

Systems Engineering Artifacts for SoS

IEEE Systems Conference
6 April 2010
San Diego, CA

Dr. Judith Dahmann

George Rebovich

The MITRE Corporation

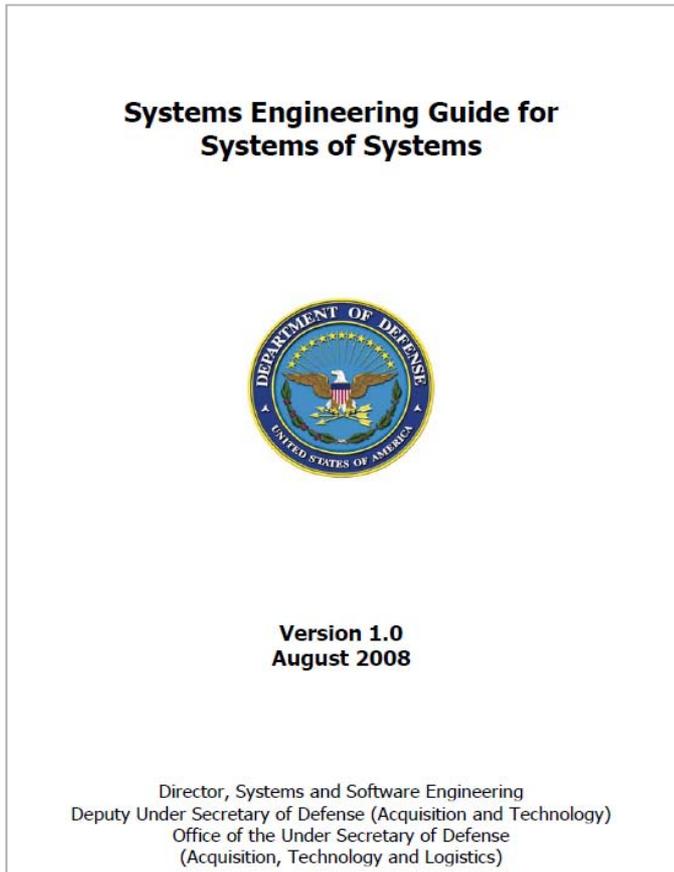
Dr. Jo Ann Lane

University of Southern California

Ralph Lowry

Modern Technology Solutions

Background



- US DoD has a continuing interest in effective application of SE both within and across programs
- SoS SE Guide provides the foundation
- Current efforts focus on extending guidance for the practitioner
 - Follow-up work with initial case examples and new SoS initiatives
 - Work on **SE artifacts for SoS** is core part of the next steps

Guidance is based on structured reviews of ongoing SoS SE efforts to identify successful patterns of practice across recent practitioner experience

Origins of Work on SoS SE Artifacts



- ❖ Initiated as a US - Australia cooperative effort
 - ❖ Continued as an international initiative under The Technical Cooperation Program (TTCP)
 - ❖ Now also includes UK and Canada
- ❖ Why focus on “SoS SE Artifacts”?
 - ◆ Tangible
 - ◆ Evident ROI in terms of a useful product
- ❖ Anticipated results
 - ◆ Examples based on actual experience
 - ◆ Compare to SE artifacts
 - ◆ Understanding of the role of the artifacts in the SoS SE process (e.g. impact analysis)
 - ◆ Basis for SoS management commitment (governance, resourcing, etc)

Provide a concrete vehicle for international collaboration

Definitions

❖ SoS

- A set or arrangement of systems that results when independent and useful systems are integrated into a larger system that delivers unique capabilities

❖ Types of SoS

- Directed
 - SoS objectives, management, funding and authority; systems are subordinated to SoS
- Acknowledged
 - SoS objectives, management, funding and authority; however systems retain their own management, funding and authority in parallel with the SoS
- Collaborative
 - No objectives, management, authority, responsibility, or funding at the SoS level; Systems voluntarily work together to address shared or common interest
- Virtual
 - Like collaborative, but systems don't know about each other

