Expanding Frontiers: Settling an Understanding of Systems-of-Information Systems

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Abstract—System-of-Systems (SoS) has consolidated itself as a special type of software-intensive systems. As such, subtypes of SoS have also emerged, such as Cyber-Physical SoS (CPSoS) that are formed essentially of cyber-physical constituent systems and Systems-of-Information Systems (SoIS) that contain information systems as their constituents. In contrast to CPSoS that have been investigated and covered in the specialized literature, SoIS still lack critical discussion about their fundamentals. The main contribution of this paper is to present those fundamentals to set an understanding of SoIS. By offering a discussion and examining literature cases, we draw an essential settlement on SoIS definition, basics, and practical implications. The discussion herein presented results from research conducted on SoIS over the past years in interinstitutional and multinational research collaborations. The knowledge gathered in this paper arises from several scientific discussion meetings among the authors. As a result, we aim to contribute to the state of the art of SoIS besides paving the research avenues for the forthcoming years.

Index Terms—Systems-of-Information Systems, SoIS, definition, characteristics, foundations.

I. INTRODUCTION

Systems-of-Systems (SoS) have become popular in scientific vehicles. Workshops, technical sessions in large events, and other forums have occurred addressing SoS and even a tertiary study was already conducted revealing the growing maturity of the area.

Apart from those advances, technological and theoretical gaps still remain. We perceive important theoretical gaps, particularly in subfields that have emerged, such as Systems-of-Information Systems (SoIS) and Cyber-Physical Systems-of-Systems (CPSoS). CPSoS, i.e., the SoS formed by Cyber-Physical Systems (CPS), are the main topic of SoSE conference in 2021 and currently involve more than 400 studies retrieved in Google Scholar at the moment of creating this paper, revealing that the area is being consolidated over the years. In turn, a systematic mapping study revealed that only 25 studies referring to SoIS had been published until 2018. The number of studies and the findings brought by the mapping could be seen as evidence of the need for further investigation in the SoIS area. Particularly, topics such as specific notations for SoIS modeling that could support its specificities and the respective engineering methods and tools are among the advances needed, once an imprecise or ambiguous specification could potentially lead to defects, malfunction and potential losses.

Due to the relative novelty and scarce literature on SoIS, researchers still ask questions such as:

Q1: What is SoIS?
Q2: What are the differences between SoS and SoIS?
Q3: What are the specific characteristics for an SoS to be considered as a SoIS?
Q4: Why is SoIS necessary as a particular type of system?

¹We will herein interchangeably use SoS acronym to express both singular and plural forms (System-of-Systems and Systems-of-Systems).
²We will herein interchangeably use SoIS acronym to express both singular and plural forms (System-of-Information Systems and Systems-of-Information Systems).
³Results of a search for "cyber-physical systems-of-systems": https://bit.ly/3a7NiVn
Q5: What are the engineering needs to be raised by SoIS as a specific SoS subtype?

We are aware that SoIS (as CPSoS) are not new types of systems, but SoS subtypes. Every SoIS or CPSoS is actually a SoS with additional characteristics. While CPSoS have been broadly explored over the past years, with well-established discussion about their definitions and fundamentals [3]. SoS still lacks this type of discussion. We noticed that SoIS impose particular engineering challenges that the state of the art on SoS had not necessarily coped with. Hence, advances on SoS fundamentals and upperlying methods and tools are needed; otherwise, future SoIS specifications can be imprecise, leading to low-quality SoIS and potential losses and/or injuries due to malfunction.

This paper focuses on an investigation on the SoIS fundamentals. The main contribution is to answer the aforementioned questions by (i) presenting evidence found in the literature and (ii) building an understanding of SoIS over the knowledge acquired over the past years of research in interinstitutional and multinational collaborations. Content of this paper reflects a consensual view involved in the discussions over the years and the knowledge built in a research network made up of 12 different institutions in four different countries. We expect to better disseminate the SoIS research area and contribute to the Systems-of-Systems Engineering community’s advances.

