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A Systematic Literature Review on Systems-of-Systems Knowledge Representation

– Technical Report –

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March, 2015

Abstract

Systems-of-Systems (SoS) are a special type of systems composed by other systems. These systems together can reach goals that they could not benefit when operating on their own. However, this emerging discipline is not consolidated yet and there is a lack of standardization in the terminology used. In this context, knowledge representation approaches can be used to support activities in the SoS field. They can also play an important role in formalizing concepts by providing a common understanding among the community and practitioners. In this technical report we present a Systematic Literature Review (SLR) conducted to identify how knowledge representation has been applied to SoS. Our results show that interoperability is the most addressed topic. We also noticed that there is a lack of formal approaches for establishing communication in the SoS field.

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1 Introduction

Systems-of-Systems (SoS) are a special type of system which are composed by other systems, named constituent systems. These systems together can reach goals that they could not benefit when operating on their own. However, this emerging discipline is not consolidated yet and there is a lack of standardization in the terminology used [22].

Knowledge representation approaches can be used to support activities in different areas. They can also play an important role in formalizing concepts by providing a common understanding among the community and practitioners. In this context, ontologies have been used to represent the knowledge in many areas, such as Systems Engineering [52], Software Architecture [1], and Software Testing [44] [3] [4].

In this technical report we present a Systematic Literature Review (SLR) conducted to identify how knowledge representation has been applied to the SoS field. The objective of this SLR is to identify existing knowledge representation approaches for SoS, the context in which they have been applied to, the problem they solve, how the approach is used, and what are the outcomes obtained using these approaches. As a result, it is expected to identify research gaps and open problems in SoS that could take benefit from knowledge representation approaches.

The remainder of this technical report is organized as follows: in Section 2 we present the necessary background for this SLR, including SoS, Knowledge Representation, and the Systematic Review process adopted. In Section 3 we present the methods used to conduct this review, which encompasses the research questions, the search string, the inclusion and exclusion criteria, the data extraction, the quality assessment, and the tools used. In Section 4 we present and discuss the results obtained. The threats to validity are presented in Section 5. Finally, in Section 6 we present our conclusions and future work.

2 Background

In this section we present the theoretical background used in this SLR. The concepts discussed include SoS, Knowledge Representation with emphasis on ontologies, and the Systematic Review process.

2.1 Systems-of-Systems

SoS are a special type of system which are composed by other systems, named constituent systems. By working alone, these constituent systems, also known as monolithic systems, cannot accomplish the objectives that they obtain when working together.

Different definitions can be found in the literature for SoS focusing on different characteristics. Some of them emphasize the fact that its constituent systems are collaboratively integrated and have two additional properties: operational and managerial independence [32]. Others highlight the features that can only exist when the constituent systems work connected and that are unachievable by them individually [27].

However, an SoS can also be defined by the presence of a majority of the five following characteristics: operational and managerial independence, geographic distribution, emergent behavior, and evolutionary and adaptive development [23] [32] [41]. Each characteristic is shortly discussed below.

- **Operational independence:** If an SoS is disassembled, its component systems must operate independently.
- **Managerial independence:** The component systems maintain operational existence independent of the SoS.
- **Evolutionary development:** The SoS keeps continually being evolved, that is, new features can be added, changed or removed, according to new requirements.
- **Emergent behavior:** The SoS function is not placed in any constituent system, but belongs to the SoS as a whole.
- **Geographic distribution:** The component systems may be in different locations.

SoS differ from monolithic systems in some aspects [39]. In an SoS the causes of problems and effects of behaviors are a combination of factors, which may be known or unknown. The dependencies are often largely outside a single program's span of control and the context may not be completely known by its engineers and managers. In a monolithic system, the dependencies are within the system itself, and it is less difficult, for instance, to estimate the impact of change requests in the system. Regarding the goals of the system, in an SoS it refers to the capabilities of the constituent systems plus the emergent capabilities of the

SoS. Also, the focus of the SoS must satisfy, suffice, and comprise to achieve the collective emergent capabilities, and not only the constituent systems' features. With respect to the negotiations and decisions, in an SoS there is more dependence on collaboration and influence at best, but sometimes, when negotiations are unsuccessful, mitigation may be the only way to deal with some problems.