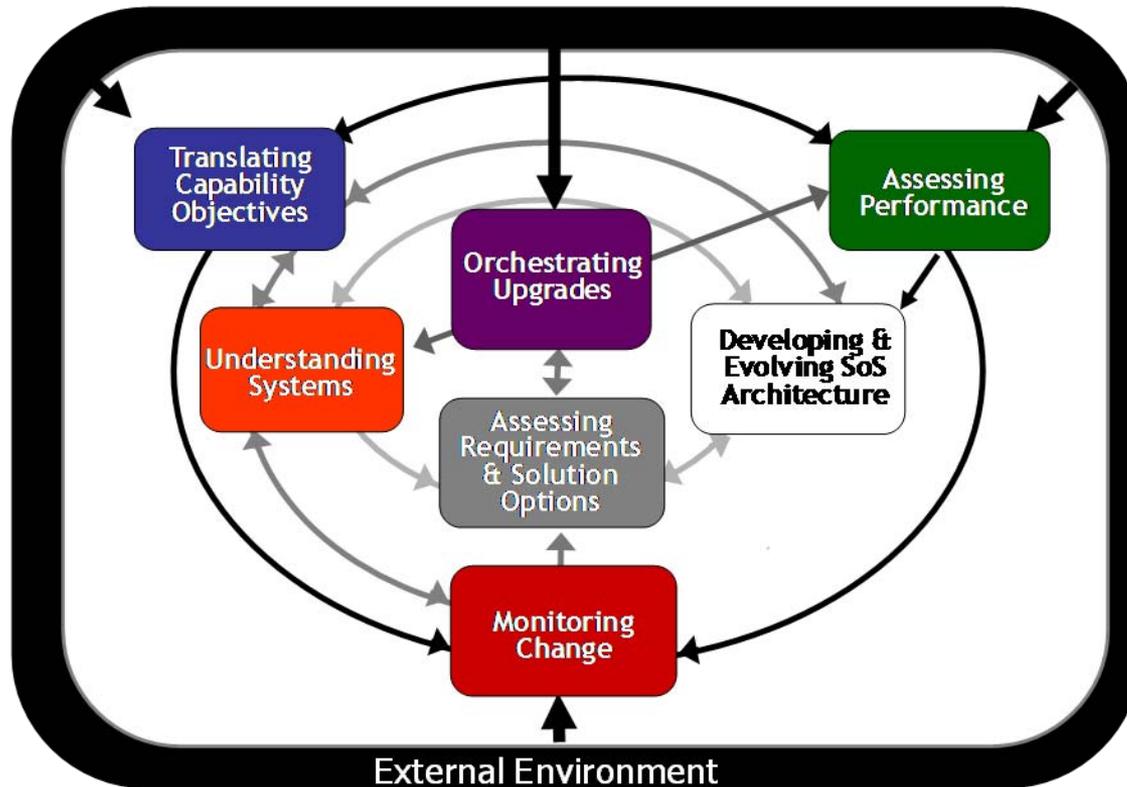
SoS Artifacts Identified and Defined

- ❖ Artifacts which have been **used** in one or more SoS cases
- ❖ Clear **role** in the conduct of SE for SoS is understood
- ❖ Focus is on critical **information** versus documents
- ❖ Comparison with comparable artifacts for systems

Artifacts	SoS Core Element
SoS SE Planning Elements	Cross cutting
SoS Master Plan	
Agreements	
SoS Architecture	
SoS Capability Objectives	Translating Capability Objectives
CONOPS	Understanding Systems
Requirements space for the SoS	
Information about systems which impact capability objectives	
Risks and Mitigations	Monitoring Change
Performance measures and methods	Assessing Performance
Data on performance of the SoS	Addressing Rqts & Solution Options
SoS Technical Baselines	
Technical Plan(s)	
Integrated Master Schedule	Orchestrating Upgrades

