



Honourcode, Inc.

Systems of Systems International Trends

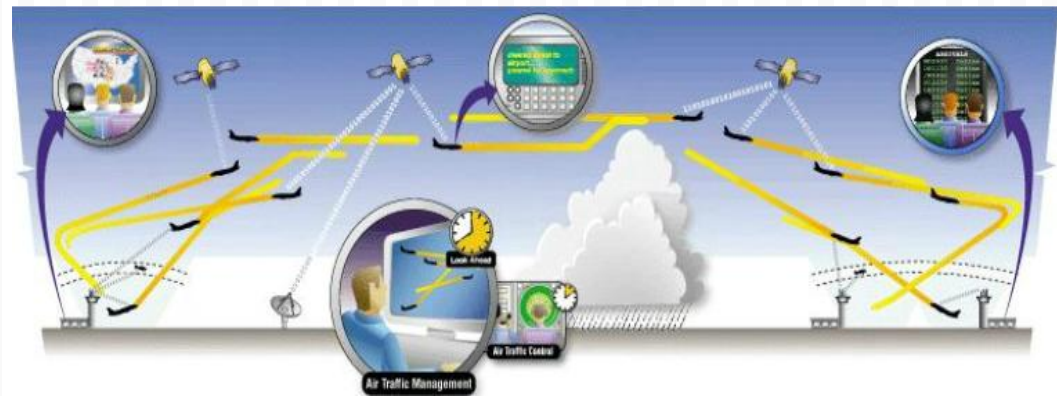
Concepts, advances, and
business opportunities

- ***Systems Engineering***
- ***Training Courses***
- ***Process Improvement***

Eric Honour
+1 (850) 450-0429
ehonour@hcode.com

Agenda

- Systems of Systems now and future
- Military versus commercial practices
- DoD trends in SoS
- EU trends in SoS
- Successful SoS trends



FAA NextGen concept





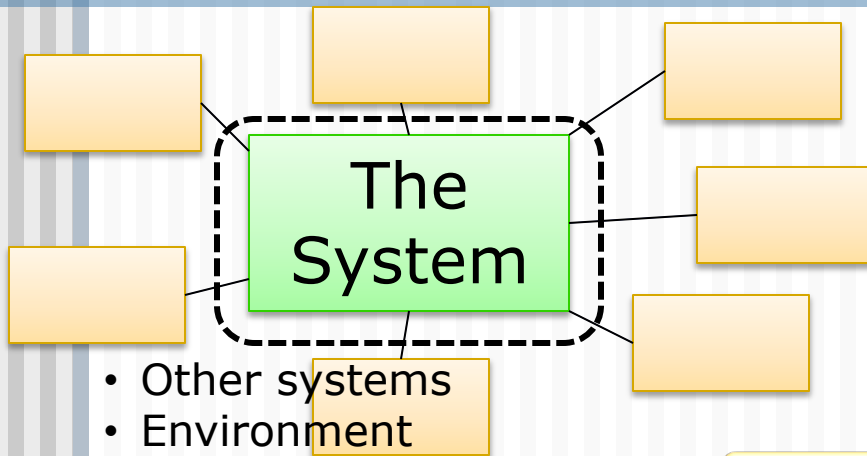
Systems of Systems: Now and Future

Concepts and examples of where
system development is going

- ***Systems of Systems***
- ***Military vs. commercial***
- ***DoD trends in SoS***
- ***EU trends in SoS***
- ***Successful SoS Trends***

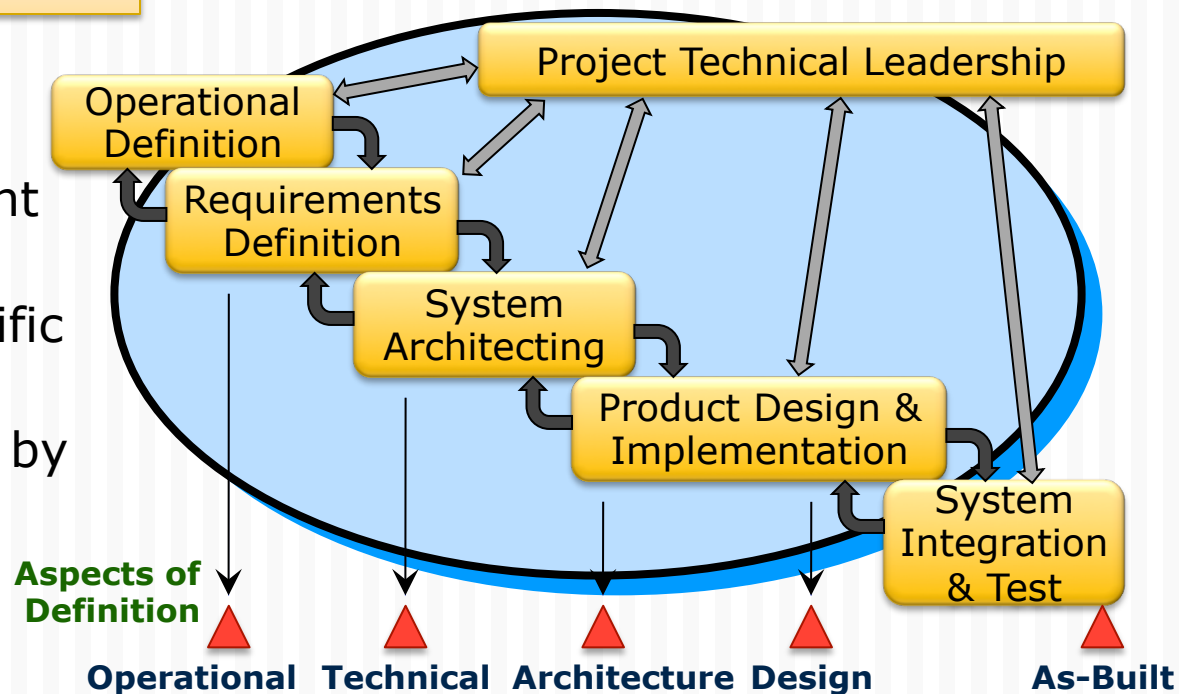
Traditional SE

Most of these assumptions are not valid today!



- Strong boundary: the system from other systems and environment
- Focus on inputs/processing/outputs
- Black box/white box views of successive reductionism

- Top-down development of single system
- Phases to create specific aspects of definition
- Work with complexity by breaking it apart
- Vee model as proof



Dynamicity in the ER SoS

Slide by Tim Lochow, EADS

SoS operational timeline and dynamicity aspects

SoSE Challenges

Modelling the SoS

Design Exploration Architecture Alternatives

Run Time Analysis & Simulation

Decades

Population increase

Life Cycle Dynamicity

New fire, police and health care department stations are built or moved (More stations in order to serve smaller city areas)

Years

New buildings, roads and crossroads are created

More fire, police and health care department units are allocated

System Dynamics

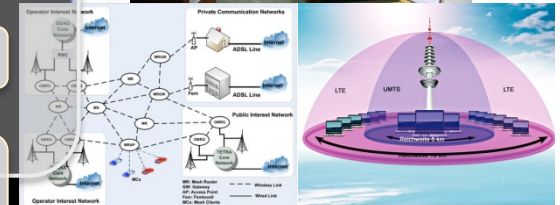
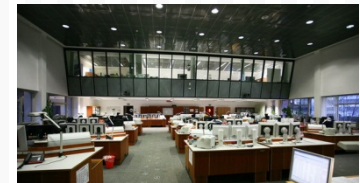
New C4I command & control organization & communication system (e.g. introduction of LTE)

Hours

Operational Dynamicity

Improved Emergency response performance in terms of response time to emergency call and situational awareness