These are common issues often found in SoS projects from different domains, such as defense integrated networks, airport systems and smart-systems, which include smart grids, smart buildings and smart cities [32]. Since there is an emergence for this kind of system, and based on the aforementioned differences, it is notable that SoS require new paradigms of working so practitioners can deal with their characteristics.

2.2 Knowledge Representation

According to Shapiro [43], Knowledge Representation is a subarea of Artificial Intelligence concerned with understanding, designing, and implementing ways of representing information so that computers can use it.

By representing the knowledge, that is, making it machine-readable, computers can use it to derive implied information, communicate with people in natural languages and solve problems that usually require human intervention or expertise [43].

2.2.1 Ontologies

In Computer Science, ontologies can be seen as an approach to represent the knowledge related to a given area. The World Wide Web Consortium (W3C) [54] defines an ontology as a set of terms used to describe and represent an area of knowledge. According to Gruber [18], an ontology is defined as an explicit specification of a conceptualization. This definition is represented in the Figure 1. Later, Studer et al. [45] extended Gruber's definition by proposing that an ontology is a formal explicit specification of a shared conceptualization. In their definition, *conceptualization* refers to an abstract model of something in the world, in which its relevant concepts are identified. *Explicit* means that the types of concepts, constraints and usage are explicitly defined. *Formal* means that the ontology should be machine-readable, that is, it should exclude natural languages. Lastly, *shared* means that the consensual knowledge captured by the ontology must be accepted by a group, that is, it cannot be private to some individual.

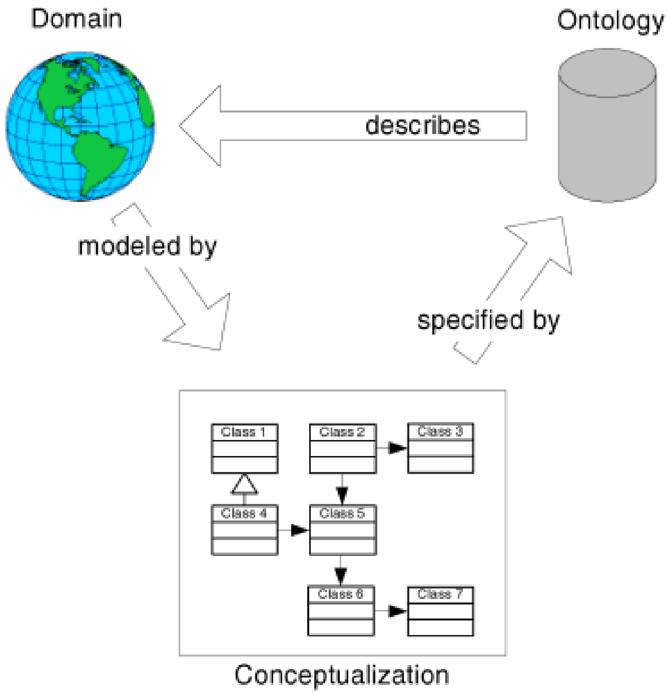


Figure 1: Gruber ontology definition [28]

Ontologies can be classified according their degree of formality [50]. An informal ontology is expressed in natural language or some restricted and structured form of a natural language, such as glossaries or controlled vocabularies. A semi-formal ontology is expressed in an artificial formally defined language, such as conceptual models or UML diagrams [49]. Formal ontologies define terms with formal semantics, including first order logic and axioms, description logics or some machine-readable language, such as OWL (Web Ontology Language) [56] and RDF (Resource Description Framework) [55].

Figure 2 shows the spectrum of ontology kinds based on their internal structure and degree of formality. Lightweight ontologies make no use of axioms, whereas heavyweight ontologies make intensive use of axioms for specification [57].

