Test and Evaluation Issues for Systems of Systems: Creating Sleep Aids for Those Sleepless Nights

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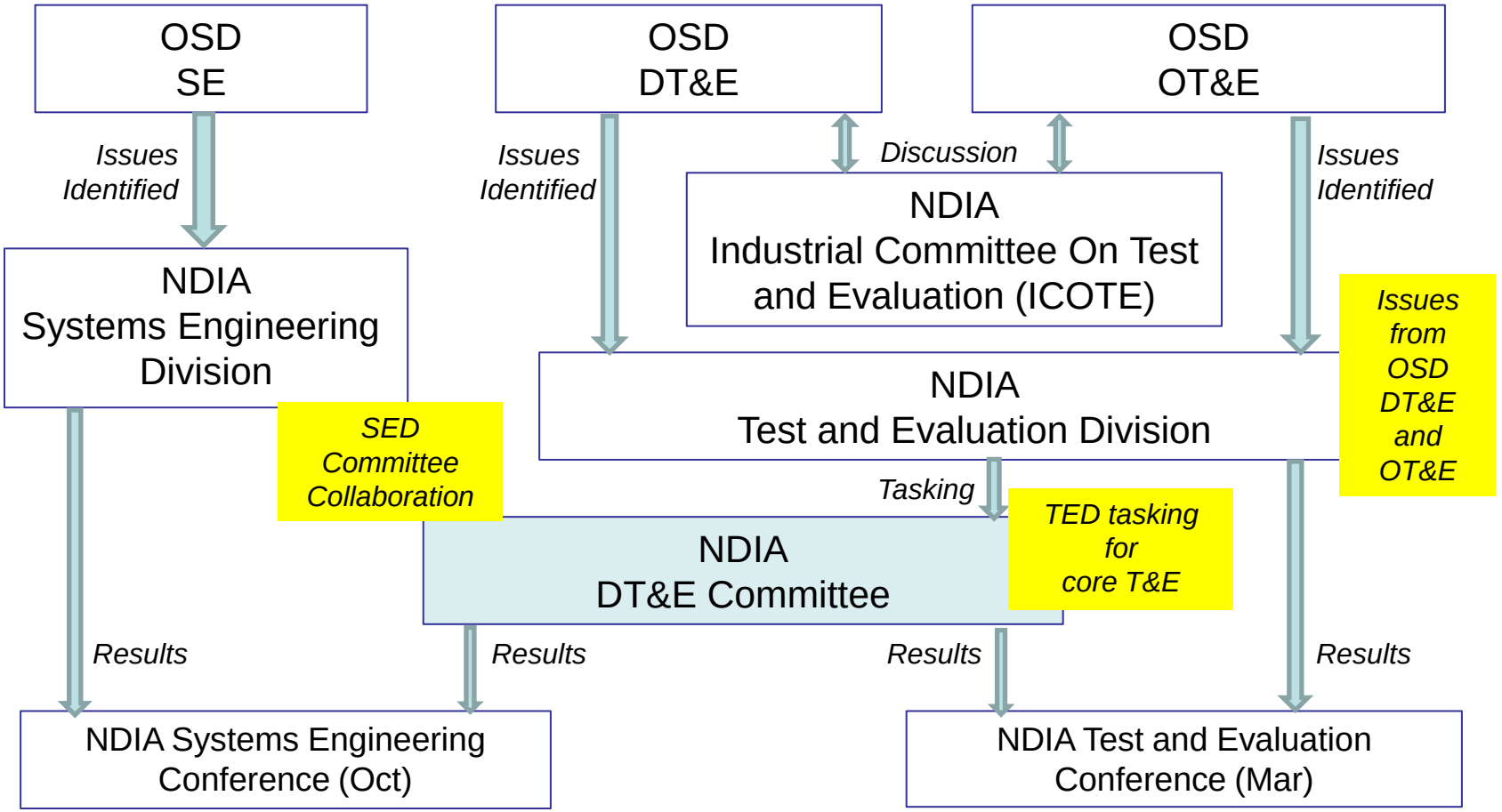
Abstract

In 2009, the NDIA System of Systems Committee developed a white paper describing test and evaluation issues that cause "sleepless nights".

In 2010, the NDIA SoS and DT&E Committees collaborated in a joint workshop to translate these issues into strategic initiatives and collaborative go-do activities as improvement areas. The issues included future T&E for systems brought together as SoS, requirements, metrics, systems changes, and end to end testing with systems not yet available.

This paper will summarize the results of that workshop and the progress being made to mitigate SoS T&E sleepless nights.

NDIA DT&E Committee Moved from SE to T&E Division



Focus of this Paper: DT&E Collaboration with SoS

Sleepless Nights: Test and Evaluation for SoS

- **Systems of Systems Topics Discussed in 2009:**
  - Compiled list of “what keeps me awake at night” topics for SoS
  - Test and evaluation for SoS topped the “Sleepless Nights” list

- **NDIA SoS and DT&E Committees Worked Jointly in 2009:**
  - Identified key T&E challenges for SoS
  - White paper described 5 top issues
  - Presented at 2009 NDIA SE Conference in joint SoS/T&E track

- **Focus for 2010: Joint Workshop August 17th**
  - Define a path from Sleepless Nights to Sominex
  - Evaluate challenges and underlying issues
  - Transition specific issues into strategic initiatives