Minutes



Honour

SoS International Trends

SoS Characteristics

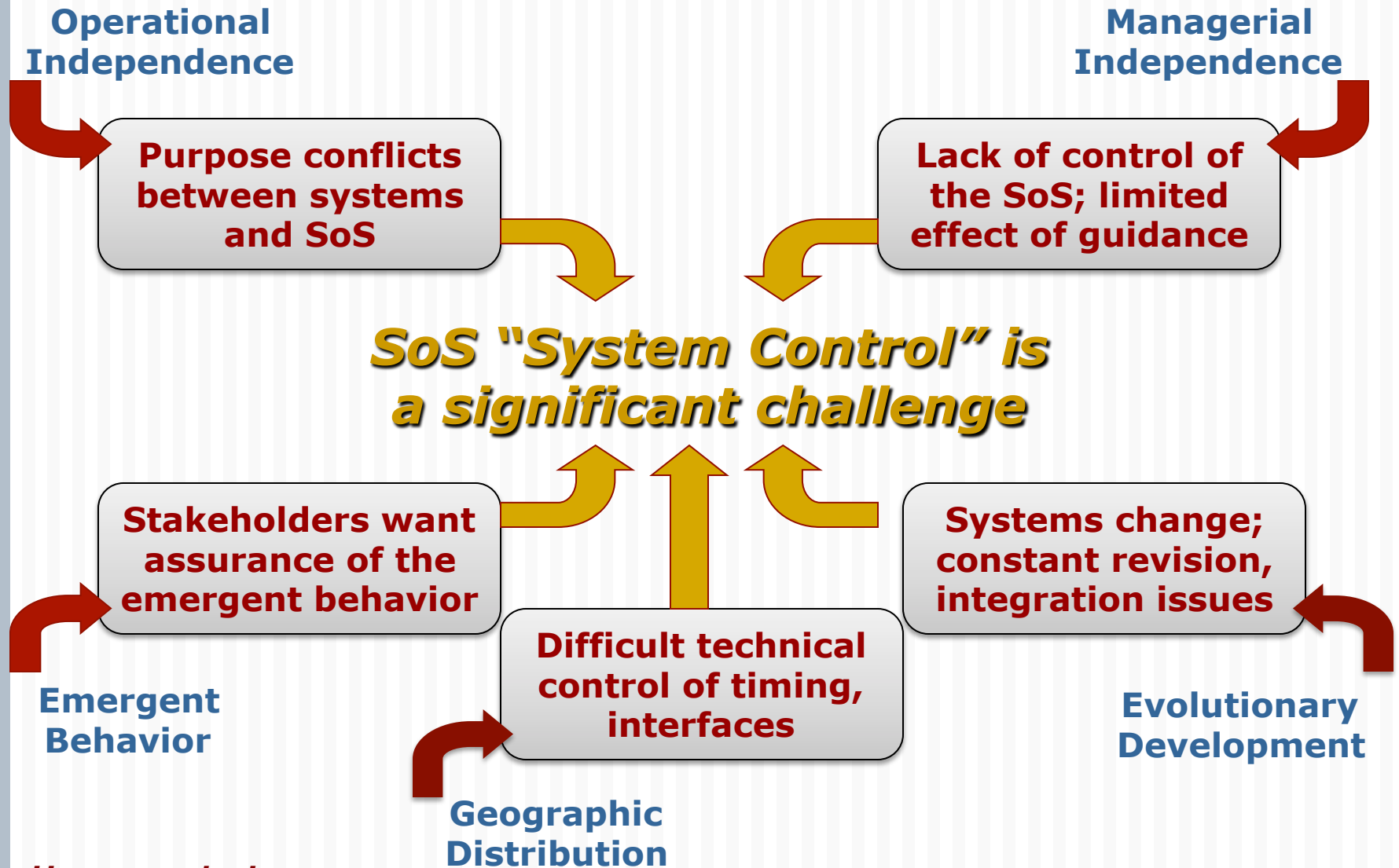
A System is a "System of Systems" if it exhibits significant amounts of:

- **Emergent behavior** - SoS performs functions not achievable by the independent component systems
- **Geographic distribution** - geographic extent forces the elements to exchange information in a remote way
- **Evolutionary development** - functions and purposes are added, removed and modified in an ongoing way
- **Operational independence** - component systems have purpose even if detached
- **Managerial independence** - component systems are developed and managed for their own purposes

- Mark Maier 1998, "Architecting Principles for SoS," Systems Engineering (INCOSE)



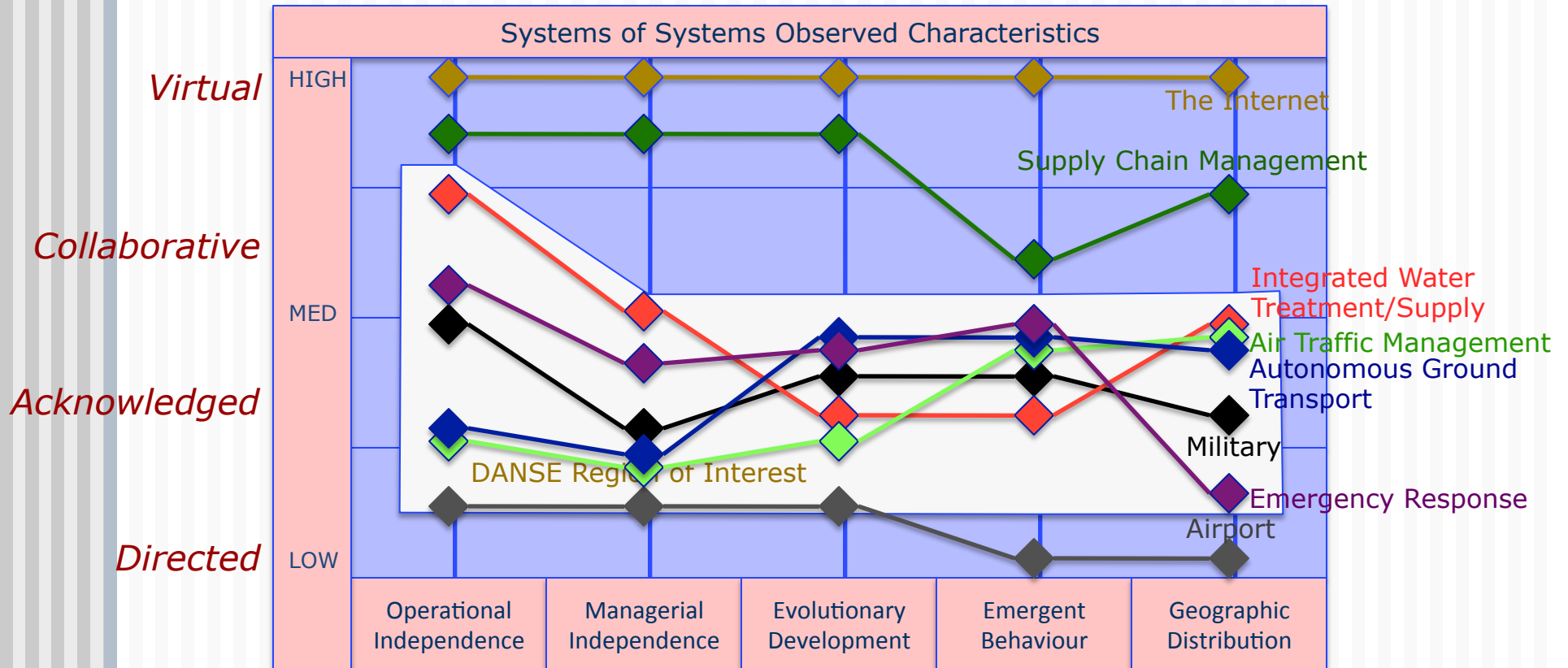
Impacts of SoS Characteristics



Types of SoS

Type	Description	Example
Directed	<ul style="list-style-type: none"> • Integrated SoS built and managed to fulfill specific purposes • Centrally managed during long-term operation • Constituent systems can operate independently, but normally operate within SoS 	<ul style="list-style-type: none"> • Airport
Acknowledged	<ul style="list-style-type: none"> • Recognized SoS objectives • Designated manager and resources for the SoS • Constituent systems retain independent ownership, objectives, funding, development, sustainment 	<ul style="list-style-type: none"> • Military systems
Collaborative	<ul style="list-style-type: none"> • Component systems interact voluntarily to fulfill agreed upon central purposes. • Central players collectively decide issues, thereby providing some means of enforcing and maintaining standards. 	<ul style="list-style-type: none"> • Banking
Virtual	<ul style="list-style-type: none"> • No central management authority • No centrally agreed SoS purpose. • Large-scale behavior emerges, may be desirable • Relies upon relatively invisible mechanisms to maintain it. 	<ul style="list-style-type: none"> • Supply chains

Differing Levels of "SoS-ness"



Traditional SE vs. SoSE

	Traditional SE	SoSE
Purpose	Meet stakeholder requirements and defined performance	Evolve new capability, leveraging synergies of legacy systems
System Architecture	Established early in lifecycle, remains relatively stable	Dynamic reconfiguration as needs change; SoA as enabler
System Interoperability	Define/implement specific interfaces to integrate components	Component systems operate independently of SoS; protocols and standards essential
System "ilities"	Reliability, maintainability, availability are typical	Added "ilities" such as flexibility, adaptability, composeability
Acquisition and Management	Centralized acquisition and management	Component systems separately acquired, managed independently
Anticipation of Needs	Concept phase activity to determine system needs	Intense concept phase analysis; continuous anticipation aided by ongoing experimentation

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

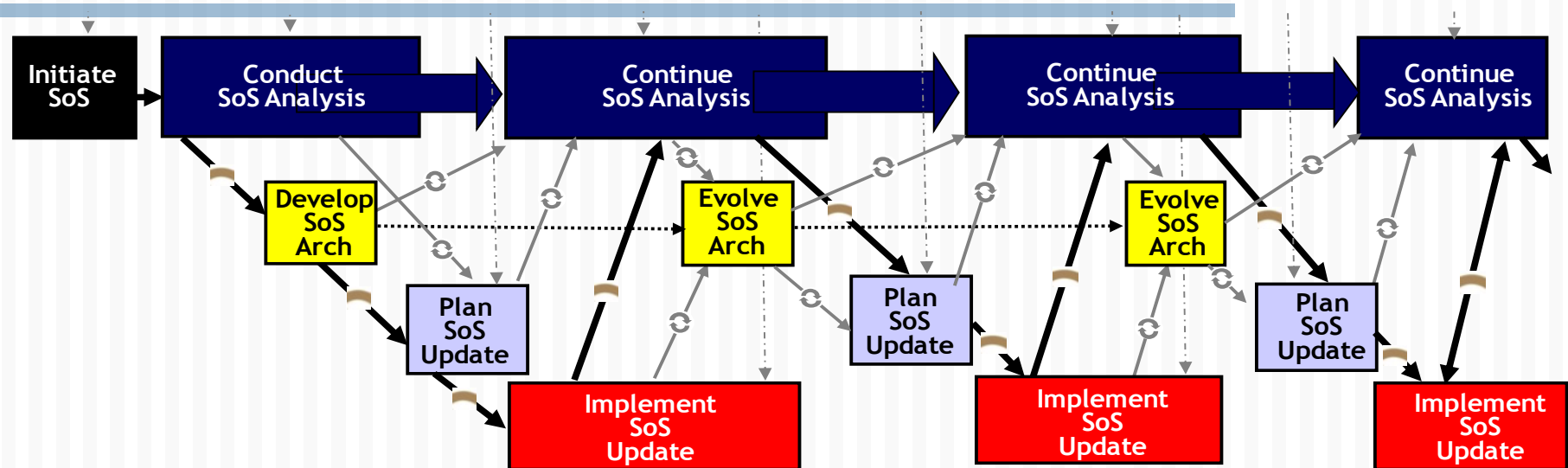


Military versus Commercial Practices

Issues of SoS control; how different domains are handling them.

