Manuele Kirsch Pinheiro
Carine Souveyet
Philippe Roose
Luiz Angelo Steffenel *Editors*

# The Evolution of Pervasive Information Systems

Springer

*Editors*

Manuele Kirsch Pinheiro
Center for Research in Informatics
Pantheon-Sorbonne University
Paris, France

Carine Souveyet
Centre de Recherche en Informatique
Pantheon-Sorbonne University
Paris, France

Philippe Roose
Université de Pau
Anglet, France

Luiz Angelo Steffenel
University of Reims Champagne-Ardenne
Reims, France



ISBN 978-3-031-18175-7 ISBN 978-3-031-18176-4 (eBook)
https://doi.org/10.1007/978-3-031-18176-4



This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

# PIS: Interoperability and Decision-Making Process—A Review

**Juliana Fernandes, Lucas Oliveira, Valdemar Vicente Graciano Neto, Rodrigo Pereira dos Santos, Rafael Angarita, Sonia Guehis, and Yudith Cardinale**



## 1 Introduction

Modern organizations are recurrently pressured to collaborate to both sustain themselves in the market and form synergistic alliances that benefit the involved enterprises. Amazon[1], for instance, has created a large ecosystem involving several

Lucas Oliveira, Valdemar Vicente Graciano Neto, Rodrigo Pereira dos Santos, Rafael Angarita, Sonia Guehis, and Yudith Cardinale contributed equally to this work.

[1] https://www.bloomberg.com/graphics/2019-amazon-reach-across-markets/?leadSource=uverify%20wall.

J. Fernandes (✉)
Federal Institute of Piauí, Campo Maior, Piauí, Brazil
e-mail: juliana.fernandes@ifpi.edu.br

L. Oliveira · R. P. dos Santos
Department of Applied Informatics, UNIRIO, Rio de Janeiro, Brazil
e-mail: oliveira.l.s@edu.unirio.br; rps@uniriotec.br

V. V. Graciano Neto
Federal University of Goiás, Goiânia, Goiás, Brazil
e-mail: valdemarneto@ufg.br

R. Angarita
LISITE, ISEP, Paris, France
e-mail: rafael.angarita@isep.fr

S. Guehis
AMSADE CNRS UMR 7243, Paris Dauphine University, PSL Research University, Paris, France
e-mail: sonia.guehis@dauphine.fr

Y. Cardinale (✉)
Grupo de Investigación en Ciencia de Datos (GRID), Universidad Internacional de Valencia, Valencia, Spain
Universidad Simón Bolívar, Caracas, Venezuela
e-mail: yudith.cardinale@campusviu.es

 
M. Kirsch Pinheiro et al. (eds.), *The Evolution of Pervasive Information Systems*,
https://doi.org/10.1007/978-3-031-18176-4_7

other companies to expand their portfolio and sell products from other companies. However, each time a set of companies aim to join business agreements, they face the recurrent challenge of interoperating their information systems (IS) to enable their business processes to be connected and, for instance, to sell a product offered, delivered, and even paid to another company (i.e., it has an impact in the decision-making processes of companies involved House et al. 2014). The IEEE defines interoperability as "the ability of two or more systems or components to exchange information and to use the information that has been exchanged" (IEEE 1990). However, achieving interoperability among IS that are managerially and operationally independent is a challenging task.

AQ1

Over the years, researchers have looked for interoperability solutions from different perspectives: (i) *the software architecture perspective* to build connectors to allow the interaction of different software components; (ii) *the middleware perspective* decouple applications and services from each others by implementing common communication systems such as a service bus; (iii) the *formal methods perspective* to analyse the behavior of participating components and compute controllers to allow interoperability; and (iv) the *semantic web perspective* that focuses on providing shared ontologies describing the meaning of informatione (Bennaceur 2013). Furthermore, increasing the interoperation of different types of systems has led to the emergence of Pervasive Information Systems (PIS) conformed by IS deployed everywhere, going beyond the traditional frontiers of organizations. PIS can be seen as Systems-of-Information Systems (SoIS)[2] (Fernandes et al. 2018, 2020; Motta et al. 2017), which comprise a dynamic set of independent IS interoperating for addressing the convergent need for collaboration among enterprises and, at the same time, operating for their individual purposes. Different from subsystems context, this scenario should led IS research community and practitioners to promote interoperability, while still preserving the independence and supporting the decision-making processes of the IS involved.

The establishment of interoperability among IS is not a trivial activity and impose a diversity of requirements, such as the needs to: (i) enable spontaneous interoperability among IS, i.e., enabling temporary (or longer) cooperation links among a set of companies joined together; (ii) deal with several types of heterogeneities, namely data format and representation, hardware and software differences, and even cultural and business differences; and (iii) address the independence of constituent IS in a PIS, seen as SoIS, which allows them to join or leave the alliance at their convenience, which can make some of the interoperability links to be ephemeral. Then, PIS should not only manage the accomplishment of their main goals but also the impact of its changing nature due to the accomplishment of the goal from companies involved, which makes part of the decision-making processes.

There have been significant research efforts to provide interoperability solutions among IS, especially in the field of complex systems. However, we observed that

[2] Henceforth, the acronyms PIS and SoIS will be interchangeably used to express both singular and plural forms.

a static and focused view only on technical solutions limits the understanding of which factors and how they can solve or produce conflicts on arrangements of independent IS in SoIS. In order to address these gaps, our aim is to report the results of an investigation on the factors (i.e., technical, human, and organizational) that can answer the research question: "*Which and how factors influence interoperability in the PIS/SoIS context?*". We build upon the analysis over these three aspects following the classic triad of factors that compose any IS, as prescribed by Laudon and Laudon (Laudon and Laudon 1998), Soares and Amaral (Soares and Amaral 2014), and also the modern perspective of business ecosystems (Luz et al. 2020). We surveyed the literature over the period 1992–2022 on influence factors that can apply to interoperability among IS through a systematic mapping study method. The survey also covers a diversity of complex systems types that could be formed by IS, such as Systems-of-Systems (SoS), Heterogeneous Systems, Large-Scale Systems, and Adaptive Systems.

From more than 5000 studies retrieved, 81 were included for extracting and discussing a set of ten factors that may influence interoperability in the SoIS domain, as well as their impact in decision-making process. These factors address since the provision of technical information about IT elements (technical factor), human thinking and perceptions (human factor) until the need for harmonized business strategies (organizational factor), because management teams have to deal with a diversity of technological, human, and managerial aspects to result in an efficient communication, towards better and smart decision-making, in complex arrangements as PIS and SoIS. We present these factors as potential issues to explain how practices around interoperability need a synergy of efforts beyond technical decisions and propose some guidelines for the design of interoperability links in PIS, seen as SoIS. These interoprability factors crosscut and surpass the enterprises boundaries to create complex networks of IS combining their business processes to achieve more complex decision-making and deliver more robust services.

## 2 Background and Related Reviews

Pervasive Information Systems (PIS) is the result of the massive introduction of current IT trends and technologies into the evolving IS. Since the emergence of technologies, such as Internet of Things (IoT), Cloud Computing, Fog/Edge Computing, Big Data, and Machine Learning, the number of smart ubiquitous computing environments has increased. These ubicomp environments are complex, heterogeneous, and mobile (Hauser et al. 2017; Kourouthanassis and Giaglis 2008). As a set of IS, PIS can be seen as SoIS. SoIS is a class of complex systems formed by an arrangement of IS, whose pervasiveness is evident, since nowadays the IT evolution makes the ubiquitous computing be present in any organization. Hence, in this chapter we treat PIS as SoIS, named PIS/SoIS.

SoIS are currently defined as *an alliance among several organizations that bring their IS together to accomplish a set of goals, sharing benefits from this* *consortium* (Fernandes et al. 2019; Saleh et al. 2015). PIS/SoIS are complex systems according to the Systems Engineering Body of Knowledge (SEBoK), since they are formed by multiple independent IS working collaboratively to achieve a mutual goal (Cloutier and NJ 2017).

SoIS is a specific type of SoS (Teixeira et al. 2019) and inherits SoS characteristics (Boardman and Sauser 2006; Fernandes et al. 2020), such as: (i) **autonomy**, which is related to how a system is governed by its own rules despite external influences; (ii) **evolutionary development**, meaning the SoIS evolves as constituent IS evolve as well; (iii) **emergent behavior**, which results from the synergistic collaboration among constituent IS and from the combination of the capabilities offered to form global behaviors; (iv) **connectivity**, since constituent IS are dispersed and depend on connectivity mechanisms for communication and information sharing; (v) **interdependence**, i.e., the mutual dependence between constituent IS to accomplish goals; (vi) **diversity**, once SoIS involves different technologies, data formats, people, processes, protocols, and even interpretations and purposes; (vii) **dynamicity**, which is characterized by the ability of a SoIS to modify its own structure and composition; and (viii) **belonging**, that represents the constituent IS perception of mutual benefit among the parts. All these characteristics are commonly considered in the literature approaching PIS as well (Najar et al. 2014; Raychoudhury et al. 2013).

Dynamicity (aka dynamic or evolutionary architecture), one of the main characteristics of PIS/SoIS, considerably increases the complexity for designing and managing interoperability, once the management of interoperability links can become dynamic and transitory, impacting on the services provided by the PIS/SoIS (Neto et al. 2017). Moreover, a PIS/SoIS should also cope with *full interoperability*, which comprises the spontaneity of forming a PIS/SoIS according to needs that emerge, in a transparent manner for the user, abstracting issues, such as middleware, network, data exchange (representation and transport), and communication support details (Maciel et al. 2017; Neto et al. 2017). To achieve this, the IS should support an instantaneous interoperability with any other type of available system, exchanging information between themselves, and being able to contribute to the accomplishment of missions, i.e., main goals and subgoals (Fernandes et al. 2019).

Interoperability is usually understood from the perspective of dimensions, i.e., levels or layers, established to provide some guidance for achieving it (Kubicek and Cimander 2009; Maciel et al. 2017). The classification around these perspectives refers to what should be provided and by which technical means interoperability should be established (Kubicek and Cimander 2009). The dimensions of interoperability most commonly addressed in the literature are: (i) the **legal interoperability**, which deals with agreements or legislation by which organizations are subject to interoperate their IS; (ii) the **organizational interoperability**, which deals with why interoperating is needed; (iii) **the pragmatic**, which has been highlighted as a key requirement to enhance collaboration; (iv) the **semantic**, which deals with what is interoperating; and (v) the **technical and syntactic**, which deals with the means with which are interoperating (Kubicek and Cimander 2009; Leal 2019; Maciel et al. 2017).

Since PIS/SoIS is composed of IS, the phenomenon of "information systems interoperability" must be also perceived, implemented, managed, and studied in a sociotechnical perspective (Soares and Amaral 2014), instead of only focusing on the technical aspects of interoperability. Thus, in this chapter, we also consider three aspects on the classic triad of factors (i.e., technical, human, and organizational) that compose any IS, as prescribed by Laudon and Laudon (Laudon and Laudon 1998), Soares and Amaral (Soares and Amaral 2014), and also the modern perspective of business ecosystems (Luz et al. 2020). As *technical factors*, we can consider elements associated with hardware and software components, networks and devices that facilitate machine-to-machine communication. As *human factors*, we consider the relationships that affect collaboration among operators who interact in technological environments (Brown 2010; Handley 2014). Finally, as *organizational factors* we consider inter- or intra-organizational connections, including interoperation of business processes for forming alliances and providing new services (Cagnin and Nakagawa 2021; Luz et al. 2020; Soares and Amaral 2014).

Over the years, studies have addressed specific aspects of interoperability in different sorts of arrangements of systems especially investigating technical interoperability. Leal (2019) present a literature review to study existing Interoperability Assessment (INAS) approaches which serve to identify potential interoperability problems and possible solutions. The key finding of this work are the following: the lack of INAS approaches addressing the performance of interoperation; the lack of INAS approaches taking into account multiple layers and concerns of the enterprise; the lack of best practices to improve interoperability based on the INAS results; and the lack of digital tools for supporting the whole or part of the assessment process. To do this analysis, Leal (2019) consider the semantic layer of interoperability concerning the format and semantics of information, the technical layer that covers applications and infrastructures; the organisational layer referring to the way in which systems align their processes, responsibilities and expectations; and the legal layer englobing legislations.