- **Resulting Effort:**
  - 3 Strategic Initiatives
  - 1 Collaborative Go-Do

Workshop Defined Path to Find Sleep Aids

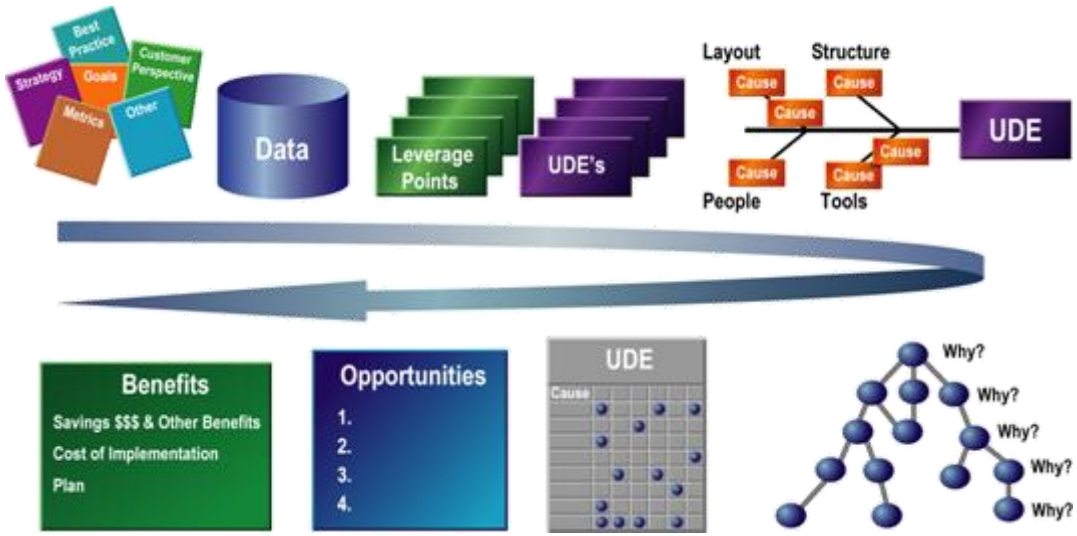
Reminder from 2009: T&E Challenges for SoS

1) **Future T&E:** If SoS are not programs of record (and not subject to T&E regulations) why should we worry about this at all?
2) **Requirements:** If 'requirements' are not clearly specified up front for a SoS, what is the basis for T&E of an SoS?
3) **Metrics:** What is the relationship between SoS metrics and T&E objectives?
4) **Systems Changes:** Are expected cumulative impacts of systems changes on SoS performance the same as SoS performance objectives?
5) **End to End Testing:** How do you test the contribution of a system to the end to end SoS performance in the absence of other SoS elements critical to the SoS results? What if systems all implemented to their specification, but the overall SoS expected changes cannot be verified?

White Paper was Starting Point

Facilitated Workshop: The Technique

Data Collection:
SoS White Paper
SE Conference Papers



Improvement Areas:
Strategic Initiatives
Collaborative Go-Do

Potential Problem Areas

1) Future T&E for Systems brought together as SoS
2) Requirements
3) Metrics
4) Systems Changes
5) End to End Testing with systems not yet available

Potential Causes

If we could only fix one thing, it would be _____

		Cable	Tasks	Setup	Testing	Security
Facility	Signal cables wrong length or incorrect	x		x		
	Power/Cooling connections	x		x		
	Safety interconnect	x				
	Test equipment			x		
	Equipment in NFR	x		x		x
Schedule Dependencies	Signal cable delivery	x	x			
	REX/NBDC/SDP availability		x		x	
	REX array availability		x		x	
	Test results prior to string integration				x	
	Detailed tasks for integration/prep	x	x	x	x	
Security	Classified shipment					x
	Classified workstations					x
	Classified field returns					x
Integration Test Conduct	Procedures incomplete or incorrect		x	x	x	
	SDP emulator				x	
	Work-arounds required	x	x	x	x	x

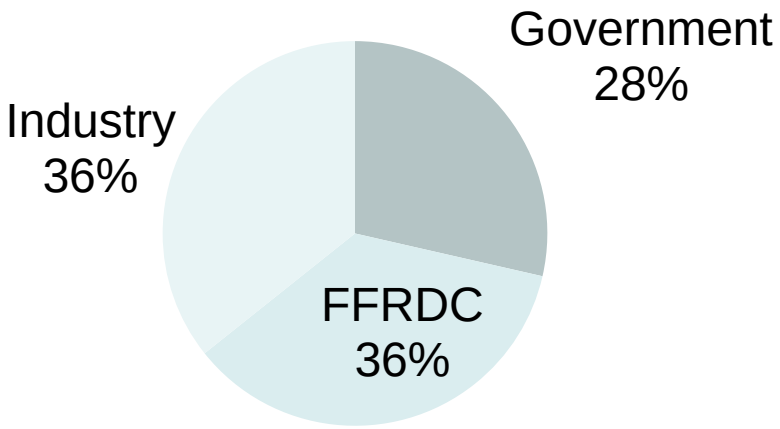
Leverage Matrix
Map Causes to problem areas

