

Systems of Systems Engineering Measurement Workshop Report

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System of Systems

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

Systems of Systems Engineering

The process of planning, analyzing, organizing, and integrating the capabilities of a mix of **existing and new systems into a system-of-systems capability** that is greater than the sum of the capabilities of the constituent parts

Maier (1998) five key characteristics of SoS

- **Operational independence** of component systems
- **Managerial independence** of component systems
- Geographical distribution
- Evolutionary development processes
- Emergent behavior

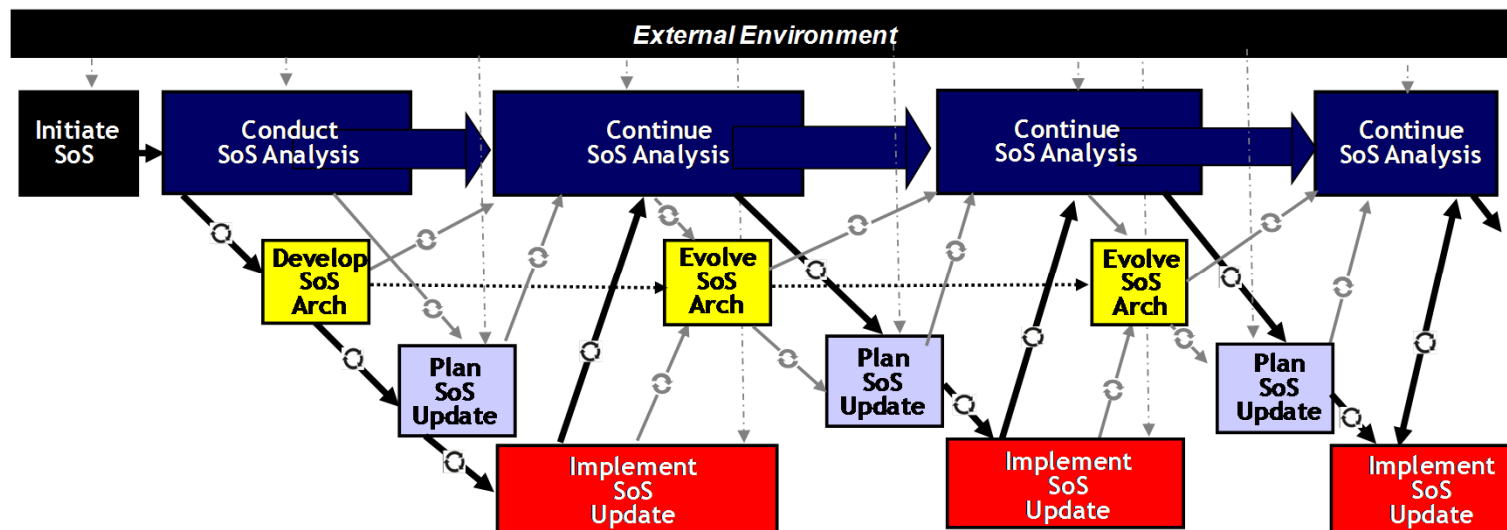


SoSE Lifecycle

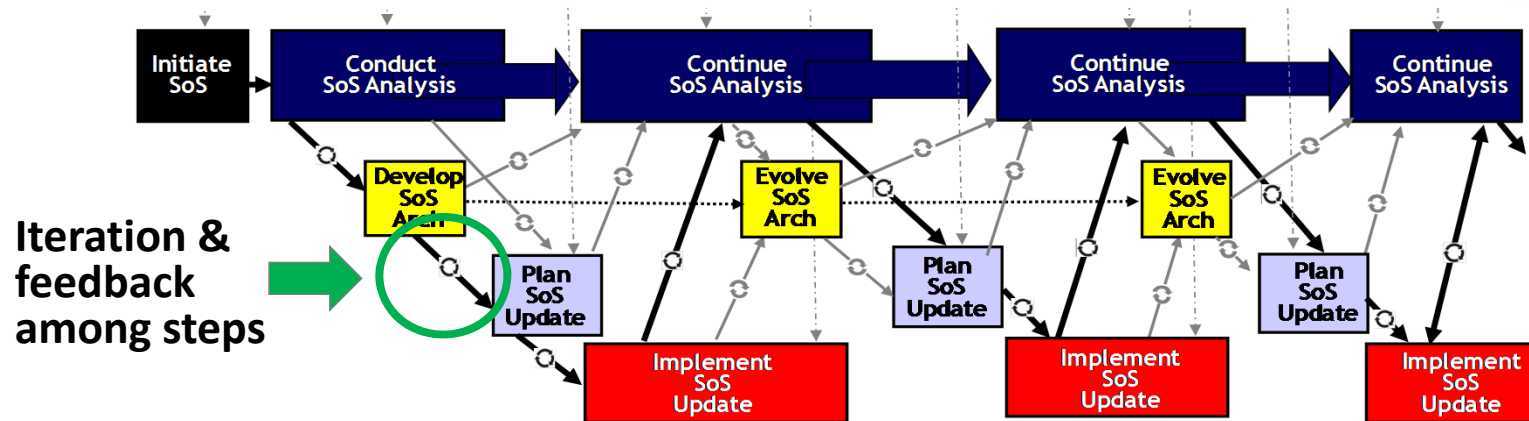


An evolutionary systems engineering approach to evolving complex systems and systems of systems

- Recognizes need for disciplined iterations to systematically address impacts of inevitable change
 - Backbone of ongoing analysis
 - Architecture evolution
