1.4

Foundational Technology Layers

SYSTEM OF SYSTEMS

1.4 System of Systems

1.4.1. SCOPE

The System of Systems (SoS) technology layer represent the upper layer of ECS technology stack for digitalisation solutions. This technology layer emerges from the composition of embedded and cyber-physical systems (CPS), connectivity and distributed software platforms.

In the ECS domain, a constituent system of a System of Systems (SoS) is defined as a set of embedded hardware hosting software designed to perform a particular task or solve a specific problem. A constituent system can be distributed, but from a logical/conceptual perspective it is "contained" in one unit and it is autonomous and/or independent from the other constituent systems, (i.e. it shows managerial and operational independence from any other constituent system). The complexity of these constituent systems is rapidly increasing with the development of the underlying HW/SW technologies, as well as the rising demand by the users of these systems for functional and extra-functional requirements.

According to the definition, SoS[1] must satisfy five characteristics: (i) the operational independence of constituent systems; (ii) the managerial independence of constituent systems; (iii) geographical distribution; (iv) emergent behaviour; and (v) evolutionary development processes. A system that does not satisfy these characteristics is not considered a SoS.
In modern hyper-connected digital solutions, systems rarely operate independently. On the contrary, the primary added value of these digital solutions is the cooperation between heterogeneous systems to solve more complex problems by exploiting the set of multi-technology, multi-brand and even multi-domain functionalities generated by the cooperation. While talking or reading, SoS is typically pronounced entirely "System of Systems". A SoS emerges from the composition/integration of multiple systems to perform a task or reach an objective that none of the constituent systems can perform or reach on their own. In the SoS, each constituent system is considered a "black box": it remains operational and managerial autonomous and/or independent, relying on its own hardware, software, and networking resources, and remaining focused on its own goals. At the SoS level, the SoS evolves with components, functions and purposes added, removed, and modified, leading to an increasing dinamicity and variability along their life cycle (a life cycle that potentially never finishes!). The SoS structure evolves with the addition or removal of the constituent systems, which always cooperate, coordinate, and adapt to achieve the SoS goals, providing additional features to the SoS as a whole, capabilities and functionalities unavailable in the constituent systems. Having an up-to-date inventory and real time monitoring of the SoS is challenging.

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[1] Architecting Principles for Systems-of-Systems, Mark W. Maier, Systems Engineering journal, John Wiley &Sons 1998

A charging station for electric vehicles represents an example of a constituent system: it is logically and physically a single CPS, is capable of autonomously providing all the functionalities required by the recharging process and is independent of other charging stations – and even the electric grid if it is equipped with solar panels. When we connect a fleet of charging stations, adopting for example an IoT-based solution, the new distributed infrastructure of charging stations becomes a SoS. Single charging stations are operationally independent, but at the SoS level can cooperate with each other and with vehicles offering new functionalities and services. As a SoS, the recharging infrastructure can support different categories of charging standards, different charging processes, different energy sources, operators, brands, etc. – features and functionalities that were not previously available. For the end user, the SoS allows the possibility to automatically plan a trip that ensures the geographical coverage of recharge points compatible with the vehicle, a functionality that single charging stations and vehicles cannot independently provide. Application areas of SoS are very diverse, covering most industrial and societal domains.

Like a nervous system – i.e., partially centralised, distributed and peripheral – a software integration platform is a key element of a SoS, partially running on the enterprise side (e.g. in the cloud), and partially in the various geographically distributed entities of the SoS (including the edge). The integration platform is the element of the SoS that is "conscious" of the SoS in its integrity, and provides the functionalities and properties to manage and operate the SoS (e.g. subsystems interfacing and integration, interoperability, full monitoring and control of the constituents embedded and CPS, operation management, engineering full lifecycle support, trust management, data acquisition and storage, data analysis and visualisation, etc.).

SoS platforms play an important role for the ECS value chain and the related ecosystem, representing the structural element that physically and virtually contributes to keeping all the elements bonded together. SoS platforms allow for control of the information flow, enabling the creation of added-value services and applications, contributing to the development of relations between the value chain stakeholders, as well as generating and implementing new business opportunities.

To create added value, a SoS need to be trustable, and here end-to-end security issues have to be properly taken into account. A secure SoS should be able to defend against both deliberate attacks and accidental threats, and also its misuse. Moreover, it is not enough to ensure that each of the constituent systems is secure in the pre-deployment phase, but also that the evolved/composed/integrated SoS, whose exact composition may be not known in advance, is secure. Dynamically adapting security requirements and risks mitigations should be considered over time, and in handling emergent functionalities, properties and behaviours arising due to the complex interactions among the constituents of the SoS. New methodology and tools for risk and vulnerability assessment and threat modeling are needed.

Artificial intelligence, Machine learning and ontologies based approaches can complement each other for improved knowledge and decision making processes in a SoS system.
AI/ML can make predictions based on experience or training, while ontologies provide information based on reasoning and can also optimize and accelerate machine learning processes.

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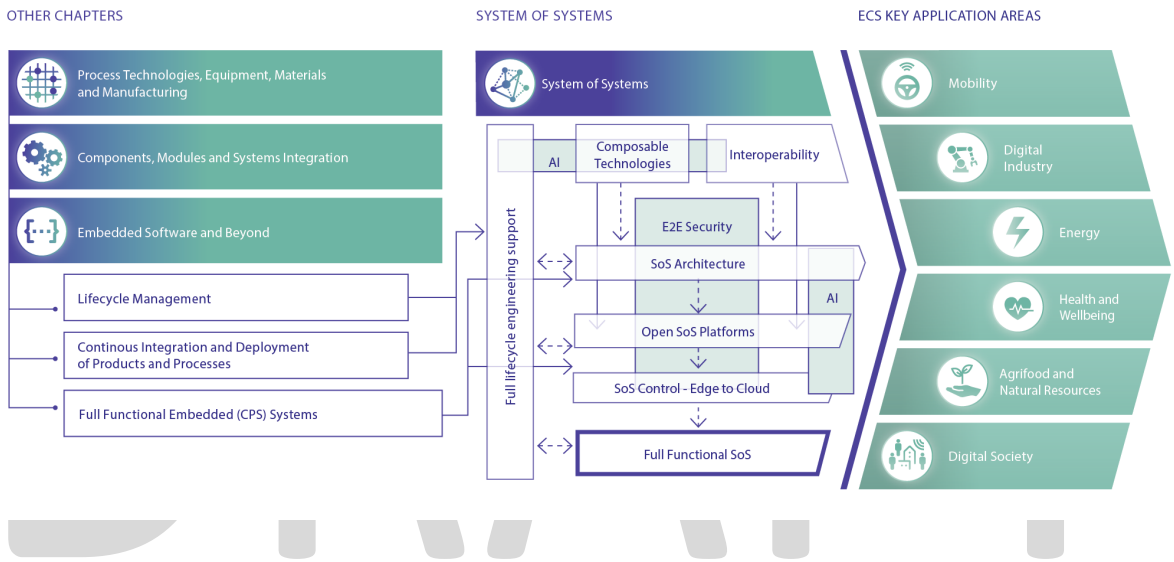
Technical solutions in the SoS platform domain should be open and ensure a certain level of domain independency, simplifying their adoption and allowing their re-use in different vertical applications. At the same time, it is also unrealistic to imagine that a single SoS platform could drive an entire market because, considering the interdisciplinarity and complexity required to develop them, very seldom will a single vendor be able to provide a complete end-to-end and domain-independent solution. However, platform "competition" will at least have to identify a set of European solutions that covers key vertical domains. For key European vertical domains an SoS have to address a multitude of cross sectorial requirements like e.g. security, safety, evolution, maintenance, trustworthy. For example security certification issues both at component, system and SoS level should be properly addressed aiming at really mitigating risks/threats in competitive scenarios, while also considering the EU Cybersecurity Certification framework.



F. 1 Structure: System of Systems

1.4.2. TECHNOLOGY-ENABLED SOCIETAL BENEFITS

There is a very strong market pull[2] for systems of embedded and cyber physical systems in supply chains, smart grids, smart cities, etc. and there is also a similar situation for very complex systems such as autonomous vehicles, distributed EV-Charging infrastructures, lithography machines, operation theatres, etc.
This market pull indicates the existence of large societal and associated market benefits. A few examples taken from the core ECS application areas include:

- goods and people logistics in high-density cities and rural areas,
- highly distributed and flexible production close to customers,
- customer adaptation in real time for service production,
- evolution of SoS solutions over long time periods and with adaptation to changing needs.