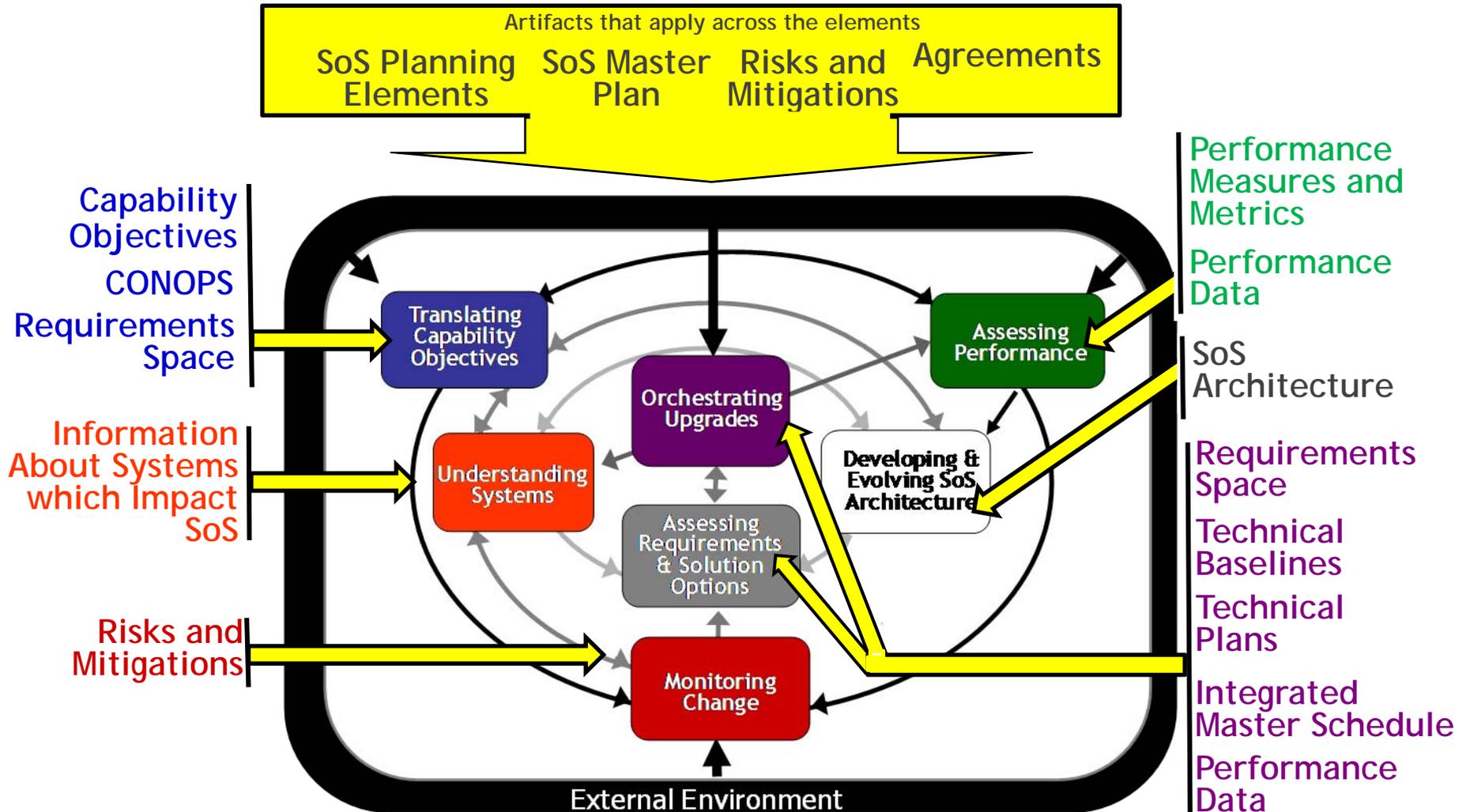
Core Elements of SoS SE

“Trapeze Chart”



Artifacts

In the Context of the Core Elements of SoS SE



Cross-Cutting Artifacts (2 of 5)

Artifacts that apply across the elements

Artifact	Producer/User Context	Use
SoS Planning Elements Key elements include (1) battle rhythm or pacing of SoS upgrades, (2) organization structures and decision processes, and (3) technical reviews	<ul style="list-style-type: none"> Developed and evolved by the SoS SE team with SE teams from systems Used by the full range of SoS participants to understand overall SoS SE process 	<ul style="list-style-type: none"> Provide the structure and process for SE for the SoS much as a System Engineering Plan (SEP) does for an acquisition program Provide the basic SE rules of engagement for the SoS

Artifact	SoS	System
SoS Planning Elements	<ul style="list-style-type: none"> Focus is on determining rhythm, organizational structure, technical reviews, and decision processes across SoS evolution. Ability and willingness of constituent systems to support SoS plans is an important consideration. 	<ul style="list-style-type: none"> Focus is on an individual system typically part of the acquisition process; takes the form of an SE Plan.

Cross-Cutting Artifacts (3 of 5)

Artifact	Producer/User Context	Use
<p>SoS Master Plan</p> <p>Integrated plan provides top level view across multiple SoS upgrades to implement the SoS evolution strategy; SoS analog to a systems acquisition strategy</p>	<ul style="list-style-type: none"> • Developed and evolved by SoS SE team with system SE teams • Used by SoS SE team, system SE team and SoS stakeholders 	<ul style="list-style-type: none"> • Understand current status and plans of the SoS. • Looks across iterations of the SoS; supports trade-off decisions and adjusting priorities over time

Artifact	SoS	System
<p>SoS Master Plan</p>	<p>Focus is on SoS-level view across multiple increments and touch points for constituent systems. Reflects the SoS evolution strategy. Focus is often on continuous improvement versus achievement of a defined end state.</p>	<p>Focus is typically on individual system and approach to achieve defined end-state. Reflects the system acquisition strategy.</p>

Cross-Cutting Artifacts (4 of 5)

Artifacts that apply across the elements



Artifact	Producer/User Context	Use
Risks and Mitigations	<ul style="list-style-type: none"> • SoS SE team works with system SE teams to capture potential risks associated with SoS capabilities and mitigations for them • Status of risks and their mitigation are updated on a periodic or event-driven basis and tracked by the SoS SE team, system SE teams, and SoS stakeholders 	<ul style="list-style-type: none"> • Understand potential risks, issues, and obstacles to achieving desired capabilities and to guide selections of alternative solutions

Artifact	SoS	System
Risks and Mitigations	<ul style="list-style-type: none"> • Focus is on desired capabilities and undesirable emergent behaviors of the SoS • Includes single system risks or dependencies essential to SoS capabilities and plans 	<ul style="list-style-type: none"> • Focus is on system issues and potential problems • Includes external dependencies that pose special risks

Cross-Cutting Artifacts (5 of 5)

Artifacts that apply across the elements



Artifact	Producer/User Context	Use
Agreements	<ul style="list-style-type: none"> • SoS SE team works with system SE teams to capture potential risks associated with SoS capabilities and mitigations for them • Status of risks and their mitigation are updated on a periodic or event-driven basis and tracked by the SoS SE team, system SE teams, and SoS stakeholders 	<ul style="list-style-type: none"> • Understand potential risks, issues, and obstacles to achieving desired capabilities and to guide selections of alternative solutions

Artifact	SoS	System
Agreements	<ul style="list-style-type: none"> • Focus is on managing relationships among multiple organizations • Agreements support SoS evolution including specific commitments to execute SoS increment development 	<ul style="list-style-type: none"> • Focus is on defining specific system dependencies (e.g. commitments to provide components to a system through Government Furnished Equipment (GFE) or Commercial Off-the Shelf (COTS) components).

