Submission date: 03/05/2021
Resubmission date: 09/09/2021
Camera ready submission date: 01/02/2022

1st round notification: 09/08/2021
2nd round notification: 22/12/2021
Available online: 04/02/2022
Publication date: 25/02/2022

Section: extended version
Extended version of selected papers from the XVI Brazilian Symposium on Information Systems

A Method for Identification of Potential Interoperability Links between Information Systems towards System-of-Information Systems

Juliana Fernandes[1], Felipe Cordeiro[2], Francisco Ferreira[3], Valdemar Vicente Graciano Neto[4], Rodrigo Pereira dos Santos[3]

[1]Federal Institute of Piauí (IFPI)
Campo Maior, Brazil

[2]Superior Institute of Education of Rio de Janeiro (ISERJ)
Rio de Janeiro, Brazil

[3]Federal University of the State of Rio de Janeiro (UNIRIO)
Rio de Janeiro, Brazil

[4]Federal University of Goiás (UFG)
Goiânia, Brasil

juliana.fernandes@ifpi.edu.br, felipecordeiro.es@iserj.edu.br, francisco.ferreira@uniriotec.br, valdemarneto@ufg.br, rps@uniriotec.br

Abstract. *Systems-of-Information Systems (SoIS) are composed of independent information systems that interoperate to provide unique capabilities. Despite this, the establishment of interoperability links in a SoIS is challenging due to factors concerning (i) the orchestration of the information systems to exchange data properly, (ii) the provision of technical solutions to make the heterogeneity transparent and to effectively mediate the information systems, (iii) the trade-offs between interoperability and other dimensions, and (iv) the need for reconfiguration to maintain a continuous delivery of services over time. In this context, this study presents a method for identifying potential interoperability links to support the emergence of a SoIS structured in three steps: method conception, proposal, and evaluation. We also present a case from a real education environment to evaluate the application of our method. Results indicate that the proposal can help in the identification of potential links among information systems in a SoIS arrangement considering ISO interoperability standard.*

Keywords. *Systems-of-Information Systems, SoIS, interoperability link, interoperability management, interoperability approaches.*

1. Introduction

Organizations have currently been stimulated to build alliances to achieve mutual benefits. When such alliances extend to their information systems (IS)[1], an arrangement of

[1]Herein, for sake of simplicity, IS will interchangeably denote both singular and plural forms.

Cite as: Fernandes, J., Cordeiro, F., Ferreira, F., Graciano Neto, V., Santos, R. P. (2021). A Method for Identification of Potential Interoperability Links between Information Systems towards System-of-Information Systems. iSys: Revista Brasileira de Sistemas de Informação (Brazilian Journal of Information Systems), 15(1), 2:1-2:26. DOI: 10.5753/isys.2022.2014

systems in collaboration, also referred to as Systems-of-Information Systems (SoIS), is formed. A representative example of SoIS took place at Rio Operations Center (COR), during the FIFA World Cup 2014 and the Olympic Games Rio 2016. Several public and private organizations combined their IS to offer to the citizens, athletes, professionals, and tourists the best - and safest - possible experience. COR encompassed IS from the Military Police, Fire Department, Civil Defense, and service concessionaires of gas, power, and transportation, to mention a few. Moreover, COR used Waze and Google Maps to monitor the points of interest and avoid traffic jams and robbery, for example[2].

The emergence of a SoIS requires the establishment of interoperability links among IS. When looking at COR example, we can observe that the establishment of interoperability links involves two main issues: technical feasibility (i.e., the effective establishment of information exchange and use of information in syntactic, semantic, and pragmatic perspectives); and practical feasibility (i.e., interoperability impact on companies, such as in their business processes, value chains, policies, and people involved). Regarding the technical feasibility, difficulties are often related to the different types of technologies (e.g., databases, data formats, and communication protocols), which are indeed a relevant challenge to be overcome [Graciano Neto et al. 2017c, Maciel et al. 2017]. On the other hand, the establishment of interoperability links among IS also involves (i) strategic goals and information, (ii) the scope of sharing information, (iii) conflicts of interest, (iv) priorities, and many other aspects related to the business and the people involved in the process of designing a SoIS [Graciano Neto et al. 2017a].

The association of IS to form a SoIS should allow low coupling and high flexibility, as IS should be able to join and leave the alliance, at runtime, whenever they want [Fernandes et al. 2020b]. However, the impact of such changes needs to be planned and measured so that the organizations are not harmed and the SoIS can be able to self-reconfigure to preserve ongoing service delivery [Graciano Neto et al. 2017b]. In this case, establishing interoperability links is a more complex task than just making them exchange data. It still requires the analysis of several details considering technical, human, and business dimensions. Both the IS research community and the Systems-of-Systems Engineering (SoSE) community point some research gaps such as the need for new lenses to analyze (i) how complex systems and their constituents are connected [Palfrey and Gasser 2012]; (ii) how to support the (often) limited ability of stakeholders to fully understand pre-established requirements for interoperability [Benson and Grieve 2021]; (iii) how to provide sufficient support to deal with all dimensions of interoperability to achieve full interoperability, especially in the context of complex systems [Maciel et al. 2017]; and (iv) how to manage the interoperability links and to adjust the level of interoperability [Graciano Neto et al. 2017c] given the difficulty in specifying how the IS should interplay in a way that maintains an appropriate level of coupling. Therefore, we present a method for assisting in the establishment of interoperability links among IS to form a SoIS. We expect that our method can support professionals in identifying potential links among IS towards a SoIS. In addition, we present an evaluation of the method in a real scenario of an educational environment. Our study is driven by the following research question: *"How to specify interoperability links to interplay IS in*

[2] https://use.metropolis.org/case-studies/rio-operations-center

a SoIS?".

This study is an extended version of a previous work published at the 16th Brazilian Symposium on Information Systems [Fernandes et al. 2020b]. In this extended version, we grounded our work on a twofold contribution: (i) the proposition of a method for identifying potential interoperability links based on SoIS, and (ii) the application of the proposed method in an educational environment SoIS reported by literature [Cordeiro and Santos 2019]. Results demonstrated that the proposed method could support engineers and architects to identify potential interoperability links for the constitution of a SoIS.

This study is organized as follows: Section 2 presents the background, and Section 3 presents related work; Section 4 describes the research method; Section 5 presents approaches for establishing interoperability links in SoIS based on ISO 14258 standard; in Section 6, we present the proposed method for identifying potential interoperability links among IS; Section 7 presents evaluation; Section 8 describes the discussion of results; Section 9 describes threats to validity; and finally, Section 10 presents conclusion and future work.

2. Background

IS are composed of elements for collecting, storing, and processing data to provide information and knowledge for supporting organizational decisions. Three dimensions support any IS: human, business, and technical [Laudon and Laudon 2009]. When multiple IS work collaboratively to achieve a mutual goal, they create a *complex system* [Board 2017]. A complex system has several independent and interdependent parts interacting in a nonlinear way, i.e., the behavior cannot be barely expressed as a result of the combination of the individual parts [Alampalli and Pardo 2014], and it often exhibits (i) adaptation, (ii) self-organization, and (iii) emergence [Ottino 2004].

One particular type of complex system is the so-called System-of-Systems (SoS) [Maier 1998]. In SoS, independent systems (known as constituent systems) work together to accomplish a goal. Organizational IS are examples of potential constituents that can cooperate with other systems to obtain mutual benefits (e.g., create new functionalities, technologies, and take advantage of business opportunities). In this context, an arrangement of independent systems that involve one or more IS is called System-of-Information Systems (SoIS) [Graciano Neto et al. 2018]. This class of SoS presents specific properties, such as (i) the existence of information flows among the constituents IS; (ii) a business process-oriented nature; and (iii) information creation and added value through interoperability among IS and their organizations, which cannot be obtained if their constituent IS operate in isolation [Fernandes et al. 2019]. While software-intensive SoS is primarily concerned with a technical artifact (e.g., software) [Maier 1998, Gonçalves et al. 2014], SoIS are concerned with other elements, such as processes, technologies, and people [Soares and Amaral 2014].

It is worth mentioning that SoIS inherits characteristics from SoS. Moreover, it typifies the scope of SoS as it crosses organizational boundaries, involving constituent IS from different domains and producing a large amount of information. The

SoS characteristics inherited by SoIS are autonomy, belonging, connectivity, diversity, dynamism, emergent behavior, evolutionary development, and interdependence [Lu et al. 2010, Graciano Neto et al. 2017c]. **Autonomy** means that each IS operates for its individual purposes since it also operates independently of the SoIS. **Belonging** means that the IS chooses to belong to the SoS on a cost-benefit basis; and also to provide a greater fulfillment of their purposes. **Connectivity** refers to the mechanisms that enable communication and information sharing. **Diversity** means that IS are heterogeneous. They are self-sufficient systems that are open for enhancement by evolution and adaptation. **Dynamism** is the characteristic of a SoIS to modify its structure over time and deal with the joining or the abandonment of IS [Manzano et al. 2020]. **Emergent behavior** results from the synergistic collaboration among constituent IS and is assigned to the SoIS as a whole. There are desirable and undesirable emergent behaviors. **Evolutionary development** means that SoIS evolves as constituent IS evolve as well. Such evolution occurs in response to the individual needs of the constituent IS and can imply benefits to SoIS, e.g., IS can deploy new functionalities, and the SoIS can take advantage of it. On the other hand, SoIS can experience disturbances if some functionalities are changed or removed. Finally, **interdependence** is the mutual dependence resulting from the need for an IS to rely on one another to accomplish a goal.

