



Military Operations Research Society (MORS) Workshop

Joint Framework for Measuring C2 Effectiveness

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Mr. Terry McKearney
Dr. Lee J. Lehmkuhl



Working Group 3: Operations Analysis for Systems of System within a Networked C2 Context

Chair: Clyde Smithson (JHU/APL)

Co-Chair: Marjorie Greene (CNA)

Members:

Bob Chalmers	JHU/APL	Chad Ohlandt	RAND
Glenn Conrad	Mitre / AFMC	Sheilah Simberg	US AMSAA
Shana Eley	JHU/APL	James Teresi	HQ ACC / A9A
Mike Ellis	TRADOC Analysis Center	Jeff Jones	Metron
John Foulkes	JBF Consulting, LLC	Tim Madgett	AFAMS
Muharrem Mane	Purdue University	JJ Tsou	USAF ACC
Tom Rothwell	Center for Army Analysis		
Carmen Tornatore	Defense Threat Reduction Agency		
Norman Yarbrough	OSDAT&L		



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- Outline



• WG 3 Objectives

- Objective 1: Understand the impact of the application of traditional operational research techniques to networked C2 systems.
- Objective 2: Develop inputs to the C2 Metrics Framework for networked C2 systems and “systems of systems” to measure and assess network behaviors.
- Objective 3: Identify and categorize families of C2 measures of effectiveness useful for networked C2 systems.



• Bottom Line Up Front

- The SoS C2 Network perspective is different from the System perspective because of how the SoS is planned, developed, integrated & tested, and operated.
- The SoS C2 Network conveys C2 Information across a variety of media and spectrum from highly technical machine-oriented methods and tools to very social human interaction.
- Analysis of a SoS C2 Network is different from the analysis of a system in how you have to plan and scope the analysis and not in the methods and tools used



- Definitions

- System - A functionally, physically, and/or behaviorally related group of regularly interacting or interdependent elements; that group of elements forming a unified whole [JP 1-02 & JP 3-0, DOD SE Guide to SoS].
- System of Systems - An SoS is defined as a set or arrangement of systems that results when **independent and useful systems are integrated into a larger system** that delivers unique capabilities [DoD, 2004(1)]. *Both individual systems and SoS conform to the accepted definition of a system in that each consists of parts, relationships, and a whole that is greater than the sum of the parts; however, although an SoS is a system, not all systems are SoS.*



- **In DoD and elsewhere, SoS can take different forms. Based on a recognized taxonomy of SoS, there are four types of SoS which are found in the DoD today [Maier,1998; Dahmann, 2008].**
 - **Virtual**. Virtual SoS lack 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 must rely upon relatively invisible mechanisms to maintain it.
 - **Collaborative**. In collaborative SoS the component systems interact more or less voluntarily to fulfill agreed upon central purposes. The Internet is a collaborative system. The Internet Engineering Task Force works out standards but has no power to enforce them. The central players collectively decide how to provide or deny service, thereby providing some means of enforcing and maintaining standards.
 - **Acknowledged**. Acknowledged SoS have recognized objectives, a designated manager, and resources for the SoS; however, the constituent systems retain their independent ownership, objectives, funding, and development and sustainment approaches. Changes in the systems are based on collaboration between the SoS and the system.
 - **Directed**. Directed SoS are those in which the integrated system-of-systems is built 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 central managed purpose.

Maier, M. (1998); "Architecting Principles for Systems-of-Systems"; Systems Engineering, Vol. 1, No. 4 (pp 267-284).

Dahmann, Judith and Kristen Baldwin, (2008), "Understanding the Current State of US Defense Systems of Systems and the Implications for Systems Engineering", Montreal, Canada: IEEE Systems Conference, 7-10 April.



- Why is analysis of an SoS different than a System?
 - Complex Stakeholder Base
 - SoS Stakeholder is not necessarily the same as the System Stakeholders
 - Independent Goals of Systems (e.g., missions other than the SoS Mission)
 - Independent Operation and Governance of Systems
 - SoS Analysis includes:
 - Aggregation of System Analyses
 - Additional Analysis at the SoS level
 - A complex Analysis problem



- Challenges (may affect measurement, methods or tool)
(Understanding the differences between analyzing a System or SoS)
 - Measuring C2 Network Effectiveness
 - Must be done in context of Problem(s) or Mission(s)
 - Systems may have non-SoS Missions
 - Socio-Technical Issues
 - Acceptance of results by multiple stakeholders
 - System data releasability and availability to the SoS level
 - Measurement (where in the SoS)
 - At the interfaces between systems
 - Within the constituent systems
 - Human actions vs. System/SoS automated/machine actions
 - Frame of reference for human performance in SoS context vs. the system context



