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Editorial

Special issue on System of Systems Engineering

Dear Readers and Contributors,

The papers showcased in this special issue are based for most of them on contributions to the 13th Annual System of Systems Engineering (SoSE) conference held on June 19-22, 2018, on the Pierre and Marie Curie campus of Sorbonne Université in Paris, France. The conference has vast ramifications in numerous engineering fields such as control, computing, communication, information technology and in applications such manufacturing, defense, national security, aerospace, aeronautics, energy, environment, healthcare, and transportation. It aims at bringing together researchers and practitioners, who have common interests in engineering Systems of Systems (SoS) and want to share their experience and findings related to theoretical frameworks, methodological approaches, tools and applications of SoSE. The 13th edition of the conference was technically co-sponsored by the IEEE System, Man, and Cybernetics Society, the IEEE Reliability Society, the International Council on Systems Engineering (INCOSE), and the French Chapter of INCOSE (AFIS).

Before discussing the content of this special issue, we think it important to recall some definitions of systems, systems of systems and constituent systems. A system is defined as a *"combination of interacting elements organized to achieve one or more stated purposes"* (ISO/IEC/IEEE 15288:2015). The standard 15288 gives guidelines to *"define the interfaces and interactions between the system elements and with external entities"* and *"the boundaries of the system"*. The external entities often include the necessary *"enabling systems"*.
The traditional view of systems exchanging different kinds of flows with their environment to fulfil their own missions is evolving. Nowadays systems are no longer interfaced with their environment only. Systems are often involved in larger systems, called Systems of Systems and contribute to fulfil new missions that constituent systems are not able to fulfil alone (*"Set of systems or system elements that interact to provide a unique capability that none of the constituent systems can accomplish on its own"* ISO/IEC/IEEE 21839:2019). Constituent systems (CS) could include enabling systems but usually include other systems with heterogeneous properties. Many challenges arise in the field of SoS engineering. For instance, the adaptation and integration of a CS in a new SoS, the evolution of an existing SoS, the opportunistic creation of an SoS architecture or the vulnerabilities of a CS due to other malfunctioning CS. An increasing number of systems will be modified during their lifecycle to interact in a new SoS. Since SoS is spreading across all domains such as aerospace, transportation, healthcare, energy, there has a great need for high quality System of Systems Engineering research.

The papers in this special issue cover a broad spectrum of systems engineering activities such as architecture definition and evaluation, vulnerability and failure aspects, design processes. They propose contributions, including a state-of-the-art on SoSE, new theoretical framework and methodologies, innovative applications of SoSE in a variety of domains.
Each submission was peer-reviewed through a rigorous two-round review process, each paper receiving four or more reviews. More than sixty reviewers were involved, all experts in Systems Engineering or more specifically in System of Systems Engineering.
Eight papers successfully emerged from the review process. It is worth noting that at the end of this process, not all topics related to SoSE are covered. For instance, the role of the human or human-system interfaces in a SoS are not addressed. However, we think that this issue well covers topics related to SoS architecture definition and evaluation.

A first group of five papers deals with architecture definition and evaluation.

During the definition of SoS, the application domain expert cannot always precisely define which constituent systems will exist in the SoS architecture when the SoS will be in operation. In their paper entitled *"Systems of Systems: from Mission Definition to Architecture Description"*, Imane Cherfa, Nicolas Belloir, Salah Sadou, Régis Fleurquin and Djamal Bennouar propose a mission conceptual model and a model-based approach to create a strong link between the SoS mission analysis stage and the SoS architecture stage. The focus is on acknowledged SoS. The authors introduce the concepts of mission and role to enable the definition of an abstract architecture of SoS. This architecture will help the system architect to define a concrete architecture during the design and evolution stages. The case study that is used to illustrate this model-based approach concerns a crowd management SoS.

In their paper *"Architecting System-of-Systems and Their Constituents: A Case Study Applying Industry 4.0 in the Construction Domain"*, Jakob Axelsson, Joakim Fröberg and Peter Eriksson investigate how Industry 4.0 standards can be used in an SoS context to make Constituent Systems (CS) more flexible and adaptive. Their focus is on what processes and activities organizations need to put in place in order to successfully support SoS and CS over their lifecycles. Equally important is to have good architectural patterns and standardized technical building blocks on these two levels, that can be used in the design of a system to make it flexible enough to easily become a constituent of a yet unknown SoS, and to prepare an existing system to become a constituent of a given SoS. Defining such patterns and building blocks is the main topic of this paper.