House et al. (2014) bring discussions beyond technical concerns. The work presents inherent complexity and dynamic nature of the major incident task environment. They discuss about different organisations that have different cultures and values that need to interoperate to deal with major incident environment. In this case, they suggest research on the factors of diversity that impact emergency organisations' social identity is lacking and further understanding needs to be developed on network governance of crisis events.

How decision-making processes benefit from interoperability has been analysed by some studies. Rezaei et al. (2014) group the interoperability factors into four granularity levels to compare e-business interoperability frameworks. The first granularity level of interoperability includes data, process, rules, objects, software systems, and cultural interoperability. The second level considers knowledge, services, social networks, and electronic identify interoperability. The third and fourth granularity levels are dedicated to cloud interoperability and ecosystem interoperability, respectively. In their comparative study, they highlight that technical, syntactic, semantic, and organizational levels of interoperability are the most considered in the revised frameworks, whose issues belong to the first and second granularity levels. Indeed, decision models in these frameworks are mainly defined in terms of data, knowledge, communication process, rules, and software systems. The interoperability issues in the third (cloud interoperability) and fourth (ecosystems interoperability) granularity levels have not been supported in these ancient frameworks, but in more recent works they play an important roll, since they could have a positive impact in the decision-making process in PIS/SoIS.

Fernandes et al. (2018) bring some factors that may affect interoperability in SoIS to discuss technical, human, and organizational factors that influence interoperability. However, the study presented in Fernandes et al. (2018) does not explore the real influence of factors in the SoIS interoperability in depth. On our study, we transcend the discussion on interoperability in complex systems by discussing not only technical aspects that influence on the establishment of interoperability links among IS but also human, and organizational factors that influence the interoperability in PIS/SoIS, and the impact on the decision-making processes. Such triad comply with the traditional view of IS and advances the state of the art by gathering the existent evidence on technical factors and also adding other factors. That is the main difference among the works. Next section discusses the research method.

## 3 Systematic Research Process

The research method we applied to perform the review follows the protocol based on the guidelines of Kitchenham and Charters (2007) for systematic mapping studies (SMS). Three phases were followed to perform this mapping: (1) planning; (2) conduction; and (3) analysis of the results. The research goal of this Goal-Question-Metric (GQM) (Basili 1992) mapping was defined as: *analyze* interoperability *with the purpose of* characterizing *with respect to* influence factors *from the point of view of* researchers *in the context of* complex software-intensive systems, as PIS/SoIS. The main research question (RQ) that drives this research is: "*Which and how factors influence interoperability in the PIS/SoIS context?*". Other derived questions also compose this research in order to answer the main question. The rationale is the need of identifying Information Technology (IT) artifacts that are commonly used for providing interoperability and can apply in PIS/SoIS domain. Artifacts mean constructs (vocabulary and symbols), models (abstractions and representations), methods (algorithms and practices), and instances (implemented and prototype systems) (Hevner et al. 2008). Figure 1 presents a research protocol summary. The scientific libraries used to search for the studies were *Scopus*[3], *ScienceDirect*[4], *ISI*

[3] http://www.scopus.com.

[4] http://www.sciencedirect.com.

| | | |
|---|---|---|
| **Research questions** | | (RQ1) Which has been done to address interoperability that may be used in PIS/SoIS? |
| | | (RQ2) Which technical, human and organizational factors influence interoperability in the PIS/SoIS context? |
| | | (RQ3) How do technical factors influence interoperability and may affect the PIS/SoIS context? |
| | | (RQ4) How do human factors influence interoperability and may affect the PIS/SoIS context? |
| | | (RQ5) How do organizational factors influence interoperability and may affect the PIS/SoIS context? |
| | | (RQ6) How interoperability and decision-making are related in the PIS/SoIS context? |
| **Search string** | **Population** | ("interop* AND decision-making") **AND** |
| | **Intervention** | ("systems of system*" OR "systems-of-system*" OR "system of information system*" OR "system-of-information-system*" OR "systems of information system*" OR "systems-of-information-system*" OR "Heterogeneous System*" OR "Large Scale System*" OR "Adaptive System*" OR "Pervasive Information Systems") |
| **Search strategy** | | Scopus, ScienceDirect, ISI Web of Science, IEEE, Engineering Village, ACM + Snowballing (backward) |
| **Inclusion criteria** | | - to discuss factors that influence on interoperability; OR to propose or applies a solution for interoperability in **intervention;** OR to discuss how interoperability and decision making are related. |
| **Exclusion criteria** | | - is secondary study; OR is similar study to another reporting the same results, in which the most recent was chosen for the analysis; OR is specific about interoperability between database systems, specific components or network protocols AND not between different IS; OR mentions interoperability, but the approach is not specifically focused on it; OR is not accessible, the authors did not respond to the study request, or the researchers' institutional IP does not give access to the library; OR is not written in English; OR is not directed related to the state-of-the-art of interoperability; OR proposes only solutions for subsystems; OR is an erratum (Corrigendum); OR is a conference preface; OR is an editorial preface. |
| **Study type** | | Primary Studies. |

**Fig. 1** Protocol summary

*Web of Science*[5], *IEEE*[6], *Engineering Village*[7], and *ACM Digital Library*[8]. They are the most important repositories for research in computer science (Afonso et al. 2020). In addition, these digital libraries also encompass studies relevant to IS domain.

On step 1, the electronic search was run using search string. The retrieved studies were stored in Parsifal.[9] Adaptations for each library can be checked on a report generated by Parsifal tool.[10] On step 2, Parsifal supported us to remove duplicate studies. On step 3, the first filter was applied, i.e., inclusion and exclusion criteria after reading titles, abstracts, and keywords. On step 4, we applied the second filter by reading introduction and conclusion. On step 5, the backward snowballing technique was applied to complete the search (Wohlin 2014). Inclusion and exclusion criteria were applied to the studies retrieved in steps 3 to 5 of the selection process. On step 6, the third filter (reading of full text) was applied on the selected studies. Finally, on step 7, data was extracted from the selected studies. The number of included and excluded studies at each step is shown in Fig. 2.

We based our analysis procedure to investigate influence factors on textual analysis following a method of four steps: (1) define the theoretical lens; (2) define the categorization; (3) analyze the discussions of the studies; and (4) identify and extract the factors and identify if the studies address interoperability and decision-



[5] http://www.isiknowledge.com.
[6] http://ieeexplore.ieee.org.
[7] http://www.engineeringvillage.com.
[8] https://dl.acm.org/.
[9] https://parsif.al/.
[10] http://bit.ly/Report-SMS-2020.

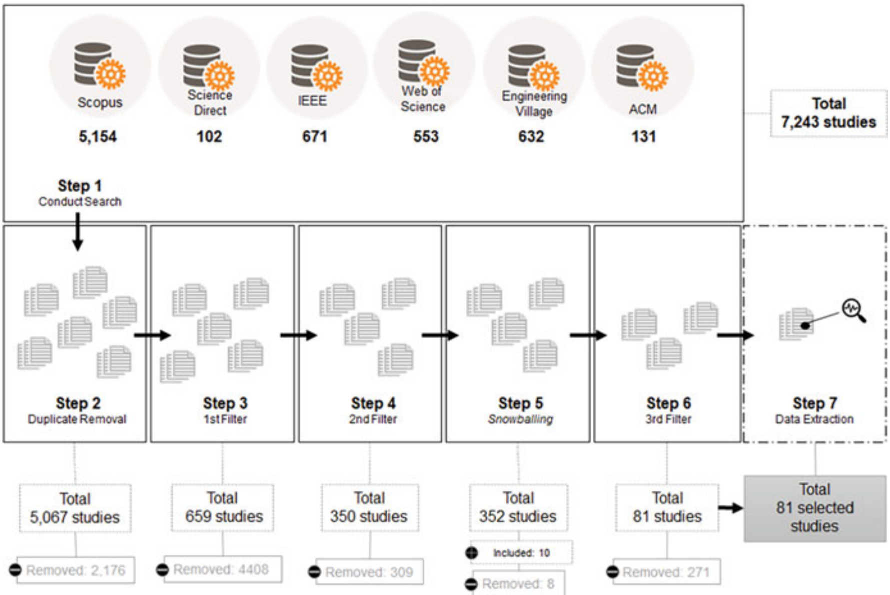


**Fig. 2** Number of included and excluded papers during the selection process

making. In order to identified factors and decision-making issues, we investigate the analysis and discussion sections from the included studies. The rationale for this decision is that generally in those sections authors often expose details about the application of the solutions reported in the research. We based our textual analysis using codes to assign factors of each relevant quote, expression, phrase or word from the extracted data, based on the open coding procedures for qualitative analysis (Corbin and Strauss 2014).

Data were extracted from the 81 selected primary studies. This study recovered publications from 1992 to 2022 regarding it. RQs were answered from data extracted from the selected published studies.

## 4 IT Artifacts for Interoperability and Their Implications in PIS/SoIS

Obtained results help us to answer RQ1 (*Which has been done to address interoperability that may be used in PIS/SoIS?*). The research field about interoperability has popularity in the literature. Indeed, the number of publications recovered in the first stages of this study can confirm our perception (7,243 publications, see Fig. 2). However, researches specific about PIS/SoIS domain are still incipient, ratifying the result of the study conducted by Teixeira et al. (2019) on the status quo of

PIS/SoIS. As such, we seek to recover similar types of complex systems structures to find artifacts that are commonly used for providing interoperability that can be extended for PIS/SoIS. We analysed the artifacts considering IS characteristics in a PIS/SoIS (autonomy, evolutionary development, emergent behavior, connectivity, interdependence, diversity, dynamicity, and belonging—see Sect. 2). In the IS interoperability scenario, despite involved entities should be able to operate together to promote the image of a whole, their independence and autonomy should be maintained (Lueders 2005); thus, allowing them to preserve their own identity and way of working (Lueders 2005; Soares and Amaral 2014). Based on these reflections, if we consider a PIS/SoIS, we have to be critical of artifacts that have a tightly coupled nature because the constituent IS in a SoIS can belong to different organizations. Even if the artifact has a loosely coupled nature, it is necessary to check if its manager agrees to follow some recommendations for interoperability of the PIS/SoIS arrangement. In Table 1, we summarize the identified artifacts, their sources (studies), level of interoperability they can provide, and if the artifacts can be extended for supporting interoperability in PIS/SoIS.

We provide an additional view about artifacts identified by categorizing them according to the strategies to provide some level of interoperability for the PIS/SoIS context (Fig. 3). Such strategies can be used for the production of knowledge, such as (i) **conceptual** and (ii) **descriptive**; and also for (iii) **software production**, which can directly **affect the decision-making processes**. The production of knowledge through some approach or paradigm can nourish the design of **conceptual** artifacts, such as architectural models, meta-model, conceptual or reference model, business process. Conceptual artifact represents the idea of what we aim to build technically. The **descriptive** artifacts includes framework, guidelines, recommendations, set of indicators or techniques. A descriptive artifact represents conceptual elements that can be prototyped through software-intensive solutions. **Software production** represents the final product developed to accomplish real business demands.

Each type of artefact allows some level of interoperability to be established. Interoperability levels are represented in this study through the dimensions discussed in Sect. 2, which are also known as layers. Software production with its technological artifacts feeds the syntactic and technical dimensions. On the other hand, descriptive and conceptual artifacts are able to feed more than one dimension. Both can feed the semantic and intra/inter-organizational interoperability dimension directly or feed them through the pragmatic layer. In conjunction, these artifacts become essential for "anytime, anywhere" decision-making processes of IS implemented "everywhere", as in PIS/SoIS.