Given the elucidative nature of this paper, its organization may be different from others since we use the literature to both support the background and answer the raised questions. Section II presents the background with essential concepts, besides SoIS examples in literature and advances from the state of the art. Section III establishes an understanding for SoIS by answering the raised questions. Section IV brings further discussions derived from the established foundations. Section V lists some research challenges and gaps. Finally, Section VI concludes the paper with final remarks.

II. BACKGROUND

SoIS are understood as SoS subtypes that necessarily involve software-intensive information systems (IS), i.e., IS whose life cycle is directly impacted by software, from its conception to deployment and maintenance, and that has software as an inherent part [4]. A single IS is often materialized as a software-based set of associated components deployed in a hardware and operated by humans that collect (or retrieve), process, store, and distribute information [5], [6]. As the IS definition is quite broad and could include several systems, such as an autonomous car or a smartwatch, our matter of investigation here are those IS that do not involve only physical counterparts, such as drones or smart sensors (that we consider as CPS). Instances of IS can be decision support systems, enterprise systems, public finance systems, and social networks. This is important to remark since CPSoS and other SoS potential subtypes do not necessarily involve IS as constituents. For instance, a Flood Monitoring SoS [7], [8] and Smart Parking SoS [9] are often CPSoS since they majorly (or even totally) involve CPS, i.e., independent systems characterized by an extensive number of physical devices (e.g., sensors, controllers, etc.) and cyber components (software counterparts employed to collect data from sensors, act on the environment, monitor, and manage the underlying infrastructure) [10]. In turn, smart cities or their inner sub-SoS can be considered SoIS [11]–[14], once they potentially involve IS to manage the city infrastructure, which can dramatically change the way the emergent behaviors are planned and designed.

Some SoIS initiatives. Some examples of SoIS exist in the literature. Neves et al. [15] investigate the need for interoperating several different educational IS (essentially virtual learning environments, known as VLE) to (i) complement each other regarding the provided functionalities, (ii) abstract away the need of using several different VLE from users, and (iii) allow users to share all the functionalities offered by the constituents that form the SoIS. This SoIS is essentially formed by several IS, not involving other types of constituents. Majd and Marie-Hélène [16] also worked on educational SoIS. They modeled and developed the MEMORAESoIS as a support for the learning ecosystem. The aim was to facilitate resource management in a SoIS, combining resources from several IS and managing them within the leader system. This resulted in an added-value that would not be present if they were operating separately.

In another context, Graciano Neto et al. [12] deal with smart cities as an example of SoIS. The authors motivate a scenario by analyzing a smart city. Several constituents are involved in a smart city SoIS, such as (i) autonomous cars and buses, (ii) intelligent bus stops, (iii) public finances IS, (iv) fuel station IS, and (v) the smart transportation system itself. Those systems then establish interoperability links to achieve a specific goal: enabling efficient transportation for population. Fig. 1 illustrates a scenario in which buses are too crowded. As such, the buses communicate with the intelligent bus stops and autonomous cars so that passengers can be reallocated to arrive in their destination accordingly. Thus, passengers in that specific bus stop have their mobiles connected to a local spot. The bus stop, once received the crowding alert from the bus, notifies the passengers they will be reallocated to autonomous cars that are available for a ride because drivers and passengers share close destinations. Once a driver gives the ride to a passenger, s/he receives a discount in fuel stations readily authorized due to interoperability among the smart transportation system (formed by autonomous cars, buses, and bus stops), the public finance IS, and the fuel station IS.

SoIS advances and state of the art. Besides SoIS examples being described in the literature, other conceptual advances have also been proposed, such as a systematic mapping study on SoIS [6], a conceptual model for SoIS [13], a study on factors that influence interoperability in SoIS [14] and a prototype of a SoIS essentially formed by several virtual learning environment systems [15].
III. ESTABLISHING AN UNDERSTANDING FOR SOIS

Although all that knowledge on SoIS has already been disseminated in several vehicles, the questions raised in Section I were not yet readily answered. We then proceed with a deeper discussion to answer those questions.

