Results of M&S Committee Survey on M&S in SoS SE

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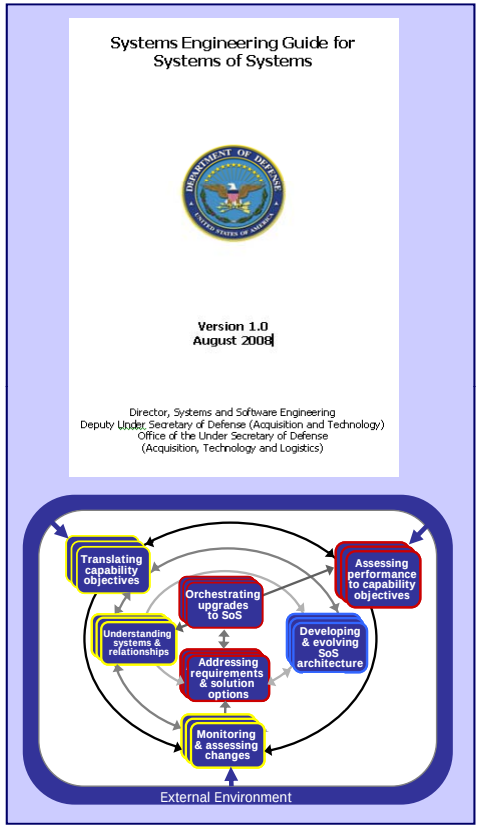
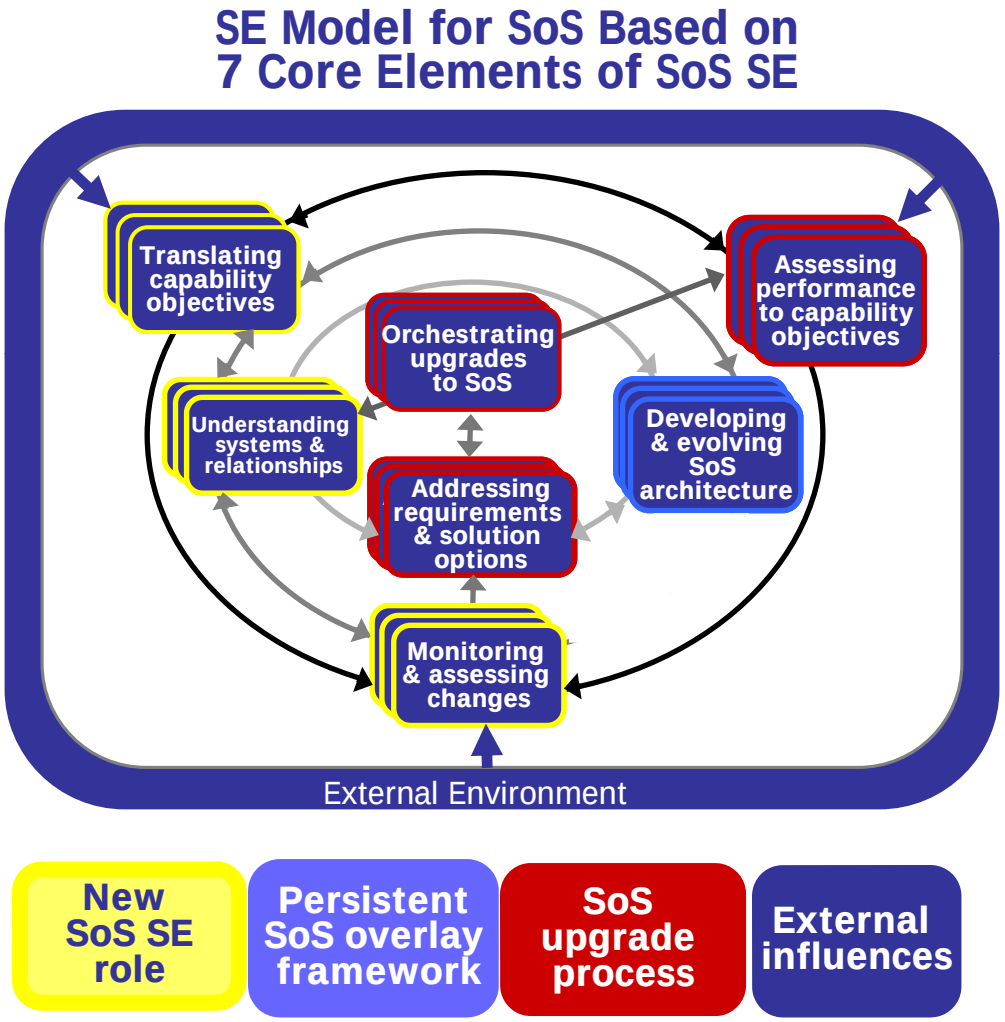
Systems Engineering for Systems of Systems



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

- AT&L Released "Systems Engineering for Systems of Systems" Version 1.0 in August 2008
- How does the SoS SE Guide address M&S?
  - Initial .9 Version included M&S throughout the draft
  - The practitioner reviews indicate limited use of M&S
    - Main place where M&S was cited is in the emulation of systems not otherwise available for testing
  - Consequently the 1.0 Working Draft limited M&S to this area
  - Comments on the draft identified more uses of M&S
  - The final 1.0 Version has an M&S section and added places where M&S is discussed
- Requested M&S Committee provide input on use of M&S to support SE for SoS

Specific Request



For each of the seven core elements of SoS systems engineering (SE), please share your views on:

- The potential for applying modeling and simulation, including why M&S has potential value
- Your experience using M&S for this SoS SE element, including the context of the application, the ways M&S was applied, the products produced, how they were used, and the value added by M&S
- The enablers for use of M&S in this element, including what attributes made successful use of M&S possible (in cases where it was applied)
- and barriers that inhibited use of M&S (in cases where the potential is not being realized).