[2] Embedded Intelligence: Trends and challenges, Artemis report, 2019

Such capabilities are applicable to all the targeted application areas of this SRIA. An example here is autonomous vehicles, which will become components in the complex logistics systems of cities, countries, and regions. SoS-related technologies will be key to providing efficient utilisation of autonomous vehicle assets while also offering timely delivery of goods and personnel. Another example is the integration infrastructures adopted in production to allow it and meet customer demands locally. Here, the interoperability of SoS technologies across domains is an essential capability. Yet a third example is how services can be adapted to local environments and customer needs without the need for prohibitively costs (re-engineering).

This market pull is motivated by societal requirements such as the European Green Deal, environmental footprint, rapid societal changes, quality of life, safety and security, etc. In the past, embedded systems technology has been a key to enabling automation to address this. The progression to SoS will become an even more powerful technology for addressing high-level societal priorities.

The further integration of "smart everything" into "ubiquitous smart environments" will introduce large and very complex SoS with complex physical interactions. Mastering this technology will enable European industry to provide solutions to meet ECS application areas and associated societal benefits. In this context the technology competence and innovation in the field of embedded and cyber-physical based SoS will be a critical asset to succeed in the market.

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1.4.2.1. Application breakthroughs

Improvements in SoS technology will have an impact on all ECS application areas. For health and wellbeing, the challenges addressed within the field of systems of embedded and cyber-physical systems will enable faster translation of ideas into economically viable solutions, which can be further scaled up in daily health practice. Examples of health and wellbeing application breakthroughs supported here are:

- Interoperability of health data.
- Strengthening where and how healthcare is delivered, supporting home-based care.
- Supporting the clinical workforce and healthcare consumers to embrace technology-enabled care.
- High level of digital trust.
- Data security technology for interoperability between security hardware and software components.
- Improved integration and analysis of multimodal data.
- Integration platforms for embedded ultrasound, low-power edge computing, and AI and digital health.

For the mobility application area, the provision of EU capabilities within SoS will support breakthroughs regarding:

- Achieving the Green Deal for mobility with the 2 Zero goals of –37.5% CO_2 by 2030.
- Increased road safety through the CCAM[3] programme.Competitiveness of the European industrial mobility digitalisation value chain.

[3] https://www.ccam.eu

- Ensuring inclusive mobility for persons and goods by providing mobility access to everyone, with a focus on special needs.

In the energy application domain, the provision of improved SoS capabilities and engineering efficiency will support breakthroughs regarding:

- Significant reduction and recovery of losses (application and SoA-related).
- Increased functionality, reliability, and lifetime (incl. sensors & actuators, ECS HW/SW, semiconductor power devices, artificial intelligence, machine learning, monitoring systems, etc.).
- Management of renewables via intermediate storage, smart control systems, share of renewable energies, peak control or viability management for the increase of energy flexibility. Grid stabilization through e-vehicle charging.
- Energy supply infrastructure for e-mobility, digital live, and industry 4.0.
- "Plug and play integration" of ECS into self-organised grids and multi-modal systems, real- time digital twin capability in component and complete system design (to simulate system behaviour).
- Safety and security issues of self-organised grids and multi-modal systems through smart edge devices and high-level IT security (resilient communications and trustworthy AI).
- Optimisation of applications and exploitation of achieved technology advances in all areas where electrical energy is consumed.
- Energy technologies in the circular economy approach: predictive and condition-based maintenance with repair and recycle capabilities.
- Aligning with standardization of our energy systems.

In the industry and agrifood application domains, the provision of advanced SoS architectures, platforms and engineering automation will support the EU regarding:

- Intelligent control room systems to enable correlations between machine malfunctions and load parameters to be detected immediately, thereby enabling maintenance work to be carried out early and on schedule, with a reduction in costly downtimes.
- Food industry imposes specific requirements (e.g. in food processing) that may take advantage of smart (bio-)sensing for high-quality monitoring to reduce the amount of water and chemicals used in such processes, and to prevent contamination.
- AI/machine learning (ML) and big data models must be devised and used to offer further intelligent decision-making and, whenever possible, should be employed directly at-the-edge for greater energy efficiency.
- Industrial IoT (IIoT) systems can provide the flexibility to tailor-make new products to help cope with ever- demanding diets.
- Remotely piloted autonomous unmanned aerial vehicles (UAVs), either flying alone or in swarms, to improve efficiency.
- Smart systems based on portable real-time pest disease diagnostics and monitoring platforms to provide rapid local and regional disease incidence alerts (georeferenced) – e.g. weather/climate information for predictive models providing risk assessments and decision support for Integrated Pest Management (IPM).

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- IoT devices specialising in pests and disease measurements, such as insect traps and other systems based on image recognition or AI models.
- Large-scale and high-precision measurements of plant growth, architecture and composition.
- Winning the global platform game on various application sectors (that are currently strong) and in building effectively and, at a high level, outperforming applications and systems for industrial and business needs.
- Preparing for the 5G and beyond era in communications technology, especially its manufacturing and engineering dimension.
- Solving IoT and SoS cybersecurity and safety problems, attestation, security-by-design, as only safe, secure and trusted platforms will survive.
- Interoperability-by-design at the component, semantic and application levels.
- IoT configuration and orchestration management that allows for the (semi)autonomous deployment and operation of a large number of devices.
- Decision support for AI, modeling and analytics in the cloud and also in edge/fog settings.

In the digital society application domain, the provision of improved, robust, secure and interoperable connectivity will support the overall strategy regarding:

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- Use energy and resources more efficiently within the existing installed base of industrial processes. Reduce or prevent waste.
- AI into the design, manufacturing, production and deployment processes, productivity can be improved.
- Collaborative product-service engineering, life cycle engineering: extending R&D to consider how products and systems will be integrated into the industrial service programme of the company. This should possibly be enhanced by obtaining further knowledge to provide services for other similar products (competitors!) as well their own installed base.
- Remote engineering and operations, telepresence: operating or assisting in operations of industrial systems from remote sites.
- Local and global services: organising services locally close to customers and centrally at vendors' sites.
- Edge/cloud solutions: implementing distributed service applications on effective edge cloud systems.
- Full lifecycle tutoring: monitoring activities, level of stress and performance-oriented behaviour during the product's life, from anticipating its end of life to properly handling its waste and recycling, including improved re-design for the next generation of products.

1.4.3. STRATEGIC ADVANTAGE FOR THE EU

As societal demands for efficiency and sustainability will increase over the coming decade, the ability to design tools and architectures to fulfil these demands becomes of high strategic value in the SoS and high-tech systems market. Europe has a globally leading

position in the automotive and industrial automation sector – for both sectors, this lead is based on legacy technology and market appreciation.

The shift in the automotive sector towards electrification and autonomous driving necessitates a large adoption of systems of embedded and cyber-physical systems in vehicles and also roadside infrastructure. The European market has a high-end profile that can pave the way for this technology shift. Fast-paced technology and competence development, combined with the practical innovation scenarios outlined in the Part on applications, will help develop strategic advantages for European industry.

Similar situations can be identified in healthcare technology and in the electronics and components sectors, where world-leading companies provide very complex products and services. These can be internally regarded as a SoS or a monoilitic system of cyber-physical systems . It is obvious that these products and services will interact with surrounding production technology and services. Market competitiveness is built on capabilities such as flexibility and interoperability – again, a strong industrial technology, competence and innovation capability in this direction will provide a strategic advantage for Europe.

SoS have been originally conceived and studied in the defence domain, but they are (and will be) vital infrastructure for many other vertical domains, including transportation, energy, healthcare and wellbeing, natural resource management, agriculture, disaster response, consumer products, finance, media, etc. In all these verticals, the shared enabling technology is represented by open SoS platforms that can play a central role in digitalisation solutions to orchestrate entire supply chains, manage assets, production, operations, processes, marketing and sales, and also in ensuring business continuity and resilience during global crises. The market for open SoS platforms is still very new, and several aspects still need to be completely constructed. Nevertheless, IoT platforms, which currently represent the larger subset of the SoS platforms market, is a very rapidly growing market: a recent study indicated that IoT platform revenues already amounted to US $55 billion in 2019 and estimated have reached US $66 billion by 2020, with an annual growth of 20%[4]. With the impact of IoT and its evolution towards SoS, the current and future expectations of the market justify investment in SoS research and innovation[5].
The Advancy report on embedded intelligence very clearly points to the SoS market pull for the complete ECS value chain, with market growth being projected at €3.4–10.6 trillion[6]. Rapid EU advancement in the SoS area is therefore critical to the whole ECS value chain.