 - Overlapping iterations
 - Forward movement with feedback



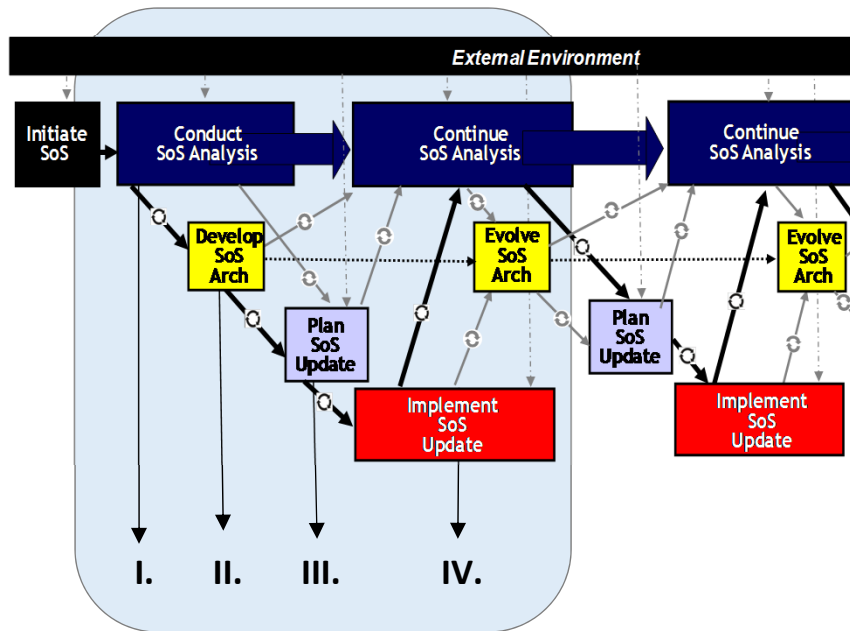
SoS Wave Model Steps



- **Initiate SoS:**
Provides foundational information to initiate the SoS
- **Conduct/Continue SoS Analysis:**
Provides analysis of the 'as is' SoS and basis for its evolution
- **Develop/Evolve SoS Architecture:**
Develops/evolves the persistent technical framework for SoS evolution and a migration plan identifying risks and mitigations
- **Plan SoS Update:**
Evaluates SoS priorities, backlog of SoS changes, 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 the state of and plans for the SoS as the basis for SoS evolution

Focus of the Workshop


Measurement Through the SoS Life Cycle



Measurement at Each Step in the Wave Model

- At each step (I – IV)
 - What are the questions to be addressed?
 - What **measures** would you need?
 - What are the measurement challenges?
 - What ISO/IES/IEEE 15288 SE processes apply?
- Start with Acknowledged SoS
 - Assess what is different for other types

