Systems of Systems Engineering Measurement Workshop

February 26, 2016

Introduction

- Layout the basic characterization of SoS, the SoS engineering workflow and the implications for measurement, with some examples.
- The workshop will then focus on reviewing the PSM measurement approach and how it applies or can be adapted to SoS, including challenges and opportunities.

Structure of the Workshop

- Introduction (30 minutes)
  - Review basic characteristics of SoS
  - Review steps in the SoSE Lifecycle
  - Describe a notional regional transportation example
  - Introduce ICM measurement considerations
    - What questions are addressed?
    - What are prospective indicators?
    - What are some sample base measure?
    - Note if these apply to SoS, system, or both
    - Identify challenges/risks
- Working Sessions (45 minutes each)
  - Review the key activities at key steps in the SoSE lifecycle and address ICM measurement considerations at they apply in each step
    - Conduct SoS Analysis
    - Develop SoS Architecture
    - Develop and Implement SoS Plan
- Plenary review and summary discussion (40 minutes)

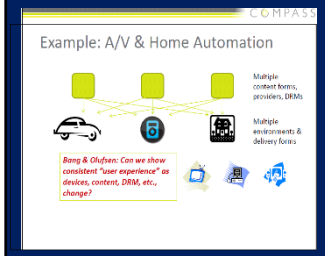
Agenda

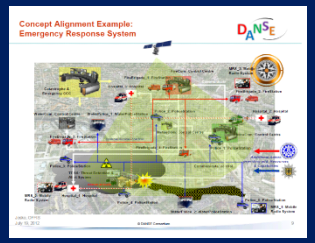
130 - 200	Intro and Setup
200 - 215	Step 1 (Conduct Analysis) Plenary
215 - 245	Step 1 (Conduct Analysis) Small Group
245 - 300	Step 2 (Develop Arch) Plenary
300 - 330	Step 2 (Develop Arch) Small Group
330 - 345	Step 3/4 (Plan/Implement) Plenary
345 - 415	Step 3/4 (Plan/Implement) Small Group
415 - 500	Plenary Summary and Review

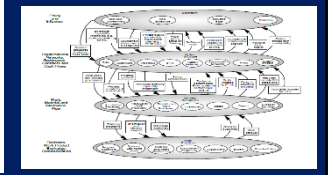
Maier SoS Characterization

- Maier (1998) postulated five key characteristics of SoS:
  - Operational independence of component systems
  - Managerial independence of component systems
  - Geographical distribution
  - Evolutionary development processes
  - Emergent behavior

Scale and Scope of SoS







Technical ----- Socio -Technical ----- Enterprise

SoS Types

SoS Types

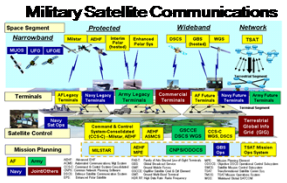
- **Directed**
  - SoS objectives, management, funding and authority; systems are subordinated to SoS
- **Acknowledged**
  - SoS objectives, management, funding and authority; however systems retain their own management, funding and authority in parallel with the SoS
- **Collaborative**
  - No top down 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

- Many SoS exist but are not recognized and develop and evolve without benefit of SE
- Types apply when the SoS is recognized and treated as an SoS
- In reality, most actual SoS are a combination of these types

SoS Domain

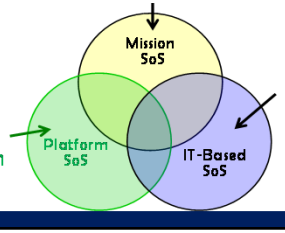
Platforms

A military platform (e.g. ship, aircraft, satellite, ground vehicle) equipped with independent systems (e.g. sensor, weapons, communications) needed to meet platform objectives



Missions

Sets of systems working together to provide a broader capability or mission



Information Technology

Networked information systems to support operations within or across platforms or systems to meet mission or capability objectives