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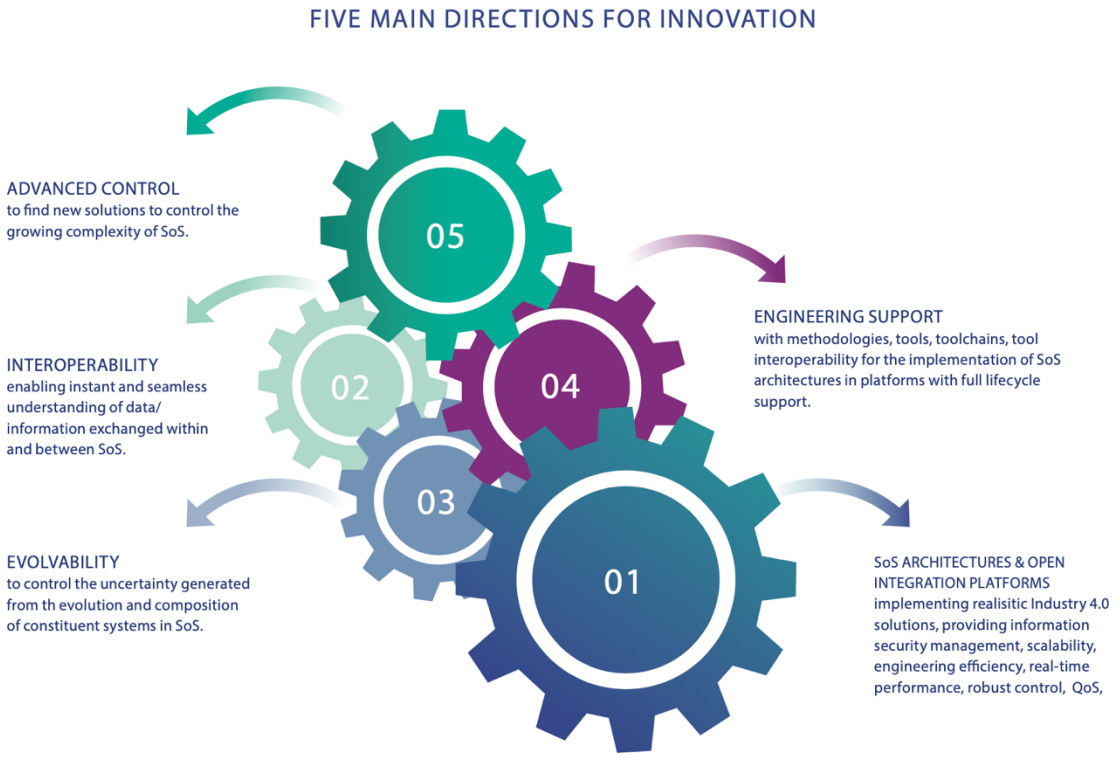
[4] The Internet of Things: Consumer, Industrial & Public Services 2020-2024, Juniper Research, 2020/05/05
[5] From Internet of Things to System of Systems – Market analysis, achievements, positioning and future vision of the ECS community on IoT and SoS, P. Azzoni, Artemis 2020.
[6] Advancy, 2019: Embedded Intelligence: Trends and Challenges, A study by Advancy, commissioned by ARTEMIS Industry Association. March 2019.



F. 2 Fine Main Directions of Innovation (source: Eurotech).

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1.4.4. MAJOR CHALLENGES

Six major challenges have been identified for the System of Systems domain:

- **Major Challenge 1**: SoS architecture and open integration platforms.
- **Major Challenge 2**: SoS interoperability.
- **Major Challenge 3**: Evolvability of SoS composed of embedded and cyber-physical systems.
- **Major Challenge 4**: SoS integration along the life cycle.
- **Major Challenge 5**: Control in SoS composed of embedded and cyber-physical systems.
- **Major Challenge 6**: SoS monitoring and management.

1.4.4.1. Major Challenge 1: SoS architecture and open integration platforms

SoS architecture and open implementation platforms encompassing the multidimensional, multi-stakeholder, multi-technology and evolutionary nature of large SoS with key aspects along the full life cycle regarding e.g. safety, security, scalability, engineering efficiency, real time performance, advanced control, QoS, distributed intelligence.

1.4.4.1.1. State of the art

SoS requires architecture that encompasses the multidimensional, multi-stakeholder, multi-technology and their evolutionary nature. Architecting SoS is fundamentally different from architecting a single embedded system. The complexity of SoS architecting can be

exemplified by the architecture of a complete smart city, with all its subsystem, stakeholders, technologies and evolutionary nature.
Current industrial state of the art are a couple of major commercial and proprietary information/communications/control/technology platforms offering industrial solutions for complex automation solutions from companies like e.g. Schneider Electric[7], Siemens[8], Bosch[9], Emerson[10], ABB[11], Advantech[12], AutoSAR. These proprietary digital platforms, at various levels, support design, implementation and operation of SoS architectures tailored for dedicated solutions in sectors including e.g. manufacturing, water and wastewater, minerals and mining, oil and gas, energy sectors, smart cities and automotive.
The current industrial state-of-the-art SoS are based on extensions to existing major enterprise resource planning (ERP), manufacturing execution system (MES), supervisory control and data acquisition (SCADA), distributed control systems (DCS), robot controllers (RC), computer numerical controllers (CNC), and programmable logic controllers (PLC) products. Such extensions are mostly based on a central service bus concept. Such service buses are responsible for integrating legacy ERP, MES, SCADA, DCS, RC, CNC and PLC technologies from multiple vendors, at best. For emerging SoS application areas like autonomous driving, smart energy grid, smart agriculture and smart cities, the SoS technology is still in an emerging phase. Still Europe is the leading player for industrial automation and digitalisation, with a very strong position in the upcoming areas of autonomous driving, smart energy, smart agriculture and smart cities.

To take the next step, Europe and other regions have invested in a number of open SoS integration frameworks and platforms. A summary of these is shown in Figure F. 4[13]. Most platform initiatives are based on Service Oriented Architectures (SoA) and microservices, which points towards a primary technology for such platforms. Although none of these open SoS platforms are currently in wide commercial usage, early examples can be found in small IoT solutions in various application areas. Major industrial usage remains rare, but MES-level adoption can be found in automotive production, for example.

Open architectures and reference implementations such as e.g. the IMC-AESOP approach[14], Eclipse Arrowhead[15], Eclipse Basyx[16], FiWare[17], PERFoRM30[18] are providing a link to standardisation activities in national and international innovation platforms. In the automotive domain, AutoSAR is developing in the microservice direction. Such

[7] https://ecostruxure.schneider-electric.com/
[8] https://www.plm.automation.siemens.com/ global/en/webinar/iiot-the-next-big-digital- disruption/31921
[9] https://blog.bosch-si.com/bosch-iot-suite/
[10] https://www.emerson.com/de-de/ automation/operations-business- management/plantweb-digital-ecosystem
[11] https://ability.abb.com/
[12] https://www.advantech.com/resources/ news/advantech-launches-30-iiot-solutions- through-the-co-creation-model-and-the- wise-paas-platform-and-announces-a- large-scale-showcase-in-november
[13] Industrial Frameworks for Internet of Things: A Survey, IEEE System journal 2020
[14] https://link.springer.com/ book/10.1007/978-3-319-05624-1
[15] https://www.taylorfrancis.com/ books/e/9781315367897
[16] https://www.eclipse.org/basyx/
[17] https://www.fiware.org/
[18] https://www.taylorfrancis.com/ books/e/9780429263316

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standardisation activities are e.g. DIN Specification 91345[19] "Reference Architecture Model for Industry 4.0" (RAMI 4.0), the "Industrial Internet Architecture" (IIA), the "High Level Architecture of the Alliance for Internet of Things Innovation", the "NIST Big data Reference Architecture", to name just a few. A complementary overview of such high-level architecture frameworks is shown in Figure F. 3[20].

