S&T Stakeholders Conference

Modeling and Simulation (M&S) Guidelines

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Abstract

M&S is an important tool for operations analysis, experimentation, system acquisition, and training. This tutorial outlines guidance for program managers, M&S developers, and decision makers on the judicious use of M&S, which incorporates guidelines from reference material and standards, policies, processes, and “best practice” developed in Federal departments, agencies, and entities. Focus areas include examples of departmental M&S capabilities and approaches to M&S development, management, and evaluation.
Draft M&S Course Outline

What is a “Model”, “Simulation”, etc.?

How is M&S used for homeland security?
- National Infrastructure Simulation and Analysis Center (NISAC)
- National Atmospheric Release Advisory Center (NARAC)/Inter-Agency Modeling and Atmospheric Analysis Center (IMAAC)
- Emerging Capabilities in DHS S&T Directorate

Who in DHS should consider using M&S?

When and where in DHS is M&S useful?

What are some considerations in acquiring M&S capabilities?
- Economics
- Development
- Data
- Evaluation

Why are M&S guidelines, standards, and “best practice” important for DHS?

How do other Federal agencies/organizations approach M&S?
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Definitions

Model

(1) An approximation, representation, or idealization of selected aspects of the structure, behavior, operation, or other characteristics of a real-world process, concept, or system. Note: Models may have other models as components.

(2) To serve as a model as (1).

(3) To develop or use as a model as in (1).

Simulation

(1) A model that behaves or operates like a given system when provided a set of controlled inputs.

(Synonymous with: Simulation model)

(2) The process of developing or using a model as in (1).


Lists 33 different types of models (e.g., computational, descriptive, discrete, iconic, mathematical) and 20 different types of simulations (e.g., continuous, discrete, event-oriented, Monte Carlo, process-oriented).
# Definitions from DoD and EPA

## Model

**DoD:** A physical, mathematical, or otherwise logical representation of a system, entity, phenomenon, or process.

**EPA:** A representation of the behavior of an object or process, often in mathematical or statistical terms. Models can also be physical or conceptual.

## Simulation

**DoD:** A method for implementing a model over time. Also, a technique for testing, analysis, or training in which real-world systems are used, or where real-world and conceptual systems are reproduced by a model.

**EPA:** One complete execution of the computer program, including input and output.

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**Sources:** M&S Management. DoD Directive 5000.59.

Guidance for Quality Assurance Project Plans for Modeling. EPA QA/G-5M

DoD/Live, Virtual, Constructive (LVC)

Live simulations are simulated operations of real systems using real people in realistic situations.

Virtual simulations put the human-in-the-loop (HITL)

Constructive Simulations are computer simulations that are strictly mathematical representations of systems and do not employ any actual hardware.
A “Model” for M&S

Draft M&S Course Outline

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Modeling, Simulation and Analysis and The National Infrastructure Simulation and Analysis Center (NISAC)

S&T Stakeholders Conference - 2 June 2008

Merrick E. Krause, Director
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Office of Infrastructure Protection

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NISAC

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OUTLINE

• NISAC Mission & Mandate
• Where NISAC fits in DHS
• What is NISAC
  – Not a product
  – Not a model
  – Not the only MS&A capability
• Modeling and Simulation for Analysis
  – Examples
• Summary
NISAC Mission

• **HSPD-7**
  – “[DHS] will utilize existing, and develop new capabilities as needed to model comprehensively the potential implications of ... vulnerabilities in critical infrastructure and key resources ...”