- *Systems of Systems*
- *Military vs. commercial*
- *DoD trends in SoS*
- *EU trends in SoS*
- *Successful SoS Trends*

US DoD SoSE Wave Model

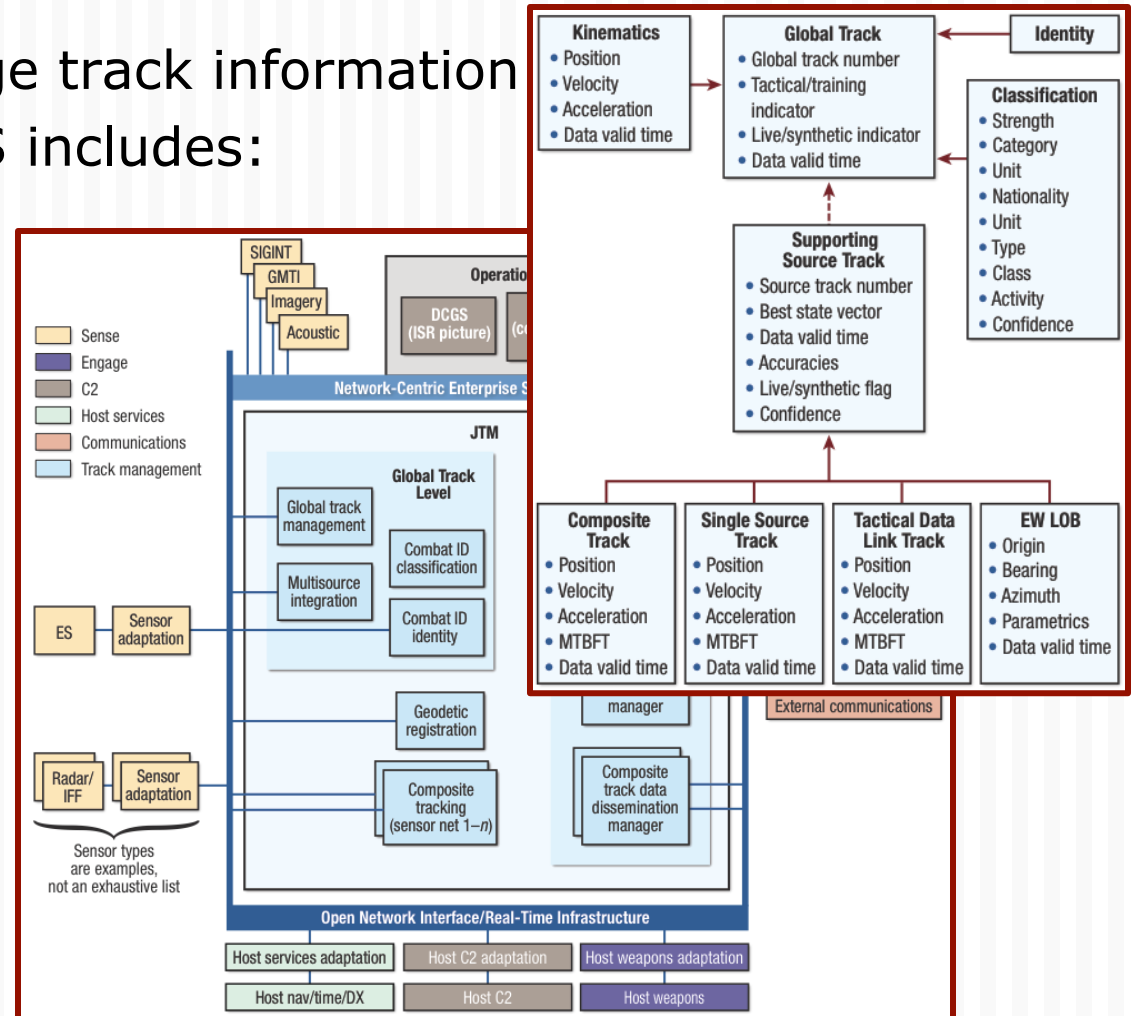


- **Initiate SoS:**
Provides foundational information to initiate the SoS
- **Conduct SoS Analysis:**
Provides analysis of the 'as is' SoS and basis for its evolution
- **Develop SoS Architecture:**
Develops/evolves the persistent technical framework for SoS evolution and a migration plan identifying risks and mitigations
- **Plan SoS Update:**
Evaluates SoS priorities, backlog of SoS changes, and options to define plans for the next SoS upgrade cycle
- **Implement SoS Update:**
Oversees system implementations and plans/conducts SoS level testing, resulting in a new SoS product baseline
- **Continue SoS Analysis:**
Ongoing SoS analysis revisits the state of and plans for the SoS as the basis for SoS evolution

SoS Example

Joint Track Management

- Navy systems to manage track information
- Long-term evolving SoS includes:
 - Sensors
 - Information systems
 - Displays
 - Filters and simulators
- Series of efforts over decades:
 - AEGIS
 - CEC
 - SIAP
 - JTM
- Systems acquired separately

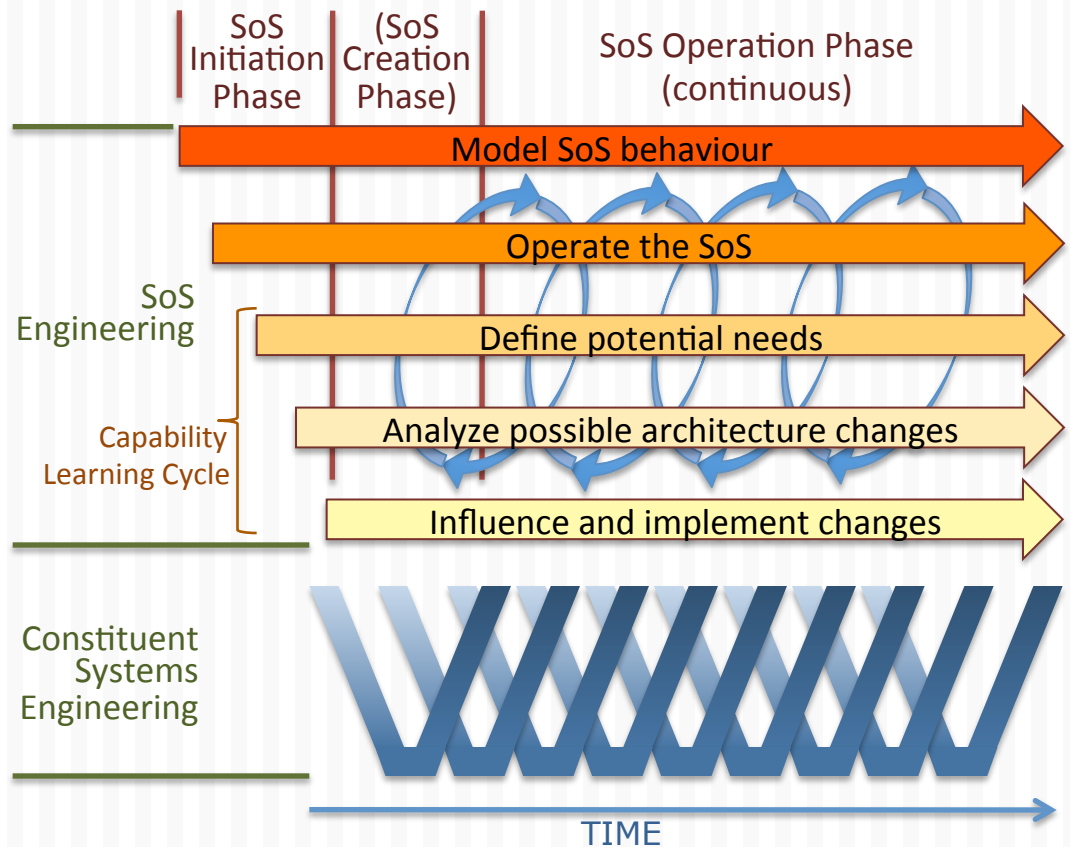


Sommerer et al., (2012) "Systems of Systems Engineering in Air and Missile Defense," Johns Hopkins APL Technical Digest, vol 31, nbr 1

