14th ICCRTS
"C2 and Agility "

Title of Paper:
Interoperability Risk Mitigation through the Application of Operational Capability Based Engineering

Authors: Jack Lenahan, Captain (S) Scott Heller USN, Don Pacetti, Rebecca Reed, Paul Mori
POC: Jack Lenahan

Organization: Office of the Chief Engineer
Space and Naval Warfare Systems Center Atlantic
Charleston, S.C.

Address: P.O. Box 190022
N. Charleston, South Carolina: 29419
Phone: 843-218-6080
Email: John.Lenahan@Navy.mil

Agenda

- Abstract
- Issue to Be Addressed
- Proposal
- Cost of Interoperability Failures After Shipboard Deployment
- Definitions
- What is Interoperability?
- Fabric Discussion
- More on Interoperability
- Capability Based Engineering Framework (CBEF) Discussion
- Future CBEF Directions
- Summary

Abstract

- We are interested in investigating an operational system of systems engineering approach to the resolution of interoperability issues discovered after system deployment.
- Operational systems of systems engineering focuses on the engineering of systems in an end to end mission thread context.
- Such a methodology shifts the acquisition focus from simple ‘box engineering’ to the behavior of systems in their ***operational*** ecosystem.

Issue to be Addressed - The Lack of a Pre-Specification, DoD SoS Interoperability Engineering Processes

- We begin with the assumption that formal system of systems interoperability engineering at the mission level rarely occurs in the DoD prior to acquisition.
- The lack of a DoD SoS interoperability engineering process leaves the procured systems exposed to expensive interoperability repair issues after system deployment.
- Ignoring the need to define interoperability specifications at the beginning of a system's lifecycle, it seems difficult to avoid contractual incompleteness in terms of the acquisition community.
- If we enlarge our discussion to include so called net centric composeable applications, weaved together as a tapestry of web services and BPEL sequences to satisfy our mission needs in new and novel ways, then our interoperability problems explode exponentially

Proposal

- This paper proposes a Capabilities Based Engineering Framework[1] (CBEF) to provide a methodology that will deliver operations focused enterprise requirements, in addition to traditional systems requirements. Capability based approaches are used to identify *and understand* interactions, patterns, structures and properties of the end to end architecture.
- A System of Systems (SoS) refers to an integrated package of individual solutions that interoperate to provide a required capability. In addition to interoperability requirements, an analytically based operational capability process results in the identification of *capability gaps* for a given end to end mission thread. The resulting capability gaps become expressed in terms of *functional* requirements, *interaction* requirements and *performance requirements* for the optimal "pack" of systems and distributed services.

Cost of Interoperability Failures after Shipboard Deployment

According to the study conducted by NIST[2] (the National Institute of Standards and Technology) as depicted the figure below. the cost of error correction after product release is thirty times more expensive than at the requirements stage time of a system life cycle.

Requirements Gathering and Analysis/ Architectural Design	Coding/Unit Test	Integration and Component/RAISE System Test	Early Customer Feedback/Beta Test Programs	Post-product Release
1X	5X	10X	15X	30X

What is Interoperability? Everything works, but no one can communicate.

- Interoperability is the ability to exchange and use information. (Interoperability definition from: wordnet.princeton.edu/perl/webwn)[3]
- The use of the data is as important as is the exchange of the data.
- For example, are American telephones interoperable[4]? If two English speaking people call each other, then the answer is probably yes. They can exchange voice data and understand it. If a telephone user calls a wrong number and the person who answers only speaks Russian, then they are not said to be interoperable in that case. Please note that the phones worked properly, the voice data was precisely replicated at both ends of the call, but the voice data was unusable by the participants.
- We are expanding the definition of interoperability for systems as follows: systems are interoperable in clearly specified contexts (operational) such that all pre-existing constraints for data exchange and usage are met.
- For purposes of this paper, the clearly specified context is the mission thread. Thus, for our telephone example above, the system is interoperable for any two users who can effectively communicate given a functional technology.
- To summarize, without the operational context, everything works, but no one can communicate.