Focus on Acknowledged SoS



Type	Definition
Directed	Directed SoS are those in which the SoS is engineered and managed to fulfill specific purposes. It is centrally managed during long-term operation to continue to fulfill those purposes as well as any new ones the system owners might wish to address. The component systems maintain an ability to operate independently, but their normal operational mode is subordinated to the centrally managed purpose.
Acknowledged	Acknowledged SoS have recognized objectives, a designated manager, and resources for the SoS; however, the constituent systems retain their independent ownership, objectives, funding, development, and sustainment approaches. Changes in the systems are based on cooperative agreements between the SoS and the system.
Collaborative	In collaborative SoS, the component systems interact more or less voluntarily to fulfill agreed-upon central purposes.
Virtual	Virtual SoS lacks a central management authority and a centrally agreed-upon purpose for the system of systems. Large-scale behavior emerges—and may be desirable—but this type of SoS relies upon relatively invisible, self-organizing mechanisms to maintain it.

- Situation where there is a Systems Engineer for the SoS but the SoS level management does not have management control over the constituent systems

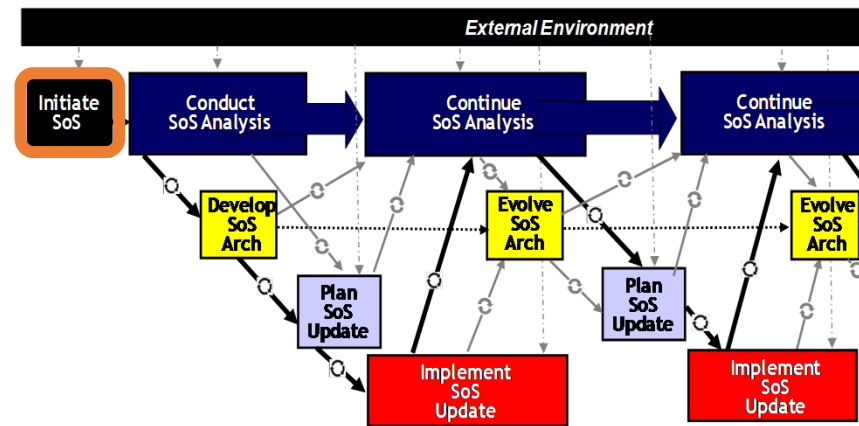
Initiate SoS

Establish foundations for SoS engineering



Provides the basic information needed to start the SoS SE process, including an understanding of the

- SoS objectives
- The key players, their roles and expectations
- Core systems supporting capabilities



Artifacts

- A statement of **top-level objectives for the SoS**
- Identification of key systems currently supporting **the mission or capability**
- A description of how systems in the SoS will be **employed** in an operational setting
- **Programmatic and technical information** about systems that affect SoS capability objectives
- Initial identification of risks

Initiate SoS

Establish foundations for SoS engineering



- Sets the stage for the engineering of the SoS SE
- Critical to have a common understanding of the **top-level objectives for the SoS**
 - Provides the basis for SoSE Technical Measurement
- 15288 Technical Processes
 - Business or mission analysis

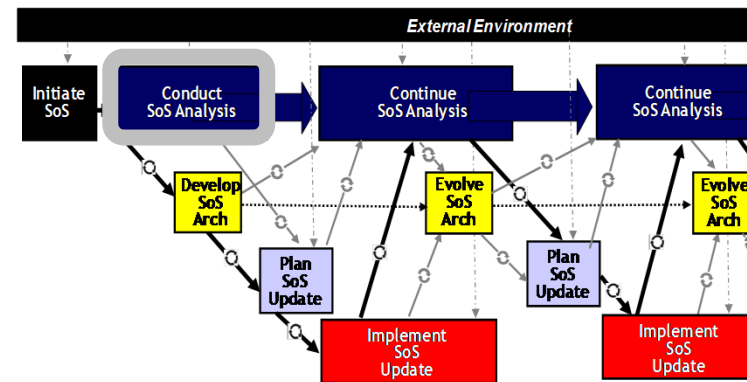
Conduct SoS Analysis

Characterize and analyze current SoS in terms of SoS objectives



Provides an analysis of the “as is” SoS, including

- Describe current SoS
 - CONOPS
 - Systems
 - System relationships
- Assess performance against objectives
 - Expected performance
 - Actual (measured) performance
- Fault isolation
 - Source of gaps