DANSE Methodology

Single model to embody the integrating thoughts

- An initiation phase
- Optional creation phase
- Forward movement through the SoS life
- Constant cycling of events/scenarios
- A "capability learning cycle"
 - Constant improvement!
- Normal Vee-based SE in the constituent systems



Alternate starting points:

- SoS is acknowledged among existing systems
- SoS is created by a Lead System Integrator

SoS Example

Supply Chain Mgmt

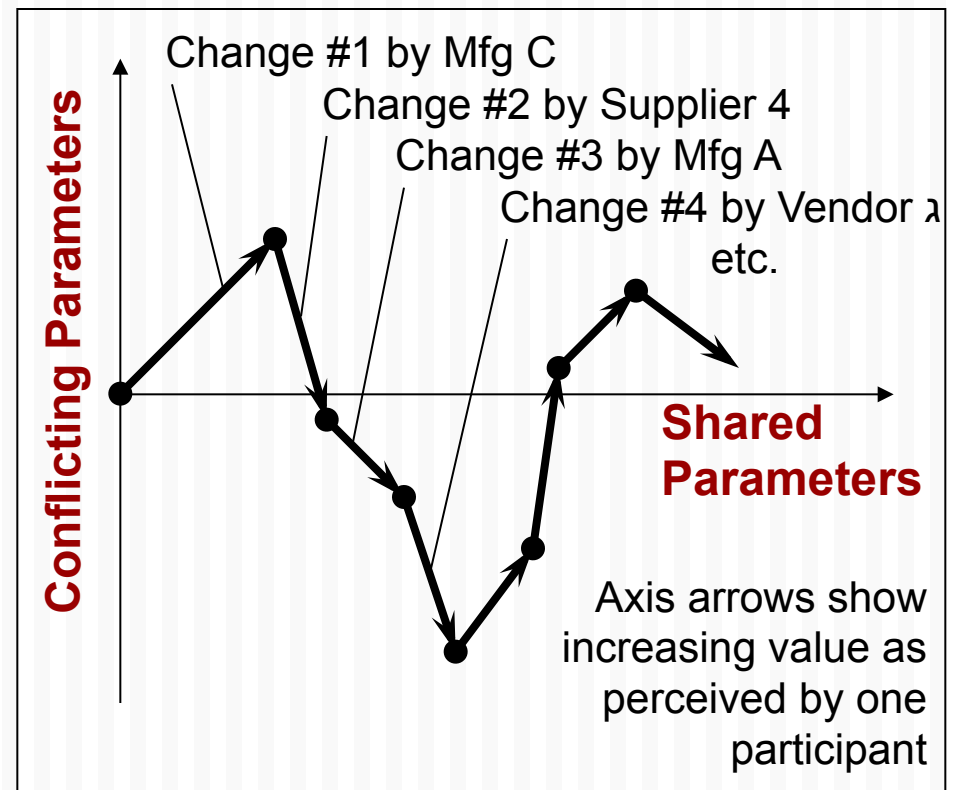
- Component systems
 - Production management systems
 - Inventory systems
 - Transportation tracking systems
 - Internet for connectivity
- Functions
 - Reduce inventory costs
 - Just-in-time inventory production
- Development
 - Each system developed separately
 - Little coordination
 - Systems upgraded separately



Dynamic Optimization of the SoS

- Decisions by each participant cause SoS change
- Conflicting parameters move competitively
- Shared parameters move consistently

***"Random"
coopetition
causes the SoS
to "improve"***





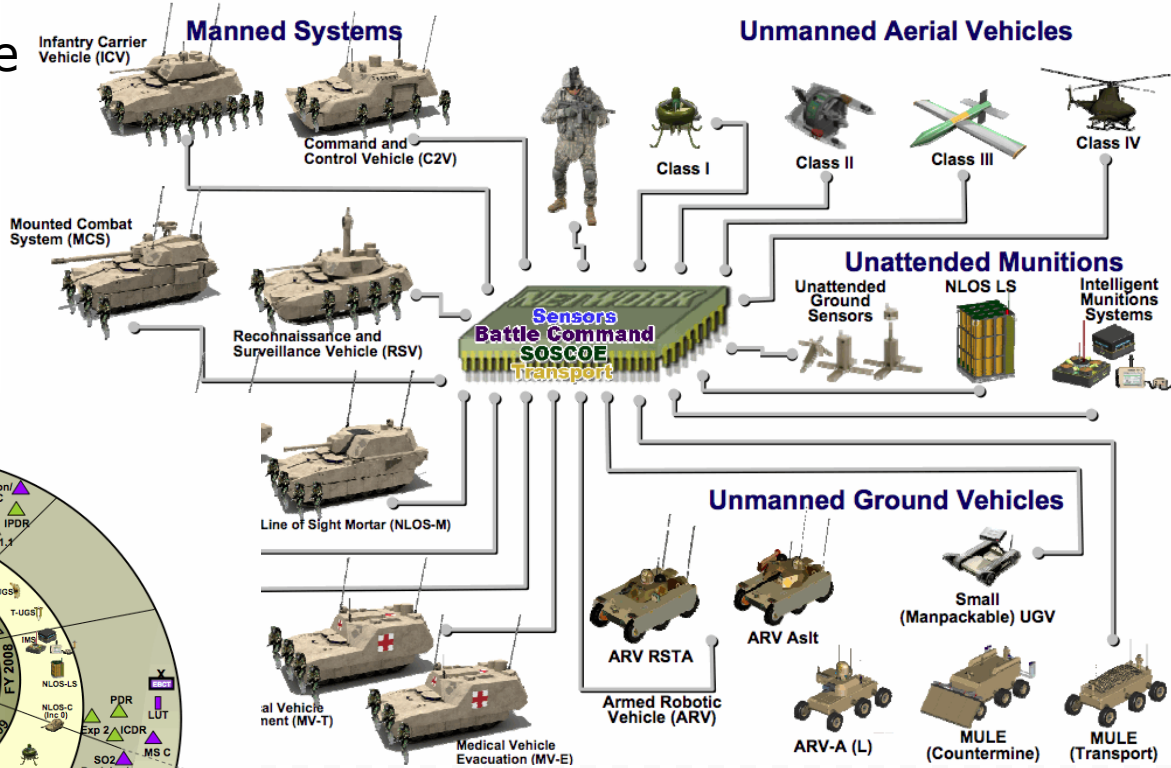
DoD Trends in SoS

How is the US Department of Defense treating systems of systems?

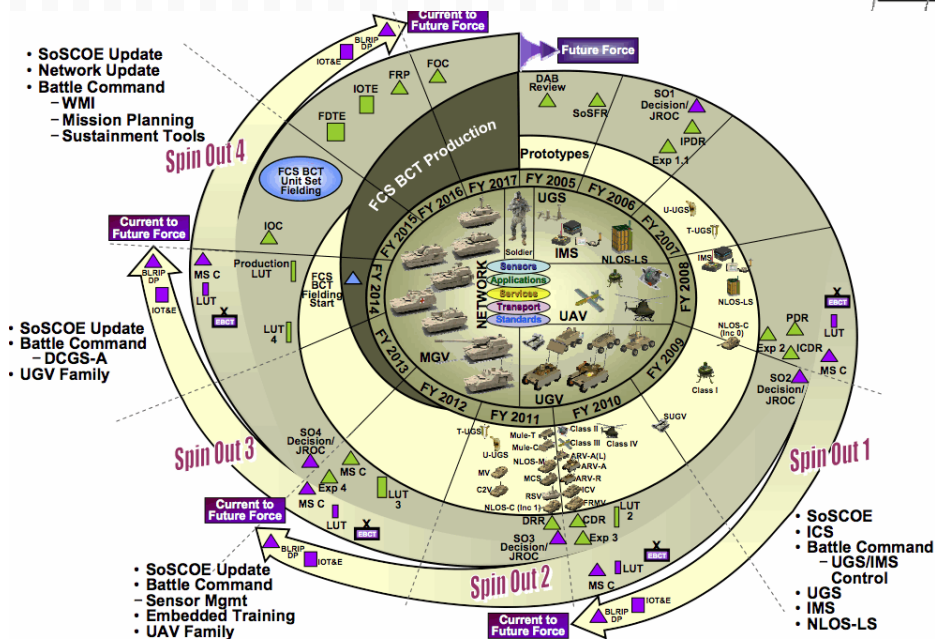
- *Systems of Systems*
- *Military vs. commercial*
- *DoD trends in SoS*
- *EU trends in SoS*
- *Successful SoS Trends*

US Army Future Combat Systems

- Build the Army of the future
- Network centric design
- Planned as Directed SoS



Decades-long Schedule



Component Systems

- The single largest acquisition program ever attempted by US DoD

FCS Approach and Results

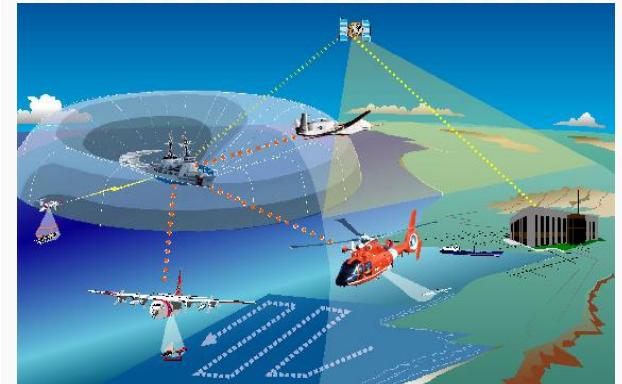
- Technical approach 2003-2009
 - Single contractor to plan, integrate entire SoS
 - Layered, networked architecture
 - Worked to develop SoS Common Operating Environment (SOSCOE) to standardize interfaces
 - Task Integration Networks as a Service-Oriented Architecture
 - Extensive use of DoDAF to manage information
- Program cancelled after six years of work
 - Unable to meet goal of first FCS unit by 2008 (target was moved outward to 2015)
 - Too expensive to continue
 - All component systems growing in cost and complexity