• **Patriot Act, 2001**
  – NISAC will “serve as a source of national competence to address critical infrastructure protection and continuity through support for activities related to counterterrorism, threat assessment, and risk mitigation”

• **Homeland Security Appropriations Act of 2007**
  – Expanded NISAC’s responsibilities and mission
  – NISAC ... “shall serve as a source of national expertise to address critical infrastructure protection and continuity

• **National Infrastructure Protection Plan**
  – NISAC provides advanced modeling and simulation capabilities for the analysis of CIKR interdependencies, vulnerabilities, and other complex interactions
Where NISAC Fits in the Office of Infrastructure Protection

- The only Congressionally mandated CIKR analysis activity responsive to the NIPP
  - Cross-Sector Expertise
  - Operational Perspective
NISAC

- Two separate DOE National Laboratories
- Responsive to DHS / IP

- Approx 100 scientists & technicians
  - Multi-disciplinary
  - Innovative, and still evolving
  - Scientifically credible
NISAC Provides

**Sector & Cross Sector Knowledge**
- Operations
- Locations
- Structure
- Services & Dependencies

**Mission Space Understanding**
- CIKR
- Population
- Topography
- Economics
  - Critical Interdependencies

**Risk Mitigation**
- Incident Response

**MS&A Adds**
- Documented Methods
- Documented Results
- Reproducible Processes
- Qualified Multidiscipline Analysts
- FAST Analysis (when required)
- All-Sector Perspective
NISAC Business Model

- **Point of Entry:** IASD NISAC Branch
- ASIP is priority customer and defines priorities
- **Joint Ventures encouraged**
  - Tasking exceeds resources
  - Unique capabilities for cross-sector and multi-sector analysis
- **Outreach** to CIKR Sectors, DHS Components, and Federal Interagency partners
  - HSIN
  - R&D Community via IASD Portal (Beta test in 2008)
Summary

• NISAC integrated into IP Mission through IASD
  – HITRAC
  – R&D Branch sector analyses & requirements

• Excels at Pre-incident analysis
  – Preparation, Prevention, Mitigation
  – Improving capability for Response
  – Data bases are not real-time

• NISAC performs cross-sector interdependency and cascading consequence analysis
  – Joint Ventures encouraged
IMAAC Provides Federal Dispersion Modeling During Events Requiring Federal Coordination

- Created by Homeland Security Council (April 2004)
- NARAC designated as the interim provider of IMAAC services
- Eight-agency Memorandum of Understanding and Interagency Working Group
- National deployment plan
  - Federal operations centers
  - Regional response assets (DHS/FEMA, DOE, EPA, NOAA)
  - States
- Local Integration of NARAC w/Cities pilot program
- Permanent site selection process underway

“The IMAAC provides a single point for the coordination and dissemination of Federal dispersion modeling and hazard prediction products that represent the Federal position during actual or potential incidents requiring federal coordination” - National Response Plan (NRP) Notice of Change May 2006
NARAC/IMAAC Provides Operational Services, Tools, Expertise for Preparedness and Response

**Event Information**
- Weather data
- Nuclear, radiological, chemical, and biological source information
- Terrain, land use, and population databases
- Measurement data and observations

**Operational Services and Expertise**
- Suite of stand-alone to advanced WMD modeling tools (multi-scale models)
- 24/7/365 expert scientific staff (< 5 min. reachback)
- Detailed analysis, expert interpretation, quality assurance, and training
- Event reconstruction

**Actionable Information**
- Hazard areas
- Health effects and exposed populations and facilities
- Casualty, fatality, and damage estimates
- Protective action recommendations and response strategies
- Threat assessments
Internet- and Web-based Software Tools Provide Easy Access and Distribution of Predictions

**Local/State Emergency Operations Center**

- Information distribution & decision making

**Local, Regional, State Responders**

- Fast-running local models
- Access to advanced models
- iClient software

**IMAAC Web**

**Collaborating City, County, State & Federal Agencies**

- Advanced modeling tools
- Scientific support and analyses
Standard Operational Procedures Couple Modeling and Monitoring in a Cyclical Process

Set 1. An initial automated plot shows downwind location only with no estimate of health effects

Automated Web-Initiated or via Emergency Call; Only know release time and location

Set 2. We use revised event data to produce quality assured reach-back plots

Example revised data: Updated source location, detailed weather

Set 3. We compare the model with a few initial field measurements to make an initial estimate of the amount released

