Cost-Effective Verification and Validation of Modeling and Simulation

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Purpose of This Talk

- Show what V&V is (and what it is not!) – and how it applies to modeling and simulation
- Show the difference between testing and V&V
- Explain Accreditation
Is V&V the same as Testing? NO!

- Testing is a specific a post-development activity

  - Testing “Uncovers errors that were made inadvertently as it was designed and constructed” (Pressman, *Software Engineering, A Practitioners’ Approach*)

  - Testing is “An activity in which a system or component is executed under specified conditions, the results are observed or recorded, and an evaluation is made of some aspect of the system or component” (IEEE Std 610-12, 1990)
V&V vs. Testing

• V&V (especially V&V of models and simulations) is NOT designed to find and remove bugs. It is designed to guarantee that “due diligence” has been performed in all areas of the systems development, including testing.

• V&V - “The process of determining whether the requirements for a system or component are complete and correct, the products of each development phase fulfill the requirements or conditions imposed by the previous phase, and the final system or component complies with specified requirements.” (IEEE Std 610-12, 1990)
VV&A vs. Testing

• Testing is a discrete phase
• V&V activities should occur during each phase, making sure that quality artifacts are being collected and that “due diligence” in terms of quality is occurring.
“The first mistake that people make is thinking that the testing team is responsible for assuring quality”

—Brian Marick, as quoted in Pressman
Modeling vs. Simulation

- **Model**: A physical, mathematical or otherwise logical representation of a system entity, phenomenon or process. (i.e. a cardboard cutout of an instrument panel)

- **Simulation**: A method for implementing a model over time, or 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.
Modeling and Simulation (M&S): The development and use of live, virtual, and constructive models, including simulators, stimulators, emulators, and prototypes, to investigate, understand, or provide experiential stimulus to either (1) conceptual systems that do not exist or (2) real life systems which cannot accept experimentation or observation because of resource, range, security, or safety limitations.
What type of Simulation?

- A way to classify simulations
  - Live – Real people, real systems
  - Virtual – Real people, simulated systems
  - Constructive – Simulated people and simulated systems (but can include man-in-the-loop and hardware-in-the-loop)
Verification and Validation – Definitions

- **Verification**
  - The process of determining that a model implementation accurately represents the developer's conceptual description and specifications.
  - “Did I build the system right?”

- **Validation**
  - The process of determining (a) the manner and degree to which a model is an accurate representation of the ‘real-world’ from the perspective of the intended uses of the model.
  - “Did I build the right system?”
Accreditation

Accreditation is the official certification that a model or simulation is acceptable for use for a specific application.

Three steps:
- Identify gaps in the model and simulation
- Assess the risks
- Recommend acceptable uses
Benefits of VV&A

- Increase confidence in the models and simulations
- Reduce risk
- Increase usability
- Increase user satisfaction and confidence
- Lower Costs
“When Quality is vital, independent checks are necessary, not because people are untrustworthy but because they are human.”

Watts Humphrey, *Managing the Software Process*
Why VV&A??

U.S. DOD Software Success Rate

- 46% Not Used
- 29% Used As Is
- 20% Modified
- 3% Cancelled
- 2% Minor Changes

Source: 1999 Joint Application Warfare Seminar
Standish Group 2003 Data

Percentage of Successful Projects

- 1994: 84%
- 1996: 73%
- 1998: 74%
- 2000: 72%
- 2002: 66%

Unsuccessful
Successful
Standish Group 2003 Data
Percentage of Requirements Delivered

Not Delivered
Delivered

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<thead>
<tr>
<th>Year</th>
<th>1994</th>
<th>2000</th>
<th>2002</th>
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<td>%</td>
<td>58</td>
<td>33</td>
<td>46</td>
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One more data point

- Data from about 250 large software projects
- Each project more than 10,000 function points (roughly 1,250,000 lines of C code)

Data from “Software Project Management Practices: Failure Versus Success”, Capers Jones, Crosstalk, October 2004
...and one more