Artifacts

- Capability objectives
- SoS CONOPs
- Constituent system info
- SoS Technical Baselines
- SoS Performance Measures & Methods
- SoS Performance Data
- SoS Requirement Space
- SoS Risks & Mitigations
- SE Planning Elements
- SoS Master Plan
- Agreements

Conduct SoS Analysis

Characterize and analyze current SoS in terms of SoS objectives



- SoS objectives established in the Initiate SoS step used to derive key technical measures
 - SoS Performance Measures & Methods
- Use available data to characterize SoS technical performance against objectives, however it may be necessary to generate new data
 - SoS Performance Data
- Several questions and challenges
 - What data do I have access to that will support relevant measures?
 - Do I have an understanding of how the data was generated by the systems owners, and are the test conditions relevant to the SoS context?
 - Do we have consistency in how the systems are conducting and interpreting measurement?
 - Getting data from the systems owners may be difficult; need cooperative agreement
 - Important to ask for only the data needed and to be clear about why the data is needed and how it will be used
 - SoS objectives may change over time, as well as the understanding of the objectives

Conduct SoS Analysis

Characterize and analyze current SoS in terms of SoS objectives



- 15288 Technical Processes
 - Business or mission analysis
 - Stakeholder needs and requirements definition
 - System requirements definition

Develop SoS Architecture

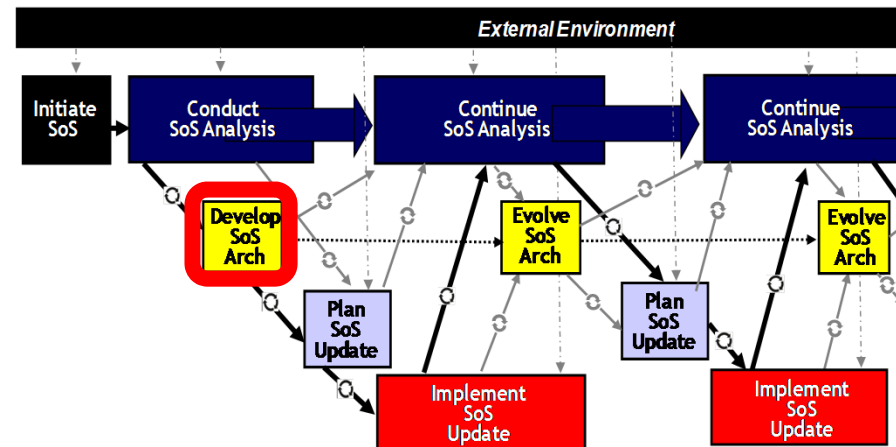
Identifying, analyzing and recommending changes to the SoS architecture



Technical analysis of changes or alternatives to the current architecture to improve SoS effectiveness or performance

- New, added, different or updated systems in current architecture
- New architecture with new ways to organize and employ systems

Produces recommendations for changes



Artifact - SoS Architecture

- Defines the way in which the constituent systems work together
- Includes systems, SoS functions, relationships and dependencies, as well as end-to-end functionality, data flow & communications

Develop SoS Architecture

Identifying, analyzing and recommending changes to the SoS architecture



- The output of this step is the architecture that we want to achieve
- There may be multiple architectures and options to consider
 - New, added, different or updated systems in current architecture
 - New architecture with new ways to organize and employ systems
- There may be existing constituent systems we want to use, but there may not be an architecture that has any of those constituents connected
- Focus is on understanding which systems, or lack of systems, contribute to the SoS-level objectives
- Build on the **SoS Performance Measures & Methods** from last step, compare results for options with baseline, to recommend future architecture
- Many of the same questions and challenges from the last step apply

