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Systems of Systems: An Application for Systems Engineering or the Systems Engineering of the Future?

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Definitions

System of Systems

Set of systems that interact to provide a unique capability that none of the constituent systems can accomplish on its own. Each constituent system is a useful system by itself, having its own management, goals, and resources, but interacts within the SoS to provide the unique capability of the SoS

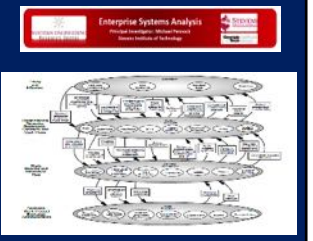
Systems of Systems Engineering

The process of planning, analyzing, organizing, and integrating the capabilities of a mix of existing and new systems into a system-of-systems capability that is greater than the sum of the capabilities of the constituent parts

Maier SoS Characterization

- Maier (1998) postulated five key characteristics of SoS:
  - Operational independence of component systems
  - Managerial independence of component systems
  - Geographical distribution
  - Evolutionary development processes
  - Emergent behavior

Scale and Scope of SoS



Technical ----- Socio -Technical ----- Enterprise

SoS Types

- **Directed**
  - SoS objectives, management, funding and authority; systems are subordinated to SoS
- **Acknowledged**
  - SoS objectives, management, funding and authority; however systems retain their own management, funding and authority in parallel with the SoS
- **Collaborative**
  - No top-down objectives, management, authority, responsibility, or funding at the SoS level; Systems voluntarily work together to address shared or common interest
- **Virtual**
  - Like collaborative, but systems don't know about each other