A. Q1: What is SoIS?

Teixeira et al. [2] identified two main research groups in SoIS: the group of Saleh, Abel, and colleagues [17] and ours. Our group claims the fact that SoIS requires distinct engineering techniques, while the other group faces SoIS as an SoS that behaves as an IS, not precluding that SoIS require distinctive engineering techniques.

Given the differences between the conceptualization of SoIS, our group proposes the following definition for SoIS as a result of a compilation of the literature and a systematic mapping study [2]: “A System-of-Information Systems (SoIS) is a specific type of SoS oriented to business processes in which the constituent systems include information systems that interoperate among them and belong to different organizations.” From this definition, we can discuss some important concerns. Oriented to business processes means that, essentially, SoIS goals are drawn as well-established information flows among constituents, and the activities (sub-goals) performed by the constituents are interdependent, i.e., there is a specific sequence that should be followed to achieve the goal realization. Constituent systems include IS means that other types of systems can also be involved in the SoIS, but at least one IS should be a constituent so that such SoS can be considered a SoIS. Belong to different organizations means that the SoIS are formed by constituents with managerial independence.

In this context, herein the concept of organization can be relative for SoS/SoIS. For instance, in the Educational SoIS described by Neves et al. [15], the multiple VLE were deployed at the same university. This happened because the institution politics allowed (i) different departments to adopt their preferred VLE, (ii) professors adopt other VLE, and (iii) the university itself had a major VLE required to be used by everyone. However, each one was managed by a different department, which represents the constituents’ managerial independence. Therefore, a SoIS can exist within the same organization, but different inner entities can manage constituents. To be more inclusive about scope of a SoIS, we deliver the following definition:

“A SoIS is a specific type of SoS in which the set of constituent systems include IS that interoperate with other constituents to achieve goals.”

We remark that SoIS goals are the realization of planned emergent behaviors and they are achieved as the result of the interoperation (information exchange) among the constituents. A necessary corollary is that, due to the inherent characteristics of SoS, the information exchange among constituents will be frequently expressed as a business process that is inter-organizational/inter-entities and flexible.

B. Q2: What are the differences between SoS and SoIS? and Q3: What are the specific characteristics for an SoS to be considered a SoIS?

As a SoIS is an SoS, it inherits the set of five characteristics that define SoS [18]: operational independence, managerial independence, emergent behavior, evolutionary development, and distribution. We argue that, for being an SoS, a SoIS should additionally hold the following characteristics:
• **Characteristic 1: IS Presence.** At least one IS should be present in the set of constituents. From our experience, more than one IS is frequently involved in a SoIS. This means that the SoIS nature depends on the nature of the constituents that contribute to the SoIS.

• **Characteristic 2: Goals are expressed as flexible and inter-organizational business processes.** SoIS are also concerned with the flow of information and knowledge among different IS. As stated by the definition, the SoIS goals are achieved by means of interoperation among constituents. Such an interoperation is materialized in the establishment of business processes that characterize the data exchange among constituents to achieve a goal, as also found in a deep investigation that we performed on the relationship between SoS and Business Processes [19]. We understand that business processes exist to support a set of organizational goals and there are, at least, two types of emergent behaviors: (i) the planned emergent behavior, which supports pre-established business process; and (ii) unexpected emergent behavior, which can be beneficial or not to the SoIS. If the unexpected emergent behavior brings benefits, it can raise opportunities to create new business processes for SoIS. However, we highlight both result from interoperation among IS. As the architecture of a SoIS can be dynamic and constituents are management independent, goals should be expressed as business processes that should be splitted into smaller goals to be assigned to the involved constituents. However, since constituents can leave, enter, or be replaced in a SoIS at runtime, the business process should then be: (i) flexible, i.e., the flows and activities should be allowed to change at runtime; and (ii) inter-organizational, i.e., encompass multiple organizations. A business process establishes the interdependence among subgoals and sequences of interdependent activities to achieve the goals. If a given SoIS goal is expressed as a business process, then the subgoals should be performed in a given order; otherwise, the effect would not be the intended one. This is important to remark because this is not necessarily true for other types of SoS. For instance, in a Flood Monitoring SoS, the emergent behavior (a flood alert) is usually achieved due to a pure message forwarding between the smart sensors until the gateway that processes the information and eventually triggers the flood alert. Hence, the goal is not established as a business process, but only as a message forwarding mechanism.