Relative Cost of Software Fault Propagation

Steps in a Credible V&V Effort

1. Identify the key players
2. Develop a V&V (or VV&A) plan
3. Establish activities that will be performed
4. Monitor development, if possible (although some V&V is performed after development is completed)
5. Evaluate product and artifacts
6. Prepare report, and make recommendations for accreditation
M&S VV&A Key Players

- **M&S Application Sponsor**
  - organization that utilizes the results or products from a specific application of a model or simulation
- **M&S Developer**
  - The organization responsible for managing the development of the models and simulations
- **V&V Agent**
  - The organization designated by the M&S application sponsor to perform validation (or verification) of a model or simulation.
- **Accreditation Agent**
  - The organization designated by the application sponsor to conduct an accreditation assessment of an M&S application.
Mature Process for System Development

Users View

- User's Views
- Reqts
- System Spec
- System Design
- Module Design

- User Trial Plan
- Accept Test Plan
- Integ Test Plan
- Unit Test Plan

Delivered System

System & int. testing

Acceptance testing

System Spec

System Design

Module Design

Developers View

- Acceptance testing
- System & int. testing

The V&V View

Ould86

- User's Views
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Developers View

- Acceptance testing
- System & int. testing

The V&V View

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VV&A: Right Product built Right

- Inspect Conceptual Model
- Inspect Requirements
- Inspect Design
- Inspect CM practices
- Formal Document Review

- User's Views
- Reqts
- System Spec
- System Design
- Module Design

- Delivered System
- Integ System
- Modules
- Coded Units

- Validate Equations/Algorithms
- Inspect Code
- Verify Equations/Algorithms
- Inspect Test Plans/Test Results

- System testing acceptance
- Integration testing
- Unit testing

- Module coding
- Coding

- Functionality Testing
- VV&C Input/Default Data

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The Steps Involved

<table>
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<tr>
<th>Report Type</th>
<th>Description</th>
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<tbody>
<tr>
<td>VV&amp;A Acceptability Criteria Report</td>
<td>Documents the acceptability criteria for deciding if the model or simulation is suitable for the application</td>
</tr>
<tr>
<td>Accreditation Plan</td>
<td>Describes info needed to approve the use of mod/sim for specific application and planned approach to collect info</td>
</tr>
<tr>
<td>V&amp;V Plan</td>
<td>Describes V&amp;V requirements and approach</td>
</tr>
<tr>
<td>V&amp;V Report</td>
<td>Documents results of executing V&amp;V Plan</td>
</tr>
<tr>
<td>Acceptability Assessment Report</td>
<td>Compares requirements to capabilities and limitations based on info collected from accreditation plan</td>
</tr>
<tr>
<td>Accreditation Report</td>
<td>Documents decision to use or not use a mod/sim</td>
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VV&A Taxonomy

**Verification**
- Of Basic Logic and Mathematics
- Of Implementation in Program Code

**Validation**
- Provisional, for Application Cases
- As Part of a Specific Analysis Plan

**Accreditation**
- Empirical Evaluation
  - Using Historical Data
  - Using Field-Test Data
  - Using Laboratory Data
  - Using Data from Maneuvers and other Exercises
- Theoretical Evaluation
  - For Analytic Rigor
  - For Relevant Verisimilitude
  - By Criteria of Clarity & Economy
  - By Comparison with Other Validated Models & Scientific Theories
- Evaluation by Other Comparisons
  - To Expert Opinion
  - To Doctrine
  - To other Models of Uncertain Validity
  - To other Sources of Information (e.g. Intelligence)
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<th>Static</th>
<th>Dynamic</th>
<th>Formal</th>
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<td>Cause-Effect Graphing</td>
<td>Acceptance Testing</td>
<td>Induction</td>
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<td>Desk Checking</td>
<td>Control Analysis</td>
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<td>Inductive Assertions</td>
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<td>Data Dependency</td>
<td>Authorization</td>
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<td>Data Flow</td>
<td>Performance</td>
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<td>Semantic Analysis</td>
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**Static**
- Cause-Effect Graphing
- Control Analysis
- Calling Structure
- Concurrent Process
- Control Flow
- State Transition
- Data Analysis
- Data Dependency
- Data Flow
- Fault/Failure Analysis
- Interface Analysis
- Model Interface
- User Interface
- Semantic Analysis
- Structural Analysis
- Symbolic Evaluation
- Syntax Analysis
- Traceability Assessment

