System Interoperability Influence on System of Systems Engineering Effort

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SoSE Collaborators Information Exchange

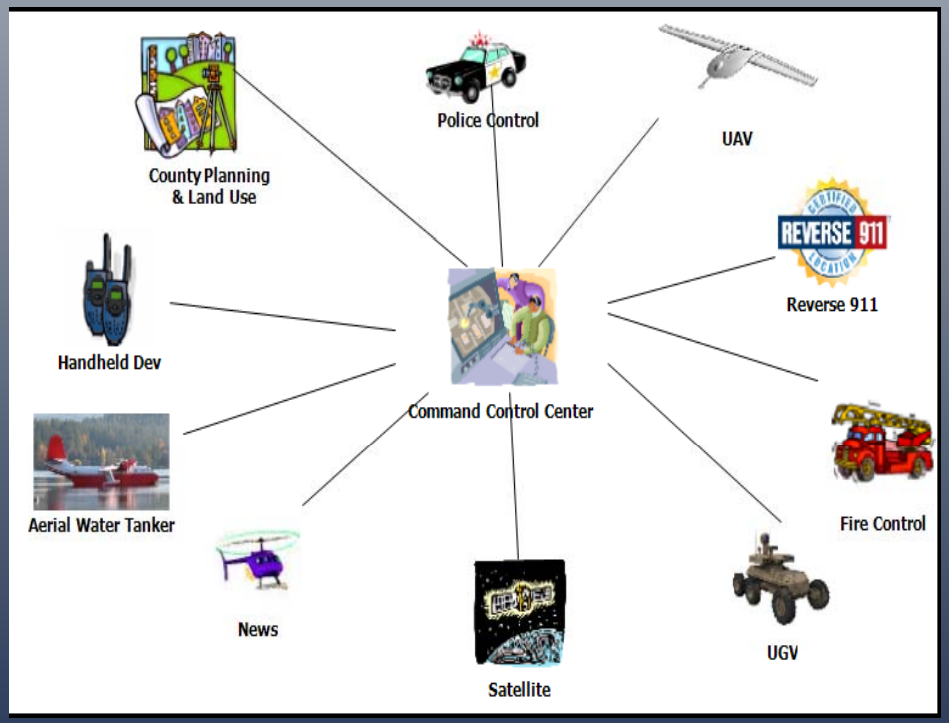
San Diego Cedar Fire

Reported: 5:37 p.m., Saturday, Oct. 25, 2003
Extinguished: Dec. 5, 2003
Deaths: 14 civilians, 1 firefighter
Injuries: 113 firefighters
Damage: 2,232 residences (destroyed)
22 commercial properties (destroyed)
566 outbuildings (destroyed)
53 residences (damaged)
10 outbuildings (damaged)
148 vehicles (destroyed)
Acreage Burned: 273,246
Firefighting Cost: $32 million

Source: http://interwork.sdsu.edu/fire/resources/fire_facts.htm

SoS Interoperability

- Definition
  - The ability of systems, units, or forces to provide services to and accept services from other systems, units, or forces and to use the services so exchanged to enable them to operate effectively together (DoD 1977 definition)
- Challenges
  - How to understand current level of interoperability
  - How to best communicate across a given set of systems/platforms
  - How to manage protocols and interfaces in general as systems come and go in SoSs
  - How to estimate systems engineering effort to provide/enhance interoperability



Common Approaches for Addressing Interoperability

- Conversion techniques
  - Point-to-point data conversion/synchronization
  - Data conversion between constituent systems through a general framework (service-oriented architectures)
- Standardization techniques
  - Standardization of interface protocols or “convergent” protocols
  - Standardization of data formats