## 5 Ten Factors Influencing PIS/SoIS Interoperability

In this section, we answer RQ2 (*Which technical, human, and organizational factors influence interoperability in the PIS/SoIS context?*). We identified 10 technical, human, and organizational factors (Fig. 4). We present these factors discussing how

**Table 1** Identified artifacts and their source, level of interoperability, and if they can be extended for supporting interoperability in PIS/SoIS

| | Artifact identified | Source (included publication) | Level of interoperability | Can be extended for PIS/SoIS? |
|---|---|---|---|---|
| t50.2 | Agent-based platform | Mendes et al. (2018), Papageorgiou et al. (2021) | Technical and syntactic | ✓ |
| t50.3 | Mediator system | Benaben et al. (2018), Touzi et al. (2008) | Technical | ✓ |
| t50.4 | Prototype application | Agostinho and Jardim-Goncalves (2015) | Technical | ✓ |
| t50.5 | Architectural model | Bicocchi et al. (2018), Vargas et al. (2018), Mazzetti and Nativi (2012), Song et al. (2011), Zarour et al. (2011), Kuehn et al. (2011), Diallo et al. (2010), Neaga and Henshaw (2010), Mantzana and Koumaditis (2010), Dividino et al. (2018), Buhalis and Leung (2018), Dolk et al. (2012), Kazemzadeh et al. (2010) | Semantic | ✓ |
| t50.6 | Meta-model | Chapurlat and Daclin (2012), Jardim-Goncalves et al. (2010), Chen et al. (2008), Rosener et al. (2004) | Semantic | ✓ |
| t50.7 | Conceptual model | Zeinali et al. (2016), Soares and Amaral (2014), Athanasopoulos et al. (2006) | Semantic | ✓ |
| t50.8 | Maturity model | Guédria et al. (2015) | Organizational | |
| t50.9 | Macro-process model | Fouletier et al. (1997) | Organizational | ✓ |
| t50.10 | Reference model | Jamoussi et al. (2017), Marlowe et al. (2012), Jardim-Goncalves et al. (2012) | organizational | ✓ |

(continued)

**Table 1** (Continued)

| | | | | |
|---|---|---|---|---|
| t53.1 | Framework | Espadinha-Cruz and Grilo (2019), Mordecai et al. (2016), Zacharewicz et al. (2017), Zdravković et al. (2017), Coutinho et al. (2016), Weichhart et al. (2016), Chalmeta and Pazos (2015), Cuenca et al. (2015), Li et al. (2013), Ostadzadeh et al. (2015), Tripathi et al. (2013), Wang et al. (2010), Camara et al. (2010), Widergren et al. (2010), Qureshi et al. (2010), Pyarelal et al. (2004), Chituc et al. (2009), Wang et al. (2009), Barchetti et al. (2009), Yahia et al. (2009), Agostinho and Jardim-Goncalves (2009), Bittencourt et al. (2009), Ullberg et al. (2009), Ambrosio and Widergren (2007), Whitman and Panetto (2006), Hollenbach and Alexander (1997), Hollenbach and Alexander (1997), Mazzetti et al. (2022), Buhalis and Leung (2018), Kalatzis et al. (2019) | Technical, semantic, organizational | ✓ |
| t53.2 | Guidelines/ recommendations | Yahia et al. (2009), Chen et al. (2008), Arakelian et al. (2022), Kalatzis et al. (2019) | Semantic | ✓ |
| t53.3 | Methods | Giachetti et al. (2019), Ullberg et al. (2012), Cornu et al. (2012), Naudet et al. (2010), Ford et al. (2009), Perrone and Finkelstein (2007), Rhodes and Wilson (1992) | Organizational | |
| t53.4 | Methodologies | Daclin et al. (2016), Deniaud et al. (2012), Agostinho et al. (2011) | Organizational | |
| t53.5 | Ontology | Rosener et al. (2004), Mazzetti et al. (2022), Lima et al. (2022), Dividino et al. (2018) | Semantic | ✓ |
| t53.6 | Set of indicators | Billaud et al. (2015), Muller (2009) | Technical, organizational | ✓ |
| t53.7 | Set of strategies | Agostinho et al. (2016), Klischewski et al. (2011), Lewis et al. (2008), Mills and Ruston (1990) | Organizational | ✓ |
| t53.8 | Set of techniques | Anderson and Boxer (2008) | Organizational | ✓ |
| t53.9 | Thesaurus/vocabulary | Naudet et al. (2008), Yaacoubi et al. (2006), Navigli and Velardi (2005) | Semantic | ✓ |

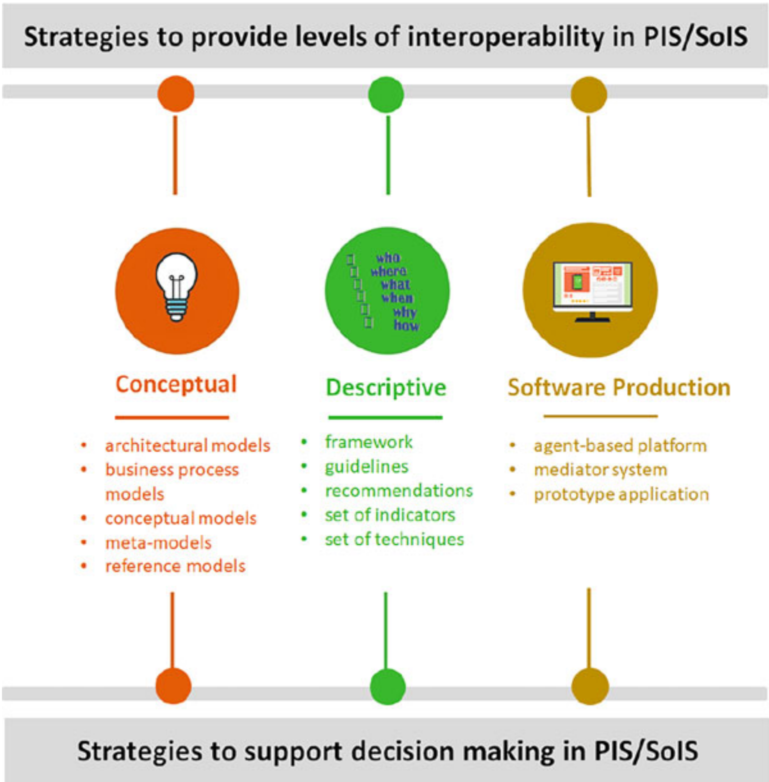


**Fig. 3** Strategies to provide levels of interoperability in PIS/SoIS

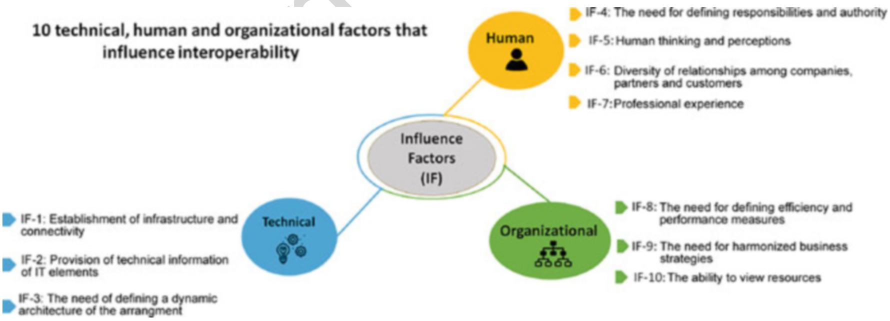


**Fig. 4** Set of influence factors for interoperability in PIS/SoIS

each one influences interoperability in SoIS, more especifically in RQ3, RQ4, and RQ5 (*How technical, human, and organizational factors influence interoperability in PIS/SoIS?*).

### 5.1 Technical Factors

The first factor is **establishment of infrastructure and connectivity (IF-1)** (Ambrosio and Widergren 2007; Athanasopoulos et al. 2006; Chapurlat and Daclin 2012; Chen et al. 2008; Chituc et al. 2009; Diallo et al. 2010; Espadinha-Cruz and Grilo 2019; Giachetti et al. 2019; Hollenbach and Alexander 1997; Jardim-Goncalves et al. 2012; Klischewski et al. 2011; Muller 2009; Naudet et al. 2010; Neaga and Henshaw 2010; Ostadzadeh et al. 2015; Ullberg et al. 2012; Wang et al. 2010; Zarour et al. 2011; Zeinali et al. 2016). This factor includes structural aspects (Ullberg et al. 2012) as a platform (Chituc et al. 2009; Klischewski et al. 2011; Mazzetti and Nativi 2012) or system (Klischewski et al. 2011). An infrastructure for interoperability is often composed of physical connectivity (Ambrosio and Widergren 2007; Buhalis and Leung 2018; Dolk et al. 2012; Kalatzis et al. 2019; Muller 2009; Papageorgiou et al. 2021), such as cables, connectors (Ambrosio and Widergren 2007; Muller 2009), network connectors, and protocols for communication links. Studies indicate the use of protocols, such as SOAP[11] or REST[12] (Benaben et al. 2018; Ullberg et al. 2012; Wang et al. 2010). The type of interface that will be used is a relevant aspect for the connectivity of the arrangement (Chapurlat and Daclin 2012; Chituc et al. 2009; Mantzana and Koumaditis 2010; Mordecai et al. 2016; Naudet et al. 2010; Neaga and Henshaw 2010; Song et al. 2011; Vargas et al. 2018; Weichhart et al. 2016). In this case, layers of user interface and web services have been identified as ways to facilitate interoperations (Lima et al. 2022; Song et al. 2011; Weichhart et al. 2016).

In addition, some type of definition of common operating environments was discussed as an aspect of influence for interoperability (Athanasopoulos et al. 2006; Billaud et al. 2015; Touzi et al. 2008; Wang et al. 2010). This is because it can facilitate automated data exchange between heterogeneous platforms in terms of operating systems or hardware systems and programming languages (Chen et al. 2008; Rosener et al. 2004; Wang et al. 2010). This factor is important so that some level of technological compatibility can be established when a more automated level of technical interoperability is desired.

Technical interoperability supports electronic interaction between constituent systems, capitalizing on hardware, software, and firmware infrastructure (Buhalis and Leung 2018; Espadinha-Cruz and Grilo 2019; Mordecai et al. 2016). Therefore, **IF-1** influences interoperability by treating the interconnectivity layer of the systems through the interfaces that enable the use of services (Agostinho et al. 2011; Bicocchi et al. 2018; Billaud et al. 2015; Camara et al. 2010; Chituc et al. 2009; Cuenca et al. 2015; Diallo et al. 2010; Guédria et al. 2015; Jardim-Goncalves et al. 2010; Klischewski et al. 2011; Navigli and Velardi 2005; Ostadzadeh et al. 2015; Touzi et al. 2008; Whitman and Panetto 2006; Yaacoubi et al. 2006).



[11] SOAP (Simple Object Access Protocol) is a network protocol for exchanging structured data among nodes.

[12] REST (Representational State Transfer) defines characteristics for building web applications.

**Provision of technical information of IT elements (IF-2)** Mordecai et al. (2016), Vargas et al. (2018), Weichhart et al. (2016), Chapurlat and Daclin (2012), Song et al. (2011), Neaga and Henshaw (2010), Mantzana and Koumaditis (2010), Naudet et al. (2010), Chituc et al. (2009), Mills and Ruston (1990) include metadata information (e.g., structural, syntactic, and semantic data formats) that facilitate the integration of information around the heterogeneity of data models (Chituc et al. 2009; Cornu et al. 2012; Diallo et al. 2010; Kalatzis et al. 2019; Kazemzadeh et al. 2010; Wang et al. 2010), ontologies (Dividino et al. 2018; Lima et al. 2022; Mazzetti et al. 2022; Zarour et al. 2011), meta-model (Cornu et al. 2012), and frameworks (Anderson and Boxer 2008; Mazzetti et al. 2022). However, for this information supply to be carried out with better precision, some studies defend the need for technical functions and procedures by which the responsible professionals can benefit (Agostinho and Jardim-Goncalves 2009; Billaud et al. 2015; Chapurlat and Daclin 2012; Chen et al. 2008; Chituc et al. 2009; Mordecai et al. 2016; Muller 2009; Soares and Amaral 2014; Zeinali et al. 2016). This factor is related to media exchange and standardization procedures when exchanging and analyzing functional compatibility or requirements (Billaud et al. 2015; Fouletier et al. 1997). Hence, the need for articulation among IS comes as an aspect that directly assists the need to reconfigure components so that there is adaptability (Deniaud et al. 2012; Jardim-Goncalves et al. 2012) and conformity (Muller 2009) among systems. of an arrangement.

In turn, providing of technical information from the IT elements (**IF-2**) involved in the interoperation influences decisions about design of interoperability links by considering information, such as data structures, i.e., attributes and formats (Giachetti et al. 2019). An arrangement of PIS/SoIS being subject to changing formation implies that new data formats, semantics, procedures, and technologies are continuously adopted (Billaud et al. 2015; Fouletier et al. 1997; Soares and Amaral 2014), such as data anonymization for preserving the privacy of patients in the context of health IS (Lima et al. 2022). The existence of functions and technical procedures that support the emergence demands of PIS/SoIS is one way.

