Establishing Confidence in Federations-of-Models

SoS Engineering Collaborators Information Exchange

Defense Connect On-Line / WebEx

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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)***

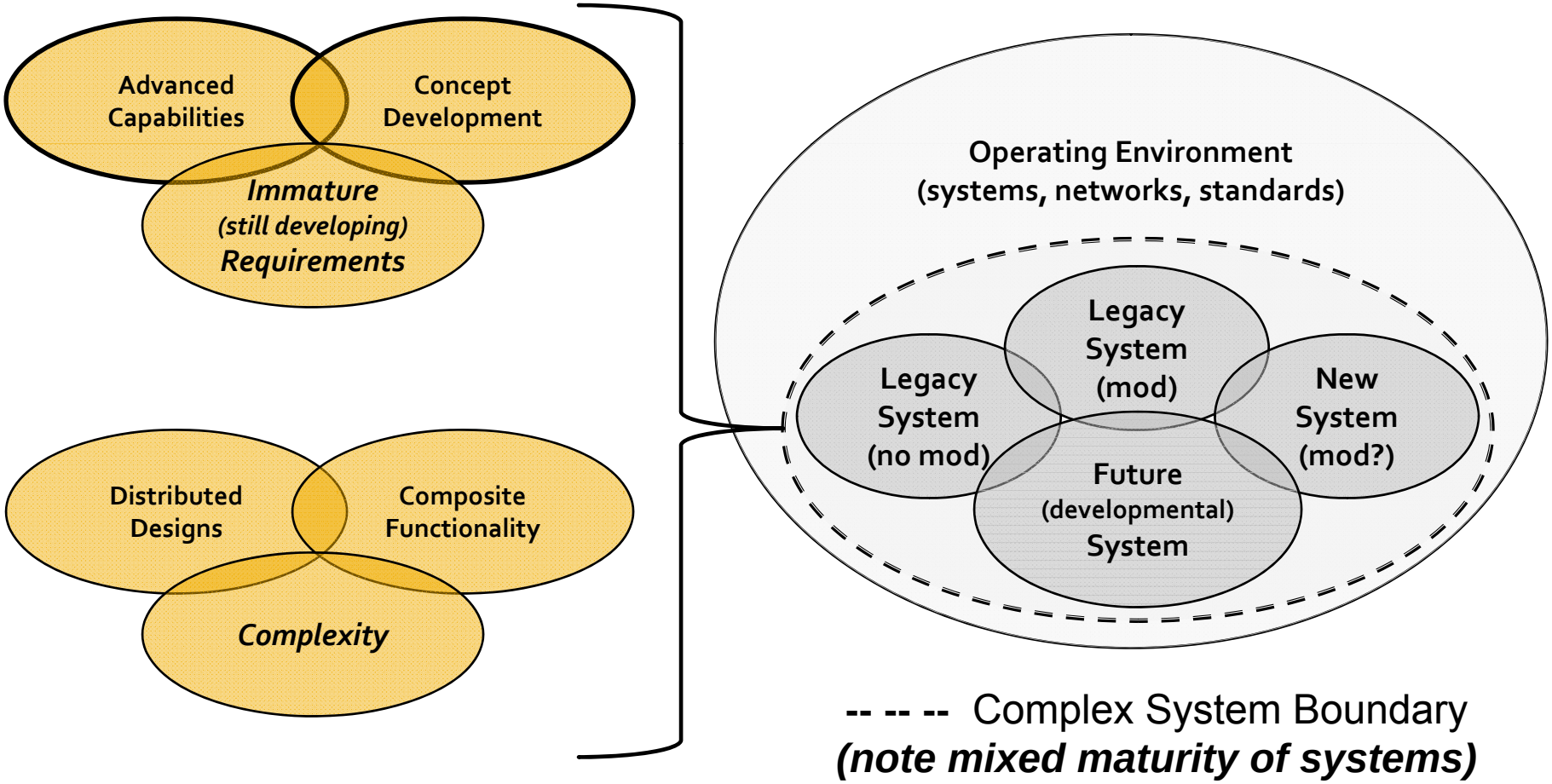
"Establishing a Systems Engineering Academic Research Agenda"