Survey of Interoperability Models*

- Spectrum of Interoperability Model (SoIM)
- Quantification of Interoperability Methodology (QoIM)
- Military Communications and Information Systems Interoperability
- Levels of Information System Interoperability Model (LISI)
- Interoperability Assessment Methodology (IAM)
- Organizational Interoperability Maturity Model for C2 (OIM)
- Stoplight
- Levels of Conceptual Interoperability Model (LCIM)
- Layers of Coalition Interoperability (LCI)
- NATO C3 Technical Architecture Reference Model for Interoperability (NMI)
- System-of-Systems Interoperability Model (SoSI)
- Non-Technical Interoperability Framework (NTI)
- Organizational Interoperability Agility Model (OIAM)
- Layered Interoperability Score (i-Score)

* Ford, T., Colombi, J., Graham, S., and Jacques, D. "A Survey on Interoperability Measurement." *Twelfth International Command and Control Research and Technology Symposium (12th ICCRTS)*, Newport, RI, June 19-21 2007

Survey of Interoperability Models (continued)

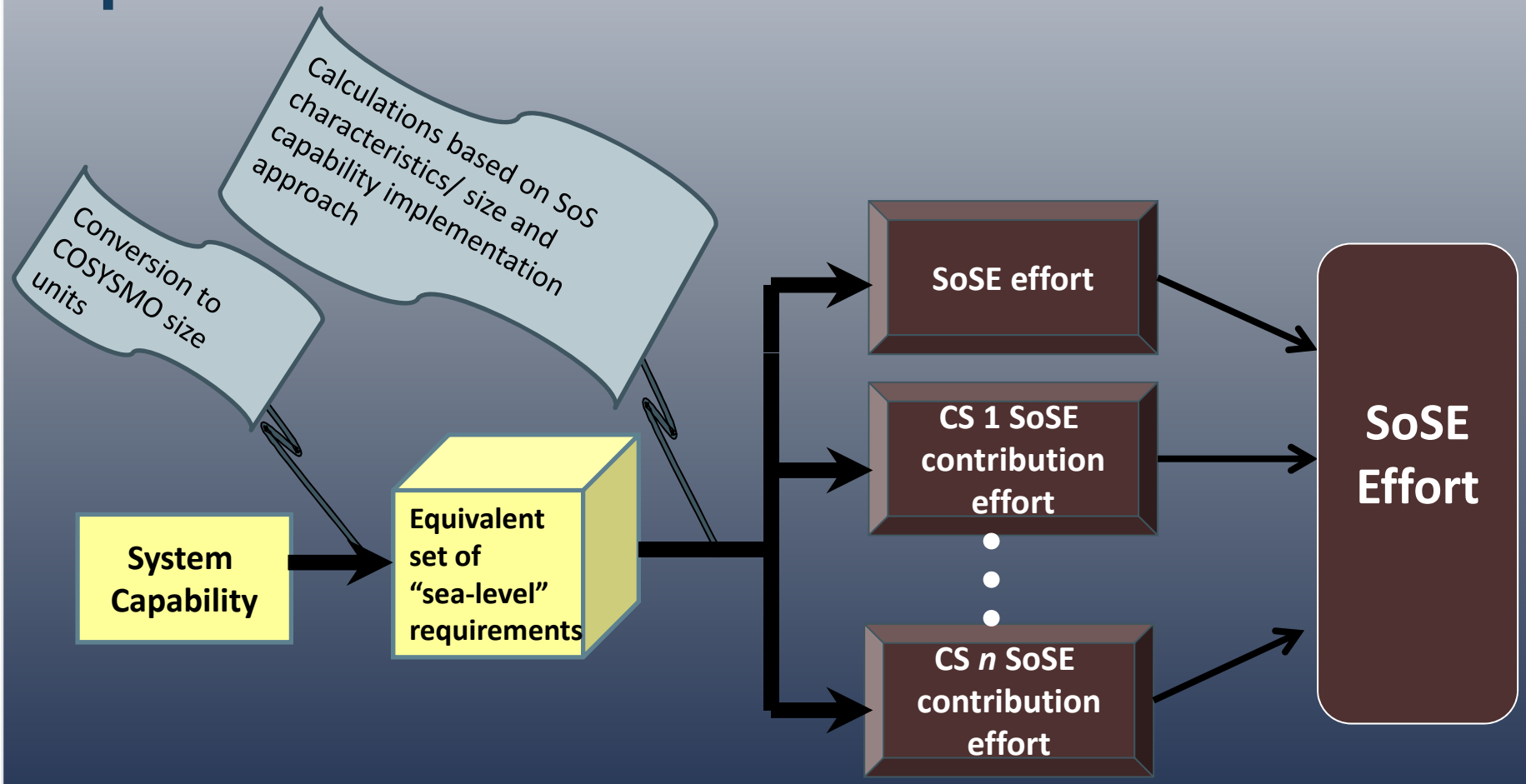
- Types of interoperability
  - Technical
  - Governance
  - Operating procedures
  - Training
  - Usage
- Results of comparative analysis of models
  - Focus on interoperability of information systems
  - Several models are refinements or extensions of earlier models
  - Little evidence that models have been institutionalized to any great extent
  - MITRE LISI model referenced in the DoD CJCSI 6212.01C interoperability instruction but later dropped in CJCSI 6212.01D