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[19] https://www.en-standard.eu/din-spec-91345-reference-architecture-model-industrie-4-0-rami4-0/

[20] On devising an architecture framework for system-of-systems, Bedir Tekinerdogan, SiSoS@ECSA '16: Proceedings of the International Colloquium on Software-intensive Systems-of-Systems at 10th European Conference on Software Architecture, November 2016 Article No.: 4 Pages 1–6 https://doi.org/10.1145/3175731.3175732

ID	NAME	SCOPE
AF-EAF	Air Force Enterprise Architecture Framework	Air Force IT systems
AFIoT	IEEE P2413 – Architecture Framework for the Internet of Things	IoT
AF4Orgs	Architecture Framework for Organisations	A whole organisation or part of an organisation situated in its environment.
CAFCR	Customer Objectives, Application, Functional, Conceptual and Realisation model	Embedded systems
CBDI-SAE CBDI	Service Architecture and Engineering (CBDI-SAE,™) for SOA	Service-oriented architectures
DoDAF US	Department of Defense Architecture Framework	US DoD
ESAAF	European Space Agency Architecture Framework	Space-based SoS
IIRA	Industrial Internet Reference Architecture	Industrial Internet systems
4+1	Kruchten's 4+1 view model	Software architecture
MEGAF	MEGAF	Software, system and enterprise architecture
MODAF	(UK) Ministry of Defence Architecture Framework	Defence
NAF	NATO C3 Systems Architecture Framework	C3 systems interoperability
NIST-EAM	NIST Enterprise Architecture Model	Enterprise systems
OSSAF	Open Safety and Security Architecture Framework	Public safety and security (PS&S)
RM-ODP ISO	Reference Model for Open Distributed Processing	Open distributed processing systems
RWSSA	Rozanski and Woods	Information systems
TOGAF	The Open Group Architecture Framework	Enterprise systems
ZF	Zachman Framework	Enterprise systems

*F. 3 SoS architecture panorama**Error! Bookmark not defined.***

Europe has a strong investment in large projects that have delivered open platforms for the implementation of solutions based on SoS platforms[21]. Considering the platforms referred

[21] From Internet of Things to System of Systems – Market analysis, achievements, positioning and future vision of the ECS community on IoT and SoS, P Azzoni, Artemis 2020.

to in Figure F. 4, Eclipse Arrowhead, AUTOSAR, FiWare and BaSys have all been developed with substantial European leadership and partnership.

FEATURES	ARROWHEAD	AUTOSAR	BASYX
Key principles	SOA, local automation clouds	Run-time, electronic control unit (ECU)	Variability of production processes
Realtime	Yes	Yes	No
Run-time	Dynamic orchestration and authorisation, monitoring, and dynamic automation	Run-time environment (RTE) layer	Run-time environment
Distribution	Distributed	Centralise	Centralise
Open source	Yes	No	Yes
Resource accessibility	High	Low	Very low
Supporters	Arrowhead	AUTOSAR	Basys 4.0
Message patterns	Req/Repl, Pub/sub	Req/Repl, Pub/sub	Req/Repl,
Transport protocols	TCP, UDP, DTLS/TLS	TCP, UDP, TLS	TCP
Communication protocols	HTTP, CoAP, MQTT, OPC-UA	HTTP	HTTP, OPC-UA
Third-party and legacy systems adaptability	Yes	Yes	Yes
Security manager	Authentication, authorisation and accounting Core system	Crypto service manager, secure onboard communication	--
Standardisation	Use of existing standards	AUTOSAR standards	Use of existing standards

FIWARE	IOTIVITY	LWM2M	OCFW
Context awareness	Device-to-device communication	M2M, constrained networks	Resource-oriented REST, Certification
No	Yes (IoTivity constrained)	No	No
Monitoring, dynamic service selection and verification	No	No	No
Centralise	Centralise	Centralise	Centralise
Yes	Yes	Yes	No
High	Medium	Medium	Low
FIWARE Foundation	Open Connectivity Foundation	OMA SpecWorks	Open Connectivity Foundation
Req/Repl, Pub/sub	Req/Repl, Pub/sub	Req/Repl	Req/Repl
TCP, UDP, DTLS/TLS	TCP, UDP, DTLS/TLS	TCP, UDP, DTLS/TLS, SMS	TCP, UDP, DTLS/TLS, BLE
HTTP, RTPS	HTTP, CoAP	CoAP	HTTP, CoAP
Yes	No	No	No
Identity manager enabler	Secure resource manager	OSCORE	Secure resource manager
FIWARE NGSI	OCF standards	Use of existing standards	OCF standards

F. 4 Open SoS integration frameworks and platforms[22]

For the cross domain requirment on e.g. security, safety, evolution application and business critical details need to be considered. As an examples thereof security takes on new dimensions in the case of SoS. In this Chapter, security is taken to be the ability to prevent leaking information and to prevent the taking over of control of the SoS by agents not being part of the SoS, but also the guarantee that no hostile party can prevent the sharing of essential information between the systems comprising the SoS. Several security aspects require attention. First, the level of security of each individual system requires attention: the lower bound to security of a SoS is determined by the system with the lowest security level, and by the link with the lowest security level between systems ("weakest link in the chain"). Thus requirements like Quality, Reliability, Safety and Cybersecurity at the system and SoS level are covered in Chapter 2.4 of this ECS-SRIA.

[22] Industrial Frameworks for Internet of Things: A Survey, C. Paniagua and J. Delsing, in IEEE Systems Journal, vol. 15, no. 1, pp. 1149-1159, March 2021, doi: 10.1109/JSYST.2020.2993323.,

However, the more combining of systems in a SoS can also create a SoS with a lower security level than the lowest security level of any system in the SoS: an attacker can now combine and relate information from two or more systems which in combination can reveal new information.

Systems must not only defend and monitor possible attacks, but also measures must be taken allowing the communication of intrusions in one system to the other systems in the SoS. Only in this way resilience and cybersecurity can be attained.

The spectrum of systems making up a SoS includes both systems in the cloud, where security can be closely monitored as in e.g. data warehouses, and systems at the edge. Edge systems pose a higher level of cyber insecurity because of the limited resources often available at the edge (e.g. power, communication bandwidth).

Another aspect is SoS safety. Here architectures and platforms need to address safety from various application domains and their standards and regulations. More details related to the ECS application domain requirements on Quality, Reliability, Safety and Cybersecurity at the system and SoS level are covered in Chapter 2.4 of this ECS-SRIA.

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1.4.4.1.2. Vision and expected outcome

This Major Challenge is expected to lead to a set of EU strategic open SoS integration platforms capable of supporting a wide range of solutions in diverse fields of applications covering the ECS supply chain and supporting efficient lifecycle management.
This requires new and improved platform technologies comprising:

- Robust design- and run-time integration and orchestration of functionalities at the edge.
- Platform support for multi-level security, security management, safety, safety management,scalability, engineering efficiency, real-time performance, closed loop and digital control, QoS, distributed intelligence and other key application area requirements.
- Interoperability to legacy SoS technology.
- Interoperability to existing and emerging IoT and SoS technologies and platforms.
- A high degree of autonomous operation and failure mitigation.
- Enabling SoS flexibility.

The expected outcome is a set of EU strategic open source platforms. These platforms should have long- term governance with industry-friendly licensing schemes such as Eclipse. Such platforms should also have strong EU-based value chain support.
To cope with increasing complexity, the SoS engineering community is constantly researching improvements to its engineering processes. To ensure the complexity remains manageable, modeling approaches are used. The challenge in these approaches is to find the right level of abstraction that also allows for reasoning about the system while still containing sufficient information to connect to lower levels of abstraction, often by generating code for some underlying implementation platform.

It is not only that the complexity of the SoS is growing, but there are also extra-functional requirements that are often interlinked playing an increasingly important role. For example, with the demand for greater speed and the concomitant energy consumption, systems are often required to process information quickly but within a tight energy budget. These two requirements are clearly conflicting and choosing the right trade-off can be a balancing task. With the realisation that the planet's resources are limited, as exemplified in the European Green Deal, also comes the demand for resource conservation, resulting in more and intertwined requirements, putting greater demand on the dynamic and evolution capabilities of both the SoS architectures and the architecture tools that support the complexity of SoS.

Some important but necessary aspects of SoS architecture are:

- security and trust,
- safety,
- robustness,
- composability,
- evolution,
- interoperability,
- engineering tools and procedures,
- advanced control,
- energy consumption.

This Major challenge is expected to lead to a set of EU strategic open SoS integration platforms capable of supporting a wide range of solutions in diverse fields of applications covering the ECS supply chain and supporting efficient lifecycle management.
This requires new and improved platform technologies comprising:

- robust design- and run-time integration and orchestration of functionalities at the edge,
- platform support for safety, multi-level security, security management scalability, engineering,
- efficiency, real-time performance, closed loop and digital control, QoS, distributed intelligence and other key application area requirements,
- interoperability to legacy SoS technology,
- interoperability to existing and emerging IoT and SoS technologies and platforms,
- a high degree of autonomous operation and failure mitigation,
- enabling SoS flexibility.

