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System-of-Systems, a new way to see systems

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IRT SystemX - SoS seminar, 12 January 2016
Technical Directorate, System Domain

Who am I?

30+ years of experience:

- 5 years in the “NTIC" : Networks, telecoms, compilers and language theory, simulation.

20 years in development of systems:

- Radar : signal processing, data processing and hardware architecture
- Integrated Modular Avionics (ARINC, ASAAC)
- Electronic Warfare: architecture and Domain Design Authority
- Systems of Systems, Net-Centric Operation and Network-Centric Warfare: Architecture and Principles

Current position:

- Responsible for Systems Engineering and Architecture in the Thales Corporate Technical Directorate.
- Coauthor of the Thales Systems Engineering Methodology (Sys-EM)
- AFIS Technical Director and INCOSE CAB representative
- Convener on standardization works: ISO, AFNOR, EDA, NATO
- Coach and Trainer for Architecture and Operational Concepts (Thales and externally)

Thales Global Presence

Employees

61,000

Global presence

56 countries

IRT SystemX - SoS seminar, 12 January 2016

Technical Directorate, System Domain

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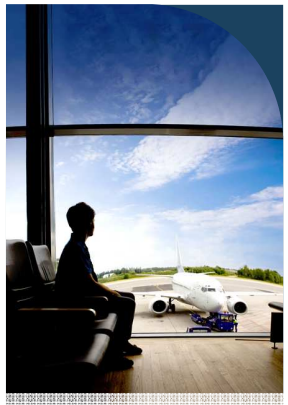
Thales Businesses


AEROSPACE


SPACE


GROUND TRANSPORTATION


DEFENCE


SECURITY

EACH OF THE MARKETS THAT THALES SERVES PLAYS A VITAL ROLE IN SOCIETY.

13 billion euros

Self-funded R&D

675 million euros

Aims of the presentation

- Why to care about Systems of Systems (SoS), even if working on “simple” products or systems.
- The added value of the SoS approach
- The SoS pain points and challenges (opportunities for research!)

Agenda (45')

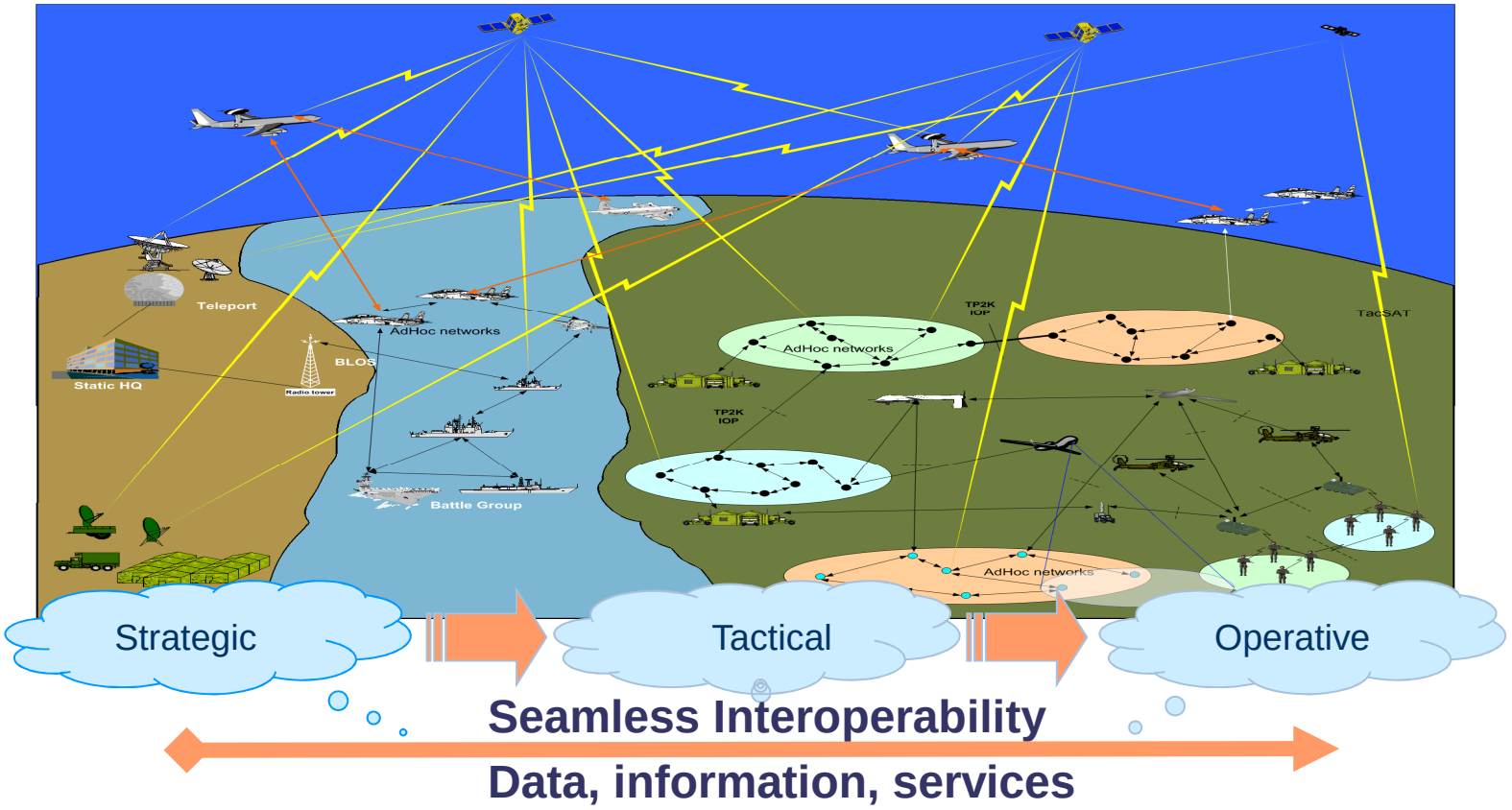
- "Well-known" examples of large Systems of Systems
- Definitions: Product, System, System of Systems, Solution
- Characteristics and classifications of SoS
- Systems Engineering principles for SoS
- Focus of modelling and Architecture Frameworks
- SoS approach for products and systems
- Paint points and challenges regarding SoS
- Conclusion

An example with Air Operations (Source: SESAR)

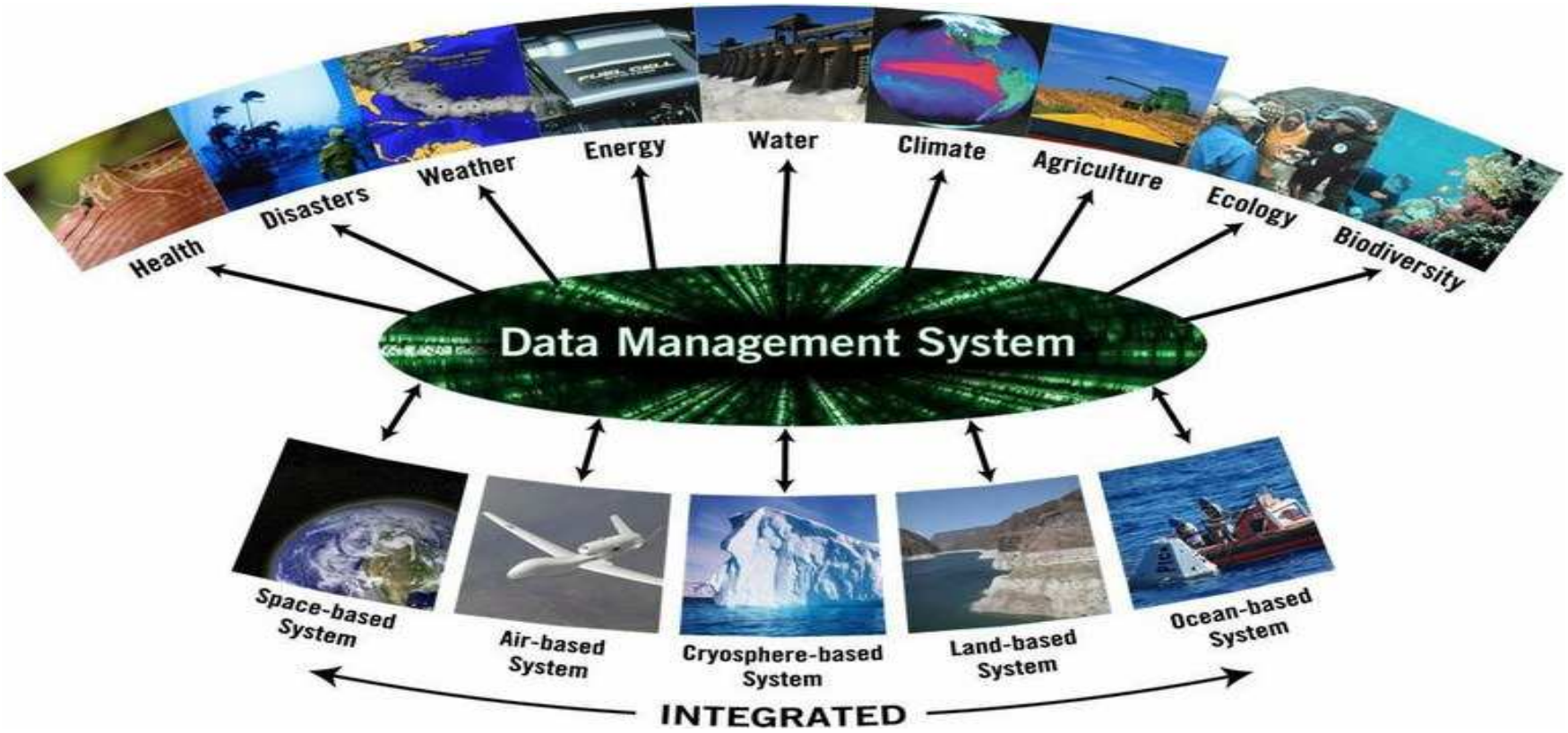
Make several systems working together and get synergy towards common objectives: end-to-end services, traffic, energy, time, etc.