Summary of Survey Inputs

	Name	Organization	Quick Summary	Example
1	Andrew	Raytheon	Views and specific experiences	X
2	Christian	AF Research Lab (AFRL/XPT)	Organizational experience	
3	Dubuque	Aegis Technologies	Perspective on issues	
4	Grange	Lockheed Martin	Views and specific experiences	X
5	Griffis	Aeronautical Sys Ctr (ASC/END)	Organizational experience	
6	Haley	NUWC Newport	Views based on M&S for SE	
7	Hall	Lockheed Martin	Views and specific experiences	
8	Harris	Lockheed Martin	Perspective on issues	
9	Hazelrig	National Science Foundation	Views based on M&S for SE	
10	Koury	Lockheed Martin	Views and specific experiences	X
11	Lopez	3CE	Views and specific experiences	X
12	Lyda	NAVAIR	Views based on M&S for SE	
13	McGough	MC Systems Command	Views and specific experiences	X
14	Prochnow	MITRE	Views and specific experiences	X
15	Small	NSWC Dahlgren	Perspective on issues	
16	Thomas	Aegis Technologies	Perspective on issues	
17	Tucker	Boeing Company	Views and specific experiences	X
18	Upchurch	Aegis Technologies	Perspective on issues	
19	Chen	Australia	Paper	

- 19 Responses from 14 organizations
- 10 volunteers to help to synthesize the report on survey results
- Responses were of several types
  - Views and specific experiences with M&S and SoS
  - Perspective on issues of M&S and SoS
  - Views based on M&S for SE
  - Organizational experience
  - Relevant papers on topic
- 8 specific project experiences cited in survey responses or papers

- Data was extracted from surveys
- Compiled into an Excel workbook
  - Seven worksheets
  - One worksheet for each core SoS SE element
  - Each sheet includes 3 sections: Potential Opportunities, Experience, Enablers/Barriers
  - Each response is tagged with: number of the source survey, whether the comment is explicitly an SoS comment, whether it is based on experience with systems, or is a general comment
- Workbook plus papers provide rich source of data

NDIA Survey Analysis: What We Did and Why We Did It

What we did …..

- **Identified key SoS SE activities for each core element**
- **Mapped survey responses to each of these key activities by asking ourselves "how can M&S support this key SoS SE activity?"**
- **We retained the *potential-experience-enabler/inhibitor* organization of responses under each activity – it is a useful organizing principle for presenting information**
- **Added a "General" category for those responses that were relevant but not easy to categorize by SoS core element**

Why we did it …..

- **We saw the audience for this information as SoS SEs asking 2 basic questions:**
  - ***What are the critical or unique SE activities in each core element?***
  - ***What are the potential, experience, & enablers/inhibitors of M&S to support me in executing each core element activity?***

Overview of M&S Survey Responses (1 of 4)

Core Element	Element Activities	M&S Responses		
		Ptnl	Exp	En/ In
Translating Capability Objectives	SoS SE translates needed capabilities into high-level requirements at the outset of the program & as the situation changes & SoS evolves	3		
	SoS SE needs to understand nature & dynamics of SoS & anticipate areas likely to vary in implementation & over time			
	SoS SE defines functions to provide capability & variability in environment that impacts different ways they are executed			
	Evaluate operational utility & derive requirements via reference missions & use cases		1	
Understanding Systems and Relationships	Focus on components and dynamics vs boundaries	1		
	Extends beyond technical to broader context of management, organizational, development plans, funding, etc.	1	1	
	Gain understanding of ensemble of systems that affect the SoS capability and the way they interact & contribute to capability objectives	2	1	1
	Key systems may be outside the direct control of SoS management but have large impacts on SoS objectives	1		
	Understand players, relationships & their drivers to identify & evaluate options for addressing SoS objectives	1	1	1
	Define functionality of the systems and how they share data during operations			1
	Understanding (impact of) plans for the systems and SoS			3

Overview of M&S Survey Responses (2 of 4)

Core Element	Element Activities	M&S Responses		
		Ptnl	Exp	En/ In
Assessing Performance to Capability Objectives	SoS SE establishes metrics & methods for assessing performance of SoS capabilities independent of implementation alternatives	2	2	2
	SoS SE focuses assessments on end-to-end performance	1	3	3
	SoS SE pro-actively identifies changes needed, emergent behavior & impacts on the SoS of changes in constituent systems	2	1	
Developing and Evolving an SoS Architecture	Establish a persistent technical framework for addressing the evolution of the SoS to meet user needs	3	2	
	Analysis and assessment of trades among different options	1	1	
	Identify scalability issues or knees in the curve beyond which performance starts to break down		1	
	Development of metrics for assessment of SoS performance and maturity		2	
	Conduct focused investigations of functionality and relationships to address core issues	2	1	
	Extent to which changes in constituent systems are affordable and feasible	1		
	Functionality that the individual systems contribute to the SoS can be described in a functional architecture that puts the key functions in order, thereby sequencing the SoS tasks			
	Functional architecture details the complete set of functions to be performed within the SoS as well as the relationships among the functions			

