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

NDIA Systems Engineering Conference
San Diego, California
October, 2010

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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…

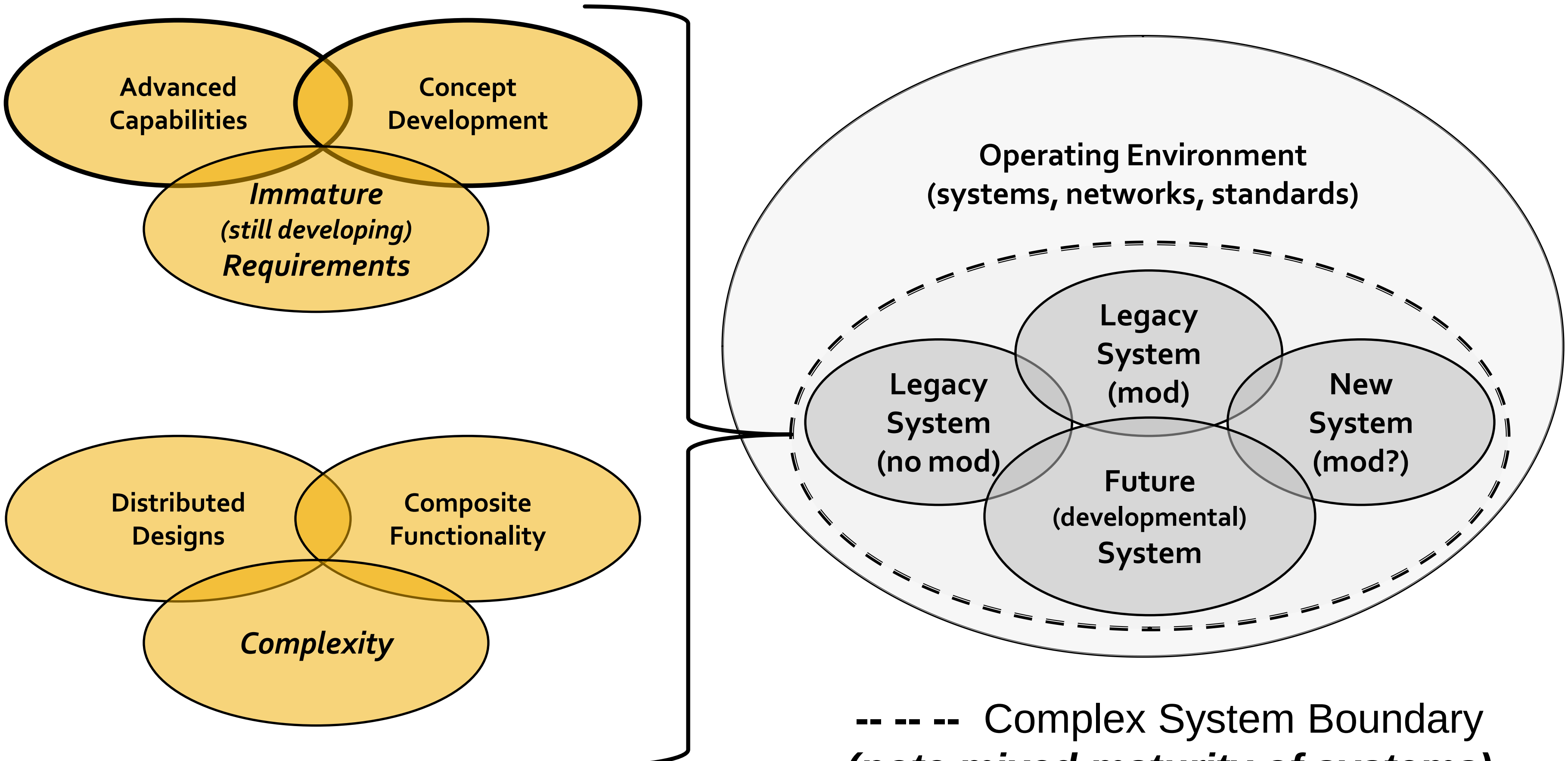
  "INCOSE Research Plan: 2008-2020"
  - *INSIGHT, July 2009 (p.47)*

  "Establishing a Systems Engineering Academic Research Agenda"
  - *Roy Kalawsky, CSER 2008, Paper #216*
  - *Research Grand Challenge #4*
    - *"M&S Total System Representation"*

Complex System (CxS) "Landscape"

NOT A CLEAN SLATE !!!