We claim that Characteristic 1 is mandatory for a SoS to be considered as a SoIS while Characteristic 2 is essentially a consequence of the presence of multiple organizations/entities involved in the SoIS. We emphasize that SoIS is oriented towards inter-organizational business processes, which intensively impacts on the notations to support their specification and in their engineering itself. As such, SoIS has the potential to trigger the emergence of and also establish inter-organizational business process (and associated interoperation) among the constituents to achieve the SoIS goals. In this scenario, we introduced the concept of Process-of Business Processes [20], which brings a new understanding of the business processes associated with SoIS and necessarily required new means to manage such complex, dynamic processes [21].

**C. Q4: Why is SoIS necessary as a particular type of system? and Q5: What are the engineering needs to be raised by SoIS as a particular subtype of SoS?**

In short, SoIS is needed as a particular type of SoS to motivate advances that SoS notations and tools have not coped with. We discuss it more in-depth in Section V where we discuss gaps and research opportunities.

**IV. DISCUSSION**

After answering the aforementioned questions, further issues could still arise. We use some motivating scenarios for discussing them.

Some facts motivate the study of SoIS as a particular type of systems. Maier [13] argues in his seminal paper that “what justifies the creation of a new class of systems is the insufficiency of the existing techniques to deal with the particularities of those emerging systems”. For SoIS, we claim that the presence of IS is the particularity that makes the state-of-the-art techniques for SoS not being sufficient, in particular, concerning the specific means to design, implement, and evolve them, including the tight relationship between technical and business levels.

From a hierarchical point of view, a smart city SoIS can be composed of several Emergency Management SoS (SoS1), Smart Building SoS (SoS2), a Smart Traffic SoS, and Power Distribution SoS, besides a different management IS (Constituent IS 1). An Emergency Management SoS (SoS1) can also be itself composed of a SoIS as a constituent. As illustrated in Fig. 2 an SoS can be composed of other inner SoS and SoIS. We argue that an SoS is only considered a SoIS when it directly contains one or more IS in its set of constituents, i.e., in its immediate hierarchy level. From Fig. 2 we can say that SoS1 is not a SoIS, although one of its constituents is itself a SoIS. The rationale for this decision is that an SoS should contain one or more IS to be considered a SoIS. If the IS is not in that hierarchical level, then the SoS should not be treated as a SoIS since it will not demand SoIS engineering needs and it will not involve a business process to interoperate the constituents, which is the colorary of characteristic 2 (i.e., goals expressed as a business process, which is not mandatory, but important).

**V. RESEARCH GAPS AND CHALLENGES**

SoIS engineering is still a maturing discipline. As such, gaps and research challenges remain as discussed below.

Studies in the literature revealed that [2], [13], [15], [22]: (i) at least three different definitions for SoIS were available in the literature, thus being not consensual yet; (ii) there was
a lack of a common sense on a set of characteristics that determine what is a SoIS and what is not; and (iii) the main problems introduced by SoIS and not solved by SoS until now are majorly on modeling and, by extension, its engineering.