- ***Roy Kalawsky, CSER 2008, Paper #216***
- ***Research Grand Challenge #4***
  - ***"M&S Total System Representation"***

Complex System (CxS) "Landscape"

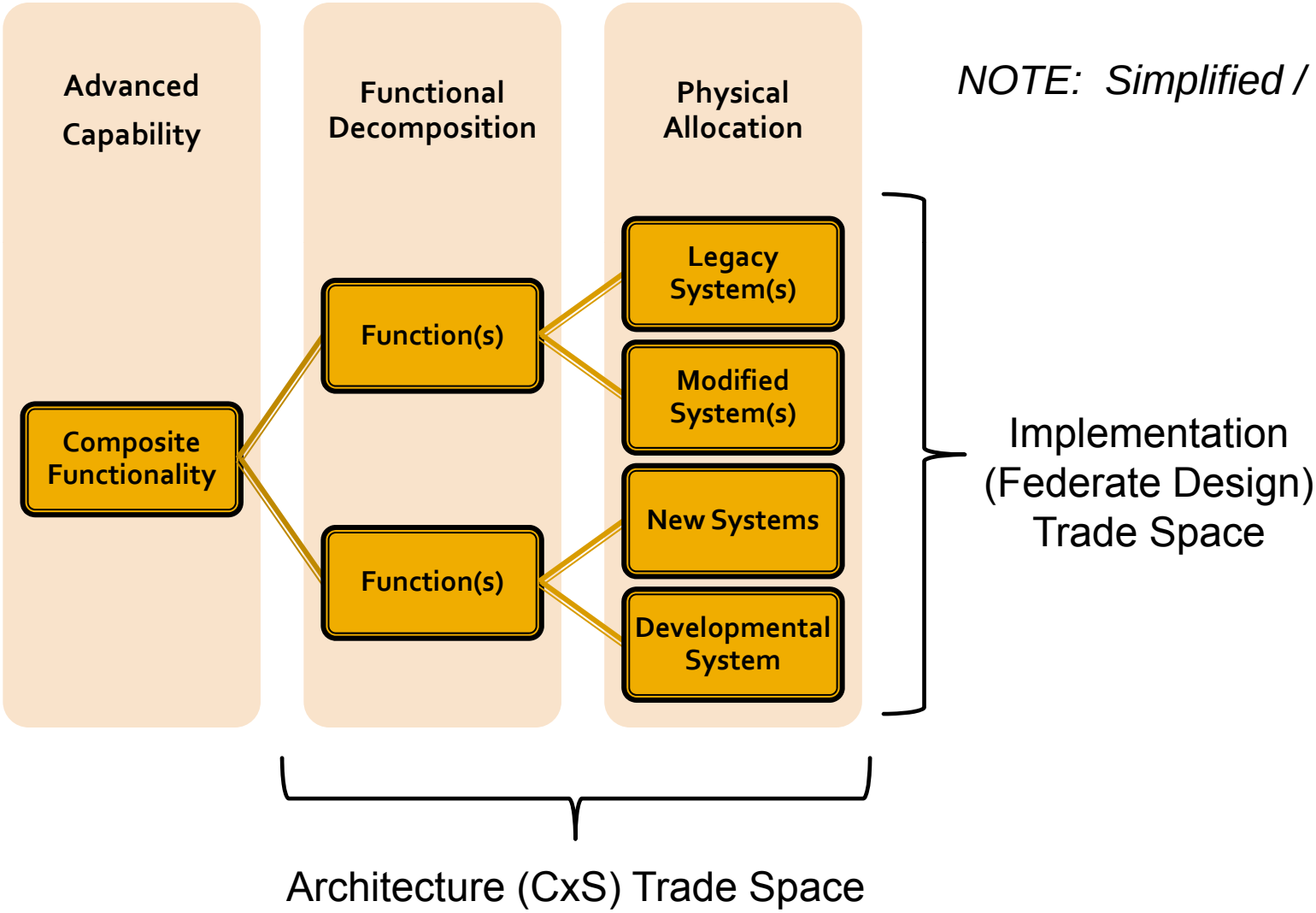
NOT A CLEAN SLATE !!!