Implementation of SoS is already started [more or less known as such]

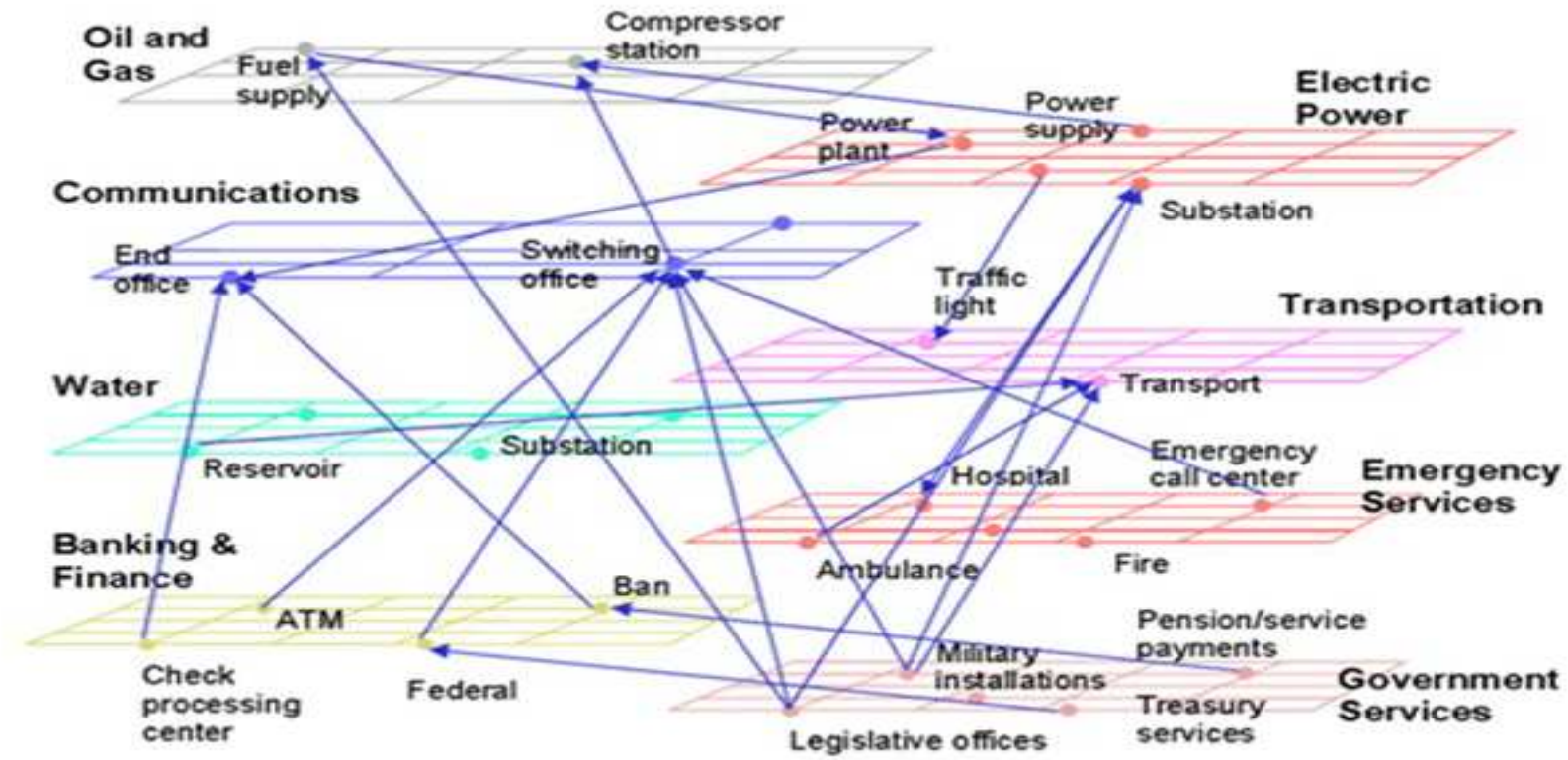
Military operation (Source: US-DoD)



Global Earth Observation (Source: ESA)



Interdependence between Domains in Societal SoS (Source: T-AREA-SoS)



Definitions

Product:

- Result of a process. [Source: ISO/IEC 15939:2007]
- A Product is intended to be sold, directly or indirectly (internal product) to customers for satisfying their expectations and meeting their operational requirements. A Product can be a hardware or software equipment or a service or a system or a generic solution. [Source: Thales]

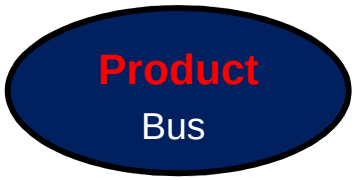
System:

- Combination of interacting elements organized to achieve one or more stated purposes.
  An integrated set of elements, subsystems, or assemblies that accomplish a defined objective. These elements include products (hardware, software, firmware), processes, people, information, techniques, facilities, services, and other support elements. [Source: INCOSE]

Solution scope:

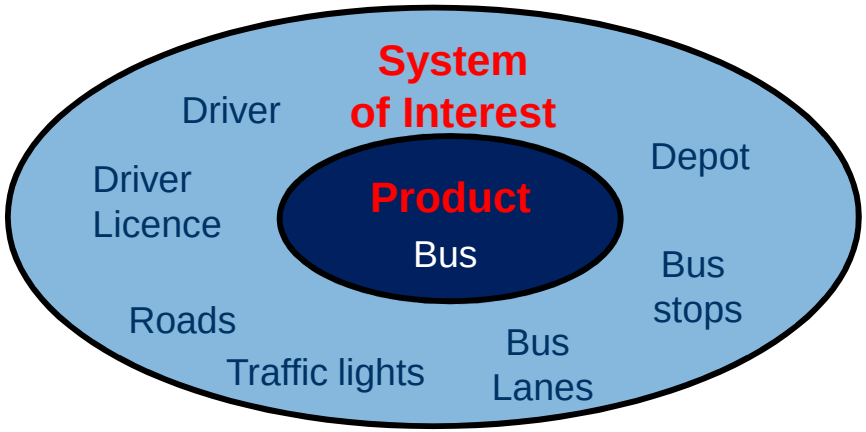
- The solution covers not only the development of the operational system but also the enabling products: system for designing, producing, installing the operational system (e.g., test resources), support system (system supporting the operational system, e.g., training, distribution and repair network). [Source: Thales]