1.4.4.1.3. Key focus areas

The key focus is how SoS architectures and their open implementation platforms can enable and leverage important and necessary aspects while also enabling efficient adaptation to specific application solutions.
To support EU strategic autonomy, a small number of SoS architectures and integration platforms should be driven by EU-based ecosystems. Important features that such platforms should provide include:

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- a robust SoS integration platform capable of supporting a wide range of solutions in diverse fields of applications,
- integration platform and associated engineering tools and toolchains that support the complete engineering process in both design- and run-time, including SoS critical aspects such as e.g. security, safety and risk mitigation,
- suitable and adaptable engineering processes, with associated training material for solution engineering.

2.4.4.1. Major Challenge 2: SoS interoperability

SoS interoperability enables instant and seamless understanding of information exchanged within and between networked and distributed systems.

2.4.4.1.1. State of the art

Interoperability in the SoS domain is a rising problem for cost-effective engineering and operation of systems of embedded and cyber-physical systems (see Figure F. 5).

There is currently no industrial solution to this problem. Academia and industry are experimenting with approaches based on, for example, ontologies[23], machine learning[24] and open semantic frameworks[25]. Even if no clear winning approach can be identified based on current research results, growing interest can be noted for e.g ontology, data and model driven approaches. Automating considerable parts of interoperability engineering (design-time and run-time) will improved SoS operational quality.

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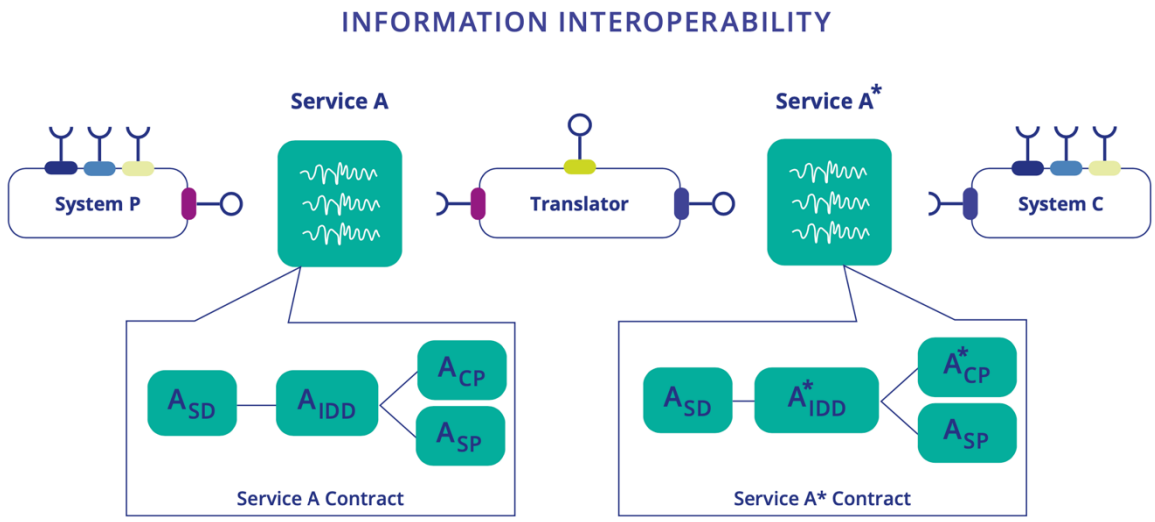

F. 5 Information interoperability between two service providers can be addressed by means of translators. The design of such translators for the payload information is currently necessary to provide for every situation where interoperability is requested.

[23] Extended semantic annotations for generating translators in the arrowhead framework, F Moutinho, L Paiva, J Köpke, P Maló - IEEE Transactions on Industrial Informatics, 2017

[24] Interoperability and machine-to-machine translation model with mappings to machine learning tasks, Jacob Nilsson, Fredrik Sandin and Jerker Delsing, IEEE INDIN 2019

[25] An open semantic framework for the industrial Internet of Things, S Mayer, J Hodges, D Yu, M Kritzler, F Michahelles - IEEE Intelligent Systems, 2017

2.4.4.1.2. Vision and expected outcome

To enhance EU leadership and sovereignty in the field of SoS based onembedded and cyber-physical systems, autonomous information translation for understanding is a necessity. Some integration platforms already focus on protocol and information interoperability (Derhamy, 2018[26]). To enable the cost- and time-efficient engineering of solution integration and extension, their updates and upgrades over the lifecycle is crucial. Therefore, integration platforms have to provide mechanisms for dynamic and instant information translation across the ontologies and semantics used the individual constituent systems of the SoS.

2.4.4.1.3. Key focus areas

To facilitate substantial cost reductions for SoS solutions, autonomous and dynamic mechanisms for information translation are required. Such mechanisms should cover:

- Translation between standardised data models (e.g. ISO 10303[27], ISO 15926[28], BIM[29]).
- Translation between different implementations of standardised data models.
- Automated data model translation.
- Autonomous data model translation.
- Efficient and flexible engineering procedures.
- Engineering tools that support the complete engineering process in both design- and run-time.
- Support for key automation requirements.
- Automated engineering.

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3.4.4.1. Major Challenge 3: Evolvability of SoS composed of embedded and cyber-physical systems

SoS intrinsic nature is dynamic and SoS evolve with components, functions and purposes added, removed, and modified along their continuously evolving lifecycle (a life cycle that potentially never finishes). A SoS has properties, behaviours and functionalities that mainly do not reside in any constituent system but in the SoS as a whole and allow the SoS to achieve its own goals. These properties, functionalities and behaviours at the SoS level emerge in a direct relationship to the SoS evolution and, being potentially unknown, must be managed, i.e., detected, identified, understood and controlled. Because the results of the composition/evolution could be uncertain, SoS architectures and platforms, open and propritery in conjunction with the proper engineering support (methods and tools), should provide solutions to manage the evolution and resulting uncertainty emergent properties, functionalities and behaviours.

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[26] H. Derhamy, J. Eliasson and J. Delsing, "IoT Interoperability—On-Demand and Low Latency Transparent Multiprotocol Translator," in *IEEE Internet of Things Journal*, vol. 4, no. 5, pp. 1754-1763, Oct. 2017, doi: 10.1109/JIOT.2017.2697718.

[27] https://www.iso.org/standard/66654.html

[28] https://15926.org/home/

[29] https://en.wikipedia.org/wiki/Building_information_modeling

3.4.4.1.1. State of the art

Evolvability and composability is a multi-dimensional key aspect of SoS evolution, one that affects their architectures, properties, functionalities and behaviours from different perspectives (evolvability, trust, interoperability, scalability, availability, resilience to failures, etc.). Primarily, composability must ensure the persistence of the five major attributes that characterise a SoS (see Maier, 1998[30]). Vertical (hierarchical) composability provides the most common way to build a SoS that is typically structured in a hierarchical stack composed of adjacent layers. Vertical composability has to deal with the different abstraction levels of the stack layers, adopting aggregation and de-aggregation solutions as references to compose the constituent systems of the SoS. Architectural composability, on the other hand, is fundamental for SoS design, specifically when critical requirements such as trust or safety must be satisfied (see Neumann 2004[31], for an extensive report on trustworthy composable architectures).

In the hierarchical structure of a SoS, the constituent systems that are at the same level typically compose horizontally (in parallel or serially), potentially generating competing chains of constituent systems. Serial composability represents a critical issue for all properties that are not automatically transitive, such as trust. Indeed, the inclusion of AI in embedded and cyber-physical systems increases the required level of trust, as well as the uncertainty of the results of the composition process (see, for example, Wagner, 2015[32]).

When the constituent systems expose high-level services, service composability allows for the creation and provision of new added-value services at the SoS level, combining the resources, functionalities, information, etc., of the constituent systems. Eventually, the engineering process deals with composability, enabling it by design (already present from the constituent systems level) and/or managing it during the operations of the SoS, to address the dynamic nature of SoS in time (run-time composability associated with evolutionary development and potential emergent properties, behaviours, and functionalities).

3.4.4.1.2. Vision and expected outcome

The dynamic nature of SoS is based on the composition and integration of embedded and cyber-physical systems. The role of composability is to ensure that functional and extra-functional properties (scalability, quality of service (QoS), performance, reliability, flexibility, etc.), and the functionalities and behaviours of the constituent systems are preserved in the SoS or combine in a predictable and controlled way, even when the constituent systems recombine dynamically at run time. The lack of solutions to dynamically manage composability represents one of the limitations preventing the diffusion of SoS.

