System-of-Systems and Large-Scale Complex Systems Architecting

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An example as a starter
Response to Disasters: Enable the global coordination of observing and information systems to support all phases of the risk management cycle associated with hazards (mitigation and preparedness, early warning, response, and recovery).
GEO and GEOSS (Global Earth Observation System of Systems)

- GEO was launched in response to calls for action by the 2002 World Summit on Sustainable Development, and by the G8 leading industrialized countries.
- GEO was created in 2005, to:
  - develop a coordinated and sustained **Global Earth Observation System of Systems (GEOSS)** to enhance decision making in nine Societal Benefit Areas (SBAs): health, disasters, forecasts, energy, water, climate, agriculture, ecology, oceans.

The goal of GEOSS is to access the right information, in the right format, at the right time, for the right people, to make the right decisions.
GEOSS: space-based assets
GEOSS: *in situ* assets
GEO today: 90 Government Members, 67 Participating Organizations
Strategic targets

- **Architecture**: Achieve sustained operation, continuity and interoperability of existing and new systems that provide essential environmental observations and information, including the GEOSS Common Infrastructure (GCI) that facilitates access to, and use of, these observations and information.

- **Data Management**: Provide a shared, easily accessible, timely, sustained stream of comprehensive data of documented quality, as well as metadata and information products, for informed decision-making.

- **Capacity building**: Enhance the coordination of efforts to strengthen individual, institutional and infrastructure capacities, particularly in developing countries, to produce and use Earth observations and derived information products.

- **Science & Technology**: Ensure full interaction and engagement of relevant science and technology communities such that GEOSS advances through integration of innovations in Earth observation science and technology, enabling the research community to fully benefit from GEOSS accomplishments.

- **User**: Ensure critical user information needs for decision making are recognized and met through Earth observations.
Governance: structure for GEO

STT = Strategic Target Task: 1 per Strategic Target – (except Archi & Data Mgt)
SBA = Societal Benefit Areas
MB = Management Board
WP = Work Package
From systems to systems-of-systems engineering
Think system (recursively)!

- The system and its context:
  - mission, environment.

- Inside / outside:
  - Frontier.

- The interfaces of the system:
  - one-way or two-way exchanges, closed loops, feedback.

- The global view of the system throughout its life.

- The **whole is more than the sum** of its parts (emergence due to interactions).
- The **whole is less than the sum** of its parts (less degrees of freedom due to interactions).
Increasing complexity: *more parts, longer cycles, larger (even multicultural) teams*
Systems-of-systems: definition (in the 90’s)

- Usual criteria to characterize an SoS (extensive Maier’s definition):
  - **complexity** (number of interrelated components),
  - **operational independence** of the elements (each system can be used alone),
  - **managerial independence** (multiple acquisitions, independent uses),
  - **evolutionary development** (evolving definition and design),
  - **emergent behavior**,
  - **geographic distribution**.

Developed from Maier, 1997
Current trends for systems-of-systems (2010’s vs 1990’s)

- Maier’s definition is:
  - restricted to the technical view of systems,
  - restricted to a static snapshot of the lifecycle,
  - restricted to the engineer’s point of view,
  - not user-oriented.

- To adapt to the current context, one should consider:
  - political, financial, legal, technical, social, ethical, operational, and organizational factors,
  - including the stakeholders’ perspectives and relationships,
  - during development, management, and operations.

- **(Comprehensive) definition**: a system-of-systems is an assemblage of systems that can be potentially acquired and/or used independently, for which the designer, the acquirer and/or the user tries to maximize the performance of the global value chain, at a given time and for a set of foreseeable assemblages.

A majority of processes and sub-processes are non-technical!
Know your web!

- **Market-related risks:**
  - Market
  - Financial
  - Supply

- **Completion risks:**
  - Technical
  - Construction
  - Operation

- **Institutional risks:**
  - Regulatory
  - Social acceptability
  - Ethics
  - Sovereign
Increasing interplay between institutions and projects

Large-scale complex projects affect institutions: smart governments and regulatory agencies try to design efficient arrangements that encourage economic development.
Governance arrangements

- Sharing of risks among partners through contracts (preemptive commitments).
- Collaborative rationality instead of top-down rationality.
- Innovative practices: project financing, BOT (build-operate-transfer) concessions, risk seminars...
- Collaboration between owners, contractors, suppliers is a key driver for cost and time reductions.
- Credible and reputable sponsors and partners.
New relations between sponsors and contractors

Transition client-supplier towards long-term sharing, collaboration

- Trust
- Sharing
- Preservation of knowledge and know-how (legacy and IPR issues)

Strategic Alliances: define competitive advantage for a community and not individuals
Architecture Definitions

- “The structure of components, their relationships, and the principles and guidelines governing their design and evolution over time.”

- “An architecture is the fundamental organization of a system embodied in its components, their relationships to each other, and to the environment, and the principles guiding its design and evolution.”
  IEEE STD 1471-2000

- “An abstraction of a current or future state that represents the whole existence of an enterprise, represented by a specification of a system of systems at a technical level which also provides the business context for the system of systems.”
M&S: to “give life” to the different views, in accordance with architecture frameworks, building the reference of the global system, in order to increase trust in the global system.
Towards integrated and shared tools

- **Battle-labs:**
  - Approach initiated in the 90s by US DoD: CDE (concept definition & experimentation).
  - Approach used then by civilian domains (aeronautics, automobile...).

- **Provide to all players of the game (stakeholders, contractors, users) a set of methods, tools and an organization, in order to define and manage the system-of-systems.**

- **SoS level:**
  - specificities: multi-sponsor, multi-programs, multi-contractors, not bounded in time,

- **Why work within a battle-lab?**
  - To work as an integrated team “Sponsor+Procurement+Contractor”.
Concluding remarks
Think global!

- Systems are integrated in a global environment
  - Quick, complex and non-predicted changes

- Focus on people, services, organizations
  - Applied to new industrial and societal problems

- New business practices & tools
  - Distributed enterprises, virtual teams, collaborative environments
    (design, decision support) → information & knowledge management

- Coopetition (competition / collaboration depending on opportunities).

- Evolution of intellectual property management strategies:
  - Preserve the critical added-value;
  - Share between partners what has a non-critical added value ≠
  - Open to large collaboration what has weak added value.
Non-technical issues interfere strongly with technical issues… and conversely!

- Governance (acquisition) impacts contract engineering, which impacts architecting (work breakdown structure: work share and intellectual property issues).

- Governance (in operation, with various regulatory environments) and in-operation scenarios (cost profile issues with return on investment) impact contract engineering, which impacts architecting (work share, maintainability and evolution potential).

- Organizational issues in operation impact architecting (work share, levels of competence of operators).

- Cost issues impact architecting and trade-offs, as well as in-operation scenarios.

- Regulatory issues impact architecting (new constraints), governance and organizations (new actors, mandatory audits).
More on SoS (French and English)