SoS Example

USCG Integrated Deepwater

- Replace the aging USCG fleet and aircraft
 - New cutters, fixed wing, helicopters, C4ISR
- 20-year contract 2002 \$20B to Integrated Coast Guard Systems LLC
 - Joint venture Lockheed Martin and Northrop Grumman
 - Expanded 2005 25-year \$24B
- Performance problems
 - Fast Response Cutter non-feasible
 - Offshore Patrol Cutter removed
 - 123' Patrol Boat converted from existing 110' cutters, failed
 - UAV effort halted
 - Logistics support cancelled
- 2007 all acquisition and integration efforts returned to USCG offices



SoS Example

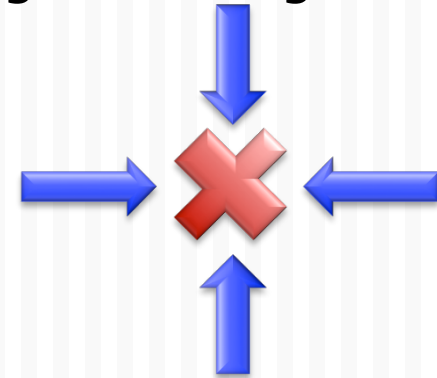
FAA NextGen Air Traffic Mgmt

- Revise existing ground-based radar systems with satellite-based and GPS systems (years 2012-2025) (\$15-20B)
 - Automatic Dependent Surveillance-Broadcast (ADS-B) – GPS self-location with inter-a/c real-time reporting
 - Data Communications replacing some voice comms
 - En Route Automation Modernization (ERAM) – new ground display network with smart functionality for controllers
 - Network Enabled Weather – real-time weather information
 - NAS Voice Switch – upgrade, modernize voice comms
- Coordinated with EU Single European Sky ATM Research (SESAR)
- Moving forward, but issues arising
 - Community noise problems due to new flight paths
 - Cost of upgrades on aircraft
 - ERAM delay impacting other systems
 - Budget reductions



DoD Approaches to SoS

- Tendency to treat every SoS as “Directed”
 - Traditional SE applied, top-down
 - Central manager
 - Hierarchical requirements management
 - Gradually learning this method is not effective
- Changing to Acknowledged model
 - Holistic capabilities defined and disseminated
 - SoS capabilities linked to system requirements
 - Motivate constituent system managers through vision, politics, standards, coercion
 - Maintain central management of SoS vision, modeling





EU Trends in SoS

What different approaches are in use within Europe?

- *Systems of Systems*
- *Military vs. commercial*
- *DoD trends in SoS*
- *EU trends in SoS*
- *Successful SoS Trends*

SoS Example

Single European Sky ATM Research

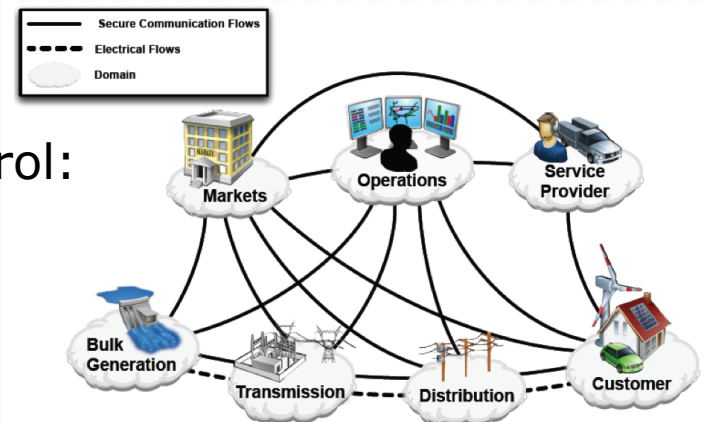
- SESAR project to upgrade, unify EU Air Traffic Mgmt
 - 2004-2008 definition: ATM master plan (some delays)
 - 2008-2013 development: technology systems (not complete)
 - 2014-2020 implementation
- Elements
 - Network operations planning
 - Integrate airport operations into ATM
 - Trajectory management
 - New aircraft separation modes
 - System-Wide Information Management (SWIM)
 - Humans as decision-makers, aided by automation
- Progressing with some delays
- No major issues



SoS Example

Smart Grid

- Upgrade electricity supply grid to be responsive to changes in suppliers and consumers
 - EU: Smart Grid European Technology Platform
 - USA: DoE SmartGrid.gov
- Features of the smart grid
 - Reliability: fault detection, tolerance, self-healing
 - Topology flexibility: bidirectional energy flow
 - Load adjustment/balancing for sudden changes
 - Peak leveling, time of use pricing
 - Variable energy sources
- Created by influence rather than control:
 - Sustainability initiatives
 - Cost initiatives
 - Political marketing
- Concerns over control and security



NIST Smart Grid Framework 1.0 January 2010

EU Approaches to SoS

- Tendency toward collaborative management
 - Cultural issue: European Union collaboration
 - SoS management by consortia, central committees
 - Seek agreement among member nations
- SoS control methods
 - Interface and protocol standards
 - Exclusion, marginalization of non-standard systems
 - SoS vision
 - Goals, societal benefits, capabilities
 - Use of defined standards
 - Distributed implementation





Successful SoS Trends

What seems to be working to support SoS development?

- *Systems of Systems*
- *Military vs. commercial*
- *DoD trends in SoS*
- *EU trends in SoS*
- *Successful SoS Trends*

Architecture Framework

A resource that guides the development or description of an architecture.

Elements

- Standard vocabulary
- Standard views and view descriptions
- Standard data structure to retain and exchange information
- Standard approach to develop architectures

Benefits

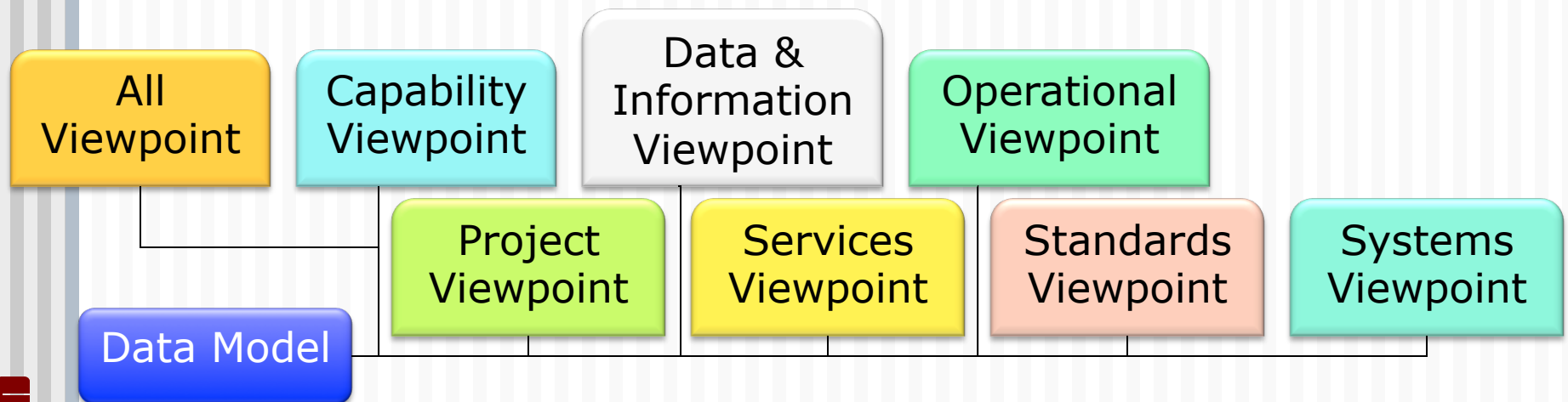
- Communications among those who share the framework
- Accurate data interchange among models
- Automated/visual evaluation of architectures
- Assists decision making
- Lower cost, greater assurance
 - Training and processes standardized



