

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



Document	Document Number	Revision	Published
M&S Standard	NASA-STD-7009	Baseline	July 2008
M&S Handbook	NASA-HDBK-7009	Baseline	October 2013
M&S Standard	NASA-STD-7009	Rev. A	July 2016
M&S Handbook	NASA-HDBK-7009	Rev. A	In Development

- M&S Standard Development Prompted by findings from Shuttle Columbia Accident
- M&S Handbook Development An Implementation Guide to NASA-STD-7009
- 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



		Decision Consequence				
		I: Negligible	II: Minor	III: Moderate	IV: Significant	V: Catastrophic
	1: Negligible	(G)	(G)	(G)	(G)	(Y)
M&S Results Influence	2: Minor	(G)	(G)	(G)	(Y)	(Y)
&S Resul Influence	3: Moderate	(G)	(Y)	(Y)	(Y)	(R)
sults	4: Significant	(G)	(Y)	(Y)	(R)	(R)
	5: Controlling	(G)	(Y)	(R)	(R)	(R)

Sample Matrix is 5x5

Lifecycles

Pre-	Phase	Phase	Phase	Phase	Phase	Phase
Phase A	Α	В	C	D	Е	F
Conceptual Studies	Concept & Technology Development	Preliminary Design & Technology Completion	Final Design & Fabrication	System Assembly, Integration, & Test	Operations & Sustainment	Closeout

Development

Ops / Use

Model	Concept	Model	Model	Model	Model	Model/Anal.
Initiation	Development	Design	Construction	Testing	Use / Ops	Archiving

M&S Lifecycle

M&S Life Cycle



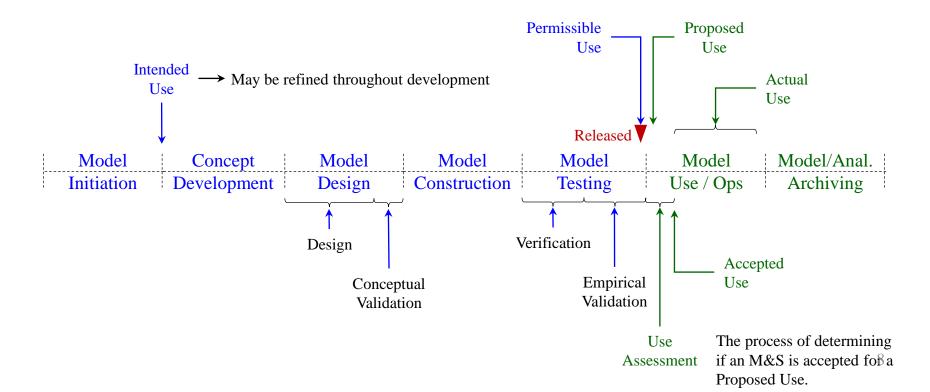
Intended Use – The expected purpose and application of an M&S.

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

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

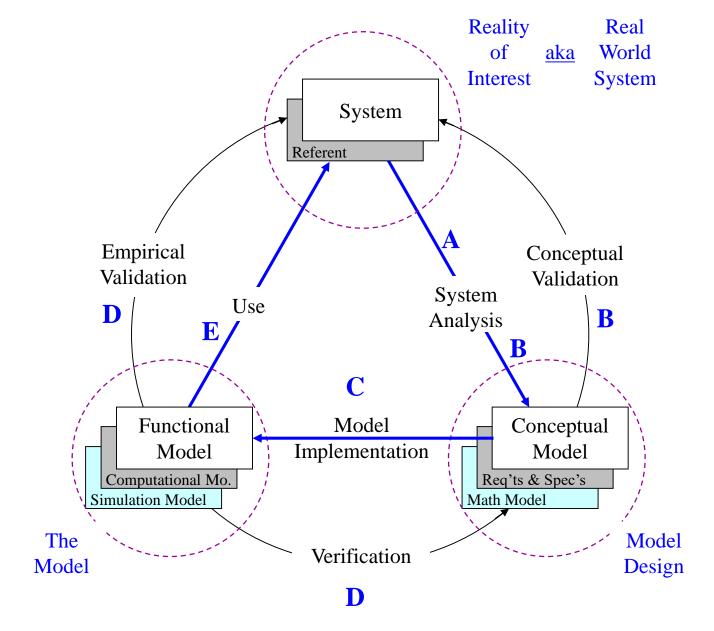
Accepted Use – The successful outcome of a Use Assessment designating that the M&S is accepted for a Proposed Use.