Transition from Problem Space to Solution Space

Facilitated Workshop: Attendees

Mr. Robert Aaron	Army	Government
Col (Ret) Suzanne M. Beers	MITRE	FFRDC
Dr. William D. Bell	MITRE	FFRDC
Mr. Aumber Bhatti	MITRE	FFRDC
Clyneice Chaney	MITRE	FFRDC
Mr. Peter H. Christensen	MITRE	FFRDC
Mr. David W. Coleman	MITRE	FFRDC
Dr. Judith S. Dahmann	MITRE	FFRDC
Ms. Indira Deonandan	MIT	Government
Mr. John W. Diem	OSD/ MSCO	Government
Mr. Mark E. Fenicle	DoD	Government
Mr. Tanya Gobel	SAIC	Industry
Mr. Robert Heilman	DOD	Government
CDR (Ret) Bryan Herdlick	JHU APL	Government

Dr. JoAnn Lane	USC CSSE	Industry
Mr. Steven S. Lee	DoD	Industry
Mr. Marty Leek (Facilitator)	Raytheon	Industry
Mr. Favio L. Lopez	Army	Industry
Mr. John R. Palmer	Boeing	Industry
Mr. George Rebovich Jr.	MITRE	FFRDC
Mr. Frank J. Serna	Draper	Industry
Mr. Michael Shanahan	USMC	Government
Dr. Carol A. Sledge	SEI	FFRDC
CDR (Ret) James D Smith II	SEI	FFRDC
Mr. Thomas Wissink	Lockheed Martin	Industry
Mr. Jack Zavin	OSD NII/DoD CIO	Government
Dr. Janice A. Ziarko	MITRE	Industry
Ms. Robin E. Ziradinovic	SAIC	Industry



Workshop Results

	Initiative Title	Action Plan	Initiative Vision Statement
Strategic Initiatives	Best Practices Model for SoS T&E	Define a best practices model	SoS T&E as a continuous improvement process supporting capabilities and limitations information for end users and feedback to SoS and System SE teams toward evolution of the SoS
	Radical Approach to SoS T&E	Define SoS capability test approach	Rethink T&E of systems in an operational context and systems interoperability away from system testing toward integrated capability SoS testing
	SoS Governance	Define characteristics of successful SoS T&E	Indentify the process by which we can change and influence the governance of SoS. Mature and improve templates to define a minimum set of characteristics that are required to govern SoS T&E efforts
Go-Do	SoS SE Policy and Guidance	Recognize and employ SoS guidance	Ensure that guidance or SoS SE (DoD SoS SE Guide) is recognized and employed on growing number of SoS

Initiatives Identified with Action Plans

Initiative Teams

#1	Best Practices
Leads	Judith Dahmann, (MITRE &ASD R&E/SE) Rob Heilman (TRMC)
Team Members	George Rebovich, (MITRE) Jim Buscemi (GBL&TRMC) Paola Pringle (Navy) Kent Pickett (MITRE) Chris Scrapper (MITRE) Aaron Budgor, (GBL Systems, TRMC) Laura Feinerman, (MITRE) Joe Lucidi, (Army OTC)

#3	Governance
Leads	Bob Aaron (ATEC) James Smith (SEI)
Team Members	John Palmer (Boeing) Carol Sledge, PhD (SEI) Robin Zivadinovic (JFCOM/Ctr)

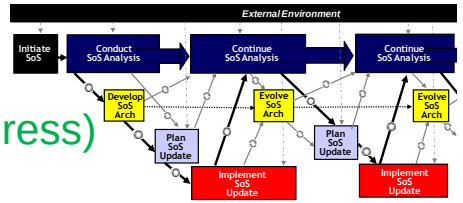
#2
Define SoS Capability Test

2 Initiatives Launched, Will Feed Results into 3rd

#1: Best Practices Model Approach and Status

Complete
In Process
Planned

1. **Form core team (Complete)**
   - Core team will implement activities
   - Share results for feedback from SoS and DT&E committee
2. **Define scope (Complete)**
   - Focus on Acknowledged SoS *(SoS objectives, management, funding and authority; however systems retain their own management, funding and authority in parallel with the SoS)*
   - Investigating potential for Directed SoS *(SoS objectives, management, funding and authority; systems are subordinated to SoS)*
3. **Develop a draft description of the proposed model**
   - Review the workshop discussions (Complete)
   - Review current SoS SE guidance on T&E (Complete)
   - Framework for model and implementation approaches (In Progress)
   - Draft model description and circulate for review (Planned)

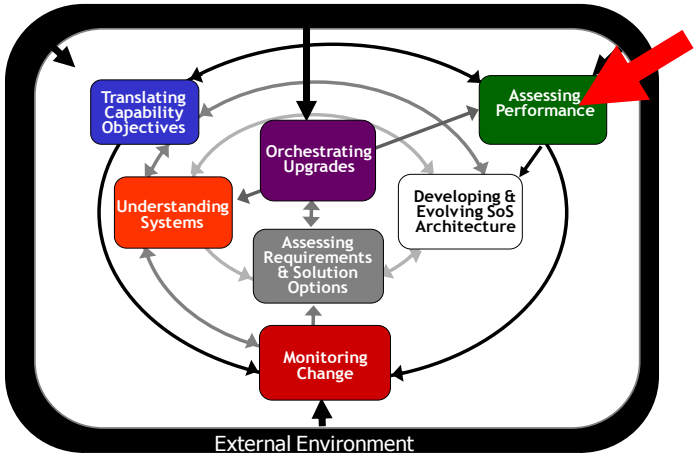


4. **Review use cases to support and/or adapt the model**
5. **Update the model based on use cases**
6. **Review and assess state and utility of the model**