Definitions

- Capability[5] is defined as ability to perform actions. A requirement[6] is a singular documented need of what a particular product or service should be or do. A mission defines a specific goal to be achieved through a sequence of well orchestrated actions. For example, in order to carry out a mission to find and destroy enemy submarines, the mission participants would need the capability to detect, identify, and prosecute sub surface targets, (the action of detection, the action of identification, and the action of target destruction). In order to accomplish this mission, system of systems engineers will need to derive requirements for each activity to be successful. The sequencing of these activities in order to be successful constitutes a mission thread.
- Combining the total number of systems needed to satisfy the mission capabilities into a successful cohesive whole, is systems of systems engineering in a mission thread context.
- The ability of each system to provide useable data throughout the mission thread from an end to end perspective is known as systems of system interoperability engineering in an end to end mission thread context.

Fabrics Discussion

- The mission thread is the tool with which we weave composite fabrics that we call C4ISR[7] solutions.
- There can be time critical strike fabrics, surface warfare fabrics, interdiction fabrics, anti-submarine fabrics, etc.
- In geology, the term fabric describes the spatial and geometric configuration of all the elements that make up a particular rock[8].
- In mission thread centric, systems of systems architectures, the multiple layers of: interfaces; systems; composeable data consuming services; fusing services; applications; systems; platforms; communications and networks capabilities constitute the spatial and geometric configurations of the elements of the architectural fabric.
- In simpler terms, we are using the term fabric to identify a set of architectures used to construct a system of systems architecture, or a SoS fabric if you will.
- The set of systems required to deliver an operational capability is also known as an end to end architecture.
- We chose the term fabric because the authors find it confusing to use the term architecture to simultaneously describe anything from a simple software system, to PC internals (the CPU architecture for example), or an entire set of communications architectures, network architectures or DODAF SV-6 architectures, etc.
- The set of capabilities delivered by multiple, integrated end to end architectures are operational fabrics.

More on Interoperability

- *Interoperability*[9] "would seem to be a straightforward concept. Put simply, interoperability is a measure of the degree to which various organizations or individuals are able to operate together to achieve a common goal.
- From this top-level perspective, interoperability is a good thing, with overtones of standardization, integration, cooperation, and even synergy.
- Interoperability specifics, however, are not well defined. They are often situation-dependent, come in various forms and degrees, and can occur at various levels—strategic, operational, and tactical as well as technological.
- They are also far more likely to be recognized when interoperability problems emerge and taken for granted when such problems do not". Remember the telephone example mentioned above.

Introducing CBEF

- The failure of any of the key pieces in any portion of the composite fabric prevents the desired capabilities from emerging. The most commonly identified failure in composing end to end mission thread operational fabrics is interoperability.
- The authors of this paper believe that operational interoperability issues can best be addressed by a ***capability based engineering framework or CBEF.***
- This framework is designed to enhance the acquisition life cycle. We are hoping that operational fabric analysis or system of systems architecture analysis will occur prior to specification development.