Solutions-Systems-Products



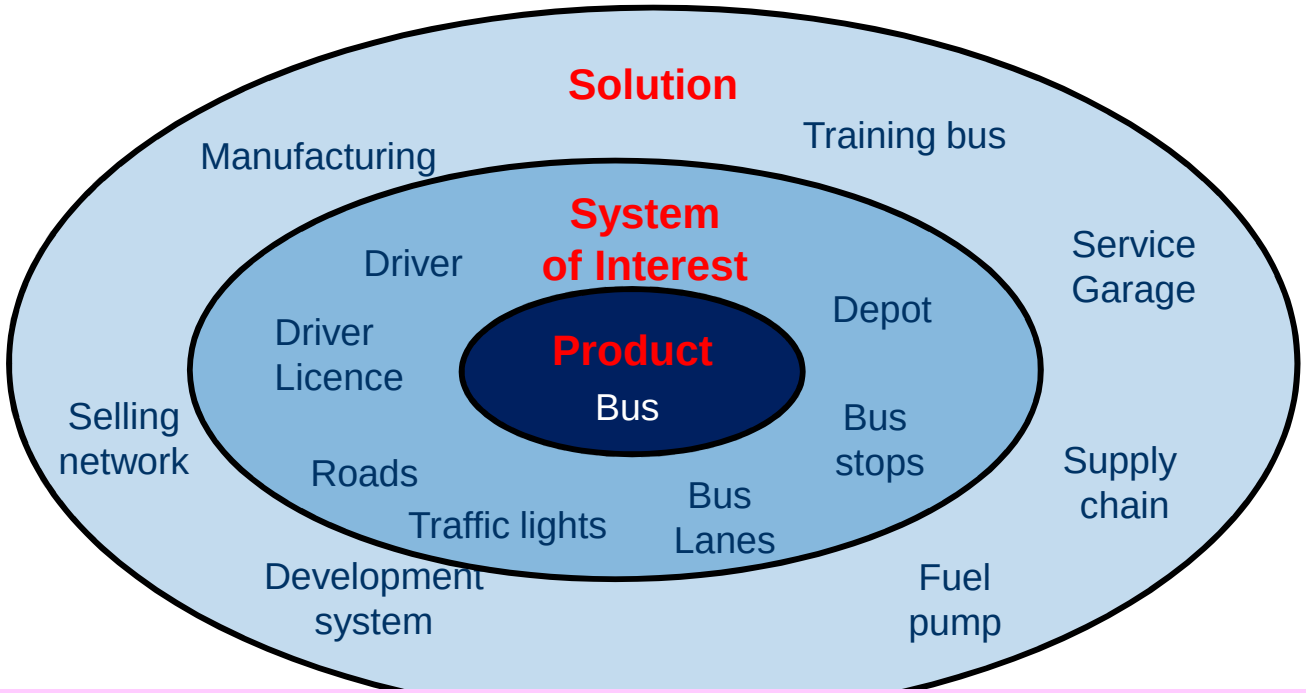
In this example, we develop and sell buses.

Solutions-Systems-Products



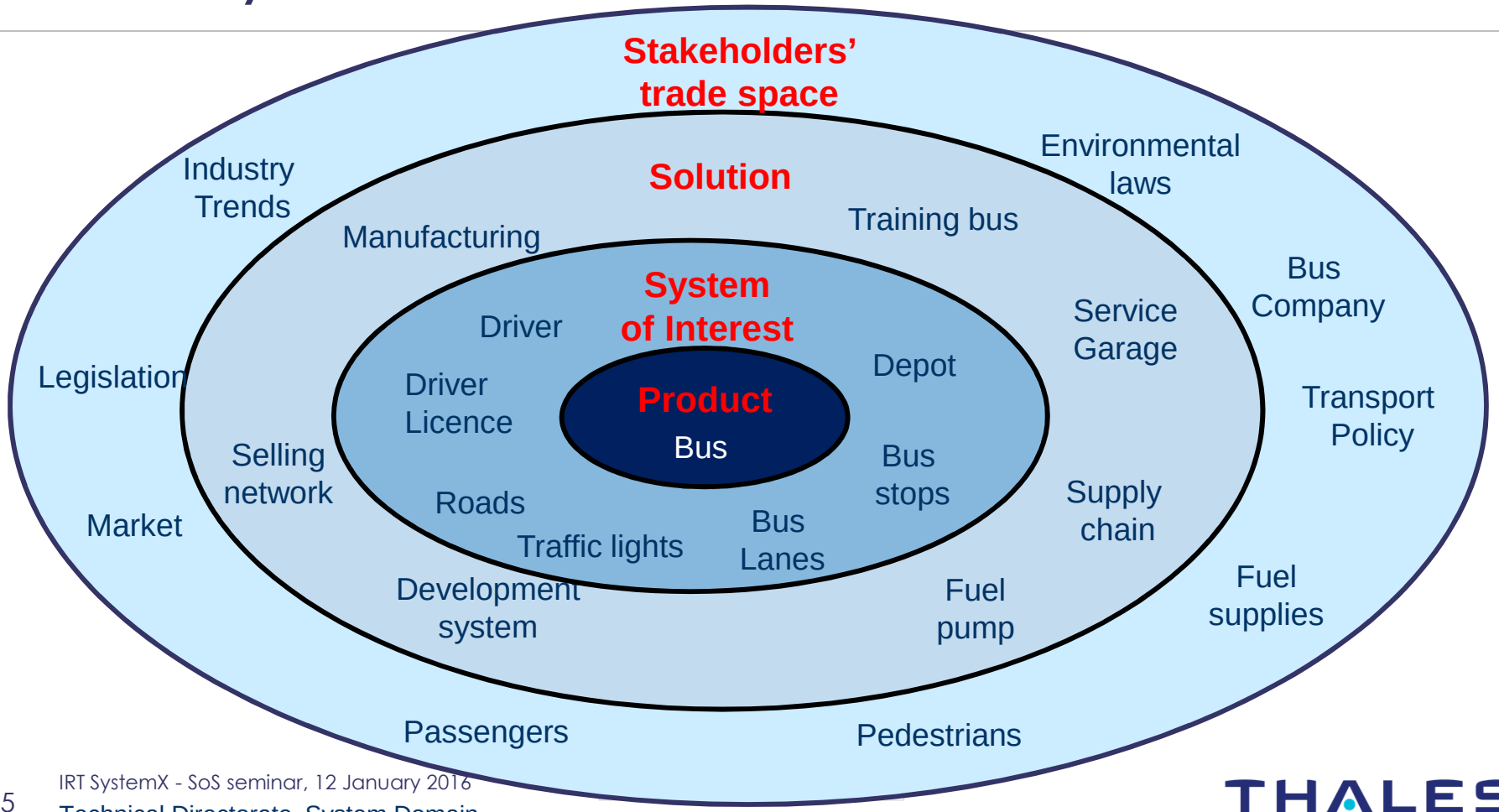
Any element necessary to understand the product in its environment, over its life cycle (Systemic Approach).
Note: The Operators (Driver(s)) are part of the system