Source scaled to initial set of measurements

Set 4. We develop a health-effects plot based on a source term estimated from field measurements

Later sets: We develop Relocation and Food-Ingestion plots

Set 5. We use more extensive sets of field measurements to improve the accuracy of the source term calculation

Cycle of new products based on updated sets of measurements
## Integrated Modeling Capabilities Include In-House and Externally Built Models

<table>
<thead>
<tr>
<th>Model</th>
<th>Source</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADAPT</td>
<td>LLNL</td>
<td>Diagnostic meteorological model</td>
</tr>
<tr>
<td>BLAST</td>
<td>SNL</td>
<td>Pressure effects model for high explosives and RDDs</td>
</tr>
<tr>
<td>COAMPS</td>
<td>NRL/LLNL</td>
<td>Mesoscale forecast model</td>
</tr>
<tr>
<td>WRF</td>
<td>NCAR</td>
<td>Community weather research forecast model</td>
</tr>
<tr>
<td>EPICODE</td>
<td>Commercial</td>
<td>Gaussian plume model with hazardous chemical databases</td>
</tr>
<tr>
<td>GridGen</td>
<td>LLNL</td>
<td>Grid generation software for ADAPT/LODI using terrain data</td>
</tr>
<tr>
<td>Hotspot</td>
<td>LLNL</td>
<td>Gaussian plume model for radioactive and nuclear material</td>
</tr>
<tr>
<td>KDFOC</td>
<td>LLNL</td>
<td>Gross fission products fallout effects model</td>
</tr>
<tr>
<td>LODI</td>
<td>LLNL</td>
<td>Lagrangian stochastic particle dispersion model</td>
</tr>
<tr>
<td>NUKE</td>
<td>SNL</td>
<td>Prompt dose, thermal, and overpressure effects model for nuclear weapon</td>
</tr>
<tr>
<td>WRF</td>
<td>NCAR</td>
<td>Community numerical weather prediction model (in-house versions)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>UDM</th>
<th>DSTL</th>
<th>Empirical urban model (prototype integration completed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FEM3MP</td>
<td>LLNL</td>
<td>Multiprocessor computational fluid dynamics (CFD) building-resolving model</td>
</tr>
</tbody>
</table>
## Collaborations Provide Additional Models & Data

### Stand-Alone Models from Collaborations

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<tr>
<th>Model</th>
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</tr>
</thead>
<tbody>
<tr>
<td>CAMEO/ALOHA</td>
<td>NOAA/EPA</td>
<td>Gaussian plume model with toxic industrial chemical databases</td>
</tr>
<tr>
<td>HPAC</td>
<td>DTRA</td>
<td>Plume modeling system with SCIPUFF</td>
</tr>
<tr>
<td>RASCAL</td>
<td>NRC</td>
<td>Radiological source terms and Gaussian plume/puff model for nuclear power plant releases</td>
</tr>
<tr>
<td>Turbo FRMAC</td>
<td>SNL</td>
<td>Radiological dose calculations from air and ground contamination</td>
</tr>
</tbody>
</table>

### Forecast Model Results from External Sources

<table>
<thead>
<tr>
<th>Agency</th>
<th>Model</th>
<th>Resolution/Coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Force Weather Agency (AFWA)</td>
<td>MM5</td>
<td>45 and 15 km resolution, special regional forecasts</td>
</tr>
<tr>
<td>Fleet Numerical Meteorology and Oceanography Center (FNMO)</td>
<td>NOGAPS 4.0</td>
<td>1° resolution, global</td>
</tr>
<tr>
<td></td>
<td>COAMPS</td>
<td>Special regional forecasts</td>
</tr>
<tr>
<td>National Weather Service (NWS)</td>
<td>WRF</td>
<td>40 km and 12 km resolution, US</td>
</tr>
<tr>
<td></td>
<td>GFS (AVN)</td>
<td>0.5° and 1° resolution, global</td>
</tr>
<tr>
<td></td>
<td>RUC</td>
<td>20 km resolution, US</td>
</tr>
</tbody>
</table>
NARAC/IMAAC Models and Operations are Extensively Tested and Evaluated