Soares and Amaral [Soares and Amaral 2014] consider interoperability as a collective and federalist phenomenon, not just an integration phenomenon, a "limiter of freedom" phenomenon, or an exclusively technological phenomenon. It encompasses a cultural, social, and human communication, negotiation, and diplomacy phenomenon. A SoIS embraces social and human elements, such as strategies to represent stakeholders' decisions and behaviors to enable the creation of value and innovative ideas [Soares and Amaral 2014, Laudon and Laudon 2015]. Hence, we brought these elements for our discussion since interoperability is about technical integration among systems and combining their business processes and also social and human aspects.

We also highlight that SoIS is a maturing investigation area. Thus, we sought to look at interoperability including studies regarding the identification of interoperability in the traditional area of IS, not only SoIS. We have considered the Ontology for Enterprise Interoperability (OoEI) [Naudet et al. 2010] since it establishes an understanding of concepts provided by the Framework for Enterprise Interoperability [Chen 2017] and the Ontology of Interoperability [Naudet et al. 2006]. The OoEI also considers concepts from ISO 14258 standard [ISO 14258 1998], which describes three recurrent approaches to establish interoperability links: Federated, Unified, and Integrated. Each approach imposes a different level of coupling between IS that can be considered for the design of SoIS. For instance, depending on the approach, the level of interdependence over constituent IS can increase, which implies a high level of coupling [Fernandes et al. 2020b].

Integrated Approach means that a standard is shared by all constituent IS [Chen and Doumeingts 2003, Kosanke 2006, Weichhart and Wachholder 2014] and implies in the adoption of a *Common Template* for the representation of all the concerned models or for building systems [Naudet et al. 2010]. **Unified Approach** means that a **common meta-model** establishes semantic and syntax equivalence [Kosanke 2006, Naudet et al. 2010]. This terminology allows a translation between constituents models even though some loss of semantics or information can occur [Tu et al. 2016]. **Federated Approach** aims to establish interoperability "on the fly" and means that an **adaption to requirements occurs at runtime** [Weichhart and Wachholder 2014]. This approach does not impose models, languages, or methods of work [Weichhart and Wachholder 2014, Tu et al. 2016], and interoperability problems are fixed while systems are running [Naudet et al. 2010].

Based on a previous study that discusses how interoperability approaches can affect SoIS intrinsic characteristics [Fernandes et al. 2020b], we assume that any interoperability solution should consider an appropriate approach that preserves such characteristics. For clarity and a proper understanding of interoperability, we argue that it is important to expose the differences among integration, compatibility, and interoperability since the concepts seem similar but differ in important aspects. Functional dependencies in integration imply less flexibility and resilience [Dassisti et al. 2013]. Integrated systems are sensitive to failures, and local functional or structural changes may unpredictably impact different parts of an integrated system [Weichhart and Wachholder 2014]. Compatibility means that a system does not interfere in another's functioning. However, two compatible systems might not be able to collaborate. Thus, SoIS should be a structure composed of compatible constituents simultaneously, as each IS should work collaboratively to achieve a goal. Finally, interoperability promotes a loosely coupled approach, in which systems remain independent but coordinated insofar some collaboration is possible to occur [Weichhart and Wachholder 2014]. The interoperability concept relies on a *continuum* from compatibility toward integration (Figure 1). Studies regarding the establishment of interoperability links in complex systems are discussed in the next section.

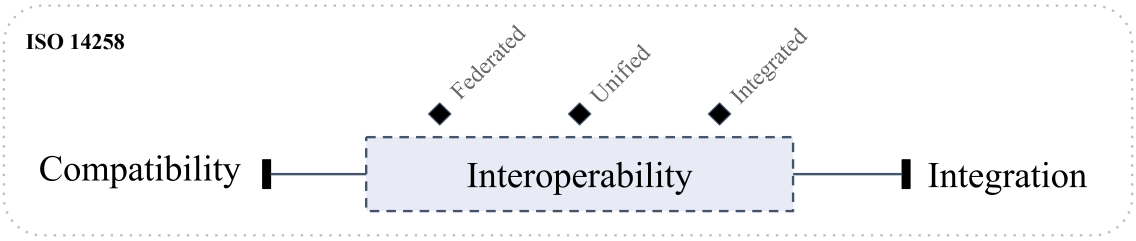

Figure 1. Difference between the integration and interoperability. Adapted from [Weichhart and Wachholder 2014].

3. Related Work

Over the years, several studies reported results of research on interoperability. In particular, studies have been conducted on the identification of interoperability links in the traditional IS field. For instance, OoEI, briefly discussed in Section 2, describes a classification scheme to categorize interoperability knowledge [Naudet et al. 2010]. In that study, the authors discuss and integrate problems and related solutions regarding the interoperability domain on the ontology. However, that study does not cover all systemic solutions, and it is focused on interoperability among IS in a specific enterprise context. On the other hand, our study aims to provide a systematic method to embrace all elements around IS (technical, human, organizational) to support the identification of interoperability links even though these IS belong to different enterprises. Therefore, we argue that the proposed method can systematically analyze the IS elements within a SoIS.

The architecture of SoIS should deal with heterogeneous sources of information. In this context, Saleh *et al.* [Saleh et al. 2016] present a model in which a SoIS is described as a group of systems connectors, services, and databases. The model allows users to manage the IS resources considering the SoIS environment. However, it does not consider potential critical points of the solution based on specific characteristics of SoIS. This can imply a lack of dynamism in interactions between constituent IS, stakeholders, and the business processes of organizations. Our work aims to support the identification of potential interoperability links by promoting a reading not limited to three elements (systems connectors, services, and databases) but including organizational elements, as well.

As SoIS arrangements essentially depend on constituent IS surrounding people, processes, and technologies, the proposed method should systematically aggregate an understanding of which elements and challenges are involved in the interoperability of these types of arrangements. The next section presents the proposed method.

4. Research Method

Our research method was inspired by evaluation studies as in [Fontão 2016]. Thus, we followed a systematic style composed of three steps, as shown in Figure 2: (1) **Conception** includes the following tasks: (i) analysis of approaches defined in [ISO 14258 1998] standard for interoperability (i.e., integrated unified, and federated), and (ii) analysis and evaluation of the influence of those approaches on SoIS context; (2) **Method Proposal** involves the design of potential interoperability links; and (3) **Evaluation** including the following tasks: (i) instantiation of the method on a specific real case by a SoIS stakeholder, (ii) evaluation of the instantiation, (iii) refinement of method, and (iv) analysis and discussion of results.

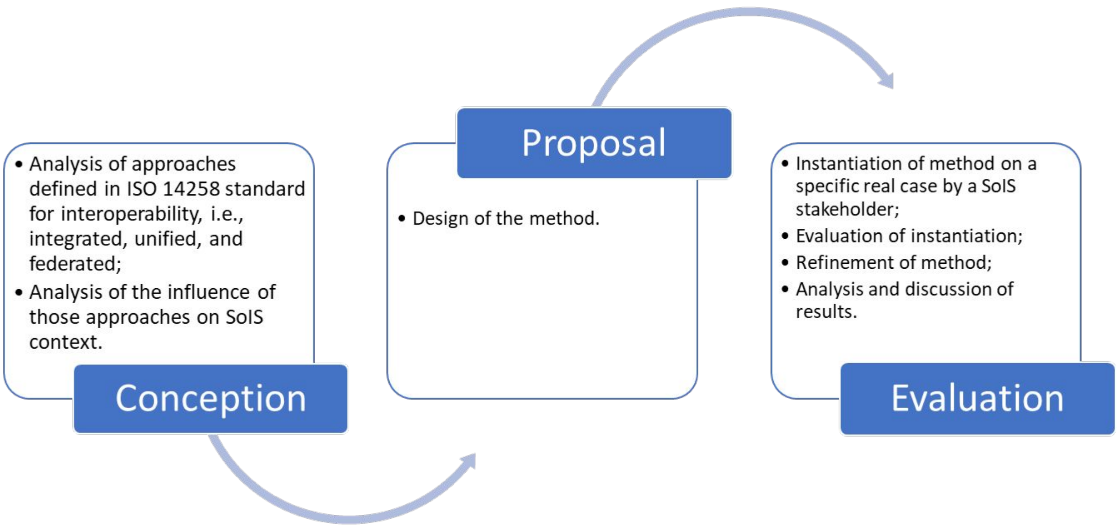

Figure 2. Research method.