Coalescence of Challenges



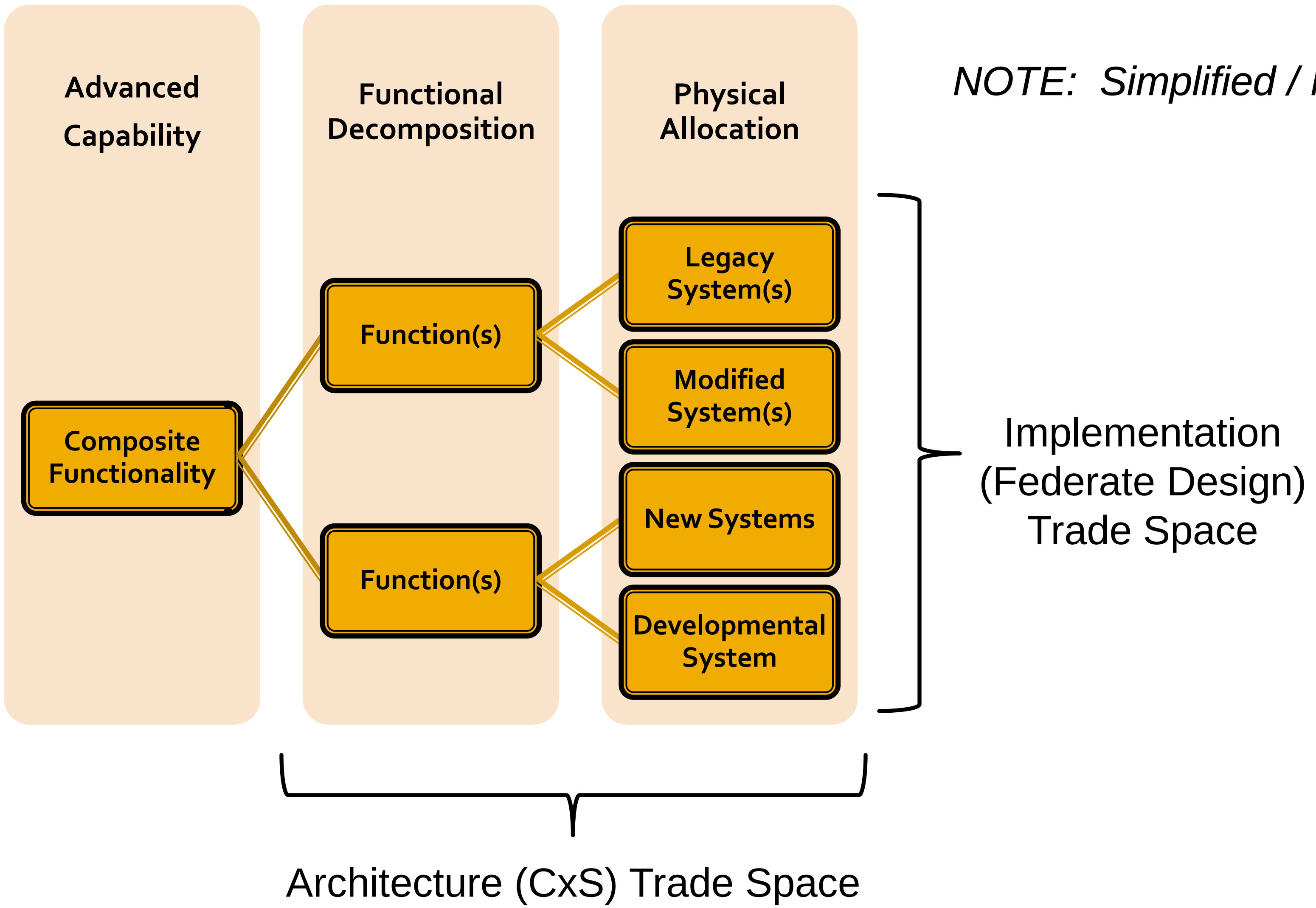
-- -- -- Complex System Boundary

(note mixed maturity of systems)