Coalescence of Challenges



Conceptual Development

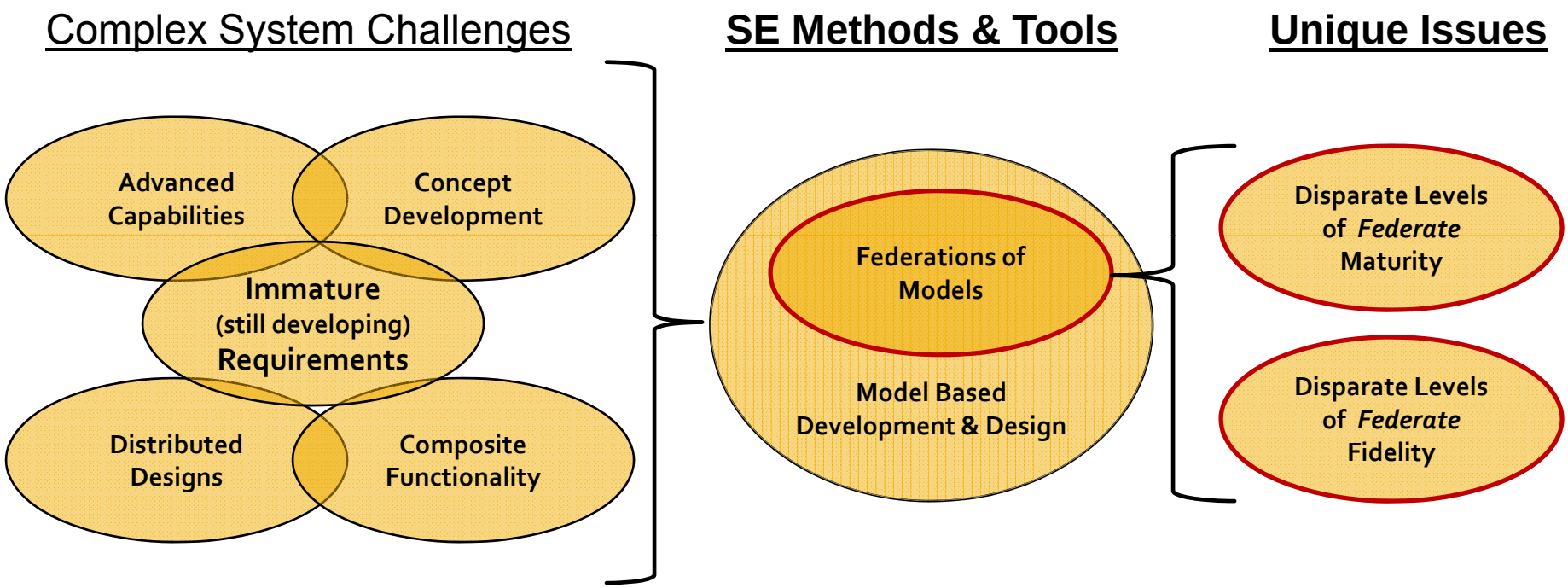
ENGINEERING "TRADE SPACE" INVESTIGATION



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
"VV & 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 entire federation to a completed 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 (under development in late 2010)*
    - *Distributed Simulation Engineering & Execution Process*

HLA FEDEP and VV&A "Overlay"