Differences Between Systems and SoS as They Apply to SE

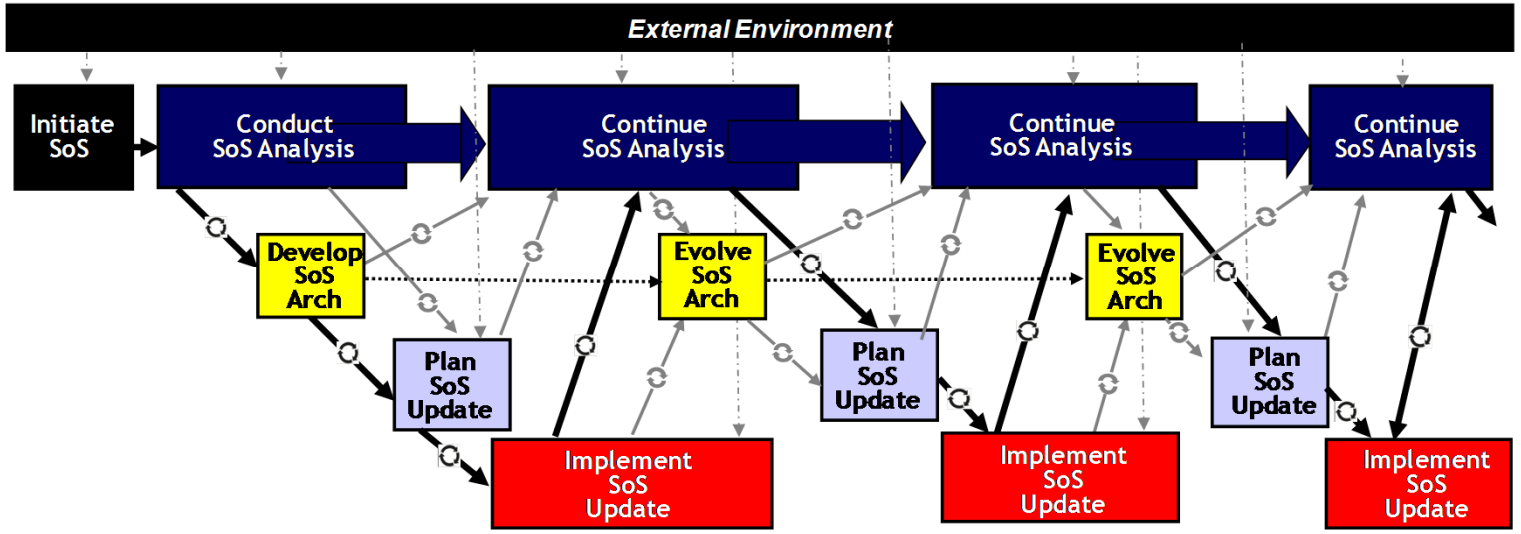
	Systems Engineering	Systems of Systems Engineering
Management & Oversight		
System	Physical engineering	Socio-technical management and engineering
Stakeholder Involvement	Clear set of stakeholders	Multiple levels of stakeholders with mixed and possibly competing interests
Governance	Aligned management and funding	Added levels of complexity due to management and funding for both SoS and systems; SoS does not have control over all constituent systems
Operational Focus (Goals)		
Operational Focus	Designed and developed to meet common objectives	Called upon to meet new SoS objectives using systems whose objectives may or may not align with the SoS objectives
Implementation		
Acquisition/Development	Aligned to established acquisition and development processes	Cross multiple system lifecycles across asynchronous acquisition and development efforts, involving legacy systems, developmental systems, and technology insertion
Process	Well-established	Learning and Adaptation
Test and Evaluation	Test and evaluation of the system is possible	Testing is more challenging due to systems' asynchronous life cycles and given the complexity of all the parts
Engineering & Design		
Boundaries and Interfaces	Focuses on boundaries and interfaces	Focus on identifying systems contributing to SoS objectives and enabling flow of data, control and functionality across the SoS while balancing needs of the systems OR focus on interactions between systems. Difficult to define system-of-interest
Performance and Behavior	Performance of the system to meet performance objectives	Performance across the SoS that satisfies SoS use capability needs while balancing needs of the systems
Metrics	Well defined (e.g. INCOSE handbook)	Difficult to define, agree, and quantify