Step 1. Conception. In this step, we performed an analysis of the interoperability approaches from ISO 14258 [ISO 14258 1998]. We analyzed how the state-of-the-art approaches influence on SoIS characteristics. To ensure better accuracy of our analysis, three researchers analyzed how each interoperability approach potentially affects a SoIS. Each researcher investigated the characteristics of each approach against each SoIS characteristic. The researchers selected which characteristics of SoIS that a given approach could influence in the interoperability design (Figure 3). Then, a qualitative analysis was conducted from the researchers' answers, and a consensus was obtained.

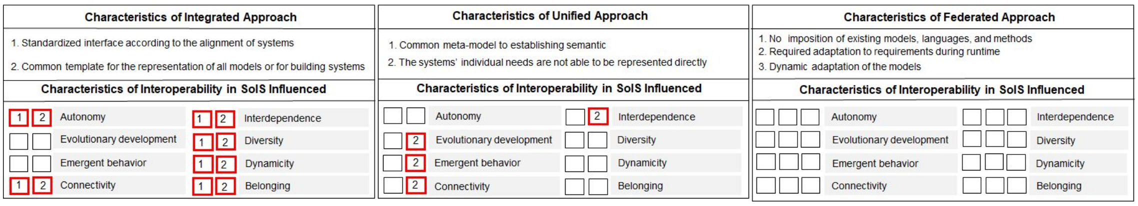

Figure 3. An example of the Analysis process.

Next, we surveyed experts to evaluate the accuracy and suitability of the concepts and how they are related. The answers were submitted for evaluation by two interoperability experts in SoIS. One of them was indirectly involved in this study. We used the Likert scale and asked them whether (i) they agree on the concepts depicted in Figure 4, (ii) they agree on the relations established between the links, and (iii) they agree on how each of the approaches (Federated, Unified, and Integrated) can potentially impact a SoIS. The experts were unanimous in strongly agreeing on the suitability and accuracy of the results, even though they highlighted the speculative nature of the results. The results support the discussion presented in Section 5.

Step 2. Method Proposal. In this step, we defined a method to support the identification of potential interoperability links between IS for SoIS. It is presented in Section 6.

Step 3. Evaluation. Finally, to evaluate the effectiveness of the method, the method was instantiated in an educational environment. The collected data were analyzed, and the results are presented and discussed in Section 7.

The following section presents how each interoperability approach (Integrated, Unified, and Federated) from [ISO 14258 1998] can affect the characteristics of a SoIS.

5. Implications of ISO 14258 Interoperability Approaches on Systems-of-Information Systems

In this section, we discuss how SoIS characteristics can be affected by the interoperability approaches [Fernandes et al. 2020b]. Figure 4 summarizes the results of this discussion. The cells marked with the red ball indicate that the corresponding approach harms the SoIS characteristic, and the cells with the blue symbol represent the characteristic that is positively affected by that listed approach.

	Ways of dealing with interoperability considering the approaches	Autonomy	Evolutionary development	Emergent behavior	Connectivity	Interdependence	Diversity	Dynamicity	Belonging
INTEGRATED	Standardized interface according to the alignment of systems	●	●	●	✓	✓	●	✓	✓
	Common template for the representation of all models or for building systems	●	●	●	●	●	●	✓	✓
UNIFIED	Common meta-model to establishing semantic	✓	✓	✓	✓	✓	✓	✓	●
FEDERATED	No imposition of existing models, languages, and methods	✓	✓	●	●	✓	✓	✓	✓
	Required adaptation to requirements during runtime	✓	✓	●	●	✓	✓	✓	✓
	Dynamic adaptation of the models	✓	✓	●	●	✓	✓	✓	✓
Legend	● threatened feature ✓ maintained feature								

Figure 4. How approaches potentially impact the characteristics of SoIS [Fernandes et al. 2020b].

5.1. Integrated Approach

The integrated approach affects the **autonomy** of constituent IS. It can be strongly affected by standardization, especially through the use of common templates and meta-templates. Such an approach requires constituents to be forced to comply with standards that may conflict with individual goals. Moreover, the premise that constituent IS prioritizes its individual goal, even if a SoIS belongs to a single organization, should be considered.

The integrated approach requires constituent ISs to be designed and developed following shared standards. Considering the SoIS context, this can represent a limitation as the constituent IS are often in operation before being part of a SoIS. Therefore, constituent IS have data formats or standards to meet a set of specific business requirements. IS owners can be reluctant to changes for joining a SoIS. The integrated approach presumes that the formation of SoIS involves a specific architecture for the arrangement of IS and specific functional and non-functional requirements to achieve the SoIS goal, such as data format, the layout of reports, database types, and protocols. Moreover, **evolutionary development** is also affected as it depends on the ability of constituents to evolve. When a SoIS is designed, the **emergent behaviors** are planned, but unplanned behaviors can emerge over time. Unplanned behaviors can be welcome if they represent business opportunities. The integrated approach might limit unplanned behaviors. The constituent IS must absorb every change regardless it is related to individual goals or not. As a consequence, a certain level of authority over the constituent IS is needed. An integrated approach does not threaten **connectivity**, **interdependence**, and **dynamicity**. The reason is the natural trend towards standardization. On the other hand, **belonging**, which is related to the cost-benefit of IS participation in SoIS, can be positively affected as integrated approaches involve stable models, roles, and responsibilities. This scenario facilitates the engagement of stakeholders in an arrangement. The higher the sense of belonging, the higher the availability of resources (human and technical) required. Finally, according to [Chen 2017], integrated approaches are appropriate if the constituent IS needs to be developed rather than applying it to existing systems. In general, SoIS are comprised of

IS that are already in operation.

5.2. Unified Approach

The unified approaches affect fewer characteristics of SoIS comparing it with integrated approaches. However, according to [Tu et al. 2016], a unified approach cannot directly represent the individual needs of the constituent IS.

A SoIS may not perform as desired if SoIS stakeholders are unaware of the constituent IS restrictions in their context. Such restrictions may overcome organizational boundaries and conflict with the SoIS objectives. In the unified approaches, each constituent IS maintains its characteristics, but there is a need to maintain an up-to-date standard meta-model for all constituent IS. Still, **autonomy**, **diversity**, **connectivity**, **interdependence**, **emergent behavior**, **dynamics**, and **evolutionary development** are probably preserved. If the meta-model is not updated, there may be negative implications given the difficulty of the SoIS as a whole to absorb emerging changes (e.g., adaptability to change, temporality, technologies, costs).

5.3. Federated Approach

In general, federated approaches are more flexible and maintain the **autonomy** of constituent IS since they are free to evolve according to their individual needs, observing its constraints and the context to which they belong. Therefore, the **evolutionary development** of constituent IS is the characteristic that is little affected by federated approaches.

Dynamicity and **diversity** also remain preserved when federated approaches are used. However, the dynamism of 'on the fly' negotiations relies on **connectivity** (which includes communication protocols) that can be affected if negotiations do not address all the issues that should be considered for collaboration using a communication channel. As a consequence, emergent behaviors may not be achieved precisely due to connectivity failures, which may also have implications for **interdependence** among constituent IS. In critical situations, fast responses are required, and a federated approach may not meet all the requirements, or there may not be enough time for negotiation. For instance, in an ocean oil spill scenario, a SoIS manager without some active contingency plans for oil pollution incidents can result in the death of marine animals and flora.

From the discussion of the approaches and their implications on the characteristics of SoIS, we move forward to the attempt to apply the choice of an approach to the constitution of a SoIS. To do so, we propose a method with phases covering what is necessary to identify potential interoperability links between IS that can constitute a SoIS. This method is presented in the next section.

6. A Method for Identification of Interoperability Links in Systems-of-Information Systems

SoIS are formed from the establishment of interoperability links among existing IS to fulfill a higher goal. Hence, a method to identify interoperability links can assist professionals in the constitution of a SoIS. Often, some stakeholders may not glimpse which specifications for interoperability help to constitute an IS arrangement in a way that maintains a reasonable level of coupling, especially in the SoIS context. Our method is presented along with the phases for identification of interoperability links between IS, as shown in Figure 5. The phases are: (1) to define SoIS main goal, (2) to define SoIS subgoals, (3) to define SoIS business processes, (4) to map inputs and outputs, (5) to identify IS candidates, and (6) to define SoIS architecture. The phases are not independent since each one can improve the next one and deliver its output as an input for the next phase.