Solutions-Systems-Products

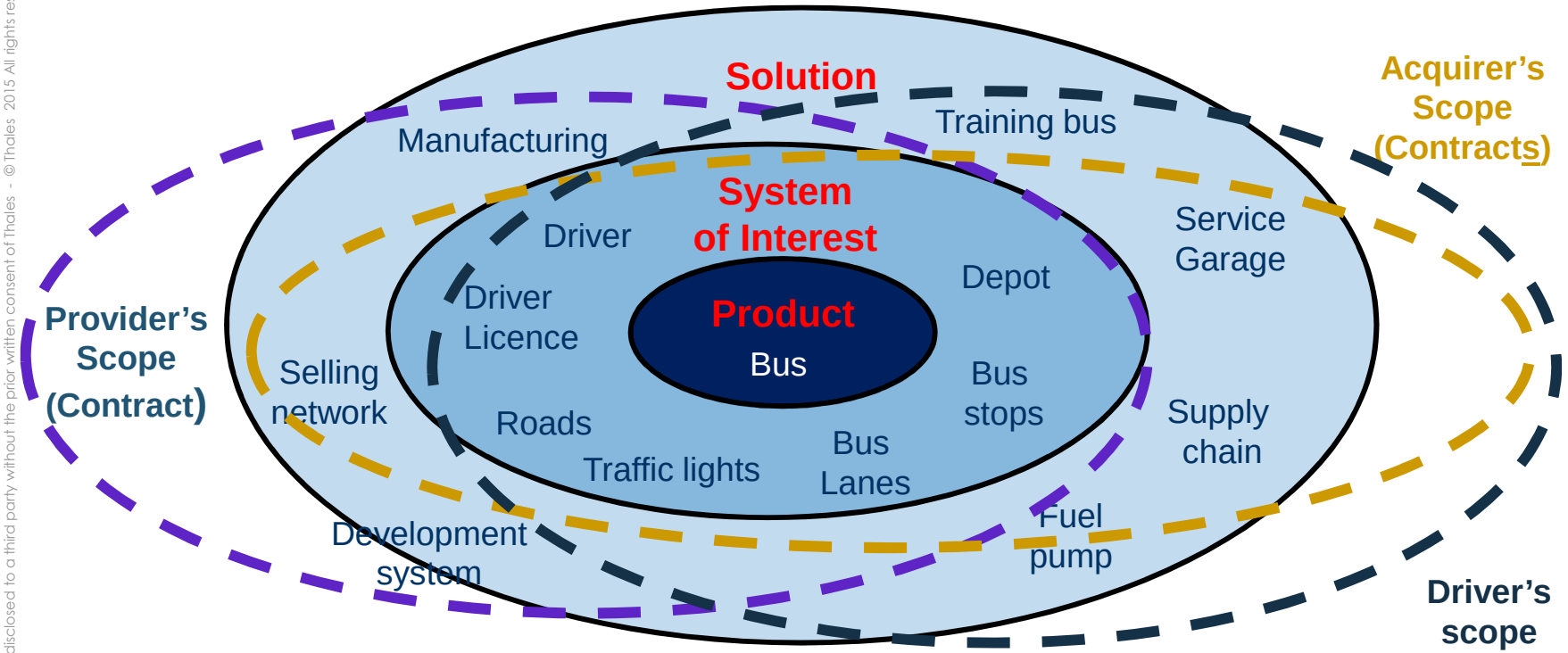


Any enabling system sustaining the system of interest over its life cycle: development system, delivery system, maintenance system, etc.

Solutions-Systems-Products

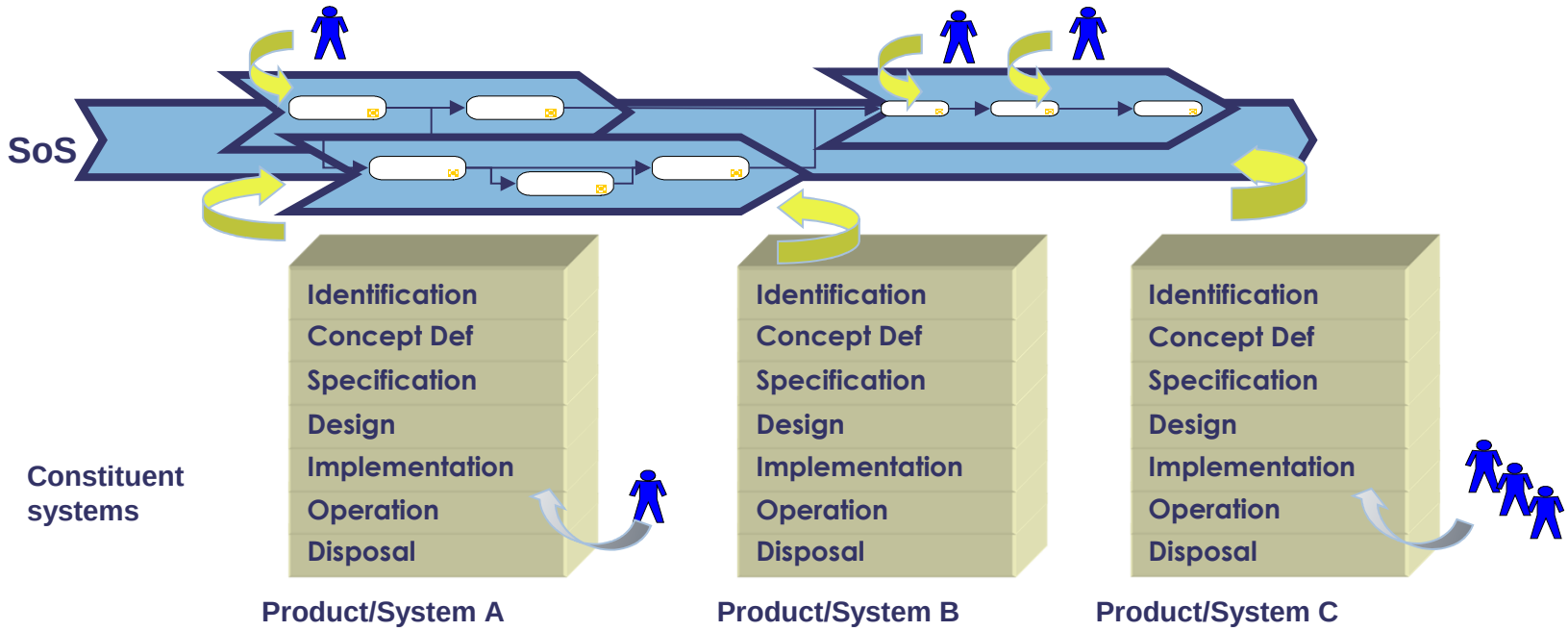


Be careful about the different scopes of solution



What is a System of Systems?

- SoS is defined as an arrangement of systems that results when independent and useful systems are integrated into a larger system that delivers unique capabilities (Defense Acquisition Guide).



Note: Any of the constituent systems could be an SoS

Some agreed bases… but far from being formal

Need for research!

MAIER's criteria

- Operational independence of the component systems
- Managerial independence of the component systems
- Evolutionary development
- Emergent behavior
- Geographic distribution *(no shared resource)*

Considering criteria dependencies

- **Evolutionary development is a consequence of integration of independent component systems**
- **Emergent beavior is a consequence of operation of independent component systems**
- **Resource segregation is required for independent systems**

Pain points are:

- **Operational independence → interoperability**
- **Managerial independence → Project management and Systems Engineering**

Some agreed bases… but far from being formal

Need for research!

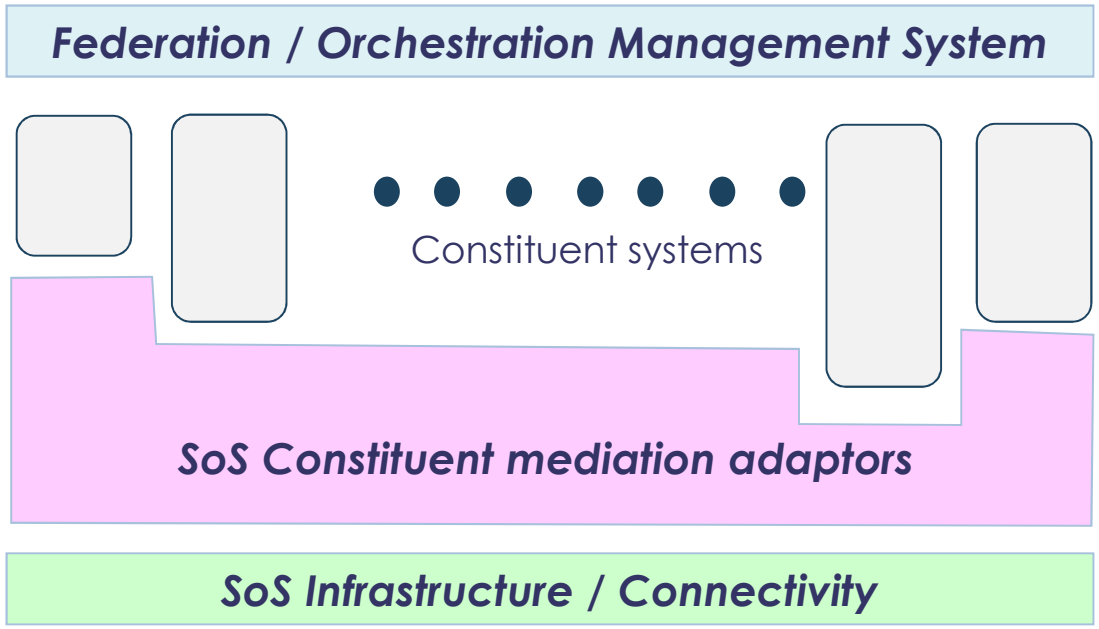
- **MAIER's criteria**
  - Operational independence of the component systems
  - Managerial independence of the component systems
  - Evolutionary development
  - Emergent behavior
  - Geographic distribution *(no shared resource)*