From SEBoK 1.1

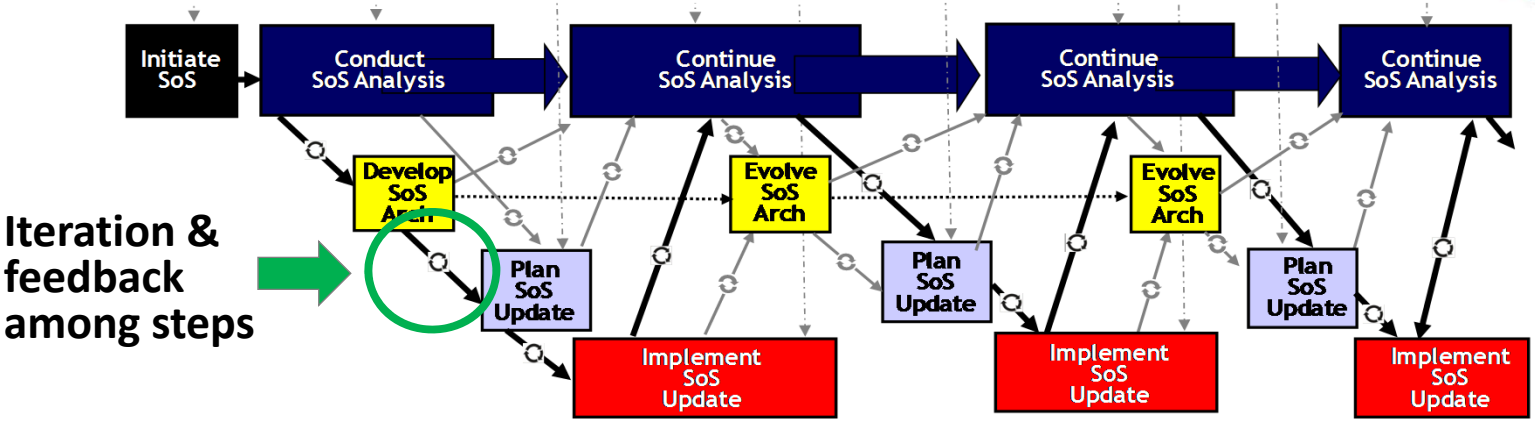
SoSE Lifecycle

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

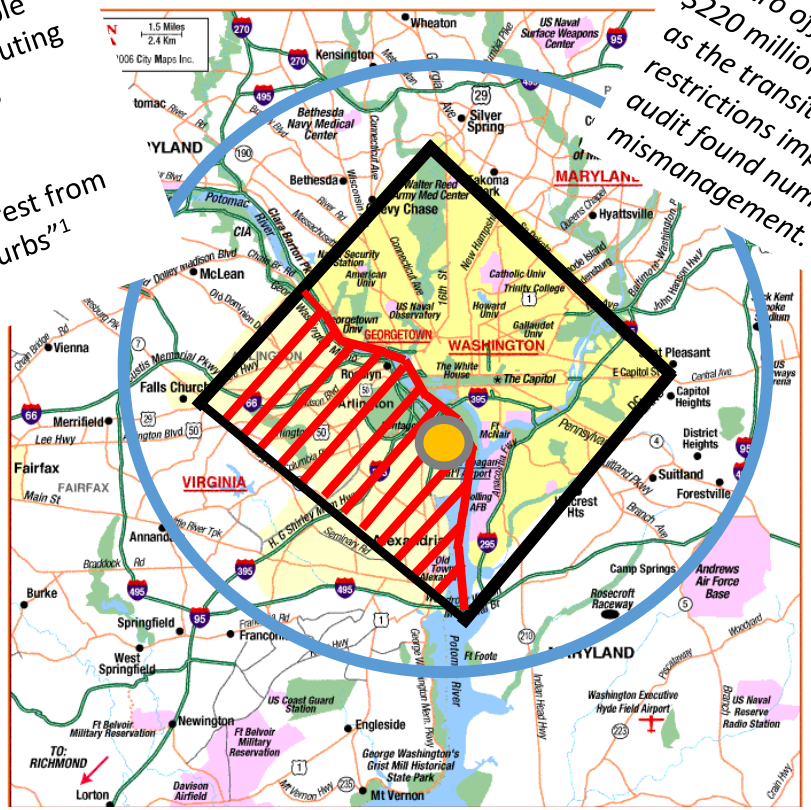


- Initiate SoS:
  Provides foundational information to initiate the SoS
- Conduct/Continue SoS Analysis:
  Provides analysis of the 'as is' SoS and basis for its evolution
- Develop/Evolve SoS Architecture:
  Develops/evolves the persistent technical framework for SoS evolution and a **migration plan 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

Example: RTRANS SoS
Regional Transportation SoS

"Commuters have a major influence on travel patterns, with only 28% of people employed in Washington, D.C. commuting from within the city, whereas 33.5% commute from the nearby Maryland suburbs, 22.7% from Northern Virginia, and the rest from Washington, D.C.'s outlying suburbs"[1]

"Metro officials want permission to borrow $220 million to cover a loan coming due in October, as the transit agency continues struggling under restrictions imposed last year after a federal audit found numerous instances of financial mismanagement."[2]



"Washington, D.C., beat out commuting misery stalwarts Los Angeles, San Francisco and New York for the dubious honor of worst rush hour congestion in the country, a nationwide traffic study found...
Overall, drivers lose nearly 7 billion hours each year to traffic congestion – an average of 42 hours per commuter – and waste 3 billion gallons of fuel, according to the 2015 Urban Mobility Scorecard."[3]

Core Elements of ICM

Question Indicator Measure

Information Category-Measureable Concept-Prospective Measures

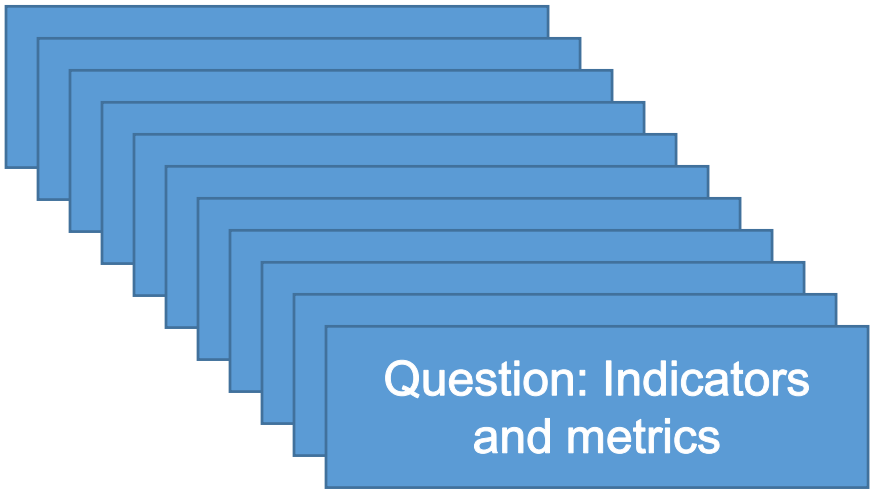
Information Categories	Measurable Concepts	Questions Addressed	Measures: Prospective Indicators	Measures: Sample Base Measures	Notes
Project	Schedule and Progress	Milestone Completion	Is the project or service meeting scheduled milestones? Are critical tasks or delivery dates slipping?	- Milestone Progress	- Number of milestones started and completed versus plan	- Completion should be based on achieving specific quantifiable milestone completion criteria - Include updates as schedules change - Milestones may include inch stones, or major critical milestones - Might also look at critical path performance (slack time)
		Work Unit Progress	Are specific activities and products completed as scheduled?	- Requirements Progress - Problem Reports Progress - Reviews Progress - Change Requests Progress - System Elements (Units) Progress - Test Cases Progress - Action Items Progress	- Requirements defined, traced, verified, validated - Problem reports discovered, closed - Reviews completed - Change requests opened, resolved - System elements designed, implemented, integrated, approved, qualified, accepted - Test cases developed, attempted, passed - Action items opened, completed	- Other work unit progress measures may be defined based on the work in progress - Other schedule performance indicators are included with financial performance indicators (e.g. earned value measures)
		Work Backlog	Is the backlog of work units growing? Has the backlog of work units been adequately addressed?	- Work Unit Backlog Trends - Burndown Rates	- Work units in backlog, work units in backlog resolved	- Measure/categorize by priority level and age - Work units may be: -- actions, assignments -- service requests -- story points or features -- maintenance actions -- open defects or open stakeholder problem reports
		Incremental Capability	Is capability being delivered as scheduled in incremental builds, releases, or service provisions?	- System Elements Integrated - Functionality Integrated	- Systems elements integrated (planned versus actual) - Functions integrated (planned versus actual)	
	Resources and Cost	Financial Performance	Is the project or service meeting budget and schedule objectives? Is the project or service at risk of exceeding established cost and schedule objectives?	- CPI, SPI Trends - Earned Value Cost and Schedule Variance - Budget Adequacy and Trends - Cost Trends - Cost and Schedule Impact Risk Trends	Earned Value: - Budgeted Cost of Work Scheduled (BCWS) - Budgeted Cost of Work Performed (BCWP) - Actual Cost of Work Performed (ACWP) - Budget at Completion (BAC) - Latest Revised Estimate (LRE) - Estimate at Completion (EAC) - Budget, planned, and actual costs - Cost and schedule risk	- For deployed systems, costs include those to operate, maintain (resolve problems), and enhance system - Include updates as funding changes - For risks, develop a range of cost values with associated probabilities, not just a single "cost" value, to facilitate improved awareness of potential cost exposure. Note that this should be related to both cost and schedule risk.
		Personnel Effort	Is effort being expended according to plan? Is there enough staff with the required skills?	- Staff Level Sufficiency - Effort Distribution and Trends - Skill Profiles - Staff Turnover Rates	- Number of staff on project and projected - Number of staff by skill level - Number of staff by activity - Staff added, removed, quit	- Can also focus on key staff - Effort distribution and trends by activity provides a more detailed profile - Look at these measures for the current state and future projection - Skills include expertise, experience, training, education, and domain knowledge
		Facilities and Support Resources	Are needed facilities, equipment, tools, and materials available as needed to meet milestones?	- Resource availability - Resource utilization	- Quantity needed, available - Time required, available, used	
	Size and Stability	Physical Size and Stability	How big is and how much change is occurring with the product's physical size, physical characteristics, or interfaces?	- System Element Trends - Interface Complexity - Interface Compatibility - Lines of Code Trends	- System elements added, modified, deleted - Interface number (unique), complexity, growth, approval rates, changes, TBD/TBR closure per plan - Lines of code added, modified, deleted	- Consider both internal and external interfaces - System elements can include software or hardware elements
		Functional Size and Stability	How big is and how much change is occurring with the product's functional size, content, or logical characteristics?	- Requirements Trends - Architecture Element Trends - Functional Element Trends - Work Unit Backlog Size Trends - Function Points Trends - Call Center Request Trends - TBD/TBRs Trends	- Number added, modified, deleted	- This can be applied at any part or level of the system definition - Functional architecture changes can be at the level of architecture description, model, or elements - Call center requests can be categorized as problems or enhancements