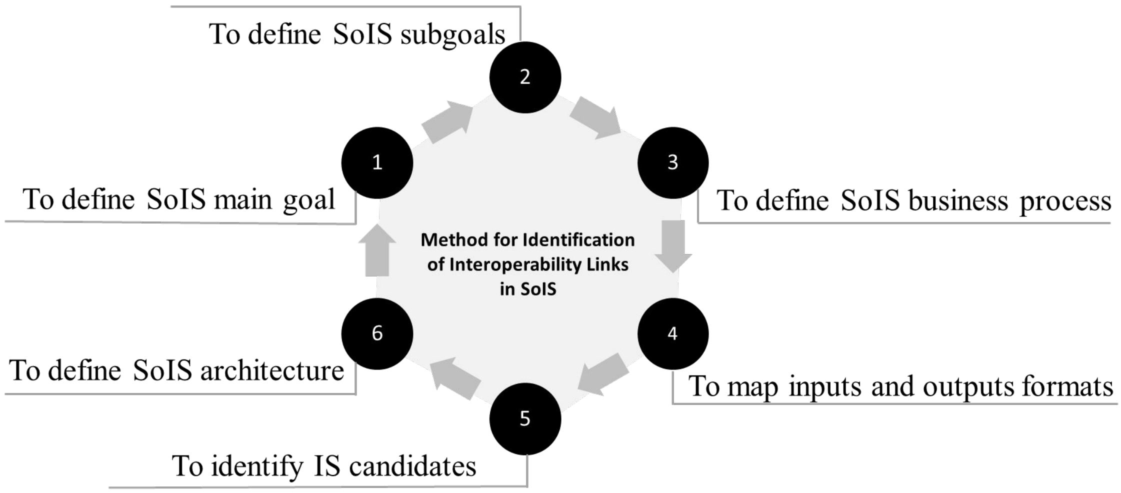

Figure 5. Method for identification of interoperability links in SoIS (first version).

To define SoIS main goal is the first phase towards the constitution of a SoIS. This phase is essential to understand and justify the reasons to interoperate constituent IS belonging to a specific organization/enterprise or various organizations. At this point, SoIS stakeholders should define the main goal because it can be refined into more tangible secondary goals [Fernandes et al. 2019].

For instance, a public education institution needs to fulfill an emerging or particular goal. To do so, a new IS may be required. However, after checking with the financial sector, the stakeholders understand that developing a new IS is impossible. The main goal is to *make available a temporary modality of remote learning during the quarantine period imposed by the COVID-19 pandemic*[3]. In this case, the main goal requires a set of concrete actions (the secondary goals or subgoals) that result from the refinement of the main goal.

Thus, **to define SoIS subgoals** is the result of refining the SoIS main goal [Fernandes et al. 2019]. SoIS subgoals can be identified as specific and tangible actions essential for eliciting the requirements of the SoIS. For the decomposition of requirements and the creation of SoIS specifications requirements, the software engineering or SoSE tools as V-model can be used [Clark 2009, Mathur and Malik 2010, Lana 2020]. SoIS subgoals help to identify the capabilities of the constituent IS necessary to form

[3] https://www.who.int/emergencies/diseases/novel-coronavirus-2019/advice-for-public

the arrangement. Proceeding with the example, to make the SoIS main goal feasible, a management team (known as SoIS stakeholder) needs to define actions such as to access (i) academic information of students (academic sector), (ii) socioeconomic information of students (student assistance sector), and (iii) subjects taught by the professors in the current period (academic sector).

To define SoIS business process corresponds to the establishment of the logical sequence and flow direction among the activities to be performed to achieve a specific goal. A business process shows who is responsible for each activity and how interoperation takes place, i.e., how the actors in a process interact so that the desired result is achieved. The identification of interactions allows a better understanding of the SoIS and the interdependencies between the IS, responsibilities, and possible risks. These interactions can be machine-machine, machine-human, or human-human, depending on the level of interoperability required.

At this phase, there is a need for agreed business strategies to support decisions on intra or inter-organizational interoperability, which include: (i) preparation of risk management plans [Cuenca et al. 2015]; (ii) intervention strategies in the evolution of the network nodes formed by the interoperability links [Jardim-Goncalves et al. 2012]; and, finally, (iii) investments in techniques for requirements analysis [Rhodes and Wilson 1992]. The definition of a SoIS business process can help in the identification of interoperability links as it structures a set of interdependent activities or actions that the involved constituents IS should perform. Moreover, it is important for the next phase of mapping inputs and outputs.

To map inputs and outputs formats consists of establishing the formats to ensure that SoIS works with homogeneous data. SoIS are hopefully formed by loosely coupled and independent IS that hold their data model. Therefore, this step is essential to identify differences in the types and formats of data between the IS (e.g., currency, measures such as height, weight, and distance). Furthermore, knowing how to deal with the technical challenges arising from this step can help on the proposition of strategic decision-making when mapping SoIS inputs and outputs.

To identify IS candidates is essential for the fulfillment of the SoIS main goal, and it depends directly on the capabilities of each constituent IS. The combination of these capabilities should match the corresponding emergent behaviors. Therefore, this step includes identifying constituent IS with the necessary resources to achieve the SoIS objectives defined in the previous steps. When dealing with this step, it is essential to highlight any condition and pattern that, in general, does not arise without resistance [Mintzberg and Waters 1982]. The implementation of interoperability is a communication phenomenon involving negotiation mechanisms [Naudet et al. 2008, Naudet et al. 2010, Soares and Amaral 2014, Weichhart et al. 2016], compensation [Naudet et al. 2008], and diplomacy [Soares and Amaral 2014]. Hence, a recommendation is to define a consensual set of norms and rules to be presented to stakeholders, if necessary [Soares and Amaral 2014].

To define SoIS architecture is a high-level description of the design that includes the representation of software components (e.g., objects, processes, data repositories), properties of those externally visible components, and relationships [Bass et al. 2003]. In the SoIS context, the constituents are the corresponding concepts for *components* and are essentially IS and their elements. In this phase, we recommend the analysis of how each [ISO 14258 1998] interoperability approach (integrated, unified, and federated) can affect the characteristics of a SoIS before describing the architecture of the arrangement (Section 5). Thus, the table shown in Figure 4 should be consulted as support for architectural decisions. Interoperability in SoIS should not be addressed only as an integration phenomenon, because maintaining a SoIS operating to fulfill a goal while the autonomy of the constituent IS is preserved to deal with human and business factors is an important aspect. Some studies point out that a high level of integration among IS may not be appropriate for business environments that do not intend to compromise the flexibility and responsiveness of dynamic operations [Pavlou and Singletary 2002, Aubert et al. 2003, Lee and Myers 2004, Soares and Amaral 2014]. Beyond technical factors, human and business factors affect the definition of the SoIS architecture. The main reason is that a SoIS stakeholder is responsible for driving teams' effort to achieve the goals and subgoals, identifying which points can be improved to increase the SoIS quality and performance, and influencing or bringing organizations to create alliances.

The phases are essential to improve the identification of interoperability links because they guide the SoIS stakeholder to understand which information should be gathered to identify constituent IS. Moreover, since these IS were not initially developed to interoperate, they have the autonomy to pursue particular goals and can be managed by different teams from the same organization or an external organization. The method, in turn, emerges as a way to elucidate the possibilities of creating these interoperability links, bringing together a team of professionals with different expertise. The next section presents the planning, execution, assessment, and refining of the proposed method in a real case.

7. Evaluation of the Method using a Real Case

7.1. Planning

The evaluation planning involved some steps, as shown in Figure 6.

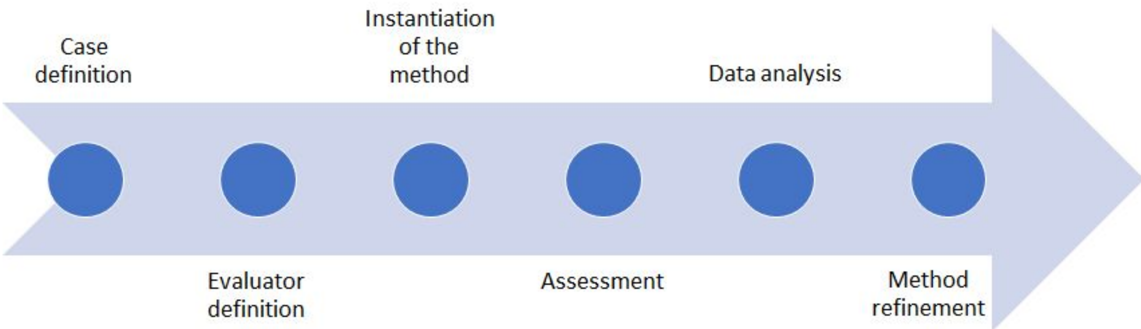

Figure 6. Evaluation planning.