In reality: never totally satisfied

- **John Boardman & Brian Sauser "System of Systems – *the meaning of* of"**
  - Autonomy (independence) vs Belonging to SoS
  - Geographical distribution VS Connectivity
  - Diversity & Emergence VS SoS objectives

Compromise have to be got

SoS-Specific developments



Major problems

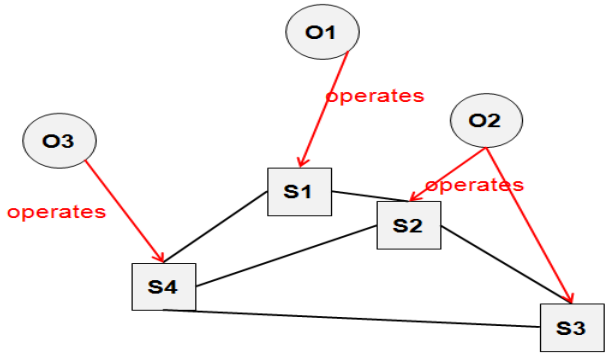
- **Doctrines**
- **Semantic**
- **Protocols**
- **Interfaces**

E.g. See NATO NC3 taxonomy and NISP (unclassified) and NCOIC

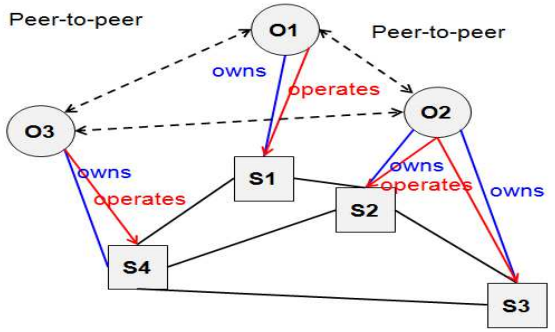
One of the proposed classifications

Based on Dahmann & Baldwin, 2008

T-AREA-SoS

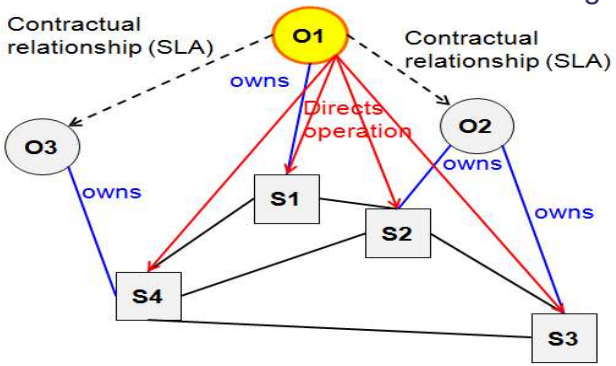


Virtual SoS

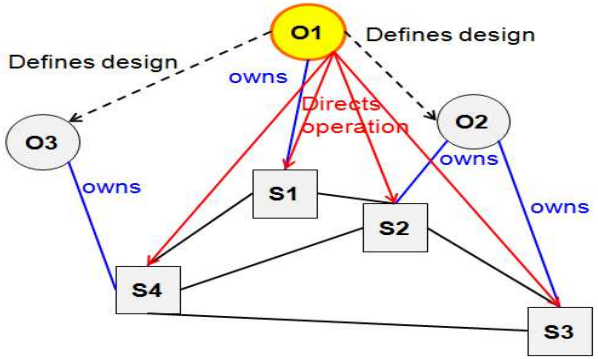


Collaborative SoS

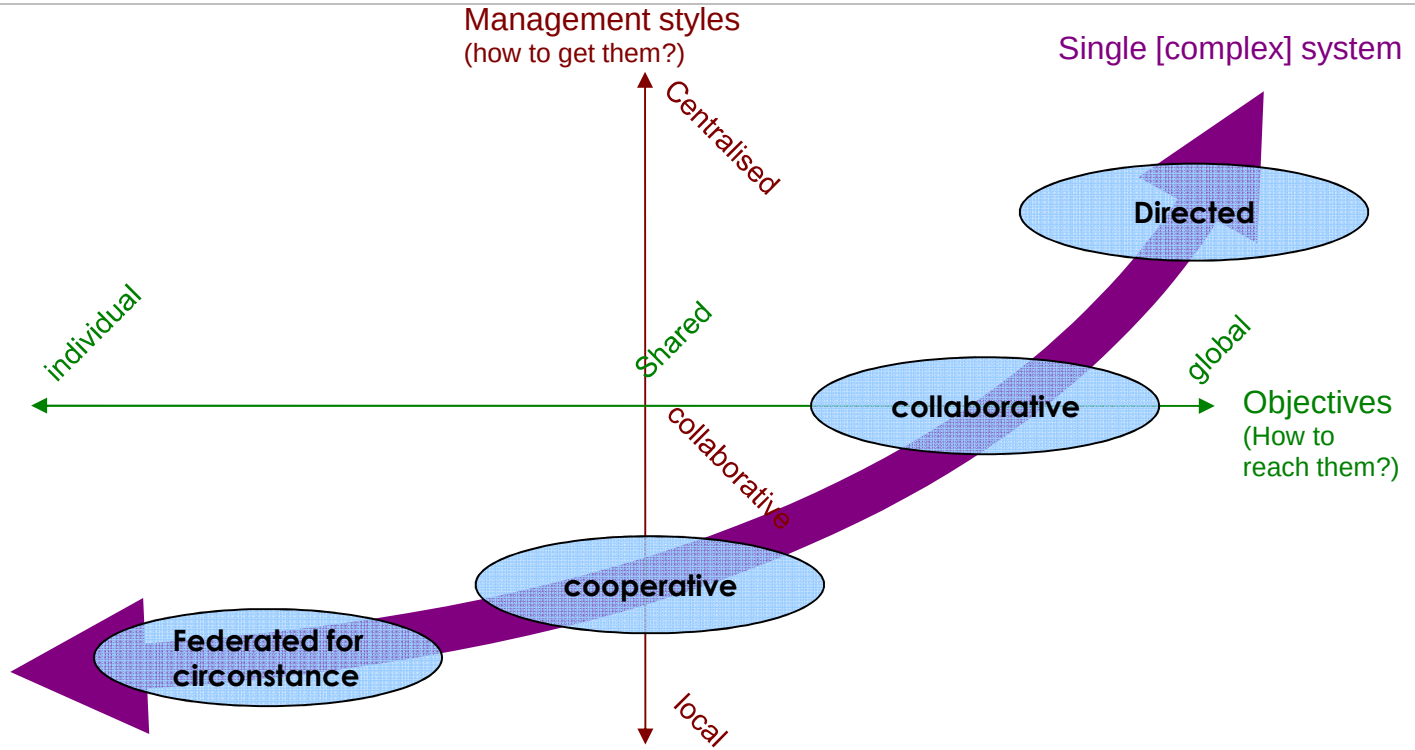
Acknowledged SoS



Directed SoS



Another Classification from the French MOD



Various types of SoS have to be considered

SoS Engineering Key Concepts

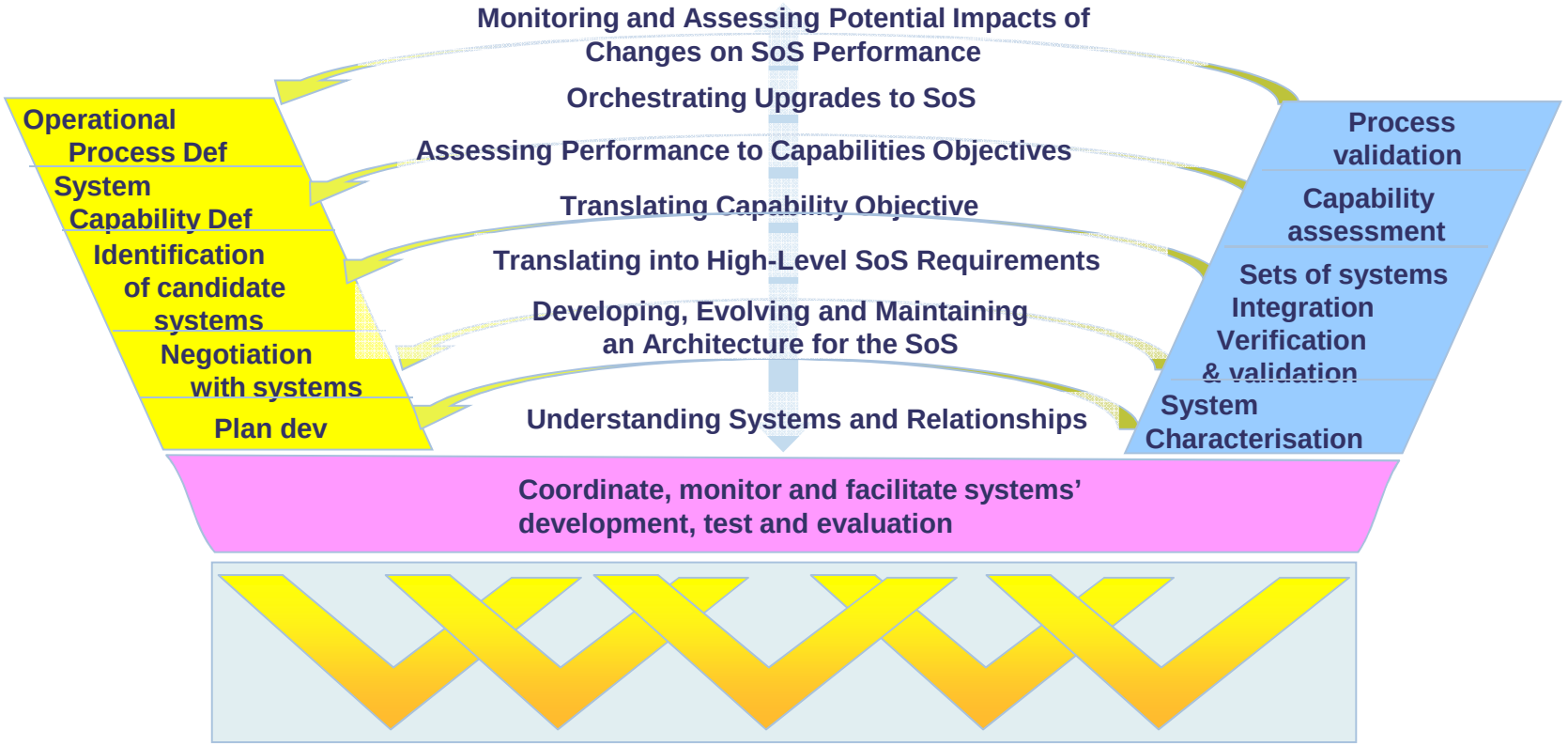
	Traditional Systems Engineering	System-of-Systems Engineering
Purpose	Development of single system to meet stakeholder requirements and defined performance	Evolving new system-of-systems capability by leveraging synergies of legacy systems