Translating Capability Objectives

(1 of 3)

Translating
Capability
Objectives

❖ Translating SoS capability objectives into high level requirements over time

- SoS objectives based on broad capability objectives
- SE team plays strong role in establishing requirements and understanding dynamics of the environment

• Capability Objectives

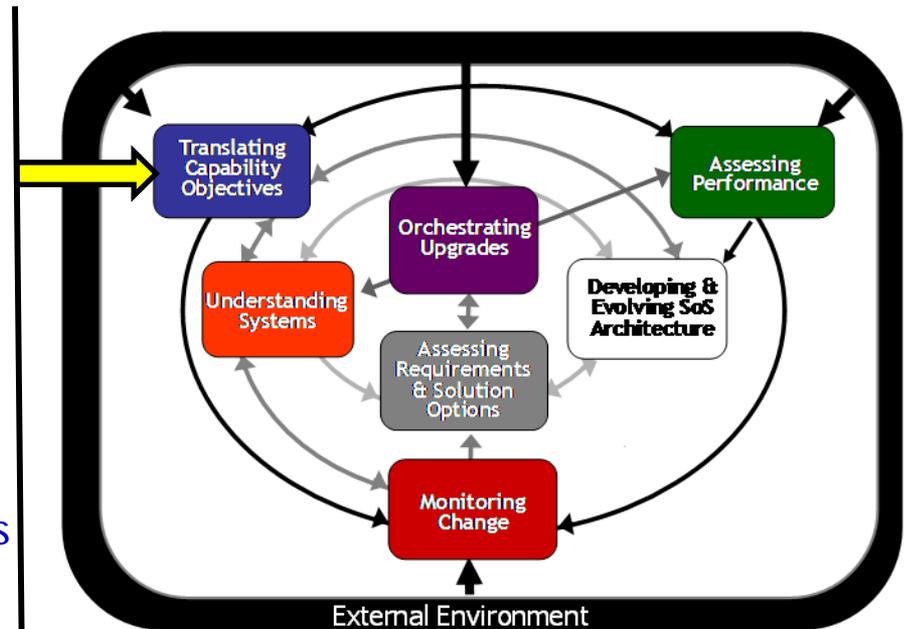
- Statement of top level SoS objectives

• CONOPS

- Describes how functionality of the systems in the SoS are employed in an operational setting

• Requirements Space

- Bounds first order SoS user needs
- Often set of use cases or mission threads
- 'Space' because in an SoS requirements are taken on by systems to support SoS objectives



Translating Capability Objectives

(2 of 3)

Artifact	Producer/User Context	Use
<p>Capability Objectives</p> <p>Top level objectives for the SoS</p>	<ul style="list-style-type: none"> • Authoritative materials (e.g. Charter, Policy) external to SoS • Used by SoS management, stakeholders, and SE teams 	<p>Provide basis for</p> <ul style="list-style-type: none"> • Translating needs into high level requirement • Assessing performance of SoS • Developing an SoS architecture and specific solution options
<p>CONOPS</p> <p>How system functionality will be employed in an operational setting to meet SoS objectives</p>	<ul style="list-style-type: none"> • Developed by the operational users and with active participation from the SoS systems engineers • Used by SoS management and SE teams 	<ul style="list-style-type: none"> • Define the SoS requirements space • Identify aspects of systems which could impact SoS design • Select performance metrics and test environments
<p>Requirements Space</p> <p>Bounds first order SoS user needs Often described as set of use cases or mission threads based on CONOPs</p>	<ul style="list-style-type: none"> • Developed by the SoS SE team with SoS/system operators communities and constituent system SE teams • Used by the SoS and system SE teams 	<ul style="list-style-type: none"> • Determine needed systems information • Compare performance to capability objectives • Develop an SoS architecture • Identify solution options • Develop plan(s) for SoS increment(s) include T&E plans

Translating Capability Objectives

(2 of 3)

Artifact	SoS	System
Capability Objectives	<ul style="list-style-type: none">• Focused on capabilities at the SoS-level• Solution(s) typically require multiple constituent systems• Evolve over time often substantially	<ul style="list-style-type: none">• Addresses a gap in a user capability as defined by formal process
CONOPS	<ul style="list-style-type: none">• Multiple system focus• Often developed after constituent systems have been fielded• Evolves over time, sometimes substantially.	<ul style="list-style-type: none">• Single system focus• Defined when systems acquisition begins
Requirements Space	<ul style="list-style-type: none">• Requirements 'space' versus set of specific requirements• Defined at a level of detail that enables trades among potential and actual constituent systems and interfacing external systems	<ul style="list-style-type: none">• Defined by needs of the operational users of the system and by the threat• Usually articulated as detailed operational requirements or specified technical requirements

