Key System of Systems Engineering Artifacts to Guide Engineering Activities

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Abstract

The recent Department of Defense (DoD) guidebook, *Systems Engineering for Systems of Systems*, analyzed 18 systems of systems (SoSs) and characterized SoS systems engineering (SE) using seven core elements, then expanded this research effort by identifying key engineering artifacts that are used to guide the SoS engineering activities. These key artifacts are used to capture and convey information to the various engineering teams both at the SoS and constituent system level as well as to guide cross-cutting engineering activities such as overall SoS performance, security, and flexibility to evolve quickly to meet new challenges.
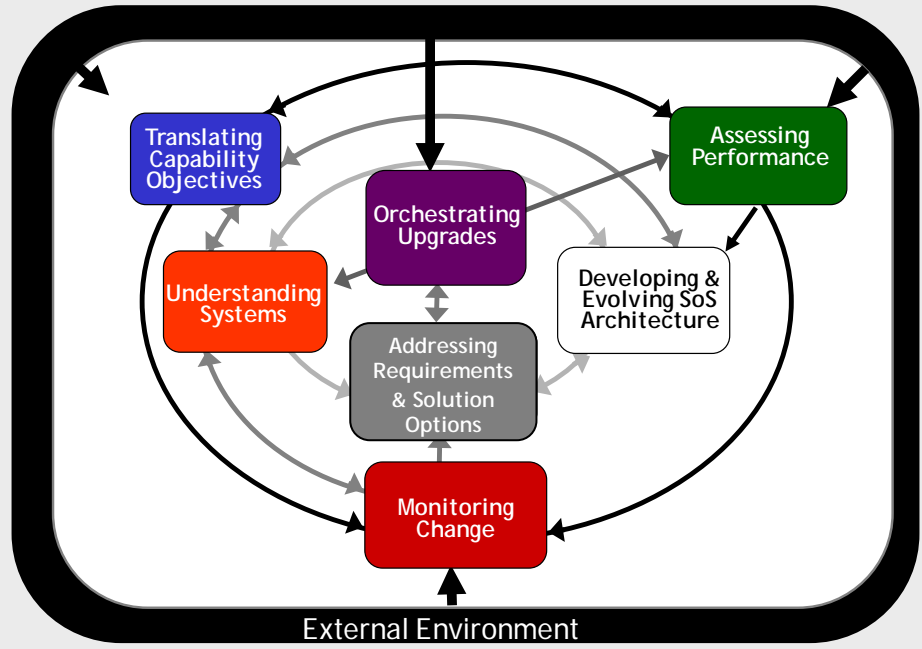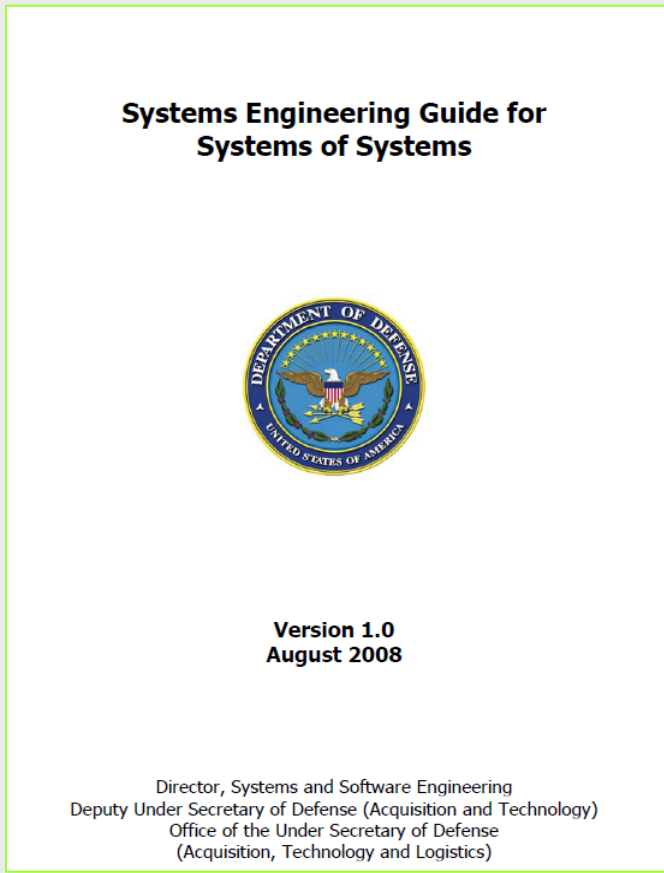
This presentation reviews core SoS SE artifacts and how they are employed in the implementation of SoS SE. An 'implementers view' of SoS SE is presented showing how SoS SE artifacts support each step in SoS SE implementation.