MERITS & SHORTFALLS

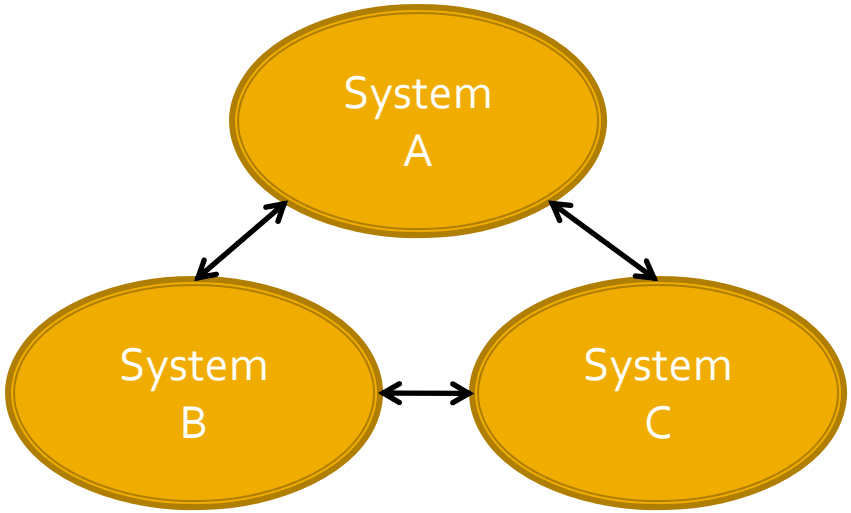
- Merits
  - Widespread adherence offers the potential for enhanced interoperability among models & simulations
    - Would facilitate compositing necessary for the creation of federations of models
- Shortfalls
  - Applicable only to HLA applications
    - DSEEP attempts to generalize practices & expand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

$$SRL = f(TRL, IRL)$$

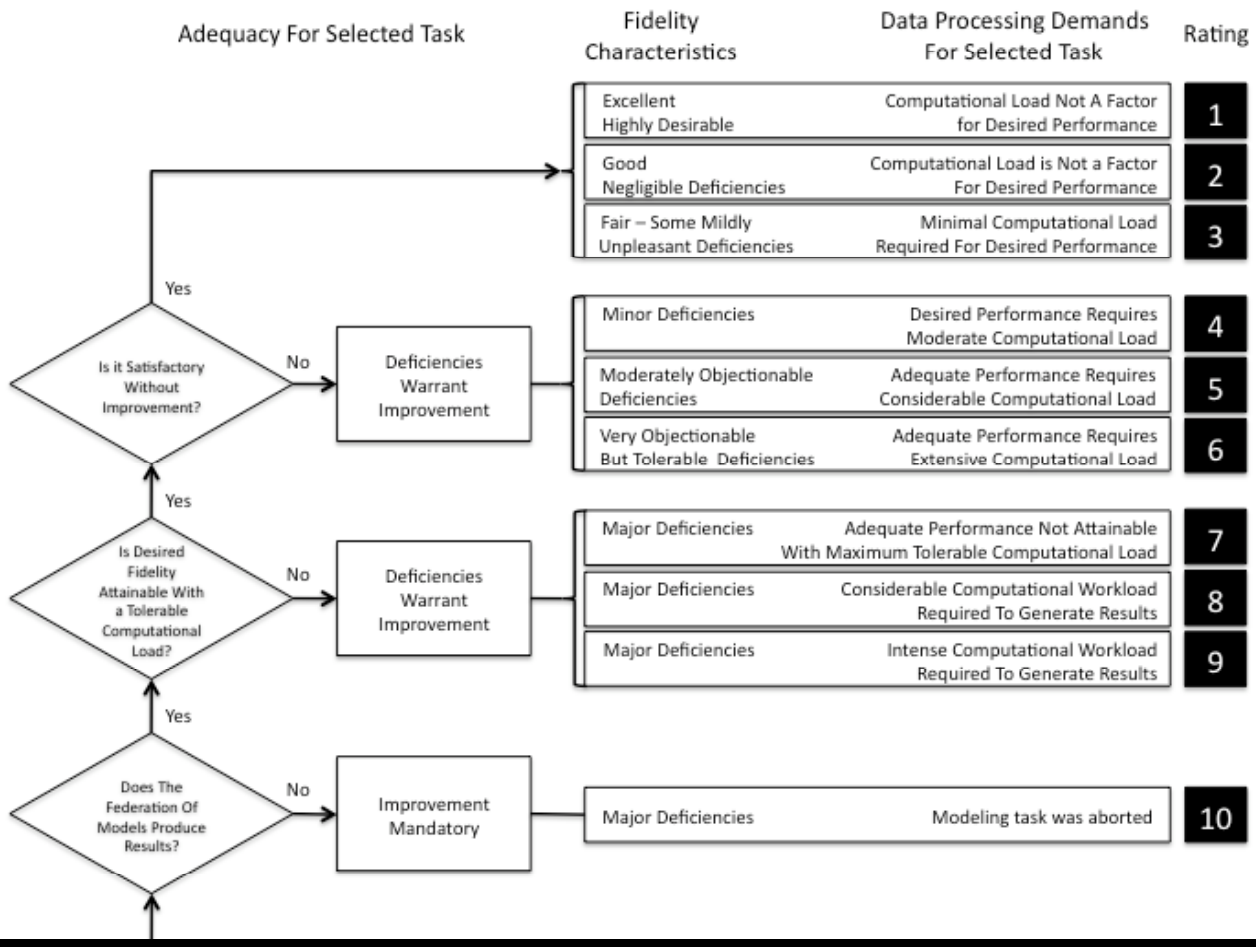
System Readiness Levels
MERITS & SHORTFALLS

