Tutorial Summary: Challenges in Building Net-Centric System-of-Systems

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Agenda for Summary

- Introduction
  - Motivation for net-centric solutions
  - What makes net-centric different?
- Systems-of-systems (SoS)
- Interoperable Acquisition
- Unresolved issues
- Recommendations

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Introduction

Motivation For Net-Centric Solutions

- **Why is net-centricity worth changing every aspect of how systems have been developed, acquired, deployed, and sustained?**
- **Simple: the traditional systems approach to fielding capability cannot cope with the realities of a dynamic, multipolar geopolitical environment and rapidly-changing technology and threats.**
  - **You can't state with confidence what operational environment a given system may be required to perform in two years down the road, much less 15-20!**

What Makes Net-Centric Different?

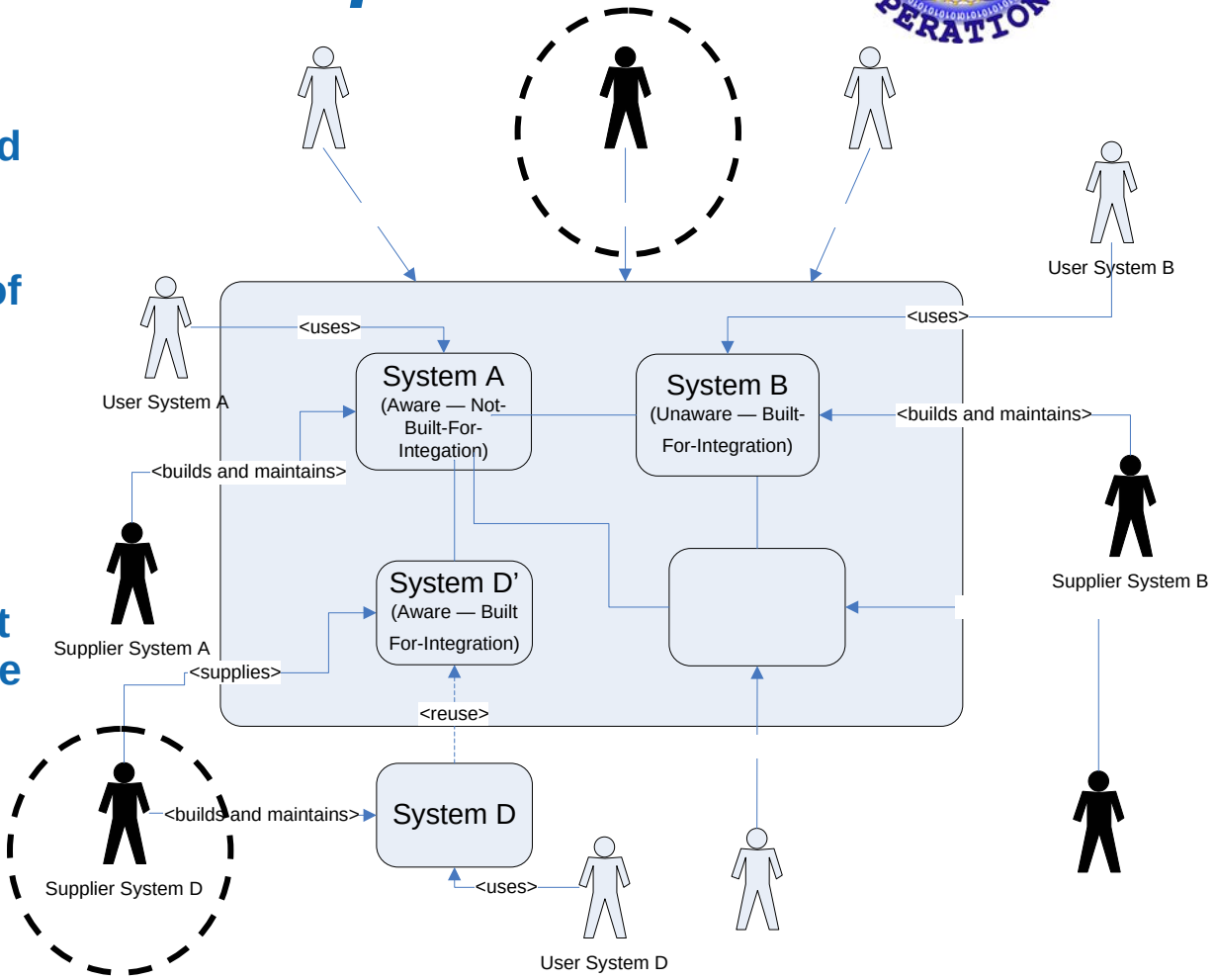
- **In short … *everything!***
  - **Emphasis shifts from platform (e.g., ship, aircraft, brigade) to capability (e.g., area interdiction, SEAD, etc.)**
  - **Capability is no longer the product of a single platform/system, but now requires the participation of multiple constituents within a system-of-systems (SoS)**
  - **Multiple capabilities involve multiple, overlapping SoS: one constituent may actively participate in multiple capabilities, with different roles**
- **Just as designing for flexibility and dynamic composability is a challenge, so is planning and managing—(almost) everything you know is wrong!**