Overview of M&S Survey Responses (3 of 4)

Core Element	Element Activities	M&S Responses		
		Ptnl	Exp	En/ In
Developing and Evolving an SoS Architecture (continued)	Output of the design process is the design of the SoS, or the physical architecture that defines the physical components (constituent systems) of which the SoS will be composed			
	Understand the variability in the execution of these functions and factor it into the SoS architecture			
	Regularly assess the architecture to ensure that it supports the SoS evolution	1		2
Monitoring and Assessing Changes	Continually monitor proposed or potential changes and assess their impacts on the SoS	5		1
	Identify opportunities for enhanced functionality and performance		1	
	Preclude or mitigate problems for the SoS and individual systems	1	1	
	Negotiate with systems engineers for constituent systems regarding how system changes are made, in order to preclude undesirable effects on the SoS and vice versa			
	Update the SoS product baseline as individual system updates/changes are deployed			3
	Establish awareness and understanding of trends in enabling technologies, technology insertion, and mission evolution	2		1
	Identify alternatives for implementing the changes that would not affect the SoS and work to influence the systems to adopt alternatives			

Overview of M&S Survey Responses (4 of 4)

Core Element	Element Activities	M&S Responses		
		Ptnl	Exp	En/ In
Addressing Requirements and Solution Options	Review, prioritize and recommend which requirements to implement in each iteration	1		
	Control top level SoS requirement changes to maintain stability and coherence			1
	Develop and evaluate technical approaches to address requirements	5	1	1
	Select approaches to meet requirements	3	1	3
Orchestrating Upgrades to SoS	Facilitate, monitor, and coordinate changes being implemented in the systems to effect SoS performance improvements and added capability	3	3	1
	Determine the best phasing of the iterations to meet scheduled upgrade rhythms	3	1	
	Manage external factors affecting the ability to implement changes			3
	Assess performance of the modified SoS (e.g., test and evaluation	3	3	
	Integrate, verify, and validate changes across the suite of system updates under an SoS increment	7	3	2
General				12
	Total:	57	31	41

Total number of surveys analyzed: 19 respondents from 14 organizations

General Observations on Survey & Responses (1 of 2)

- Many feel that M&S can be value-adding for many aspects of SoS development and evolution
- M&S is better suited to some SoS domains/aspects than others
- However, there seems to be limited SoS-level experience with M&S and often this experience is with low-fidelity M&S tools with limited usefulness
- Most experience appears to be with respect to testing, with results fed back to the next evolution/development cycle
- There seems to be considerable inhibitors/barriers to effective M&S in the SoS environment:
  - Inexperienced staff (developers to develop needed models/sims, analysts that can interpret/make use of the results, and people with both M&S and domain experience)
  - Low-fidelity tools (when high-fidelity tools are needed)
  - Data to drive the models/sims
  - Flexible/easily-adapted tools
  - Funding

General Observations on Survey & Responses (2 of 2)

- Some comments suggested that M&S can replace some testing
  - Additional insights into that would be useful
- Validation of information collected
  - Initial survey did not allow real-time interaction/follow-up with NDIA committee respondents for comment clarification/deeper dives
  - Recommendations
    - Request committee respondents review use of their comments to assure intent is right
    - Validate summary with active SoS SE practitioners (e.g., SoS SEG pilot participants)

Modeling and Simulation in SoS*

- **A technical toolset used regularly in systems acquisition & engineering [NDIA, 2004]**
- **Applied throughout system development lifecycle**
  - Supports early concept analysis, through design, DT&E and OT&E
- **Supports SoS SE in a number of areas**
  - Understand complex & emergent behavior of systems that interact with each other
  - Provides an environment to help SoS SE team create new capability from existing systems
  - Illuminates integration issues that can have a direct effect on the operational user
  - Analysis of architecture approaches & alternatives
  - Analysis of requirements & solution options
  - Support T&E when difficult or infeasible to do in other ways, particularly end-end performance
- **Challenges**
  - Ensuring M&S validity
  - Include M&S considerations early in SE planning, including resources to identify, develop, evolve & validate M&S to support SE and T&E.

**** From SEG Reference Guide, section 1.7.4***

M&S in *Translating Capability Objectives Into High Level Requirements*

- **SoS SE translates needed capabilities into high-level requirements at the outset of the program & as the situation changes & SoS evolves**
  - **Potential:** Use of low-resolution, low-granularity M&S is a working tool for the translation of SoS capability objectives into requirements.
  - **Potential:** M&S provides a means to measure the performance, effectiveness, or capability of non-existing system of systems which is made up collection of systems driven by requirements.
  - **Potential:** M&S can identify SoS capability gap
- **SoS SE needs to understand nature & dynamics of SoS & anticipate areas likely to vary in implementation & over time**
  - No responses associated with tis SoS SE activity
- **SoS SE defines functions to provide capability & variability in environment that impacts different ways they are executed**
  - *No responses associated with this SoS SE activity*
- **Evaluate operational utility & derive requirements via reference missions & use cases**
  - **Experience:** Wargames using SoS M&S help establish futuristic capability objectives, architecture alternatives and warfighter CONOPS