Background and Purpose

- Background
  - DoD SoS SE Guide provides a foundation for SoS SE
  - Current efforts have focused on translating guidance into 'implementers' view
  - Next step is to understand information needs critical to successful SoS SE decision making

- Purpose
  - Present an 'implementers view' of SoS SE ['the wave model']
  - Show how artifacts support engineering activities across the SoS SE implementation

- Key concepts
  - *SoS Artifact:* work products developed/composed from various sources by the SoS SE team, configuration managed at the SoS level, and used/consumed by SEs at both the SoS and single system level in the process of developing, maintaining, enhancing, deploying, and assessing SoS capabilities
  - *Relationship between SoS and single system artifacts:* SoS SE engineers tend to use familiar SE artifacts, but have evolved them to support SoS needs

Foundations

Systems Engineering Guide for Systems of Systems

Version 1.0
August 2008

Director, Systems and Software Engineering
Deputy Under Secretary of Defense (Acquisition and Technology)
Office of the Under Secretary of Defense
(Acquisition, Technology and Logistics)

Trapeze Model*

Translating Capability Objectives

Assessing Performance

Orchestrating Upgrades

Understanding Systems

Developing & Evolving SoS Architecture

Addressing Requirements & Solution Options

Monitoring Change

External Environment
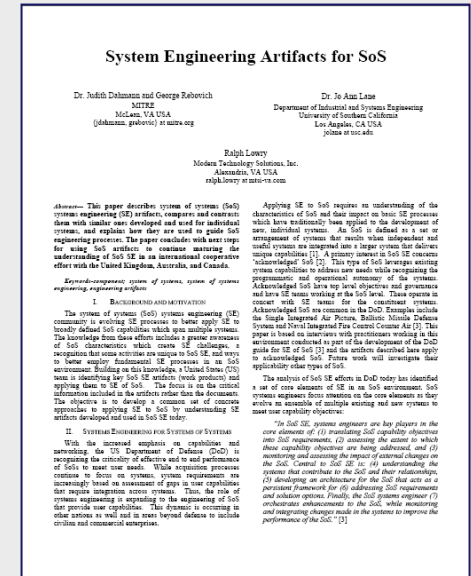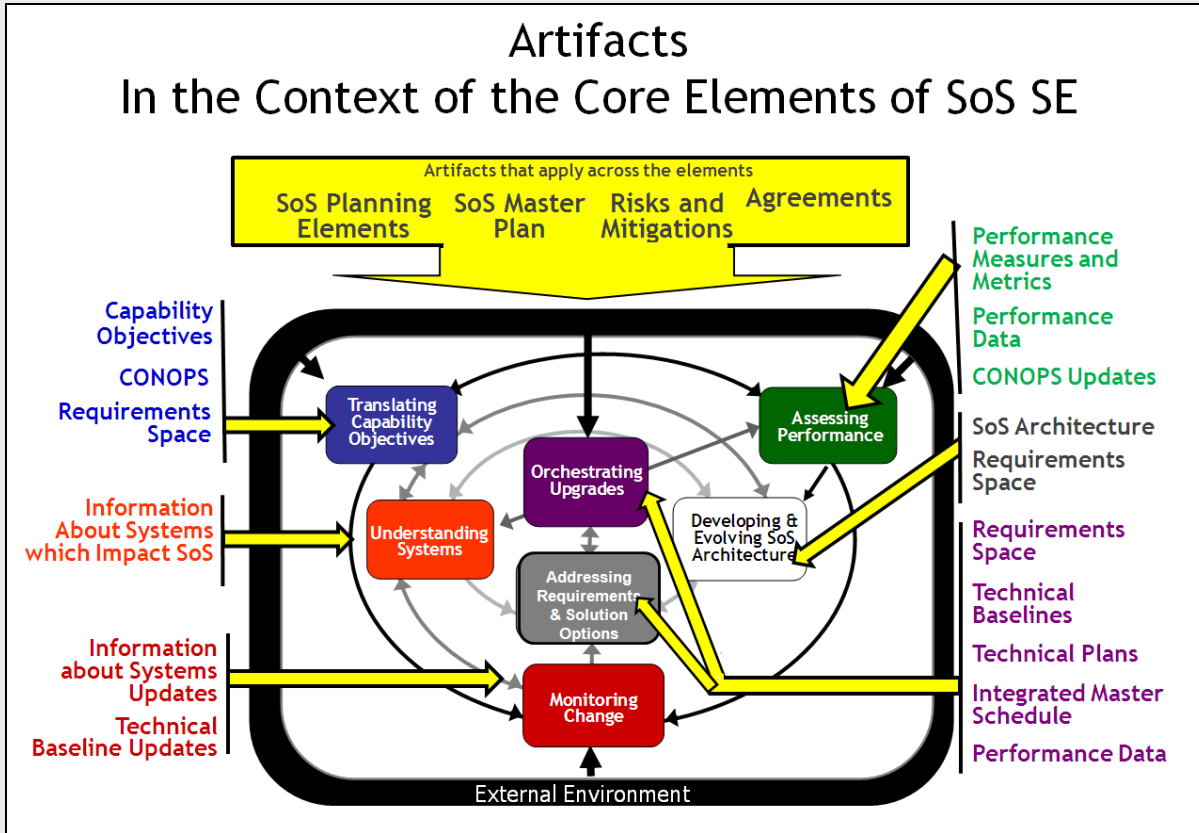
SE Model for SoS Based on
7 Core Elements of SoS SE

