow

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**CxDES Architecture**

**PAI Ariana**  
Input scenarios / Output Data & Graphs

- Ariana populates Arena based on user inputs prior to run
- Arena outputs are exported to Ariana post-run

**RS Arena**  
DES Model

**MS Excel**  
Order Lead Times / Schedule Inputs

- If running the model with Manifest Data and/or Order Lead Times, data is imported from Excel at the start of the run
- Arena outputs are exported to Excel for post-run individual mission analysis
Inputs:
- Production Rates
- Process Times
- Transport Times
- Event Probabilities
- Policies (shifting)

Outputs:
- Mission Rate & Distribution
- Cycle Times
- Utilizations
- Waiting Times

**DES Analysis Cycle**

**Understanding System Performance**
- Critical Path
- Risk to Launch Rate
- Margin

**Manufacturing through Launch**

Duration Comparisons

765 days
Manufacturing through Launch
Duration Comparisons

765 days

Ares I/Orion shall be able to launch every 45 days
Baseline (With Scrubs/Rollbacks)

Cumulative Probability of Achieving X or More Launches
45-Day Mission Request; Pad Scrubs and Rollbacks On;
Integration: 5x3 Shifting

- 22% probability of 5 launches during one year
- Average of 4.01 launches per year
Ares I/Orion shall be able to launch every 45 days
Baseline (With Scrubs/Rollbacks)

- Average is **91.35** days between launches

Ares I/Orion shall be able to launch every 45 days
Baseline (No Scrubs/Rollbacks)

- Change in Integration Shift Schedules
Conclusions

• 2 & 4 Launches per Year possible with Baseline Assumptions
• $\approx 90\%$ of Cycle time is in Manufacturing & Assembly
• Dependencies to 45-day launch-to-launch cycle:
  - Integration & Pad Shifting Policy
  - FHE readiness for Integration
    • Manufacturing
    • Assembly
    • Off-Line Ground Ops
  - Aft Skirt quantity (of reusable FHEs)
• 1-time 30-day launch-to-launch cycle not possible using current model data

Future Work

• Input Data Refinement
  - Level 3 Projects Data
• Automate Chart Production
• Refine Analyses
• Logic for minimum launch spacing
• Adjust manufacturing start time based on system behavior (manage ETE Cycle Time)
• Shelf Life of FHEs
• Lunar SRR
Thoughts to Discuss

- M&S Practices
- Reporting to Decision Makers
- Credibility discussion
  - V&V, VV&A
- Placarding results
Why a New Standard?

- Why Aren’t Software Standards Enough?
  - Don’t cover models developed only in hardware
    - With simulations carried out as an exercise using the hardware models
  - M&S use is focused towards understanding a system for the purpose of decision making

Why NASA? / Why Now?

- Feb 1, 2003

- Resulting Columbia Accident Investigation Board (CAIB) developed set of Recommendations, Observations, & Findings (R-O-Fs)
  - Directed towards the Space Shuttle Program
  - Some were related to Models & Simulations
Findings of Shuttle Accident Investigation Related to Modeling & Simulation

- Operating a model outside known limits
  - Conditions are outside known limits

- Model Operator
  - Training
  - Experience

- Assumptions Communicated
  - Also, Abstractions

- Model Management
  - Maintenance
  - Support
  - Configuration Control

- Data V&V (I & O)
  - Model Verified with Real Data
  - Model Data is Current
  - Sensitivity Analysis Performed

Basic Ideas

- Documentation of M&S Activities (Sections 4.1 – 4.6)

- Credibility Assessment (Section 4.7 & Appendix B)

- Reporting to Decision Makers (Section 4.8)
  - M&S Analysis Results
  - A statement on the uncertainty in the results
  - Credibility of M&S Results
  - Identify
    - Unfavorable outcomes
    - Violation of assumptions
  - Unfavorable Use Assessment
    - Difference Between V&V & Use Assessment
Accreditation Results

Depth of Development
- Development
  - Ver
  - Val
- Operations
  - Input Pedigree
  - Uncertainty Quant.
  - Robustness
- Supporting Evidence
  - Use History
  - Model Mgt
  - People Qual.

Depth of Analysis
- Use Assessment
- Fidelity
  - Within Validated Domain

Depth of Support
- Technical Review

V&V Foundation

© Sargent, R. G. (c. 1980).
Verification & Validation

**Verification**
- Structure
- Flow
- Fidelity

**How:**
- Comparing to Conceptual Model
- Entity (Code) Tracing
- Primitive Tests (All 1’s)
- Min/Max Value Tests

**Validation:** "... determining the degree to which a model or a simulation is an accurate representation of the real world ..."