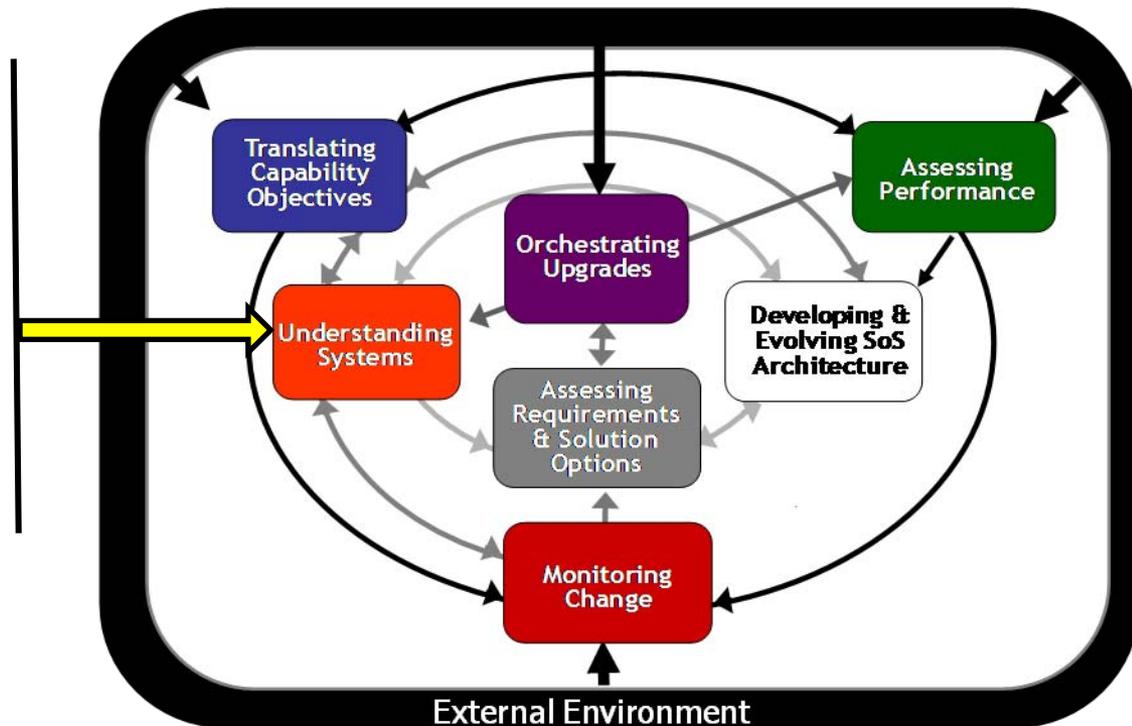
Understanding Systems (1 of 2)

❖ Identifying and understanding the systems that impact SoS objectives

- Focus on components and dynamics vs boundaries
- Extends beyond technical to broader context of management, organizational, development plans, funding, etc.

• Information About Systems which Impact SoS

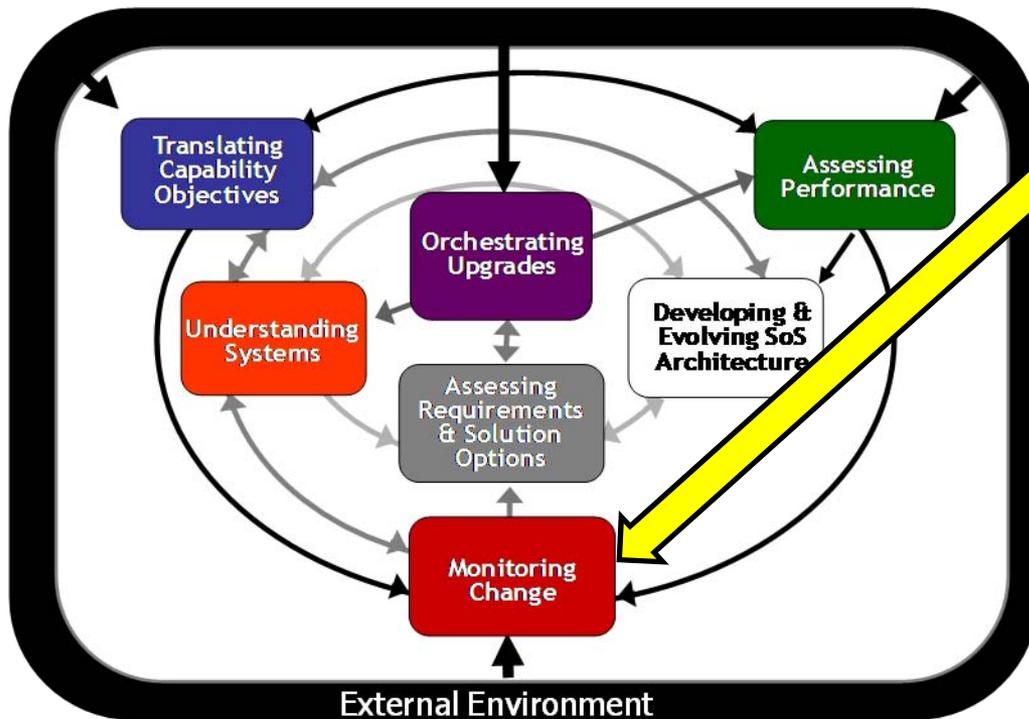
- Both technical and programmatic
- Used as one basis for making trades as the SoS evolves