* Department of Defense, Systems Engineering Guide for System of Systems, Version 1.0, 2008.

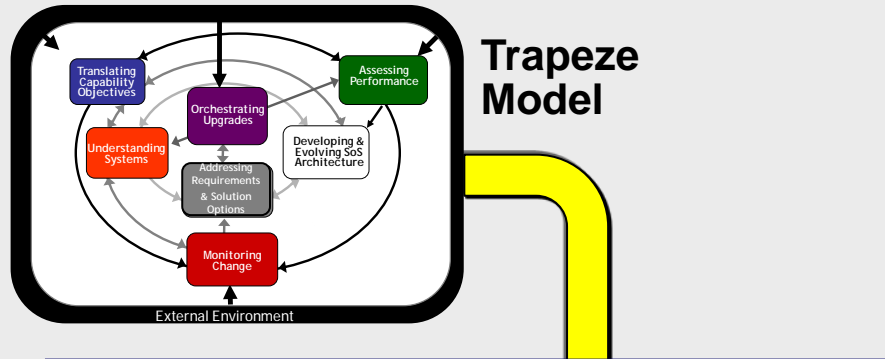## Next Step: Provide guidance for implementation

SoS SE Artifacts

Artifacts
In the Context of the Core Elements of SoS SE

Described in 2010 IEEE Systems Conference Paper

SoS SE Artifacts Developed as Part of an International SoS SE project under The Technical Cooperation Program (TTCP)

Practitioners View of SoS SE: Wave Model
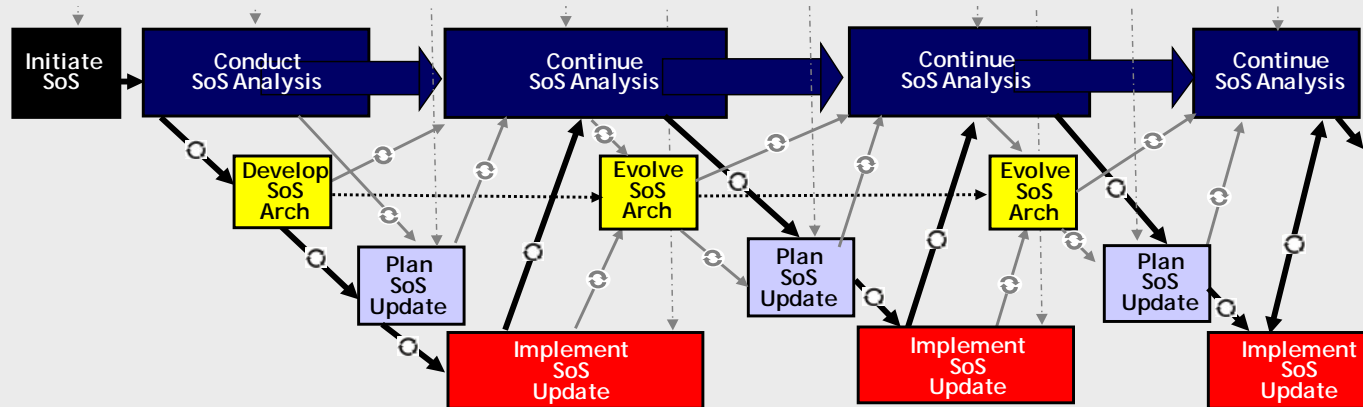