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Input Pedigree

**Input:**
- **Source**
  - Notional
  - Subject Matter Expert
  - Applicability to current problem
    - Referent Quality relative to current problem
      - Referent System
      - Referent Environment
    - Authoritative Data

- **Quantity** of Source Data

**Input Form:**
- What's the character of your analysis?
  - Average
  - Uniform
  - Triangular
  - Estimated PDF (from min, mode, 95%)
  - PDF from adequate real-world data
Accuracy & Uncertainty

Accuracy:

- True Value
- 'Modeled' Value
- Effect of drug: Increase
- 'Modeled' Value uncertainty
- Uncertainty in True Value

Uncertainty:

- Types
- Sources
- 'Size' (i.e., how big)
- How Confident
- Epistemic
  - Reducible
  - Subjective
  - Model Form
  - Assumptions
  - Abstractions
  - Incomplete Information
- Aleatory
  - Irreducible
  - (Natural) Variability
  - Inherent
  - Stochastic

Uncertainty

- 2 Types
  - Epistemic
    - Reducible
    - Subjective
    - Model Form
    - Assumptions
    - Abstractions
    - Incomplete Information
  - Aleatory
    - Variability
    - Irreducible
    - Inherent
    - Stochastic
- Parametric Uncertainty
  - Aleatoric
  - Stochastic Parameters
- Model Form
  - Epistemic
  - Model Structure/Selection
- Why M&S Results may not be correct
  - Variability
  - Uncertainty
  - Error
- Methods
  - Representation
  - Aggregation
  - Propagation
  - Interpretation of Results

More Experiments → More System Knowledge → Less Epistemic Uncertainty
Robustness

Robustness of Results, i.e., Sensitivity of:
- The Real World System (RWS)
- The M&S

Use History & Management

Use History:
- Similarity of Uses
  - Analogous Systems
  - Exact Systems
- Length of Time in Use
  - Just Developed
    - Just Updated
  - Long-Term Successful Use

M&S Management:
- Models & Data under Configuration Control
- Models are
  - Maintained
  - Sustained
People Qualifications & Tech Review

**People Qualifications:**
- Education
- Training
- Experience
  - In M&S
  - With the Modeled (Real World) System
- Use of Recommended Practices

**Technical Review:**
- When accomplished
  - During M&S Development
  - During M&S Operations

<table>
<thead>
<tr>
<th>Development</th>
<th>Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ver</td>
<td>Val</td>
</tr>
</tbody>
</table>

- Qualifications & Independence of the 'Peer' Review Group:
  - Self
  - Internal Organization
  - External
  - Non-Expert to Expert

- Level of Formalism
  - Planning
  - Documentation

Sample Report Formats

![Sample Report Formats](image)

*This briefing is for status only and does not represent complete engineering data analysis*
Scope of the M&S Standard

- Standard covers the use of M&S affecting:
  - Human Safety
  - Mission Success

As defined by each Program

Sample Risk Matrix

<table>
<thead>
<tr>
<th>M&amp;S Results Influence</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>5: Controlling</td>
<td>(O)</td>
<td>(Y)</td>
<td>(R)</td>
<td>(R)</td>
</tr>
<tr>
<td>4: Significant</td>
<td>(O)</td>
<td>(Y)</td>
<td>(R)</td>
<td>(R)</td>
</tr>
<tr>
<td>3: Moderate</td>
<td>(O)</td>
<td>(Y)</td>
<td>(Y)</td>
<td>(R)</td>
</tr>
<tr>
<td>2: Minor</td>
<td>(O)</td>
<td>(O)</td>
<td>(Y)</td>
<td>(Y)</td>
</tr>
<tr>
<td>1: Negligible</td>
<td>(O)</td>
<td>(O)</td>
<td>(O)</td>
<td>(O)</td>
</tr>
</tbody>
</table>

IV: Negligible  III: Marginal  II: Critical  I: Catastrophic

Decision Consequence

Models / Modeling

Modeling Aspects:
- Incidents (events, activities)
- Lifecycle (phases)
- Functions

Model Dynamics
- Social
- Physical
- Environmental
- Economic
- Organizational
- Infrastructure
- Other (e.g., Engineering Processes)

Model Representations:
- Conceptual
- Mathematical
- Dynamic
- Programming Paradigms
- Analytical Techniques