Conceptual Development

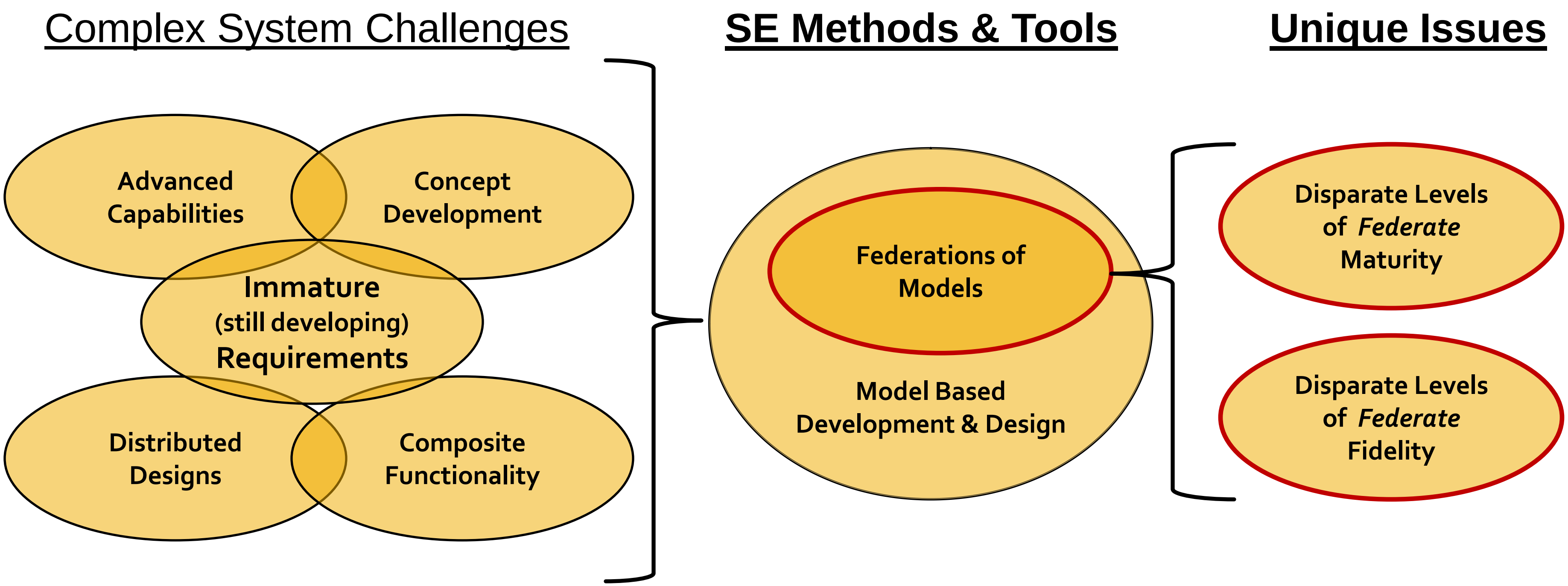
ENGINEERING "TRADE SPACE" INVESTIGATION

NOTE: Simplified / Notional



Model Based Development

CxS → FEDERATION OF MODELS



- 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*

Model Based Systems Engineering

CREDIBILITY IS EVERYTHING

- 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

CREDIBILITY ←→ ACCEPTANCE ←→ ACCREDITATION
Key terms that are very closely related

Establishing Confidence…

ARE EXISTING TOOLS & METHODS ADEQUATE?

Objective

Establishing Confidence in a Federation of Models

Prospective Tools & Methods

- VV&A
- Standards & Best Practices
- Integration Readiness Levels
- Federation of Models Readiness Levels

What are the limitations of current modeling and simulation assessment methods relative to establishing the credibility of a federations of models for the purpose of concept development in the context of complex systems?

Existing Tools & Methods
"V V & A"

- 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)

VV&A

SHORTFALLS

- 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)

VV&A

POINTS OF CLARIFICATION

- 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

Existing Tools & Methods
RELEVANT STANDARD(s)

- 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

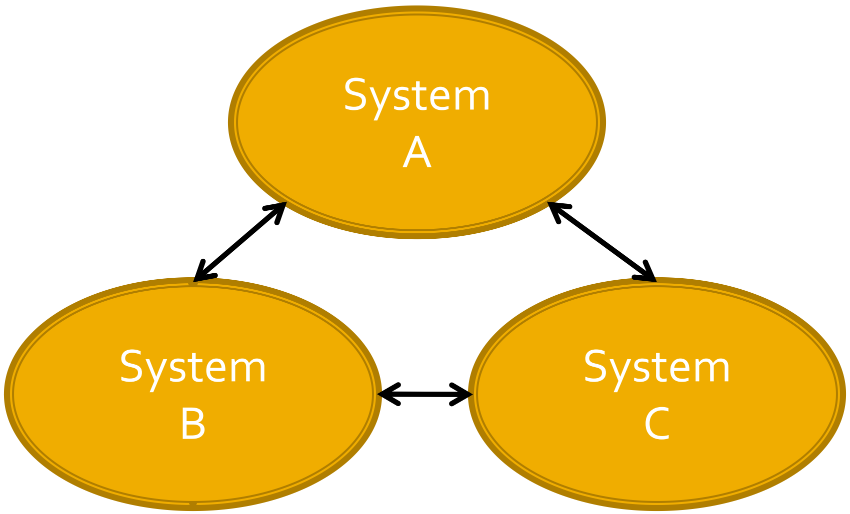
- Merits
  - Widespread adherence offers the potential for enhanced interoperability among models & simulations
    - Would facilitate compositing necessary for the creation of federations of models
- Shortfalls
  - Applicable only to HLA applications
    - DSEEP attempts to generalize practices & expand 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