Trapeze Model

Wave Model

- Trapeze Model
  - Presents the core elements of SoS SE and relationships
  - Provides a good 'conceptual' view of SoS SE
  - Not very useful to practitioner to help chart an implementation approach

- Wave Model
  - 'Unwinds' the trapeze model
  - Provide a view of SoS SE in terms of series of major steps in implementing an SoS SE process
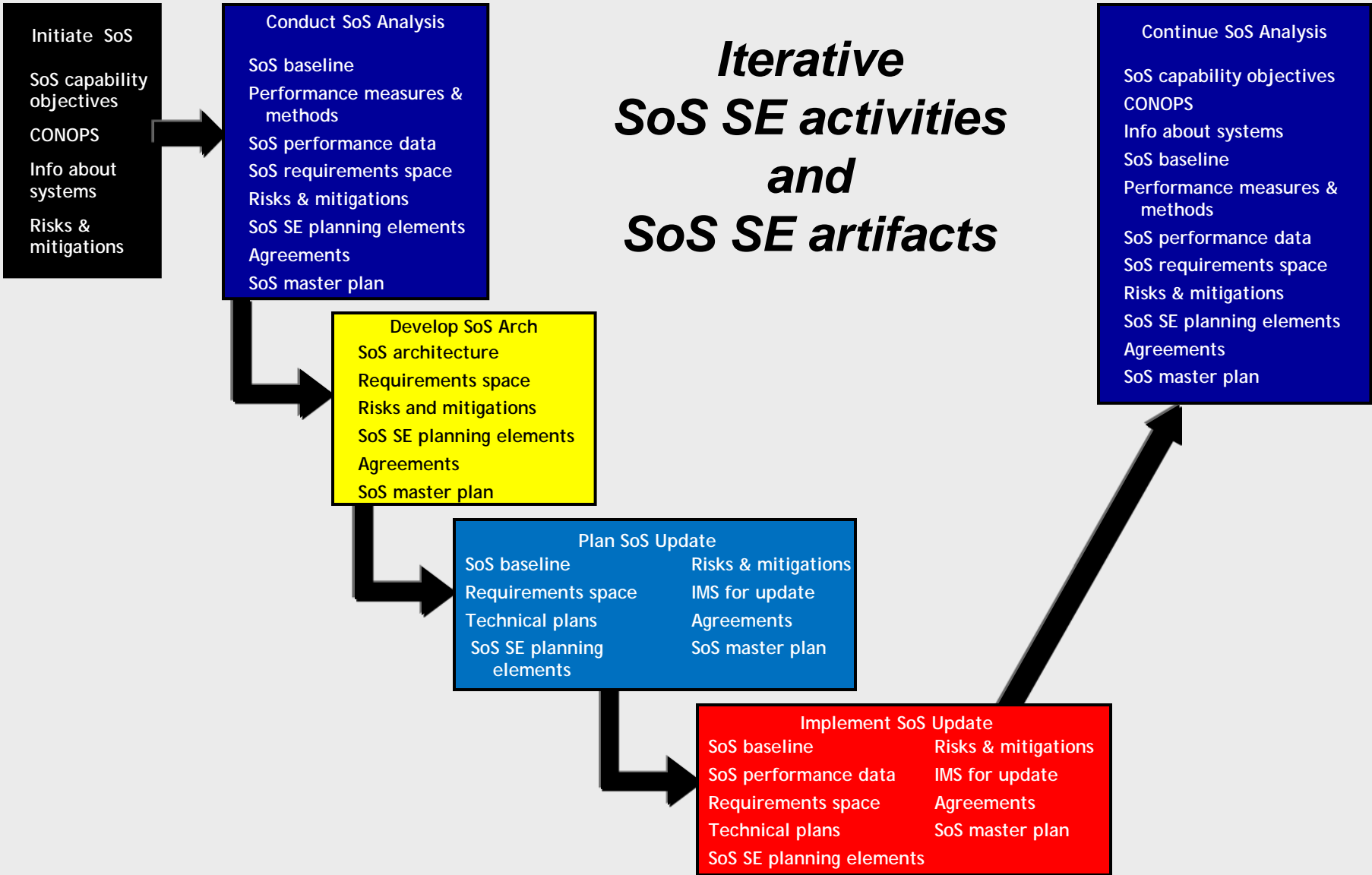
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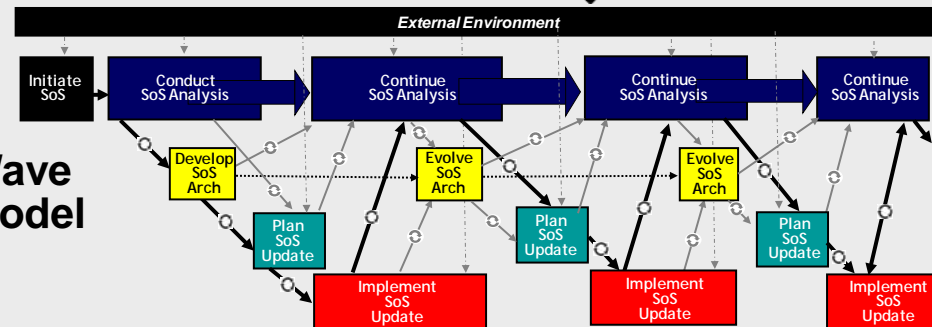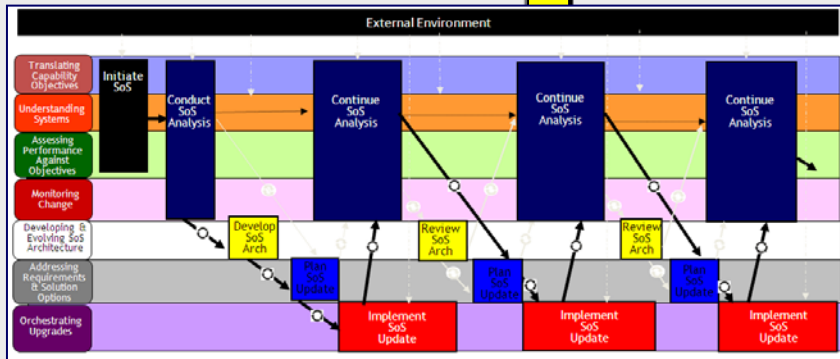
Wave Model Elements