- **Challenges**

- Analyzing the contribution of SoS C2 Network on Mission Outcome
- Human decision-makers act inside and/or outside the system and SoS C2 Network and Processes
 - More Open SoS – Creative/Manual Processes
 - More Closed SoS – Rule-based/Automated Processes



- OR Techniques for Networked C2 Systems (1 of 2)
 - OR Techniques should be applied by:
 - C2 Framework Layer (Social, Cognitive, Information, Physical)
 - Applicability to Mission, Task
 - Method/Tool
 - Difficulty in Achieving useful Result
 - SoS Life-Cycle Environment (orientation to JCIDS)
 - Development, Integration, Test, Operations
 - Traditional Process (based on WG1 & past literature)
 1. Characterize System
 2. Define Objectives and Goals of System
 3. Define the Required System Analysis
 4. Identify the Measures of Merit (MoMs)
 5. Apply OR Tools



- OR Techniques for Networked C2 Systems (2 of 2)
 - SoS Process
 1. Characterize SoS
 - Interdependencies – interoperability, connectivity, resiliency, redundancy, security, etc.
 - System Types – level of autonomy (deterministic, stochastic, chaotic, etc.)
 - Authority/Ownership – control, physical, operational, technical, financial, governance
 2. Define the System and SoS-unique Analysis
 3. Define Objectives and Goals of Systems and SoS
 4. Identify the Measures of Merit (MoMs)
 5. Apply OR Tools
 - Necessary Elements for Analysis:
 - Metrics, Mission, Architecture, Scenarios



• Example of SoS Metrics

Metric Framework	Characteristic	SOS Metric	NATO category	Sub Metric	OR Technique								C2 Network Layers					
					Decision Theory	Game Theory	Queuing Theory	Modeling (static)	Statistical Analysis	Optimization techniques	M&S/ Dynamic Simulation	Network Theory	Reliability Theory	Physical	Information	Cognitive	Social	
C2 SOS	Interoperability	Connectivity	MOCE					X				X		X	X			
		Clarity						X				X		X	X			
		Completeness			X			X				X	X	X				
		Data Assurance, Integrity											X	X	X			
		Service Demand					X	X				X		X	X			
	Interdependency	Timeliness (staleness, delay, latency)						X						X				
		Responsiveness (to command, info need)					X	X				X		X			X	
		Connectivity						X						X			X	



- ## Summary

- Traditional OR techniques may not change but how they are applied can change based on the scope of the C2 Network.
- Non-traditional analysis techniques may be required to account for the effect of the decision-makers interacting with C2 Network Systems and SoS.
- In general, System-type metrics apply at the SoS-level, but there are additional levels of complexity in applying them to the problem and they reveal different characteristics about the SoS
- Identification of SoS Mission/Goals, Architectures, Scenarios are necessary to determine/derive appropriate metrics
- Measures of Effectiveness do not always relate directly to Measures of Performance
- Multiple Stakeholders more likely in SoS, and may affect the acceptance of SoS results



- Recommendations
 - Frame the discussion before breaking into the Working Groups
 - Integration of C2 Metrics Framework across the WG Perspectives



- Back-up Material



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Aspect of Environment	Acknowledged SoS*	Virtual SoS	Collaborative SoS	Directed SoS
Management & Oversight				
Stakeholder Involvement	Stakeholders at both system level and SoS levels (including the system owners), with competing interests and priorities; in some cases, the system stakeholder has no vested interest in the SoS; all stakeholders may not be recognized.	A virtual SoS has no centrally established purposes but rather the purpose expresses itself as the collective actions of the individual systems.	Stakeholders negotiate among themselves to establish a common purpose. The SoS is built to this purpose and the individual systems negotiate among themselves to determine which part of this responsibility each fulfills. Central players often establish the ground rules by which other players participate.	A central SoS authority usually establishes the purpose to be achieved by the SoS. The SoS is built to this purpose and the individual systems are generally directed by the central authority.
Governance	Added levels of complexity due to management and funding for both the SoS and individual systems; SoS does not have authority over all the systems.	No central body controls the purpose or management of the SoS or individual systems. Governance may emerge from politics or policies agreed to by stakeholders but none is compelled to comply.	In collaborative SoS there is no central authority with the power to enforce a particular SoS purpose. A central authority may establish purposes, standards, etc., which are usually complied with, but does not have authority to enforce them.	Individual systems are governed by membership to a common SoS command structure which usually includes a central governing authority.
Operational Environment				
Operational Focus	Called upon to meet a set of operational objectives using systems whose objectives may or may not align with the SoS objectives.	Individual systems are operated independently. Operation of the SoS is complex because there is no centrally directed/controlled purpose. Participation by systems is voluntary and they often have conflicting purposes which they will try to attain simultaneously with other systems.	Collaborative SoS differs from directed SoS in that a central authority is not able to enforce particular operation of the system. Systems collaborate of their own will to achieve a central purpose; however, from time to time SoS operational needs are subjugated to the needs of a particular system.	The systems are connected by command and control structures. The SoS directs the operation of individual systems to achieve the SoS purpose (a centralized control authority). Systems are usually allowed operational independence to deal with local situations.