M&S in *Understanding Systems and Their Relationship* (1 of 2)

- **Focus on components and dynamics vs boundaries**
  - **Potential:** M&S plays an important role in understanding how robust the SoS behavior is to system losses or how agile/adaptive it is to changing environmental circumstances.
- **Extends beyond technical to broader context of management, organizational, development plans, funding, etc.**
  - **Potential:** M&S also supports the design and use of Service Level Agreements (SLAs) among elements in an SoS
  - **Experience:** M&S tool to depict organizational relationships among the systems
- **Gain understanding of ensemble of systems that affect the SoS capability and the way they interact & contribute to capability objectives**
  - **Potential:** M&S can support system of systems interactions down to the interface level to understand system performance, dependencies, and shorten the overall life cycle.
  - **Potential:** It supports to fully understand relationships between components of the SoS in order to develop meaningful requirements
  - **Experience:** Utilized the JCSS M&S tool to demonstrate systems, functions, and relationships and dependencies, both internal and external.
  - **Enabler:** Consistent and reusable “Use Cases” to evaluate systems
- **Key systems may be outside the direct control of SoS management but have large impacts on SoS objectives**
  - **Potential:** M&S can expose what are inherently second-order (or “deeper”) element relationships that are consequent to mission or scenario dynamics

M&S in *Understanding Systems and Their Relationship* (2 of 2)

- **Understand players, relationships & their drivers to identify & evaluate options for addressing SoS objectives**
  - **Potential:** The ability to model the behavior of a system of systems is needed to understand complex behaviors and to support model based testing.
  - **Experience:** M&S can represent "background loading" from other concurrent missions or operationally realistic activity implied in a scenario.
  - **Enabler:** Establish clear, explicit, and breakdown interfaces for interacting with external interfaces independent of specific external system
- **Define functionality of the systems and how they share data during operations**
  - **Enabler:** Integration or federation of simulations at the appropriate level of granularity
- **Understanding (impact of) plans for the systems and SoS**
  - **Enabler:** Integration or federation of simulations at the appropriate level of granularity.
  - **Enabler:** Integration between the system modeling tools (e.g. SysML) with the simulation and analysis tools.
  - **Inhibitor:** Understanding how they are evolving is relatively simple but understanding either why they are evolving this way or what the behavioral implications of those evolutions are is far less simple

M&S in *Assessing Performance to Capability Objectives* (1 of 2)

- **SoS SE establishes metrics and methods for assessing performance of SoS capabilities independent of implementation alternatives**
  - **Potential:** M&S can be applied to systems as they are developed and then re-applied to systems as they are combined to prove concepts at each development phase
  - **Potential:** Measurements of envisioned performance can be determined such as the amount of time it takes for an associated function of the capability to be performed (e.g., an hour to get updated information on pilot availability from an envisioned Pilot Skills System).
  - **Experience:** M&S-based interoperability HWIL testing to assess performance of the fielded SoS configuration provides key data for the accreditation authority's decisions about caveats and limitations in accreditation of the constructive simulation of the SoS
  - **Experience:** We have used hardware in place of the ship simulation and still provided the environment to the hardware through a Force-On-force or Mission level simulation. Examples of this approach include performance analysis of a C4I network connection of a SoS, missile flyout for design verification, an Asymmetric Missile Defense architecture concept, and a proof of concept for a Wide Area Surveillance of land and sea.
  - **Enabler:** Availability of appropriately high-resolution element M&S for integration into the SoS-level M&S in performance assessment
  - **Enabler:** Define and supply the data necessary to construct a valid M&S solution.

M&S in Assessing Performance to Capability Objectives (2 of 2)

- **SoS SE focuses assessments on end-to-end performance**
  - **Potential:** A high fidelity system federated simulation to a Campaign, Force-On-Force, or Mission level simulation
  - **Experience:** At MDA, M&S is being used to predicting current and future capability/performance of the BMDS which is an SoS, but not to define high level requirement.
  - **Experience:** The M&S approach used to support assessment of the capability of this SoS would be quite different from one used to analyze the capability of a carrier task force.
  - **Experience:** Combinations of HWIL systems and modeled systems can interact. Additionally, this simulator can interact with other simulators of submarine systems (such as combat fire control systems) via HLA or DIS.
  - **Enabler:** Infrastructure (authority, processes, skilled practitioners, tools) for VV&A of SoS M&S
  - **Enabler:** A robust HLA middleware embedded in our simulations, a standard federation object model, and the modular approach to simulation development.
  - **Enabler:** Higher fidelity simulations are used and integrated with the process flows to provide a more detailed analysis of the performance.
- **SoS SE pro-actively identifies changes needed, emergent behavior & impacts on the SoS of changes in constituent systems**
  - **Potential:** Often anomalous behavior must be traced to component systems, but that behavior may manifest infrequently and or under conditions difficult to reproduce in field testing
  - **Potential:** M&S as a SE tool in performance assessment of SoS helps to identify undesirable emergent behaviors for elimination, as well as discovering desirable emergent behaviors for promotion
  - **Experience:** Force-On-Force simulation provides the operational context by characterizing the naval operation in the form of a scenario which includes ship placement. It is providing only the functions from this particular element (ship) of the SoS which is of interest to the SoS design as whole

M&S in *Developing, Evolving, and Maintaining SoS Architecture* (1 of 5)