Interaction Methods:
- Live
- Virtual
- Constructive

Uses / Objective:
- Decision Support
- Planning
- Analysis
- Systems Engineering
- Training / Gaming
- Performance Measure
- Component / Module
Questions to Ask

- Type of Analysis
- Level of Detail
- Type of M&S
- Application S/W
- Uncertainty
- Use History
- Config Mgt
- V&V Domain/Range
- Analysis Domain/Range

Model Types

- **Behavior Mimicking** (Simulations)
  
  \[ y = x^2 \]

  Mathematical, Physical, or Chemical Formula
  (Algebraic Equations, ode, pde, Physical Formulas & Chemical Reaction Equations)

  \[ 2H_2 + O_2 \rightarrow 2H_2O \]

- **Behavioral**

  Listing & Relating Pieces of Information (Databases, Object-Oriented, Hierarchy, Organizational, Conceptual)

- **Narrative**

  Word Descriptions (Prose, Poetry, Req's, Spec, Speech)

- **Equation-based**

  Visual Form or Representation (Pictures, Graphs)

- **Relational Info**

  Physical/Tangible (Abstract, Scaled, Versions, Model Cars, Dolls)

- **Physical**

  Visual
Sim Types

- Process Analysis (Operations)
- Scenario Analysis (Autonomous Entity Interaction in an Environment)
- Computational Science & Engineering (Physics-based, pdeFEM)
- Continuous Simulation
- Agent Based Simulation
- Real-Time, Sim-Based Testing & Training
- Geometric Simulation, High Fidelity Visualization
- Process Feasibility (Visualizing, Form, Fit, Function)

Military View of M&S
(from an 'Interaction Modes' perspective)

- This looks at M&S from an 'Interaction Mode' perspective
- Description of categorization from:
  - Lee Lacey (DRC) - OneSAF 2008 Conference
- Pink box is from conversation with Lee Lacey (DRC)
Analysis Methods

System

Experiment with Actual System
Experiment with Model of System

Physical Model
Mathematical Model

Mental Model
Analytical Model

Numerical / Computational
Static or Dynamic
Deterministic or Stochastic / Probabilistic
Continuous or Discrete
Simple to Complex

Visualization
Sensory Immersion

M&S Uses:
Analysis
Prediction
Training
Testing
Gaming

Experiencing
Visualizing
Analyzing

Modified by Steele with added detail

Level of Detail

Organizational System
Engineered System
Engineered Component
Engineered Part
Physics / Chemistry
Atomic
Sub-Atomic
Network Layered Protocol Approach

Sender
Application
Presentation
Session
Transport
Network
Data Link
Physical

Receiver
Application
Presentation
Session
Transport
Network
Data Link
Physical

Like the Layered Network Protocol Model

Layered M&S View
(Influences in M&S Results)

User Input including Run Setup
M&S V&V and Credibility Assessment
Industry Standards and Broad Use

M/S Input
Model / Simulation
Application Software
Operating System Software
Computer Hardware

M/S Output

Analyzing Output including Post-Processing of Output Data

Need for a Clearinghouse for Commercial & Open Source M&S Languages & Application Software
Martin's Response

'Measured' Value = M&S Result

Comparing Values that have Uncertainty

**Short Definitions**

**Accuracy** – Agreement between a measurement (M&S Result) & the True Value

**Uncertainty** – A range of values likely to enclose the True Value

**Validation** – Process of determining the accuracy of a M&S

To know how much agreement there is between a measured & true value, the uncertainty of each must be evaluated.
Use Assessment

![Diagram of expected output range and intended input domain]

**Note** - this is a 2-dimensional example of a potentially multi-dimensional input domain & multi-dimensional output range

Information Reported to Decision-makers

**Additional Information**

**Section 4.7 Supplement: CAS Operational Concept**
- The test estimate
- The uncertainty statement
- The credibility assessment
- Test results
- Any comments

![Graph showing test estimate and uncertainty]

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[CAUTION]
Use Assessment Not Performed

This briefing is for status only and does not represent...
Something to say about models:

Hurricane Ivan Track Prediction Models
Something to say about models:

- **Model Map Display from the Mid-Atlantic WX.com** (shown on previous page)

**IMPORTANT!** This map does *NOT* represent the OFFICIAL FORECAST TRACK! Although the "official track" may be included, this is not a product of the Tropical Prediction Center/The National Hurricane Center.

This map is a graphic representation of computer generated projected tracks. This information is EXPERIMENTAL and subject to extreme fluctuations. It is provided for informational purposes only. Do not rely on this information!

Jeanne, Sept 16, 2004 – Track Prediction