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



The Fundamental M&S Process





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}

Appendix E

Results Credibility Assessment (Table 3)

	M&S Development			M&S Operations			Supporting Evidence	
Level	Data Pedigree	Verification	Validation	Input Pedigree	Uncertainty Characterization	Results Robustness	M&S History	M&S Process / Product Management
4	All data known & traceable to RWS with acceptable accuracy, precision, & uncertainty.	all model errors satisfy requirements.	All M&S outputs agree with data from the RWS over the full range of operation in its real operating environment.	All input data known & traceable to RWS with acceptable accuracy, precision, & uncertainty.	Statistical analysis of the output uncertainty after propagation of all known sources of uncertainty.		Nearly Identical Model <u>and</u> Use.	Controlled processes are applied; measurements used for process improvement.
3	All data known & traced to sufficient referent. Significant data has acceptable accuracy, precision, & uncertainty.	applied to verify the end-to-end model; all important errors satisfy requirements.	All key M&S outputs agree with data from the RWS operating in a representative environment.	All input data known & traced to sufficient referent. Significant input data has acceptable accuracy, precision, & uncertainty.	quantitatively through propagation	the key concitivation	At most minor changes in Model and at most minor differences in Model Use.	Controlled processes are applied; process compliance is measured.
2	formally traceable	practices applied to	Key M&S outputs agree with data from a sufficiently similar referent system.	Some input data known & formally traceable with estimated uncertainties.		for a few	At most moderate changes in Model and at most moderate differences in Model Use.	Formal processes & requirements are applied.
1	Some data known and informally traceable.	some features of the model and assess errors.	Conceptual model addresses problem statement and agrees with available referents. Note: This is a prerequisite to Levels 2, 3, & 4	Some input data known and informally traceable.	Sources of uncertainty identified and	Quantative estimates	New Model or major changes in Model, or major differences in Model Use; but, model/changes/uses documented.	Informal processes & requirements are applied.
	Insufficient evidence.	Insufficient	Insufficient evidence.	Insufficient evidence.	Insufficient evidence.		Insufficient evidence.	Insufficient evidence.
	evidence.	evidence.	evidence.	ovidence.	ovidence.	o videlice.	evidence.	ovidence.

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

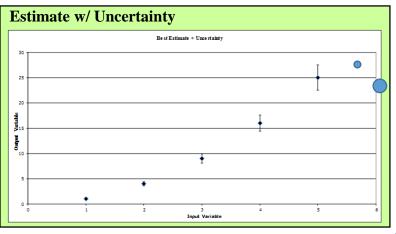
M&S Results Reporting

Estimate



Documented Evidence

[M&S 33]



[M&S 32]

Analysis Caveats:

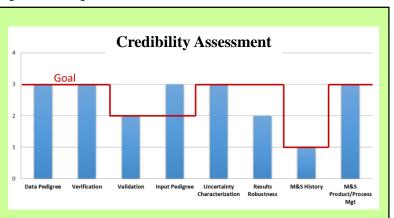
- Unachieved acceptance criteria
- Violation of Assumptions
 Violation of Limits of
- Operation Wassings 8
- Execution Warnings & Errors
- Unfavorable Intended Use
- Req't Waivers

CAUTION

Analysis Performed Outside the Limits of Operation

[M&S 26 (2)]

[M&S 35]



[M&S 39]

M&S Risk Elements:

- Criticality
- Caveats
- Uncertainty
- Credibility
- Technical Review
- People Qualifications
- M&S Doc'n

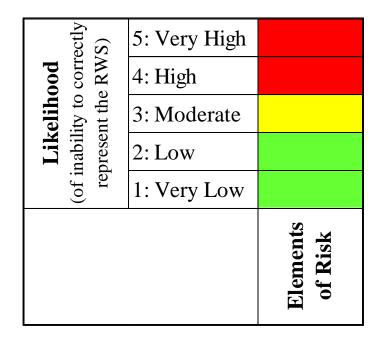
Likelihood	(of inability to correctly	represent the RWS)

- 5: Very High 4: High 3: Moderate 2: Low
- 2: Low 1: Very Low
 - lements

M&S Risk Assessment



• Taken with the knowledge of Criticality (Appendix D)



• 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