**Dynamic**
- Acceptance Testing
- Alpha Testing
- Assertion Checking
- Beta Testing
- Bottom-Up Testing
- Comparison Testing
- Compliance Testing
- Authorization
- Performance
- Security
- Standards
- Debugging
- Execution Testing
- Monitoring
- Profiling
- Tracing
- Fault / Failure Insertion Testing
- Field Testing
- Functional (Black-Box) Testing
- Graphical Comparisons
- Interface Testing
- Data
- Model
- User
- Object-Flow Testing
- Partition Testing
- Predictive Validation
- Product Testing
- Regression Testing
- Sensitivity Testing
- Special Input Testing
- Boundary Value
- Equivalence Partitioning
- Extreme Input
- Invalid Input
- Real-Time Input
- Self-Driven Input
- Stress
- Trace-Driven Input
- Statistical Techniques
- Structural (White-Box) Testing
- Branch
- Condition
- Data Flow
- Loop
- Path
- Statement
- Submodel / Module Testing
- Symbolic Debugging
- Top-Down Testing
- Visualization / Animation

**Formal**
- Induction
- Inference
- Logical Deduction
- Inductive Assertions
- Calculus
- Lambda Calculus
- Predicate Calculus
- Predicate Transformation
- Proof of Correctness
Typical VV&A Activities Selected

- Logic Verification: Walkthrough of Conceptual Model
- Logic Verification: Requirements Trace
- Logic Verification: Walkthrough of Design
- Logic Verification: Analysis of Dataflow, Control Flow, and Object Flow
- Logic Verification: Execution Tracing
- Code Verification: Walkthrough of selected code modules
- Code Verification: Loop testing
- Code Verification: Failure analysis
- Code Verification: Sensitivity Analysis of selected parameters
- Code Verification: Invalid Input Testing
- Code Verification: Comparison against current approaches
- Code Verification: Dimensional Analysis for XXX System Software
- Logic Validation: Equation and Algorithm Checks for XXX
- Logic Validation: Validation of Software Requirements
- Functional Validation: Beta Testing
- Functional Validation: User Interface Testing
- Functional Validation: Acceptance Testing
- Verify, Validate, and Certify Data
- Inspection of Configuration Management Process
- Formal Document Review
What activities do you select?

- It depends upon
  - Available time
  - Available funds
  - Confidence in the model
  - Initial or incremental accreditation?
  - Type of activity
  - User needs and desires

- Determine what activities you will perform in a VV&A plan
VV&A Plan

- What activities you will perform
- What the UUT (Unit Under Test) is for each activity
- The entrance / exit criteria
- The process for each activity

Following is a sample skeleton for one item in a VV&A plan
**UUT:** The UUT for this activity is comprised of the XXXX System Documentation and related documents. Documents reviewed will include XXXX development documentation that may be assigned to four broad categories: 1) system design reference documents, 2) software design reference documents, 3) user reference documents, and 4) other reference documents.

**Process:** The process for this activity shall consist of compiling and reviewing the XXXX documentation package for completeness, consistency, clarity, and correctness. The reviewer will use current DoD guidance to establish what specific documents must be included in this document review. Discrepancies or inadequacies will be recorded.
Criteria: This review shall establish that the XXX documentation package is complete, adequately detailed, and properly organized to provide a potential user a clear, fundamental understanding of the tool and its various components and functions, and the adequacy of the documentation to support the software life cycle.