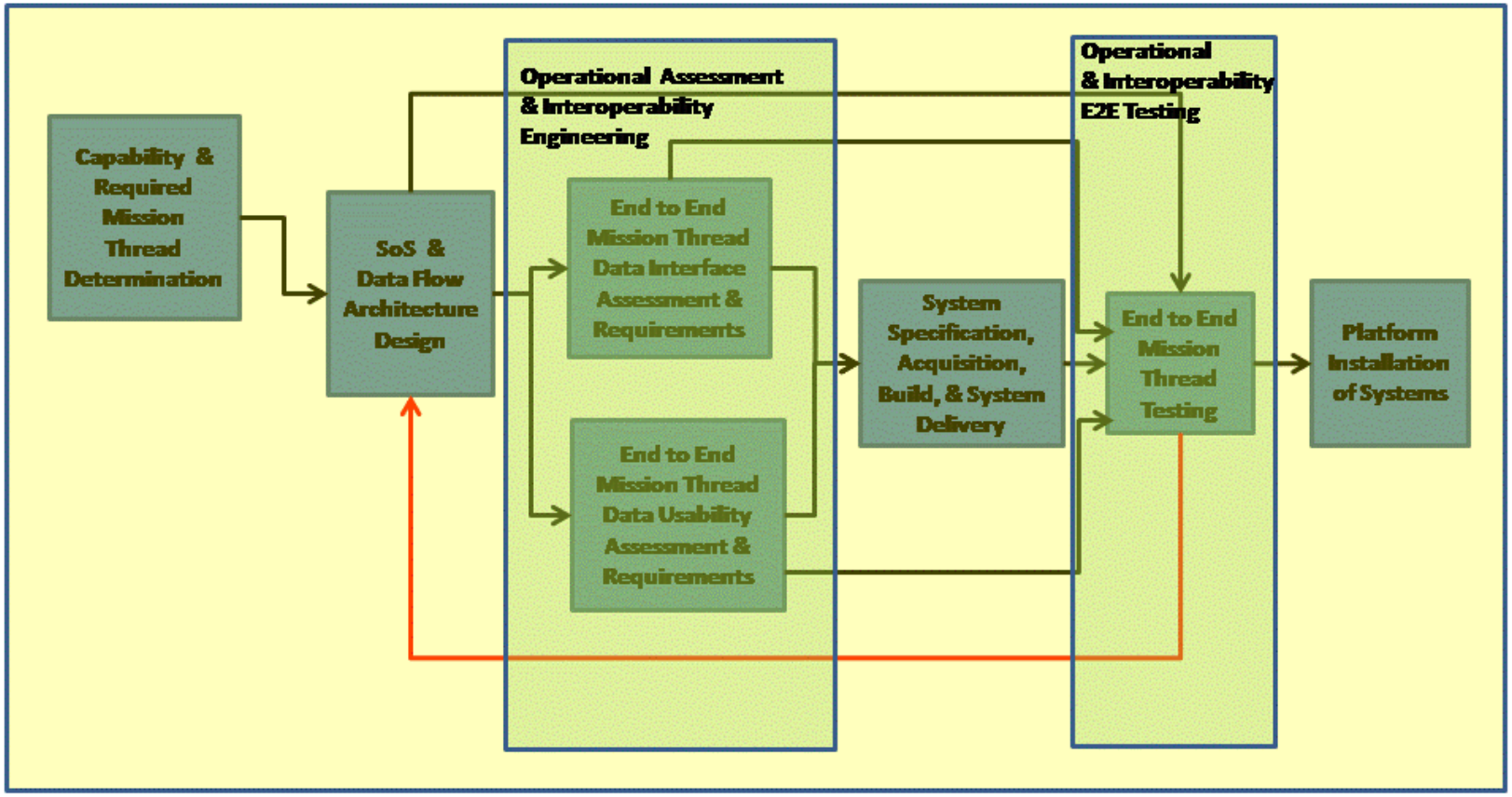
What is CBEF?

- SPAWAR Systems Center Atlantic has developed several toolkits designed around capability based engineering assessments.
- The SPAWAR toolkits also focus on data usage. This permits a greater possibility of reducing or solving interoperability problems.
- The set of these toolkits is collectively known as the capability based engineering framework.
- The toolkits consist of several knowledge bases and intelligent user assistants.
- Our knowledge bases have mapped the Joint Capability Areas (JCA), service specific capabilities lists (NMTLS, UJTLS, etc.) common system function lists (CSFL), and other authoritative data sources to platforms and systems.

CBEF Discussion

- Our team believes that this constitutes a professionalization of interoperability requirements engineering since operational and interoperability needs will be procured rather than 'fixed in the field'.
- Please remember the goal of CBEF is to reduce the risk of discovering expensive interoperability issues after the deployment of the newly developed system(s) on military platforms. Our CBEF process provides an environment which serves two specific interoperability related purposes:
  - ***Engineering interoperability requirements into initial specifications***
  - ***Reverse interoperability engineering after post deployment issues are identified.***

Capability Based Enterprise Systems Interoperability Engineering Process



CBEF Discussion Continued

- The model above emphasizes several key features of the CBEF process.
- First, we introduce a system of systems engineering activity prior to system acquisition.
- The SoS activity is followed by a detailed analysis of data flows and their corresponding interfaces along with a data usability assessment associated with each downstream mission thread consuming system or human activity.
- This would permit interoperability data to appear in the system specification prior to contract award.
- This activity includes two specific interoperability functions:
  - ***end to end mission thread data flow modeling which will produce data interface requirements as it outputs (at a SoS level);***
  - ***end to end mission thread data usage model (to satisfy the formal interoperability definition requirements of data exchange and usability).***