The third factor is related to the **need of defining a dynamic architecture of the arrangement (IF-3)** (Agostinho et al. 2016; Billaud et al. 2015; Buhalis and Leung 2018; Camara et al. 2010; Chen et al. 2008; Giachetti et al. 2019; Ullberg et al. 2009). In this case, types of model-oriented architecture (MDA, i.e., model-driven architecture) or high-level architecture (HLA, i.e., high-level architecture) were mentioned by Barchetti et al. (2009) and Touzi et al. (2008). Also, a list of negative technical factors has been identified in some publications. In Kuehn et al. (2011), authors highlight as critical points: (i) lack of redundancy in system arrangements; (ii) limited resistance of equipment during emergencies that hinder the execution of the arrangement; and (iii) lack of coordinated planning or contingency plans to deal with disaster situations that may require the full operation of an interoperable systems arrangement.

In (Agostinho et al. 2016), the definition of architecture is seen as one of the pillars that sustain the achievement of business and sustainable interoperability. In this case, the need of defining the dynamic arrangement architecture **(IF-3)** is a factor that influences interoperability in the context of PIS/SoIS given the the need of a loosely coupled IS design (Klischewski et al. 2011). If, on the one hand, the use of common environments/interfaces favors the desired stability in the context of interoperability (Billaud et al. 2015), in PIS/SoIS it is necessary to pay attention to the fact that, depending on the belonging characteristic of the IS to SoIS, the use of common environments can cause harm.

### *5.2 Human Factors*

One of human factors identified is regarding to the **need for defining responsibilities and authority (IF-4)** (Chen et al. 2008; Espadinha-Cruz and Grilo 2019; Mills and Ruston 1990) especially to manage the operation of the system arrangements that are formed to achieve a greater objective. This definition is related to the roles or functions that members of a technical team can play to interoperate systems. Someone responsible for specifying tasks or rules to fulfill a mission, goal or objective is an example of a definition of responsibility (Arakelian et al. 2022; Benaben et al. 2018; Chalmeta and Pazos 2015; Chen et al. 2008; Daclin et al. 2016; Mazzetti et al. 2022; Mills and Ruston 1990). It was observed that there are studies that envision the importance of establishing roles for the stakeholders involved in the formation of systems arrangements that need to interoperate (Chituc et al. 2009; Mendes et al. 2018; Mordecai et al. 2016; Vargas et al. 2018; Wang et al. 2009). According to the study presented in Rhodes and Wilson (1992), it is important to stress that the overall performance of a supersystem such as this relies just as much on human actions as it does upon the performance of its technical components and in the final analysis the effectiveness can only be judged by the extent to which the operators manage to coordinate their activities (Rhodes and Wilson 1992). Some roles have been identified in publications on SoS and may contribute to discussions in the PIS/SoIS domain, such as constituent IS owners, beneficiaries, operators, and SoS users (Mendes et al. 2018; Mordecai et al. 2016; Vargas et al. 2018); SoS manager (Mendes et al. 2018); and SoS developer (Vargas et al. 2018).

Interoperability can be seen or simplified by some researchers or practitioners as an integration question. However, this study shows us this is just one of the concern for being considered. The human level is discussed in literature by Soares and Amaral on the Information Systems interoperability (ISI) domain (Soares and Amaral 2014). For ISI, the human perspective should be considered when designing, implementing, and managing interoperability (Soares and Amaral 2014). As such, human factors may influence interoperability in the PIS/SoIS domain.

The need for defining **responsibilities and authority** (**IF-4**) influences interoperability in PIS/SoIS as the relationships among stakeholders that hold IS that are interoperating (or that will interoperate) come from diverse organizational contexts and cultures. The definition of responsibilities and roles in a PIS/SoIS is valid both for the management team (authority that will benefit from the formation of the arrangement) and for the technical team allocated to operationalize the formed

SoIS. Definition of an authority also directly influences the type of SoIS that will be formed (Directed or Acknowledged). In this case, depending on the power exercised by the authority, a PIS/SoIS will be more or less subject to unwanted emerging behaviors.

We noticed that the aspects related to **human thinking and perceptions (IF-5)** are commonly discussed in the theories of human communication (Littlejohn and Foss 2010). This factor is related to the expectations and feelings that stakeholders have when making IS available to collaborate in an arrangement (Chen et al. 2008).

On the other hand, **human thinking and perceptions** (**IF-5**) influence interoperability because it is generally planned in business scenarios based on the expectations of the stakeholders of a SoIS and each stakeholders of constituent IS (Buhalis and Leung 2018). The main objective of a PIS/SoIS is driven by the perception of a person or management team about the capabilities that a set of existing constituent IS can offer to the arrangement (Lima et al. 2022).

**Diversity of relationships among companies, partners and customers (IF-6)** is a factor of influence existing in the context of interoperability (Hollenbach and Alexander 1997). This diversity is related to how people, processes, technologies, and operational demands are orchestrated in a context of interoperability (Anderson and Boxer 2008; Arakelian et al. 2022; Mazzetti et al. 2022). Aspects related to human communication and the way in which collaborations among members of technical teams, companies, partners, and customers or users are materialized tend to be in the concerns of diverse business domains (Agostinho and Jardim-Goncalves 2015; Agostinho et al. 2011, 2016; Benaben et al. 2018; Bittencourt et al. 2009; Chalmeta and Pazos 2015; Chituc et al. 2009; Diallo et al. 2010; Guédria et al. 2015; Klischewski et al. 2011; Kuehn et al. 2011; Mordecai et al. 2016; Muller 2009; Naudet et al. 2010; Navigli and Velardi 2005; Pyarelal et al. 2004; Qureshi et al. 2010; Touzi et al. 2008; Zdravković et al. 2017; Zeinali et al. 2016).

Aspects of human communication involve communication among individuals and groups (Agostinho et al. 2011), as interactions of people at intra or inter-organizational boundaries (Bittencourt et al. 2009; Diallo et al. 2010; Muller 2009; Naudet et al. 2010; Neaga and Henshaw 2010). In turn, aspects of collaboration among stakeholders (Klischewski et al. 2011) expose diversity of relationships that may arise from social behavior that influences how the articulations between IS will be made (Agostinho et al. 2016; Soares and Amaral 2014; Ullberg et al. 2009). Aspects of culture, such as language differences (Agostinho et al. 2016; Marlowe et al. 2012; Ostadzadeh et al. 2015; Soares and Amaral 2014) between technical or managerial teams can hinder or facilitate aspects of human communication and collaboration.

The nature of PIS/SoIS contemplates interorganizational aspects formed by the diversity of relationships among companies, partners, and customers **(IF-6)** (Hollenbach and Alexander 1997). This factor influences interoperability as the communication aspects and human collaboration are coordinated. This coordination should favor the process of knowledge and understanding related to the data and information to be exchanged. This knowledge in IS interoperability is obtained based on the meanings provided by a human being (Zdravković et al. 2017).

Another influencing factor for interoperability in PIS/SoIS is related to **professional experience (IF-7)** (Agostinho et al. 2016; Chapurlat and Daclin 2012; Coutinho et al. 2016). This factor is related to the competence of people who work with interoperability (Agostinho et al. 2011; Guédria et al. 2015). In general, managers expect professionals to have the ability to use the information exchanged, that is, operate it, interpret it, transform it, and extract stakeholder requirements (Billaud et al. 2015; Ullberg et al. 2012). The desirable experience involves the ability to interpret data for semantic understanding (Agostinho et al. 2011; Ambrosio and Widergren 2007; Lewis et al. 2008), as well as for the extraction and formalization of domain knowledge expressed by specialists (Navigli and Velardi 2005).

On the other hand, professional expertise (**IF-7**) influences interoperability in PIS/SoIS as the quality of the services provided by the arrangement depends on the professional profile of the management (or technical) team developed throughout the career. An example of this influence is the inconsistencies that must be noticed and corrected by professionals when checking, reevaluating, or redesigning the interoperability links (Navigli and Velardi 2005). Furthermore, as semantic understanding is important for the context of interoperability, this factor can influence rules that govern the definition of concepts and the relationships between multiple IS (Ambrosio and Widergren 2007).

### *5.3 Organizational Factors*

We identified organizational factors regarding the **need for defining measures of effectiveness and performance (IF-8)** (Billaud et al. 2015; Chen et al. 2008; Giachetti et al. 2019; Ullberg et al. 2009; Zacharewicz et al. 2017). Measures can be formed by metrics or indicators, but they are not limited to that. Studies indicate that performance measures may include the duration/time of interoperation (Agostinho et al. 2016; Billaud et al. 2015; Camara et al. 2010; Chen et al. 2008), cost of interoperation (Agostinho et al. 2016; Chen et al. 2008), integrity (Billaud et al. 2015), quality of interoperation (Billaud et al. 2015), data latency (Camara et al. 2010), and meeting IT requirements (Ullberg et al. 2009).

The need for defining **efficiency and performance measures** (**IF-8**) influences interoperability given that the purpose of identifying measures as part of the interoperability analysis is to determine whether the interoperability is sufficient to support missions in the context of SoS/PIS/SoIS (Giachetti et al. 2019). In turn, performance measures are commonly used in corporate cultures as a business strategy to improve results. Thus, defining performance measures influences interoperability because this type of information can help to measure the ability to maintain an adaptable arrangement to the mutations to which an environment such as SoS/PIS/SoIS is subject (Billaud et al. 2015). These mutations are related to inputs and outputs of constituent IS that make up a SoIS.

The **need for harmonized business strategies (IF-9)** (Cuenca et al. 2015; Espadinha-Cruz and Grilo 2019; Kuehn et al. 2011; Ostadzadeh et al. 2015; Ullberg et al. 2009) is a factor that influences decisions on interoperability if considered in the design of systems arrangements (Cuenca et al. 2015; Espadinha-Cruz and Grilo 2019; Kuehn et al. 2011; Ostadzadeh et al. 2015; Ullberg et al. 2009). Issues involving differences in organizational policies and practices pose challenges in the orchestration of business (Marlowe et al. 2012; Zarour et al. 2011). Policies and practices depend on organizational cultures (Anderson and Boxer 2008; Bittencourt et al. 2009; Chituc et al. 2009; Cuenca et al. 2015; Ford et al. 2009; Klischewski et al. 2011; Navigli and Velardi 2005; Touzi et al. 2008; Ullberg et al. 2009) that are influenced by the diversity of nationalities, languages, and linguistics. These diverse aspects also generate challenges in semantic dimension (Cuenca et al. 2015; Touzi et al. 2008). In view of the technical and human diversity involved (IF-2 and IF-6) and to deal with this organizational factor, the harmonization of the business network aiming at collaboration among companies or organization units should be sought (Agostinho et al. 2011; Chituc et al. 2009; Jardim-Goncalves et al. 2010; Touzi et al. 2008). In addition, we observed that this factor (IF-9) creates challenges related to the right of access and right to ownership of information (Chituc et al. 2009; Ullberg et al. 2009). Therefore, the definition and specification of inter-organizational collaborative activities is necessary (Chituc et al. 2009). On the other hand, political aspects also influence interoperability because it involves economics, regulation, and the need to seek compliance with legislation (Ambrosio and Widergren 2007; Chapurlat and Daclin 2012; Chituc et al. 2009; Espadinha-Cruz and Grilo 2019; Kuehn et al. 2011; Pyarelal et al. 2004; Ullberg et al. 2009; Widergren et al. 2010).

The factor related to the **need for harmonized business strategies (IF-9)** can both influence business-to-business connectivity **(IF-1)** and can assist in obtaining better performance of the arrangement **(IF-3)** (Navigli and Velardi 2005). SoIS can present complex interorganizational relationships due to the diversity of organizational cultures to which it is subject. Therefore, harmonized strategies can influence an organization's interest in maintaining or not its IS participating in a formed arrangement.

We identified that the **ability to view resources (IF-10)** is an influencing factor because the management team may not have control over technical or human resources to be allocated to achieve interoperability (Benaben et al. 2018; Cuenca et al. 2015; Perrone and Finkelstein 2007; Ullberg et al. 2009; Widergren et al. 2010). This happens due to the managerial and operational autonomy of the IS that make up a PIS/SoIS. In this sense, care must be taken to ensure that the specification and allocation of interoperability requirements is performed properly (Agostinho et al. 2011; Ambrosio and Widergren 2007; Camara et al. 2010; Cuenca et al. 2015; Daclin et al. 2016; Giachetti et al. 2019; Jamoussi et al. 2017; Neaga and Henshaw 2010; Ostadzadeh et al. 2015; Tripathi et al. 2013; Widergren et al. 2010). This factor influences interoperability in PIS/SoIS by including programmatic aspects (Ostadzadeh et al. 2015), such as: aligned operations and procedures, analysis activities and definition of missions, goals, objectives (Camara et al. 2010;

Cuenca et al. 2015; Espadinha-Cruz and Grilo 2019; Ostadzadeh et al. 2015; Perrone and Finkelstein 2007), and business needs (Agostinho et al. 2011; Ambrosio and Widergren 2007; Bicocchi et al. 2018; Cuenca et al. 2015; Daclin et al. 2016; Jamoussi et al. 2017; Neaga and Henshaw 2010; Ostadzadeh et al. 2015; Tripathi et al. 2013; Weichhart et al. 2016; Widergren et al. 2010).