From "Science and Technology to Support FORCEnet," Raytheon TD-06-008. Used by permission.

System-of-Systems (SoS)

System-of-Systems (SoS): Context and Role Viewpoints

- **Context 1: "orchestrated SoS"**
  Someone is attempting to orchestrate a bunch of systems (e.g., a LSI)
- **Context 2: "collaborative SoS"**
  I'm trying to be part of a topology, but don't necessarily know what it is and no one's in charge
- **Role A: "an integrator"**
- **Role B: "a constituent"**



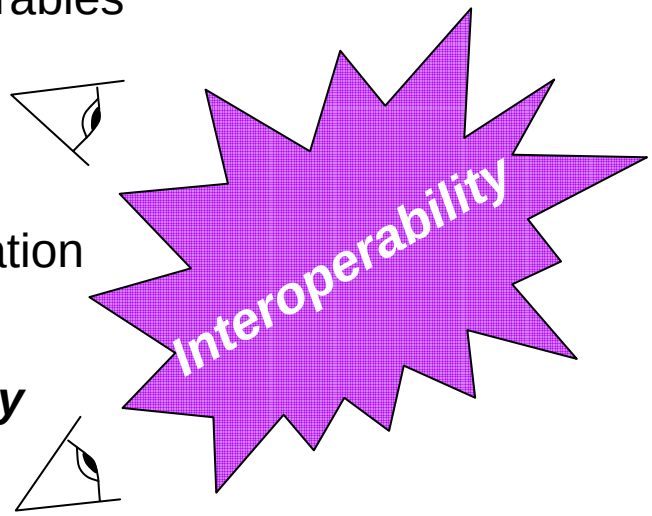
SoS Involves Multiple Perspectives

Management Perspective

- Time-phasing of deliverables
- Effects of delays
- Funding and budget
- Risk management
- Multi-supplier coordination
- etc.

Development/Assembly Perspective

- Architecture
- Systems/capabilities "mix"
- Development-based AND assembly-based construction
- Testing
- etc.



Operational Perspective

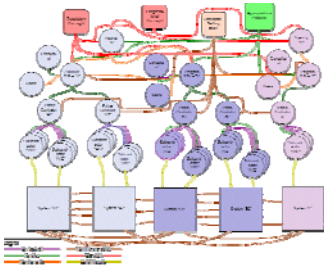
- Operational stakeholder needs
- Concept of operations
- Deployment and support
- etc.