- **Establish a persistent technical framework for addressing the evolution of the SoS to meet user needs**
  - **Concept of operations, how the systems will be employed by the users in an operational setting**
    - **Potential:** M&S contributes to coordinated development of future architectures through... discovery, refinement, training and exercise of Warfighter concepts of operations (CONOPS) and coordinated Tactics, Techniques and Procedures (TTPs)
    - **Potential:** M&S ensures that the scenarios (e.g., threats, environments) and constituent capabilities can be repeatably offered to the Operator-in-the-loop (OITL) experimenting with alternative CONOPS/TTPs
    - **Experience:** Chief Systems Engineering (CHSENG) asked the Marine Corps Systems Command (MCSC) Systems Engineering, Interoperability, Architectures and Technology (SIAT), Information Assurance & Joint Certifications (IA&JC) Modeling and Simulation (M&S) Team to model a Marine Corps Naval Surface Fire Support (NSFS) and an High Mobility Artillery Rocket System (HIMARS) Call for Fire (CFF) mission threads
  - **Systems, functions, and relationships and dependencies, both internal and external**
    - See *Understanding Systems and their Relationships—this element uses products from Understanding Systems and their Relationships*
  - **End-to-end functionality and data flow as well as communications**
    - **Potential:** M&S contributes to coordinated development of future architectures through interoperability testing of ensembles of the constituent systems...
    - **Experience:** Architectural design activities on several programs have highlighted the importance of not only good data flow between SoS design tools and the M&S applications used to represent the design and support computation of the figures of merit.

M&S in *Developing, Evolving, and Maintaining SoS Architecture* (2 of 5)

- **Analysis and assessment of trades among different options**
  - **Potential:** M&S has potential for developing and evolving a SoS Architecture. Due to the flexibility of M&S tools, an SoS architecture can be build and easily modified an analyzed during development. This is an approach that cannot be done with the actual hardware of a complex SoS architecture.
  - **Experience:** Our Government customer routinely uses SoS M&S across a time spectrum from "futuristic" (say, 10 years forward) to current operating environment. Wargames using SoS M&S help establish futuristic capability objectives, architecture alternatives and warfighter CONOPS. OITL exercises and training perfect warfighter proficiency and provide practice.
- **Identify scalability issues or knees in the curve beyond which performance starts to break down**
  - **Experience:** One can see three stages of architecture will evolve over time. These various OV-1s, which represent different SoS capabilities, are a result of swapping various elements (systems) in and out of the proposed SoS architecture. It is only through the ability of simulation to efficiently and quickly change the representation of these architectures that an analyst can analyze these various architectures. This is true for a couple of reasons; first many of the system functions making up the SoS may not be created yet and therefore can only be represented as a model or simulation, and two; the use of real systems requires operation in the physical world which can not be completely isolated. Simulation is the only means by which the operational context can be fixed. By keeping the context fixed and swapping the elements of the SoS to represent each version of the architecture the analyst can determine the performance contribution of each series of new systems. The output is measured using the same metrics within the same environment and therefore one can compare the deltas to quantify the contribution change. Additionally, many times the analyst can not predict beforehand the behaviors of the new architecture. Even if one could predict a type of behavior the range and consequences of the new behavior are not easily determined.

M&S in *Developing, Evolving, and Maintaining SoS Architecture* (3 of 5)

- **Development of metrics for assessment of SoS performance and maturity**
  - **Experience:** One can see three stages of architecture will evolve over time. These various OV-1s, which represent different SoS capabilities, are a result of swapping various elements (systems) in and out of the proposed SoS architecture. It is only through the ability of simulation to efficiently and quickly change the representation of these architectures that an analyst can analyze these various architectures. This is true for a couple of reasons; first many of the system functions making up the SoS may not be created yet and therefore can only be represented as a model or simulation, and two; the use of real systems requires operation in the physical world which can not be completely isolated. Simulation is the only means by which the operational context can be fixed. By keeping the context fixed and swapping the elements of the SoS to represent each version of the architecture the analyst can determine the performance contribution of each series of new systems. The output is measured using the same metrics within the same environment and therefore one can compare the deltas to quantify the contribution change. Additionally, many times the analyst can not predict beforehand the behaviors of the new architecture. Even if one could predict a type of behavior the range and consequences of the new behavior are not easily determined.
  - **Experience:** Technique has been applied to C4I systems, missile defense, and surveillance System of Systems. An example from our Asymmetric Missile Defense work which only became apparent as part of the modeling and simulation process was the importance or value of accurate prediction of cruise missile speed as a component of positive identification. Once this need was made apparent the architecture was adjusted to provide better speed prediction.