Develop SoS Architecture

Identifying, analyzing and recommending changes to the SoS architecture



- **15288 Technical Processes**

- Architecture definition
- Design definition
- System analysis

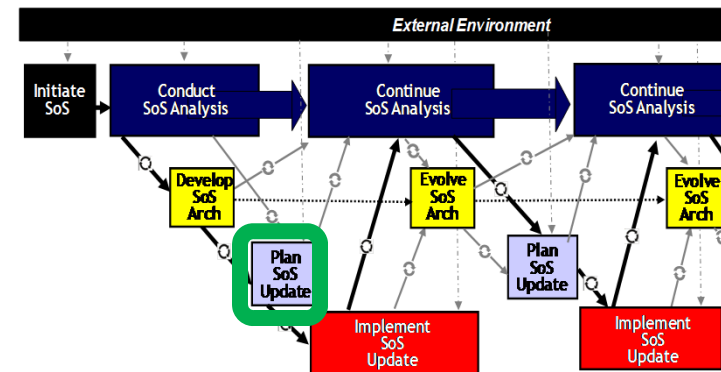
Plan SoS Update

Plan changes to SoS



Plan SoS Update

- Evaluate SoS priorities, options and backlogs
- Define the plan for the next SoS upgrade cycle.



Artifacts

- An allocated baseline
- Risks and mitigations
- Agreements
- Implementation, integration & test plans
- An integrated master schedule (IMS)
- Updated Master Plan and Requirements space

Plan SoS Update

Plan changes to SoS



- Technical management measurement is the focus in this step and the (next) implementation step
- System-level management measures for cost and schedule are applicable at the SoS level,
 - but you may have additional risk in these dimensions—at the SoS level—due to the aggregation of risk across the constituent systems
- System owners may not be willing to share management measures, such as risk
- Technical management measures also pose the challenge of non-standard definitions
 - Need to reconcile differences in the way measures are defined by different system owners
- Best to avoid measures associated with ambiguous terms, such as resilience and robustness
 - Engineers should avoid using these terms in SoS objectives and rather hash out specific, unambiguous objectives that can be measured throughout the SoS lifecycle.

Plan SoS Update

Plan changes to SoS



- 15288 Technical Management Processes
 - Project planning
 - Project assessment and control
 - Decision management
 - Risk management
 - Configuration management
 - Information management
 - Measurement
 - Quality assurance

Orchestrate SoS Update

Plan, implement, and test system changes to SoS



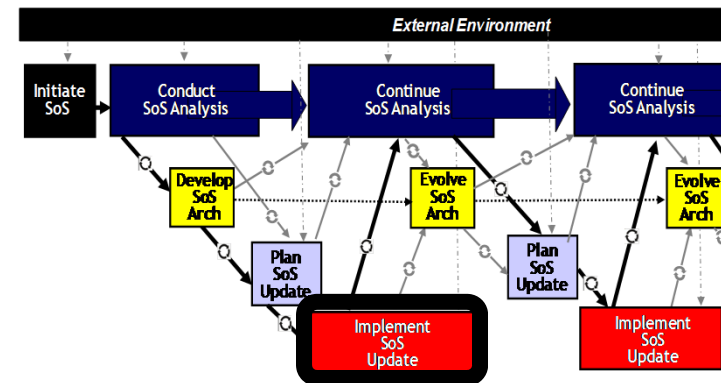
Implement SoS Update

Systems

- Implement and test changes systems
- SoS SE team leads SoS integration and test

SoS SE

- Monitors system implementation
- Conducts SoS testing
- Addresses unanticipated factors encountered



Artifacts

- SoS Test Report
- SoS Technical Plans, Requirements Space, Performance Data
- System Test Reports
- SoS IMS
- SoS Technical Baselines

Orchestrate SoS Update

Plan, implement, and test system changes to SoS



- Measurement at this step is focused on both technical and technical management
- Technical measurement applies to both systems and the SoS
- The scope is larger than at the system level, but overall the SoS technical management measurement approach would be similar.
- Challenges discussed for this step
 - May not be able to test the entire SoS to demonstrate the end-to-end capability -> simulate certain pieces of the architecture
 - Many measures may be technically similar to the system level, but the access to the measurement data is different
 - Agreements play a significant role in how the wave model is carried out, and the terms of the agreements can greatly affect the measurement approach
 - Regression testing is needed to ensure that new systems or updates in the architecture won't break other pieces of the architecture

Orchestrate SoS Update

Plan, implement, and test system changes to SoS



- 15288 Technical Processes
 - Implementation
 - Integration
 - Verification
 - Transition
 - Validation
 - Operation
 - Maintenance
 - Disposal
- 15288 Technical Management Processes
 - Project assessment and control
 - Decision management
 - Risk management
 - Configuration management
 - Information management
 - Measurement
 - Quality assurance

Summary and Discussion