Total Engineering Costs for SoSs

- ***SE for SoS capabilities***
- SE for single system capabilities
- Software development
  - Single systems
  - SoS infrastructure
- Investments in
  - Flexibility
  - Other “ilities”
- Platform/hardware development
- Maintenance including technology upgrades
- Savings from expedited development
- Technical debt realized from shortcuts

Focus for interoperability cost influence research…

Estimating SE Costs for SoS Capability Options: COSYSMO Extensions for SoS



Applies reuse factors, different cost factors for each engineering organization at each system level, and diseconomy of scale for SoS and CS-level requirements implemented in the same upgrade cycle…

Constructive Systems Engineering Cost Model (COSYSMO)*

CO SYS MO 1.0

CONSTRUCTIVE SYSTEMS ENGINEERING COST MODEL

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ENTER SIZE PARAMETERS FOR SYSTEM OF INTEREST

	Easy	Nominal	Difficult	
# of System Requirements				0
# of System Interfaces				0
# of Algorithms				0
# of Operational Scenarios				0
				0

equivalent size

SELECT COST PARAMETERS FOR SYSTEM OF INTEREST

Requirements Understanding	N	1.00
Architecture Understanding	N	1.00
Level of Service Requirements	N	1.00
Migration Complexity	N	1.00
Technology Risk	N	1.00
Documentation	N	1.00
# and diversity of installations/platforms	N	1.00
# of recursive levels in the design	N	1.00
Stakeholder team cohesion	N	1.00
Personnel/team capability	N	1.00
Personnel experience/continuity	N	1.00
Process capability	N	1.00
Multisite coordination	N	1.00
Tool support	N	1.00
		1.00