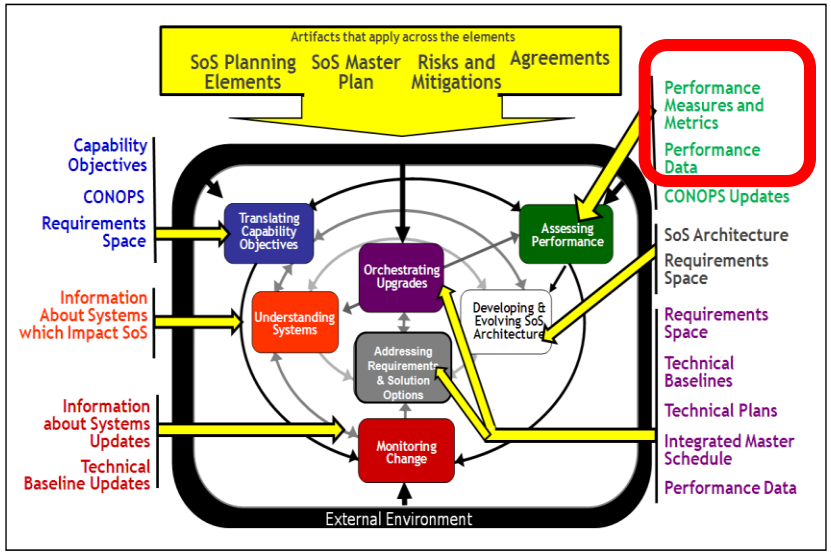
Identifying T&E inserts into SoS Wave Model
Soliciting Use Case Recommendations

#1: Best Practices Model
Role of T&E in SoS Models

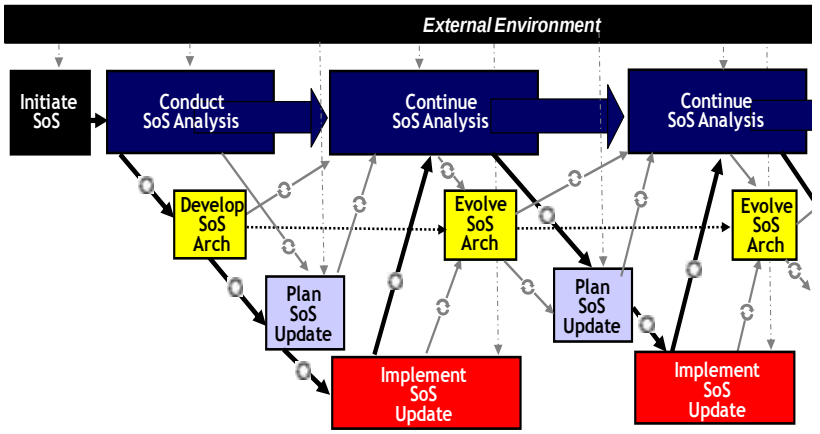
Trapeze Model



- SoS SE Guide Trapeze Model
  - "Assessing Performance" is a core element of SoS SE
- SoS SE Artifacts
  - Performance Measures and Metrics
- Wave Model
  - SoS T&E begins with SoS analysis and is addressed throughout the other steps



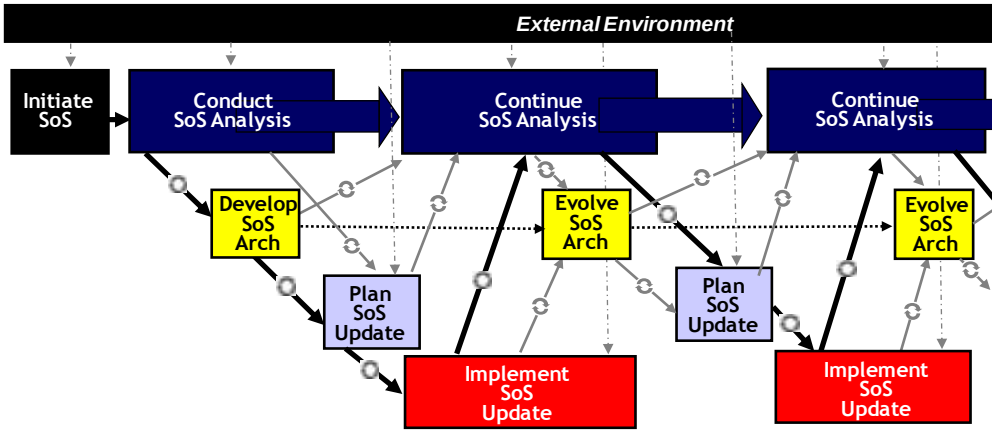
Wave Model



#1: Best Practices Model Framework for Description

SoS Wave Model

- Describe key activities at each stage as they relate to T&E of the SoS
  - Conduct (and Continue) SoS analysis
  - Develop and evolve SoS architecture
  - Plan SoS Updates
  - Implement SoS Updated



- What actions are taken at each step to support the model of SoS T&E as

  "Continuous improvement process supporting capabilities and limitations information for end users and feedback to the SoS and system SE teams toward evolution of the SoS"

- Why are these important?
- What value to they add?
- How do they contribute to the larger SoS SE and T&E outcomes?
- How do they address the challenges?
- What methods or tools apply?