Monitoring Change

❖ Anticipating and assessing impacts of potential changes on SoS performance

- Given scope of SoS authority, key to SoS SE is identifying and addressing changes in systems and other areas (e.g. threat) which may impact the SoS



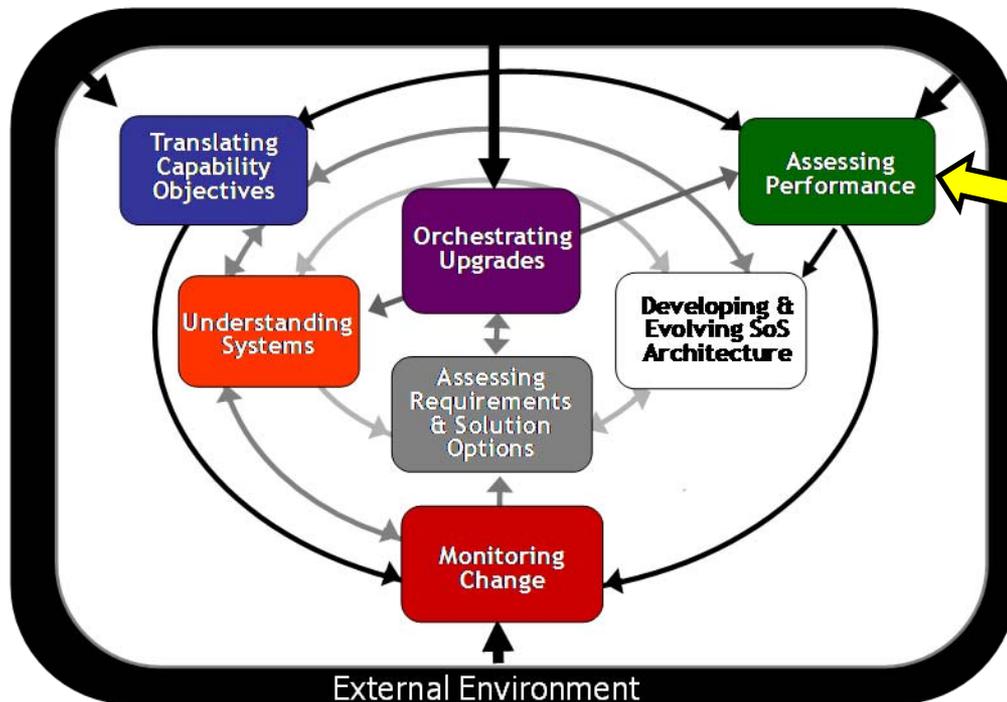
• Risks and Mitigations

- SoS risks often emanate from areas outside the SoS where changes may impact SoS objectives, particularly changes made in the constituent systems to meet system user need
- Monitoring and addressing this type of risk is an important role for the SoS SE

Assessing SoS Performance (1 of 2)

❖ Assessing SoS Performance Against Capability Objectives

- Based on measures of SoS user results applied in different settings (test, exercises, M&S, operations)
- Opportunity to identify changes and emergent behavior



• Performance Measures and Methods

- Basis for assessing overall SoS performance and for continuous improvement

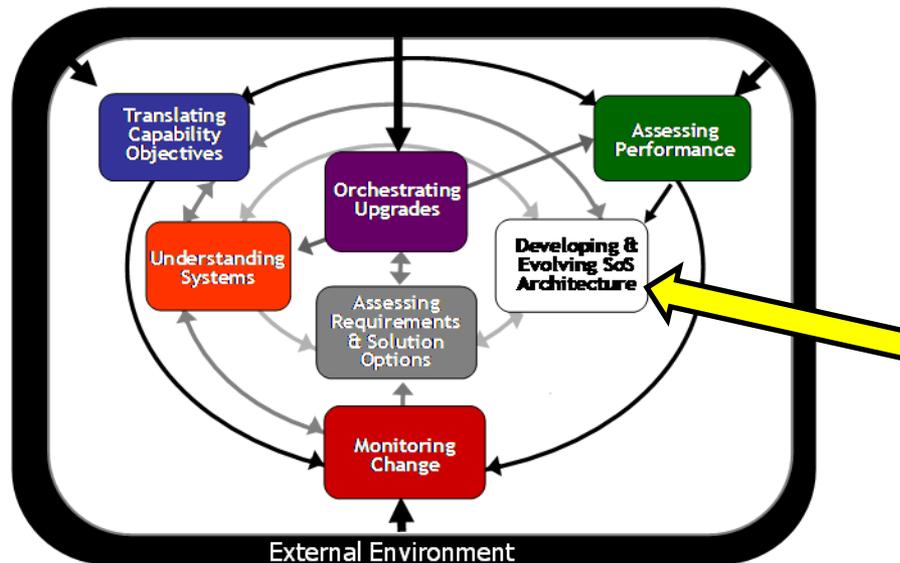
• Performance Data

- Includes data on unanticipated factors
- Gathered from different environments
- Assess progress toward objectives and identify areas needing attention