Case definition. We used data collected from a previous study [Cordeiro and Santos 2019] in which specific characteristics of each IS were analyzed, and the authors realized that the arrangement formed by them could be considered a SoIS. The case represents a real organization (i.e., educational environment - EE) with different IS forming a SoIS and several actors (teachers, students, school staff, and families). The EE has approximately 5,000 members, involving about 2,000 students (from two years old until adulthood). The EE SoIS is composed of six IS, which operate independently but share human resources, business process, organizational space, and the main goal of the SoIS is *"To promote quality education for all students levels of education aiming to contribute to an equal society"*. This main goal can be delivered only if all IS are working together. The EE case comprises the following SoIS characteristics: (a) Independence of the constituents IS – the existence, operation, and purposes of each IS are independent, but the IS can offer capabilities to collaborate to the SoIS main goal; (b) Managerial independence – each IS belongs to the same organization, but they were acquired and are maintained by different teams; (c) Evolutionary development – each IS evolves according to individual requirements, and maintains its architecture; and (d) Distribution – some strategies have been designed to establish communication and data exchange among different IS [Fernandes et al. 2020a]. However, for this set of IS representing a SoIS, the presence of emergent behavior is required, i.e., a holistic phenomenon that manifests itself as a result of interoperability among different IS and produce an overall result that cannot be independently delivered by any of them [Fernandes et al. 2020a]. Considering the characteristics of each of these IS and what they can deliver, we consider (e) Emerging behavior is the ability to produce information on the students' evasion information. This goal allows the decision-makers to ensure the retention of students. Let us suppose that a school has a set of IS capable of compiling information on (1) students' absence (students missing classes); (2) personal data; and (3) school evasion (students who abandoned the studies). According to a Nations Union report [4], students may drop out or not have access to school next year due to the pandemic's impact or because they live in poor or rural areas. Thus, data from external sources, such as public agencies, are needed for a manager to make decisions that decrease the evasion rate. Such decisions can only be made by collecting the information from several independent IS to support the demand of this goal. This emergent behavior cannot be achieved by a single IS.

Evaluator definition. To evaluate the method, a SoIS stakeholder was designated from his/her expertise on the EE case. The application of the method requires previous knowledge on ISO interoperability approaches, at least a SoIS characteristics overview, and some expertise on business process modeling. In this case, before the assessment step, the evaluator was asked about his knowledge of business process modeling and SoIS. In addition, the evaluator had access to the set of approaches and how they potentially impact the SoIS characteristics (Figure 4). Thus, the evaluator is a SoIS stakeholder who has expertise in business process modeling and SoIS.

Instantiation of the method. This step represents the method applied by a SoIS stakeholder. The evaluator has received the image (Figure 5) and the description of all phases (Section 6) as well as the instructions for use.

[4] https://www.un.org/development/desa/dspd/wp-content/uploads/sites/22/2020/08/sg_policy_brief_covid-19_and_education_august_2020.pdf

Assessment. After the instantiation process, the SoIS stakeholder was invited to answer a survey to evaluate the method. Thus, an online questionnaire[5] was applied. The questionnaire was used to collect qualitative data at four aspects:

1) How easy or hard was it to apply the method to identify potential interoperability links between IS towards the constitution a SoIS on the EE case based on the Likert scale (Very Good, Good, Acceptable, Poor, Very Poor);

2) The agreement concerning each phase of the method based on the Likert scale (Very Good, Good, Acceptable, Poor, Very Poor);

3) The agreement in regards to the effectiveness of the method;

4) The agreement about the method phases order.

We also used open-ended fields in each question so that the evaluator could provide any comments aiming to refine the method.

Data analysis. We performed a quantitative analysis based on a rating scale to record a respondent's level of agreement with statements. Then, a qualitative analysis was conducted from the answers collected from open-ended comments fields.

Method refinement. Finally, the method was refined based on the analysis of the data collected in the survey. The refinement of the proposed method considered the responses obtained in the assessment with a SoIS stakeholder, mainly concerning open-ended comments fields.

7.2. Execution

Execution encompasses the strict adoption of the method for identifying potential interoperability links between IS towards the constitution of interoperability links in the EE case (Figure 7). A SoIS stakeholder followed the method recommendation and the study execution returned the following data:

1. **To define SoIS main goal:** Diagnose accountability in the EE case;
2. **To define SoIS subgoals:** Raise empowering knowledge sharing, experiences - behaviors (right or wrong) of actors for the need of accountability strategies for IS. Accountability strategies described three main suggestions for supporting improvement in strategic planning regarding organizational objectives (engagement, management, and regulation);
3. **To define SoIS business process:** Two main goals are involved when diagnosing accountability strategies for supporting IS and effects on daily school routines: (1) manage daily teacher attendance, and (2) manage school classes;
4. **To map inputs and outputs formats:** Each IS has its own routine and procedures, alternating between inputs and outputs, e.g., Attendance Management IS (AM IS) has as input the *"Organizational Subunit (OS IS) daily teacher attendance report"* and as output *"Monthly frequency report"*. Figure 7 details input/output map for EE case (Phase 4);

[5] `http://bit.ly/copy_evaluation_instrument`

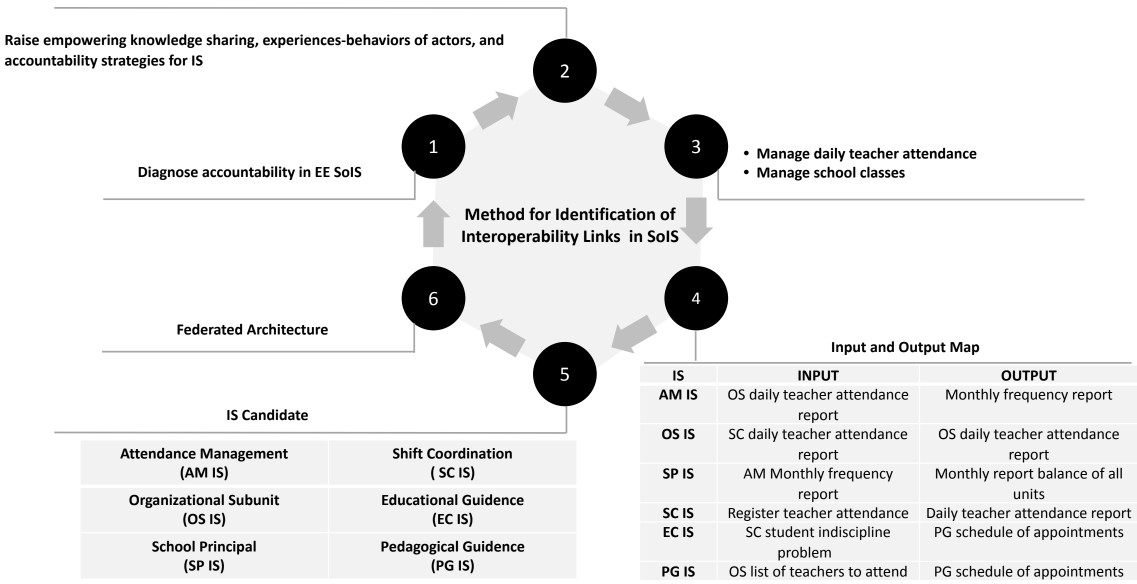

Figure 7. EE SoIS case.

5. **To identify IS candidates:** constituent IS and the interoperability among them that are part of the EE SoIS (Figure 8). Figure 9 briefly describes the constituent IS responsibility;

IS	Shift Coordination (SC IS)	Education Guidance (EG IS)	Pedagogical Guidance (PG IS)	Organizational Subunit (OS IS)	School Principal (SP IS)	Attendance Management (AM IS)
SC		X	X			X
EG			X			X
PG						X
OS	X	X	X		X	X
SP				X		X
AM	X	X	X	X	X	

Figure 8. Interoperability among constituent IS. Adapted from [Cordeiro and Santos 2019].

Regarding the management of school classes (business process), the following SoIS responsibilities were identified:

- **SC IS** must comprise the following business tasks: to (i) register teacher absence; (ii) manage class workflow; and (iii) inform classes closed early to EG IS;
- **EG IS** must comprise the following business tasks: to (i) compile educational rate as a goal; (ii) evaluate students status; (iii) attend students demands; and (iv) contact parents and relatives for educational issues;
- **PG IS** involves the following business tasks: to (i) evaluate school rate; (ii) support teaching practice; (iii) advise teachers in interdisciplinary pedagogical work; and (iv) create an agenda of educational events;

IS constituent	IS responsability
SC IS	Record student delays and inform EG Record teacher delays and inform SG Organize the flow of day classes
EG IS	Contact student's family that demands need of follow-up or have disciplinary, learning and guidance issues
PG IS	Evaluate school achievement metrics and teaching practice Advise teachers in interdisciplinary pedagogical work
OS IS	Promote articulation between the school actors: teachers, students, employees, and parents etc. Inform teachers absences from work to school principal.
SP IS	Maintain the school within the norms regarding educational system Follow ordinances and instructions Accompany the classroom daily routine
AM IS	Record student absence/presence Register teaching plan Develop educational reports and student's indiscipline cases

Figure 9. Constituent IS by responsibility. Adapted from [Cordeiro and Santos 2019].

- **AM IS** refers to the following business tasks: to (i) record student absence/presence; (ii) register teaching plan; and (iii) develop educational reports for supporting organizational sub-units.

Regarding managing daily teacher attendance (business process), the following SoIS responsibilities were identified:

- **OS IS** manages the reporting of constituent IS aiming to develop strategies for improving daily school routines, considering the following business tasks: to (i) manage teacher absence; (ii) support organizational sub-units demands; and (iii) develop annual schooling;
- **SP IS** involves manage organizational sub-units and their demands and comprises the following business tasks: to (i) evaluate each organizational demand and focusing on better strategies aiming to support then; (ii) register teachers attendance and generate a report; and (iii) evaluate each attendance case and develop a schedule evaluation.