#3: Governance Approach and Status

Complete
In Process
Planned

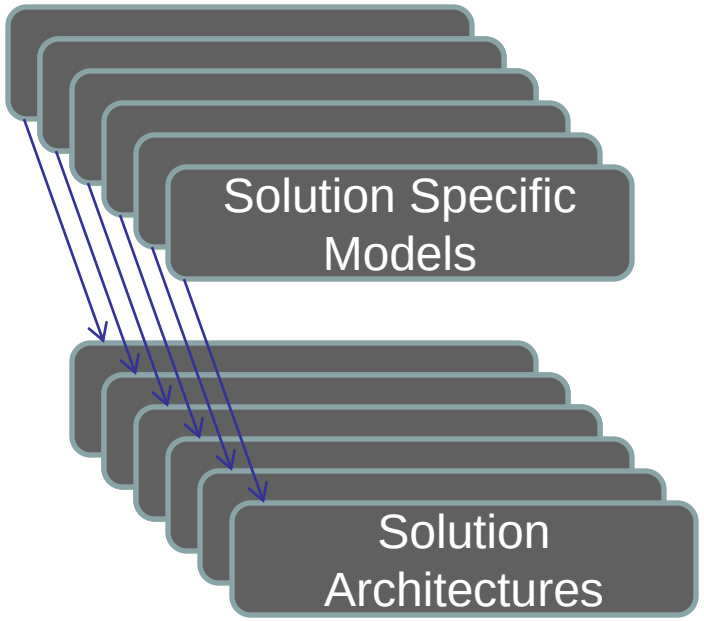
1. **Form core team (Complete)**
2. **Define scope (Complete)**
   - Purpose: to provide an integrated governance perspective for SOS development, deployment, and life cycle
   - Scope: Governance for overall acquisition, including T&E as a holistic/comprehensive view *(focus on Directed and Acknowledged SoS)*
3. **Identify Governance As-Is State (Complete)**
   - Fundamental Governance Concepts
   - Architecture Concepts & DODAF for managing complexity
4. **Develop Governance To-Be Fundamental Concepts (In Process)**
   - Organizations that produce reference models, reference architectures, and data engineering components including T&E considerations for measuring performance
   - Synchronized and aligned organizations (structures), policy, tools, technical approaches, and resources that support the selected option.
5. **Draft Recommendations to Achieve To-Be State**

Reference Architecture As Framework to Discuss Governance

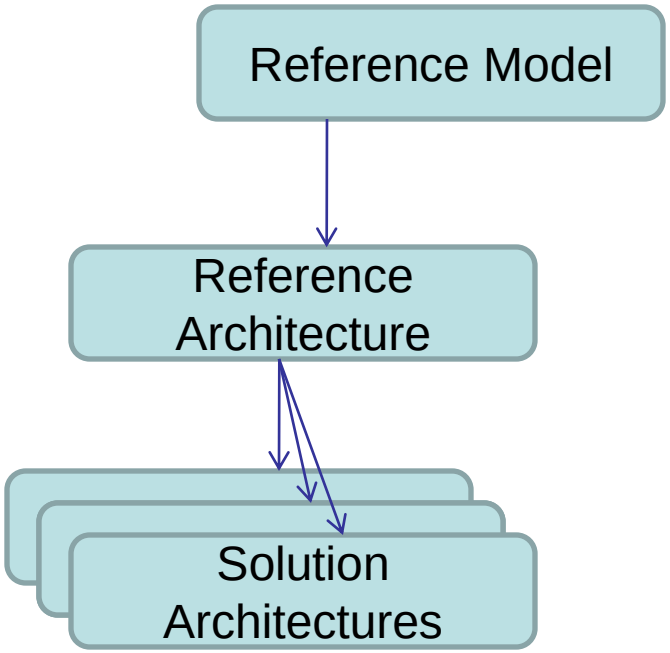
#3: Governance
Current and Objective State

Our Architecture/Technology organizations should be designed how?