Achieving SoS interoperability requires coordination with a diverse set of stakeholders—often across multiple organizations

Influence Relationships

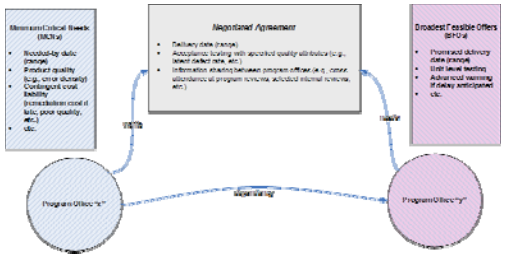
Relationships exist at multiple levels:

SoS-wide …



Near-neighbor …

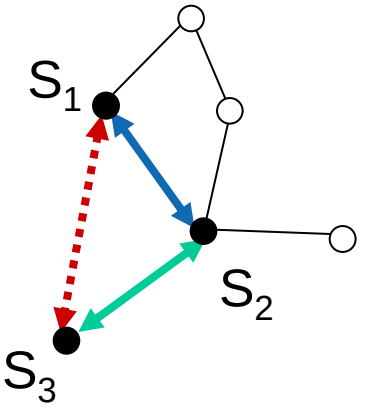
and arc-level …



Emergent Effects

- Relationships exist where constituents influence one another
- Sequences of direct neighbor interactions often generate indirect ("transitive") effects between distant constituents
- Indirect effects often cascade
  - Detailed steps often unpredictable and difficult to envision
  - Cumulative effects can be predictable
  - These emergent effects define character and utility of resulting SoS

SoS risks may not be apparent for individual constituents or by analyzing only "near neighbor" interactions



- ***S_1 has a backwards compatibility relationship with S_2***
- ***S_3 has a schedule dependency on S_2***
- ***S_1 and S_3 are indirectly related through S_2***

Summary of Characteristics of SoS

- Systems of systems are complex due to:
  - Independent operations and management of autonomous constituents
  - Independent evolution of constituents
  - Indirect, cascading, and emergent effects
- Traditional methods and approaches are inadequate:
  - Limited effectiveness of centralized control, hierarchical structures
  - Interdependence among acquisition, development, operations, sustainment, and evolution often ignored

SoS Design Challenges: Critical FORCEnet Information Infrastructure Functional Capabilities[1]*

1. **Reliable wideband mobile communications**
2. **Information management**
3. **Situation awareness and understanding**
4. **Information assurance**
5. **Modeling and simulation**
6. **Dynamic composability and collaboration**
7. **Support of disadvantaged user-personnel, platform or sensor**
8. **Persistent intelligence, surveillance, and reconnaissance**

Decision Making is contained in many of the capabilities

From "Science and Technology to Support FORCEnet," Raytheon TD-06-008.
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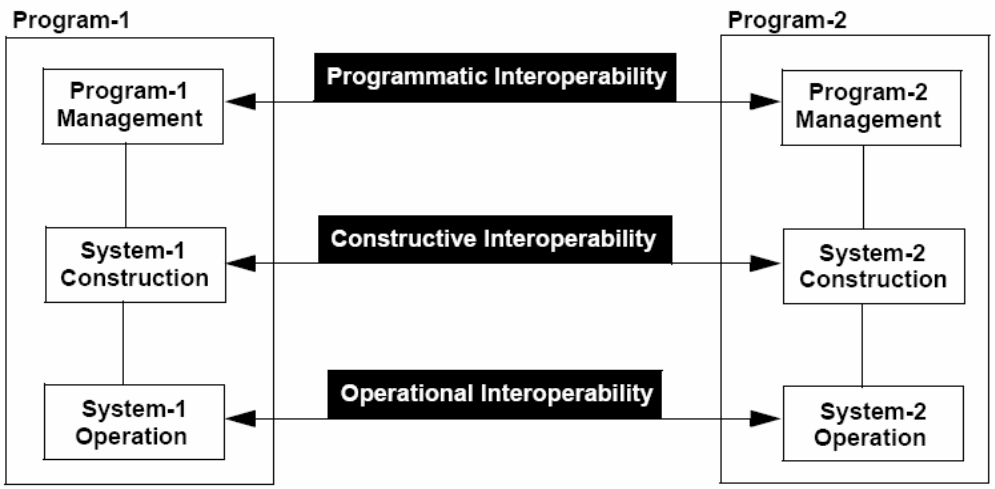
Interoperable Acquisition

