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

CxDES Architecture

PAI Ariana
Input scenarios / Output Data & Graphs

RS Arena
DES Model

MS Excel
Order Lead Times / Schedule Inputs

If running the model with Manifest Data and/or Order Lead Times, that 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)

- 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 Investigations
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

Operations

Supporting Evidence

Ver | Val | Input Pedigree | Uncertainty Quant. | Robustness | Use History | Model Mgt | People Qual.

Technical Review

Depth of Review

Use Assessment

Use

Fidelity | Within Validated Domain

V&V Foundation

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

**Verification**
- Structure
- Flow
- Fidelity

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

- Comparing to Conceptual Model
- Entity (Code) Tracing
- Primitive Tests (All 1's)
- Min/Max Value Tests

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

Uncertainty in 'Modeled' Value

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
    - Lack of Knowledge
    - 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 Epistic Uncertainty
Robustness

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

<table>
<thead>
<tr>
<th>Worst Situation</th>
<th>Best Situation</th>
</tr>
</thead>
<tbody>
<tr>
<td>M&amp;S shows a Robustness not present in the RWS</td>
<td>M&amp;S is robust (Insensitive to Changes)</td>
</tr>
<tr>
<td>- Validation Issue</td>
<td>- the M&amp;S matches the RWS</td>
</tr>
</tbody>
</table>

OK Situation
- RWS is sensitive to change & the M&S matches the RWS

Not a Good Situation
- M&S is not robust, but RWS shows a Robustness not present in the RWS
- Results will be overly conservative

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>
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<tbody>
<tr>
<td>Ver</td>
<td>Val</td>
</tr>
<tr>
<td>Input Pedigree</td>
<td>Uncertainty Quant.</td>
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</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

Bar Chart

Radar Plot

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:
  - Critical Decisions
    - Human Safety
    - Mission Success
  - As defined by each Program

### Sample Risk Matrix

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

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

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

- Visual Form or Representation (Pictures, Graphs)

- Behavioral
- Narrative
- Visual
- Physical
- Relational Info
- Equation-based

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

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

- Mental Model
- Analytical Model

Mathematical 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

Level of Detail

- Organizational System
- Engineered System
- Engineered Component
- Engineered Part
- Physics / Chemistry
- Atomic
- Sub-Atomic


Modified by Steele with added detail
Network Layered Protocol Approach

Like the Layered Network Protocol Model

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

Need for a Clearinghouse for Commercial & Open Source M&S Languages & Application Software

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

Analyzing Output including Post-Processing of Output Data
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

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

Information Reported to Decision-makers

This briefing is for status only and does not represent...
Development Progression

CAIB Report

Diaz Report

NASA OCE Direction

M&S Literature

Mgt Decision Maker Interviews

Pilot Studies

Interim Nov 06

Final Submitted Nov 07

2 Credibility Scales

1 New Credibility Scale

External Efforts

NASA-wide Formal Review

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