The required interactions between the system and its environment are described "in terms of interface properties and constraints, such as mechanical, electrical, mass, thermal, data, and procedural flows" (ISO/IEC/IEEE 15288:2015). However, in SoS engineering, other kinds of interfaces have to be identified and defined. In particular, distinguishing and modelling the interfaces in Product-Services Systems (PSS) is challenging because of the heterogeneity of the tangible and intangible components and their interactions. In their paper entitled *"Interfaces modelling for Product-Service System integration"*, Elaheh Maleki, Farouk Belkadi, Éric Bonjour, Ali Slayman and Alain Bernard consider a PSS as a specific SoS and propose a conceptual model to support the definition and classification of interfaces in PSS architecture. The application of the model is illustrated by a case study concerning a station-less bicycle-sharing system.

In their paper *“A Network Perspective on Assessing System Architectures: Foundations and Challenges”*, Matthew W. Potts, Pia A. Sartor, Angus Johnson and Seth Bullock present graph-theoretic approaches to evaluate enterprise system architectures. They explore two real-world architectures: a search and rescue NATO architecture framework-based architecture, and a military communications architecture. They identify significant challenges a system architect needs to know when employing graph-theoretic approaches to evaluate architectures, and summarize five guiding principles for the effective mobilization of network concepts to enterprise architecture evaluation.

In his paper called *“Architecting exogenous software-intensive systems-of-systems on the internet-of-vehicles with SosADL”*, Flavio Oquendo points out that no Architecture Description Language has the expressive power to describe the evolutionary architecture of SoS exhibiting emergent behavior as required on the Internet-of-Things (IoT). He considers Internet-of-Vehicles (IoV) as a sub-set of the IoT that corresponds to software-intensive SoS. These SoS are opportunistically constructed for achieving specified traffic-related missions, for instance, platooning. The author proposes “concepts and mechanisms underlying SosADL, a formal SoS Architecture Description Language”, to support the definition of self-organizing SoS architectures where connected systems are not known at the architectural design time. The case study concerns a flood monitoring and emergency response SoS and a real application of SosADL on the IoV.

A sixth paper deals with vulnerability and failure aspects.

Douglas L. Van Bossuyt, Bryan M. O’Halloran and Ryan M. Arlitt present in *“A Method of Identifying and Analyzing Irrational System Behavior in a System of Systems”* a method for analyzing irrational system behaviors in a SoS. Irrational behaviors are defined as unexpected behaviors within a system that emit events leading to potential failure. Unexpected behaviors are behaviors that have not been predicted, not previously observed, and not analyzed through simulation or failure analysis methods. The method is implemented in the Failure Flow Identification and Propagation (FFIP) framework, and an example of a network of autonomous vehicles operating in a partially denied environment is presented to demonstrate the method.

Finally, a last group of two papers deal with design processes.

In their paper *“Decision Learning Framework for Architecture Design Decisions of Complex Systems and System-of-Systems”*, Ramakrishnan Raman and Meenakshi D’Souza propose a decision learning framework for architecture design decisions for complex systems and SoS. The proposed framework adopts a decision-oriented view that factors the uncertainty associated with architectural decisions and the learning cycles and feedback loops experienced. The framework enables leverage of machine learning approaches.

In their paper entitled *"Designing Development Processes Related to System of Systems Using a Modeling Framework"*, Avi Shaked and Yoram Reich propose a development process planning approach that aims to support the design of development processes while addressing Systems of Systems related challenges. They illustrate their approach with a case study concerning the building of a new capability (i.e. Intellectual Property Protection) into a large enterprise considered as a System of Systems.

To conclude this guest editorial, we would like to express our deepest gratitude to all authors contributing to this special issue, producing valuable papers in a critically important, emerging field. We are also indebted to all the reviewers involved in the journal review rounds. Last, but not least, we wish to thank the Editor-in-Chief of Systems Engineering, Dr. Clifford Whitcomb, for his dedication, professionalism and efforts to make this special issue a success!

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