composite effort multiplier

SYSTEMS ENGINEERING PERSON MONTHS 0.0

* http://cosysmo.mit.edu/

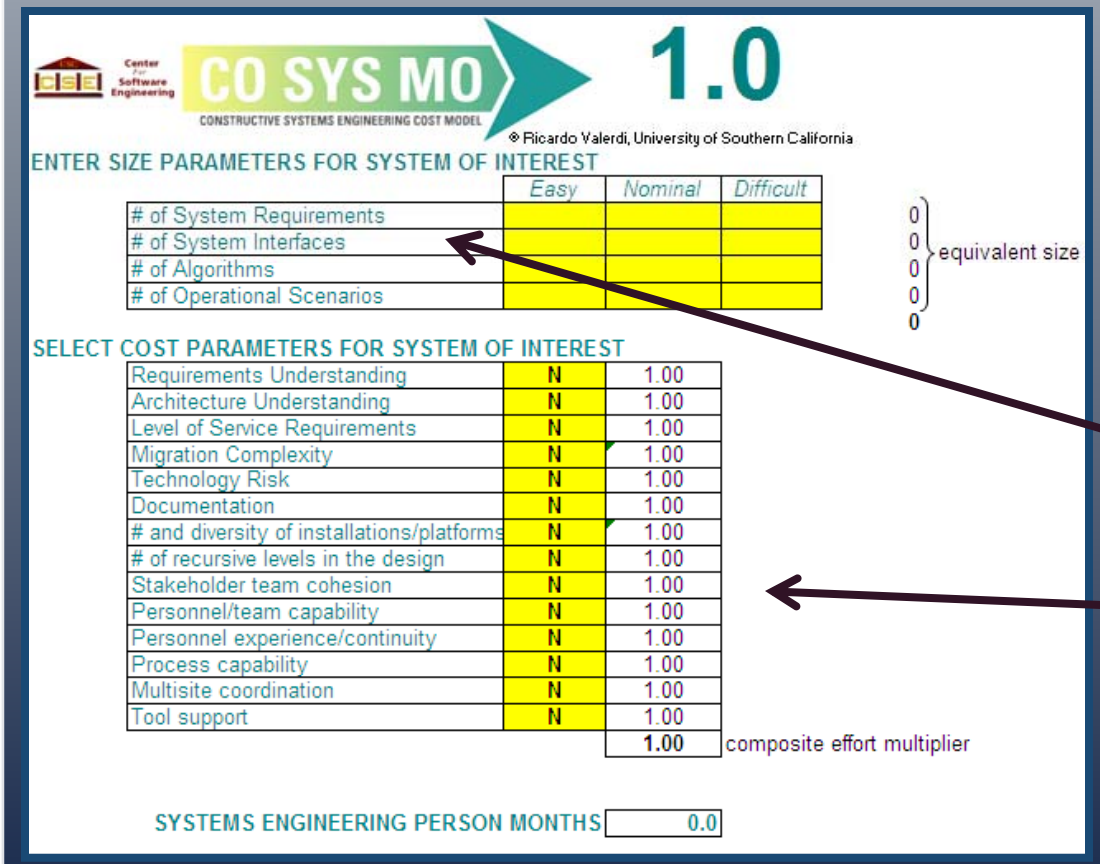
Interoperability Model Applicability to SoSE Cost Estimation

- Types of interoperability models of most interest to SoSE cost estimation
  - Mature model(s)
  - Technical focus
    - New systems
    - Upgrades to existing systems
- Interoperability models identified to support cost estimation
  - MITRE LISI model for development of new capability using existing systems
  - LCIM for systems in the conceptual phase of development

Overview of LISI and LCIM

- **LISI model**
  - Best suited for measuring existing information system interoperability
  - Five interoperability levels: Isolated, Connected, Functional, Domain, Enterprise
  - Each level has four attributes: Procedures, Applications, Infrastructure, Data
  - Outputs:
    - Highest common level of interoperability between two systems
    - Matrix visualization of the interoperability of a group of systems
- **LCIM model**
  - Similar to LISI, but used in early conceptual stages
  - Levels: None, Technical, Syntactic, Semantic, Pragmatic, Dynamic, Conceptual

Constructive Systems Engineering Cost Model



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Options for interoperability factor

1. Interoperability assessment as part of interface size driver (exponential influence)
2. Interoperability effort adjustment factor (linear influence)

Interoperability Effort Adjustment Factor

Levels of Effort/Complexity for SoS Interoperability

Type of Development	Level				
	Very Low	*Low*	*Nominal*	*High*	*Very High*
Existing systems (based upon LISI levels)	**Isolated**	**Connected**	**Functional standards employed**	**Domain standards employed**	**Enterprise standards employed**
New system(s) (based upon LCIM conceptual levels)	**System-specific data**	**Documented data**	**Aligned static data**	**Aligned dynamic data**	**Harmonized data**

Interoperability Assessment as Part of Interface Size Driver

Level of Complexity

Number of System Interfaces Rating Scale

	Easy	Medium	Difficult
Existing	Simple messages and protocols	Moderate communication complexity	Complex protocol(s)
Existing	Uncoupled	Loosely coupled	Tightly coupled
Existing	Strong consensus among stakeholders	Moderate consensus among stakeholders	Low consensus among stakeholders
Existing	Well behaved	Predictable behavior	Emergent behavior
Proposed	***Domain or enterprise standards employed***	***Functional standards employed***	***Isolated or connected systems with few or no standards***