In the spectrum of ontology kinds, *Terms* can be seen as a controlled vocabulary, that is, a finite list of terms belonging to a given area. *Glossaries* are lists of terms with their meanings specified as natural language statements. A *taxonomy* is a controlled vocabulary organized into a hierarchical or parent-child structure. *Thesauri* are similar to a taxonomy, with the addition of hierarchical relationships. *Frames* include classes and their properties. The more the ontology is placed to the right side of the figure, the more expressiveness and semantics it provides.

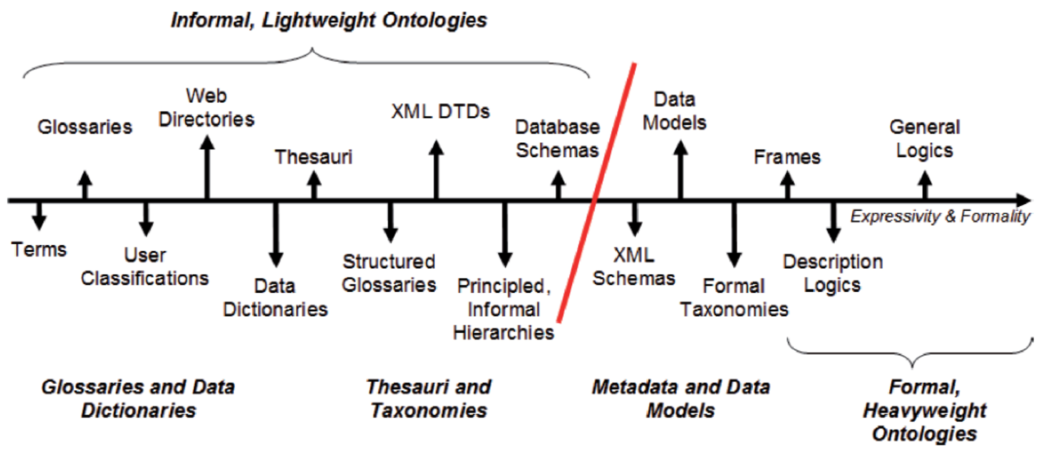


Figure 2: Spectrum of Ontology Kinds [57]

Regarding their space of use (purpose) [51] [50], ontologies can be used for communication between people, interoperability among systems, or systems engineering. Communication refers to sharing a common understanding of concepts, thus providing a standardization of the terms, their meaning and relationship in a domain for people with different needs and viewpoints in a given context. Interoperability refers to the data exchange among systems that need to interpret concepts using different software tools. Regarding systems engineering, ontologies can be used to support activities in the design and development of software systems, such as specification. Due to the focus of this SLR, we extended the Systems Engineering space of use to SoS Engineering (SoSE).

2.3 Systematic Literature Review

SLR is the name given to the research methodology which aims to systematically collect and analyse evidences about a specific topic [6]. An SLR defines a framework to collect and summarize evidences about a phenomenon or technology, helps to identify research gaps and gives theoretical support to propose new methods [24]. An SLR can be described as a three-stage process (Figure 3): Planning, Conduction and Documentation.

2.3.1 Planning

During the *Planning* stage, the objectives and the protocol of the SLR are defined. Research Questions (RQ), search strings, databases, inclusion and exclusion criteria, and data to be extracted are also defined in this stage. These information must be detailed in the protocol

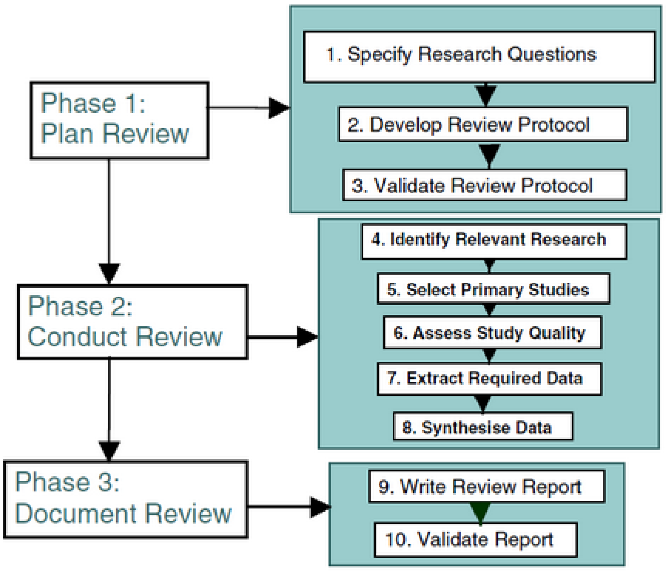


Figure 3: Systematic Review Stages [8]

and subsequently validated.