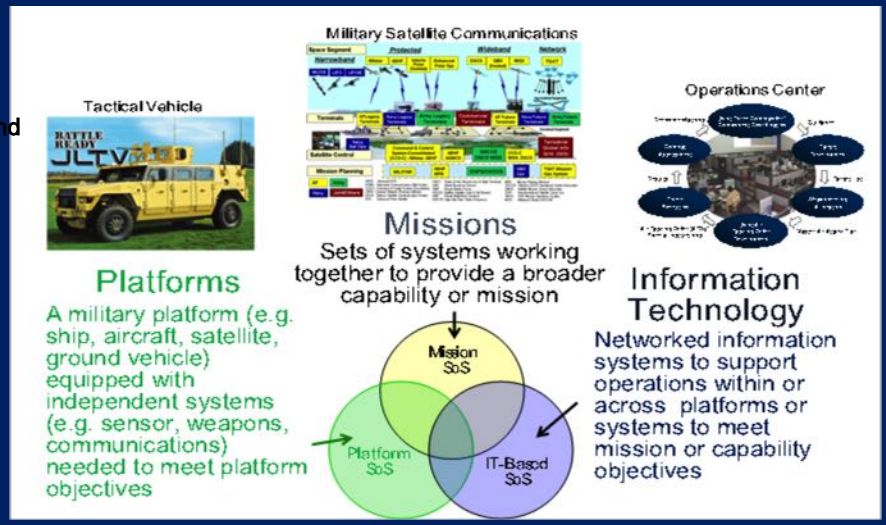
but are

and

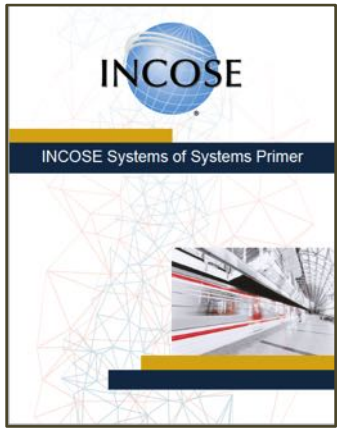
is

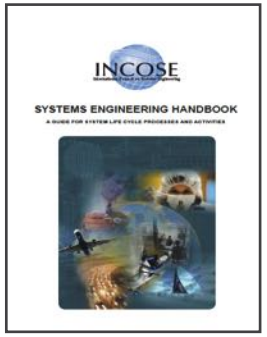
an SoS

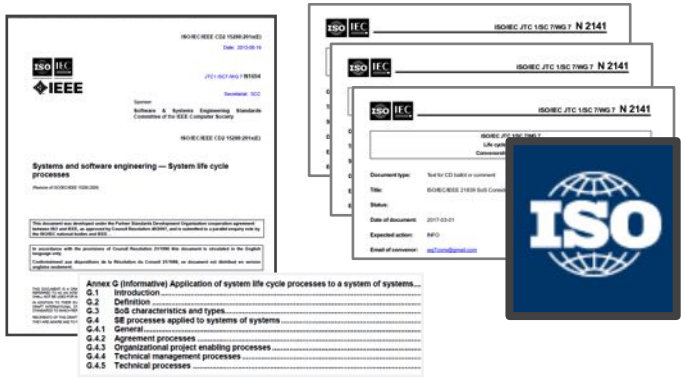
SoS Domain

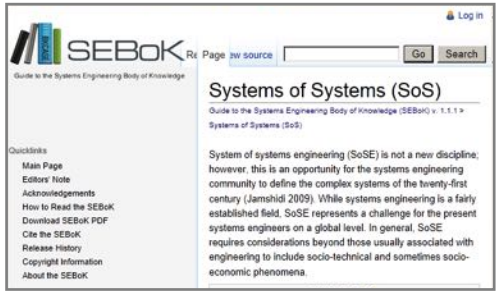


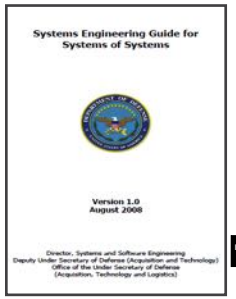
Application of SE to SoS

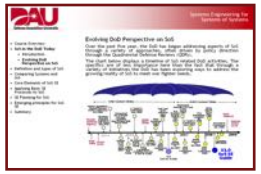


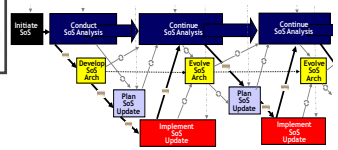


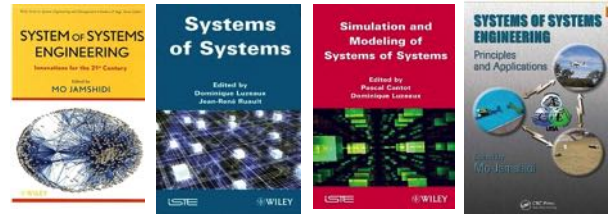






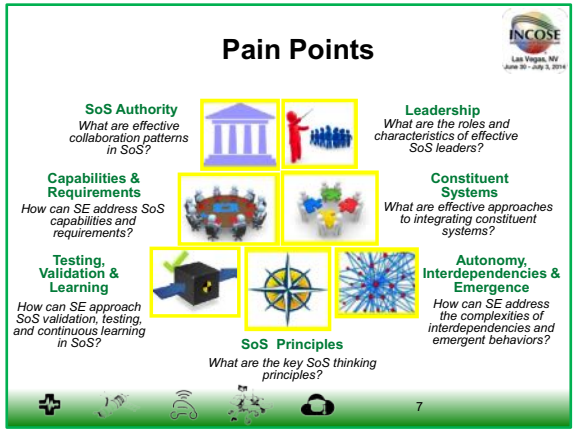






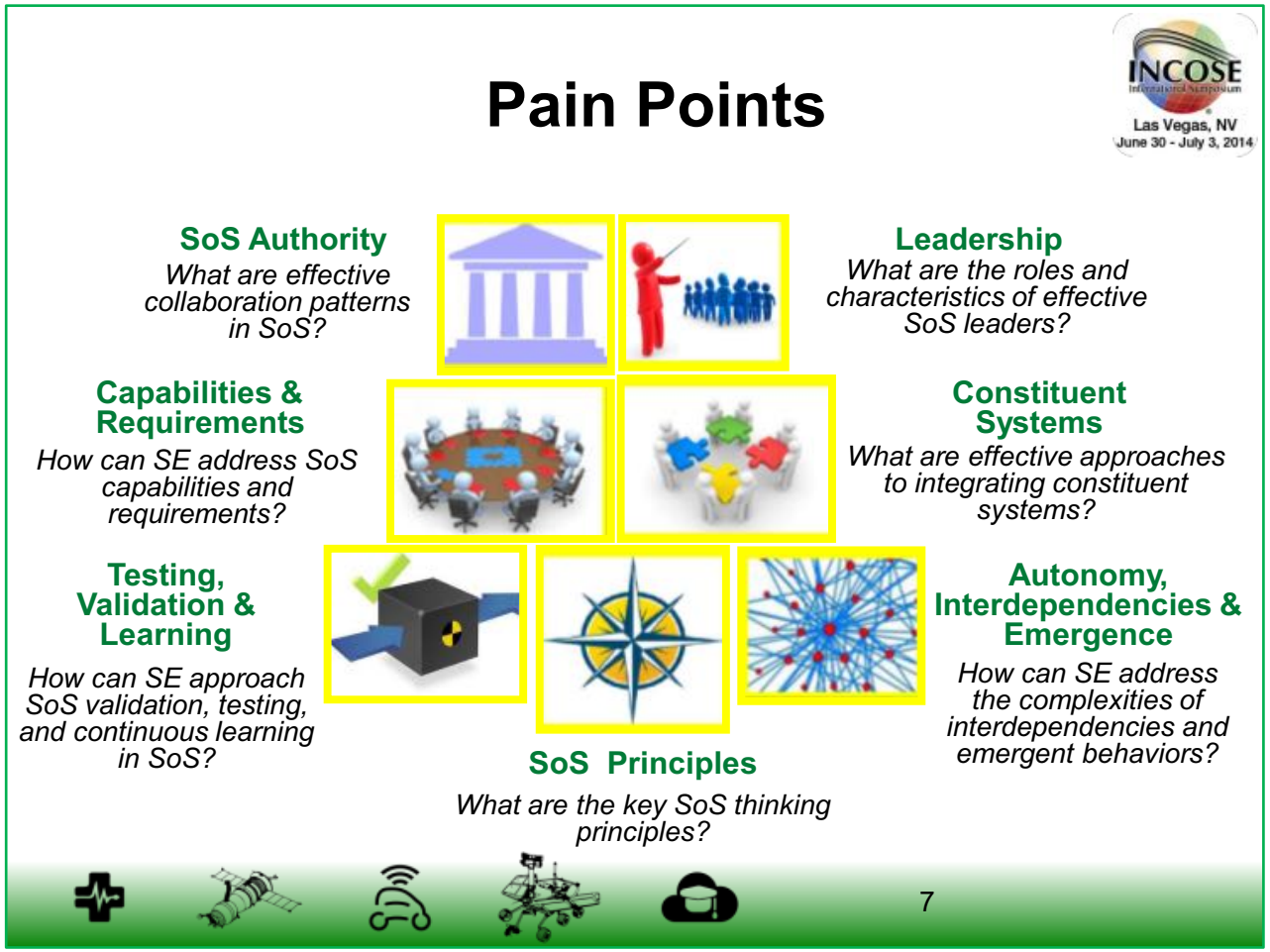
Characteristics of SoS and Impact on SoSE

- Ever since the subject of SoS was first addressed in the 1980s
  - Continuing dialog over the differences between systems and SoS and their implications for systems engineering of SoS
- Mark Maier's characterization of SoS has been a cornerstone of these discussions