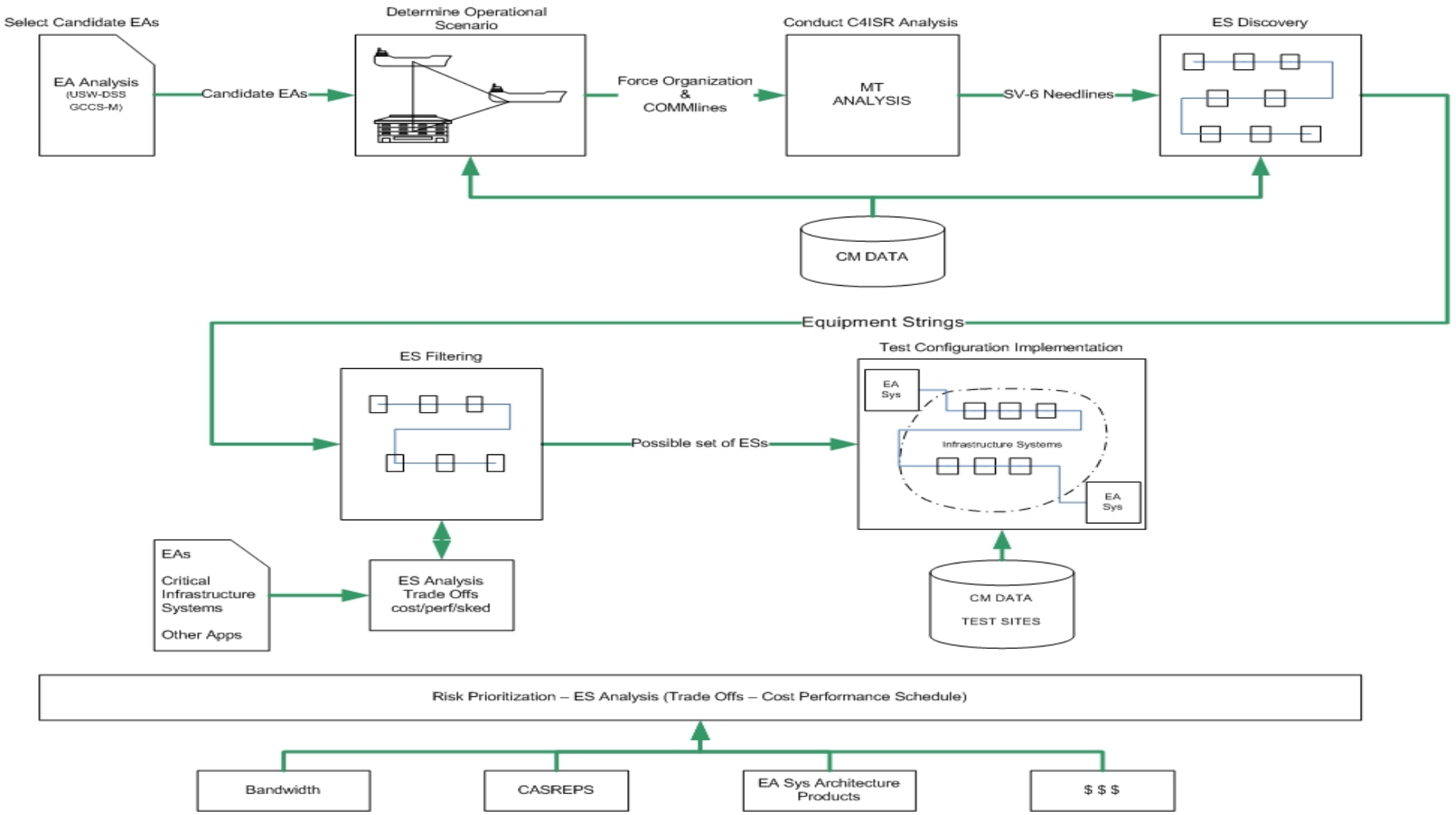
CBEF Methodology

- We believe that mapping capabilities to mission threads, followed by a process of identifying the required individual systems, services, system collections, and statistically relevant data flows, can lead to impressive results in terms of reducing interoperability risk.
- By focusing on the capability and the associated mission threads needed to provide that capability, interoperability becomes manageable at least at the data interface level. However, this still leaves open the questions surrounding data usage
- Here we believe that an important step has been missing from most SoS and other System Engineering protocols: How is the data actually used in an operational environment?
- For example, suppose that sensor data is processed by several composed service oriented architecture (SOA) functions, each function using different fusion algorithms then presenting that data to track processors for use by a commander. Can the commander actually have enough confidence in the fused data such that he could authorize weapons launch?
- If the publishers of the sensor data understood its 'downstream usage', pedigreed meta data could be added to facilitate C2 decisions based upon that data. But it would need to be designed into the specifications or SLAa.