Working Sessions

Introduction in Plenary - 15 Minutes

Step in Wave Model	Example Questions indicators and measure

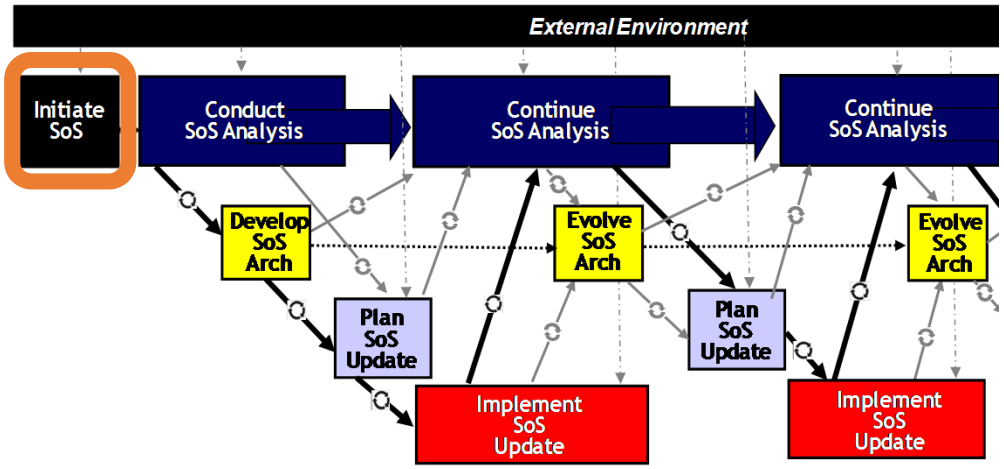
Participant post their ideas in small groups – 30 Minutes



Initiate SoS

Establish foundations for SoS engineering

Initiate SoS provides the foundational information needed to start the SoS SE process, including an understanding of the SoS objectives, the key players, their roles and expectations, and core systems supporting capabilities