- Merits
  - Mention of system architecture as context
  - Identification of both technology and integration challenges
- Shortfalls
  - Inadequate scale granularity during Concept Development
    - SRL value range in CD: 0 – 0.4 (on a scale of 0.0 to 1.0)
  - Insight limited to pair-wise assessments
    - System attributes & relationships captured in matrices and manipulated
    - Aggregation becomes problematic
  - Does not address model fidelity

An alternate tool?

"FEDERATED MODEL READINESS LEVELS"

Erhardt, Flanigan, and Herdlick
CSER 2010 Paper #1569270597



Based on the Cooper-Harper Handling Qualities Rating Scale

An alternate tool?

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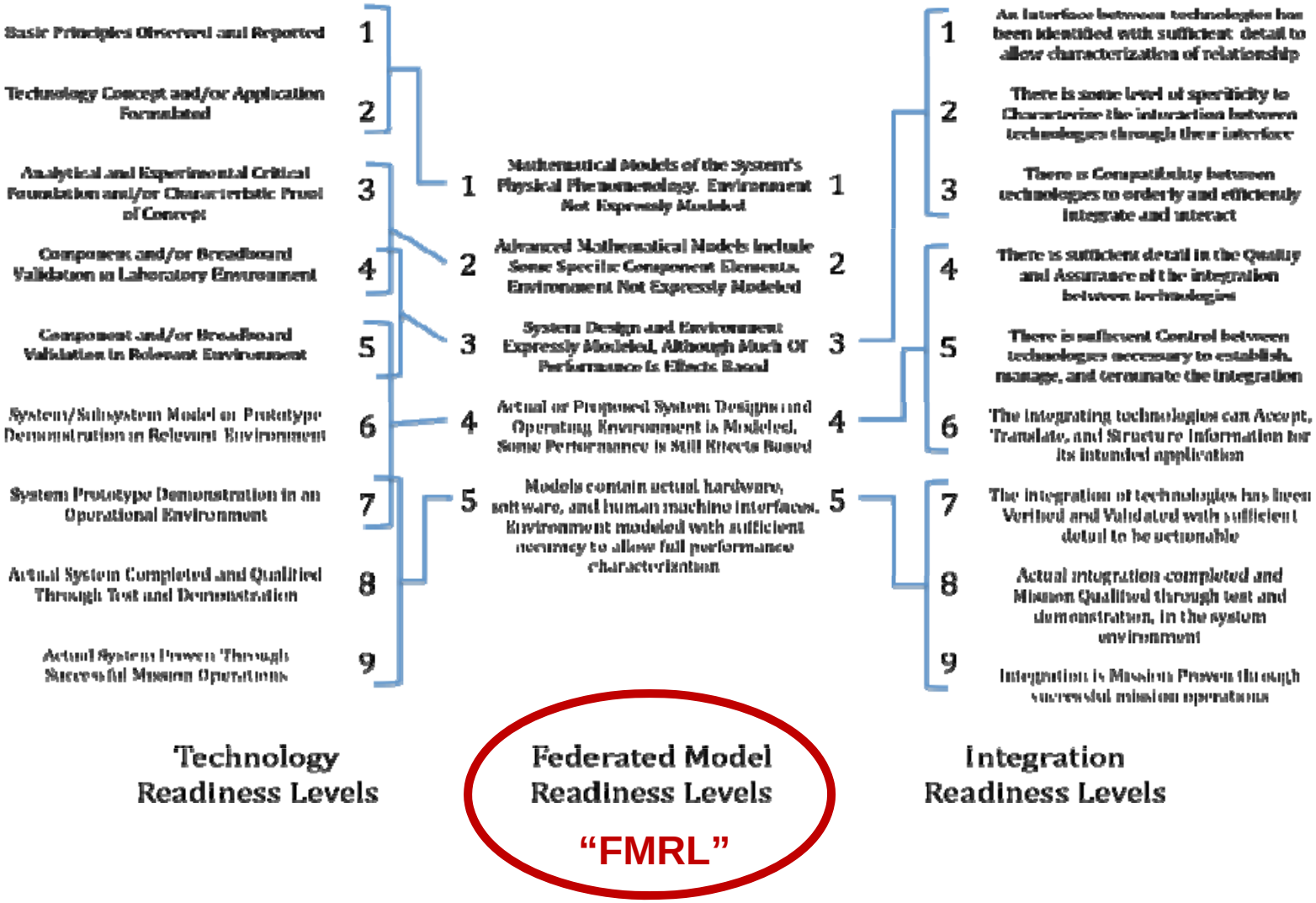