Unified Architectural Framework

UAF Overview

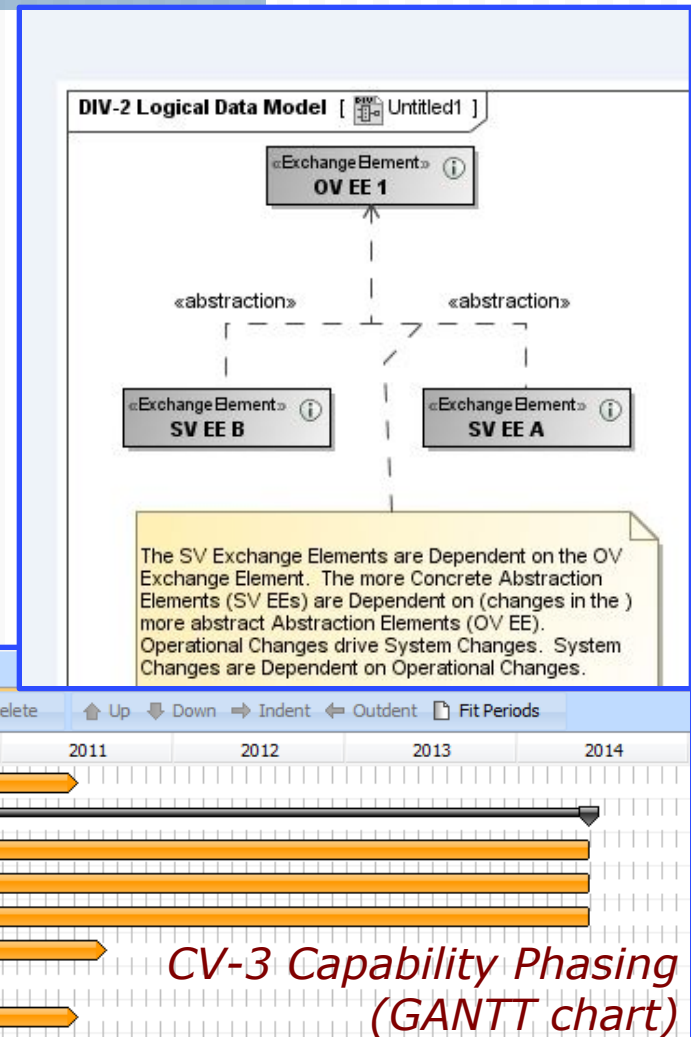
- Created in 2016 to merge issues between
 - DoD Architecture Framework (DoDAF)
 - MoD Architecture Framework (MoDAF)
 - Unified Profile for DoDAF and MoDAF (UPDM)
- Underlying data model
- Viewpoints representing the needs of different users
- 52 different views (diagrams) that show specific representations into the data model



UAF Views

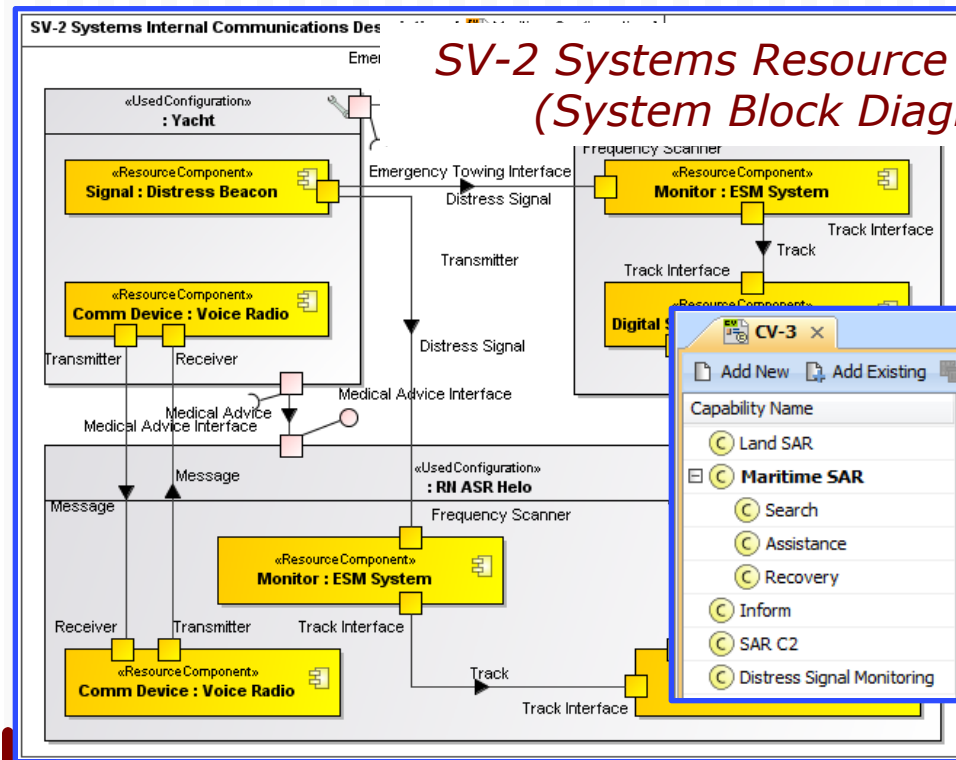
- Many diagram styles, each drawing from the same underlying data base
- Drawn from decades of diagram types
- Change diagram -> change data base

DIV-2 Logical Data Model (Entity Relationship Diagram)



CV-3 Capability Phasing (GANTT chart)

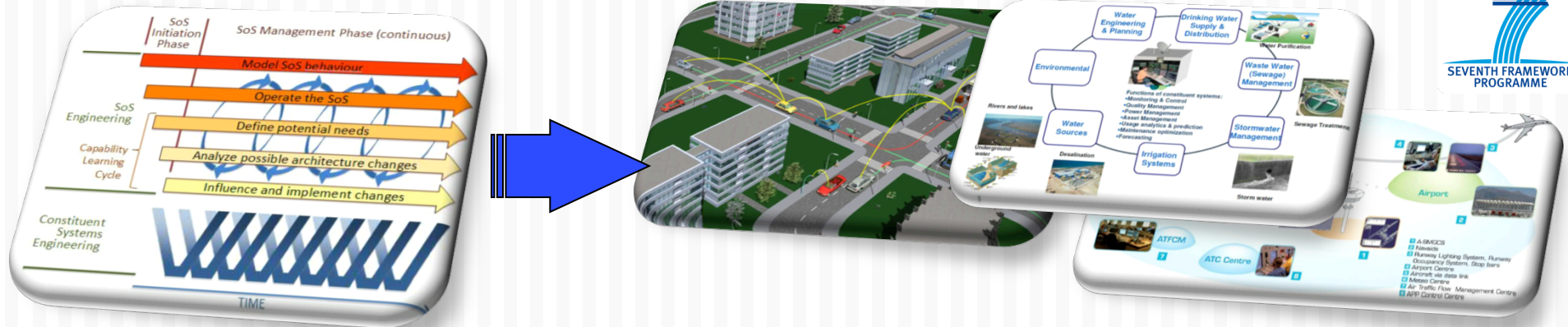
SV-2 Systems Resource Flow (System Block Diagram)



