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

Ariana populates Arena based on user inputs prior to run

Arena outputs are exported to Ariana post-run

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

11/19/2009
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
- ≈ 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

Depth of Analysis

Depth of Support

Supporting Evidence

Use History

Model Mgt

People Qual.

Use Assessment

Fidelity

Within Validated Domain

V&V Foundation

© Sargent, R. G. (c. 1980).

Model Qualification

Model Validation

Model Verification

Model Simulation

Computer Programming

Computer Programming and Implementation

Computer Model

Conceptual Model

Data Validation

Analysis and Modeling

Conceptual Model Validation

Operational Validation

Experimentation

Problem Entity (System)

© 1979 Society for Computer Simulation.
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

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

Uncertainty Occurrences

- Parameters of the model
- Accuracy of the model
- Sequence of possible event

More Experiments → More System Knowledge → Less Epistemic Uncertainty
Robustness

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

M&S

Worst Situation
- M&S shows a Robustness not present in the RWS
- Validation Issue
  - RWS not so useful

Best Situation
- RWS is robust (Insensitive to Changes)
  - M&S matches the RWS

Not a Good Situation
- M&S is not robust, but RWS is
  - Validation Issue
  - 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>
</tr>
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<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

![Bar Chart](Image)

![Radar Plot](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:
  - Critical Decisions
    - Human Safety
    - Mission Success
    - As defined by each Program

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

Sample Risk Matrix

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

Behavioral

Equation-based

Relational Info

Physical

Narrative

Visual

Behavior Mimicking
(Simulations)

$y = x^2$

Mathematical, Physical, or Chemical Formula

Algebraic Equations, ode, pde, Physical Formulas & Chemical Reaction Equations

$2H_2 + O_2 \rightarrow 2H_2O$

Listing & Relating
Pieces of Information

(Databases, Object-Oriented

Hierarchy, Organizational, Conceptual)

Word Descriptions

(Frase, Poetry, Req's Spec, Speech)

Visual Form
or Representation

(Pictures, Graphs)

Physical/Tangible

(Abstract, Scaled)

Versions

(Model Cars, Dolls)
Sim Types

**Process Analysis** (Operations)

**Scenario Analysis** (Autonomous Entity Interaction in an Environment)

**Agent Based Simulation**

**Discrete Event Simulation**

**Continuous Simulation**

**Real-Time, Sim-Based Testing & Training**

**Computational Science & Engineering** (Physics-based, pdeFEM)

**Geometry Sim, High Fidelity Visualization**

**Process Feasibility** (Visualizing, Form, Fit, Function)

**Sys & S/W Validation**

**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 (including Simulation)

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

Visualization
- Sensory Immersion

M&S Uses:
- Analysis
- Prediction
- Training
- Testing
- Gaming


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

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

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

Expected Output Range

Validated Output Range

Validation Point

Validated Input Domain

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
- Data results
- Any comments

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CAUTION

Use Assessment

Not Performed

11/19/2009
Development Progression

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!