Test Technology
Current State



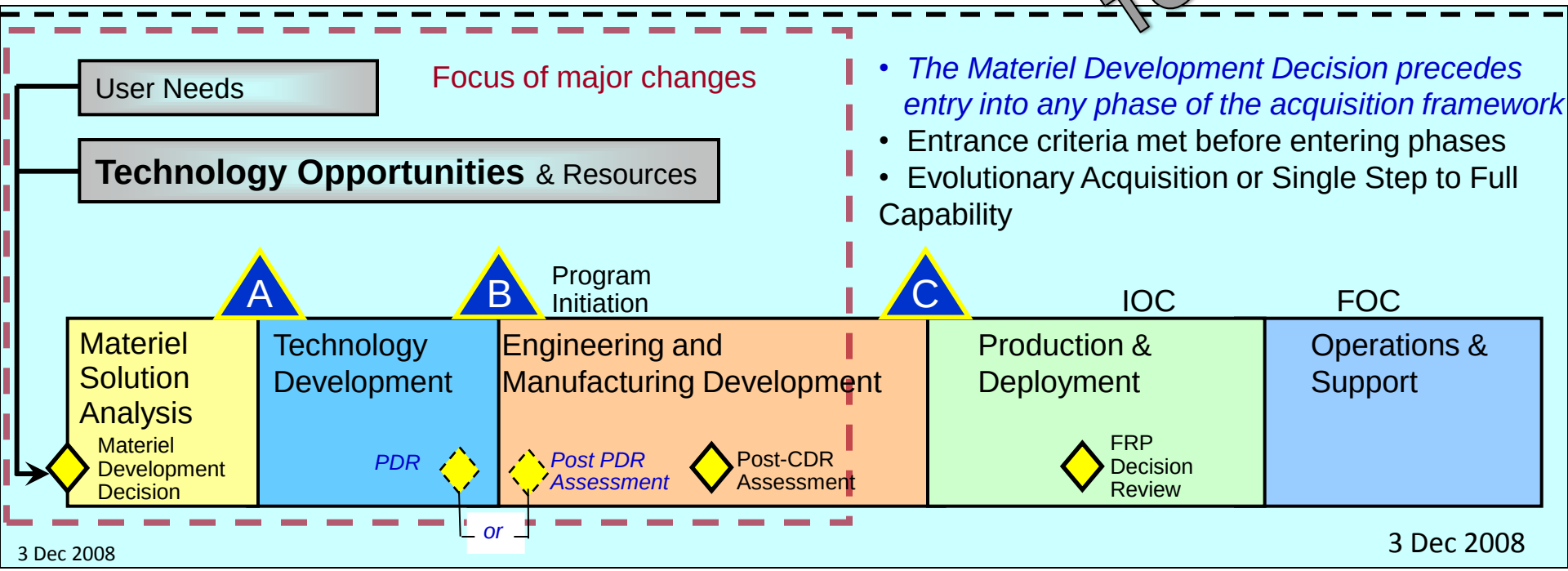
Test Technology
Objective State



Creating the Environment for NR KPP – OV-1

(NR KPP WG - Draft)

TO-BE



Use **M&S Environment** to develop Architecture

Use **M&S Environment** to develop/test Reference Architecture

CM

Use **M&S Environment** to develop/test Solution Architecture

CM

Use **M&S Environment** to deploy Solution Architecture

Use **M&S Environment** to continually improve Architecture

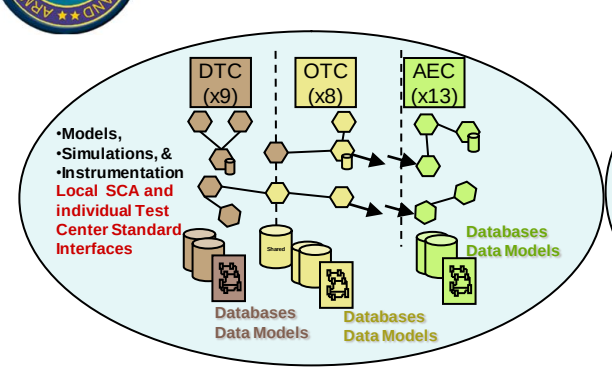
CM

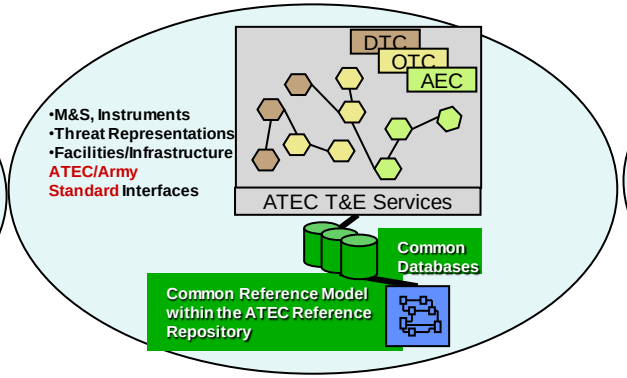
- Begins w. Reference Models
- Technology/Cost trade offs
- Model Driven Architecture (MDA)
- Integrated Development Environment (IDE) all under Configuration Mgmt
- Use M&S Environment to develop architecture and to the extent possible SOS DOTLMPS components
- Common/interoperable tools and tool kits for this acquisition domain

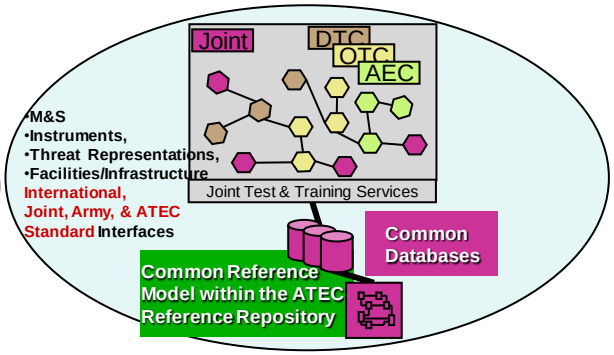
- User pulls down what he needs
- Each Phase Virtual using DOD COEs
- Designers push new patches

EXAMPLE ONLY

Test Technology "To-Be" System Evolution (SV-8)







CY08
- Initial Ref Architecture for TTD Review
- Initial Reference Repository with:
  - First AEC data models
  - Search, Submit, & Download Functions

FY09
- Initial Ref Architecture for Community Input
- Functioning Reference Repository with:
  - Initial CRM containing the following data models:
    - AEC T&E Reference Model & other available data models
    - TENA TSPI
    - Engineering Units DB

FY10
- Ref Architecture
  - Community involved in evolution
  - Initial Automation Support
- Operational Reference Repository with:
  - Initial Visualization functionality for data model comparison
  - Enhanced CRM that includes Planning metadata
  - Additional & Evolved data models

FY11
- Ref Architecture
  - Community Active in Evolution
  - Improved Automation Support
- Operational Reference Repository with:
  - Improved Visualization, Aggregation, Disaggregation functionality for data models
  - Evolved CRM that includes Execution metadata
  - Additional & Evolved data models
- Initial TT Investment Decision Support System

FY12
- Ref Architecture
  - Community Driven
  - Full Automation Support
- Reference Repository
  - Sophisticated Visualization, Aggregation, Disaggregation functionality for data models
  - Evolved CRM that includes metadata for all T&E phases
  - Additional & Evolved data models
- Improved TT Investment Decision Support System