- **Analytic solutions** test models versus known, exact results

- **Field experiments** test models in real-world cases
  Examples: Roller Coaster, Project Prairie Grass, Savannah River Musicale Atmospheric Tracer Studies, Diablo Canyon Tracer Study, ETEX, URBAN

- **Operational testing** evaluates the usability, efficiency, consistency and robustness of models for operational conditions
  Examples: Chernobyl, Kuwait oil fires, tire fires, industrial accidents, Algeciras Spain Cesium release, Tokaimura criticality accident, Cerro Grande (Los Alamos) fire
Emerging M&S Capabilities in DHS S&T Directorate

<table>
<thead>
<tr>
<th>Explosives</th>
<th>Chemical/Biological</th>
<th>Command, Control, &amp; Interoperability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computational models to predict aircraft</td>
<td>Foreign Animal Diseases Modeling Project</td>
<td>Visual Analytic and Physics-based</td>
</tr>
<tr>
<td>vulnerability to Explosive threats</td>
<td>Joint Modeling Operations Center (JMOC)</td>
<td>Simulation Program</td>
</tr>
<tr>
<td><img src="image1" alt="Explosives Image" /></td>
<td><img src="image2" alt="Chemical/Biological Image" /></td>
<td><img src="image3" alt="Command, Control, &amp; Interoperability Image" /></td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th>Borders/Maritime</th>
<th>Human Factors</th>
<th>Infrastructure/Geophysical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secure Border Initiative Systems Engineering</td>
<td>Group Violent Intent Modeling Project</td>
<td>Integrated Modeling, Mapping and</td>
</tr>
<tr>
<td>and Modeling &amp; Simulation Project</td>
<td>Open Source Modeling Applicability Project</td>
<td>Simulation Program</td>
</tr>
<tr>
<td><img src="image4" alt="Borders/Maritime Image" /></td>
<td><img src="image5" alt="Human Factors Image" /></td>
<td><img src="image6" alt="Infrastructure/Geophysical Image" /></td>
</tr>
</tbody>
</table>

**M&S is integral to analysis and supports decision making at many levels**
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  - Data
  - Evaluation

Why are M&S guidelines, standards, and “best practice” important for DHS?

How do other Federal agencies/organizations approach M&S?
M&S in Perspective

**Skilled analysts match the right M&S and data to answer the question at hand.**
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Framework For Incident Management (FIM)

Cells Represent Potential M&S Applications: Many potential uses for Incident Management!

Source: An Integrated Gaming and Simulation Architecture for Incident Management Training, NISTIR 7295, March 2006
Framework – Examples of Incident Data

For LIFECYCLE PHASE: Response

INCIDENT: MAN-MADE

- NBC bomb
- Conventional bomb
- Fire

CIVILIAN POPULATION
- Residential
- Commuters

CRITICAL INFRASTR.
- Water line
- Utility Repair
- Public Bldgs.
- Road Network

GOVT. AGENCIES
- Police Dept.
- Police cars
- Fire Dept.
- Fire Engines
- Hospitals
- Ambulances

PRIVATE SECTOR
- Hospital

# dead,
# injured,
behavior

-Damaged at a junction
-Water dept. technicians on way
-# floors, # sq. ft. damaged
-Traffic jam

Units dispatched
Arriving in 3 mins.

Units dispatched
Arrived 1 min. ago

Capacity available, performance
Arriving in 2 mins.

