NASA Models & Simulations (M&S)

Including the NASA Standard for M&S

August 2016
Premise for an M&S Standard

• A major point of understanding:
  • All M&S results *implicitly, if not explicitly*, contain *uncertainty*.

• M&S Results were presented in a variety of ways
  • Many Types of M&S
  • Many Types of Applications

• Sometimes credibility topics were addressed
  • Again, in a variety of ways
  • And, incompletely
  • Heavily focused on VV&A (Verification, Validation, & Accreditation)

• What is essential:
  • A Common Vocabulary
  • Rigorous Testing of the M&S
  • A baseline methodology for Reporting Results
The Perfect Example

• The System & Problem are understood perfectly (with extensive supporting data)
• The System & Problem are modeled perfectly – an exact match, including fidelity
• The M&S requirements are perfectly formulated
• The M&S requirements (including those from NASA-STD-7009) were all met without waivers
• All abstractions in the M&S are inconsequential
• M&S assumptions are understood and none were violated
• The M&S was used well within its limits of operation
• No errors or warnings occurred during the execution of the M&S
• The results are/appear reasonable
• Sources of error/uncertainty are known
• The error/uncertainty on the results is quantitative & acceptable
• Credibility assessment meets or exceeds P/P expectations

NASA-STD-7009 exists to help deal with the fact that in practice we rarely approach this ideal.
Background

<table>
<thead>
<tr>
<th>Document</th>
<th>Document Number</th>
<th>Revision</th>
<th>Published</th>
</tr>
</thead>
<tbody>
<tr>
<td>M&amp;S Handbook</td>
<td>NASA-HDBK-7009</td>
<td>Rev. A</td>
<td>In Development</td>
</tr>
</tbody>
</table>

- M&S Standard Development – Prompted by findings from Shuttle Columbia Accident

- Revision prompted by real-world experience in implementing the Standard
- Rev. A STD contains: 39 Requirements & 49 Recommendations
Overarching Concepts for M&S

• Applies to ALL TYPES of M&S
• Provide a Common Terminology Base
• Follow a Defined Process in the development & use of an M&S (M&S Life Cycle) {Charts 7-9}
• Define M&S Acceptance Criteria, including
  • M&S Intended Use
  • Criteria for
    • Verification
    • Validation
    • Uncertainty Characterization
    • Reporting {Chart 13}
    • Configuration Management
• Assess
  • Criticality addressed by the M&S {Chart 6}
  • Proposed Use of an M&S {Chart 11}
  • Credibility of M&S-based Results {Chart 12}
  • Risk of Accepting M&S-based Results {Chart 15}
• Document! (i.e., provide evidence of what is accomplished)
  • In Development
  • In Use
### Criticality Assessment

<table>
<thead>
<tr>
<th>M&amp;S Results</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>Influence</td>
<td>(G) (Y) (R) (R) (R)</td>
<td>(G) (Y) (Y) (R) (R)</td>
<td>(G) (Y) (Y) (Y) (R)</td>
<td>(G) (G) (G) (Y) (Y)</td>
<td>(G) (G) (G) (G) (Y)</td>
</tr>
</tbody>
</table>

#### Decision Consequence

<table>
<thead>
<tr>
<th>I: Negligible</th>
<th>II: Minor</th>
<th>III: Moderate</th>
<th>IV: Significant</th>
<th>V: Catastrophic</th>
</tr>
</thead>
</table>

Sample Matrix is 5x5
### Lifecycles

#### NASA Prog/Proj Mgt Lifecycle

<table>
<thead>
<tr>
<th>Pre-Phase A</th>
<th>Phase A</th>
<th>Phase B</th>
<th>Phase C</th>
<th>Phase D</th>
<th>Phase E</th>
<th>Phase F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conceptual Studies</td>
<td>Concept &amp; Technology Development</td>
<td>Preliminary Design &amp; Technology Completion</td>
<td>Final Design &amp; Fabrication</td>
<td>System Assembly, Integration, &amp; Test</td>
<td>Operations &amp; Sustainment</td>
<td>Closeout</td>
</tr>
</tbody>
</table>