M&S in *Developing, Evolving, and Maintaining SoS Architecture* (4 of 5)

- **Conduct focused investigations of functionality and relationships to address core issues (e.g., assess the effect of multiple systems working together under controlled conditions to understand underlying processes that will affect the SoS behavior)**
  - **Potential:** The ability to model the behavior of a system of systems is needed to understand complex behaviors...
  - **Potential:** Due to the flexibility of M&S tools, an SoS architecture can be build and easily modified an analyzed during development
  - **Experience:** Models were used to determine how to enhance a system during testing and changes made to the architecture based on those recommendations
- **Extent to which changes in constituent systems are affordable and feasible**
  - **Potential:** Cost is important and so integrating cost models with high fidelity simulations becomes important to assess trades on mission effectiveness with cost effectiveness
- **Functionality that the individual systems contribute to the SoS can be described in a functional architecture that puts the key functions in order, thereby sequencing the SoS tasks**
  - *No responses associated with this SoS SE activity*
- **Functional architecture details the complete set of functions to be performed within the SoS as well as the relationships among the functions**
  - *No responses associated with this SoS SE activity*

M&S in *Developing, Evolving, and Maintaining SoS Architecture* (5 of 5)

- **Output of the design process is the design of the SoS, or the physical architecture that defines the physical components (constituent systems) of which the SoS will be composed.**
  - *No responses associated with this SoS SE activity*
- **Understand the variability in the execution of these functions and factor it into the SoS architecture**
  - *No responses associated with this SoS SE activity*
- **Regularly assess the architecture to ensure that it supports the SoS evolution**
  - **Potential:** Simulations of each individual system proposed can be created and then integrated according to how they function in their current operational environment. Ideally, having high fidelity simulations of the operational / real systems provides an opportunity to extensively test any technology changes to the systems involved in the SoS and to determine with great confidence the impact of those changes. With these types of simulations, updates to the SoS such as the inclusion of gateways can be examined to determine if they impact the overall performance of the SoS.
  - **Enabler:** This implies a need not only for relatively rich architecture design tools and techniques, but also better data flow between design tools and analysis tools. The design too must provide some form of open communication to the M&S applications.
  - **Enabler:** This capability must also support service oriented architecture modeling and simulation as well

M&S Role in *Monitoring and Assessing Potential Impacts of Changes on SoS Performance (1 of 3)*

- **Continually monitor proposed or potential changes and assess their impacts on the SoS**
  - **Potential:** Modeling (and user driven simulation) has the potential to show emergent behavior at the SoS and enterprise levels if actors within a user driven simulation are allowed to connect or flow information between systems to solve mission objectives. This improves capabilities in the sense that potential combinations of systems are recognized and enabled prior to their actual need (and discovery of a requirement)
  - **Potential:** M&S is a capability for assessing the impacts of contemplated or anticipated changes in the elements of the SoS
  - **Potential**: Simulations of each individual system proposed can be created and then integrated according to how they function in their current operational environment. Ideally, having high fidelity simulations of the operational / real systems provides an opportunity to extensively test any technology changes to the systems involved in the SoS and to determine with great confidence the impact of those changes. With these types of simulations, updates to the SoS such as the inclusion of gateways can be examined to determine if they impact the overall performance of the SoS.
  - **Potential:** Assessing changes is the discovery of emergent behavior which may have the potential of providing a new and useful capability. A scalable and robust System of Systems simulation capability can be used to investigate potential interface issues leading to poor integration of the elements. Once these interfaces are established, tested, and accepted the simulation can be used for regression testing as the SoS evolves overtime.
  - **Potential:** Ideally, having high fidelity simulations of the operational / real systems provides an opportunity to extensively test any technology changes to the systems involved in the SoS and to determine with great confidence the impact of those changes
  - **Enabler:** Strong collaboration among element SE components must engage with SoS M&S SE to ensure M&S-based change assessment produces data to support Analysis

M&S Role in *Monitoring and Assessing Potential Impacts of Changes on SoS Performance (2 of 3)*

- **Identify opportunities for enhanced functionality and performance**
  - **Experience:** M&S offers the chance to gather a large number of data points on a small collection of systems (over a large number of simulations) to identify interoperability points to be enhanced
- **Preclude or mitigate problems for the SoS and individual systems**
  - **Potential:** Modeling and simulation enables this monitoring to be predictive … at least in the 'near' future. The essential insight is that SoS behavior while regular in some sense and wonderfully adaptive in another is profoundly unpredictable and non-repetitive at heart. It is both 'innovative' in itself and responsive to 'innovation' in its environment. The old adage 'trust but monitor' comes to mind.
  - **Experience:** KC-135 is an element of a complex and dynamic system of interacting systems working together to keep an aircraft fleet refueled. Any change to the KC-135 that affects its performance has to be tested and coordinated with every aircraft in the fleet that might be refueled by the particular airplane being modified. Proposed changes are assessed via modeling and simulation to predict the effect on the fleet, prior to deployment
- **Negotiate with systems engineers for constituent systems regarding how system changes are made, in order to preclude undesirable effects on the SoS and vice versa**
  - *No responses associated with this SoS SE activity*

M&S Role in *Monitoring and Assessing Potential Impacts of Changes on SoS Performance (3 of 3)*

- **Update the SoS product baseline as individual system updates/changes are deployed**
  - **Enabler:** Effective configuration management of the SoS is needed to ensure valid SoS M&S is applied to assessing change
  - **Inhibitor:** Lack of well-coordinated SoS CM across the element CM components
  - **Inhibitor:** Lack of well-coordinated SoS M&S CM across the element M&S CM components
- **Establish awareness and understanding of trends in enabling technologies, technology insertion, and mission evolution**
  - **Potential:** Technology changes can be incorporated into the high fidelity simulations prior to actually making the changes in the actual system. Cost is important and so integrating cost models with high fidelity simulations becomes important to assess trades on mission effectiveness with cost effectiveness
  - **Potential:** Ideally, having high fidelity simulations of the operational / real systems provides an opportunity to extensively test any technology changes to the systems involved in the SoS and to determine with great confidence the impact of those changes
  - **Enabler:** Strong collaboration among element SE components must engage with SoS M&S SE to ensure M&S-based change assessment produces data to support analysis
- **Identify alternatives for implementing the changes that would not affect the SoS and work to influence the systems to adopt alternatives**
  - *No responses associated with this SoS SE activity*