- **Initiate SoS:**

    Provides foundational information to initiate the SoS

- **Conduct SoS Analysis:**

    Provides analysis of the 'as is' and basis for SoS evolution

- **Develop SoS Architecture:**

    Develops/evolves the persistent technical framework for addressing SoS evolution and a migration plan identifying risks and mitigations

- **Plan SoS Update:**

    Evaluates SoS backlog , priorities, and options to define plans for the next SoS upgrade cycle

- **Implement SoS Update:**

    Oversees system implementations and plans/conducts SoS level testing, resulting in a new SoS product baseline

- **Continue SoS Analysis:**

    Ongoing SoS analysis revisits artifacts on the state and plans for the SoS as the basis for ongoing SoS evolution
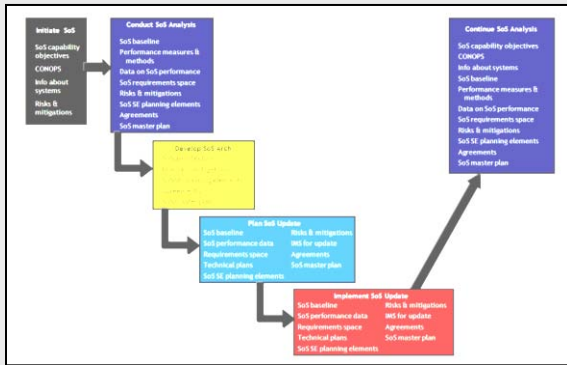
Artifacts Created or Changed at Each Step