Developing and Evolving SoS Architecture (1 of 3)

❖ Developing and evolving SoS architecture

- This includes
 - Systems, functions and relationships and dependencies, both internal and external
 - End-to-end functionality, data flow and communications within the SoS
- Provides the technical framework for assessing options and implications for meeting requirements over time
 - Persistence, tolerance for change



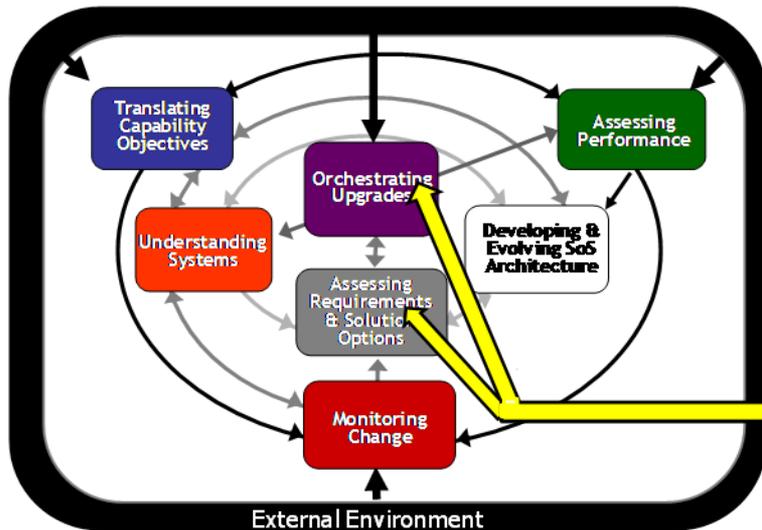
• SoS Architecture

- Defines the way the systems work together and addresses the implementation of individual systems only when the functionality is key to SoS
- Includes systems, key SoS functions supported by the systems, and relationships and dependencies as well as end-to-end functionality, data flow, and communications protocol

Addressing Requirements and Solution Options and Orchestrating Upgrades (1 of 4)

Orchestrating Upgrades

Assessing Requirements & Solution Options



For each iteration of SoS evolution

- **Requirements Space**
 - Basis for identifying areas to be addressed in SoS upgrade
- **Technical Baselines**
 - Requirements, allocated, and product baselines for the SoS and reference system baselines for each upgrade cycle
- **Technical Plans**
 - Follow the principles for technical planning for systems: critical event-driven reviews and risks throughout
- **Integrated Master Schedule**
 - Key points in the technical plans which need to be addressed in orchestrating SoS development
- **Performance Data**
 - Basis for assessing progress

In Conclusion

- ❖ The analysis of the initial set of artifacts provides the basis on which the SoS SE can identify critical knowledge elements and knowledge points in executing SE for SoS
- ❖ Next steps
 - ❖ Developing a 'practitioner view' of SoS to support understanding role of artifacts in executing SE for SoS
 - ❖ Both practitioner view and artifacts are being reviewed with practitioners
 - ❖ Develop ways to present and employ key artifact data to effectively characterize and engineer SoS
- ❖ Continued international partnership to leverage a broad set of diverse SoS experiences to support furthering understanding of systems engineering of SoS

Backup Slides

Understanding Systems (2 of 2)

Artifact	Producer/User Context	Use
<p>Information About Systems which Impact SoS</p> <p>Includes both programmatic and technical information</p>	<ul style="list-style-type: none"> • Collected and organized by the SoS SE team • Content is produced by multiple stakeholders of both the SoS and constituent systems 	<ul style="list-style-type: none"> • Used as the basis for trades as the SoS evolves <ul style="list-style-type: none"> • Assists the SoS SE to understand the components of the SoS, including technical, organizational, fiscal, and planning perspectives. • Provides the basis for <ul style="list-style-type: none"> • Developing and evolving the SoS architecture • Monitoring and assessing changes to both the SoS and individual systems • Developing solution options

SoS	System
<ul style="list-style-type: none"> • Focus is on desired capabilities and undesirable emergent behaviors of the SoS • Includes single system risks or dependencies essential to SoS capabilities and plans 	<ul style="list-style-type: none"> • Focus is on system issues and potential problems • Includes external dependencies that pose special risks

Assessing Performance (2 of 2)