**SoIS specification.** Modelling is an inherent part of Systems Engineering. A system model should provide a precise (even though abstract) representation of its counterpart in reality. mKAOS [23], the state-of-the-art notation for modeling SoS missions/goals, does not support the notion of sequence among activities, which is essential to model SoIS goals. For instance, it is important to represent a constituent held by an organization/entity solving a portion of a global mission and forwarding data or the “control flow” for another following constituent to go ahead until concluding the SoIS global goal. Even the languages that could support such representation, such as UML[4], SysML[5], and BPMN[6], do not support a precise specification of SoS/SoIS dynamic architectures and the multiple systems and organizations/entities involved (they were designed to represent single systems and single enterprises). We need modeling languages that match SoIS requirements so that we can have supporting tools and processes that work well for precisely capturing SoIS architectures. BPMN seems to be the best candidate for modeling at least the “process view” [22] [21]. However, it still needs to evolve towards coping with those requirements (dynamic architecture and native support for multiple organizations/entities).

**How embracing are SoIS compared to SoS?** To formalize part of the proposed concepts, let us consider that each SoS proposed, planned, specified or engineered so far are represented in a mathematical set ($S_{SoS}$). A question to raise is: how large is the SoIS subset ($S_{SoIS}$) compared to SoS?, i.e., how many existent/proposed SoS have some IS involved among their constituents? Firstly, we state that $S_{SoS} \supset S_{SoIS}$. We already know that some SoS are not SoIS, such as Flood Monitoring SoS, CPSoS in general, and a Smart Building [24]. i.e., $\exists s \in S_{SoS} \mid s \notin S_{SoIS}$. One can argue that if the cardinality of SoIS is close to SoS, then most of the SoS are SoIS and perhaps the existence of SoIS as a particular type of system could be questioned. Further research should be conducted to answer this question.

**Modeling and simulation for SoIS.** Although there has been extensive work on SoS software architecture modeling, verification, and simulation over the years [1], the same has not happened to SoIS. SoIS needs specific formal modeling and verification techniques to deal with its underlying complexity/dynamism, mainly that associated with the business process level [25] [20]. At an abstract level, SoIS architectural models should have the capability to describe structures and behaviors with suitable notations for achieving goals with the collaborative IS constituents and dealing with organizational and business processes needs. As a SoIS has a heterogeneous set of constituent systems, formal models with well-defined architectural styles/patterns can address interoperability for better exchange of information among diverse constituent systems. The resulting architectural models should be executable to validate emergent behaviors and conformance of core quality attributes of SoIS with formal verification and simulation tools coupled with model-driven engineering.

**Implementation of real-world SoIS.** We still observe the absence of more complete implementations of real-world SoIS. Saleh et al. [17] described the implementation of a SoIS in the educational domain, while Neves et al. [15] presented a prototype of a controller for a directed SoIS, but SoIS in other diverse domains should also be implemented. Overcoming this challenge is inherently related to overcome other challenges, such as: (i) the full interoperability for constituents [20] [26], (ii) the SoIS dynamic architectures [27], and (iii) challenges

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4https://www.omg.org/spec/UML
5https://www.omg.org/spec/SysML
6https://www.omg.org/spec/BPMN/2.0/
related to operational and managerial independence [28]. For achieving it, we could use an arrangement of IS from organizations/entities with the lenses of SoS to discover and balance business processes (SoIS and constituent IS) that could be established among them, besides analyzing and involving the corresponding IT architecture for means of interoperability [20].

VI. Final Remarks

The main contribution of this paper was to compile, summarize, and establish an understanding of Systems-of-Information Systems (SoIS). The content of this paper is the product of a five-year research project on SoIS developed in cooperation between multiple institutions in Brazil with international cooperations in Australia, the USA, and France. We remark that SoIS has been recognized as a promising and prominent research area and listed as one of the Grand Challenges in Information Systems for the Decade 2016-2026 in Brazil [11]. As CPSOs has evolved over the past years to become an important area of interest for the SoSE community, we also expect that SoIS can also reach such status in the forthcoming years, attracting researchers and contributors. We expect this paper works as a theoretical milestone to motivate newcomers and experienced researchers to further consolidate a SoIS international community.