6. **To define SoIS architecture:** Based on Figure 4 and the analysis about how each interoperability approach defined by [ISO 14258 1998] can potentially affect the characteristics of a SoIS, the Federated approach was identified as the more adequate. In this case, EE SoIS involved federated structure since the IS arrangements are focused on manual IS, sensitive to business process change and runtime IS demands.

7.3. Assessment

The results of the assessment were summarized in Table 1. The discussion of these results is presented in detail in the next section.

Table 1. Evaluation process result.

	SoIS Stakeholder Evaluation	Open-ended Comment
1. How easy or hard was the application of the method	*Very Good*	*no comment*
2. The agreement in relation to the instance in each phase		
- To define SoIS main goal	*Very Good*	*no comment*
- To define subgoals	*Very Good*	*no comment*
- To define SoIS business process	*Very Poor*	*see comment 1 bellow*
- To map inputs and outputs	*Very Good*	*see comment 2 bellow*
- To identify IS candidates	*Very Good*	*see comment 3 bellow*
- To define SoIS architecture	*Good*	*see comment 4 bellow*
3. The agreement in relation to the method effectiveness for identifying interoperability links	*Good*	*see comment 5 bellow*
4. The agreement in relation to the order of the method phases	*Poor*	*see comment 6 bellow*

7.4. Refinement

After collecting and analyzing the answers, the method was refined and evaluated considering weaknesses and strengths of the design of interoperability links in SoIS. On a smaller scale, the results pointed to difficulties already presented in the SoIS literature, such as those related to the representation of dynamic interaction flows among actors, business process, and constituent IS. However, since these occurrences depend on deeper studies, we will address this research opportunity as a future work. Next, we report on the agreement with the instantiation of each phase.

About phases ***To define SoIS main goal*** and ***To define SoIS subgoals***, the SoIS stakeholder positively evaluated it scoring *very good* on the scale. ***Define SoIS business process*** did not have a positive evaluation. The SoIS stakeholder mentioned an issue in this phase:

> *"I believe that phase 3 should focus on Identify IS candidates."* [Comment 1]

Although the SoIS literature has highlighted the importance of SoIS business processes, it is fair to consider this comment because it represents a real difficulty faced during the activities proposed using the method. Any business process design requires minimal knowledge of tasks, actors, activity flows that may not be known before identify IS candidates. However, to prevent the 'business process modeling' design phase to be a barrier during the establishment of IS arrangements, in the refinement process, we renamed that phase as *"Define interaction flows between IS"*.

The phases ***To map inputs and outputs formats*** and ***To identify IS candidate*** scored *very good*. The following comments refer to these phases, respectively:

> *"It's really worth identifying that each IS can have several inputs and outputs in SoIS. So I believe that detailing such interactions help to better understanding SoIS dynamics, majorly considering how the interoperability links support such interactions."* [Comment 2]

> *"Designing SoIS architecture is a challenge for architects; thus, identifying IS candidates should be a pre-condition when investigating any SoIS architecture."* [Comment 3]

The phase ***To define SoIS architecture*** had was scored as *good*. Architecture design has being extensively researched [Guessi et al. 2019, Cadavid et al. 2020, Manzano et al. 2020] given the challenges of representing the dynamism of the SoIS arrangement. On this phase, the SoIS stakeholder has commented as follows:

> *"I believe that more research is necessary for better understanding the effects of SoIS architecture considering that SoIS must focus on organizational objectives that change overtime. It is complex for any organization defining with 100% of sure which arrangement is right one."* [Comment 4]

Regarding the method being effective for the design of interoperability links, the SoIS stakeholder scored *good* and added the following comment:

> *"It is relevant for theory and practice since it promotes a discussion around interoperability and how it should be considered."* [Comment 5]

Regarding the order of the method phases, the SoIS stakeholder realized that the mapping of inputs and outputs should be a further step to the identification of constituent IS.

> *"I believe that the right phase should be: 1-2-3-5-4-6."* [Comment 6]

This feedback makes sense because it is challenging to map what will be provided by one IS and what will be consumed by another IS before knowing the characteristics of each one. By understanding the constituents characteristics, SoIS architects can describe the type of data/information format that each constituent IS is capable of delivering.

After an analysis of the difficulties and suggestions listed by the stakeholder, the method was refined and the new phases were established: (1) to define SoIS main goal; (2) to define SoIS subgoals; (3) to identify and characterize IS candidates; (4) to define interactions flows among IS; (5) to map inputs and outputs formats; and (6) to define SoIS architecture. The phases of the method were reorganized as shown in the Figure 10.

A follow-up evaluation with SoIS stakeholder was performed to bring the opinion on the refinement. The method was presented and the evaluator was invited to give a feedback. Concerning to the method evaluation, the study participant mentioned that the use of the method is:

> *"relevant, as it allows for the analysis of responsibilities among activities, notably listing characteristics of constituent IS."*

Thus, the six main phases of the evaluation method were considered relevant to support SoIS dynamics comprehension, mainly because it identifies potential interoperability links between constituent IS, since the method stimulates mapping people-process-technology infrastructure that supports the organizational objectives accomplishment. Another positive point concerns the organization of information about technological support, mentioned as:

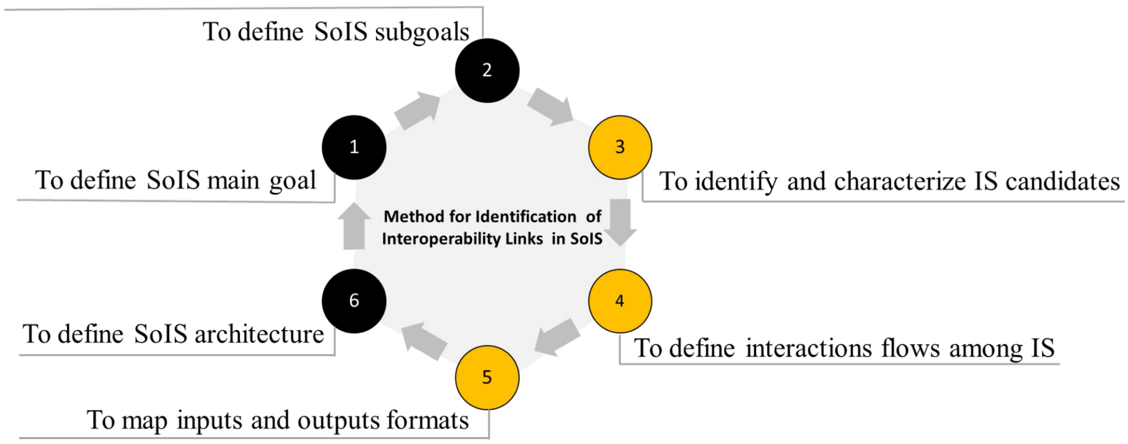

Figure 10. Method for identification of potential interoperability links in SoIS (refined version).

> *"the study showed how we need to evolve our business processes and advance in a strategy of greater use of technology."*

In contrast, a negative point was the need to understand the concepts for implementing the method. Another point that deserves to be further explored is the characterization of federated, unified, and integrated. The participant mentioned that:

> *"it is not trivial to define the type of SoIS arrangement, for example, I believe our arrangement is integrated, but we can't evaluate dynamicity."*

Finally, it is worth highlighting the need to reflect on the fact that we can still confirm the operational independence and, consequently, name the arrangement as SoIS if some constituent IS gives up a certain level of autonomy to participate in the SoIS arrangement.

8. Discussion

SoIS expands the vision of stakeholders towards looking at a set of IS belonging to several organizations, enabling business alliances that resemble coopetition[6] models [Ritala et al. 2014, Daidj and Egert 2018, Velu 2018]. This study presented a method that can be helpful for the professionals to identify interoperability links in SoIS, which results from such alliances. The method serves as a guide for the SoIS stakeholder to understand which information should be gathered to identify constituent IS that can be part of a SoIS. Since certain IS were not previously developed to interoperate, they exhibit autonomy because they operate in favor of their particular goals and can be managed by different teams from the same organization or external organizations. The method is a way to elucidate the possibilities of forming interoperability links, bringing together professionals with different expertise.

[6] Coopetition (collaboration among competing organizations) is a phenomenon that has recently gained notoriety due to its increasing relevance to business [Ritala et al. 2014, Basso et al. 2019, Graciano Neto et al. 2019]

The phases after the method refinement include: to (1) define SoIS main goal; (2) define SoIS subgoals; (3) identify IS candidates; (4) define interactions flows among IS; (5) map inputs and outputs formats; and (6) define SoIS architecture. The phases are interdependent because each one requires information collected from the previous one. *To define SoIS main goal* is the pivotal principle for composing this sort of arrangement. However, that goal has a high level of abstraction, requiring its refinement into secondary goals that represent actions or tasks to be delivered by some constituent IS (to define SoIS subgoals). From the second phase, the SoIS stakeholder can seek for IS that can provide functionalities or capabilities [Fernandes et al. 2019] that meet the defined subgoals.