Capacity available, performance

Modeling, simulation & visualization capabilities can be used to understand current and future impact and plan response.
System Reference Architecture Concept

Figure 2. Architecture concept for Simulation and Gaming Incident management Training System

Source: An Integrated Gaming and Simulation Architecture for Incident Management Training, NISTIR 7295, March 2006
M&S in Systems Engineering
The HW/SWIL simulations are often described as engineering level simulations. They typically consist of multiple classes of simulations. The HW/SWIL includes actual hardware and software, mathematical models, and external stimuli used together to demonstrate the capability of a system or subsystem to operate within an environment simulating actual conditions. A HW/SWIL simulation has proven to be an important tool in system development, test and operational support.

Table 1. Overview of M&S Application in Support of T&E.

1. Support pretest planning.
2. Identify key test parameters earlier.
3. Bound, in a gross manner, the problem and propose solutions based on the intended environment, force structure, threat, tactics, strategy, and doctrine.
4. Identify oversights and flawed logic.
5. Determine sensitivity of a system to various input parameters.
6. Allow non-destructive testing of high cost items.
7. Provide better understanding when full-scale testing is not possible.
8. Augment, extend, and enhance test results, as appropriate.
10. Provide advantages of test compression, control expenditures, enable replication, and reduction of variables under study.
11. Assess impact of known parameters of unavailable threat systems.
12. Accomplish human factors supportability or soldier-machine interface analyses in part-task or limited fidelity "mock-ups."
13. Provide estimates of potential test outcomes.
14. Extrapolate, with caution, test results into other scenarios and levels of force aggregation.
15. Address issues which cannot be physically tested.
16. Address "what if" questions during post-test analyses.
17. Develop and refine test scenarios and data matrices to obtain maximum data from limited test resources.
18. Develop new tactics for the employment of new weapon systems under test.
19. Provide overall system, scenario, or environment representation.
20. Represent the input, process, and output of non-available systems, subsystems, or components (friendly or threat).
21. Represent the whole integrated system when all components are not available.
22. Allow an assessment of test events that would otherwise be exposed to threat intelligence exploitation.
23. Act as a system driver or stimulator in order to stress a system beyond available test scenarios.
24. Determine adequacy of the planned operational, maintenance, and supportability concepts.
25. Estimate mature system mission reliability, availability, and logistics support frequency.
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Economics of M&S

<table>
<thead>
<tr>
<th>Step 1: Develop a Decision Framework</th>
<th>Step 2: Alternatives Analysis</th>
<th>Step 3: Pull the Information Together</th>
<th>Step 4: Communicate and Document</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TASKS</strong></td>
<td><strong>TASKS</strong></td>
<td><strong>TASKS</strong></td>
<td><strong>TASKS</strong></td>
</tr>
<tr>
<td>1) Identify and define value structure</td>
<td>1) Identify and define alternatives</td>
<td>1) Aggregate the cost estimate</td>
<td>1) Communicate value to customers and stakeholders</td>
</tr>
<tr>
<td>2) Identify and define risk structure</td>
<td>2) Estimate value and cost</td>
<td>2) Calculate the return on investment</td>
<td>2) Prepare budget justification document</td>
</tr>
<tr>
<td>3) Identify and define cost structure</td>
<td>3) Conduct risk analysis</td>
<td>3) Calculate the value score</td>
<td>3) Satisfy ad hoc reporting requirement</td>
</tr>
<tr>
<td>4) Begin documentation</td>
<td>4) Ongoing documentation</td>
<td>4) Calculate the risk score</td>
<td>4) Use lessons learned to improve processes</td>
</tr>
</tbody>
</table>

Development
Figure 2. Typical Life-Cycle of a Three Step Modeling Project
Data

Source: A Discussion of Data Quality for Verification, Validation, and Certification, Jeff Rothenberg, Rand Corp., 1997

Figure 1: Data as model

Source: The Office of Science Data-Management Challenge, Report from DOE Workshop, March – May 2004

Figure 2: Alternate data “views” of reality


How Data Affects Modeling
Data (continued)

Assessing the Reliability of Computer-Processed Data

Figure 1: Factors to Consider in Making the Decision on Using the Data

Figure 3: Data Reliability Assessment Process

Source: GAO.
Evaluation

‘All models are wrong, but some are useful.’