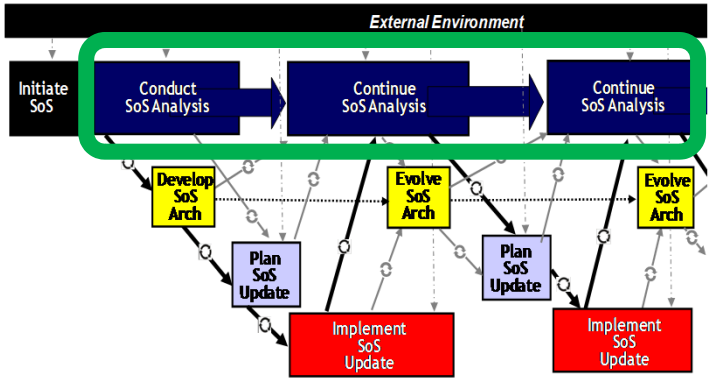


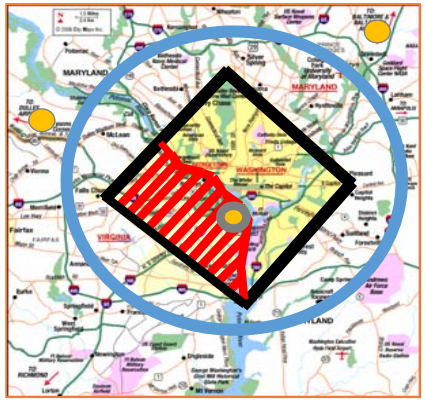
Artifacts

- 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
RTRANS SoS Example

- **Decision to treat RTRANS as SoS**
  - **Capability Objective**: Improve regional transportation for commuters
  - **Key systems**: Multiple area bus and rail systems
  - **CONOPS**: Commuters use combination of metro, buses and rail services to commute
  - **Authorities:** RTRANS Authority responsible for SoSE, but systems continue to report to their own jurisdictions independently, manage, operate, and fund these systems





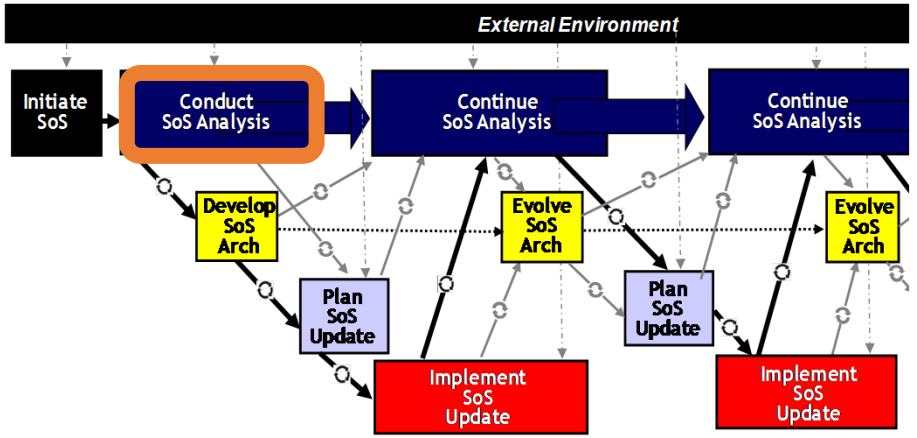
Critical that the overall capability objective is understood and shared from the outset

Step 1:
Conduct SoS Analysis

Conduct SoS Analysis

Characterize and analyze current SoS in terms of SoS objectives

Conduct/ Continue SoS Analysis provides an analysis of the "as is" SoS and the basis for SoS evolution by establishing an initial SoS baseline and developing initial plans for the SoS engineering efforts.



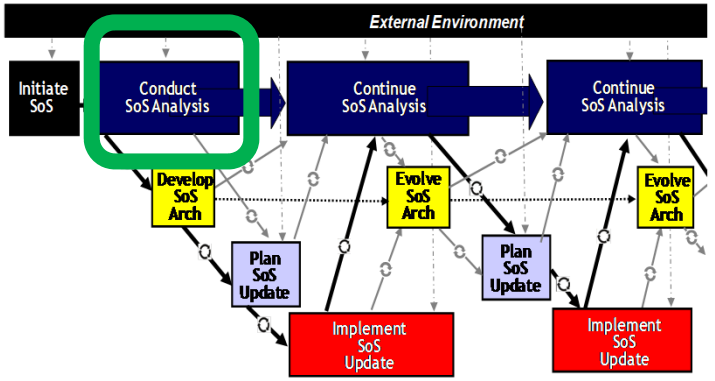
Technically characterize SoS

- Capability objectives
- SoS CONOPs
- Constituent system info
- SoS Technical Baselines
- SoS Performance Measures & Methods
- SoS Performance Data
- SoS Requirement Space
- SoS Risks & Mitigations

Programmatic, technical management planning for SoSE

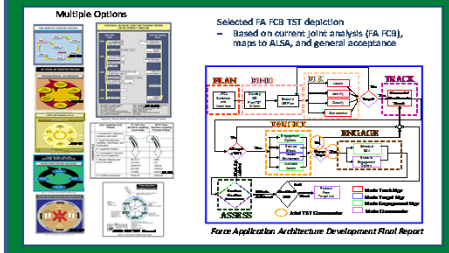
- SE Planning Elements
- SoS Master Plan
- Agreements

Conduct SoS Analysis



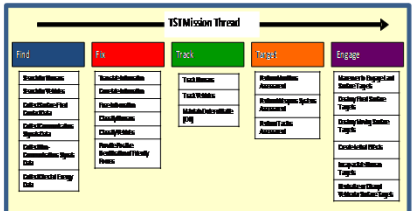
Provides analysis of the 'as is' and basis for SoS evolution

CONOPs



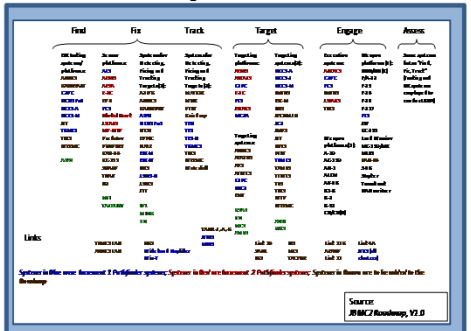
Understand operational context and developing a CONOPS -- Includes key steps in process and constraints on those steps; may be a set of mission threads, conditions, players and performance objectives

Functional Baseline



Layout the specific tasks for each component of the activity sequence to further delineate the functionality supporting the E2E capability objective