In addition, we identified a list of negative organizational factors on some publications. The lack of mediation results in difficulty in solving problems produces degrees of uncertainty or low levels of confidence around interoperations (Cuenca et al. 2015). Another negative point is the constant occurrence of new restrictions of products and processes to the IS because they cause the need for interference in the interoperability links (Marlowe et al. 2012). Moreover, non-transparent processes between organizations participating in an arrangement cause incompatibilities ranging from techniques issues to business interests (Athanasopoulos et al. 2006; Pyarelal et al. 2004).

**The ability to view resources (IF-10)** influences interoperability in SoIS as a manager or management team in this domain may not have full access to the resources of all the IS involved. Thus, the specification and allocation of interoperability requirements (Perrone and Finkelstein 2007; Ullberg et al. 2009) requires SoIS management to be able to collect information with semantic understanding (Athanasopoulos et al. 2006; Ullberg et al. 2009; Widergren et al. 2010). Through this understanding, one or more business models are produced (Zarour et al. 2011) and strategic alignment can be achieved (Klischewski et al. 2011).

### *5.4 Impact of Interoperability Factors in the Decision-making Processes*

The expansion of IS beyond the traditional frontiers of organizations, thus deployed everywhere, has fostered the creation of complex systems as PIS/SoIS. Such unbounded deployment represents the possibility of enlarging decision-making processes beyond traditional IS and the possibility of deeply observing the impact of technical, human, and organizational factors in which such processes occur. Hence, this new "anytime, anywhere" perspective for decision-making processes makes interoperability from the three perspectives discussed in the previous sections a key aspect to consider. Most studies revised, implicitly state the need of considering decision-making and dependencies among interoperability perspectives. Some of them, explicitly detail which specific interoperability factors directly impact on decision-making processes. In this section, we respond the RQ6 (*How interoperability and decision-making are related in PS/SoIS context?*).

Technical factors, as **establishing infrastructure and connectivity (IF-1)** are considered to provide interoperability to support decision-making. The studies presented in Jardim-Goncalves et al. (2010) and Agostinho and Jardim-Goncalves (2009) provide an interconnectivity layer of systems through the interfaces that enable the use of services, for monitoring and decision support. The proposal presented in Rosener et al. (2004) facilitates automated data exchange by integrating a decisional model and a technical aspects model that includes persistence, communication, security, etc. In Papageorgiou et al. (2021), it is proposed an interoperability approach to support the interactions among unmanned aerial vehicles by the context of airborne radar surveillance to support decision-making during missions, operations, and analysis. In Buhalis and Leung (2018), authors propose an architecture of smart hospitality systems supported on big data analytics, artificial intelligence, cloud services, sensors, and ambient ecosystem. The study described by Kalatzis et al. (2019) treats the semantic interoperability for IoT platforms in support of decision making. In Dolk et al. (2012), authors propose a Global Information Network Architecture, a smart mobile systems deployed in support of organizational decision-making objectives, based on a model-based architecture and component-based development. In Zarour et al. (2011), authors propose a P2P-based architecture to allow interoperability among distributed heterogeneous systems, and the sharing of information towards decision making. In Mazzetti and Nativi (2012), authors propose a Service Oriented Architecture (SOA) towards the interoperability of Earth Observation Systems, which include sensors providing real-time information.

For decision-making, data, information, and knowledge are key elements that must provide high levels of interoperability. Semantic and pragmatic information help to reduce the gap between data and policy- and decision-making goals that are actionable knowledge for decision-makers. Thus, the goal of linking the data managed by the constituent IS is to provide comprehensive data summaries and visualisations that can support technicians, professionals, managers, politicians, etc., in their decision-making process. Thus, formal representation of knowledge, as ontologies have been developed to provide **technical information of the IT elements involved (IF-2)** that support decisional models (Agostinho and Jardim-Goncalves 2009; Dividino et al. 2018; Jardim-Goncalves et al. 2010; Kalatzis et al. 2019; Kazemzadeh et al. 2010; Lima et al. 2022; Mazzetti et al. 2022; Rosener et al. 2004; Weichhart et al. 2016; Zarour et al. 2011). In Weichhart et al. (2016) and Zarour et al. (2011), authors propose approaches based on agents, an ontology of concepts and relations allowing organizational interoperability, and a P2P-based architecture to allow the interoperability among distributed heterogeneous systems, and the sharing of information towards decision making. The core component of the sustainable interoperability framework proposed in Jardim-Goncalves et al. (2010) and Agostinho and Jardim-Goncalves (2009) is a knowledge base supported on harmonized ontologies that represent environmental knowledge and human preferences. A model-based ontology of interoperabilty problems in IS is presented in Rosener et al. (2004), which integrates a decisional model and technical aspects model. In Mazzetti et al. (2022), authors propose an ontology for annotating resources with their type, role, and relations in the knowledge generation process for decision-making. In Lima et al. (2022), an approach towards data integration and sharing among health IS to support the construction of evidence-based decision making tools is proposed; this approach is based on web services and on an ontology considering clinical concepts, the multiple existing IS, and concepts related to diseases, diagnostics, therapies, and patients with an emphasis on data anonymization for preserving their privacy.

In Dividino et al. (2018), it is defined an ontology for ocean-related decision-making in military environments, in which data comes in the form of continuous streams from multiple IS; this ontological data architecture is used for real-time data representation, integration, and querying over a multitude of heterogeneous data streams and visualisations. Authors in Kalatzis et al. (2019) treat the semantic interoperability for IoT platforms in support of decision making, by providing a solution towards the support of uniform data exchange and adapts, extends data model, API standards enabling, and the use of IoT data analytics and intelligent decision making. In Kazemzadeh et al. (2010), authors present a proposition of a novel knowledge management framework for a Clinical Decision Support System. They address the issues of data and knowledge interoperability by adopting health-care and data mining modeling standards in order to assist healthcare personnel to improve the quality of clinical practice.

Novel technologies, such as big data analytics, artificial intelligence, and cloud computing are being included to achieve smart decision-making systems supported in **dynamic architecture of the arrangement (IF-3)**, as in Klischewski et al. (2011), Buhalis and Leung (2018), and Kalatzis et al. (2019). In Klischewski et al. (2011), authors propose a SOA to provide the government with improved data about the population for decision making purposes.

Multiple studies focused on interoperability and decision-making coincide in considering the three human factors—i.e., **defining responsibilities and authority (IF-4)** (Arakelian et al. 2022; Espadinha-Cruz and Grilo 2019; Mazzetti et al. 2022), **human thinking and perceptions (IF-5)** (Chen et al. 2008; Lima et al. 2022), and **diversity of relationships among companies, partners, and customers (IF-6)** (Arakelian et al. 2022; Klischewski et al. 2011; Marlowe et al. 2012; Mazzetti et al. 2022).

In Espadinha-Cruz and Grilo (2019), authors propose a business interoperability decomposition framework to support the analysis of interoperability conditions in buyer- supplier dyads. Authors in Chen et al. (2008) highlight the importance of considering expectations and feelings of stakeholders in the decisional models of IS available to collaborate in an arrangement. Authors in Mazzetti et al. (2022) acknowledge that achieving complete interoperability towards policy- and decision-making goals requires a dialogue among the different worlds inhabited by different people. In Arakelian et al. (2022), authors study the obstacles to interoperability in the context of Human Resource IS (HRIS) with a focus on the use case of the Uganda HRIS; they map existing HRIS and the administrative processes and data flows of three decision-making use cases (recruitment and deployment of health workers, salary payments, and performance management) and suggest some directions to tackle the HRIS interoperability barriers, such as sharing and integration among HRSI that enables decision-making with a focus on preserving user privacy. In Lima et al. (2022), authors highlight the need to address interoperability from a socio-technical perspective in the sense of engaging different actors, such as users and developers into the conception of new solutions and strategies, remaining in the domain of user experience regarding the final solution. In Marlowe et al. (2012), authors state that, since decision making mechanisms are typically oriented towards reaching consensus, interoperability becomes a matter of how to interact instead of just linking entities and operations, thus, collaborating entities must focus on semantic and personal features to facilitate those interactions and improve decision making processes.

Since decision-making implies the aggregation of business, managers, and technical goals, in some how, all studies analysing the influence of interoperability on decision-making consider the organizational factors: the need for defining **efficiency and performance measures (IF-8)** (Buhalis and Leung 2018; Daclin et al. 2016; Dolk et al. 2012; Jamoussi et al. 2017; Kalatzis et al. 2019; Mazzetti et al. 2022; Rosener et al. 2004), the need for **harmonized business strategies (IF-9)** (Agostinho and Jardim-Goncalves 2009; Espadinha-Cruz and Grilo 2019; Jardim-Goncalves et al. 2010; Klischewski et al. 2011; Lima et al. 2022; Marlowe et al. 2012; Rosener et al. 2004; Zarour et al. 2011), and the **ability to view resources (IF-10)** (Daclin et al. 2016; Kazemzadeh et al. 2010; Klischewski et al. 2011; Mazzetti et al. 2022; Rosener et al. 2004; Tripathi et al. 2013; Zarour et al. 2011). In Espadinha-Cruz and Grilo (2019), it is proposed a framework that generates new scenarios, proposed to decision-makers, in order to scale-up cooperation between buyer and supplier, achieve optimal interoperability, and increase performances. The study presented in Jamoussi et al. (2017) proposes a guidance-based approach for enhancing the e-government interoperability, by elaborating a Requirement Model (modeling e-government interoperability in business term) and after that modeling the satisfaction (align these specific requirements with the needs of requesters). From decision making's point of view, this approach allows ministries to identify their problems in terms of interoperability and select solutions adapted to their needs. Authors in Daclin et al. (2016) and Rosener et al. (2004) propose enterprise interoperability frameworks based on interoperability measurements, such as availability, scalability, feasibility, and cost, to select and combine solutions suitable to the enterprises involved. Similarly, the physical/empirical model of the proposed framework in Mazzetti et al. (2022) includes indicators and indices to allow decision makers to reduce the gap between data and goals.

In Tripathi et al. (2013), differences in organizational policies and practices are tackled by the implementation of a Multi Agent System to support the organizational, syntactic, and semantic interoperability. This harmonization via the collaboration and coordination of software agents provides the basis of common agreements and decision making. In Klischewski et al. (2011), the proposed SOA allows planning strategies towards implementing e-government interoperability, hence, multiple stakeholders with independent agendas can interact with top-down approaches to reach governing public information infrastructure. In Jardim-Goncalves et al. (2010) and Agostinho and Jardim-Goncalves (2009), the decision support system is a key component relayed on an ontological knowledge base to allow capturing the environment and relating human choices and preferences, towards the harmonized enterprise interoperability. In Marlowe et al. (2012), authors highlight the importance of complex and harmonized collaboration supported on interoperability; they propose a strategy interoperability level to help in the creation of high level goals and objectives of participating IS, aligned with the collaborative business plan in the context of decision-making. In Buhalis and Leung (2018), the use of big data and cloud computing allows the decisional support system to generate different scenarios for services in hotels, thus decision makers can adjust the services in real-time.

The decision engine proposed in Kalatzis et al. (2019) automatically assesses how critical an emergency situation is (early wildfire detection), based on a predefined scale (i.e., low, medium, high), supported on data interoperability of the IoT and social media services; it supports the cross application domain reasoning, through the homogenisation of information and automated identification of an emergency situation. In the healthcare domain, PIS/SoIS are common (Kazemzadeh et al. 2010; Lima et al. 2022; Zarour et al. 2011), in which interoperability must ensure a consistent interaction among the constituent IS, as well as providing facilities to visualise results, resources, in the support of decision-making.