Artifact	Producer/User Context	Use
SoS Performance Measures and Methods	<ul style="list-style-type: none"> Created by SoS and system SE teams and the test and evaluation (T&E) community 	<ul style="list-style-type: none"> Structure events to generate the data needed Assess status and progress in meeting SoS capability objectives
SoS Performance Data	<ul style="list-style-type: none"> Gathered from different environments by SoS SE and T&E teams and operators to assess progress toward achieving SoS capability objectives Along with data on unanticipated factors observed during performance analysis 	<ul style="list-style-type: none"> Assess impact of changes and to identify areas needing more attention (new gaps/requirements) Provide feedback on architecture implementation variability; factors impacting capability; and additional capability needs based on operational user experience Serves as a basis for addressing requirements and orchestrating SoS upgrades

SoS	System
<ul style="list-style-type: none"> Focus is on desired capabilities and undesirable emergent behaviors of the SoS Includes single system risks or dependencies essential to SoS capabilities and plans 	<ul style="list-style-type: none"> Focus is on system issues and potential problems Includes external dependencies that pose special risks

Developing and Evolving SoS Architecture (2 of 3)

Artifact	Producer/User Context	Use
<p>SoS Architecture Defines the way the systems work together and addresses the implementation of individual systems only when the functionality is key to SoS</p>	<ul style="list-style-type: none">• SoS SE team defines the desired approach to organize existing and newly developed systems working with SE teams for the systems• SoS and system SE teams use the architecture	<ul style="list-style-type: none">• Provides framework for developing SoS solutions• Offers a shared representation of the SoS technical framework used to inform and document decisions and guide evolution of the SoS

Developing and Evolving SoS Architecture (3 of 3)

Artifact	SoS	System
Architecture	<ul style="list-style-type: none">• Shared framework primarily aimed at informing analysis and decisions for developing or evolving SoS• Context for understanding relationships among systems and developing solution options• Key constituent systems information, connectors and protocols used to communicate and/or synchronize processing across the constituents<ul style="list-style-type: none">• Key data elements/structures that cross interfaces• Key data conversions to facilitate data sharing and communications between constituents	<ul style="list-style-type: none">• Framework for analyzing and making decisions on system development and interfaces with external systems• Includes<ul style="list-style-type: none">• Information about system's top level components (i.e. sub-systems)• Connectors between the components• Protocols used to communicate between the components and synchronize processing across the components• Key data elements/structures that cross interfaces between the components and any interfacing external systems

❖ SoS Requirements and Solution Options

- Requirements addressed at both SoS & systems
- Recommend SoS requirements based on both priority and practicality
- SoS and system SE teams identify and assess options
- Result is plan for development for next increment

❖ Orchestrating SoS Upgrades

- Upgrades implemented by systems under system SE teams
- SoS SE team plans, facilitates, integrates and tests upgrades to the SoS
- Development based on incremental approaches (bus stop, wave) which accommodate asynchronous system developments

Addressing Requirements and Solution Options and Orchestrating Upgrades (3 of 4)

Artifact	Producer/User Context	Use
<p>Technical Baselines Requirements, allocated, and product baselines for the SoS and reference system baselines</p>	<ul style="list-style-type: none"> Developed for each SoS increment by SoS SE teams working with system SE teams Used by these teams to guide and manage SoS incremental evolution 	<ul style="list-style-type: none"> Plan and orchestrate updates to the SoS through changes in the systems SoS level maintained by SoS SE and system baselines maintained by systems
<p>Technical Plans Follow the principles for technical planning for systems, paying attention to defining critical event-driven reviews and risks throughout</p>	<ul style="list-style-type: none"> Developed for each SoS increment by SoS SE teams working with SE teams of the systems Used by SoS and systems managers and SE teams as well as T&E community 	<ul style="list-style-type: none"> Guide activities and document agreements on changes to be made in an SoS increment(s) Track implementation Identify changes/issues in implementation
<p>Integrated Master Schedule Key points in the technical plans which need to be addressed in orchestrating SoS development</p>	<ul style="list-style-type: none"> Developed for each SoS increment by SoS SE teams working with SE teams of the systems Used by the SoS and system SE teams 	<ul style="list-style-type: none"> Monitor key points across elements of the SoS for an increment(s)

Addressing Requirements and Solution Options and Orchestrating Upgrades (4 of 4)

Orchestrating Upgrades

Assessing Requirements & Solution Options

Artifact	SoS	System
Technical Plans	<ul style="list-style-type: none">• Focus is on SoS-level description plus identification of constituent system baselines that are part of the SoS baseline	<ul style="list-style-type: none">• System detailed artifacts/components that comprise the system baseline
Technical Baseline	<ul style="list-style-type: none">• Focus is on planning the implementation of changes to constituent systems to execute an SoS increment	<ul style="list-style-type: none">• Focuses on implementation of changes to the system, including those required for the system to interface with external elements
Integrated Master Schedule	<ul style="list-style-type: none">• Set of SoS SE activities and milestones plus key single system activities and milestones that are driving SoS critical path• Focus is on key synchronization points among SoS constituents and pointers to development schedules of constituent systems for the current SoS increment	<ul style="list-style-type: none">• Detailed list of development activities, milestones, and associated schedule for the system