More Automation - Less Manual Effort, Greater Accuracy, & Less Time
Increasing Community Involvement, Modeling and Governance –
Greater Interoperability & Less Ambiguity
Growing Architectural Cohesion Enabling Informed Decision Making

#2: Capability Testing Approach Planned

Complete
In Process
Planned

1. **Assess inputs from Strategic Initiatives #1 and #3**
2. **Form core team**
3. **Define scope**
4. **Define SoS T&E As-Is State**
   - Build up of systems testing in operational context
   - Build up of systems interoperability
5. **Define SoS Capability T&E To-Be State**
   - Define gaps in implementation as integrated capability SoS
   - Identify barriers responsible for these gaps
6. **Draft Recommendations to Achieve Capability SoS T&E**

Rethink T&E of SoS in Operational Context

Summary

- **Successful Workshop with SoS and T&E Practitioners**
- **Framework Established for Continuing Collaboration**
- **Transition Discussion from Challenges to Solutions**
- **Strategic Initiatives to Develop T&E Solutions for SoS**:
  1. **Define a best practices model**
  2. **Define SoS capability test**
  3. **Define characteristics of successful SoS T&E**
  – **Recognize and employ existing guidance for SoS (DoD SoS SE Guide)**

Not Too Late to Join a Team!

BACKUP

Details on T&E Issue Discussions

Issue 1 If SoS are not programs of record (and not subject to T&E regulations) why should we worry about this at all?

Discussion

- **Restatement of issue:**
  - How do we define, articulate, and enforce the relationship between the SoS and the constituent systems?
  - How does T&E support/help this?
- **Governance/Roles/Stakeholders**
  - Need a shepard (architect?) and support from users
  - Need to educate stakeholders
  - What are rules of governance?
  - What are the regulations, standards, and policies?
  - Need to obtain resources (funding, test assets, time)
  - SoS leadership focus: architecture views, who "owns"
  - Potential conflicts between SoS and constituents
  - Business case for PMs to do SoS
- **SoS T&E Focus**
  - SoS T&E operationally driven (vs. DT-ish)
  - SoS edge of the envelop
  - What is an AoA of SoS?
  - Emergent behaviors (good and bad)
  - SoS resource consumption (e.g. data pipeline)
  - Continual assessment (joint exercises, deployments)
  - How to define test strategies to efficiently continuously test?
  - How do we help the T&E process help the SoS work?
- **Understand SoS Capabilities**
  - What is the SoS expected to do?
  - Define and articulate relation between SoS and systems
  - Flexible composition
  - Artfully sub-optimize the systems in favor of the SoS
  - System performance bounds are not rigid in real operation
  - Candidate solution: SoS requirements document with annex for each constituent system (what is constituent contribution to SoS capability)

Issue 1 If SoS are not programs of record (and not subject to T&E regulations) why should we worry about this at all?

Approach to addressing issue

- Define a minimal set of SoS governance characteristics of a successful acknowledged SoS
  - Roles/resources
  - Rules/regs/standards/policies
  - Managing conflicts
  - Establishing cooperation of constituent systems
  - Includes responsibility to define SoS capabilities, architecture, and associated test strategy
  - Concept of continual change and test in operational and training environment
  - Lean management, taking advantage of available opportunities
  - Recognize the large number of SoS across the DoD, and the fact that many systems support multiple SoS.anf the potential impacts of governance

Issue #2 If "requirements" are not clearly up front from a SoS, what is basis for T&E of an SoS?

Discussion

- Requirements vs expectations; Mission objective vs. technical requirements
- Mission threads linked to capability strands as architecture model
- Who/what has responsibility for architecture/requirement- another DOD layer?
- Standards for participating or acceptance of each system into SoS
- Requirements model for architecture encompassing time, space changes
- SoS level requirement T&E at program or SoS level balance?
- T&E of aggregation of systems level requirements (SOS level TEMP)
- Integrated development environment/ reference architecture as model
- Need operations/architecture view of SoS that individual systems must plug into- need someone responsible for this
- Prioritization of SoS capabilities at high (OSD) level required to permit constituent PM to manage development and delivery. With funding at SoS
- Measure and baseline SoS capability thru T&E w/o requirements. Where do we get metrics?
- Must have an "enforcer" capability manager - carrots and sticks
- Measure SoS capabilities when changes to SoS Baseline
- CONOPs vs innovative use of systems in face of changing threat
- Move from paper to 4 dimensions to capture SoS capabilities requirements.
- Use of modeling tools of SoS components delivered with each component to communicate requirements
- Capability flow down to systems, demo meeting systems capability

Issue 2: If "requirements" are not clearly defined up front for a SoS, what is basis for T&E of an SoS?

Approach to addressing issue

- The DOD needs a top-down (architecture, requirements, context, expectation) flow-process to systems within the SoS
- Needs authority & funding to enforce capability fulfillment
- Needs to be flexible enough to meet changing needs and threats and CONOPS/operator innovation.
- Determine the right balance between system test to sos- test to SOS level test

Issue 3 What is the relationship between SoS metrics and T&E objectives?