M&S in *Addressing Requirements and Solution Options* (1 of 2)

- **Review, prioritize, and recommend which requirement to implement in each iteration**
  - **Potential:** High fidelity simulations can be used to optimize what requirements should be implemented when and the associated impacts to the individual systems and the SoS
- **Control top level SoS requirement changes to maintain stability and coherence**
  - **Enabler:** High fidelity simulation for managing a multitude of changes
- **Develop and evaluate technical approaches to address requirements**
  - **Potential:** M&S enables SoS SE with increased confidence about functional coordination, element interoperability and selection of element engineering solutions that will be supportive of SoS capability objectives.
  - **Potential:** Simulation provides the designer and analyst the means to test a solution's ability to meet a requirement.
  - **Potential:** It can also accurately measure a set of requirements to judge the ability of a solution to meet that set of requirements.
  - **Potential:** Rapid assembly of a capability solution (agility) from existing, fielded systems in response to unanticipated challenge
  - **Potential:** One of the practical and intuitive means of systematically searching the SoS design space is through the use of evolutionary algorithms wrapped around the core SoS M&S environment. Pragmatically this is both one of the obvious/intuitive ways to 'intelligently' search the SoS design space for the desired self-organizing process and an obvious way to configure an initial SoS force size and mix before deployment
  - **Experience:** M&S is used to assess the "goodness" of a design solution
  - **Enabler:** Lack of cross-element M&S VV&A culture and centralized authority can confound requirements engineering across the SoS

M&S in *Addressing Requirements and Solution Options* (2 of 2)

- **Select approaches to meet requirements**
  - **Potential:** M&S provides the only way to assess the ability of the conceptual system element to satisfy the need it is intended to address
  - **Potential:** High fidelity simulation is important to truly assessing the impact of identified changes before implementing them
  - **Potential:** The use of cost models integrated with an end-to-end simulation of the SoS becomes increasingly important in understanding the cost implications of changes
  - **Experience:** M&S is used in the area of trade-off analysis for affordability, a process which combines performance, cost, and risk within the context of a solution baseline to optimize requirements subject to cost
  - **Enabler:** A simulation can be devised that yields the appropriate levels of granularity, then the issues of requirements traceability, AOA, and V&V testing (through model based testing) could be enhanced
  - **Enabler:** Risk and parametric cost modeling
  - **Enabler:** The integration of cost models is a key enabler to successfully assessing impacts associated with mission effectiveness

M&S in *Orchestrating SoS Upgrades* (1 of 4)

- **Facilitate, monitor, and coordinate changes being implemented in the systems to effect SoS performance improvements and added capability**
  - **Potential:** It can model systems behavioral codependency relationships and deployment size which can have significant impacts on consequent SoS behavior
  - **Potential:** During training, M&S realistically stimulates Operator system consoles with scenarios and "other system" interactions, including SoS responses under the stressing conditions (e.g., high-density threats) capable of triggering emergent behaviors. Once Operators master CONOPS/TTPs for a SoS, M&S-driven exercises offer trained Operators low-cost opportunities to evaluate CONOPS/TTPs against new scenarios or in broader SoS contexts, such as extended regional/theater campaigns
  - **Potential:** It is very important that the key, overall SoS simulations be kept current with the system design, even after PDR and CDR to support analysis of the effects of the inevitable changes in design, as well as the changes in operational scenarios hat occur during system development
  - **Experience:** The M&S provides assessment data for determining capabilities and limitations of a fielded configuration for which test is not possible
  - **Experience:** Simulations of basic military operations form a "ground truth" that is fed into sensor simulations and, in turn, sent to operational systems that may consist of sensor fusion and sensor exploitation systems
  - **Experience:** Modeling and simulation process was the importance or value of accurate prediction of cruise missile speed as a component of positive identification
  - **Enabler:** Concurrent training/operations capabilities in deployed element established as an "appliqué" after element entered sustainment

M&S in *Orchestrating SoS Upgrades* (2 of 4)

- **Determine the best phasing of the iterations to meet scheduled upgrade rhythms**
  - **Potential:** Modeling the architectures and attaching performance through the use of simulation for each Epoch provides a very powerful means to understand the capabilities each epoch is providing.
  - **Potential:** It enables the design of legacy systems and parallel changes/upgrades among different organizational entities that can be merged.
  - **Potential:** High fidelity simulations can be used to optimize what requirements should be implemented when and the associated impacts to the individual systems and the SoS
  - **Experience:** Not all elements of the new SoS come available at the same time, so the nature of the fielded SoS, including functions, operational context, and internal and external interfaces changes over time.
- **Manage external factors affecting the ability to implement changes**
  - **Enabler:** The need for understanding of the constituent systems, how they are, or can be used, and how they work together is critical (*Understanding Systems and Their Relationships*)
  - **Inhibitor:** Disagreement within or among warfighter, fielding and/or sustainment authorities regarding SoS configurations
  - **Inhibitor:** Poor SoS and/or element baseline management (including data and the M&S itself)
- **Assess performance of the modified SoS**
  - **Potential:** The ability to model the behavior of a system of systems is needed to understand complex behaviors and to support model based testing.
  - **Potential:** M&S based analysis and testing is required to insure that system capability is maintained throughout the transition period
  - **Potential:** SoSs can be measured in terms of how integrated and coordinated the 'behavior' of the constituent systems is. Fully cohesive responses are appropriate when the SoS needs to respond as a cohesive unit … but such cohesiveness is always at the cost of situation awareness. On the contrary, 'exploratory' behavior provides higher fidelity 'situation awareness' but at the cost of concerted force application. M&S as in the other behavior prediction modes can support on operator in evaluating the impact of a specific level of cohesiveness

