Are stakeholders in the constituent systems SoS aware?

Reflecting on the current status in multiple domains

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***Abstract*—Most systems are actually a constituent system of a System of Systems (SoS). Similarly, many SoSs are constituent SoS of a SoS of Systems. This nesting process repeats itself several times; we can observe many levels of SoSs. This paper provides a number of cases in various domains to illustrate the nesting of SoSs.**

From observing many participants in architecting courses, we derive a lack of awareness of stakeholders in constituent systems of their encompassing SoSs. This lack of awareness may result in problems during integration, commissioning, or deployment of systems in their broader context.

Keywords—System of Systems, domain, case study, stakeholders, integration

I. Introduction

After active participation, consulting, and educating in a wide variety of domains, we observe that amazingly few stakeholders of constituent systems of a system of systems (SoS) are aware of the SoS nature of their context. At the same time, most SoSs are in fact Systems of SoSs, where these recursively applies several times.

The purpose of the paper is to reflect on:

- The nested nature of SoSs, and relating these to the types of SoSs
- The limited horizon of most stakeholders in any level of such nested SoS
- The potential impact of the limited horizon on the encompassing SoS

The means for this reflection are several example domains as case study. Some of these case studies have been published before, so interested readers can read further about them via the references.

II. Types of SoS

Dahmann and Baldwin describe in [1] several types of SoSs, briefly paraphrased as:

Directed - The SoS is centrally managed

Acknowledged - The SoS has recognized objectives, and active cooperation between SoS and constituent systems

Collaborative - The constituent systems and stakeholders cooperate

Virtual - The SoS nature more or less emerge from the constituent systems

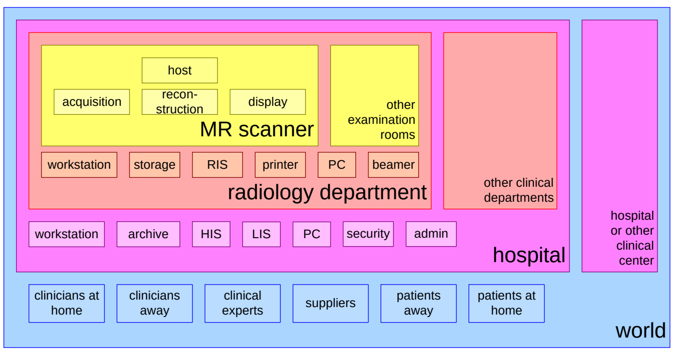
III. Example domain and case studies

A. Health care

The health care case study starts at equipment level used for diagnosis and treatment. Examples of equipment are Magnetic Resonance (MR) scanners, Computer Tomography (CT) scanner, Ultra Sound (US) imaging, and X-ray equipment. Users and suppliers typically perceive such equipment to be single systems. However, [2] describes the need for interoperability of this equipment and image and information handling systems at department and hospital level.

Fig 1 visualizes various levels of SoSs from equipment to hospital; context. This diagram from [2] is a simplified diagram to explain the multitude of levels. One can argue that an examination room is a level of SoS between MR scanner and radiology department.

Fig. 1. Four nested level of health care systems



The radiology department is closer to collaborative than acknowledged. The level of conscious control has increased over time. Health care equipment suppliers have gradually increased their scope of delivery from equipment to examination room. Facility management and IT departments try to get grip at departmental and hospital level SoSs. However, the high complexity limits todays hospitallevel SoSs to virtual or collaborative.

B. *Semiconductor equipment and manufacturing*

A semiconductor manufacturing factory ("fab") is a complex and expensive SoS. The case study described in [3] starts at wfer stepper level. A wafer stepper is the core machine in the lithographic process, where wafers are exposed to form the desired electric circuit via many sequentially applied chemical processes. Fig 2 shows a highly simplified block diagram of a wafer fab.

Fig. 2. Semiconductor wafer fab, with many constituent systems

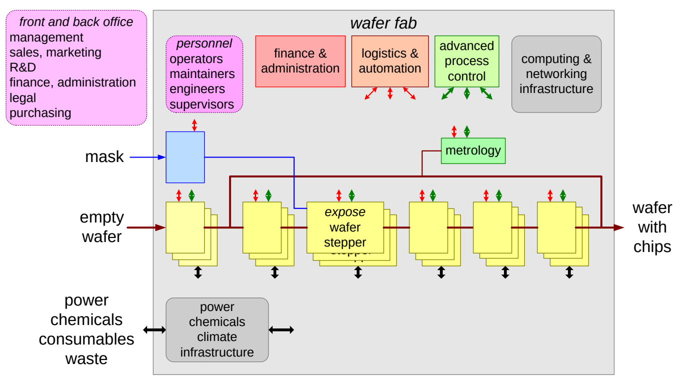
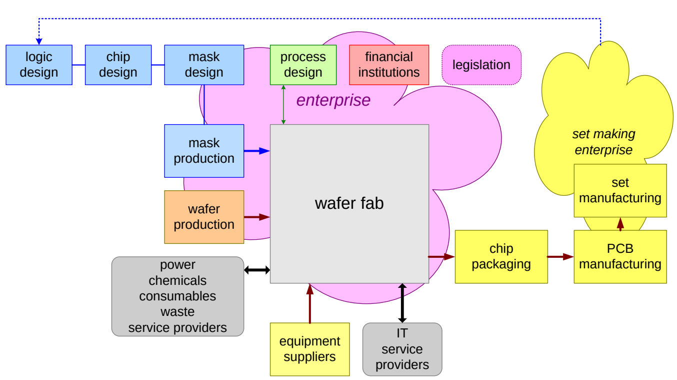