Interoperable Acquisition$_1$

- **Interoperability comprises multiple dimensions*:**



- **Suitable acquisition practices are necessary to achieve interoperability**

*From *System of Systems Interoperability*, CMU/SEI-2004-TR-004

Interoperable Acquisition$_2$

- **Key principles:**
  - **No one stakeholder group or individual can have complete SoS insight**
  - **“Central control” has limited effectiveness; distributed control is essential**
  - **SoS capabilities and properties emerge from the influence of cumulative, indirect effects of local actions and near neighbor interactions**
  - **Broader set of stakeholders, including users, must be directly involved throughout the life of a SoS**
  - **Local decisions and reward systems must be tempered by understanding of SoS purpose and goals**

Unresolved Issues

Unresolved Issues

- **The FORCEnet study identified gaps in eight critical technology areas. In addition, there are some software-specific technology gaps which warrant further examination:**
  - **Web services**
  - **Service-oriented architectures (SOA)**
- **The limitations of existing systems engineering and management practices fall short of the requirements for interoperable acquisition:**
  - **Cost and schedule estimating and tracking**
  - **Understanding/predicting/mitigating emergent effects (including transitive and cascading effects)**

Unresolved Issues: Estimating and Tracking

- **Several technologies under development:**
  - **Modeling cost and schedule using COSOSIMO, COSYSMO, COCOTS, etc.**
  - **Modeling cost and schedule using SoSIP**
    - **Accounts for organizational and programmatic relationships, as well as emergent behaviors**
  - **Identifying critical points in migrating from legacy systems to service-oriented architectures**
  - **Exchange theory-based transactional cost modeling**
    - **Multivariate regression analyses based on collection of ACAT I program estimates and actuals**

Recommendations

Recommendations$_1$

- **No easy answers, but there are some steps you can take**
- **The *only* absolute is that continuing to do what you've done in the past—for system acquisition, design/development, deployment, sustainment, and operation—is a recipe for failure**

Recommendations$_2$

- **Adopt a net-centric "friendly" engineering/ management approach**
  - **"Central-office," hierarchical structures won't work**
    - **Need to understand influence relationships and emergence**
  - **Avoid "big bang" development approaches: use risk-driven spiral or iterative lifecycle**
    - **Also beware of the "prolonged train wreck," which is often passed-off as "spiral" or "iterative" development: it is neither**

Recommendations$_3$

- **Cost and schedule estimating is a challenge**
  - **Recognize that SoS cost estimating is a very immature science/art: you need to begin—NOW—to understand how SoS realities impact your organization's cost and schedule estimates**
  - **Adopt work-breakdown structures and earned value measurements suitable for spiral development***

*See *Using Earned Value Management (EVM) in Spiral Development* (CMU/SEI-2005-TN-016) for a discussion.

Recommendations$_4$

- **Design with change in mind: don't presume that the operational context that your system will actually be used in will remain the same**
  - **Don't assume that you will have reliable communications (or unlimited bandwidth, zero latency, etc.)**
  - **Don't assume that your system will be used in a well-defined, bounded environment—the internet (or NIPRnet/SIPRnet, etc.) changes everything**

Recommendations$_5$

- **Several critical net-centric technologies are immature**
  - **Don’t assume that just because you have all the requisite checks in the proper boxes in the NR-KPP checklist that your system will actually work as intended in a net-centric environment**
  - **Make the investments to keep abreast of emerging technologies (and to understand their limitations)**

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Integration of Software-Intensive Systems (ISIS) Initiative

http://www.sei.cmu.edu/isis/index.html

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