## 6 Key Findings and Reflections

Given the current definition of SoIS, that also includes the definition of PIS (Fernandes et al. 2019; Motta et al. 2017), we can consider that one of the main challenges in the context is to coordinate interest in maintaining the arrangement formed to fulfill the main goal of PIS/SoIS, while the essence of each participant constituent IS is preserved. This concern makes us deal with interoperability in PIS/SoIS not only as an integration phenomenon. The integration phenomenon on interoperability of IS has been discussed by Soares and Amaral (2014). They point out that the existence of a high level of integration among IS may not be the most appropriate solution for any given business environment, since it may significantly compromise the agility or flexibility, and responsiveness of operations (Aubert et al. 2003; Lee and Myers 2004; Pavlou and Singletary 2002), especially when in the arrangement are involved IS from different organizations. From this point of view, this idea can be extended to the context of PIS/SoIS, given the need to preserve the autonomy of the constituent IS, to deal with the distribution of IS, the emerging behavior, evolutionary development, and dynamic architecture of PIS/SoIS.

The **establishment of infrastructure and connectivity (FI-1)** is a factor that affects interoperability in PIS/SoIS, because the **autonomy** of the constituent IS can limit the alternatives that a SoIS manager has to make the arrangement feasible. At this point, the establishment of infrastructure in PIS/SoIS must consider that the weak **belonging** that these IS may have in relation to the arrangement is a barrier to connectivity.

The technological **diversity** of the constituent IS resembles any arrangement of heterogeneous systems. However, unlike other arrangements, PIS/SoIS deals with **dynamism**, which causes an IS to leave the arrangement (Salado 2015).

In that case, the establishment of PIS/SoIS infrastructure and connectivity is not static as it would be in a formation of Federated Information Systems (FIS), for instance (Busse et al. 1999). This sort of arrangement does not prioritize the preservation of constituent autonomy. PIS/SoIS deals with the emergent behavior influenced by the evolutionary development of the IS that, when working to fulfill their particular objectives, they can not prioritize PIS/SoIS. The **interdependence** of the constituent IS in relation to the PIS/SoIS is weaker, because the arrangement must be designed by counting that an IS can leave the arrangement at the decision of the IS stakeholder.

**Providing of technical information of the IT elements involved (IF-2)** is a factor that affects interoperability in PIS/SoIS because the IS **autonomy** can make it difficult to fully understand the technical information. The fact that IS belonging to PIS/SoIS is not clear and mandatory as it happens in an Enterprise Resource Planning (ERP) may not be enough for the management of PIS/SoIS. For IF-1 to be efficient for the running of the arrangement, IF-2 is important for PIS/SoIS manager to have full knowledge in relation to the diversity of the IS involved. PIS/SoIS management also has the guarantee of IF-2 due to the dynamism of this arrangement.

The **need for defining a dynamic architecture (IF-3)** is a factor that affects interoperability, especially because the IS **autonomy** leads to the abandonment of the arrangement's constituents. In this sense, the architectural planning of a PIS/SoIS that takes into account the **diversity** of IS that initially make up the arrangement may be subject to constant changes. **Emerging behavior** and constant **evolutionary development** mean that IF-3 is adapted to dynamism necessary for this domain.

In PIS/SoIS, human influences on interoperability, such as **the need for defining responsibilities and authority (IF-4)**, represent a reality because the integration provided by a requirement is not a rule as occurs in the federation of systems. Defining responsibilities and authority becomes necessary in PIS/SoIS because the existence of an actor who acts for the governance of the arrangement can be a point of balance in relation to the **interdependence** of the IS that have autonomy.

**Human thinking and perceptions (IF-5)** is a factor that influences interoperability because it affects the design of interoperability links. We consider that thinking and perceptions direct the needs for formation of PIS/SoIS arrangements are forged. At this point, human perceptions go along with thoughts. This occurs from the moment that the way in which human beings abstract the real world, based on their personal experiences and experiences, can envision the formation of arrangements. **Connectivity** and **interdependence** of IS in a PIS/SoIS will be planned initially based on IF-5, since different constituent IS may not be directly related to the PIS/SoIS stakeholder. This factor can be considered as a guide for the desired **emerging behaviors** and **evolutionary development** to be a priority.

The **diversity of relationships among companies, partners and customers (IF-6)** affects interoperability in PIS/SoIS, as it is reflected in the **autonomy** of the constituent IS. PIS/SoIS **connectivity** must be planned considering the technological **diversity** of the IS that will be part of the arrangement. It may not be trivial for a PIS/SoIS stakeholder to deal with actors that cannot be predicted during the design of interoperability links, given the lack of prior knowledge of the relationships of partnerships and customers that are part of the IS universe. PIS/SoIS can be formed to serve a business domain as an educational one, for instance; however, they may need IS from other domains to achieve the main objective, such as urban mobility.

**Professional experience (IF-7)** is a factor that affects interoperability in the PIS/SoIS domain, as it makes the process of designing interoperability links more complex without a minimum experience in practical work with interoperability. In conventional contexts where an IT professional works in the sector development of an organization, interoperability occurs on demand. On the other hand, PIS/SoIS is a domain whose premise is interoperability. Therefore, professional knowledge about different approaches and technologies used for IS connectivity must exist so that IF-5 and IF-6 can lead the professional to forge arrangements.

**The need for defining efficiency and performance measures (FI-8)** affects the interoperability in PIS/SoIS due to the **diversity** and **autonomy** of the constituent IS. In this case, the governance of a dynamic arrangement as PIS/SoIS can be undermined without there being no way to measure the effectiveness and performance of the arrangement in fulfilling the mission. The entry and exit of the constituent IS within a PIS/SoIS can come spontaneously from the holders of these systems, although also due to the influence of PIS/SoIS management.

**The need for harmonized business strategies (IF-9)** is a factor that influences interoperability in PIS/SoIS, mainly because the management team has to deal with IF-6. Harmonized strategies are necessary because PIS/SoIS is a type of arrangement that may involve constituent IS from different domains that, in order to communicate, may require PIS/SoIS stakeholder interference.

The **ability to view resources (IF-10)** is a factor that affects interoperability in PIS/SoIS, especially if the design of interoperability links involves IS from different organizations. PIS/SoIS stakeholder may not have a direct relationship with the IS management team. Therefore, the ability to view all IS resources can be impaired. Having knowledge about the resources that an IS may be able to provide to PIS/SoIS is important, especially in the planning of emerging behavior and evolutionary development of the arrangement.

Most works acknowledge the key role of interoperability in decision making. Indeed, decision making in PIS/SoIS relies heavily on making sense of data coming from heterogeneous IS which offer interfaces that can differ regarding the names and types of the data they provide or consume, and the granularity and ordering of the operations they interface provide (**IF-1**); hence, semantic interoperability is a key aspect in this regard (**IF-2**). Some of the works we reviewed propose interoperability approaches based on ontologies, which can provide a precise description of all relevant concepts and relationships found in the involved IS. These ontologies can contain concepts regarding decision making such as data, decision criteria, and decision types. Domain experts are the ones who build and maintain ontologies, which can be efficient in IS that are more or less static, whose properties do not change continuously. There is still the need for researching how to build and maintain ontologies for decision making in PIS that continuously evolve and which properties emerge on-the-fly.

Moreover, decision making is a complex process that deserves to have more attention in the context of interoperability of PIS/SoIS . Indeed, decisions are required to be coherent, that is, by relying on common information and reaching consensus (particularly in the context of collective decisions) (**IF-3**); thus, PIS/SoIS should act as one confronted with different inputs and stimuli. This is challenging due to the complexity and dynamicity of PIS/SoIS and the multiple and heterogenous technical, human, and organizational factors that influence interoperability, and hence, influence decision making processes.

Several fields have considered the importance of interoperability in the decision-making process: healthcare, airborne radar surveillance, smart hospitality systems, smart mobile systems, earth observation systems, military environment, clinical decision support, e-government, human resource IS, buyer-supplier relationship, real-time hotels services, critical emergency situation detection. The common decision-making strategies to all these fields are based mainly on frequently used terms: exchange, communication, knowledge generation, harmonized information, negotiation, dialogue, consensus, interaction between partners, a clear and homogenized representation of data, information and knowledge, security. New technologies as big data analytics, cloud computing, IoT, domain-specific ontologies, multi agent systems, artificial intelligence, social media services, real-time process and streaming data flow are solutions to strengthen communication and harmonize knowledge. All these aspects are directly related to the integration of all interoperabilty factors, emphasizing of course, human (**IF-4, IF-5, IF-6**) and organizational factors (**IF8, IF-9, IF-10**).

To finish, we propose some guidelines for the design of interoperability links in PIS/SoIS, and thus better support the decision-making processes, based on the influencing factors. The influence that technical, human, and organizational elements can have on the interoperability of complex systems, such as PIS/SoIS, is a determining factor in achieving good results regarding meeting the goals of forming an IS arrangement. A PIS/SoIS manager is an actor who provides the tools necessary for the team can successfully orchestrate the achievement of PIS/SoIS main goal, such as:

- *Clear and accurate planning of PIS/SoIS goals:* Increasing the chances of generating the expected results requires clear technical functions and procedures that converge towards the fulfillment of the purposes of a PIS/SoIS, that is, the main objective and secondary objectives. In this case, collect information IT elements (IF-2) helps this need;
- *Business strategy planning:* Human and organizational factors for PIS/SoIS management are important because they involve elements capable of guiding business strategies for establishing alliances, even if temporary. PIS/SoIS deal with inter-organizational alliances whose diversity of cultures may be present. Therefore, the search by harmonized business strategies (IF-9) is essential for the formation of inter-organizational alliances. This harmonization is a factor

that converges to the need to specify and allocate interoperability requirements. On the other hand, the complexity of inter or intra-organizational relationships may be linked to factors such as political aspects. In this case, managing these relationships is complex in itself. Factors such as the ability to view resources may be limited in an inter-organizational alliance (IF-10);

- *Interoperability links management:* To increase the chances of establishing connectivity among constituent IS in PIS/SoIS, an articulation around these IS is necessary. This connectivity depends on the use of appropriate types of interfaces to guarantee the autonomy of the constituent IS (IF-2). However, it is worth mentioning that the definition of the architecture of the arrangement in PIS/SoIS must take into account the dynamic (changeable) nature. Therefore, this factor requires that the provision of technical information from the IT elements involved and the existing technical functions and procedures for the operationalization of interoperability be reviewed;
- *Definition of performance and effectiveness measures:* In technical terms, the need for definition of the performance measures (IF-8) is an important factor in helping to measure the ability of an arrangement to remain viable or adaptable to emerging behaviors to which PIS/SoIS is subject. In business or organizational terms, the definition of effectiveness measures can influence the constituent IS stakeholders in decisions to interoperate or leave from the PIS/SoIS arrangement. Effectiveness measures such as costs, benefits or needs (Sobkowski and Freedman 2013) can be used to demonstrate to stakeholders the benefits of their IS collaborating in the PIS/SoIS arrangement.
- *Incorporate decisional models into the process of modeling interoperability:* Interoperability constitutes one methodological approach to achieve consistent enterprise-wide decision-making. Semantic features can be resolved with harmonized business strategies (IF-9) and domain-specific ontologies (IF-2). Big data, multi agent systems enhance the reconciliation of policies and practices (IF-2). Artificial intelligence and big data analysis can be solutions to knowledge generation and homogenized visualizations (IF-10). Service oriented architecture, social media services, real-time processing, and streaming data flow improve consensus and communication challenges.

In short, seeking to understand the human and organizational factors that are part of this domain can help who glimmer the formation of an arrangement PIS/SoIS seek answers on how best to conduct activities, create arrangement running strategies, or even increase assertiveness in the search for potential IS candidates to compose an arrangement.

## 7 Final Remarks and Future Directions

This chapter present a study of influence factors for interoperability in PIS, considered as SoIS (PIS/SoIS), and also provides theoretical and practical implications considering their impact in decision-making processes. We selected 81 studies for discussion and from them we identified ten technical, human, and organizational influence factors that affect interoperability, which in turn impact the decision-making process in the PIS/SoIS domain. The systematic mapping studies (SMS) protocol is another contribution because researchers can benefit from a schema for a research wide-open field as interoperability. In addition, this SMS brings a set of papers about the understanding of interoperability and its impact in decision-making processes in PIS/SoIS. The state-of-art of interoperability is been widely addressed in literature given the wide range of studies retrieved in the first steps, in this case, researchers can also use this chapter to conduct a tertiary study about interoperability and decision-making based on the literature revised in this chapter. The main aspects we extract from this study are summarized in the following points:

- Interoperability in PIS/SoIS characterizes as a capability to seek the synergy among constituents to accomplish the PIS/SoIS main goal (and subgoals), while the constituent IS keep their operation for the fulfillment of their own individual goals;
- Dealing with a PIS/SoIS domain calls us to notice which technical, human, and organizational factors that can influence the design or analysis of interoperability given its business nature;
- Each choice of technology (technical factor) will bump into a human factor that is important in an intra/inter-organizational context (organizational factor);
- Who glimmer the formation of a PIS/SoIS is exposed to the need to join the requirements necessary to form an interoperated PIS/SoIS arrangement considering that some concerns also may be inherited from different organizational contexts;
- Interoperability and decision-making are closely linked in the PS/SoIS context. The focus is on the harmonization of business-strategies as well as the exchange and the visualization of information, data and knowledge. Several technical, human, and organizational factors influence interoperability, and hence, influence decision making processes.