Product: The product for this activity shall be a section in the XXXX V&V Report documenting the findings of the activity.
**Resources:** Resources required for this activity are as follows:

- **Labor:** 1 person level of effort (LOE) over a two-week period.

- **Technical Data:** All formal documentation such as Software Requirements Specification, Software Development Plan, Software Design, Software Folders, Software Test Plans, User guides, software quality assurance (SQA) audit reports, previous V&V documentation, and associated materials supporting the development of XXXX.

**Schedule:** This activity requires 2 person-weeks and is contingent on the availability of mature documentation.
Example Recommended Activities for Model X

**Verification**

Activity 1: Formal Model X Document Review
Activity 2: Walkthrough of Model X Software Requirements
Activity 3: Walkthrough of Model X Design
Activity 4: Walkthrough of Model X Code
Activity 5: Dimensional Analysis for Model X System Software
Activity 6: Equation and Algorithm Checks for Model X
Activity 7: Functionality Testing of Model X Software
Activity 8: Evaluation of User Interface and User Manual
Activity 9: Sensitivity Testing of Selected Parameters
Example Recommended Activities for Model X

Validation
Activity 10: Evaluate Fidelity/Detail of Model X Representations
Activity 11: Comparison of Model X Representation to other Models/Simulations
Activity 12: Face Validation of Model X with Designated Users

Related Activities
Activity 13: Verify, Validate, and Certify Model X Data
Activity 14: Analysis of Simulation Techniques
Activity 15: Inspection of Model X Configuration Management Process
Example Activity 1 – Formal Document Review

- Look for
  - Statement of need
  - Conceptual Model
  - SRS
  - Development Plan
  - Design Documentation
  - Test Plans
  - Users Guides and Manuals
  - SQA Reports
  - CM Plans

- …and anything else you can find!!
## Example Overall Assessment for Model X

<table>
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<th>Activity</th>
<th>Comments</th>
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<tr>
<td><strong>Verification</strong></td>
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<tr>
<td>1. Formal Model X Document Review</td>
<td>No SDP, CMP, or Test Plan</td>
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<tr>
<td>2. Walkthrough of Model X Software Requirements</td>
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<tr>
<td>3. Walkthrough of Model X Design</td>
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<td>4. Walkthrough of Model X Code</td>
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<td><strong>Related Activities</strong></td>
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<td>14. Analysis of Simulation Techniques</td>
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<td>15. Inspection of Model X Configuration Management Process</td>
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</table>
Decision can be one of the following

a. The system will be used as described in VV&A Plan for this application.

b. The system will be used as described in VV&A Plan for this application with limitations.

c. The system will be used as described in VV&A Plan for this application after modifications.

d. The system requires additional V&V to be considered suitable for accreditation.

e. The system should not be used.
Accreditation

• Based on the V&V results and the safety and security needs of the user, you select one of the previous five options.

• The accreditation is a match-up of the system against the documented requirements.

• All models and simulations have SOME limitations. You need to know the boundaries – where the model does not match the real world.
Accreditation Options

Considerable overlap – accredit with limitations or modifications

No (or minimal) overlap – don’t accredit, or additional V&V

Perfect overlap (almost never happens) – unrestricted use
Further guidance

- DoD Directive 5000.61 (DOD M&S VV&A)
- Army Pamphlet 5-11 (VV&A of Army Models and Simulation)
- AFI 16-001 (VV&A)
Summary - Why V&V is so hard!

- Lack of artifacts (especially in requirements and design)
- Having to “backtrack” and fill in blanks long after development
- Lack of design
- No previous requirements validation
- Lack of coding standards (which leads to difficulty in verification)
- Nobody thinks of formal V&V until the project is finished
- V&V is NOT testing – but certification of the model
Why V&V?

- Long-term view (for maintenance and sustainment)
- The V&V agents act as the customer, and check for quality at detailed level
- Save money by identifying opportunities for quality at earliest possible opportunity
- “Due Diligence” at reasonable cost