#### Development

- **Model Initiation**
- **Concept Development**
- **Model Design**
- **Model Construction**
- **Model Testing**

#### Ops / Use

- **Model Use / Ops**
- **Model/Anal. Archiving**

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### M&S Lifecycle
M&S Life Cycle

**Intended Use** – The expected purpose and application of an M&S.

**Permissible Use** – The purposes for which an M&S is formally allowed.

**Proposed Use** – A desired specific application of an M&S.

**Accepted Use** – The successful outcome of a Use Assessment designating that the M&S is accepted for a Proposed Use.

**Actual Use** – The specific purpose and domain of application for which an M&S is being, or was, used.

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**Appendix F**

The process of determining if an M&S is accepted for a Proposed Use.
The Fundamental M&S Process

System

Empirical Validation

Conceptual Validation

Use

System Analysis

Model Implementation

Verification

Reality of Interest aka Real World System

Appendix F
M&S Development Concepts

• Document Aspects of the RWS to Model

• Document M&S Design
  • Conceptually Validate the M&S Design prior to Implementation

• Implement the M&S

• Distinctly & Separately
  • Verify the M&S
  • Validate the M&S, including:
    • Accuracy (& Precision)
    • Abstractions & Assumptions
    • Characterizing Uncertainty
    • Characterizing Sensitivities

• Document Permissible Uses of the M&S
M&S Use Concepts

• Assessment of the Use of the M&S – Compare its Proposed Use to its Permissible Uses
• Plan & Document M&S Setup & Scenarios for Use
• Characterize M&S Uncertainties in
  • The M&S
  • M&S Scenarios (Inputs)
  • M&S Output (Results)
• Understand Sensitivities in M&S Results
• Placard Results for Uses outside Permissible Uses {Charts 13-14}
• Assess Credibility {Chart 12}
• Report Results Completely {Charts 13-15}
## Results Credibility Assessment (Table 3)

<table>
<thead>
<tr>
<th>Level</th>
<th>Data Pedigree</th>
<th>Verification</th>
<th>Validation</th>
<th>Input Pedigree</th>
<th>Uncertainty Characterization</th>
<th>Results Robustness</th>
<th>Supporting Evidence</th>
<th>M&amp;S History</th>
<th>M&amp;S Process / Product Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>All data known &amp; traceable to RWS with acceptable accuracy, precision, &amp; uncertainty.</td>
<td>Reliable practices applied to verify the end-to-end model; all model errors satisfy requirements.</td>
<td>All M&amp;S outputs agree with data from the RWS over the full range of operation in its real operating environment.</td>
<td>All input data known &amp; traceable to RWS with acceptable accuracy, precision, &amp; uncertainty.</td>
<td>Statistical analysis of the output uncertainty after propagation of all known sources of uncertainty.</td>
<td>Sensitivities known for most parameters; most key sensitivities identified.</td>
<td>Nearly Identical Model and Use.</td>
<td></td>
<td>Controlled processes are applied; measurements used for process improvement.</td>
</tr>
<tr>
<td>3</td>
<td>All data known &amp; traced to sufficient referent. Significant data has acceptable accuracy, precision, &amp; uncertainty.</td>
<td>Formal practices applied to verify the end-to-end model; all important errors satisfy requirements.</td>
<td>All key M&amp;S outputs agree with data from the RWS operating in a representative environment.</td>
<td>All input data known &amp; traced to sufficient referent. Significant input data has acceptable accuracy, precision, &amp; uncertainty.</td>
<td>Uncertainty of results are provided quantitatively through propagation of all known uncertainty.</td>
<td>Sensitivities known for many parameters including many of the key sensitivities.</td>
<td>At most minor changes in Model and at most minor differences in Model Use.</td>
<td></td>
<td>Controlled processes are applied; process compliance is measured.</td>
</tr>
<tr>
<td>2</td>
<td>Some data known &amp; formally traceable with estimated uncertainties.</td>
<td>Documented practices applied to verify all model features; most important errors satisfy requirements.</td>
<td>Key M&amp;S outputs agree with data from a sufficiently similar referent system.</td>
<td>Some input data known &amp; formally traceable with estimated uncertainties.</td>
<td>Most sources of uncertainty identified, expressed quantitatively and correctly classified. Propagation of the uncertainties is assessed.</td>
<td>Sensitivities known for a few parameters. Few or no key sensitivities identified.</td>
<td>At most moderate changes in Model and at most moderate differences in Model Use.</td>
<td></td>
<td>Formal processes &amp; requirements are applied.</td>
</tr>
<tr>
<td>1</td>
<td>Some data known and informally traceable.</td>
<td>Informal practices applied to verify some features of the model and assess errors.</td>
<td>Conceptual model addresses problem statement and agrees with available referents. <strong>Note: This is a prerequisite to Levels 2, 3, &amp; 4</strong></td>
<td>Some input data known and informally traceable.</td>
<td>Sources of uncertainty identified and qualitatively assessed.</td>
<td>Qualitative estimates only for sensitivities in M&amp;S.</td>
<td>New Model or major changes in Model, or major differences in Model Use; but, model/changes/uses documented.</td>
<td></td>
<td>Informal processes &amp; requirements are applied.</td>
</tr>
</tbody>
</table>
Reporting M&S Results