Fig 3 shows the context of the fab, with many systems that chipmakers need to design and manufacture ICs. The wafer context forms a mind boggling complex eco-system. There are players in the market, such as factory automation, that have more control over specific functions (such as storage, transportation, and automation, or quality control). Partially, wafer fabs are only collaborative; partially they are acknowledged or even directed. The context of wafer fabs shows a mixed status as well. The tooling chain has advanced beyond the virtual stage. Other aspects are still at the virtual level.

Fig. 3. Wafer fab context



C. *Factory for manufacturing of airplane engine parts*

Factories in general, are complex and large SoSs, where many systems and humans interoperate. [4] discusses a case study of production lines for airplane engines.

Fig. 4. SoS visualization of factory of airplane engine parts

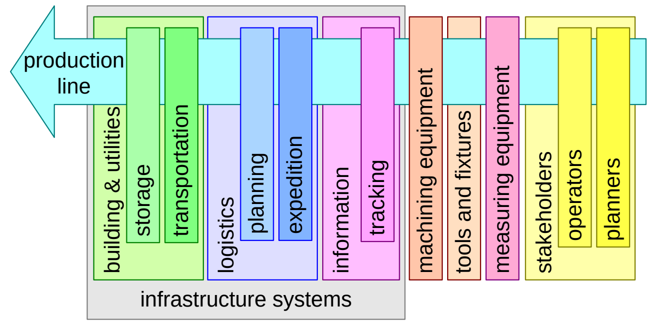


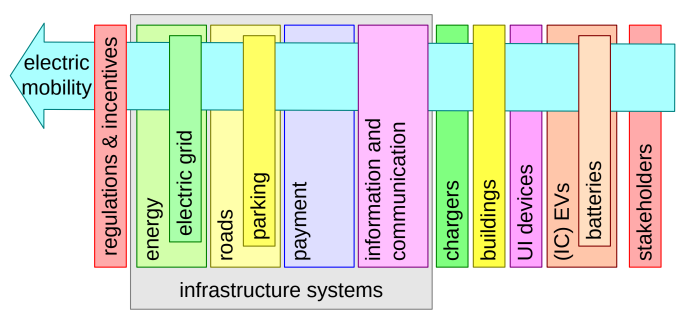
Figure 4 shows a classification of the systems in this case study. When visiting the factory, then the manufacturing equipment is dominating in size, noise, and smell. Since this equipment is capital intensive, these systems also dominate in tactical and operational meetings. However, from factory performance point of view, the interoperability of all classes of systems is crucial.

The production line may be moving from collaborative to acknowledged; the factory is closer to virtual than collaborative.

D. *Electric mobility*

Electric mobility is a fast growing domain. Governments see electric mobility as an essential step in the transition toward a sustainable society. Electric transport is not polluting while it fits better with sustainable energy sources, such as solar, wind, and wave energy.

Fig. 5. Systems involved in electric mobility

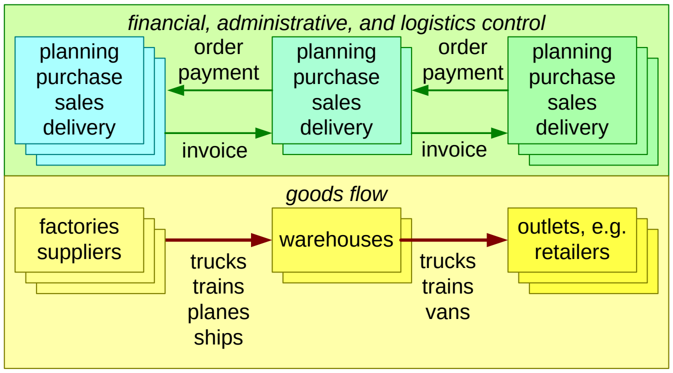


[5] Describes electric mobility as SoS and its challenges to evolve into practical transportation. In the preparation of this pper, we made a similar classification as shown in Fig 4. Fig 5 shows the wide variety of systems involved in electric mobility. The SoSs in this domain are still emerging; standards are proliferating. Some stakeholders clearly recognize the need for collaboration or even more central control. At the same time, the dynamics is so high that the entire SoS is more virtual.