Considering that constituent IS operate independently of a SoIS [Oliveira 2021], they have a set of individual goals [Fernandes et al. 2019]. This implies some challenges, such as engaging IS stakeholders to bring constituents to participate in the SoIS. However, once constituent IS participate in a SoIS, they can prioritize individual goals since IS are managerially and operationally independent. The next phase that defines interaction flows among IS should be introduced to IS stakeholders and encourage participation in a SoIS alliance. After identifying IS candidates, the next phase includes mapping inputs and outputs formats. In this phase, we highlight that business conflicts [Lewis et al. 2009] can take place as stakeholders can have different concerns. This can lead to interoperability problems and, consequently low accuracy to identify potential interoperability links. For instance, a SoIS goal may require a specific data type/format or functionality that a particular IS is not interested in providing. This may occur because the constituent IS has another established interoperability link with another arrangement with different requirements.

Understanding human and business factors around the constituent IS can be helpful in the formation of an IS arrangement. The reason is that SoIS formation demands to assemble requirements, data, and information that can be not readily available because SoIS inherit concerns from different business contexts. Soft skills are desirable to increase assertiveness in seeking potential IS candidates to compose an SoIS.

The method does not address details on data formats because it depends on the needs of each SoIS scenario. For example, there may be more than one identified constituent IS with similar capabilities but with different types and formats of data, which is a positive factor in ensuring the functioning of the SoIS. On the other hand, there is a need to design a dynamic architecture [Graciano Neto et al. 2017c] for SoIS, as this type of arrangement provides that a constituent can leave SoIS at any time. *Define SoIS architecture* is the last phase proposed by the method. SoIS architecture can be designed based on the analysis of the approaches prescribed by ISO (integrated, unified, federated) and discussed in this article in light of the SoIS characteristics (Section 5). Furthermore, some studies deepen the discussion on how business process models from different IS can help SoIS architecture design [Oliveira et al. 2020, Oliveira 2021].

9. Threats to Validity

We identified some threats to validity in this research. First, in the discussion on how approaches potentially impact the characteristics of SoIS, there is a slight bias in the results since one of the experts was indirectly involved in the design of the evaluation framework. However, there was a consensus among the three researchers who also agreed with the results. Moreover, this study does not establish the degree to which each SoIS characteristic is affected by a particular ISO approach, which deserves further investigation as future work.

One expert evaluated the method in SoIS academic research and the educational environment. The expert was indirectly involved in the conduction of the study. This can be explained by the fact that studies and discussions about SoIS are evolving in academia. Thus, applying the method in other business contexts, involving people who are not part of research in SoIS, can be hard and we consider this can also be expanded as a future work proposal.

This study used "ready-made" data that might affect/impact the proper application of the method and, hence, its entire evaluation. To mitigate this threat, the evaluator with experience in the educational case was asked to review the description of the constituent IS ready to detect possible flaws in the scenario. It is noteworthy that real SoIS cases depend on access to information that is not usually easy to obtain, given the independent nature of the constituent IS and the scarcity of real SoIS. An important point concerning the evaluation of the method was that it was not applied in exhaustion and it was instantiated only in one real case. This represents a threat because we cannot generalize the conclusion for all cases of SoIS. Although only one participant conducted the evaluation, we carefully selected a participant who has extensive knowledge in the research areas of this work and the case investigated, as well. The next section concludes the paper with final remarks and directions for future work.

10. Conclusion and Future Work

This study presented a method to support the identification of interoperability links between IS towards a SoIS. We supported our proposal by considering (i) the concepts of the Ontology for Business Interoperability to rescue interoperability key concepts in IS traditional area, and (ii) the well-accepted SoS characteristics to address SoIS characteristics and implications for interoperability. We envisioned that, depending on the ISO interoperability approach used to establish interoperability links among constituent IS towards to constitution of a SoIS, autonomy (independence), belonging, and other characteristics could be affected.

To expand the discussion, we moved forward to applying an approach to the constitution of a SoIS. Therefore, we proposed a method to identify interoperability links between IS that can constitute a SoIS. We have brought a case from a genuine education environment to support an initial evaluation of the application of the method. Indeed, establishing interoperability links in other scenarios may be different due to the underlying infrastructure of the constituents of the other domains. As a limitation, the results of this study are not so far subject to generalization. For a subsequent study, we intend to perform an additional Grounded Theory-based study to create a possible theory and generalization. Another limitation is related to the knowledge level required to the adoption of the method effectively, such as a certain degree of (i) understanding about approaches for interoperability defined in ISO 14258 [ISO 14258 1998], (ii) reading about SoIS characteristics and architecture [Fernandes et al. 2020b], (iii) practice on business process, and (iv) expertise on IS, requirements software or SoSE engineering. To reduce the likely influence of that limitation, before the application of the method, training to present the basic principles of the subjects mentioned can be carried out.

Results pointed out that the method can guide researchers and professionals in understanding how to constitute a SoIS considering interoperability approaches that better apply to the desirable characteristics of such types of arrangements. As future work, we intend to apply the method to different cases to collect data, refine the phases, and evaluate if the method might be used in complex scenarios that the applier has different profiles professional. It is worth creating a more flexible flow for different levels of familiarity with the IS involved. The proposed method helps guide establishing interoperability links in SoIS, so we also intend to elaborate a set of implementation recommendations because this study addresses interoperability at a higher level. The recommendations for implementation should cover the technical, human, and business dimensions. However, we highlight this method can be considered a further step towards the consolidation of SoIS as an maturing independent and relevant research area, with independent methods to support a reliable and practical engineering of real SoIS.

11. Acknowledgement

This study was partially financed by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001. The first author also thanks to Instituto Federal do Piauí (IFPI). The third author also thanks to the Federal University of Juiz de Fora (UFJF). The fifth author also thanks to UNIRIO and FAPERJ (Proc. 211.583/2019).

References

Alampalli, S. and Pardo, T. (2014). A study of complex systems developed through public private partnerships. In *Proceedings of the 8th International Conference on Theory and Practice of Electronic Governance*, pages 442–445, Guimarães, Portugal. ACM.

Aubert, B., Vandenbosch, B., and Mignerat, M. (2003). Towards the measurement of process integration. *Cahier du GReSI no*, 3(06).

Bass, L., Clements, P., and Kazman, R. (2003). *Software architecture in practice*. Addison-Wesley Professional.

Basso, F. P., Rodrigues, E., Bernardino, M., Werner, C., and Oliveira, T. (2019). Implementations supporting automated technology transfer in mde as a service. In *Anais do I Workshop em Modelagem e Simulação de Sistemas Intensivos em Software*, pages 104–113, Salvador, Brazil. SBC.

Benson, T. and Grieve, G. (2021). *Why Interoperability Is Hard*, pages 21–40. Springer International Publishing, Cham.

Board, B. E. (2017). The guide to the systems engineering body of knowledge (sebok). Technical report, IEEE Systems Council, and Stevens Institute of Technology (INCOSE).

Cadavid, H., Andrikopoulos, V., and Avgeriou, P. (2020). Architecting systems of systems: A tertiary study. *Information and Software Technology*, 118:106202.

Chen, D. (2017). *Framework for Enterprise Interoperability*, chapter 1, pages 1–18. John Wiley & Sons, Ltd.

Chen, D. and Doumeingts, G. (2003). Basic concepts and approaches to develop interoperability of enterprise applications. In *Working Conference on Virtual Enterprises*, pages 323–330, Lugano, Switzerland. Springer.

Clark, J. O. (2009). System of systems engineering and family of systems engineering from a standards, v-model, and dual-v model perspective. In *2009 3rd Annual IEEE Systems Conference*, pages 381–387.

Cordeiro, F. and Santos, R. P. (2019). Systems thinking as a resource for supporting accountability in system-of-information-systems: Exploring a brazilian school case. In *7th International Workshop on Software Engineering for Systems-of-Systems (SESoS) and 13th Workshop on Distributed Software Development, Software Ecosystems and Systems-of-Systems*, pages 42–49. IEEE/ACM.

Cuenca, L., Boza, A., Ortiz, A., and Trienekens, J. J. (2015). Conceptual interoperability barriers framework (cibf). In *Proceedings of the 17th International Conference on Enterprise Information Systems*, volume 2, pages 521–531.

Daidj, N. and Egert, C. (2018). Towards new coopetition-based business models? the case of netflix on the french market. *Journal of Research in Marketing and Entrepreneurship*.

Dassisti, M., Jardim-Goncalves, R., Molina, A., Noran, O., Panetto, H., and Zdravković, M. M. (2013). Sustainability and interoperability: Two facets of the same gold medal. In *OTM Confederated International Conferences" On the Move to Meaningful Internet Systems"*, pages 250–261. Springer.

Fernandes, J., Baião, F., and Santos, R. P. d. (2020a). Kipo opportunities for interoperability decisions in systems-of-information systems in the domain of environmental management. In Santos, R. P. d., Maciel, C., and Viterbo, J., editors, *Software Ecosystems, Sustainability and Human Values in the Social Web*, pages 21–41, Cham. Springer International Publishing.