System Architecture	System architecture established early in lifecycle and remains relatively stable	Dynamic reconfiguration of architecture as needs change; use of service oriented architecture approach as enabler
System Interoperability	Defines and implements specific interface requirements to integrate components in system	Component systems can operate independently of SoS in a useful manner. Protocols and Standards essential to enable interoperable systems
System "ilities"	Reliability, Maintainability, Availability are typical ilities	Added "ilities" such as Flexibility, Adaptability, Composability
Acquisition and Management	Centralized acquisition and management of the system	Component systems separately acquired and continue to be managed as independent systems
Anticipation of Needs	Concept phase activity to determine system needs.	Intense concept phase analysis followed by continuous anticipation, aided by ongoing experimentation

Saunders, T. *et al,* "United States Air Force Scientific Advisory Board Report on System-of-Systems Engineering for Air Force Capability Development," SAB-TR-05-04, July 2005

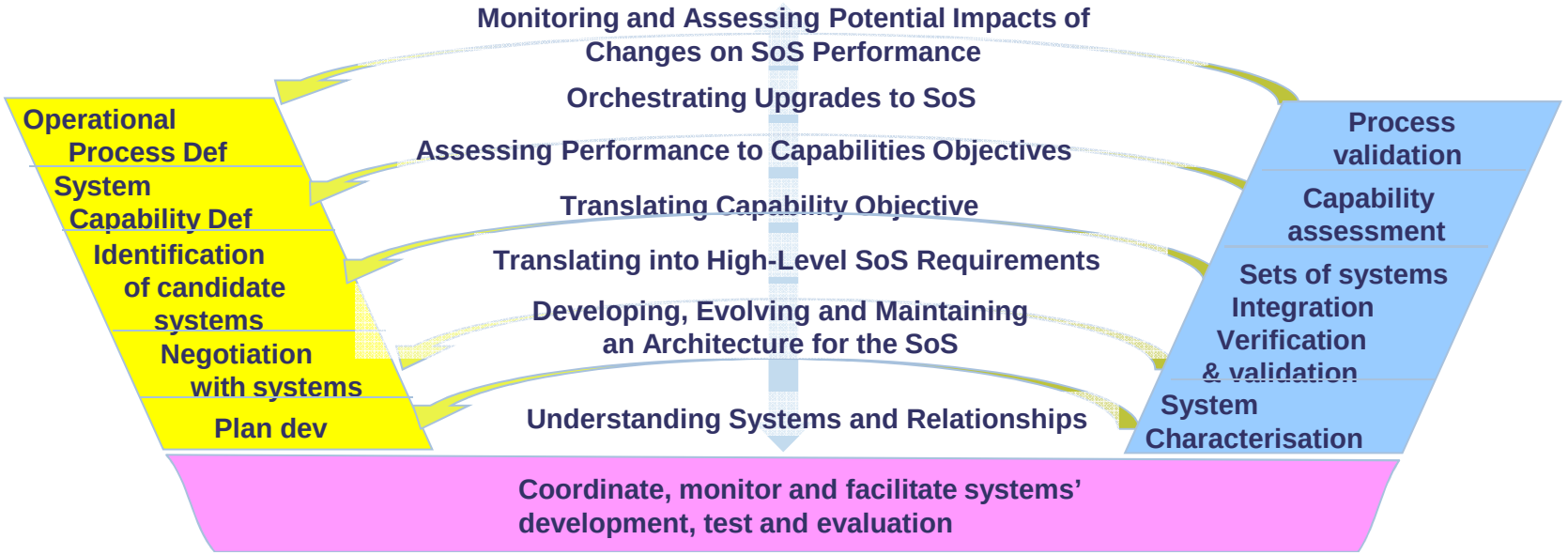
With "Agile" approach, Systems Engineering will move towards SoS Engineering!