E. Distribution center

Chapter 6 of [6] describes a distribution center as a SoS. Fig 6 shows the control and goods flow of a distribution SoS. In the middle, with the warehouse and the planning, we see the core of the distribution center.

Fig. 6. Control and goods flow for a distribution center

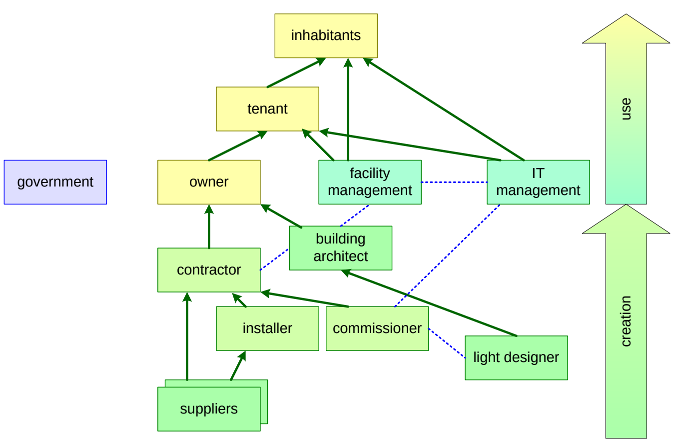


At the level of a distribution center, we can recognize a directed SoS. The supplier of the warehouse takes the role of project developer for the combination of warehouse and control functions. At the level above, with the entire logistics chain, the SoS is either acknowledged or collaborative, dependent on market and instantiation.

F. Lighting systems in office buildings

The lighting systems in office buildings used to be a closed system, where the stakeholders in the value chain have reasonably clear tasks and related competences. The introduction of networking technology (IP-based), following the Internet of Things, promises more integrated functionality [7]. In combination with the transition from traditional bulbs and fluorescent lamps to LEDs, we see a disruptive change in lighting systems and the involved stakeholders.

Fig. 7. Stakeholders in the value network of lighting systems



This disruptive change just started. Other systems in buildings are, for instance, Building Management Systems, IT systems, heating and air conditioning, access control, surveillance, emergency and public address systems. Most systems in buildings still have to discover what the paradigm shift means for their system. Domains like public address, surveillance, and access control are somewhat more advanced in this transition, although they suffered from similar transition challenges in the value chain. Especially the transition from physical installation of dedicated cables to commissioning of networks is quite a challenge.

G. Subsea Production Systems

Fig. 8. Subsea production system

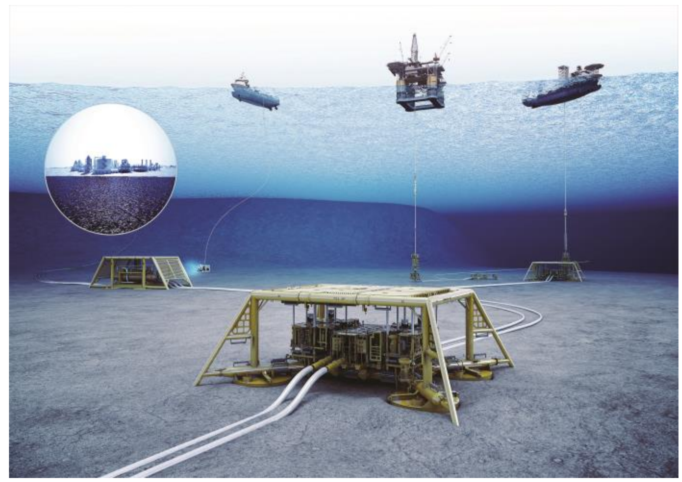


Fig 8 shows a subsea production system, in itself consisting of multiple systems at the bottom of the sea, connected to systems topside, such as platforms and other vessels. During installation and workover additional systems, such as riser systems and Remotely Operated Vehicles, connect to and operate upon subsea systems.

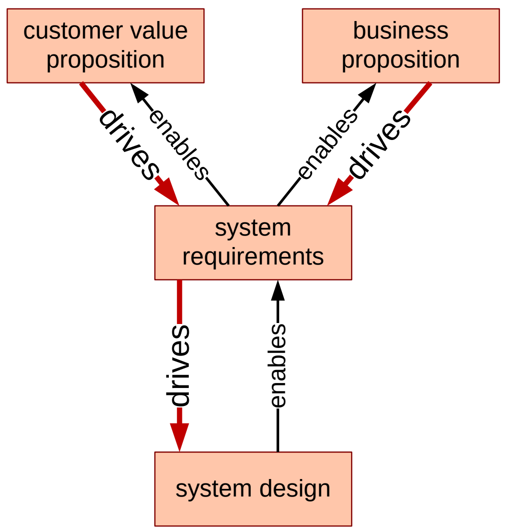
This industry approaches most installations as turn-key project, bringing it close to a directed SoS.