The results of this extensive investigation bring some implications for researchers. As such, results may be affected by incompleteness of study search, bias on study selection, inaccuracy of data extraction and data synthesis, high amount of publications recovered. Nevertheless, these results provide some impressions and common aspects in the literature reviewed that can be a good input to continue the research in this direction. We deduce for example that the immediate future hold for practitioners to deal with interoperability in PIS/SoIS should consider that although each influence factor (IF) is grouped into three categories to answer research questions, these factors are not dissociated on interoperability in this domain. We are conducting the analysis and discussions around surveys with industry practitioners on the frequent challenges of interoperability in practice and what has been done to mitigate the problems faced. Knowing the influence factors for interoperability provide to team manager recommendations in favor of reasonable technology support. In this light, PIS/SoIS interoperability among managerial and operationally independent IS can be better designed to yield impactful solutions for emergency demands or optimized business goals, supported on improved decision-making processes.

**Acknowledgments** This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001 and FAPERJ (Proc. 211.583/2019).

## References

Afonso, A.T.Q., Chueri, L.V., d. Santos, R.P.: Business process management in digital and software ecosystems: A systematic mapping study. In: IEEE Internat. Conf. on Software Architecture Companion, pp. 226–233 (2020)

Agostinho, C., Jardim-Goncalves, R.: Dynamic business networks: a headache for sustainable systems interoperability. In: OTM Confederated International Conferences" On the Move to Meaningful Internet Systems", pp. 194–204 (2009). Springer

Agostinho, C., Jardim-Goncalves, R.: Sustaining interoperability of networked liquid-sensing enterprises: A complex systems perspective. Annual Reviews in Control 39, 128–143 (2015)

Agostinho, C., Jardim-Gonçalves, R., Steiger-Garcao, A.: Using neighboring domains towards setting the foundations for enterprise interoperability science. In: Symp. on Collaborative Enterprises (2011)

Agostinho, C., Ducq, Y., Zacharewicz, G., Sarraipa, J., Lampathaki, F., Poler, R., Jardim-Goncalves, R.: Towards a sustainable interoperability in networked enterprise information systems: trends of knowledge and model-driven technology. Computers in industry 79, 64–76 (2016)

Ambrosio, R., Widergren, S.: A framework for addressing interoperability issues. In: Power Eng. Society General Meet., pp. 1–5 (2007)

Anderson, W.B., Boxer, P.J.: Modeling and analysis of interoperability risk in systems of systems environments. In: The Journal of Defense Software Engineering (2008)

Arakelian, M., Brown, A.N., Collins, A., Gatt, L., Hyde, S., Oketcho, V., Olum, S., Schurmann, A., Siyam, A.: Getting human resource information systems right: A case presentation of uganda (2022)

Athanasopoulos, G., Tsalgatidou, A., Pantazoglou, M.: Interoperability among heterogeneous services. In: IEEE Internat. Conf. on Services Computing, pp. 174–181 (2006)

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

Barchetti, U., Guido, A.L., Mainetti, L.: A conceptual framework for business driven integration. In: Internat. Conf. for Internet Technology and Secured Transactions,(ICITST), pp. 1–6 (2009). IEEE

Basili, V.R.: Software modeling and measurement: the goal/question/-metric paradigm. Technical report (1992)

Benaben, F., Truptil, S., Mu, W., Pingaud, H., Touzi, J., Rajsiri, V., Lorre, J.-P.: Model-driven engineering of mediation information system for enterprise interoperability. Internat. Journal of Computer Integrated Manufacturing **31**(1), 27–48 (2018)

Bennaceur, A.: Dynamic synthesis of mediators in ubiquitous environments. PhD thesis, Université Pierre et Marie Curie-Paris VI (2013)

Bicocchi, N., Cabri, G., Mandreoli, F., Mecella, M.: Dealing with data and software interoperability issues in digital factories. In: Trans disciplinary Engineering Methods for Social Innovation of Industry 4.0, pp. 13–22. IOS Press, New York (2018)

Billaud, S., Daclin, N., Chapurlat, V.: Interoperability as a key concept for the control and evolution of the system of systems (sos). In: Internat. IFIP Working Conf. on Enterprise Interoperability, pp. 53–63 (2015)

Bittencourt, I.I., Costa, E., Braz, L., Pacheco, H., Dicheva, D.: Supporting interoperability between web-based educational systems. In: IEEE Frontiers in Education Conf., pp. 1–6 (2009)

Boardman, J., Sauser, B.: System of systems - the meaning of 'of'. In: Internat. Conf. on System of Systems Engineering, pp. 1–6. IEEE, Los Angeles, USA (2006)

Brown, A.: Human interoperability and building partnership capacities: Introduction to human interoperability. Human interoperability and netcentric series (2010)

Buhalis, D., Leung, R.: Smart hospitality—interconnectivity and interoperability towards an ecosystem. Internat. Journal of Hospitality Management 71, 41–50 (2018)

Busse, S., Kutsche, R.-D., Leser, U., Weber, H.: Federated information systems: Concepts, terminology and architectures. Forschungsberichte des Fachbereichs Informatik **99**(9), 1–38 (1999)

Cagnin, M.I., Nakagawa, E.Y.: Towards dynamic processes-of-business processes: a new understanding. Business Process Management Journal **27**(5), 1545–1568 (2021)

Camara, M., Ducq, Y., Dupas, R.: Methodology for prior evaluation of interoperability. In: Working Conf. on Virtual Enterprises, pp. 697–704 (2010). Springer

Chalmeta, R., Pazos, V.: A step-by-step methodology for enterprise interoperability projects. Enterprise Infor. Systems **9**(4), 436–464 (2015)

Chapurlat, V., Daclin, N.: System interoperability: definition and proposition of interface model in mbse context. IFAC Proceedings Volumes **45**(6), 1523–1528 (2012)

Chen, D., Doumeingts, G., Vernadat, F.: Architectures for enterprise integration and interoperability: Past, present and future. Computers in Industry **59**(7), 647–659 (2008)

Chen, D., Vallespir, B., Daclin, N.: An approach for enterprise interoperability measurement. In: Internat. Workshop on Model Driven Information Systems Engineering: Enterprise, User and System Models, vol. 341, pp. 1–12 (2008)

Chituc, C.-M., Azevedo, A., Toscano, C.: A framework proposal for seamless interoperability in a collaborative networked environment. Computers in industry **60**(5), 317–338 (2009)

Cloutier, R.J., NJ, H.: The Guide to the Systems Engineering Body of Knowledge (SEBoK), v. 1.9.1. BKCASE Editorial Board. https://www.sebokwiki.org/ (2017)

Corbin, J., Strauss, A.: Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory. Sage publications, (2014)

Cornu, C., Chapurlat, V., Quiot, J.-M., Irigoin, F.: Interoperability assessment in the deployment of technical processes in industry. IFAC Proceedings Volumes **45**(6), 1246–1251 (2012)

Coutinho, C., Cretan, A., Da Silva, C.F., Ghodous, P., Jardim-Goncalves, R.: Service-based negotiation for advanced collaboration in enterprise networks. Journal of Intelligent Manufacturing **27**(1), 201–216 (2016)

Cuenca, L., Boza, A., Ortiz, A., Trienekens, J.J.: Conceptual interoperability barriers framework (CIBF). In: Internat. Conf. on Enterprise Information Systems, vol. 2, pp. 521–531 (2015)

Daclin, N., Chen, D., Vallespir, B.: Developing enterprise collaboration: a methodology to implement and improve interoperability. Enterprise Information Systems **10**(5), 467–504 (2016)

Deniaud, I., Quiguer, S., Breuil, D., Le Maguet, P., Lecourt, J., Pourcel, C., Ruault, J.-R., Somat, A.: Interoperability dimensions for multimodal mobility management. IFAC Proceedings Volumes **45**(6), 1529–1536 (2012)

Diallo, S.Y., Padilla, J.J., Tolk, A.: Why is interoperability bad: towards a paradigm shift in simulation composition. In: Fall Simulation Interoperability Workshop, pp. 20–24 (2010)

Dividino, R., Soares, A., Matwin, S., Isenor, A.W., Webb, S., Brousseau, M.: Semantic Integration of Real-time Heterogeneous Data Streams for Ocean-related Decision Making. STO, NATO/OTAN (2018)

Dolk, D., Anderson, T., Busalacchi, F., Tinsley, D.: Gina: System interoperability for enabling smart mobile system services in network decision support systems. In: Hawaii Internat. Conf. on System Sciences, pp. 1472–1481 (2012)

Espadinha-Cruz, P., Grilo, A.: The business interoperability decomposition framework to analyse buyer-supplier dyads. Computers in Industry 109, 165–181 (2019)

Fernandes, J.C., Neto, V.V.G., Santos, R.P.D.: Interoperability in systems-of-information systems: A systematic mapping study. In: Brazilian Symposium on Software Quality, pp. 131–140 (2018). ACM

Fernandes, J., Ferreira, F., Cordeiro, F., Graciano Neto, V.V., Pereira dos Santos, R.: A conceptual model for systems-of-information systems. In: IEEE Internat. Conf. on Information Reuse and Integration for Data Science, pp. 364–371 (2019)

Fernandes, J., Ferreira, F., Cordeiro, F., Graciano Neto, V.V., Santos, R.: How can interoperability approaches impact on systems-of-informationsystems characteristics? In: Brazilian Symposium on Information Systems (2020)

Ford, T.C., Colombi, J.M., Jacques, D.R., Graham, S.R.: A general method of measuring interoperability and describing its impact on operational effectiveness. The Journal of Defense Modeling and Simulation **6**(1), 17–32 (2009)

Fouletier, P., Park, K.H., Favrel, J.: An inter-organizational information system design for virtual enterprises. In: IEEE Internat. Conf. on Emerging Technologies and Factory Automation, pp. 139–142 (1997)

Giachetti, R., Wangert, S., Eldred, R.: Interoperability analysis method for mission-oriented system of systems engineering. In: Internat. Systems Conf., pp. 1–6 (2019). IEEE

Guédria, W., Naudet, Y., Chen, D.: Maturity model for enterprise interoperability. Enterprise Information Systems **9**(1), 1–28 (2015)

Handley, H.A.: A network model for human interoperability. Human factors **56**(2), 349–360 (2014)

Hauser, M.M., Günther, S.A., Flath, C., Thiesse, F.: Designing pervasive information systems: A fashion retail case study. In: ICIS (2017)

Hevner, A.R., March, S.T., Park, J., Ram, S.: Design science in information systems research. Management Information Systems Quarterly **28**(1), 6 (2008)

Hollenbach, J.W., Alexander, W.L.: Executing the dod modeling and simulation strategy—making simulation systems of systems a reality. In: Conf. on Winter Simulation, pp. 948–954 (1997)

House, A., Power, N., Alison, L.: A systematic review of the potential hurdles of interoperability to the emergency services in major incidents: recommendations for solutions and alternatives. Cognition, technology & work **16**(3), 319–335 (2014)

IEEE: IEEE Standard Glossary of Software Engineering Terminology. IEEE Std 610.12-1990, 1–84 (1990)

Jamoussi, Y., Al-Khanjari, Z., Kraiem, N.: A guidance based approach for enhancing the e-government interoperability. Journal of Information and Organizational Sciences **41**(1), 35–56 (2017)

Jardim-Goncalves, R., Steiger-Garcao, A., Agostinho, C.: Sustainable systems' interoperability: A reference model for seamless networked business. In: Internat. Conf. on Systems, Man and Cybernetics, pp. 1785–1792 (2010). IEEE

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

Kalatzis, N., Routis, G., Marinellis, Y., Avgeris, M., Roussaki, I., Papavassiliou, S., Anagnostou, M.: Semantic interoperability for iot platforms in support of decision making: An experiment on early wildfire detection. Sensors **19**(3) (2019)