SoS System Engineering Steps and cycles

Systems Engineering Guide for Systems of Systems, Version 1.0, August 2008



Strong need for evolution of the S.E. standards to deal with SoS

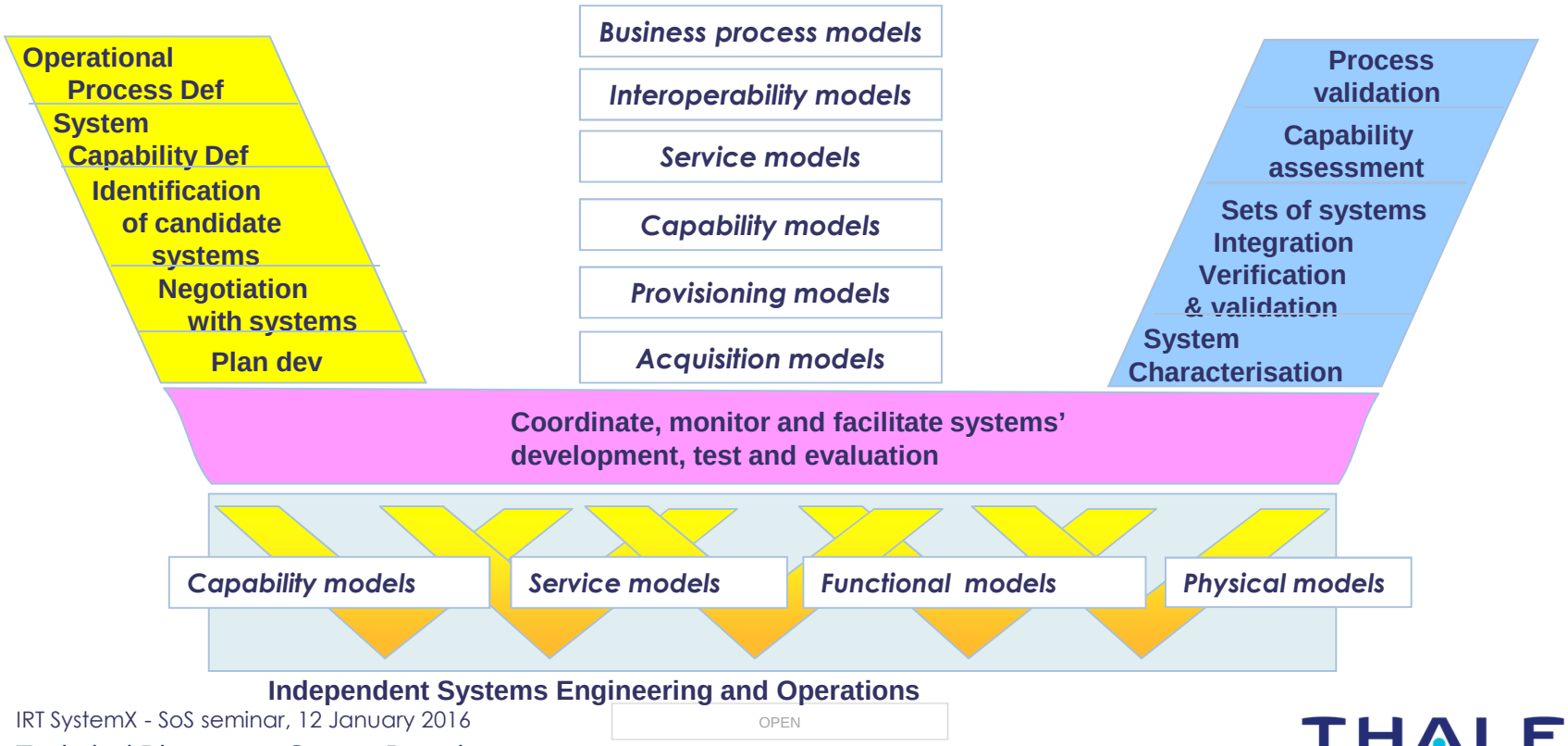


Main Systems Engineering reference documents:

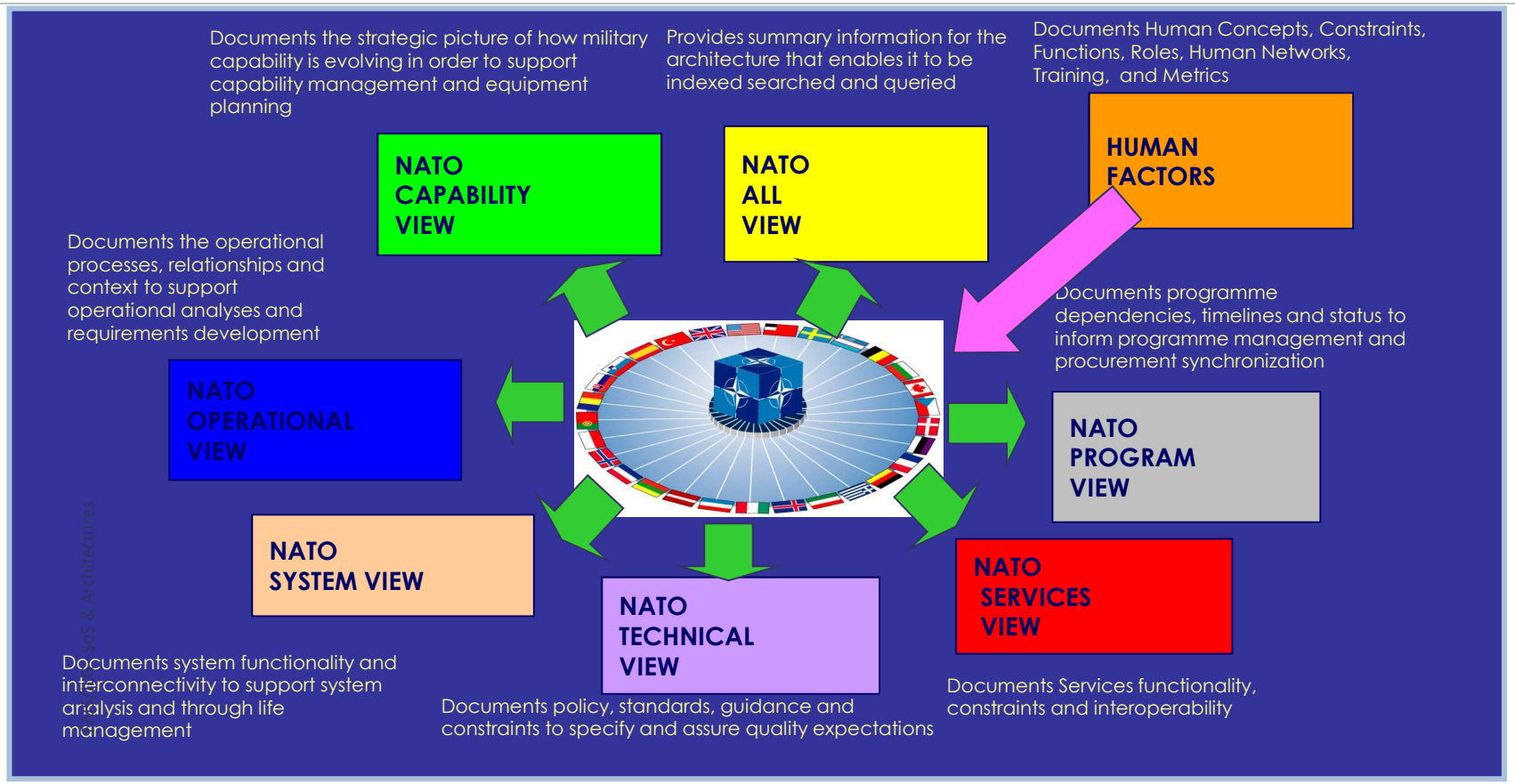
- **ISO/IEC/IEEE 15288 Systems and software engineering — System life cycle processes**
- **ISO/IEC/IEEE 15289 Systems and software engineering — Content of life-cycle information products**
- **ISO/IEC 24748 Systems and software engineering — Life cycle management**
- **INCOSE Systems Engineering Handbook**

A handbook is available in the Thales Reference System to provide guidance on SoS