Initiate SoS

SoS capability objectives

CONOPS

Info about systems

Risks & mitigations

Conduct SoS Analysis

SoS baseline

Performance measures & methods

SoS performance data

SoS requirements space

Risks & mitigations

SoS SE planning elements

Agreements

SoS master plan

*Iterative
SoS SE activities
and
SoS SE artifacts*

Continue SoS Analysis

SoS capability objectives

CONOPS

Info about systems

SoS baseline

Performance measures & methods

SoS performance data

SoS requirements space

Risks & mitigations

SoS SE planning elements

Agreements

SoS master plan

Develop SoS Arch

SoS architecture

Requirements space

Risks and mitigations

SoS SE planning elements

Agreements

SoS master plan

Plan SoS Update

SoS baseline | Risks & mitigations

Requirements space | IMS for update

Technical plans | Agreements

SoS SE planning elements | SoS master plan

Implement SoS Update

SoS baseline | Risks & mitigations

SoS performance data | IMS for update

Requirements space | Agreements

Technical plans | SoS master plan

SoS SE planning elements

Provide information needed to progress through the process

Artifact Logical Groups

- **System-related artifacts**
  - Information about systems that impact SoS capability objectives

- **SoS management and planning artifacts**
  - SoS risks and mitigations
  - Plans
    - SoS system engineering planning elements
    - Master plan
    - Technical plan(s)
    - IMS
  - SoS-level agreements

- **SoS capability-related artifacts**
  - SoS capability objectives
  - SoS-level CONOPS
  - Requirements space

- **SoS technical artifacts**
  - SoS architecture
  - SoS performance-related artifacts
    - Performance measures and methods
    - Performance data
  - SoS technical baselines

SoS Capability Related Artifacts

- **SoS capability objectives**: a statement of top level objectives for the SoS that describes the capabilities needed by the user, ideally based on some definitive or authoritative materials

- **SoS-level CONOPS:** describes how systems in the SoS will be employed in an operational setting and is developed collaboratively by the operational users and the systems engineers to describe the way users plan to operate and use material assets to achieve the objectives

- **Requirements space:** identifies the needed SoS functions independent of the systems within the SoS for various capability options; based upon the SoS capability/requirements backlog and SoS problem reports

Artifact	Initiate SoS	Conduct SoS Analysis	Develop SoS Arch	Plan SoS Update	Implement SoS Update	Continue SoS Analysis
SoS capability objectives	*Establishes* to identify critical need(s) that provide justification for an acknowledged SoS	*Uses* for initial analysis	*Uses indirectly* through performance-related artifacts	*Uses* to drive evaluation of alternatives and refine solution requirements	*Uses* to focus SoS-level testing and assessment	*Updates* to include new or changing needs; *uses* to continue SoS assessment
SoS-Level CONOPS	*Creates* to provide context for critical need(s). Initial SoS CONOPS may be limited and focus only on current capabilities of interest	*Uses* as part of initial analysis	*Uses indirectly* through performance-related artifacts	*Uses* to guide evaluation of alternatives and refine solution requirements	*Uses* to guide SoS-level testing and assessment	*Updates* to include changes to ways existing capabilities are employed and to incorporate new changes; *uses* to continue SoS assessment
SoS requirements space		*Establishes* as part of the initial analysis	*Updates* as new architecture needs are identified	*Identifies and tags* requirements and problem reports in the requirements space to be implemented/fixed in the upgrade being planned	*Updates* as capabilities, requirements, and problem fixes are implemented and tested	*Updates* as new capability needs and problems are identified

SoS Technical Artifacts

- **SoS architecture**: persistent technical framework in which the systems interoperate as a system of systems; identifies SoS systems, key SoS functions supported by the systems, and relationships and dependencies as well as end-to-end functionality, data flow, and communications protocols

- **Performance measures and methods:** set of measure definitions and methods for collecting the measures that are a) traceable to the capability objectives established for the SoS and b) the basis for assessing overall performance of the SoS and guiding "continuous SoS improvement"

- **Performance data:** actual data collected to assess progress toward achieving SoS capability objectives

- **SoS technical baselines:** Consists of requirements, allocated, and product baselines at the SoS level