  - Operational and managerial independence of systems comprising an SoS as the defining features of SoS and drivers for systems engineering them
- Continuing interest in questions
  - How do SoS characteristics affect the application of systems engineering principles and practices to SoS?
  - How does SoSE differ from 'traditional' systems engineering?



Characteristics of SoS and Impact on SoSE

- Characteristics of SoS influence how we apply SE to SoS with particular focus on
  - Collaborative patterns of engagement with need for SoS leadership
  - Understanding top-level SoS capabilities with the challenge of integrating constituent systems which may be changing independent of the SoS
  - Addressing complexities of interdependencies and emergence
  - Recognizing need for innovative approaches to SoS validation and continuous learning



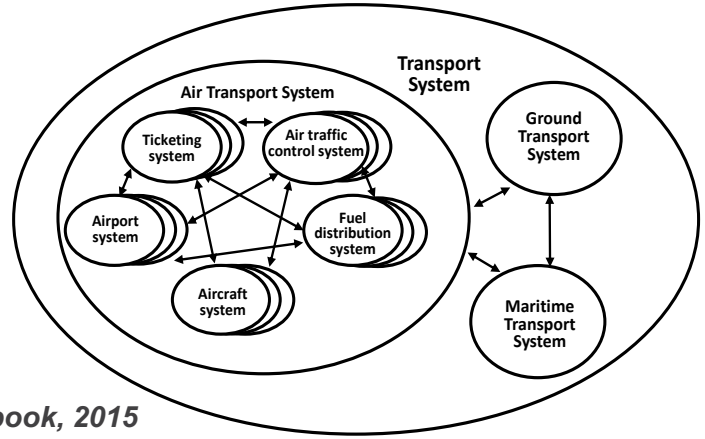
What next?