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[30] Architecting Principles for Systems-of-Systems, Mark W. Maier, Systems Engineering journal, John Wiley & Sons 1998

[31] Peter G. Neumann, "Principled Assuredly Trustworthy Composable Architectures", DARPA, Computer Science Laboratory SRI International EL-243, 333 Ravenswood Ave, Menlo Park, California 94025-3493, USA.

[32] Wagner, M.; Koopman, P. A Philosophy for Developing Trust in Self-driving cars. In Road Vehicle Automation 2; Meyer, G., Beiker, S., Eds.; Lecture Notes in Mobility; Springer: Cham, Switzerland, 2015; pp. 163–171, doi:10.1007/978-3-319-19078-5_14.

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Composability should be conceived as a quality of SoS that makes them future proof: (i) the relationships between components that allow them to recombine and assemble in different and potentially unlimited architectural combinations, and ensure and exploit the re-use of components; (ii) the extension of components lifetime within the evolution of the SoS during its lifecycle; (iii) the possibility that SoS will easily evolve, adapting to new contexts, new requirements and new objectives; and (iv) the simple substitution of faulty, inadequate and/or new components with a minimal impact for the SoS, guaranteeing the survival and sustainable evolution of the SoS. Composability also have to consider cross sectorial requirement like e.g. security, safety, trust, evolution.

Ensuring composability at the SoS level represents a very challenging goal, potentially generating serious and critical consequences, and even preventing the integration of the SoS. Indeed, considering a property that characterises a constituent system with a certain attribute, it is not guaranteed that the same property will characterise it when the constituent system becomes part of a SoS. In addition, if the property is still present, it is not guaranteed that it will have the same attribute. The same applies to the constituent system's functionalities, behaviours, etc.

As a consequence, one major effect of the composition, integration, evolution of the constituent systems is the evolution of the SoS, with emergent properties, functionalities and behaviours which generate uncertainty. E.g. when SoS evolution affects e.g. security, safety, trust, interoperability, scalability, availability, resilience to failures, etc, the impact of the uncertainty could potentially be extremely serious.

The inclusion of AI in SoS increases the importance of composability, because it may significantly increase the complexity, variability and fuzziness of composability results. AI enables a completely new category of applications for SoS. Therefore, the availability of specific solutions for the validation, verification and certification of SoS composed of AI-based systems is a critical requirement.

Predicting and controlling the effects of composability is also fundamental for the interaction of humans along the SoS lifecycle and the protection of human life should be ensured in SoS evolution. Uncontrolled and unmonitored composition could lead to deviations from expected behaviours or generate unknown emergent behaviours potentially dangerous for humans. The increasing level of automation introduced by SoS accentuates this criticality, and will require that humans still intervene in cases of emergency (for example, in automated driving).

The solutions proposed to manage composability will also have to support the multi-domain nature of SoS, the presence of different stakeholders in its lifecycle, and the different regulations and standards that apply to these domains. From an engineering perspective, emergent behaviours require that the development of SoS, applying composability, is evolutionary and adaptive over the SoS continuously evolving lifecycle, which potentially may never finish. In fact, SoS architectures and platforms, jointly with the proper engineering support, will have to provide solutions to control the uncertainty of evolvability and ensure adequate countermeasures.

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3.4.4.1.3. Key focus areas

Since the technology base, and the organisational and human needs are changing along the SoS lifecycle, SoS architecting will become an evolutionary process based on composability. This means: (i) components, structures, functions and purposes can be added; (ii) components, structures, functions and purposes can be removed; or (iii) components, structures, functions and purposes can be modified as owners of the SoS experience and use the system. In this sense, the dynamically changing environmental and operational conditions of SoS require new architectures that address the SoS goal(s), but thanks to composability will also evolve to new system architectures as the goal(s) change.

Evolution in SoS is still an open research topic requiring significant effort and the key areas of research and innovation include:

- Methods and tools for engineering evolvability of systems of embedded and cyber-physical systems.
- Evolutionary architectures in systems of embedded and cyber-physical systems.
- Evolvable solutions for trust, availability, scalability, and interoperability.
- Evolvable solutions capable for managing resulting uncertainty emergent properties, functionalities and behaviours, including resilience to failures.
- Evolvability in systems of cyber-physical systems supported by virtual engineering (e.g. digital twins).
- Methods and tools to manage emergencies in embedded and composable systems of cyber-physical systems.
- Service-based vertical and horizontal evolvability to enable high-level, and potentially cross-domain, interoperability of embedded and cyber-physical systems.

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4.4.4.1. Major Challenge 4: SoS integration along the life cycle

Integration and engineering methodologies, tools, tool chains and tool interoperability are fundamental to enable the implementation of SoS solutions using SoS architectures and platform technologies, supporting the whole lifecycle.

4.4.4.1.1. State of the art

Europe is a world leader in the engineering of systems of embedded and cyber-physical systems. Major European companies such as Siemens, ABB, Schneider, Valmet, Bosch and Endress+Hauser, together with a number of large system integration companies (e.g. Afry, VPS and Midroc), offer complete engineered solutions, making Europe the leading global automation SoS provider.

Most solutions for embedded and cyber-physical systems engineering are based on highly experienced teams of engineers supported by a heterogeneous set of SoS engineering tools. For example, engineering practice and associated standards provide design-time solutions based on, for example, IEC 61512 (ISA 88)[33], IEC 62264 (ISA95)[34], IEC81346[35], ISO 10303, ISO

[33] https://www.isa.org/standards-and-publications/isa-standards/isa-standards-committees/isa88
[34] https://www.isa.org/standards-and-publications/isa-standards/isa-standards-committees/isa95
[35] https://en.wikipedia.org/wiki/IEC_81346

15924, IEC 62890[36]. The proposed Industry 4.0 architectures, formally provided by the DIN specification 91345 RAMI 4.0, have not yet made it into industrialised engineering procedures, or associated tools and toolchains. Therefore, the industrial state of the art for SoS engineering still has its major base in legacy technology.

The current state of the art engineering of SoS remains more an art than a well-structured integration and engineering process. For example, the analysis of emergent behaviour of very large SoS is still at a foundational research level in academia.

4.4.4.1.2. Vision and expected outcome

The European leadership in application fields such as distributed automotive and industrial automation and digitalisation indicates some excellent skill sets in the art of SoS engineering. In the short to medium term, Europe has to transfer these skills into systematic and robust engineering procedures supported by integrated and efficient tools and toolchains.

This is expected to lead to engineering processes, tools and toolchains covering the whole life cycle that to significant extent can be automated while supporting integration between multiple stakeholders, multiple brand and multiple technologies. To support such integration and engineering efficiency, solution quality and sustainability concrete advancements like in (Figure F. 6)[37] will become necessary. The advancement may include integration and engineering process capabilities like:

- Flexible integration and engineering procedures.
- Model-based engineering procedures and tool,
- Supported by interoperable and flexible toolchains.
- Integration of multi-stakeholder engineering processes.
- Automation of substantial parts of the integration and engineering process.