M&S in *Orchestrating SoS Upgrades* (3 of 4)

- **Assess performance of the modified SoS *(continued)***
  - **Experience:** The M&S provides assessment data for determining capabilities and limitations of a fielded configuration for which test is not possible.
  - **Experience:** SoS-level, constructive M&S (i.e., no HWIL or OITL) as an interoperability "test harness" for spiral builds of operational software for the overarching element in the SoS
  - **Experience:** Modeling and assessing S&T improvements in Live, virtual & constructive simulations and wargames, at engineering, mission, & campaign levels. These assessments are executed from both the "Blue" and "RED" perspectives
- **Integrate, verify, and validate changes across the suite of system updates under an SoS increment**
  - **Potential:** (M&S provides) consistent and reusable "Use Cases" to evaluate systems
  - **Potential:** M&S contributes to coordinated development of future architectures through interoperability testing of ensembles of the constituent systems, as well as through discovery, refinement, training and exercise of Warfighter concepts of operations (CONOPS) and coordinated Tactics, Techniques and Procedures (TTPs)
  - **Potential:** The ability to model the behavior of a system of systems is needed to understand complex behaviors and to support model based testing.
  - **Potential:** It offers the only practical alternative in which T&E of SoS are generally so limited by hard constraints of cost, safety or treaty
  - **Potential:** M&S based analysis and testing is required to insure that system capability is maintained throughout the transition period

M&S in *Orchestrating SoS Upgrades* (4 of 4)

- **Integrate, verify, and validate changes across the suite of system updates under an SoS increment *(continued)***
  - **Potential:** M&S is an essential and cost effective tool where large and complex SoS can not readily brought together at the same time for full range testing (flight or ground). **I Potential:** It offers the potential for quantitative verification of element requirements flowed down from an SoS
  - **Potential:** SoSs can be measured in terms of how integrated and coordinated the 'behavior' of the constituent systems is. Fully cohesive responses are appropriate when the SoS needs to respond as a cohesive unit … but such cohesiveness is always at the cost of situation awareness. On the contrary, 'exploratory' behavior provides higher fidelity 'situation awareness' but at the cost of concerted force application. M&S as in the other behavior prediction modes can support on operator in evaluating the impact of a specific level of cohesiveness
  - **Experience:** The M&S provides assessment data for determining capabilities and limitations of a fielded configuration for which test is not possible.
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  - **Enabler:** Develop interface diagnostic tools to record the operation of systems across interfaces
  - **Enabler:** Support provided by the M&S environment for automating test conditions and 'intelligently' exploring them

M&S in SoS - General Observations

- **Enabler:** M&S can be useful in mitigation of technical risks associated with distribute real-time simulations.
- **Enabler:** The combination of high SoS complexity and high level of detail needed means that multiple levels of M&S detail/resolution/speed are needed.
- **Enabler:** Skilled SoS analysts! SoS Conceptual Model. Coherent system engineering process and products.
- **Enabler:** Integrated product teams or chartered working groups complementary to SoS element SE to build SoS M&S
- **Enabler:** The key to success is the availability of the required descriptive data that allows the system aspect of interest to be represented, to the required level of detail, as quickly and economically as possible. This means that a variety of simulation tools and architectures are required. There is no single M&S tool or approach to solve every problem but the representations used must be consistent in that they represent the same thing.
- **Enabler:** Technology to create service oriented "wrappers" of existing HLA enabled models in automated or semi-automated fashion would be really helpful here
- **Enabler:** Flexible and reconfigurable architecture for SoS performance simulation suite.
- **Enabler:** Realistically driven (driven by active intelligence) immersive simulations that project of range of future operational environments.
- **Enabler:** The ability of the M&S environment to model the interaction of multiple adversarial complex adaptive systems.
- **Enabler:** Must understand adversarial CAS/SoS architectures sufficiently to model them with validity … or have the computational resources to explore a sufficient parametric space.
- **Inhibitor:** Unbalanced element lifecycle strategies with respect to futuristic tech refresh (e.g., some elements participate in wargaming while others do not)
- **Inhibitor:** Lack of central authority regarding common, consistent scenarios, threats and environments (including unrealistic expectations about "Intell-credible" scenarios for futuristic wargaming)

Summary and Conclusions

- Big picture from surveys
  - Lots of potential and associated enablers/inhibitors for M&S in the SoS SE environment
  - Much less experience (8 specific project experiences) with M&S in the SoS SE environment
    - Consistent with SoS SE pilot program interviews
- Some follow-on may be warranted
  - Details of experiences
  - Additional insights into using M&S instead of testing