IV. Reflections on SoS Nature and Stakeholder Awareness

The cases shown in a wide variety of domains vary in their type of SoS over all 4 classes. This classification suggests that there is a reasonable awareness of the SoS nature at many levels of SoSs. However, in many cases this awareness is limited to a small group of principals and systems engineers.

While teaching to engineers and systems engineers in these companies, another perception emerges. During this teaching, the main topic is architecting: relating the design of a system-of-interest to the context of that system; see Fig 9. Typically, the participants of these courses work at (part of) the specification, design, and engineering of the system-of-interest. One objective of the course is to help participants to broaden their perspective several steps. The desired breadth is that participants are able to relate considerations of the encompassing system and the lifecycle to concept and technology choices within the system-of-interest. While broadening the participants, the majority of them discover that they know way too little about encompassing system and life cycle.

Fig. 9. Architecting relates the customer context (customer, business) to the system design



If we take this observation toward the SoS cases, then the conclusion is that most stakeholders working on a constituent system lack awareness and knowledge of the next level of SoS (the encompassing system).

Fig. 10. Leveling of systems based on TRIZ

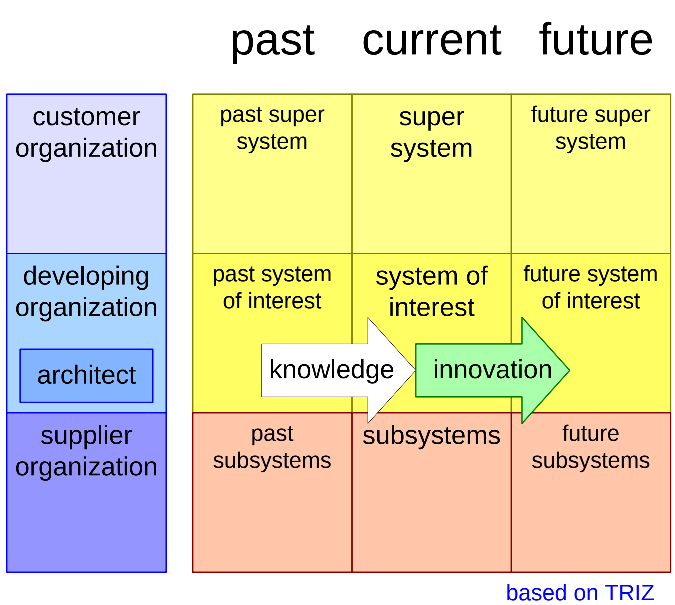


Fig 10 shows a 3*3 matrix from TRIZ [9]. This matrix shows the time dimension horizontally and the system level in vertical direction. Core of architecting a system-of-interest is to understand the past and current system, such that the architect can design a future innovated system. This architecting effort requires understanding of encompassing system and constituent subsystems. Fig 9 shows that each system level has its organizational equivalent. Architects need to work with stakeholders in their own organization, the customer organization, and the supplier organizations.

When observing all these course participants, who have the ambition to become systems engineer or systems architect, then we see that they tend to be too "low" in Fig 9. If these participants know little of their context, then we may expect that their less ambitious colleagues probably know even less of the context.

Consequence of (too) little awareness of the encompassing system is that designers who change a system are unable to foresee and reason about the impact of a change within the system-of-interest on the encompassing system. Undesired emergent behavior may show up during integration, commissioning or during the deployment of the system. An example for subsea systems are the costs of late design changes, due to insufficient understanding of the operational needs [10].

Another observation of two decades of training in these various domains and organizations is that larger organizations tend to produce employees that are more specialized; employees who fill a narrow niche quite well. This high degree of specialization prevents them to reach out and to explore the system context (or worse to explore the system of interest itself).

Finally, we observe that in most cases we have several levels of SoSs. We assert that the lack of awareness of the encompassing SoS repeats itself at each level. Consequently the problem of anticipating impact on higher levels of the SoS will repeat itself also, showing up again during integration, commissioning, or deployment of the higher levels of SoS.

V. Conclusions

Reviewing many SoSs in diverse domains by observing potential systems engineers taking architecting courses reveals that exploration and understanding of encompassing systems is poor. For SoSs we argue that most stakeholders of constituent systems are insufficiently aware of the next level of SoS that encompasses the system of interest.

These case studies show that most systems are part of several levels of SoSs. In other words, the problem of insufficient awareness repeats itself at each level. Consequently, such changes may propagate to higher levels of SoSs, and show up during integration, commissioning, or deployment.

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