How is SoSE affecting the way we do systems engineering?

Two Perspectives

- **Almost all systems today are part of one or more SoS**
  - So how do we engineer systems to prepare for this?
- **More and more systems are comprised of elements that look increasingly like independent systems**
  - So how does what we now understand about SoSE help in the engineering of these ‘composite’ systems?

Today Almost All Systems Are Part of One or More SoS

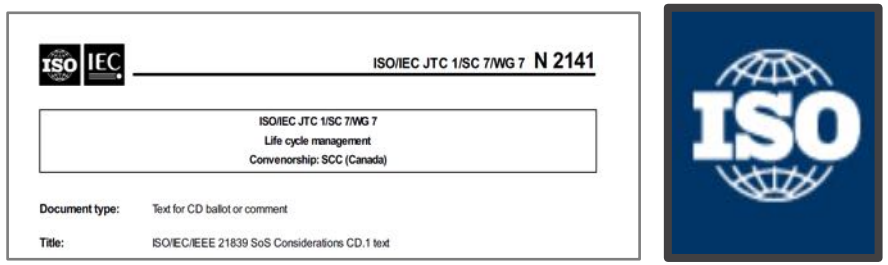


INCOSE Handbook, 2015

Roedler and Dahmann, SOSE 2017

- Rarely, if ever, is a system built and deployed that does not interact with other systems
- However, our current systems engineering practices start with mission and business analysis; the focus is on a system's functionality, boundaries and interfaces
- For systems to be effective today, it is increasing important that they consider the context in which they will be used – including their relationship to other systems

SoS Considerations throughout a System's Life Cycle - ISO/IEEE/IEC 21839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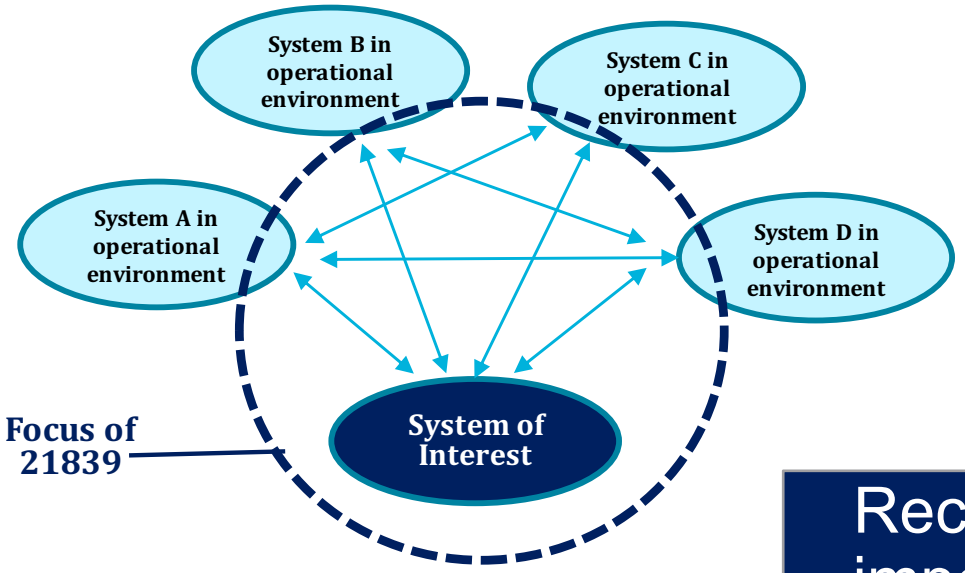
ISO/IEC JTC 1/SC 7/WG 7
Life cycle management
Convenorship: SCC (Canada)

Document type: Text for CD ballot or comment

Title: ISO/IEC/IEEE 21839 SoS Considerations CD.1 text



- As a consequence, more attention is being given to SoS considerations when engineering systems
- Draft International is codifying these SoS considerations to enable systems engineers to more readily develop systems in an SoS context
  - Sets the context for viewing new systems as 'components' of larger systems or, in SoS terms, as constituents of a system of systems

Recognizes that to effectively engineer a system, it is important to consider the impacts of the external SoS environment(s) in all stages of engineering the system

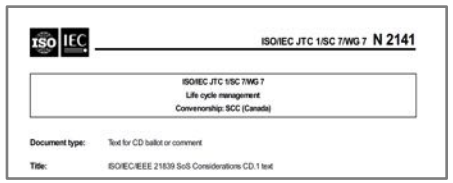
SoS Considerations Posed as Questions

- What are the SoS considerations which impact systems?
  - Capability
  - Technology
  - Management