Discussion

- SoS T&E is focused on continuous improvement of the SoS (as compared to system T&E which is focused on the field, fix, or don't field decision)
- Continuous SoS T&E requires
  - Stable/consistent metrics
  - Consistent approach to defining evolving baseline
  - A way to deal with emergent behavior (technical, organization, human) – positive or negative
  - Need to leverage wide range of opportunities for test environments
  - Continuous improvement means continuous testing ; Built in test instrumentation for feedback from field
- SoS metrics
  - Do not address discrete behaviors of systems (as do system metrics)
  - Do address end to end performance across systems in SoS toward capability objectives of the SoS
- What is objective of T&E for an SoS?
  - Development information on capabilities and limitations of SoS to inform end users and ongoing SoS evolution (as compared to system T&E which is assessment of whether system meets requirements)
- SoS T&E customers?
  - End user and SoS SE team (as compared to system T&E where aquisition community is the customer)
- SoS T&E should be risk driven: focus on areas of risk to SoS or systems

Issue 3 What is the relationship between SoS metrics and T&E objectives?

Approaches to addressing issue

- Characterize SoS T&E as continuous improvement, document the approach and share with the community
- Radically change how we look at testing given the growing prevalence of SoS
  - Concepts of DT and OT don't really fit
  - Inefficient to address systems in operational SoS environment on a system by system basis (OT today)
  - Continue to test individual systems to assess whether we have developed what we asked for
  - Create a new approach to OT, by cross systems support for testing capabilities

Issue 4 Are expected cumulative impacts of systems changes on SoS performance the same as SoS performance objectives?

Discussion

- To address these issues you need to fix
  - Define the SoS and its performance objectives
    - Constituent systems that are part of the SoS
    - Which parts of the constituents contribute to the SoS objectives
  - Describe the current and future state of the changing systems (Baselines)
  - Assign ownership of SoS performance objectives
  - Big challenge; leadership issue, etc
    - More collaborative approach for stakeholders of SoS
- Emergent behavior – interaction of systems, humans, system and organization along with constant change of the parts
- Bounds of human impact
  - Operator – leader – mission
  - The people side of systems
- Training and development of the evaluators (and the end users)
- Expensive to assess if capabilities are realized (hard to do)
  - Doing more with less?
  - Disconnect thinking and reality?
- Leadership understanding of SE and SoS
  - Is there competency to make decisions and know the impact and implications?
    - Trades without know the desired outcome can be achieved
  - Evaluation on an SoS basis vs individua;l systems and their acquisitions
  - Timing and who benefits (lack of rewards systems)
  - Accountability for SoS
- Continued improvement, assessment, and alignment because objectives have changed
  - More data from fielded systems
- Connections to fielded side of the house (doesn't deal well with change)
- "Measurement system' for system
  - Analysis of impacts
  - M&S?
  - Risks; "we are not sure but…" with some mitigation
  - Regression testing and configuration of SoS
  - Comparative analysis

Issue 4 Are expected cumulative impacts of systems changes on SoS performance the same as SoS performance objectives?

Approaches to addressing issue

- Influence assigning leadership responsibility and ownership of defined SoS capability and associate performance objectives
- Establish incentives of constituent systems to collaborate and achieve SoS performance objectives
- Map SoS capabilities and performance objectives to constituent systems (under configuration control)
- Continual assessment, improvement, and realignment is required (incremental approach) focused on end user)
- Create a guidance framework for emergent behaviors of changing to be measured and managed

Issue 5

Are expected cumulative impacts of systems changes on SoS performance the same as SoS performance objectives?

How do you test the contribution of a system to the end to end SoS performance in the absence of other SoS elements critical to the SoS results?

Discussion

- Trying to assemble all piece parts for T&E
- So many variables that can impact T&E outcome
- Reliance on other programs (e.g., JTRS) for capabilities that can slip in schedule or are never delivered
- Spanning "use-case" space with a reasonable set of resources and schedule
- Need defined set of requirements (but, of course, this is part of the problem space)
- What does a T&E strategy look like?
- How account for "the network" and stresses to it?
- DoD should require programs to share/ make transparent to other programs their development, DT and other data (obstacles: proprietary/security)
- Recommend ways to systems instrument to enable post-fielding collection of "test" data
- Operations, exercises, training
- DoD should develop a common approach to accounting for "the network" as a constituent of all SoSs for purposes of T&E
- DoD articulate purpose of SoS T&E
  - Is it a capability demo ("what do we have?")
  - Is it a classical check against requirements?
  - The real purpose of SoS T&E is to answer:
    - Is the new capability operationally useful (whether or not it "met" requirements); what are risks?
  - How can the new capability be used?
  - What further changes are required?

Issue 5

Are expected cumulative impacts of systems changes on SoS performance the same as SoS performance objectives?

How do you test the contribution of a system to the end to end SoS performance in the absence of other SoS elements critical to the SoS results?

Approach

- **M&S of piece parts that are not yet ready to be tested (but issues between M&S for individual system performance versus effects-based M&S) – potential solution to issue #1.**
- **Architectures and synchronizing them an enabler of T&E (provides well-defined baseline; can measure deltas against the baseline)**
- **Combinatorial test & design (suggested as potential solution to issue #2).**
- **Model-test-model approach suggested for way to accommodate emergent behavior**
- **Field exercises – instrumentation to collect data**
- **Training as a T&E opportunity**
- **No SoS requirement => no TEMP for SoS capabilities => no SoS T&E funding. Therefore need a capability (SoS) focused, cross-system, integrated test schedule that builds to a graduation-level event. (some disagreement re. existence of such an event). Push SoS T&E to fleet/operators as proof of IOC (need fleet experimentation funding).**