Kazemzadeh, R.S., Sartipi, K., Jayaratna, P.: A framework for data and mined knowledge interoperability in clinical decision support systems. Int. J. Heal. Inf. Syst. Informatics 5, 37–60 (2010)

Kitchenham, B., Charters, S.: Guidelines for performing systematic literature reviews in software engineering 2 (2007)

Klischewski, R.: Architectures for tinkering? contextual strategies towards interoperability in e-government. Journal of theoretical and applied electronic commerce research **6**(1), 26–42 (2011)

Kourouthanassis, P.E., Giaglis, G.M.: Pervasive Information Systems. ME Sharpe, New York (2008)

Kubicek, H., Cimander, R.: Three dimensions of organizational interoperability. European Journal of ePractice 6, 1–12 (2009)

Kuehn, A., Kaschewsky, M., Kappeler, A., Spichiger, A., Riedl, R.: Interoperability and information brokers in public safety: an approach toward seamless emergency communications. Journal of theoretical and applied electronic commerce research **6**(1), 43–60 (2011)

Laudon, K.C., Laudon, J.P.: Information Systems and the Internet. Harcourt College Publishers, (1998)

Leal, G.: Decision support for interoperability readiness in networked enterprises. PhD thesis, Université de Lorraine (2019)

Lee, J.-C., Myers, M.: The challenges of enterprise integration: cycles of integration and disintegration over time. ICIS, 75 (2004)

Lewis, G.A., Morris, E., Simanta, S., Wrage, L.: Why standards are not enough to guarantee end-to-end interoperability. In: Internat. Conf. on Composition-Based Software Systems, pp. 164–173 (2008)

Li, W., Liu, K., Liu, S.: Semiotics in interoperation for information systems working collaboratively. In: Internat. Joint Conf. on Knowledge Discovery, Knowledge Engineering, and Knowledge Management, pp. 370–386 (2013). Springer

Lima, V.C., Bernardi, F.A., Domingues, M., Kritski, A.L., Rijo, R.P.C.L., Alves, D.: A computational infrastructure for semantic data integration towards a patient-centered database for tuberculosis care. Procedia Computer Science 196, 434–438 (2022)

Littlejohn, S.W., Foss, K.A.: Theories of Human Communication. Waveland press, New Mexico (2010)

Lueders, H.: Interoperability and open standards for egovernment services. In: 1st Intern. Conf. on Interoperability of Enterprise Software-Applications, Switzerland (2005)

Luz, P.B.V., Fernandes, J., Valença, G., Santos, R.P.d.: Exploring sustainability in real cases of emerging small-to-medium enterprises ecosystems. In: Santos, R.P.d., Maciel, C., Viterbo, J. (eds.) Software Ecosystems, Sustainability and Human Values in the Social Web, pp. 42–59. Springer, Cham (2020)

Maciel, R.S.P., David, J.M.N., Claro, D.B., Braga, R.: Full interoperability: Challenges and opportunities for future information systems. I GranDSI-BR, 107 (2017)

Mantzana, V., Koumaditis, K., Themistocleous, M.: Is soa a solution to healthcare information systems interoperability? In: Internat. Conf. on Information Technology and Applications in Biomedicine, pp. 1–4 (2010). IEEE

Marlowe, T., Jastroch, N., Nousala, S., Kirova, V.: Complex collaboration, knowledge sharing and interoperability. In: Internat. ICE Conf. on Engineering, Technology and Innovation, pp. 1–10 (2012). IEEE

Mazzetti, P., Nativi, S.: Multidisciplinary interoperability for earth observations: some architectural issues. Journal of Selected Topics in Applied Earth Observations and Remote Sensing **5**(3), 1054–1059 (2012)

Mazzetti, P., Nativi, S., Santoro, M., Giuliani, G., Rodila, D., Folino, A., Caruso, S., Aracri, G., Lehmann, A.: Knowledge formalization for earth science informed decision-making: The geoessential knowledge base. Environmental Science & Policy 131, 93–104 (2022)

Mendes, A., Loss, S., Cavalcante, E., Lopes, F., Batista, T.: Mandala: an agent-based platform to support interoperability in systems-of-systems. In: Internat. Workshop on Software Engineering for Systems-of-Systems, pp. 21–28 (2018)

Mills, J.A., Ruston, L.: The osca architecture: enabling independent product software maintenance. In: EUROMICRO Workshop on Real Time, pp. 64–70 (1990)

Mordecai, Y., Orhof, O., Dori, D.: Model-based interoperability engineering in systems-of-systems and civil aviation. IEEE Transactions on Systems, Man, and Cybernetics: Systems **48**(4), 637–648 (2016)

Motta, R.C., De Oliveira, K.M., Travassos, G.H.: Rethinking interoperability in contemporary software systems. In: Joint Internat. Workshop on Software Engineering for Systems-of-Systems and Workshop on Distributed Software Development, Software Ecosystems and Systemsof-Systems, pp. 9–15 (2017). IEEE

Muller, G.: 3.1. 2 interoperability: a reliability challenge across systems and humans; illustrated by health care examples. In: INCOSE Internat. Symposium, vol. 19, pp. 368–377 (2009). Wiley Online Library

Najar, S., Pinheiro, M.K., Le Grand, B., Souveyet, C.: A user-centric vision of service-oriented pervasive information systems. In: Internat. Conf. on Research Challenges in Informat. Sc., pp. 1–12 (2014). IEEE

A systemic approach to interoperability formalization. IFAC Proceedings Volumes **41**(2), 11925–11930 (2008)

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

Navigli, R., Velardi, P.: Automatic acquisition of a thesaurus of interoperability terms. IFAC Proceedings Volumes **38**(1), 100–105 (2005)

Neaga, E.I., Henshaw, M.J.D.C.: Modeling the linkage between systems interoperability and security engineering. In: Internat. Conf. on System of Systems Engineering, pp. 1–6 (2010). IEEE

Neto, V.V.G., Oquendo, F., Nakagawa, E.Y.: Smart systems-ofinformation systems: Foundations and an assessment model for research development. Grand Research Challenges in Information Systems in Brazil 2016 - 2026 10, 1–12 (2017)

Ostadzadeh, S.S., Shams, F., Badie, K.: An architectural model framework to improve digital ecosystems interoperability. In: New Trends in Networking, Computing, E-learning, Systems Sciences, and Engineering, pp. 513–520. Springer, CHAM (2015)

Papageorgiou, A., Ölvander, J., Amadori, K., Jouannet, C.: Development of analysis and simulation models for evaluating airborne radar surveillance system of systems. In: AIAA Scitech Forum, p. 0303 (2021)

Pavlou, P., Singletary, L.: Empirical study of stakeholders perceived benefits of integration attributes for enterprise it applications. AMCIS, 358 (2002)

Perrone, V., Finkelstein, A.: Analyzing requirements for a large scale system for cancer research. In: IEEE Internat. Symposium on Computer-Based Medical Systems, pp. 103–108 (2007)

Pyarelal, S.: Interoperability framework for e-governance (ifeg)-strategic approach to evolve national standards. (2004). Informatics

Qureshi, N.A., Nguyen, C.D., Perini, A.: Analyzing interoperability requirements for adaptive service-based applications: A goal-oriented approach. In: Annual Computer Software and Applications Conf. Workshops, pp. 239–244 (2010). IEEE

Raychoudhury, V., Cao, J., Kumar, M., Zhang, D.: Middleware for pervasive computing: A survey. Pervasive and Mobile Computing **9**(2), 177–200 (2013)

Rezaei, R., Chiew, T.K., Lee, S.P.: A review on e-business interoperability frameworks. Journal of Systems and Software 93, 199–216 (2014)

Rhodes, C.J., Wilson, G.B.: Interoperability problems-prevention is better than cure. In: Internat. Conf. on Information-Decision-Action Systems in Complex Organisations, pp. 138–142 (1992)

Rosener, V., Latour, T., Dubois, E.: A model-based ontology of the software interoperability problem: Preliminary results. In: Grundspenkis, J., Kirikova, M. (eds.) CAiSE Workshops, pp. 241–252 (2004)

Salado, A.: Abandonment: A natural consequence of autonomy and belonging in systems-of-systems. In: 10th System of Systems Engineering Conf., pp. 352–357 (2015)

Saleh, M., Abel, M.-H., Mishra, A.: An architectural model for system of information systems. In: Internat. Workshop on Information Systems in Distributed Environment, vol. 9416, pp. 411–420 (2015)

Soares, D.D.S., Amaral, L.: Reflections on the concept of interoperability in information systems. Internat. Conf. on Enterprise Information Systems, 331–339 (2014)

Sobkowski, I., Freedman, R.S.: The evolution of worker connect: A case study of a system of systems. Journal of Technology in Human Services **31**(2), 129–155 (2013)

Song, F., Zacharewicz, G., Chen, D.: An architecture for interoperability of enterprise information systems based on soa and semantic web technologies. In: Internat. Conf. on Enterprise Information Systems, vol. 4, pp. 431–437 (2011)

Teixeira, G., Lopes, V.H.L., Santos, R.P., Kassab, M., Graciano Neto, V.V.: The status quo of systems-of-information systems. In: SESoS/WDES (2019)

TOUZI, J., BENABEN, F., PINGAUD, H.: Model transformation of collaborative business process into mediation information system. IFAC Proceedings Volumes **41**(2), 13857–13862 (2008)

Tripathi, R., Gupta, M., Bhattacharya, J.: Effect of organizational factors on interoperability adoption for indian portals. Transforming Government: People, Process and Policy (2013)

Ullberg, J., Chen, D., Johnson, P.: Barriers to enterprise interoperability. In: IFIP-International Workshop on Enterprise Interoperability, pp. 13–24 (2009). Springer

Ullberg, J., Johnson, P., Buschle, M.: A language for interoperability modeling and prediction. Computers in Industry **63**(8), 766–774 (2012)

Vargas, I.G., Gottardi, T., Braga, R.T.V.: An approach to integrate systems towards a directed system-of-systems. In: European Conf. onSoftware Architecture: Companion Proceedings, pp. 1–7 (2018)

Wang, W., Tolk, A., Wang, W.: The levels of conceptual interoperability model: applying systems engineering principles to M&S. arXiv preprint arXiv:0908.0191 (2009)

Wang, Y., Zhang, J., Wang, J., Chong, X.: Inter-organization collaboration management in dynamic virtual alliances. In: Internat. Conf. on E-Business and E-Government, pp. 42–45 (2010). IEEE

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

Whitman, L.E., Panetto, H.: The missing link: Culture and language barriers to interoperability. Annual Reviews in Control **30**(2), 233–241 (2006)

Widergren, S., Levinson, A., Mater, J., Drummond, R.: Smart grid interoperability maturity model. In: PES General Meet., pp. 1–6 (2010)

Wohlin, C.: Guidelines for snowballing in systematic literature studies and a replication in software engineering. In: Internat. Conf. on Evaluation and Assessment in Software Engineering. Association for Computing Machinery, New York, NY, USA (2014)

Yaacoubi, A.N., Pollet, Y., Ben, A.M.: Formal framework for semantic interoperability. In: Internat. Conf. on Software and Data Technologies, pp. 139–144 (2006)

Yahia, E., Bigand, M., Bourey, J.-P., Castelain, E.: Supply chain business patterns definition for process interoperability. IFAC Proceedings Volumes **42**(4), 169–174 (2009)

Zacharewicz, G., Diallo, S., Ducq, Y., Agostinho, C., Jardim-Goncalves, R., Bazoun, H., Wang, Z., Doumeingts, G.: Model-based approaches for interoperability of next generation enterprise information systems: state of the art and future challenges. Information Systems and e-Business Management **15**(2), 229–256 (2017)

Zarour, K., Zarour, N., Charrel, P.-J.: Towards enhancing interoperability in medical information systems. In: Internat. Symposium on Health Informatics and Bioinformatics, pp. 16–21 (2011). IEEE

Zdravković, M., Luis-Ferreira, F., Jardim-Goncalves, R., Trajanović, M.: On the formal definition of the systems' interoperability capability: an anthropomorphic approach. Enterprise Information Systems **11**(3), 389–413 (2017)

Zeinali, N., Asosheh, A., Setareh, S.: The conceptual model to solve the problem of interoperability in health information systems. In: Internat. Symposium on Telecommunications, pp. 684–689 (2016). IEEE