DANSE Project

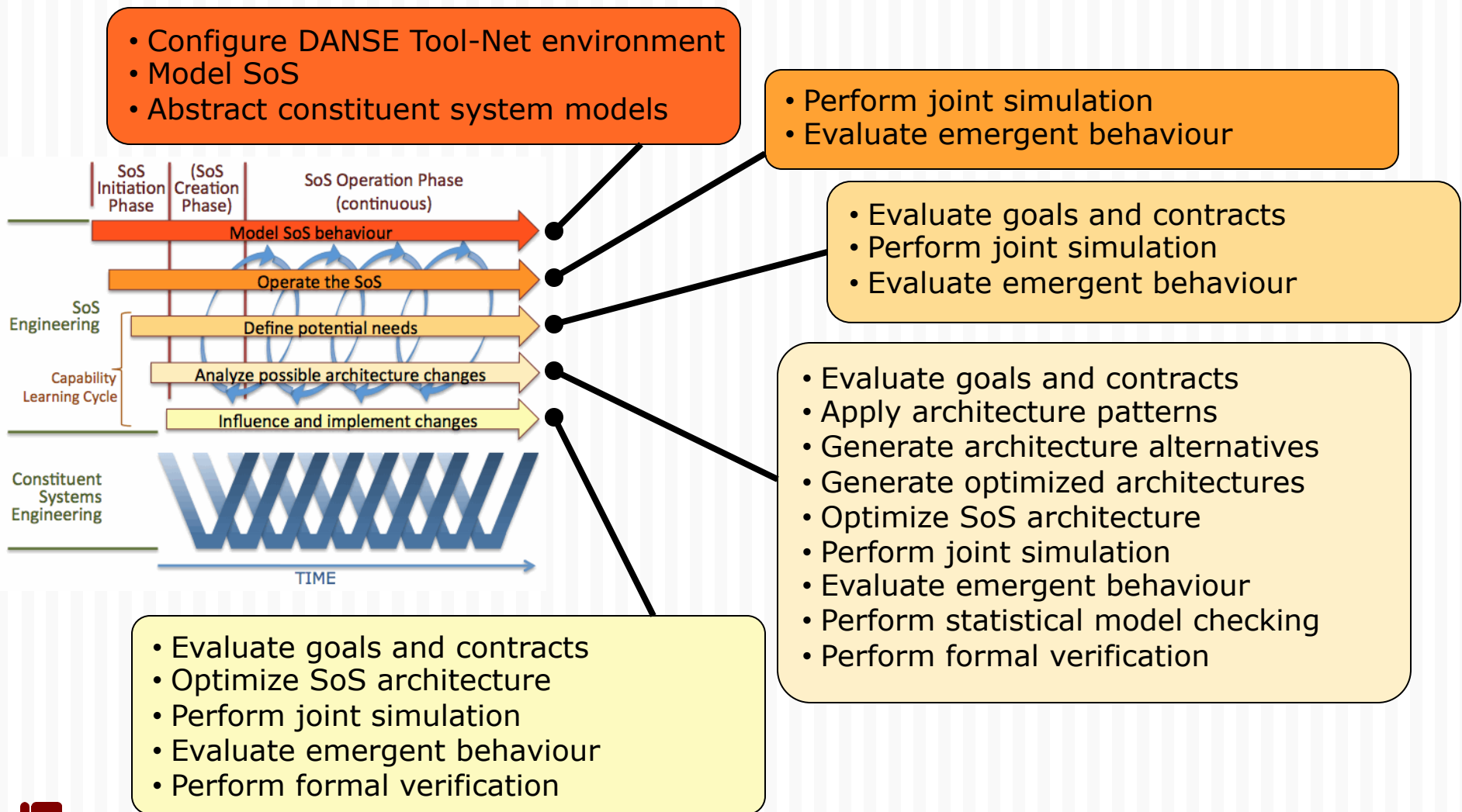
DANSE

SEVENTH FRAMEWORK PROGRAMME

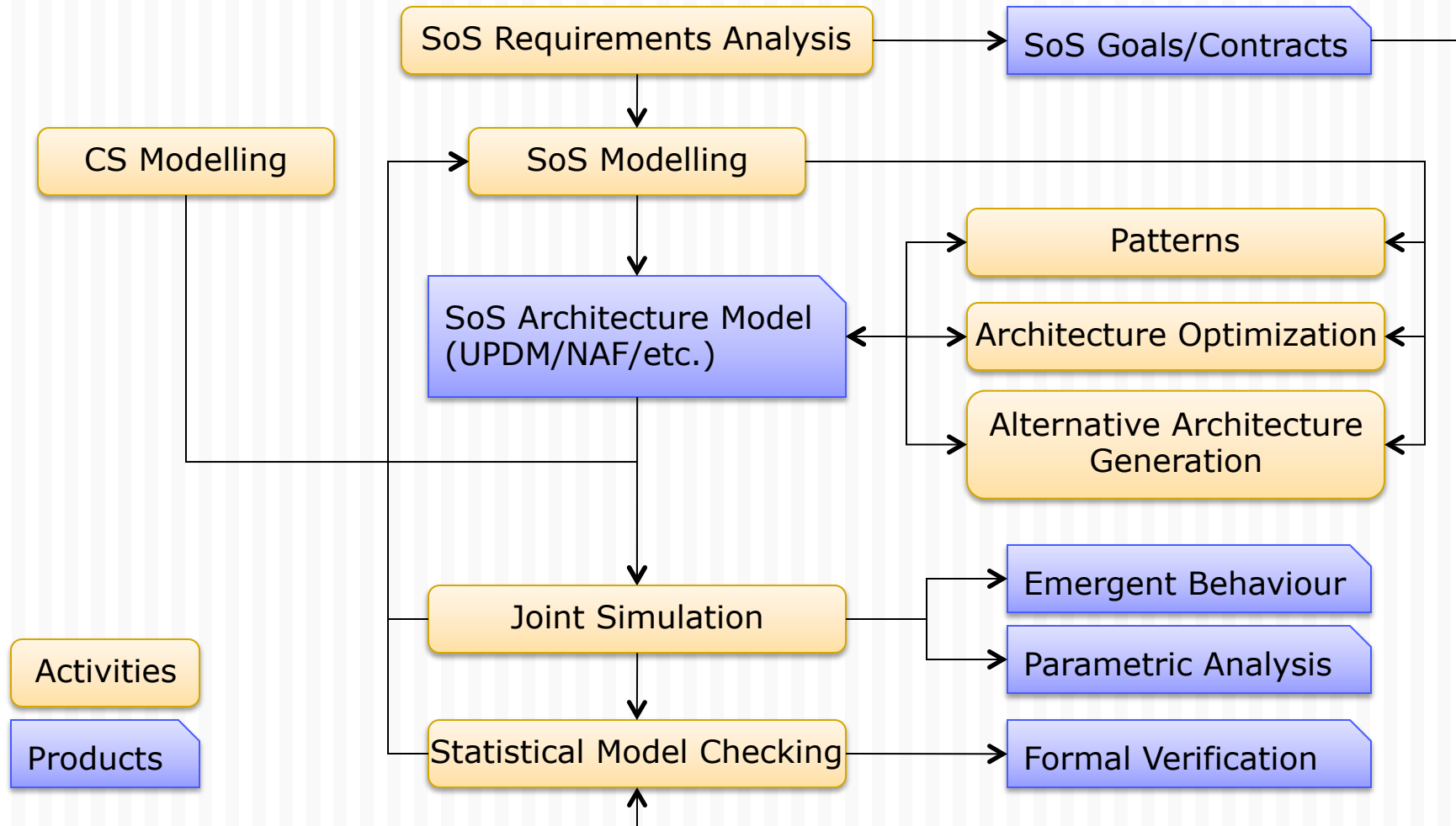


- Develop approaches for SoS engineering (design + manage)
 - Methodology to support evolution, adaptive and iterative SoS lifecycle
 - Contracts as semantically-sound model for SoS interoperations
 - Architecting Approaches for SoS – continuous and non-disruptive constituent system integration
 - Supportive tools for SoS analysis, simulation, optimization
- Validation by real-life test cases
 - Emergency Response; Air Traffic Management; Autonomous Ground Transport; Integrated Water Treatment and Supply