Four Years Later in San Diego

Witch Creek Fire 2007

Started: October 21 at 11:00 a.m.
Acreage burned: 197,990
Damage:
- Structures destroyed:
  - 1,040 homes
  - 414 outbuildings
  - 239 vehicles
- 70 homes damaged
- 25 outbuildings damaged

Deaths: 2
Injuries: 39 firefighters, 2 civilians
Firefighting costs: $11.3 million

Cedar Fire 2003 Comparison

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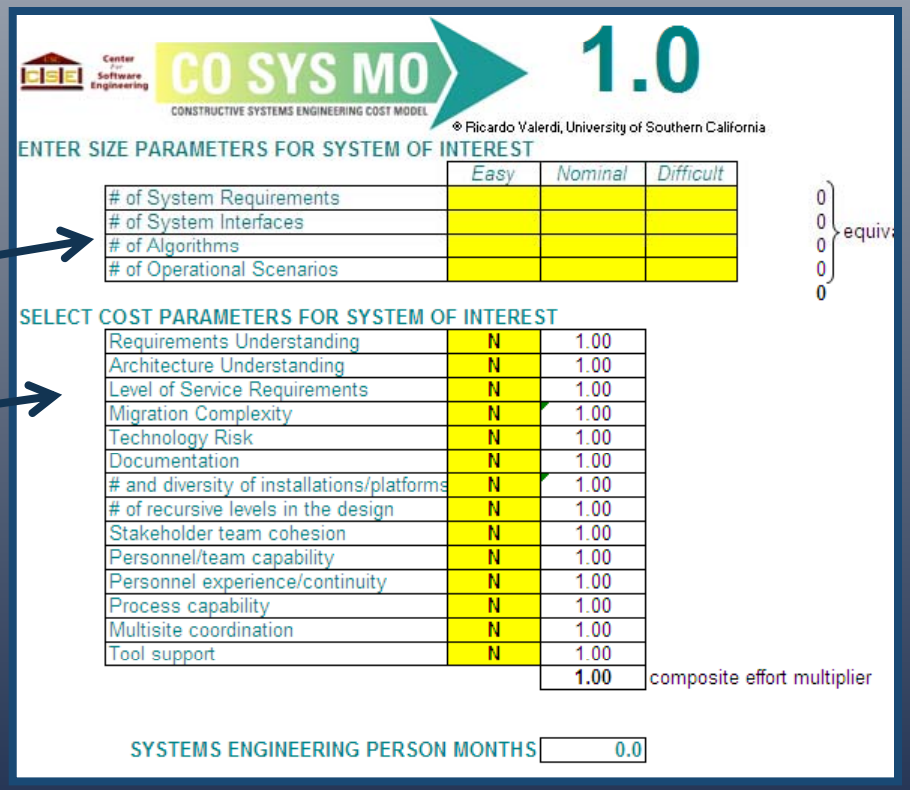
Source: http://en.wikipedia.org/wiki/October_2007_California_wildfires and http://www.goldenstatephoto.com/weather/ca/fires/witchcreekfire

Next Steps

- Determine how to best incorporate interoperability influence
  - Size driver (exponential influence)
  - Cost factor (linear influence)
  - Some combination of both
- Collect and analyze actual engineering effort data to determine levels of influence



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References for Additional Information

- J. Lane and R. Valerdi. System Interoperability Influence of System on Systems Engineering Effort, *Proceedings of the Conference on Systems Engineering Research*, 14-16 April 2011, Los Angeles, CA.
- J. Lane. Cost Model Extensions to Support Systems Engineering Cost Estimation for Complex Systems and Systems of Systems, *Proceedings of the Seventh Conference on Systems Engineering Research*, 20-22 April 2009, Loughborough, UK.
- Ford, T., Colombi, J., Graham, S., and Jacques, D. A Survey on Interoperability Measurement. *Twelfth International Command and Control Research and Technology Symposium (12th ICCRTS)*, 19-21 June 2007, Newport, RI.