Artifact	Initiate SoS	Conduct SoS Analysis	Develop SoS Arch	Plan SoS Update	Implement SoS Update	Continue SoS Analysis
SoS architecture			*Documents* initial "as is"; *updates* over time. Both "as is" and "to be" maintained	*Uses* to plan updates	*Uses* to guide implementation	*Uses indirectly* as part of SoS analysis
Performance measures and methods		*Defines* initial set of measures and methods	*Uses* to identify and "build in" opportunities to measure architecture performance	*Uses* to identify and plan mechanisms to measure SoS performance	*Uses* to "build in" mechanisms to measure SoS performance	*Updates* as SoS evolves
SoS performance data		*Captures* initial data; initializes repository and performs initial analysis	*Uses* to assess architecture and guide its evolution	*Uses* results of analyses to guide planning for the next update cycle	*Updates* with data generated & captured in testing; *uses* results of analyses to guide next update cycle	*Updates* with data captured in performance assessments; *uses* results of analyses to identify problems for resolution or new requirements for the backlog
SoS technical baselines		*Creates* initial SoS product baseline ("as is" baseline)	*Uses* to guide architecture evolution	*Creates* requirements and allocated baselines for update from requirements in the SoS requirements space	*Creates* product baseline for update based on requirements that were implemented in the update cycle	*Updates* product baseline based on non-SoS constituent system changes identified through monitoring activities; *uses* previous baselines to assess current status of SoS

System—Related Artifacts

- **Information about systems that impact SoS objectives**: programmatic and technical information about systems that reflects their ability to support SoS short and long term SoS capability objectives; used to assess various SoS capability options

Artifact	Initiate SoS	Conduct SoS Analysis	Develop SoS Arch	Plan SoS Update	Implement SoS Update	Continue SoS Analysis
Info about systems	*Captures* initial information for analysis	*Uses* to guide initial analysis activities	*Uses* to evaluate architecture evolution options and to identify potential risks	*Uses* to evaluate and select capability options for current update cycle and to identify potential risks	*Uses* to guide risk monitoring activities	*Updates* to reflect current system status as new releases of the constituent systems are deployed

SoS Management and Planning Artifacts

- **SoS risks and mitigations**: technical and programmatic risks at the SoS level that are identified and managed throughout the SoS SE process over time; may include system-level risks that potentially impact SoS capabilities

- **SoS systems engineering planning elements:** consists of information on general SoS battle rhythm/pacing of SoS upgrades (periodic or event-driven), SoS-level organizational structures, and SoS-level decision-making authorities and responsibilities, and SoS-level processes (e.g., configuration management, technical reviews)

- **SoS-level agreements:** formal and informal agreements that address roles and responsibilities of SoS participants at a broad level as well as specific commitments of participants in a development increment