Source: Guidelines for Model Evaluation, GAO PAD-79-17, 1979

Source: Guide for Verification and Validation in Computational Solid Mechanics, ASME V&V 10-2006
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Importance of Guidelines

Five Phases Model Development
1. Problem definition
2. Preliminary Design
3. Detail Design
4. Evaluation
5. Maintenance
Importance of Guidelines (continued)

M&S is an integral tool to support the DHS mission. Guidelines should:

- Enhance Decision Maker confidence in M&S results
- Ensure M&S results meet requirements
- Promote integration and interoperability of tools
- Enable private sector and commercial involvement in developing homeland security tools
- Promulgate “best practice” from government and private sector experience
- Advance the maturity of M&S as a field of technology
Importance of Guidelines (continued)

Major Findings

1. SBES is a discipline indispensable to the nation’s continued leadership in science and engineering. It is central to advances in biomedicine, nanomanufacturing, homeland security, microelectronics, energy and environmental sciences, advanced materials, and product development. There is ample evidence that developments in these new disciplines could significantly impact virtually every aspect of human experience.

2. Formidable challenges stand in the way of progress in SBES research. These challenges involve resolving open problems associated with multiscale and multi-physics modeling, real-time integration of simulation methods with measurement systems, model validation and verification, handling large data, and visualization. Significantly, one of those challenges is education of the next generation of engineers and scientists in the theory and practices of SBES.

3. There is strong evidence that our nation’s leadership in computational engineering and science, particularly in areas key to Simulation-Based Engineering Science, is rapidly eroding. Because competing nations worldwide have increased their investments in research, the U.S. has seen a steady reduction in its proportion of scientific advances relative to that of Europe and Asia. Any reversal of those trends will require changes in our educational system as well as changes in how basic research is funded in the U.S.
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## Some Federal Guidelines for M&S

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<th>M&amp;S Guideline or Policy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Development</td>
</tr>
<tr>
<td>DoD</td>
<td>X</td>
</tr>
<tr>
<td>DOE/NNSA</td>
<td>X</td>
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<tr>
<td>EPA</td>
<td>X</td>
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<tr>
<td>FDA</td>
<td>X</td>
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<tr>
<td>Federal Highway Administration</td>
<td>X</td>
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<tr>
<td>GAO</td>
<td>X</td>
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<tr>
<td>NASA</td>
<td>X</td>
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<tr>
<td>NOAA</td>
<td>X</td>
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<tr>
<td>NRC</td>
<td>X</td>
</tr>
<tr>
<td>USGS</td>
<td>X</td>
</tr>
</tbody>
</table>
Objectives

- Provide necessary policy and guidance
- Enhance the technical framework for M&S
- Improve model and simulation capabilities
- Improve model and simulation use
- Shape the workforce

Figure 1: Acquisition M&S Objectives and Actions
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The Next Ten Years

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DOE/NNSA
Prepared by: The Council for Regulatory Environmental Modeling

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Figure 1. The Role of Modeling in the Public Policy Process. This guidance recommends best practices to develop, evaluate, and apply models that are to be used in the public policy process.
Table 2. Examples of Modeling Projects with Differing Intended Uses

<table>
<thead>
<tr>
<th>Purpose for Obtaining Model-Generated Information (Intended Use)</th>
<th>Typical Quality Assurance Issues</th>
<th>Level of QA</th>
</tr>
</thead>
</table>
| Regulatory compliance  
Litigation  
Congressional testimony                                      | Legal defensibility of data sources  
Compliance with laws and regulatory mandates applicable to data gathering |             |
| Regulatory development  
State Implementation Plan (SIP) attainment  
Verification of Model                                          | Compliance with regulatory guidelines  
Existing data obtained under suitable QA program  
Audits and data reviews                                       |             |
| Trends monitoring (non-regulatory)  
Technology development  
“Proof of principle”                                            | Use of accepted data-gathering methods  
Use of widely accepted models  
Audits and data reviews                                       |             |
| Basic research  
Bench-scale testing                                              | QA planning and documentation at the facility level  
Peer review of novel theories and methodology                  |             |
GUIDELINES FOR MODEL EVALUATION