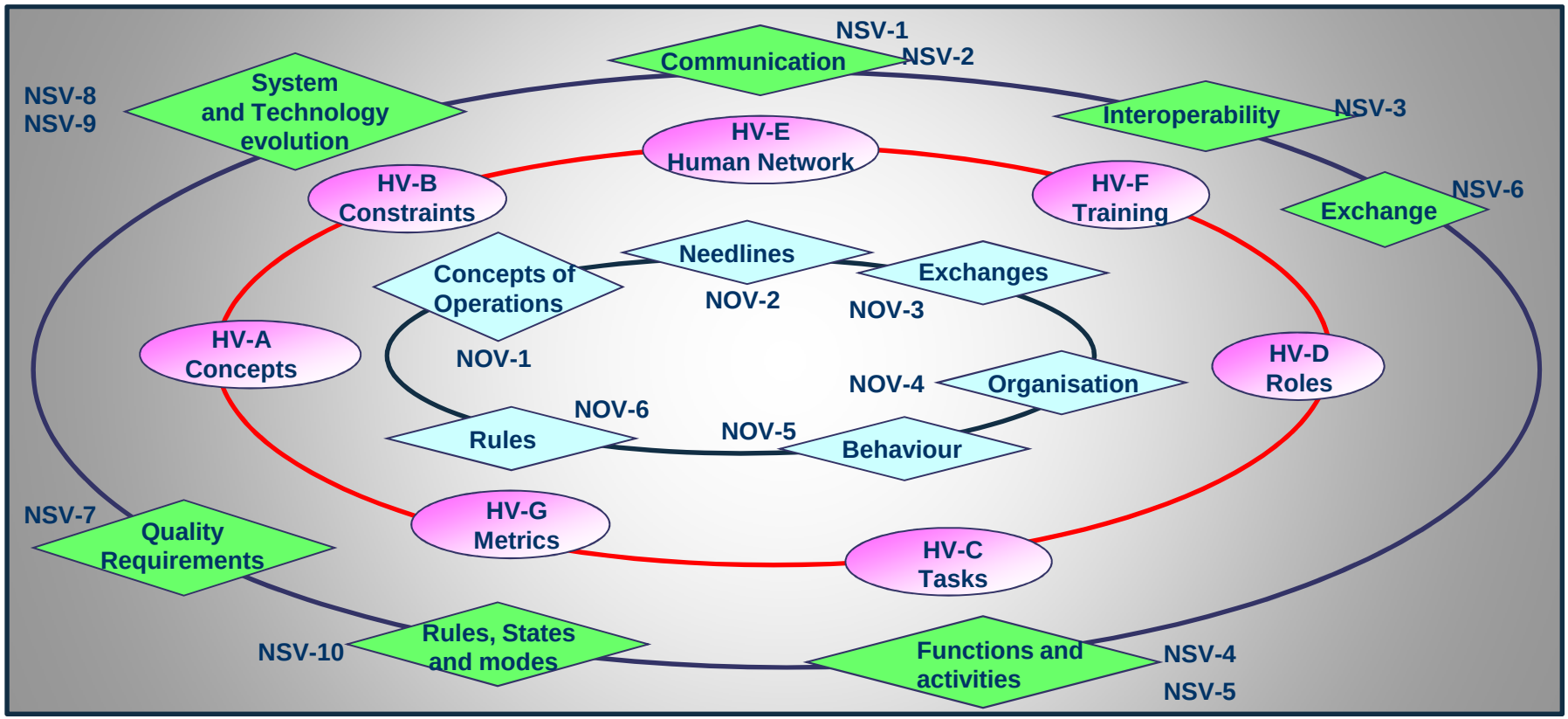
Main models to be considered for SoS



Architecture Frameworks: NATO example



Human views: Adaptation of UK-MOD and NATO works



Back to systems and products

Let's consider this

And also this

Or this

OPEN

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SoS criteria apply to products (systems)

Do you think the provider master the life cycle of the components?

- Operating systems Windows, Linux, Android, etc)
- Devices (disk drive, hardware pug-ins, etc).

Call this "managerial independence"

Do you think we master the life cycle of the applicative components?

- Office tools
- On-board and off-boards apps.

Call this "Operational independence"

SoS approach is a way to better understand problems in products and systems:

- Emergent behavior
- Evolutionary development
- Dependability (segregation resources and functions)

Maier's criteria also work for products!

SoS approach is a way to better understand multi-systemic composition

- Each of the major product parts can be studied with a systemic approach.
  I.e Combination of interacting elements organized to achieve one or more stated purposes.
  An integrated set of elements, subsystems, or assemblies that accomplish a defined objective.
  These elements include products (hardware, software, firmware), processes, people, information, techniques, facilities, services, and other support elements [see INCOSE definition]

SoS approach is a way to better understand multi-systemic composition

Product parts can be studied with a systemic approach:

- Driving system
- Energy system
- Propulsion system
- Breaking system
- Navigation system
- Multi-media system
- Etc.

SoS criteria allow refining the operational analysis, WBS, OBS & PBS.

SoS approach is a way to better understand multi-systemic composition

Example 1: after Jeep hack, Chrysler recalls 1.4 M vehicles for bug fix.

Example 2: In a car, battery is a single point of failure: break-down consequence? Why not having two?

Product parts can be studied with a systemic approach:

- Driving system
- Energy system
- Propulsion system
- Breaking system
- Navigation system
- Multi-media system
- Etc.

SoS criteria allow refining the operational analysis, WBS, OBS & PBS.

SoS approach could be a way to secure the development and operations:

I.e. to prevent emerging problem, dependability, etc.

SoS approach is a way to better understand the PLM challenges

	System 1	System 2	System 3	System 4	System ..
Product A	Usage / System Life-cycle				
Product B	Period 1		Period 4	Period 4	Period 1
Product C			Usage / component life-cycle	Usage / component life-cycle	
Product D	Period 1	Usage / system life-cycle			
Product E	Period 2				Period 2
Product ..					

Life-cycles of the systems are transverse to the life-cycles of the reused products.
N-P complexity problem.

Main challenges identifies for SoS development (Source: Thales)

Challenges
1- Contracting of SoS dynamically defined
2- Multi-layer agile Systems Engineering and agile SoS breakdown
3- Dynamic loose coupling and (re)configuration of constituent systems
4- Flexible paradigms for interaction (mix of services, artefacts, events and streams)
5- Behaviour (multi-level consistent scheduling + non-functional properties)
6- Multi-level life cycles management
7- Engineering process to meet both bottom-up; top-down; dynamic system insertion/removal; legacy alignment
8- Run-time Management, Integrated logistic support and training on SoS or system built dynamically
9- Modelling and simulation to estimate feasibility, forecast behaviour and provide a reference for management

4 main European support actions on SoS

https://www.tareasos.eu/

http://www.road2sos-project.eu

T-Area-SoS:

- Towards a SoS roadmap
- Supply-side driven
- Top-Down approach
- Systems Engineering
- US-EU

Road2SoS:

- Towards a SoS roadmap
- Sector/demand-side driven
- Bottom-up approach
- Consulting industry experts
- Use cases: Energy, Manufacturing, Crisis Management, Traffic Control

Danse:

- Designing for adaptability and evolution in SoS Engineering
- SoS engineering approaches
- Use cases: Air Traffic Management; Autonomous Ground Transportation; Water Treatment and Supply

Compass

- Comprehensive Modelling for Advanced Systems of Systems
- Model-Based tools
- Use cases: Emergency Response; Audio/Video/Home; Automation Ecosystem; Integrated Modular Avionics.

http://www.danse-ip.eu/home/

http://www.compass-research.eu/

Conclusion

Systems of Systems

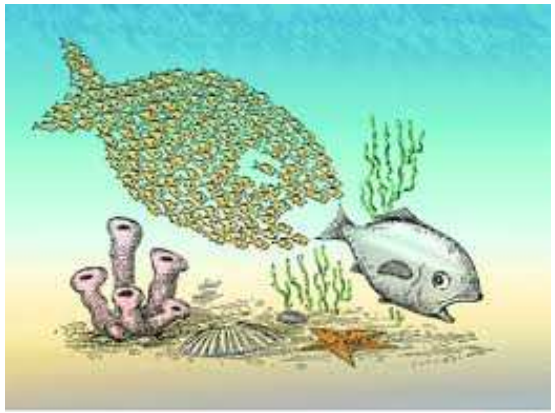
- Literature gives the main principles about Systems Engineering of SoS
- Systems of Systems are now characterised
- Architecture Frameworks strongly help for SoS Systems Engineering
- Major pain points remain about SoS

SoS approach is also valid for product development

- Systems using products might be engineered with an SoS approach
- Systems Engineering will move towards the SoS approach → Agile SE and SE with multiple Life cycle management.

Many research opportunities exist…

- But, need focus on the right problems



If you are interested in Systems Engineering of SoS:

- INCOSE SoS Working Group
- ISO JTC1/SC7 SoS Study Group
- AFIS “3S-AI” Technical Committee
- IEEE SoSE 2016 conference, 12-16 June, Kongsberg, Norway (http://www.sose2016.org/organization.html)