REFERENCES

[1] H. Cadavid, V. Andrikopoulos, and P. Aveliou, “Architecting systems of systems: A tertiary study,” Information and Software Technology, vol. 118, 2020.

[2] P. Teixeira, V. Lopes, R. Santos, M. Kassab, and V. Graciano Neto, “The status quo of systems-of-information systems,” in 7th International Workshop on Software Architecture for Engineering of Systems and 13th Workshop on Distributed Software Development, Software Ecosystems and Systems-of-Systems. USA: IEEE, 2019, pp. 34–41.

[3] S. Engell, R. Paulen, M. A. Reniers, C. Sonntag, and H. Thompson, “Core research and innovation areas in cyber-physical systems of systems,” in Cyber physical systems: Design, modeling, and evaluation, ser. Lecture Notes in Computer Science, M. R. Mousavi and C. Berger, Eds., vol. 9361. Switzerland: Springer International Publishing AG, 2015, pp. 40–55.

[4] ISO/IEC/IEEE 42010:2011, ISO/IEC/IEEE Systems and software engineering – Architecture description, ISO, Switzerland, 2011.

[5] K. Tomicic-Pupek, Z. Dobrovic, and M. T. Furjan, “Strategies for information systems integration,” in 34th International Conference on Information Technology Interfaces. USA: IEEE, 2012, pp. 311–316.

[6] K. C. Laudon and J. P. Laudon, Management information systems: Managing the digital firm, 14th ed. USA: Pearson/Prentice Hall, 2015.

[7] F. Oquendo, “Formally describing the software architecture of systems-of-systems with SosADL,” in 11th System of Systems Engineering Conference. USA: IEEE, 2016.

[8] ——, “Software architecture challenges and emerging research in software-intensive systems-of-systems,” in 10th European Conference on Software Architecture, ser. Lecture Notes in Computer Science, B. Tekinerdogan, U. Zdun, and A. Babar, Eds. Switzerland: Springer International Publishing AG, 2016, vol. 9839, pp. 3–21.

[9] A. Delécolle, R. S. Lima, V. V. G. Neto, and J. Ruisson, “Architectural strategy to enhance the availability quality attribute in system-of-systems architectures: A case study,” in 15th IEEE International Conference of System of Systems Engineering. USA: IEEE, 2020, pp. 93–98.

[10] M. Elshenawy, B. Abdulhai, and M. El-Dariby, “Towards a service-oriented cyber–physical systems of systems for smart city mobility applications,” Future Generation Computer Systems, vol. 79, pp. 575–587, 2018.

[11] V. V. Graciano Neto, F. Oquendo, and E. Y. Nakagawa, “Smart systems-of-information systems: Foundations and an assessment model for research development,” in I GrandSIS-BR: Grand Research Challenges in Information Systems in Brazil 2016-2026, R. M. Araujo, C. Boscarioli, and R. S. Maciel, Eds. Brazil: SBC, 2016, vol. 10, pp. 13–24.

[12] V. V. Graciano Neto, R. P. dos Santos, D. Viana, and R. Araujo, “Towards a conceptual model to understand software ecosystems emerging from systems-of-information systems,” in Software Ecosystems, Sustainability, and Human Values, ser. Communications in Computer and Information Science, R. P. dos Santos, C. Maciel, and J. Viterbo, Eds. Switzerland: Springer, 2020, vol. 1081, pp. 1–20.

[13] J. Fernandes, F. Ferreira, F. C. de Paula, V. V. Graciano Neto, and R. P. dos Santos, “A conceptual model for systems-of-information systems,” in 20th IEEE International Conference on Information Reuse and Integration for Data Science. USA: IEEE, 2019, pp. 364–371.