BASIC STEPS IN THE MODELING PROCESS

- DESCRIBE PROBLEM
- ISOLATE SYSTEM
- ADOPT SUPPORTING THEORY
- FORMULATE MODEL
- ANALYZE DATA REQUIREMENTS
  COLLECT DATA
- DEVELOP COMPUTER PROGRAM
- DEBUG COMPUTER PROGRAM
- DEVELOP ALTERNATIVE SOLUTIONS
- EVALUATE MODEL OUTPUT/RESULTS
- PRESENT RESULTS/PLANS
- DEVELOP MODEL MAINTENANCE PROCEDURES
- TRANSFER SYSTEM TO USERS

VERIFICATION

COMPUTER MODEL VERIFICATION EXAMINES WHETHER THE COMPUTERIZED MODEL "RUNS AS INTENDED," DEPENDING ON AVAILABLE DOCUMENTATION. VERIFICATION MAY HAVE TO EXAMINE SEVERAL OF THE STEPS IN THE MODELING PROCESS.

MODEL VALIDATION

VALIDATION EXAMINES THE CORRESPONDENCE OF THE MODEL AND ITS OUTPUTS TO PERCEIVED REALITY. DEPENDING ON THE AVAILABLE DOCUMENTATION, VALIDATION MAY HAVE TO EXAMINE OR ASSESS MANY OF THE STEPS IN THE MODELING PROCESS.
Figure 1. Microsimulation model development and application process.
Table 1—Uses of M&S for Which the Standard is Required

<table>
<thead>
<tr>
<th>M&amp;S Use</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operations</td>
<td>Analysis of the status, anomalies, and corrective actions during mission operations/simulations.</td>
</tr>
<tr>
<td>Manufacturing, Assembly, Test, and Evaluation</td>
<td>Manufacturing/assembly/evaluation/verification of hardware and software artifacts. This includes the simulation environment of control systems and displays, e.g., the atmospheric properties and aerodynamic database for a flight simulator.</td>
</tr>
<tr>
<td>Design and Analysis</td>
<td>Evaluate and explore solution spaces for current and future systems and subsystems. This includes design and analysis performed to support acquisition decisions or mission planning.</td>
</tr>
<tr>
<td>Natural Phenomena Prediction</td>
<td>Whenever the simulation of natural phenomena is a NASA responsibility and used for operational decisions affecting safety and mission success, e.g., space weather forecasting.</td>
</tr>
</tbody>
</table>

Table 2—Uses of M&S for Which the Standard is NOT Required

<table>
<thead>
<tr>
<th>M&amp;S Use</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology Investment</td>
<td>Identification and evaluation of candidate advanced technologies for future missions and systems.</td>
</tr>
<tr>
<td>Scientific Data Analysis</td>
<td>Processing of data collected by scientific instruments.</td>
</tr>
<tr>
<td>Scientific Understanding</td>
<td>Simulation of natural phenomena used for advancement of scientific knowledge.</td>
</tr>
<tr>
<td>Training and/or Education</td>
<td>Use of M&amp;S to produce learning.</td>
</tr>
<tr>
<td>M&amp;S Research</td>
<td>Conception, development, and evaluation of knowledge and practices for M&amp;S.</td>
</tr>
</tbody>
</table>
A Comprehensive Strategy of Hydrogeologic Modeling and Uncertainty Analysis for Nuclear Facilities and Sites

Figure 3-1. Contextual framework of modeling.
Figure 12. Flow chart of the ground-water flow modeling process. (From Reilly, 2001.)
Back-Up Slides