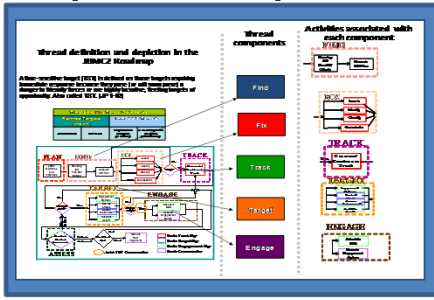
Current System Baseline



Identify systems supporting the capability objectives and align them to the components and functionality needs, with data on current performance

SoS Analysis

Requirements Space

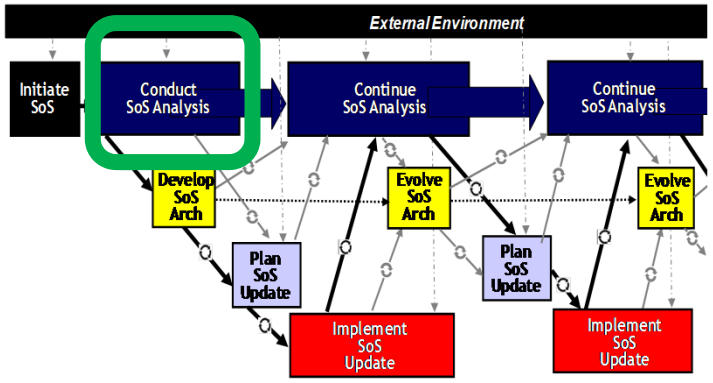


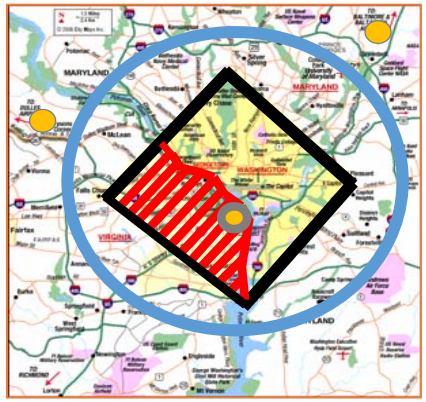
Develop an 'functional architecture' for the SoS by looking at the key functions to be supported across the 'thread' or activity sequence, including performance objectives

Results provide basis for architecture development and planning for SoS updates

SoS Analysis Example for RTRANS SoS

- How well does the current SoS support commuters, including …
  - Time
  - Variability
  - Reliability
  - Cost
  - Safety
- What are the contributors?
  - What is the end to end 'kill chain' or transportation flow for a commuter?
  - Which elements of the 'kill chain' contribute the most?
- What are the major shortfall?
  - What are the root causes?





Home	Travel time	Wait time	Sys1 org	Sys1 Dest	Wait time	Sys2 Orig	Sys2 Dest	Travel time	Work Place

SoS Analysis E
RTRANS SoS

- How well does the cu
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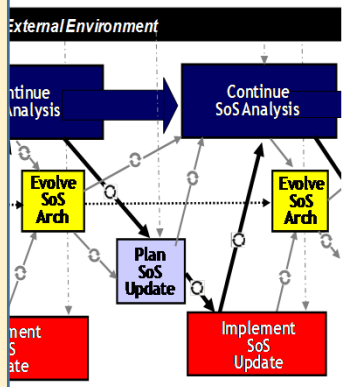
Question: How well does the SoS serve key users?

Indicators:
- Qualities of service
- …..

Base Measures
- Time
- Reliability
- Safety etc.

SoS level question

Challenges/Risks: Depends on data from multiple constituent systems



Home | Travel time | Wait time | Work Place

Small Group Sessions

- Each participant to provide ideas on post-its
  - **Question**
  - What are Prospective **Indicators** for that questions?
  - What are some Base **Measures** for the indicators?
  - Note if this is applies to **SoS** or to the **Systems**?
  - **Challenges/Risks** for SoS

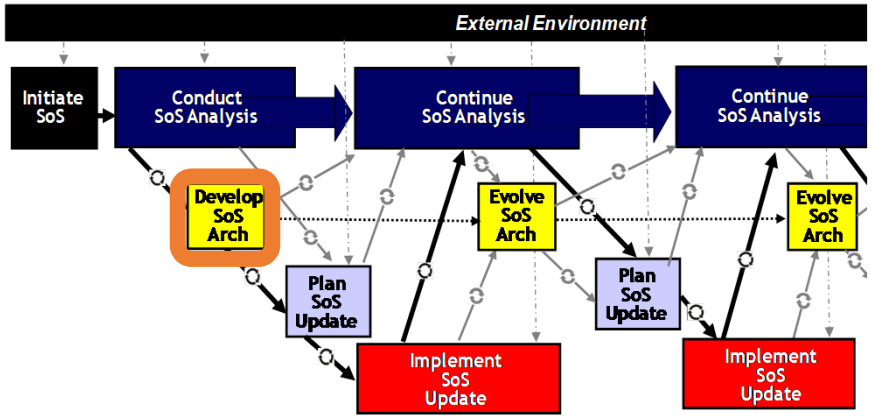
Post as many ideas as possible!