*Table adapted & Acknowledged SoS definitions from DoD SE Guide for SoS; others defined by Clyde Smithson.



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Aspect of Environment	Acknowledged SoS*	Virtual SoS	Collaborative SoS	Directed SoS
Implementation				
Acquisition	Added complexity due to multiple system lifecycles across acquisition programs, involving legacy systems, systems under development, new developments, and technology insertion; Typically have stated capability objectives upfront which may need to be translated into formal requirements.	Component systems are acquired independently without regard to other systems, except in the context that another system may perform a beneficial function for that system (usually at little or no cost) and dependably.	Systems negotiate among themselves to determine how SoS objectives are to be met and which system is to provide which SoS capability. Agreements are made between central players to form a common acquisition strategy. This can be seen as negotiated “political” objective as opposed to direction by central authority.	Individual systems are acquired through different program offices and operated separately; however, there is a central authority directing, coordinating, and balancing the various program offices. Systems may be custom built to meet the needs of the SoS.
Test & Evaluation	Testing is more challenging due to the difficulty of synchronizing across multiple systems’ life cycles; given the complexity of all the moving parts and potential for unintended consequences.	SoS testing generally occurs on an ad hoc basis. Individual systems test themselves. Testing at the SoS level is confined to aspects of the SoS at that level that affect the function and purpose of individual systems. In other words a system only tests what is important to itself at the SoS level, if any SoS testing is conducted at all.	SoS testing is established by coordination and negotiation between the central SoS players. Testing tends to change over time as the SoS purpose evolves. For a directed SoS the testing tends to be directed from top down whereas for virtual SoS it springs up organically. T&E for a collaborative system comes from a middle ground in which the central players establish goals that are tested by the entire SoS.	Testing occurs at multiple levels but is directed from the SoS level At the SoS level testing is directed to evaluate the central purpose of the SoS. Testing may occur with the entire SoS or portions of it. Additionally, testing occurs at the system level to establish that the system meets its individual requirements, including those supporting the system purpose.