• Estimated Results
• Results Uncertainty
  • The Processes to Obtain the estimate of Uncertainty
• Results Sensitivity
• Caveats to Results / Analysis
  • Unachieved Acceptance Criteria
  • Violation of
    • any Assumptions
    • the Limits of Operation
  • Warning and Error Messages
  • Unfavorable
    • Proposed use assessments
    • Setup/Execution Assessments
  • Waivers to Requirements
• Technical Review Findings
• Qualifications of
  • Developers
  • Users/Analysts
• What’s Documented
  • & What is Not Documented
• Assessment of and Rationale for the Risks associated with the M&S Use
  • Criticality
  • Caveats
  • Uncertainty
  • Credibility
  • Technical Review
  • People Qualifications
  • M&S Doc’n
M&S Results Reporting

Analysis Caveats:
- Unachieved acceptance criteria
- Violation of Assumptions
- Violation of Limits of Operation
- Execution Warnings & Errors
- Unfavorable Intended Use
- Req’t Waivers

CAUTION
Analysis Performed Outside the Limits of Operation

M&S Risk Elements:
- Criticality
- Caveats
- Uncertainty
- Credibility
- Technical Review
- People Qualifications
- M&S Doc’n

Credibility Assessment

Likelihood (of inability to correctly represent the RWS):
- 5: Very High
- 4: High
- 3: Moderate
- 2: Low
- 1: Very Low

Elements of Risk
M&S Risk Assessment

- Taken with the knowledge of Criticality (Appendix D)

<table>
<thead>
<tr>
<th>Likelihood (of inability to correctly represent the RWS)</th>
<th>Elements of Risk</th>
</tr>
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<tbody>
<tr>
<td>5: Very High</td>
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<tr>
<td>4: High</td>
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</tr>
<tr>
<td>3: Moderate</td>
<td></td>
</tr>
<tr>
<td>2: Low</td>
<td></td>
</tr>
<tr>
<td>1: Very Low</td>
<td></td>
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- Do any of the Reporting Elements increase the likelihood of the M&S incorrectly representing the RWS?
  - Caveats
  - Uncertainty
  - Credibility
  - Technical Review
  - People Qualifications
  - M&S Documentation

- The Risk incurred from a Model or Simulation is in its ability to correctly represent the Real World System (Reality of Interest)

- The Risk to the RWS is assessed by the Decision Maker
Last Words

• Application of all the Requirements in All situations may be daunting

• Applying a Standard to ALL Types of M&S is challenging

• Tailoring is permitted, if
  • Documented
  • Approved by the appropriate Technical Authority

• Consult Discipline Specific Recommended Practices