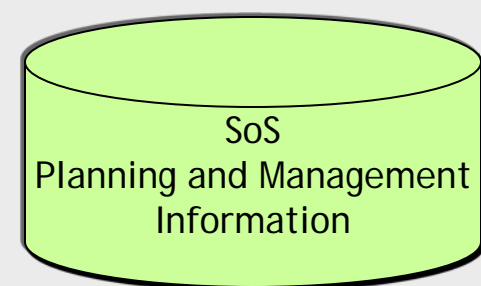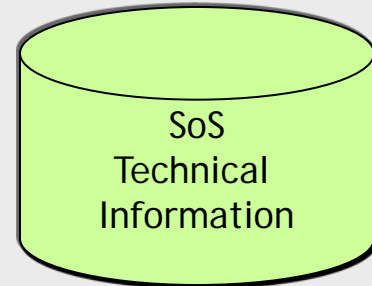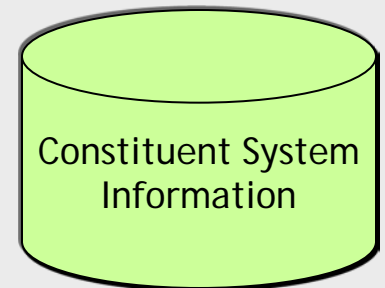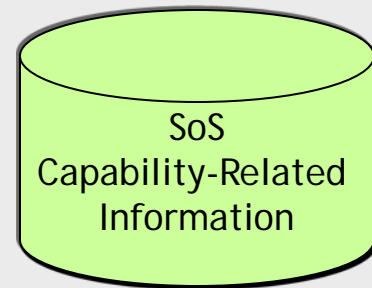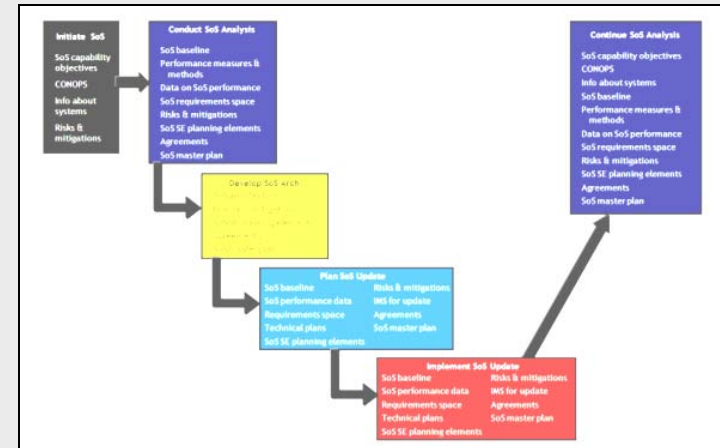| Artifact	Initiate SoS	Conduct SoS Analysis	Develop SoS Arch	Plan SoS Update	Implement SoS Update	Continue SoS Analysis
SoS risks and mitigations	*Captures* initial risks	*Updates* as needed based upon analyses	*Updates* as needed with architecture-related issues	*Updates* as needed with planning-related issues	*Updates* as needed with implementation-related issues	*Updates* as needed based upon analyses
SoS SE planning elements		*Establishes* initial elements	*Updates* as needed as the SoS environment, tools, organizations, and vendors change	*Updates* as needed as the SoS environment, tools, organizations, and vendors change	*Updates* as needed as the SoS environment, tools, organizations, and vendors change	*Updates* as needed as the SoS environment, tools, organizations, and vendors change
Agreements		*Establishes* initial agreements	*Updates* as roles of systems and vendors change over time	*Updates* as roles of systems and vendors change over time	*Updates* as roles of systems and vendors change over time	*Updates* as roles of systems and vendors change over time

SoS Management and Planning Artifacts *(continued)*

- **Master plan:** over-arching integrated plan that provides a top-level view across multiple SoS upgrade cycles; describes the longer-term SoS evolution strategy as well as the acquisition strategy for SoS capabilities that are incrementally developed and deployed

- **Technical plan(s):** includes plans for SoS implementation, integration, and test and are established for each development increment; SoS implementation plans include a high level description of requirements allocated to specific systems for current update cycle, roles and responsibilities for implementation, and details that elaborate upon IMS activities

- **Integrated master schedule:** single-increment IMS tailored to focus on key SoS SE activities, integration points , and milestones and incorporates or links to the system-level IMS elements related to the SoS activities

Artifact	Initiate SoS	Conduct SoS Analysis	Develop SoS Arch	Plan SoS Update	Implement SoS Update	Continue SoS Analysis
SoS master plan		*Establishes* initial plan	*Updates* as needed to reflect architecture evolution	*Updates* as needed to reflect changing priorities and SoS evolution	*Updates* as needed to reflect actual SoS evolution	*Updates* as needed to reflect new needs, changing priorities, and SoS evolution
SoS technical plans			*Evaluates* for potential architecture impacts	*Establishes* for current update	*Updates* as plans are executed and implementation progresses	*Uses* to identify test-related information to support performance assessments
IMS for update			*Uses* to schedule architecture re-assessments as architecture changes are completed	*Establishes* for current update; incorporates SoS-related elements from constituent systems	*Updates* as plans are executed and implementation progresses	*Uses* to update master plan

Summary

- ## SoS SE artifacts:
  Capture and convey information to the various engineering teams both at the SoS and constituent system level as well as to guide cross-cutting engineering activities

- ## 'Wave Model':
  Provides an 'implementers view' of SoS SE

- ## Artifacts support engineering activities across the SoS SE implementation:
  Act as "information repositories" across SE teams at SoS and systems levels and across steps in the SoS SE implementation process

- ## Next Steps:
  Analyze how SoS artifacts are used by the constituent systems

SoS Capability-Related Information

Constituent System Information

SoS Technical Information

SoS Planning and Management Information

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