DANSE Solution Methods

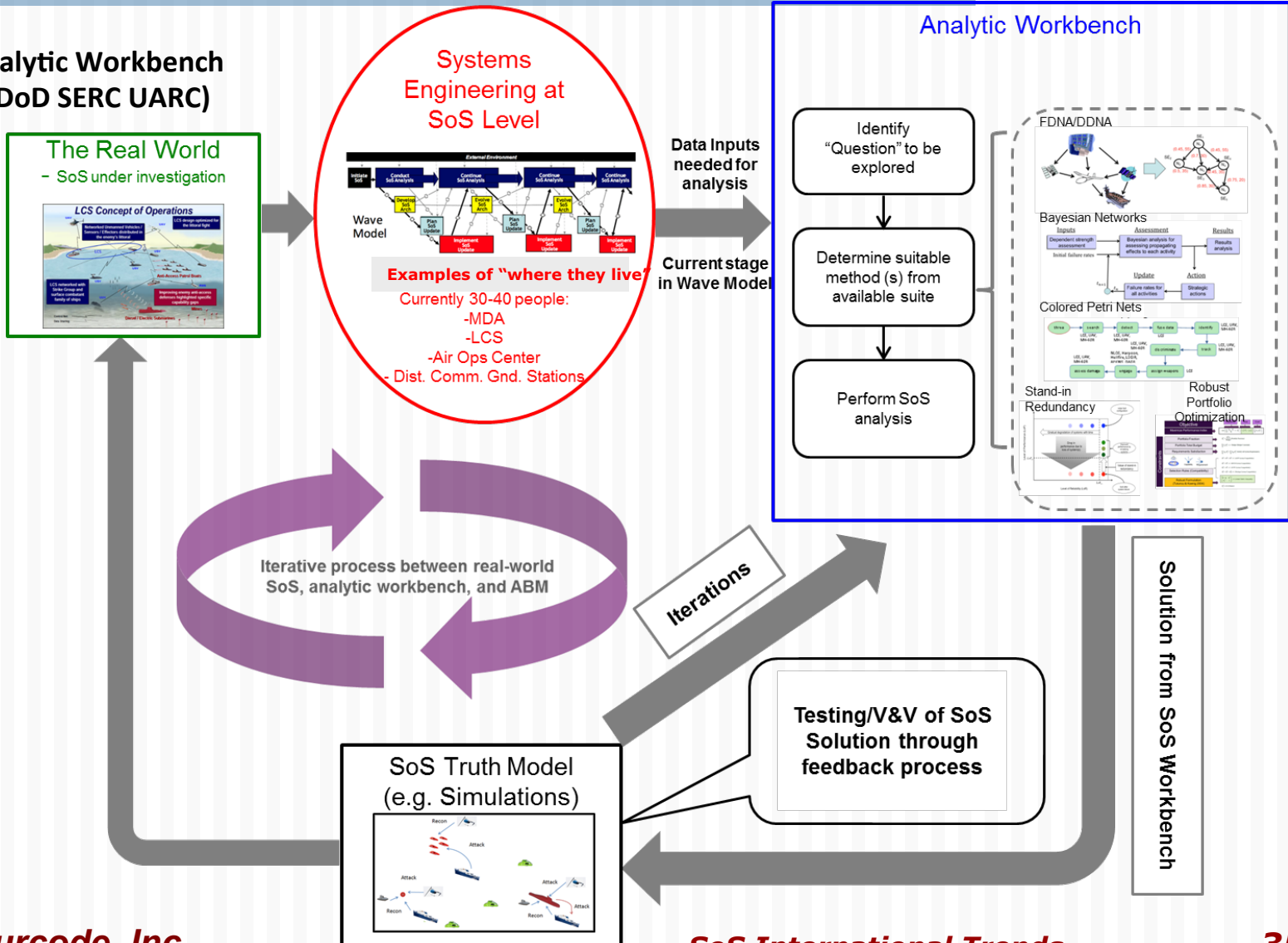


Example "Use Case" of Methodology

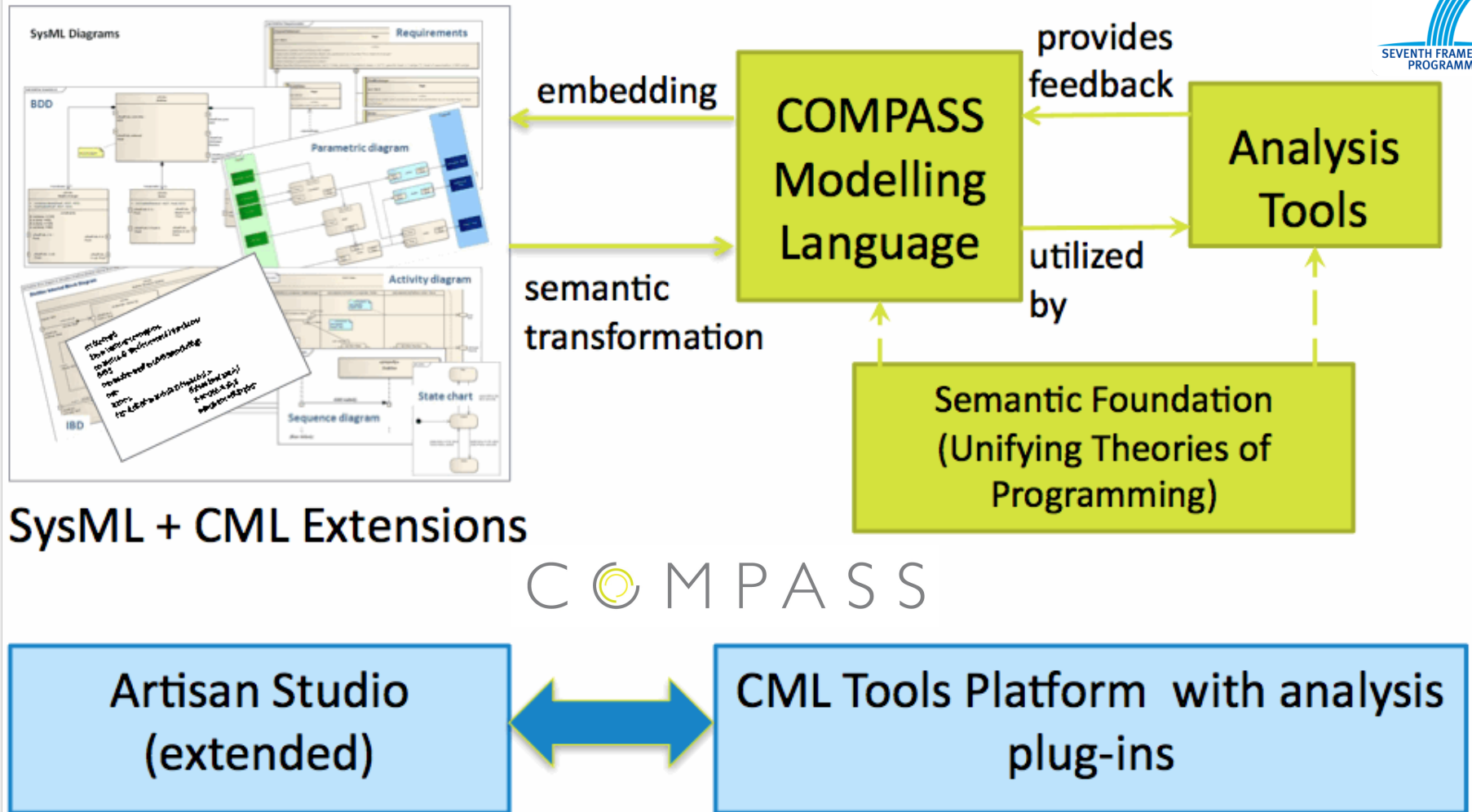


SoS Analytic Workbench

RT-44b: SoS Analytic Workbench
(sponsored by DoD SERC UARC)



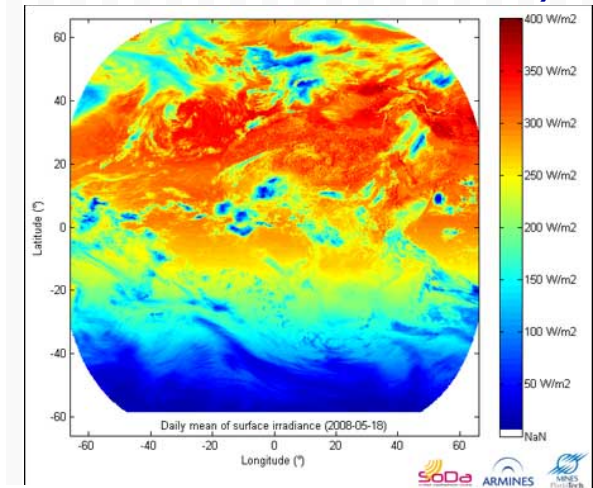
COMPASS: Modelling & Tools



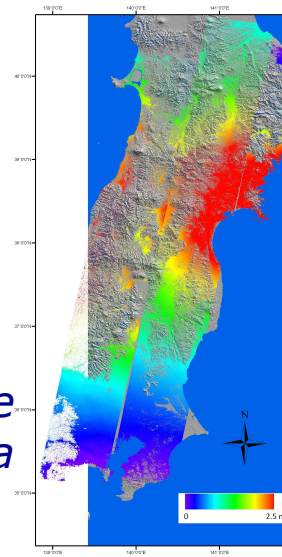
(*GEOSS*) Global Earth Observation SoS

- Worldwide initiative to pool Earth information from many sensors
- Provide information to researchers quicker and more accurately
- Originated Johannesburg 2002
- Coordinated by Group on Earth Observations (GEO)
 - Intergovernmental group
 - 60 nations, EC, 43 organizations
 - Executive committee of 12 members chairs (EC, USA, China, S. Africa)

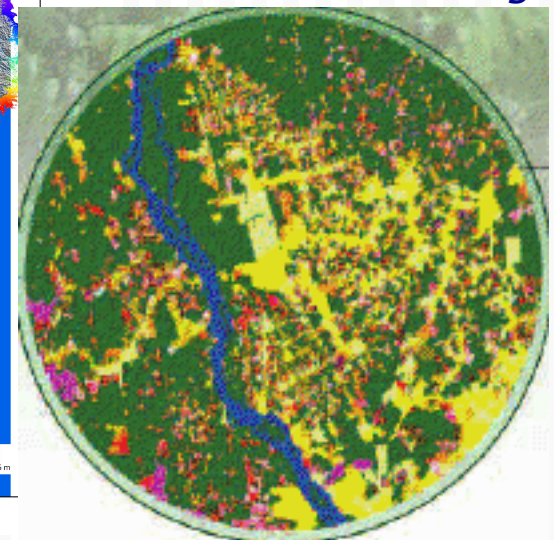
Solar activity



Earthquake data



Forest carbon tracking



GEOSS Approach and Results

- Technical approach 2003-2015
 - Create distributed/decentralized SoS recognizing charters of individual EO systems
 - Foster interoperability standards in specific technical areas
 - Pilot projects to test the ideas
 - Disaster relief, climate change, water management, weather forecasting, biodiversity, terrain elevations
- Work continues and grows
 - More data is available quicker, used widely through Internet
 - Currently working Architecture Implementation Pilot 6
 - Agricultural initiatives starting
 - Work plan for 2014 has three major areas
 - GEOSS Infrastructure for operability and sustainability
 - Institutions & Development to continue movement
 - Societal Benefits Information



System Opportunities in GEOSS

Constituent Systems

- Satellite sensors
 - Climate observation
 - Forestation
 - Weather, waves
 - Urban observation
 - Land cover
- Earth-based sensors
 - Earthquake
 - Climate change
 - Tracking pollutants
- Communications systems

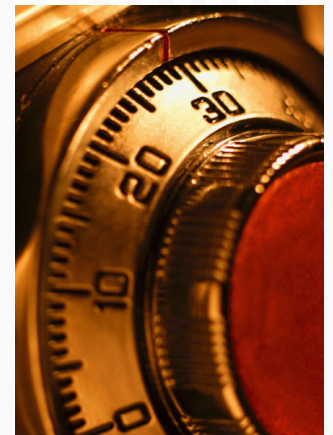
Management Systems

- Information assessment
 - Climate change correlation
 - Sensor correlation, merge
 - Military intel assessment
- Display/presentation
 - Common infrastructure
 - Data sharing
 - World-wide real-time information display
- Control/tasking
 - Conflict resolution
 - Prioritization



Summary

- Systems of Systems now and future
 - The cutting edge of system development for the next several decades
- SoS practices
 - Early attempts to apply traditional SE have failed
 - Successes come from iterative, holistic approaches
- Architecture frameworks and MBSE
 - Modeling is key to SoSE approaches
 - Extensive work is active now to improve models
- Business opportunities exist
 - Research and IP development of new methods
 - Constituent systems development, SoS enabled
 - SoS management systems and development





Honourcode, Inc.

Systems of Systems International Trends

Questions?

- *Systems Engineering*
- *Training Courses*
- *Process Improvement*

Eric Honour
+1 (850) 450-0429
ehonour@hcode.com