“Evaluating the Readiness of Federations-of-Models for use in the Simulation-Based Concept Development of Advanced Warfighting Capabilities”

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Systems Engineering Challenges
As identified by the SE community

Challenges...

- Evolution of large-scale capabilities
- Combination of legacy, new and modified systems
- Technical performance measures vis-à-vis effectiveness of the SE process
- Large-scale system modeling and assessment
- Integration of models; coupled simulations
- Trustworthiness of modeling & simulation (metrics & techniques)
- VV&A of extremely complex systems

Reflected in...

“INCOSE Research Plan: 2008-2020”
- INSIGHT, July 2009 (p.47)

“Establishing a Systems Engineering Academic Research Agenda”
- Roy Kalawsky, CSER 2008, Paper #216
- Research Grand Challenge #4
  - “M&S Total System Representation”
Complex System (C x S) “Landscape”

NOT A CLEAN SLATE !!!

Coalescence of Challenges

- Advanced Capabilities
- Concept Development
- Immature (still developing) Requirements
- Distributed Designs
- Composite Functionality
- Complexity

Operating Environment
(systems, networks, standards)

- Legacy System (mod)
- Legacy System (no mod)
- Future (developmental) System
- New System (mod?)

Complex System Boundary
(note mixed maturity of systems)
Conceptual Development
ENGINEERING “TRADE SPACE” INVESTIGATION

Advanced Capability

Functional Decomposition

Physical Allocation

Function(s)

Legacy System(s)

Modified System(s)

New Systems

Developmental System

NOTE: Simplified / Notional

Implementation (Federate Design) Trade Space

Architecture (CxS) Trade Space
Model Based Development
CxS → FEDERATION OF MODELS

Complex System Challenges
- Advanced Capabilities
- Concept Development
- Immature (still developing) Requirements
- Distributed Designs
- Composite Functionality

SE Methods & Tools
- Federations of Models
- Model Based Development & Design

Unique Issues
- Disparate Levels of Federate Maturity
- Disparate Levels of Federate Fidelity

- Large-scale & Advanced Capabilities → Complex systems → Mixed maturity
  (necessitate / result in) (that evidence)

  - Development involves mature, modified, new and developmental systems
  - Integration of models to achieve a full-system representation to support concept development ultimately constitute a federation
Credibility

- Attributed to a model or simulation when it has been accepted as “correct” for purposes an intended application
  - Implies that results can be used to inform decision-making

- Critical (and somewhat counterintuitive) axioms:
  - A model or simulation can be credible, and yet lack validity
    - Suitable for an application in spite of inability to satisfy validity
  - A model or simulation may be valid, and yet lack credibility
    - Questionable assumptions, documentation, pedigree
    - Extension of application beyond scope of prior use
What are the limitations of current modeling and simulation assessment methods relative to establishing the credibility of a federation of models for the purpose of concept development in the context of complex systems?
Verification, Validation & Accreditation

- Building-block approach to establishing credibility & confidence
- **Goal: Accreditation (a.k.a. “acceptance”)**
  - Certification of acceptability for a specific application
  - Implies and demonstrates both credibility & confidence in the virtual environment
  - Dependent upon “adequate” and “successful” Verification & Validation
    - Often constrained by program resources (e.g. time, money, manpower)

Validation

- “...the process of determining whether a simulation model is an accurate representation of the system, for the particular objectives of the study.” (Law, 2007)
  - *To truly validate a model, its performance must compare favorably with that of the “real world” system it is intended to represent*
**VV&A**
**MERITS**

- Rigorous, established approach for establishing credibility in cases where “real world” system performance data are available

- Facilitates continuous evaluation and improvement of models in situations where the collection of “real world” performance data is ongoing (e.g. iterative test & development)
Only partial validation of the federation of models is possible during the concept development of complex systems, because...

- Some systems in the CxS engineering trade space may not yet exist “in the real world”
- Modified versions of legacy systems may not yet exist “in the real world”
- Validation of a complex system model can be incremental, but cannot be additive
  - Emergent behavior can only be investigated when constituent systems perform in concert (i.e. validation would require a comparison of the federation to an extant complex system)
Terminology (a review – to avoid confusion)

- “Conceptual model validation” (DoD; Law, 2007)
  - Is a rigorous review of assumptions, limitations & constraints associated with early development of the model / simulation
  - Is NOT validation for conceptual development applications

Tailoring

- Methods have been proposed for tailoring of VV&A to accommodate variations in the fidelity of constituent models within a federation
- Validation still requires extant system performance data for purposes of comparison
Applicable standards and best practices for the development of federations of models do exist...