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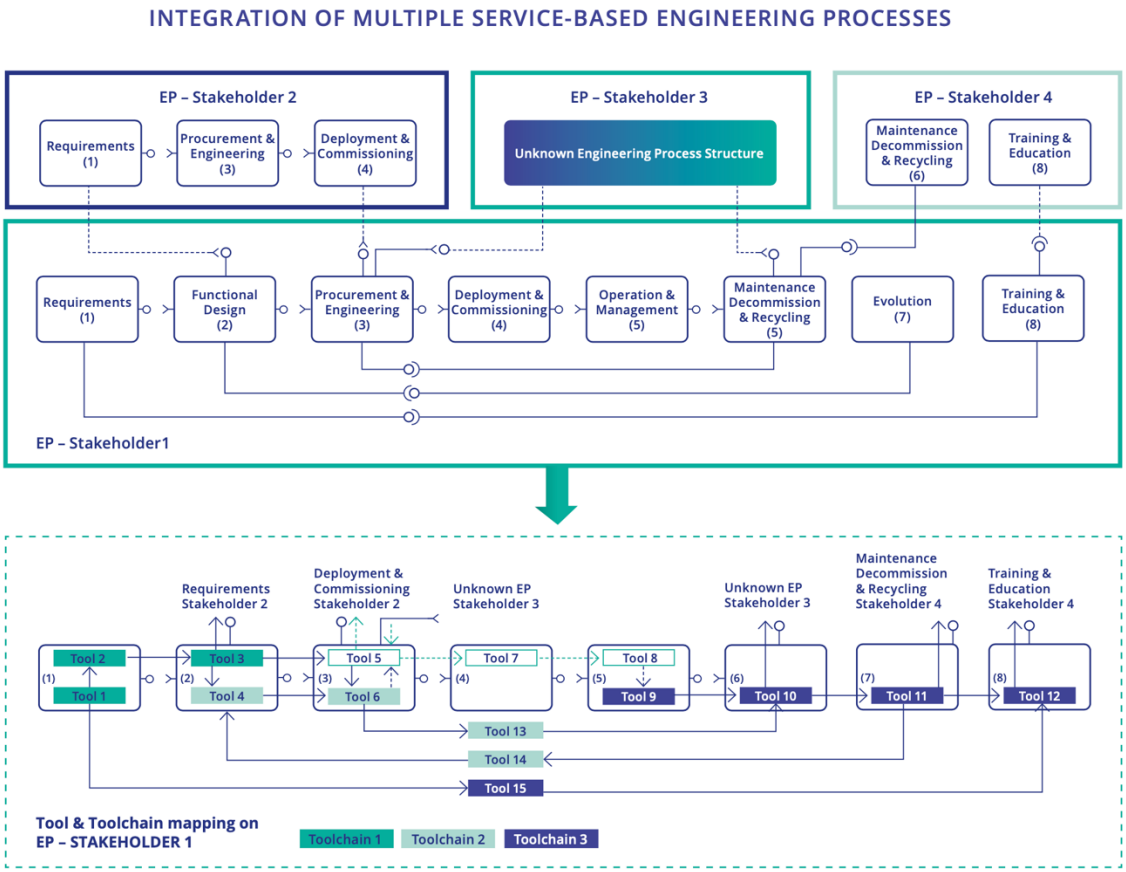
[36] https://webstore.iec.ch/preview/info_iec62890%7Bed1.0%7Den.pdf

[37] Urgese, G.; Azzoni, P.; van Deventer, J.; Delsing, J.; Macii, A.; Macii, E. A SOA-Based Engineering Process Model for the Life Cycle Management of System-of-Systems in Industry 4.0. *Appl. Sci.* 2022, *12*, 7730. https://doi.org/10.3390/app12157730



*F. 6 Example of conceptual service-oriented view on the integration of multiple service-based engineering processes (EP) from different stakeholders, including the engineering process mapping with integrated toolchains and tools**Error! Bookmark not defined.Error! Bookmark not defined.**.*

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4.4.4.1.3. Key focus areas

In support of EU leadership and sovereignty in the field of SoS engineering the ambition is to invest in a small number of integration platforms and their associated tools , toolchains and engineering processes. Strong European-based ecosystems should be created and provided with long-term governance also connected to open source. These engineering processes, methodologies, tools and toolchains shall provide, for example:

- Efficient and flexible engineering processes.
- Model based engineering.
- Engineering tools supporting the complete engineering process along the system's lifecycle.
- Support for key automation requirements.
- Automated engineering.
- SoS traceability and analytics interoperable with engineering tools and tool chains
- SoS evolution impact analysis
- Automated testing validation and verification (TV&V) along the life cycle.

In particular, SoS TV&V introduces a significant challenge, mainly due to complexity, to the effects of composition (not always known in advance) and to SoS dynamic evolution over time. For SoS, a full TV&V procedure prior to deployment is practically unrealistic. Typically, the TV&V of each constituent system is asynchronous and independent of SoS, challenging

the SoS TV&V with feature and capability evolution. For this motivation, a structured framework methodology and tools is necessary to demonstrate an appropriate level of confidence that the feature under test is present in the SoS, and that no undesirable behaviours are also present. This implies a need for end-to-end system capabilities metrics and, according to the flow of data, control and functionalities across the SoS, additional test points, recurring tests and AI-empowered data collection. This analysis should be considered to address changes in the constituent systems and to receive feedback on anomaly behaviours.

5.4.4.1. Major Challenge 5: control in SoS composed of embedded and cyber-physical systems

When control in SoS is considered, one must again consider that they represent an integration of physical systems through networks and computers. Often, the subcomponents of these systems belong to different domains, possibly with physical interactions between them. A core feature of SoS is that sensing, computation/control and data exchange through networks inextricably links physical objects to each other. Not surprisingly, at the heart there are algorithms/methodologies that provide the necessary signals for their control, ensuring that each subcomponent seamlessly integrates into the whole. Embedded computers control and monitor the physical processes using data networks. Thus, feedback loops are established where physical processes affect computations and vice versa.

Some examples of SoS where control and monitoring play crucial roles are smart grids, connected (semi)autonomous automotive systems, medical monitoring, industrial plant control systems, robotics, automatic pilot avionics and rail network control.

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5.4.4.1.1. State of the art

In alignment with the traditional architectures in “Control and Automation”, automation, control and monitoring schemes in most SoS today are characterized by a hierarchical and centralised architecture, made up of layers of sensors and actuators, controllers, and associated computers that are distributed throughout the often complex, interconnected SoS. In terms of control, the atomic unit of a SoS can be found on the field level, where direct control of so-called agents takes place. This can be e.g. the control of a single generator in a power plant, which itself is part of a smart grid. The actions of field control are directed by higher levels such as plant supervisory control, scheduling control or plant-wide optimisation.

5.4.4.1.2. Vision and expected outcome

As complexity of SoS increases steadily, so does the number of systems involved in its control performance. As a result, when using state of the art control methodologies the communication effort would grow exponentially. Thus, balancing communication effort and control performance is a key factor. In this context and in view of limiting data traffic in a SoS, synchronisation of systems becomes a major control goal as it is directly linked to the stability of the control system.

In addition, control of complex cyber physical SoS must address other important aspects such as scalability (i.e. to deal with a variable number and interconnection of systems and control loops), network phenomena (such as computation/communication latency, data loss). Looking at the aspect of data management, open SoS control platforms should ensure information security management, SoS scalability, SoS engineering efficiency and also SoS real-time performance.

5.4.4.1.3. Key focus areas

For this Major Challenge we envision the following key focus areas:

- Tools for control system analysis of SoS.
- Considering humans, environment and the economy in the loop.
- Support in SoS control design.
- Reduction of communication effort, variable structure, variable number of systems in control loops.
- Control system testing, validation and verification (TV&V).

6.4.4.1. Major Challenge 6: SoS monitoring and management

Management of SOA based cyber physical SoS will require structured and scalable approaches to status monitoring and strategies and methodologies to address SoS management from a number of perspectives e.g. functional, security, safety, maintenance, SW updates, real time, evolution.

6.4.4.1.1. State of the art

Current industrial state of the art for monitoring and management of SoS reflects back to monitoring and management of production automation, energy grid automation and similar. Looking closer we find a plethora of commercial application solutions tailored to specific applications. Many of these are very application and site specific and “home brewed”.

There is a wide set of different realms to be monitored and managed, ranging from modern production processes, smart grids, smart cities, automotive traffic networks, only to name some of them. Furthermore, for each of these realms their operation requires different competences and groups within an organisation, and it follows different guidelines. Some examples are:

- status of operation,
- safety,
- real time performance,
- real time monitoring of sensors and actuators, incl. fault detection and isolation,
- validation of signals (using redundancies created by the data network of the SoS),
- control,
- maintenance,
- assets,

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- security.

These aspects do have more or less known and understood relationships/dependencies which also will change in run-time. This provides a monitoring and management landscape which is very heterogeneous and dynamic.

A wide set of tools are available, each supporting one or a few of these dimensions. In most cases these tools mandate underlying information sources and data models, which sometimes correlates with current major industrial standards like ISA95, BIM, ISO 15926 and ISO 10303.

In summary a very complex and heterogeneous landscape of, to a large extent non-interoperable, tools and methodologies with no or little capacity to be integrated across SoS dimensions.

6.4.4.1.2. Vision and expected outcome

The emerging closer digital integration of industrial and societal functionalities and domains requires SoS integration and associated monitoring and management in very complex and heterogeneous environments. The current state of the art is far from efficiently enabling this. Such enabling will require closer cooperation and integration between several levels of the ECS domain stack. An example thereof is integration and functional interoperability between open and proprietary SoS architecture and implementation platforms, embedded software its tools and platforms and solution engineering its processes, tools and implementation platforms. Here solution requirements on lifecycle and evolution as well need to be considered.