FMRL
SHORTFALLS

- 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 unique model characteristics

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 m[illegible] ederation level
- Shou[illegible]
  - An [illegible] with) TRLs, IRLs and SRLs
    - Co[illegible] ems display maturity / ***fidelity*** / integration cha[illegible] not align
- ***Considering alternatives from other disciplines***
  - ***Some aspects of the FMRL solution may be considered in the construction of a new solution…***

Abandoned As a Solution

Research Update

New References and Information (slide 1 of 4)

- Simulation and Modeling of Systems of Systems
  - Edited by: Pascal Cantot and Dominique Luzequx
  - Released: ***May 2011***
  - Credibility (entire chapter; 50 pages)
    - Review of various techniques / tools
      - VV&A utility questionable for federations of models
      - Balanced (US DoD and European Military) approaches

Research Update

New References and Information (slide 2 of 4)

- Simulation and Modeling of Systems of Systems
  - Identifies other candidate solutions (with shortfalls)
    - ***Phenomena Identification and Ranking Table (PIRT)***
      - ***Identifies points for validation and assigns weights***
      - ***Assumes validation at lowest levels, followed by aggregation***
    - ***Hierarchical Decomposition***
      - ***Model Identification and Ranking Table (MIRT)***
        - ***Informs the validation plan, but still requires aggregation***

Research Update

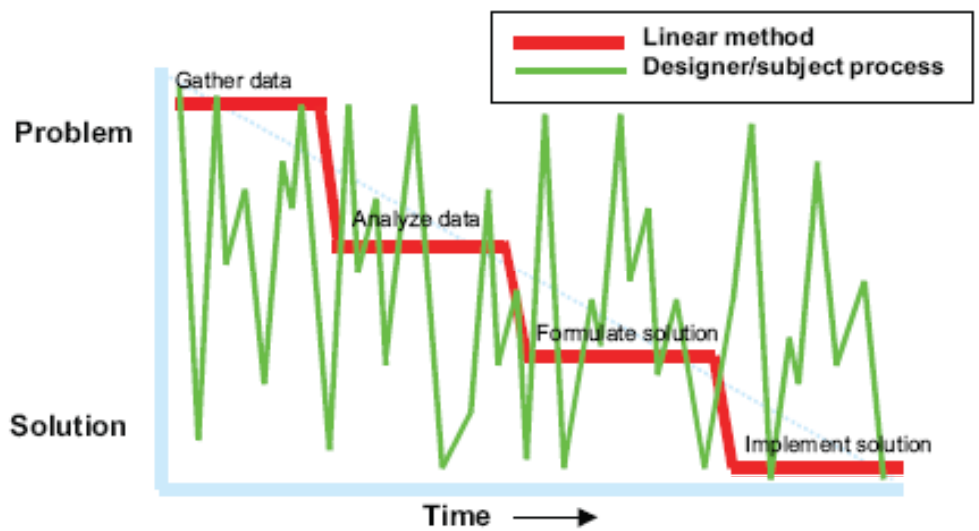
New References and Information (slide 3 of 4)