- **IEEE 1516.3 (2003)**
  - High Level Architecture (HLA) Federation Development and Execution Process (FEDEP)

- **IEEE 1516.4 (2007)**
  - Recommended Practice for VV&A of a Federation
    - An “overlay” to the HLA FEDEP

- **IEEE 1730 (2010?)**
  - *Distributed Simulation Engineering & Execution Process*
**HLA FEDEP and VV&A “Overlay”**  
**MERITS & SHORTFALLS**

- **Merits**
  - Widespread adherence offers the potential for enhanced interoperability among models & simulations
    - Would facilitate compositing necessary for the creation of federations of models

- **Shortfalls**
  - Applicable only to HLA applications
    - DSEEP attempts to generalize practices & expand applicability of FEDEP beyond HLA
      - Not yet available; update to VV&A “overlay” uncertain...
  - Does not detail specific V&V techniques for a federation
    - No analytical process established for evaluating a level of confidence for the federation
    - No criterion established for articulating a level of confidence, or demonstrating a requisite “minimum confidence” in the virtual (i.e. M&S) environment

*Not well suited for the concept development of advanced capabilities*
Each system has a technology readiness level (TRL)
Each system interaction has an integration readiness level (IRL)
A composite system readiness level (SRL) can be computed:
\[
SRL = f(TRL, IRL)
\]
System Readiness Levels
MERITS & SHORTFALLS

- **Merits**
  - Mention of system architecture as context
  - Identification of both technology and integration challenges

- **Shortfalls**
  - Inadequate scale granularity in Concept Development
    - SRL value range in CD: $0 - 0.4$
  - Insight limited to pair-wise assessments
    - System attributes & relationships captured in matrices
  - Does not address model fidelity
    - Critical aspect of federated model application not incorporated
Proposed Tool

FEDERATED MODEL READINESS LEVELS

Based on the Cooper-Harper Handling Qualities Rating Scale
Proposed Tool

FEDERATED MODEL READINESS LEVELS

<table>
<thead>
<tr>
<th>Technology Readiness Levels</th>
<th>Federated Model Readiness Levels</th>
<th>Integration Readiness Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic Principles Observed and Reported</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Technology Concept and/or Application Formulated</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Analytical and Experimental Critical Foundation and/or Characteristic Proof of Concept</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Component and/or Breadboard Validation in Laboratory Environment</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Component and/or Breadboard Validation in Relevant Environment</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>System/Subsystem Model or Prototype Demonstration in Relevant Environment</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>System Prototype Demonstration in an Operational Environment</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Actual System Completed and Qualified Through Test and Demonstration</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Actual System Proven Through Successful Mission Operations</td>
<td>9</td>
<td>9</td>
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</tbody>
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An Interface between technologies has been identified with sufficient detail to allow characterization of relationship.

There is some level of specificity to Characterize the interaction between technologies through their interface.

There is Compatibility between technologies to orderly and efficiently integrate and interact.

There is sufficient detail in the Quality and Assurance of the integration between technologies.

There is sufficient Control between technologies necessary to establish, manage, and terminate the integration.

The integrating technologies can Accept, Translate, and Structure Information for its intended application.

The Integration of technologies has beenVerified and Validated with sufficient detail to be actionable.

Actual integration completed and Mission Qualified through test and demonstration, in the system environment.

Integration is Mission Proven through successful mission operations.

“FMRL”
FMRLs
MERITS (of concept)

- Attempts to incorporate model fidelity into the readiness-level discussion
- Attempts to identify a subjective evaluation scale to lend consistency to FMRL assessment
FMRL \textbf{SHORTFALLS}

- FMRLs are assessed for the entire set of federated models, so \textit{the entire federation cannot attain a given level unless all the component models have achieved that level}
  - Lacks flexibility necessary for application to the concept development of complex systems

- FMRL scale is currently linked to level of model fidelity and “computational load”
  - Incorrectly concludes that readiness is low if fidelity is low
    - Fidelity and stability are not well defined as separate model characteristics
  - Fails to define “computational load” as other than a resource that is consumed in the pursuit of higher fidelity
Comparison to previously established readiness levels (e.g. TRL, IRL, SRL) introduces unresolved conflicts

Case: A system that is quite mature, and reasonably well integrated, but represented in the federation by an “effects based engine” is viewed negatively when it may be perfectly acceptable for a particular application.
FMRLs

CAN (should) THEY BE SAVED?

- Must address:
  - Acceptability of lower and mixed fidelity solutions at the federation level

- Should establish:
  - An identity separate from (or compatible with) TRLs, IRLs and SRLs
    - Conflicts arise in cases where systems display maturity / fidelity / integration characteristics that do not align

- May consider:
  - Incorporation of other SE methods & tools that may contribute to establishing a case for confidence and acceptance
Primary References


Defining and Measuring Federated Model Fidelity to Support System-of-Systems Design and Development, Erhardt (et al.), 2010
QUESTIONS & COMMENTS

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“Evaluating the Readiness of Federations-of-Models for use in the Simulation-Based Concept Development of Advanced Warfighting Capabilities”

Development of advanced war-fighting capabilities depends on the successful integration of prototype or modified combat systems with those already in service. Initial exploration of the associated engineering trade space is often simulation-based, and necessitates the construction of a federation of models. The readiness of such a federation for use as a concept development tool is difficult to assess due to differences in the maturity of the constituent models and the fact that conceptual development of advanced capabilities precedes the generation of mature requirements and complex system architectures. A process for evaluating Federation-of-Models Readiness Levels (FMRLs) is presented, contrasted with existing “readiness level” rubrics and accreditation techniques, and considered in the context of a candidate case study. Ultimately, FMRLs are proposed as a method for adding rigor to simulation-based concept development of complex systems and fostering greater confidence in resultant findings and decisions.