6.4.4.1.3. Key focus areas

To advance towards the vision technology and knowledge steps are required regarding:

- Monitoring and management strategies and architectural concepts in OT-IT environments.
- Methodologies and technologies for monitoring and management of multiple and interrelated SoS dimensions.
- Processes and technology for life cycle monitoring and management over SoS dimensions.

1.4.5. TIMELINE

The following table illustrates the roadmaps for System of Systems.

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MAJOR CHALLENGE	TOPIC	SHORT TERM (2022–2026)
Major Challenge 1: SoS architecture and open integration platforms	**Topic 1.1: Robust SoS integration platform capable of supporting a wide range of solutions in diverse fields of applications**	Architectures and associated implementation platforms with sufficient granularity and engineering support for efficient implementation of real-world Industry 4.0 solutions
	Topic 1.2: integration platform and associated engineering tools and toolchains that support the complete engineering process in both design- and run-time, including SoS critical aspects such as security, safety and risk mitigation	Lifecycle support for extra-functional requirements, such as energy consumption, environmental impact that translates into maintainability, sustainability, etc.
	Topic 1.3: suitable and adaptable engineering processes with training material for solution engineering	Hardware and software tools and training material suited for training of professionals and students at university level
Major Challenge 2: SoS interoperability	**Topic 2.1: Translation between standardised data models e.g. ISO 103030, ISO 15926, BIM, …**	Translation technologies enabling translation of standardised data models and demonstrated at TRL 5-6

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	Topic 2.2: Translation between different implementations of standardised data models	Translation technologies enabling translation of different implementations of standardised data models and demonstrated at TRL 5-6
	Topic 2.3: automated data model translation	Technologies and tools for automating the engineering of data model translations
	Topic 2.4: autonomous data model translation	Technology and tools for enabling autonomous data model translation in run-rime
Major Challenge 3: Evolvability of SoS composed of embedded and cyber-physical systems	**Topic 3.1: methods and tools for engineering evolvability of systems of embedded and cyber-physical systems.**	Persistence of operational independence, managerial independence, geographic distribution, emergent behavior and evolutionary development
	Topic 3.2: evolutionary architectures in systems of embedded and cyber-physical systems.	Modular and evolvable architectures.
	Topic 3.3: evolvable solutions for trust, availability, scalability, and interoperability.	Modular frameworks addressing trust, availability, scalability and interoperability-

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	Topic 3.4: evolvable solutions capable for managing resulting uncertainty emerging properties, functionalities and behaviours, including resilience to failures	Technology frameworks supporting self-adaptability
	Topic 3.5: evolvability in SoS supported by virtual engineering (e.g. digital twins)	Virtualisation of IoT and edge services based on open SoS architectures and platforms
	Topic 3.6: methods and tools to manage emergencies in embedded and composable SoS.	Technology frameworks supporting emergency self-adaptability
	Topic 3.7: service-based vertical and horizontal evolvability to enable high-level, and potentially cross-domain, evolvability of SoS	Open services enabling technology and data evolvability cross-domain
Major Challenge 4: SoS integration along the life cycle.	**Topic 4.1: efficient and flexible engineering processes**	SoA-inspired engineering processes, toolchains and tools
	Topic 4.2: model based engineering	Partial automated generation of SoS software using model based engineering
	Topic 4.3: engineering tools supporting the complete engineering process along the system's lifecycle	Engineering tools enabling run-time engineering

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	Topic 4.4: support for key automation requirements	SoS engineering process and tools partial support for fundamental automation requirements like e.g. real time, security, safety
	Topic 4.5: automated engineering	Automation of SoS software engineering from requirements to deployment
	Topic 4.6: automated testing validation and verification (TV&V)	Automated and runtime SoS TV&V for parts of the engineering process
Major Challenge 5: control in SoS composed of embedded and cyber-physical	**Topic 5.1: tools for control system analysis of SoS**	Technologies and tool for design time control analysis in SoS environments
	Topic 5.2: considering humans, environment and the economy in the loop	Technologies and tools enabling control optimisation based on human behaviour, environmental and economic impact
	Topic 5.3: support in SoS control design	Technologies and tool for efficient and robust control design in SoS environments
	Topic 5.4: dynamic optimisation of communication effort, control architecture	Technologies and tool enabling dynamic optimisation of SoS control architecture enabling communication and energy consumption minimisation
	Topics 5.5: control system testing, validation and verification (TV&V)	Technologies and tools enabling design time and run-time TV&V in complex SoS solutions.

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Major Challenge 6: SoS monitoring and management	**Topic 6.1: Monitoring and management strategies and architectural concepts in OT-IT environments**	Real time monitoring and management of evolving OT.IT environments
	Topic 6.2: Methodologies and technologies for monitoring and management of multiple and interrelated SoS dimensions	Functional, security and safety interrelations monitoring and management
	Topic 6.3: Processes and technology for life cycle monitoring and management over SoS dimensions	Approaches to life cycle monitoring and management for multiple SoS dimensions. Like e.g. functionality, security and safety

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MEDIUM TERM (2027–2031)	**LONG TERM (2032–2036)**
Architectures and implementation platform with support for a wide set of autonomous operation e.g. M2M business execution	Architectures with support for self-X e.g. self-healing, self-extension etc.
Lifecycle support for extra-functional requirements, such as energy consumption, environmental impact that translates into maintainability, sustainability, etc.	Autonomous management of functional and non-functional dimensions

Model based engineering support proving partial engineering automation of solutions	Automated SW engineering for most solution engineering stages.
Fully autonomous translation	
Full cross-domain interoperability	
Fully automated information translation	
Fully autonomous translation	
Full predictable and controllable composition of functional and extra-functional properties	Full predictable and controllable composition of functional and extra-functional properties, also covering dynamically recombining SoS
Evolvability and composability by design	Automated evolvability and composability analysis in design time and run-time

Modular frameworks and open integration platforms addressing e.g. trust, availability, scalability, interoperability	Open modular frameworks and integration platforms addressing e.g. trust, availability, scalability, interoperability, evolvability, composability
Failures resilience at SoS level	Automated manegement of uncertainty and resilience to failures.
Automated virtualisation of IoT and edge services based on open SoS architectures and platforms	Dynamic and scalable virtualisation of IoT and edge services based for run-time optimisation on open SoS architectures and platforms
Automated technology and tools supporting emergency self-adaptability	Autonomous technology and tools supporting emergency self-adaptability
Open services and integration platforms enabling technology and data evolvability cross-domain	Open services and integration platforms enabling automated technology and data evolvability cross-domain
Engineering support for SoS emergent behaviours	Engineering support for emergent behaviours of very large SoS
Full automated generation of SoS software using model based engineering	Model based engineering support providing engineering automation for very complex SoS solutions
Multi-stakeholders and multi-domains automated engineering process	Highly automated solution engineering in a multi-stakeholders and multi-domains SoS environment
SoS engineering process and tools full support for fundamental automation requirements like e.g. real time, security, safety	
Technologies and tool for highly automated design time control analysis in SoS environments	Technologies and tool for autonomous run-time control analysis in SoS environments

Automated runtime SoS TV&V for the entire engineering process	Autonomous runtime SoS TV&V
Automated technologies and tool for efficient and robust control design in SoS environments	Autonomous technologies and tool for efficient and robust control design in SoS environments
Automated technologies and tools enabling control optimisation based on human behaviour, environmental and economic impact	Autonomous technologies and tools enabling control optimisation based on human behaviour, environmental and economic impact
Automated technologies and tool for efficient and robust control designed TV&V in SoS environments	Autonomous technologies and tools for efficient and robust control run-time design and TV&V in SoS environments
Model based technologies and tool enabling dynamic optimisation of SoS control architecture enabling communication and energy consumption minimisation	Fully automated run-time technologies and tool enabling dynamic optimisation of SoS control architecture enabling communication and energy consumption minimisation
Model based technologies and tools enabling design time and run-time TV&V in complex SoS solutions	Automated technologies and tools enabling design time and run-time TV&V in complex SoS solutions
Scalable monitoring architecture applicable to large scale SoS	SoS integration platforms including scalable, and manageable monitoring capabilities

Manageable monitoring architecture of multiple SoS dimensions	SoS management based on multi-dimensional monitoring
SoS monitoring architecture along its life cycle	SoS integration platforms supporting SoS monitoring and management evolution along its life cycle

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