Step 2:
Develop/Evolve SoS Architecture

Develop SoS Architecture

Identifying, analyzing and recommending changes to the SoS architecture

Develop/Evolve SoS Architecture focuses on technical analysis of potential changes or alternatives to the current architecture to improve the SoS ability to achieve the objectives. The selected architecture is the persistent technical framework for SoS evolution. The architecture is created explicitly for the SoS in the first wave and then it is evolved over time based on incremental implementation and feedback based on implementation experience

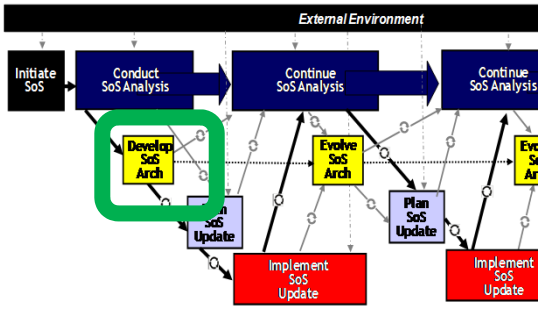


The SoS Architecture

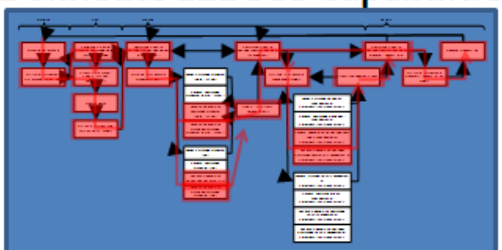
- Defines the way in which the constituent systems work together
- Includes systems, SoS functions, relationships and dependencies, as well as end-to-end functionality, data flow & communications

Develop SoS Architecture

Develops and evolves the persistent technical framework for addressing SoS evolution

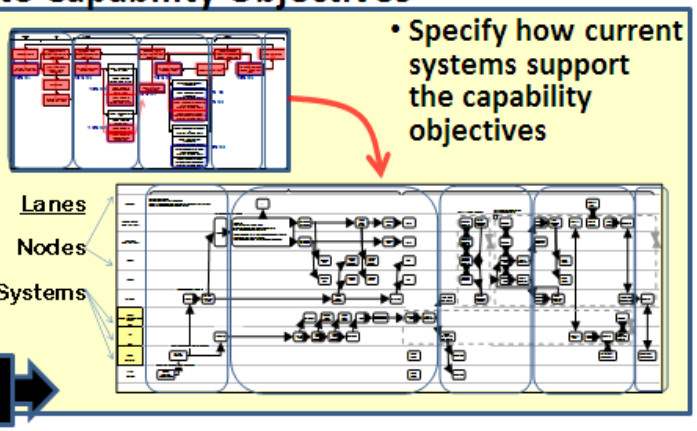


Delineate E2E SoS Capabilities



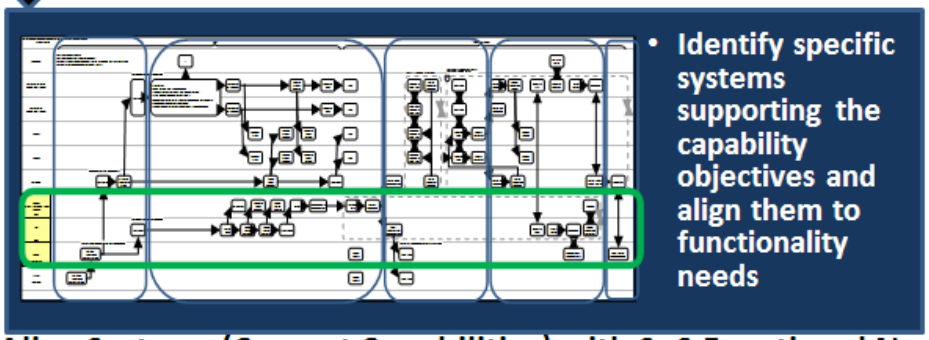
- Each mission plan / CONOPS / COA describes a path through the various steps in the mission

Identify Systems Contributing to Capability Objectives



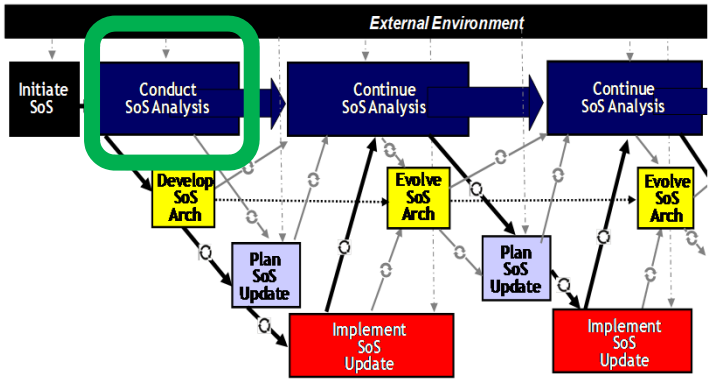
SoS Architecture

Identify and evaluate alternative approaches to organizing and augmenting systems to meet SoS needs

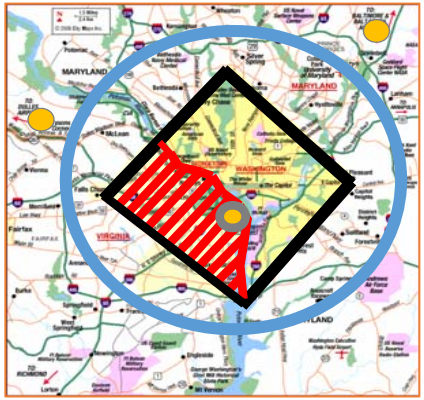


Align Systems (Current Capabilities) with SoS Functional Needs

SoS Architecture Example for RTRANS SoS



- Given results of RTRANS SoS analysis, what changes which could be made to address the gaps/shortfalls?
  - What are alternatives and trade offs?
  - Which change are recommends?
- If travel time was excessive for certain commuters using buses, due to variability in buses keeping to schedules, options include
  - More buses with more frequent services
  - Larger buses
  - Bus lanes to avoid traffic
  - Online alerts to slowdowns
- Conduct analysis of 'Kill chain' with changes to assess which are more effective; balance with other factors like cost to implement



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SoS Architecture
RTRANS SoS

- Given results of RTRANS
  changes which could be
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  - What are alternatives a
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- If travel time was excess
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- Conduct analysis of 'Kill cl
  which are more effective;
  cost to implement

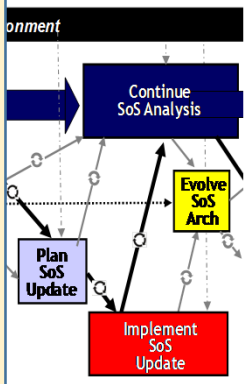
Question: How well alternative changes address the identified shortfalls?