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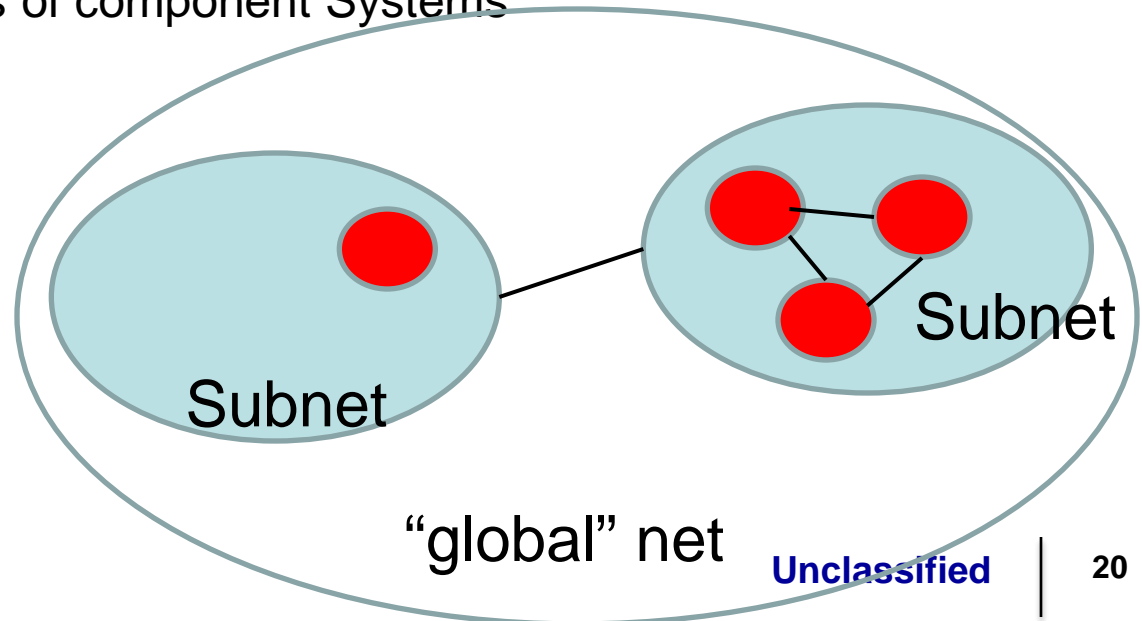
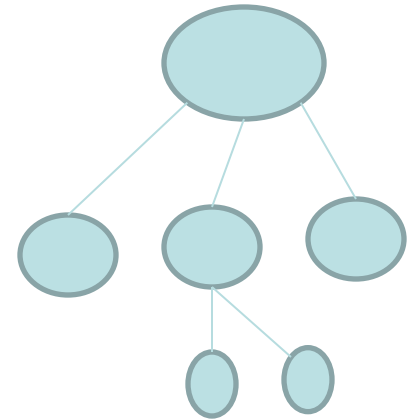
Aspect of Environment	Acknowledged SoS*	Virtual SoS	Collaborative SoS	Directed SoS
Engineering & Design Considerations				
Boundaries and Interfaces	Focus on identifying the systems that contribute to the SoS objectives and enabling the flow of data, control and functionality across the SoS while balancing needs of the systems.	Boundaries and interfaces evolve through adaptation and survival – successful standards live and are extended upon while others die out. Forces other than the technical merits of these may determine survival (e.g., VHS vs. Betamax). Systems choose to use or not use these at their own discretion. A standard may be created by an individual system, and then be adopted by others.	Certain systems rise to be central players at the SoS level. These systems usually reach agreement on what the interface standards are and what services to provide. They usually create common standards for use by the entire SoS but do not enforce them (except by operationally excluding other systems that do not conform).	Interfaces are seen as a key integrating factor for the SoS. A central authority establishes the interface requirements, with input from the component systems. Similarly, the central authority establishes the boundaries between systems.
Performance & Behavior	Performance across the SoS that satisfies SoS user capability needs while balancing needs of the systems.	The performance of the SoS is not directed, but rather is an emergent behavior. There are no established SoS performance requirements. Individual systems optimize to perform best for their own ends (i.e., best ROI at the system level) and SoS performance derives from that.	Like the virtual SoS, there are no minimum SoS performance requirements enforced by a central authority. Rather, the constituent systems agree to a set of mutual performance goals and behaviors which evolve over time. Individual systems may choose to sub optimize to benefit the SoS.	All constituent systems must met minimum performance requirements to satisfy SoS capability requirements. Individual systems may be operated sub optimally to meet SoS performance requirement. Generally, individual system performance is secondary to SoS performance.

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• SOS Viewpoints

- SOS – similar to “systems”
 - but component Systems are non-dedicated
 - Decomposition applies
- Interfaces, information flow concepts are similar to Systems analysis
- Analysis of SOS Interdependencies, control, autonomy must include analysis of component Systems





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- WG 3 Findings
 - Obj 1
 - Obj 2
 - Obj 3
- Noteworthy discussion points
- Areas for further research



- **WG Recommendations**

- Should be actionable, linked to findings
- Write or re-write regulation or instruction
- Research analytical approaches
- Build or improve a model
- Sponsor a study
- DOTMLPF

- **Identify OPR**

- MORS can be OPR if recommendation is in the Society's purview, e.g. form a MORS COP, hold classified workshop or MORSS Special Session
- MORS Sponsor
- TRADOC
- Other



- C2 Network Framework Layers
 - Physical
 - Quality of Service
 - Information
 - Quality of Information
 - Cognitive
 - Quality of Decision
 - Quality of Process
 - Social
 - Quality of Collaboration



- Where & How to Apply Metrics
 - Hierarchy of metrics in the context of the SoS
 - Policy Questions
 - Right Force Effectiveness Metrics
 - Right Mission Context
 - Right C2 Network Metrics



- Considerations for SoS C2 Network Analysis
 - Metrics used to characterize the C2 Network should be compared to mission outcome/success to determine their applicability and answer such questions:
 - Did more, or less, Information affect the outcome?
 - What was the Vital Information?
 - Did the Vital Information arrive in Time?
 - Did the Vital Information reach the Decision Maker who needed it?



- Analytical Methods & Tools
 - Systems Engineering & Architecture tools
 - Context Diagrams, Functional Block Diagrams, DODAF/MODAF, business process models
 - OR Tools/Techniques
 - Decision Theory
 - Game Theory
 - Queuing Theory
 - Modeling (static)
 - Statistical Analysis
 - Optimization techniques
 - M&S/ Dynamic Simulation
 - Network Theory
 - Reliability Theory



- SoS C2 Network Behavior
 - Decision Making
 - The degree to which a decision, or process, is centralized to one (or a subset) of systems versus distributed across the network.
 - The type of connectivity used ranging from machine to social
 - Level of system to system synchronization required



- SOS Metrics Table



- **Recommendations**
 - Stakeholder buy-in up-front and throughout the process is even more critical success in an SoS analysis