[14] ——, “How can interoperability approaches impact on systems-of-information systems characteristics?”, in 10th Brazilian Symposium on Information Systems. USA: ACM, 2020.

[15] V. O. Neves, L. Garcês, and V. Graciano Neto, “Towards educational systems-of-information systems: Reporting results of an exploratory study,” in 16th Brazilian Symposium on Information Systems. USA: ACM, 2020.

[16] S. Majd and A. Marie-Hélène, “System of system as support for learning ecosystem,” in 2nd International Symposium on Emerging Technologies for Education, ser. Lecture Notes in Computer Science, T.-C. Huang, R. Lau, Y.-M. Huang, M. Spaniol, and C.-H. Yuen, Eds. Switzerland: Springer International Publishing AG, 2017, vol. 10676, pp. 29–37.

[17] M. Saleh and A. Marie-Hélène, “Information systems: Towards a system of information systems,” in 7th International Joint Conference on Knowledge Discovery, Knowledge Engineering and Knowledge Management, vol. 3. Portugal: SciTePress, 2015, pp. 193–200.

[18] M. W. Maier, “Architecting principles for systems-of-systems,” Systems Engineering, vol. 1, no. 4, pp. 267–284, 1998.

[19] M. I. Cagnin and E. Y. Nakagawa, “Can existing approaches manage dynamic and large business processes enacted through systems-of-systems?” IEEE Systems Journal, pp. 1–8, 2021, (Under review).

[20] ——, “Towards dynamic processes-of-business processes: A new understanding,” Business Process Management Journal, pp. 1–34, 2021, (Accepted for publication).

[21] ——, “Processes-of-business processes: A novel information source of systems-of-systems requirements.” Software and Systems Modeling, pp. 1–33, 2021, (Under review).

[22] V. V. G. Neto, F. E. A. Horita, E. Cavalcante, A. J. Rohling, J. E. Hachem, D. S. Santos, and E. Y. Nakagawa, “A study on goals specification for systems-of-information systems: Design principles and a conceptual model,” in 14th Brazilian Symposium on Information Systems. USA: ACM, 2018.

[23] E. Silva, T. Batista, and F. Oquendo, “A mission-oriented approach for designing system-of-systems,” in 10th System of Systems Engineering Conference. USA: IEEE, 2015, pp. 346–351.

[24] V. V. Graciano Neto, F. Horita, R. Santos, D. Viana, M. Kassab, W. Manzano, and E. Nakagawa, “SB (Save Our Budget) - a simulation-based method for prediction of acquisition costs of constituents of a system-of-systems,” in Systems of Information Systems: A tertiary study,” in Systems of Information Systems, ser. Lecture Notes in Computer Science, R. P. dos Santos, C. Maciel, and E. Nakagawa, Eds. Switzerland: Springer International Publishing AG, 2020.

[25] M. G. Devecchio and C. L. Rubbelke, “System-of-systems requirements,” in Software and Systems Modeling, pp. 1–33, 2021, (Under review).

[26] R. S. P. Maciel, J. M. N. David, D. B. Claro, and R. Braga, “Full interoperability: Challenges and opportunities for future information systems,” in I GrandSIS-BR: Grand Research Challenges in Information Systems in Brazil 2016 - 2026, R. M. de Araujo, C. Boscarioli, and R. S. Maciel, Eds. Brazil: SBC, 2017, pp. 107–118.

[27] W. Manzano, V. V. Graciano Neto, and E. Y. Nakagawa, “Dynamic SoS: An approach for the simulation of systems-of-systems dynamic architectures,” The Computer Journal, vol. 63, no. 5, pp. 709–731, 2020.

[28] P. G. Teixeira, B. G. A. Lebtag, R. P. d. Santos, J. Fernandez, A. Mohsin, M. Kassab, and V. V. Graciano Neto, “Constituent system design: A software architecture approach,” in 2020 IEEE International Conference on Software Architecture Companion. USA: IEEE, 2020, pp. 218–225.