Indicators:
- Qualities of service
- Cost
- …..

Base Measures
- Time
- Reliability
- Safety etc.
- Fixed and operating costs

SoS level question

Challenges/Risks: Need data from multiple constituent systems



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Small Group Sessions

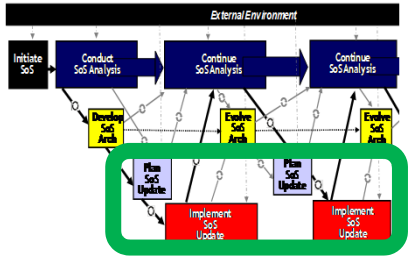
- Each participant to provide ideas on post-its
  - **Question**
  - What are Prospective **Indicators** for that questions?
  - What are some Base **Measures** for the indicators?
  - Note if this is applies to **SoS** or to the **Systems**?
  - **Challenges/Risks** for SoS

Post as many ideas as possible!

Steps 3 and 4:
Plan and Implement SoS Updates

Plan & Orchestrate SoS Update

Systems develop and implementation plans for next set of changes to support SoS objectives and SoS monitors and assess SoS impact



Plan SoS Update evaluates the SoS priorities, options and backlogs to define the plan for the next SoS upgrade cycle.

Artifacts

- An allocated baseline is created for the update
- Risks and mitigations are identified
- Agreements are developed
- Implementation and integration and test plans are created
- An integrated master schedule (IMS) is developed for update
- The SoS master plan is updated
- Update SoS technical baselines and SoS requirements space

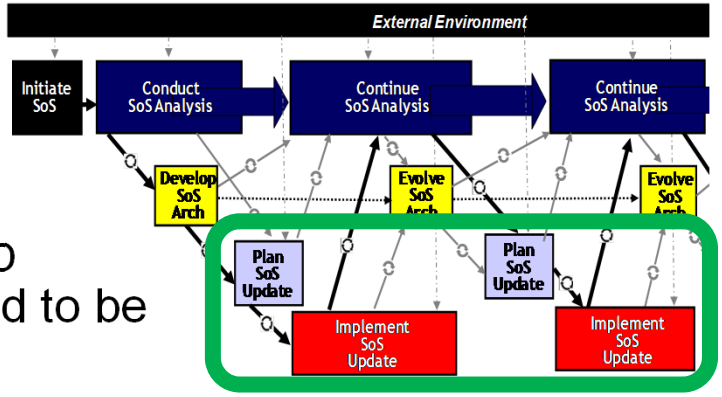
Implement SoS Update involves the SoS SE team monitoring implementations at the constituent system level and plans and conducting SoS level testing, resulting in a new SoS product baseline. The systems implement and test changes at their level while the SoS SE team monitors progress and updates the IMS. SoS SE team leads SoS integration and test, developing data on SoS performance and addresses any unanticipated factors encountered.

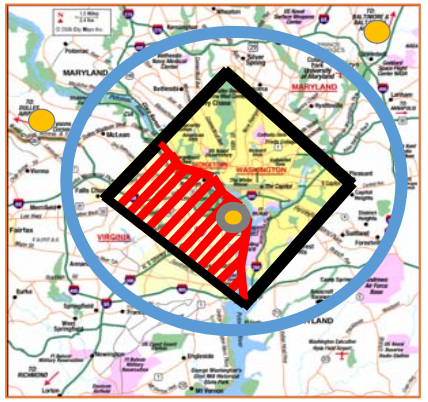
Artifacts

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

Plan and Orchestrate SoS Updates: RTRANS Example

- Given results of RTRANS SoS architecture, what changes need to be planned and implemented to improve SoS performance
- If the solution selected to improve problems of variability in buses keeping to schedules, was to provide "online alerts to slowdowns" what plans need to be made and implements to affect this
- Planning ….
  - Buses need to be instrumented
  - SW for monitoring buses needs to be purchased or developed
  - Develop implementations and test plans
  - Etc.
- Orchestration ….
  - Systems (buses, monitoring SW, need to be implement and monitored
  - Integration and test needs to be conducted





Plan and Orch
Updates: RTRA

- Given results of RTR
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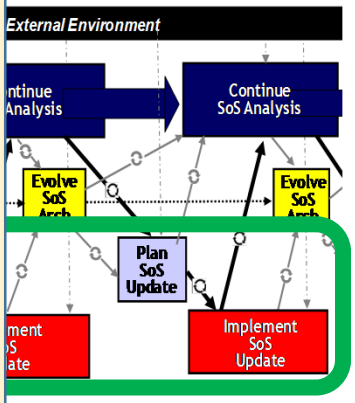
Question: How well are the systems implementation activities keeping to schedule?

Indicators:
- Milestones
- …..

Base Measures:
- Delivery percentages, etc.

System level question

Challenges/Risk: Hesitancy of systems owners to share progress/issues/risks with other members of the SoS for political reasons



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Plenary:
Summary and Discussion