Capability Considerations

- **Operational context & role of new system concept?**
  - Has the operational context of the capability gap been described?
  - Has the existing capability been described, including the systems that currently support that capability?
  - How would any new system which might address the gap fit into current–or changed - operations processes?
- **Systems context & interdependencies?**
  - Have operational or business context constraints on potential solutions been identified?
  - How would the system fit into current and future operations?
  - Have the relationships with the other constituent systems supporting the capability been considered including interfaces or required changes?
  - Have impacts on non-material factors been described?
  - How critical are the interoperability requirements to the interdependencies?
- **Multiple mission roles?**
  - Have roles of the system in different missions been identified and prioritized?

Concept	Development	Production	Utilization	Support	Retirement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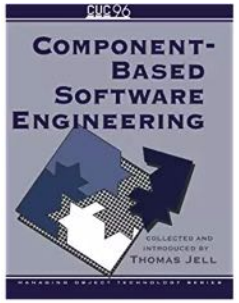
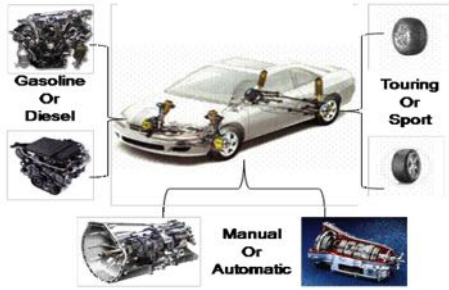
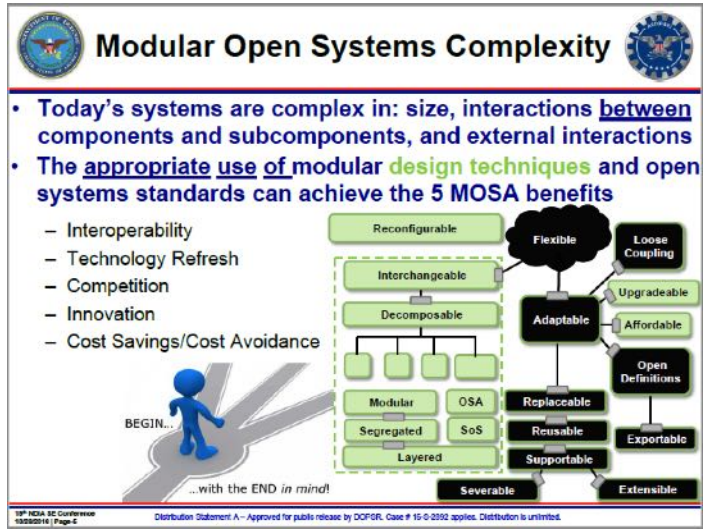
Few 'New' Systems are Developed and Sustained as 'Monolithic' Systems







Zimmerman, 2016

- Few new systems are built totally 'greenfield' from the bottom up
  - Software, in particular, increasingly reuses available commercial and open source SW components
  - Other systems integrate 'commercial off-the-shelf' components into new developments
  - Finally, there is push (in Defense, in particular) to systems based on modularity and open systems, allowing for upgrades and replacement of modules to facilitate system graceful evolution

In each case, systems now incorporate elements outside the control of the systems, making the systems look more like SoS

‘Intelligent’ Components of Systems

http://www.acnodes.com/blog/the-internet-of-things-isf-and-the-intelligent-systems-to-systems/

http://www.rtcgroup.com/intelligent-systems-source-june-steal/

- Systems are getting more ‘intelligent’
  - With the result that they are networked into a larger control system or applied in conjunction with other systems to provide an operational capability
  - Greater autonomy increases the ‘independence’ of the constituents
- Same thing applies to intelligent elements of systems
  - As system elements learn and change independently, how do you address validation of the systems?

This means that systems, with ‘intelligent’ elements outside the control of the system, look more like SoS

In Conclusion

- SoSE as an application of SE to systems of systems has grown and will continue to be part of the SE landscape
- Beyond this, as systems …
  - Continue to be part of one or more SoS
  - Incorporate more elements built and evolved independently from the new system outside the control of the systems
  - Include ‘intelligent’ elements which make changes independently of the system

  … they increasingly look more and more like SoS
- These systems pose a number of the same challenges facing systems engineering of SoS and SoS concepts are likely to become part of the broader approach to engineering systems

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