- Simulation and Modeling of Systems of Systems
  - Identifies problem areas for complex system modeling
    - ***Aggregation / propagation of validation information***
    - ***"…the problem of identification of the relevant aspects of each model an the determination of a "suitable" level of modeling is not dealt with…"***
    - ***Non-linear development process***
      - ***Development and VV&A do not necessarily precede use of models and simulation***

Research Update

New References and Information (slide 4 of 4)

- "Dialogue Mapping: Building Shared Understanding of Wicked Problems", Conklin (2006)
  - ***"Wicked Problems and Social Complexity" (2005)***
    - ***Non-linear nature of problem solving vis-à-vis "Wicked Problems"***



*www.cognexus.org/wpf/**wickedproblems**.pdf*

Solution requires a new "*lens*"

It's all about perspective…

- "System of Systems" is still just a system…
  - Simply a distributed design that delivers a composite capability
    - Admittedly, one that is difficult to develop within the U.S. DoD acquisition construct
- "Federation of Models" is still just a model…
  - Simply a collective, virtual environment that approximates a SoS
- Must get away from the "how" and focus on the "what"
  - What = Composite Capability
    - Functional Decomposition & Physical Allocation
    - Interfaces and interdependencies

Solution requires a new "*lens*"

It's all about perspective…

- Any solution must address the recognized "problem areas"
  - ***Must focus on only the <u>relevant</u> aspects of models***
    - *Capability focus*
    - *Scenario context*
  - ***Must identify <u>adequate</u> levels of federate validity / fidelity***
  - ***Must render a credible aggregate value for the federation***
  - ***Must be adequately flexible and agile***
    - *Only a "light weight" tool will offer utility in the context of design trade space exploration and non-linear development processes*

- Prospective method being developed
  - ***Initial trial : Fall 2011 (back-up : Spring 2012)***
    - *Virtual Warfare Center (St. Louis, MO)*

QUESTIONS & COMMENTS ???

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2011 System of Systems Engineering Collaborators Information Exchange Webinars

- ✓ April 12th – **A Game Loop Architecture for the Modeling and Simulation of Mission Threats**, Thomas Tanner, SAIC
- ✓ May 3rd – **Mission Engineering for Warfighting Integration of Net-Centric Systems**, Eileen Bjorkman and Timothy Menke, USAF
- ✓ May 10th – **The Role of Enterprise Architecture Updates in Guiding Decentralized Organizations**, John Schatz, SPEC Innovations
- ✓ May 24th – **Test and Evaluation Issues for Systems of Systems: Sleepless Nights to Sominex**, Dr. Beth Wilson, Raytheon & Dr. Judith Dahmann, MITRE
- ✓ June 14th – **Establishing Confidence in Federations-of-Models**, Bryan Herdlick, JPU/APL, Thomas Mazzuchi, D.Sc. and Shahram Sarkani, Ph.D., PE, George Washington University
- July 12th – **System-of-Systems Engineering for Army Battle Command Convergence**, Ms. Monica Farah-Stapleton, ASA(ALT)
- July 19th – **Systems Engineering Management and the Relationship of Systems Engineering to Project Management and Software Engineering**, Dr. Raymond Madachy, Naval Postgraduate School

For information, email dasd-se@osd.mil or visit our website: http://www.acq.osd.mil/se/outreach/sosecollab.html

Initial 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)

System Maturity Metrics for Decision Support in Defense Acquisition, User's Guide: Version 1.0, Brian Sauser, Ph.D., of the Stevens Institute of Technology. (Developed for the U.S. Army Armament Research Development Engineering Center (ARDEC)), 2007

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

Presenter Biography

BRYAN HERDLICK, CSEP-Acq.

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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Presenter Biography

THOMAS MAZZUCHI, D.Sc.

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.

Presenter Biography

SHAHRAM SARKANI, Ph.D., PE

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 doctoral 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.

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ABSTRACT

Establishing Confidence in Federations-of-Models

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 as a stepping-stone in the development of a credibility assessment method for federations of models. that will add rigor to simulation-based concept development of complex systems and foster greater confidence in resultant findings and decisions.