CBEF Methodology for Data Usage Capture

- The CBEF methodology provides for a mechanism to permit the capture of system and data usage such that ***data flow patterns*** are ***understood*** in terms of ***data usage patterns***.
- Mission Thread Operational Workstations can be Monitored by Special Equipment, such as Eye Tracker, to capture actual operational behaviors in terms of decisions, decision patterns, watch station usage patterns, etc.

CBEF Interoperability Test Process



CBEF Interoperability Test Process Steps

- Step 1 – Select candidate Enterprise Architectures (EA) to construct a fabric model
- Step 2 – Define the Operational Scenario
- Step 3 – Conduct Mission Thread and Individual Systems Analysis
- Step 4 – Perform Equipment String Discovery
- Step 5 – Perform Equipment String Filtering
- Step 6 – Design a test configuration and execute the test

Future CBEF Directions

SoS Type[10]	Definition	Currently CBEF Supported	Future CBEF Capability
Virtual SoS	Virtual SoS, lack a central management authority and a centrally agreed upon purpose for the system-of-systems. Large-scale behavior emerges	Yes	Improve Current Analytical Tools to Include Hybrid Architectures – Legacy- SOA- ESB – Event Driven - Coalition
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.	Partially	Improve Current Analytical Decision Modeling Tools to Support Interoperability Data Usage Pattern Analysis at the Collaborative Level
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.	Partially	Attempting to change the Procurement Process Model to Permit Independent Ownership to be Maintained but to increase the Specification Details at Procurement Time to Include Interoperability Requirements
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.	No	This model implies Evolutionary Capability Emergence. This would require automated assessment tools to permit faster identification of interoperability issues and possible meta data improvements or the creation of a formal interoperability markup language

Summary

- The following key points were addressed by this paper.
  - Interoperability is defined as the interfacing and usage of data. We expanded the definition of interoperability for systems as follows: systems are interoperable in clearly specified contexts such that all pre-existing constraints for data exchange and usage are met.
  - Interoperability issues are expensive to resolve after systems are deployed on platforms.
  - SPAWAR Systems Center Atlantic has developed a capability based engineering framework (CBEF) which will permit capture of interoperability requirements at system specification time during the acquisition cycle.
  - The CBEF methodology provides for a mechanism to permit the capture of system and data usage such that data flow patterns are understood in terms of data usage patterns.
  - CBEF also provides for an interoperability reverse engineering methodology by analyzing capabilities in an end to end mission thread such that interoperability issues can be resolved.
  - We have also presented the future direction for CBEF

References

1. Charles, Phil, personal correspondence, capability based engineering frameworks discussions.
2. "NIST Planning Report 02-3, "The Economic Impacts of Inadequate Software Infrastructure for Software Testing", May 2002, page 94
3. Interoperability definition from: wordnet.princeton.edu/perl/webwn
4. Campbell, Victor, personal correspondence
5. Baldwin, Kristen, "Defense View on Considerations for System of Systems SE", 25 October 2006
6. "Defense View on Considerations for System of Systems SE", 25 October 2006
7. Command, Control, Computers, Communications, Intelligence, Surveillance, and Reconnaissance
8. Source: wikipedia.org/wiki/Fabric (geology)
9. "Interoperability of US and Allied Forces: Focus on C3ISR", MR1235, Rand Corporation, 2000, chapter 2
10. Systems Engineering Guide for Systems of Systems, Version 1.0 , August 2008, Office of the Deputy Under Secretary of Defense for Acquisition and Technology, Systems and Software Engineering. Systems Engineering Guide for Systems of Systems, Version 1.0. Washington, DC: ODUSD(A&T)SSE, 2008, page 17