Existing Tools & Methods

SYSTEM READINESS LEVEL

Attributed to: Brian Sauser, Ph.D.
Stevens Institute of Technology



- 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

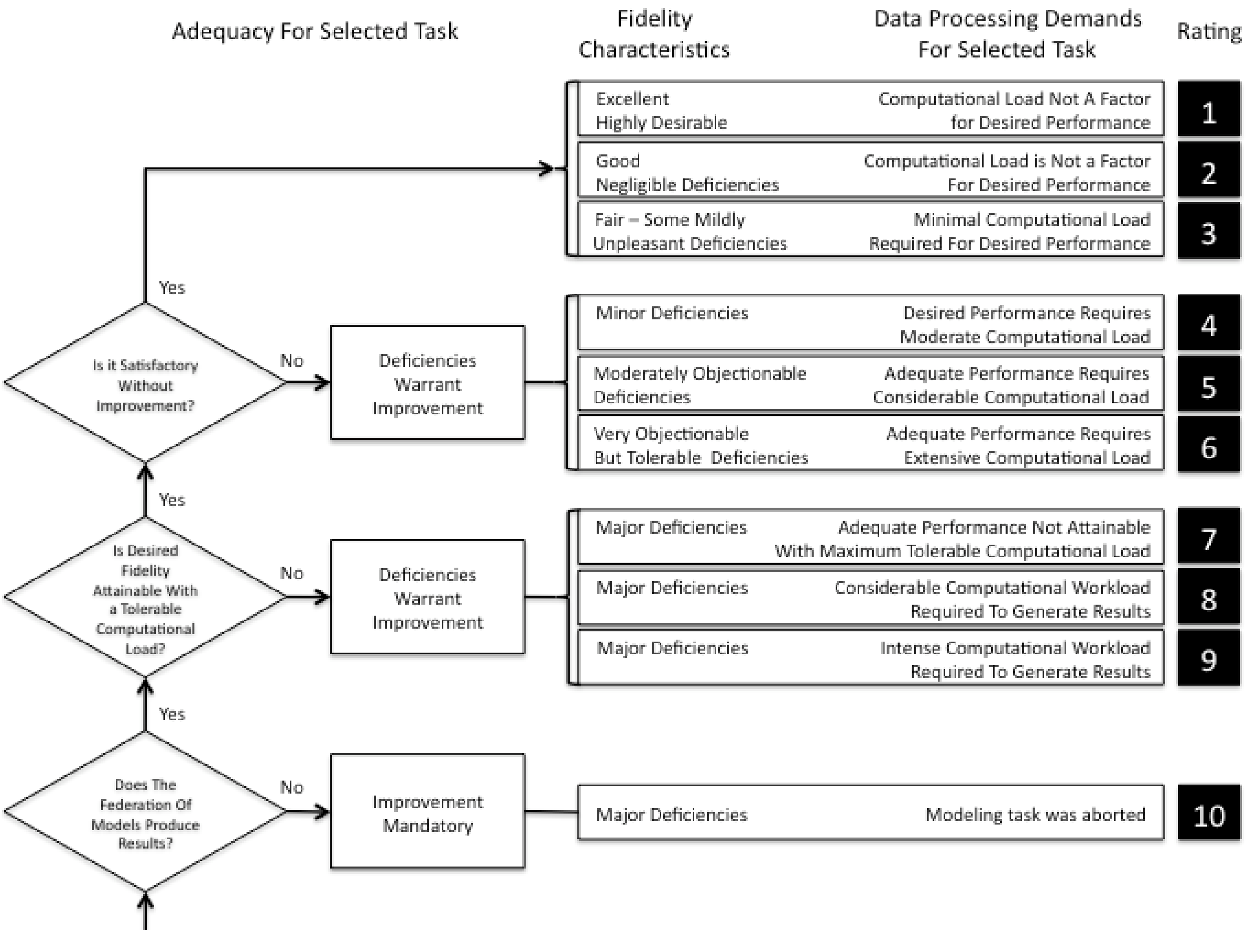
MERITS & SHORTFALLS

- 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

Erhardt, Flanigan, and Herdlick
CSER 2010 Paper #1569270597

FEDERATED MODEL READINESS LEVELS



Based on the Cooper-Harper Handling Qualities Rating Scale

Proposed Tool

Erhardt, Flanigan, and Herdlick
CSER 2010 Paper #1569270597

FEDERATED MODEL READINESS LEVELS

Technology Readiness Levels

1. Basic Principles Observed and Reported
2. Technology Concept and/or Application Formulated
3. Analytical and Experimental Critical Foundation and/or Characteristic Proof of Concept
4. Component and/or Breadboard Validation in Laboratory Environment
5. Component and/or Breadboard Validation in Relevant Environment
6. System/Subsystem Model or Prototype Demonstration in Relevant Environment
7. System Prototype Demonstration in an Operational Environment
8. Actual System Completed and Qualified Through Test and Demonstration
9. Actual System Proven Through Successful Mission Operations

Federated Model Readiness Levels "FMRL"

1. Mathematical Models of the System's Physical Phenomenology. Environment Not Expressly Modeled
2. Advanced Mathematical Models Include Some Specific Component Elements. Environment Not Expressly Modeled
3. System Design and Environment Expressly Modeled, Although Much Of Performance Is Effects Based
4. Actual or Proposed System Designs and Operating Environment is Modeled, Some Performance is Still Effects Based
5. Models contain actual hardware, software, and human machine interfaces. Environment modeled with sufficient accuracy to allow full performance characterization

Integration Readiness Levels

1. An Interface between technologies has been identified with sufficient detail to allow characterization of relationship
2. There is some level of specificity to Characterize the interaction between technologies through their interface
3. There is Compatibility between technologies to orderly and efficiently integrate and interact
4. There is sufficient detail in the Quality and Assurance of the integration between technologies
5. There is sufficient Control between technologies necessary to establish, manage, and terminate the integration
6. The integrating technologies can Accept, Translate, and Structure Information for its intended application
7. The integration of technologies has been Verified and Validated with sufficient detail to be actionable
8. Actual integration completed and Mission Qualified through test and demonstration, in the system environment
9. Integration is Mission Proven through successful mission operations

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

SHORTFALLS

- FMRLs are assessed for the entire set of federated models, so *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

FMRL

SHORTFALLS

- 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