Fernandes, J., Ferreira, F. H. C., Cordeiro, F., Neto, V. G., and Santos, R. (2020b). How can interoperability approaches impact on systems-of-information systems characteristics? In *XVI Brazilian Symposium on Information Systems*, New York, NY, USA. ACM.

Fernandes, J., Ferreira, F. H. C., Cordeiro, F., Neto, V. G., and Santos, R. P. (2019). A conceptual model for systems-of-information systems. In *20th International Conference on Information Reuse and Integration for Data Science*, pages 364–371. IEEE.

Fontão, A. d. L. (2016). Mseco-cert: uma abordagem baseada em processo para apoiar a certificação de apps em ecossistema de software móvel. Master's thesis, Universidade Federal do Amazonas, Manaus.

Gonçalves, M. B., Cavalcante, E., Batista, T., Oquendo, F., and Nakagawa, E. Y. (2014). Towards a conceptual model for software-intensive system-of-systems. In *International Conference on Systems, Man, and Cybernetics*, pages 1605–1610, San Diego, USA. IEEE.

Graciano Neto, V. V., Araujo, R., and Santos, R. (2017a). New challenges in the social web: Towards systems-of-information systems ecosystems. In *VIII Workshop on Aspects of the Human-Computer Interaction for the Social Web*, pages 1–12, Porto Alegre, RS, Brasil. SBC.

Graciano Neto, V. V., Basso, F. P., dos Santos, R. P., Bakar, N. H., Kassab, M., Werner, C., de Oliveira, T. C., and Nakagawa, E. Y. (2019). Model-driven engineering ecosystems. In *Proceedings of the 7th International Workshop on Software Engineering for Systems-of-Systems and 13th Workshop on Distributed Software Development, Software Ecosystems and Systems-of-Systems, SESoS-WDES 2019, Montreal, QC, Canada, May 28, 2019*, pages 58–61. IEEE / ACM.

Graciano Neto, V. V., Cavalcante, E., El Hachem, J., and Santos, D. S. (2017b). On the interplay of business process modeling and missions in systems-of-information systems. In *2017 IEEE/ACM Joint 5th International Workshop on Software Engineering for Systems-of-Systems and 11th Workshop on Distributed Software Development, Software Ecosystems and Systems-of-Systems*, pages 72–73.

Graciano Neto, V. V., Horita, F., Cavalcante, E., Rohling, A., El-Hachem, J., Santos, D., and Nakagawa, E. Y. (2018). A study on goals specification for systems-of-information systems: Design principles and a conceptual model. In *Proceedings of the XIV Brazilian Symposium on Information Systems*, New York, NY, USA. ACM.

Graciano Neto, V. V., Oquendo, F., and Nakagawa, E. Y. (2017c). Smart systems-of-information systems: Foundations and an assessment model for research development. *Grand Challenges in Information Systems for the next*, 10:1–12.

Guessi, M., Graciano Neto, V., and Nakagawa, E. (2019). Architectural description of systems-of-information systems. In *Tópicos em Sistemas de Informaçao: Minicursos SBSI*, pages 29–52. SBC.

ISO 14258 (1998). Industrial automation systems and integration – Concepts and rules for enterprise models. Standard, International Organization for Standardization.

Jardim-Goncalves, R., Agostinho, C., and Steiger-Garcao, A. (2012). A reference model for sustainable interoperability in networked enterprises: towards the foundation of ei science base. *International Journal of Computer Integrated Manufacturing*, 25(10):855–873.

Kosanke, K. (2006). Iso standards for interoperability: a comparison. In *Interoperability of enterprise software and applications*, pages 55–64. Springer.

Lana, C. A. (2020). *Requirements analysis for technical interoperability driven by mission engineering*. PhD thesis, Instituto de Ciências Matemáticas e de Computação, Universidade de São Paulo, São Carlos.

Laudon, K. and Laudon, J. (2009). *Management Information Systems*. Pearson, 11 edition.

Laudon, K. C. and Laudon, J. P. (2015). *Management information systems*, volume 8. Prentice Hall.

Lee, J.-C. and Myers, M. (2004). The challenges of enterprise integration: cycles of integration and disintegration over time. *Proceedings of the International Conference on Information Systems*, page 75.

Lewis, G. A., Morris, E., Place, P., Simanta, S., and Smith, D. B. (2009). Requirements engineering for systems of systems. In *2009 3rd Annual IEEE Systems Conference*, pages 247–252. IEEE.

Lu, Y., Panetto, H., and Gu, X. (2010). Ontology approach for the interoperability of networked enterprises in supply chain environment. In Meersman, R., Dillon, T., and Herrero, P., editors, *On the Move to Meaningful Internet Systems: Oracle Transportation Management 2010 Workshops*, pages 229–238, Berlin, Heidelberg. Springer Berlin Heidelberg.

Maciel, R. S. P., David, J. M. N., Claro, D. B., and Braga, R. (2017). *Full Interoperability: Challenges and Opportunities for Future Information Systems*, pages 107–118. Brazilian Computer Society.

Maier, M. W. (1998). Architecting principles for systems-of-systems. *Systems Engineering*, 1(4):267–284.

Manzano, W., Graciano Neto, V. V., and Nakagawa, E. Y. (2020). Dynamic-sos: An approach for the simulation of systems-of-systems dynamic architectures. *The Computer Journal*, 63(5):709–731.

Mathur, S. and Malik, S. (2010). Advancements in the v-model. *International Journal of Computer Applications*, 1(12):29–34.

Mintzberg, H. and Waters, J. A. (1982). Tracking strategy in an entrepreneurial firm. *Academy of management journal*, 25(3):465–499.

Naudet, Y., Latour, T., and Chen, D. (2008). A systemic approach to interoperability formalization. *International Federation of Automatic Control Proceedings Volumes*, 41(2):11925–11930.

Naudet, Y., Latour, T., Guedria, W., and Chen, D. (2010). Towards a systemic formalisation of interoperability. *Computers in Industry*, 61(2):176–185.

Naudet, Y., Latour, T., Hausmann, K., Abels, S., Hahn, A., and Johannesson, P. (2006). Describing interoperability: the ooi ontology. In *Proceedings of the Open Interop Workshop on Enterprise Modelling and Ontologies for Interoperability, Co-located with International Conference on Advanced Information Systems Engineering*, Luxembourg, Luxembourg.

Oliveira, L., de Vasconcelos, A., and dos Santos, R. (2020). Um método para geração de modelo de sistemas-de-sistemas de informação a partir da análise de modelos de processos de negócio. In *Anais Estendidos do XI Congresso Brasileiro de Software: Teoria e Prática*, pages 47–53, Porto Alegre, RS, Brasil. SBC.

Oliveira, L. S. (2021). Um método para geração de modelo arquitetural de sistemas-de-sistemas de informação a partir da análise de modelos de processos de negócio. Master's thesis, Instituto Federal de Educação, Ciência e Tecnologia Fluminense, Campos dos Goytacazes.

Ottino, J. M. (2004). Engineering complex systems. *Nature*, 427(6973):399.

Palfrey, J. and Gasser, U. (2012). *Interop: The promise and perils of highly interconnected systems*. Basic Books.

Pavlou, P. and Singletary, L. (2002). Empirical study of stakeholders perceived benefits of integration attributes for enterprise it applications. *Proceedings of Americas Conference on Information Systems*, page 358.

Rhodes, C. and Wilson, G. (1992). Interoperability problems-prevention is better than cure. In *International Conference on Information-Decision-Action Systems in Complex Organisations, 1992.*, pages 138–142. IET.

Ritala, P., Golnam, A., and Wegmann, A. (2014). Coopetition-based business models: The case of amazon. com. *Industrial marketing management*, 43(2):236–249.

Saleh, M., Misséri, V., and Abel, M.-H. (2016). Managing heterogeneous information in a system of information systems. In *8th International Conference on Knowledge Management and Information Sharing*, pages 165–172.

Soares, D. d. S. and Amaral, L. (2014). Reflections on the concept of interoperability in information systems. In *Proceedings of the 16th International Conference on Enterprise Information Systems*, volume 1, pages 331–339. SCITEPRESS–Science and Technology Publications.

Tu, Z., Zacharewicz, G., and Chen, D. (2016). A federated approach to develop enterprise interoperability. *Journal of Intelligent Manufacturing*, 27(1):11–31.

Velu, C. (2018). Coopetition and business models. In *The Routledge Companion to Coopetition Strategies*, pages 336–346. Routledge.

Weichhart, G., Guédria, W., and Naudet, Y. (2016). Supporting interoperability in complex adaptive enterprise systems: A domain specific language approach. *Data & Knowledge Engineering*, 105:90–106.

Weichhart, G. and Wachholder, D. (2014). On the interoperability contributions of s-bpm. In *International Conference on Subject-Oriented Business Process Management*, pages 3–19. Springer.