Simulation Modeling & Analysis, 4th Edition, A.M. Law (2007)

High Level Architecture Federation Development and Execution Process (IEEE Standard 1516.3 of 2003)

IEEE Recommended Practice for Verification, Validation and Accreditation of a Federation – An Overlay to the High Level Architecture Federation Development and Execution Process (IEEE Standard 1516.4 of 2007)

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

QUESTIONS & COMMENTS ???

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BRYAN HERDLICK is a Ph.D. candidate at George Washington University in the Engineering Management and Systems Engineering curriculum. As a member of the senior professional staff at the Johns Hopkins University Applied Physics Laboratory, he assists the Naval Aviation Systems Command with the development of advanced capabilities and complex systems. Bryan is an INCOSE Certified Systems Engineering Professional with additional qualifications pursuant to the U.S. Department of Defense Acquisition process (CSEP-Acq.). Bryan's academic background includes a BS in Electrical Engineering from the University of Dayton and a MS in Applied Physics from the Naval Postgraduate School. He is also a graduate of the U.S. Navy Test Pilot School and a distinguished graduate of the Naval War College. His collateral activities include volunteering as a program evaluator with ABET and teaching Systems Engineering courses for the Johns Hopkins University Whiting School of Engineering.

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THOMAS MAZZUCHI, D.Sc., is Chair and Professor at the School of Engineering Management and Systems Engineering (EMSE) at The George Washington University where he also previously served as the Chair of the Operations Research Department and as Interim Dean of the School of Engineering and Applied Science. Dr. Mazzuchi has been engaged in consulting and research in the area of reliability, risk analysis, and quality control for over twenty years. He served as a research mathematician with the Royal Dutch Shell Company, has held research contracts with numerous state and government agencies including NASA, the U.S. Army, the U.S. Air Force and the U.S. Postal Service.

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SHAHRAM SARKANI, Ph.D., P.E., is Professor of Engineering Management and Systems Engineering (EMSE) at The George Washington University. Since joining the faculty in 1986, he has served as a Department Chair and Interim Associate Dean and was appointed as Faculty Adviser and Academic Director of EMSE Off-Campus Programs in 2001. In his current role, Professor Sarkani designs and administers off-campus MS and programs at over 20 locations world-wide that serve more than 1,000 students. As author of over 150 technical publications and presentations, he remains engaged with important ongoing research in the field of systems engineering.

NDIA SE Conference

ABSTRACT

"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.