2.3.2 Conduction

Afterwards, during the *Conduction*, the studies are searched using the string. The studies found are evaluated using the inclusion and exclusion criteria and then only selected studies are completely read. Data related to the research questions are extracted according to the protocol, and summarized using, for example, a spreadsheet. The quality of the studies can also be measured using a quality criteria, as suggested in [15].

2.3.3 Documentation

During the *Documentation* stage, the obtained information is organized and presented in the format of a paper or a technical report. Supplementary materials can also be attached to the report. Threats to validity must be cited and discussed. The last stage of this process is the validation of the report. This validation can be conducted by a third-party, such as an expert in the area researched.

3 Methods of Review

This review followed the SLR process [24]. As part of the process, we defined a protocol containing details of the search string, selection criteria, and data extraction. This SLR used as source of primary studies a sort of recognized scientific database libraries, described below.

3.1 Research Questions

RQ1: Which knowledge representation approaches have been applied to SoS?

RQ1.1: What is the degree of formality of the approach (informal, semi-formal, formal)?

RQ2: What is the main motivation for using knowledge representation in SoS?

RQ3: What application domains the knowledge representation approaches of SoS have been applied to?

RQ 3.1: Is the approach applied to a real case study / system?

RQ 3.2: For what purposes the studies found were conducted? (eg., communication, interoperability, SoSE, or other uses)?

RQ4: What are the terms covered by knowledge representation approaches in SoS?

In RQ1 and sub-questions we expected to identify which are the knowledge representation approaches that have been used in the area of SoS and their degree of formality. The answer for this RQ would help us to build a list containing the approaches listed in the spectrum ontology kinds [57] that have been used, the number of studies using each one, and as well as their degree of formality. It would also show us the most predominant approaches or even research gaps.

In RQ2 we aimed to identify the main motivation for use the knowledge representation approaches in the SoS field.

In RQ3 and sub-questions we aimed to identify the context or problem, such as the scope of the approach, application domains, SoSE processes, or life cycle stages that make use of knowledge representation approaches. Additionally, if any validation processes were conducted. The nature of the problem investigated was also checked (eg. if it was a real case study / system or a toy example).

In RQ4 we intended to identify what terms were in fact included in the knowledge represented using the approaches found. It would give us a picture of the most important underlying terms, definitions, and the inter-relationship among them in the SoS field.

3.2 Databases

This SLR used as the source of primary studies a set of five recognized scientific database libraries, which are listed below.

- ACM Digital Library: http://dl.acm.org/
- Science Direct: http://www.sciencedirect.com/
- ISI Web of Science: http://webofscience.com/
- Scopus: http://www.scopus.com/
- IEEE Xplorer Digital Library: http://ieeexplore.org/

3.3 Search String

The search string used in this SLR was designed to cover variations and synonyms for terms related to "Systems-of-Systems" and Knowledge Representation, such as glossary, dictionary, thesaurus, and ontology. The terms were extracted from the spectrum of kinds of ontologies shown in the Figure 2.

The final search string was also adapted for meeting particularities of each aforementioned digital library search engine. The search scope of this SLR was limited to the content of the title, abstract, and keywords of the primary studies. The standard version of the search string used in this SLR is shown below.

> ("system of system" OR "system of systems" OR "systems of systems" OR "system-of-system" OR "system-of-systems" OR "systems-of-systems") AND ("glossary" OR "glossaries" OR "classification" OR "dictionary" OR "dictionaries" OR "thesaurus" OR "thesauri" OR "taxonomy" OR "taxonomies" OR "ontology" OR "ontologies" OR "vocabulary" OR "vocabularies" OR "schema" OR "frame" OR "hierarchy" OR "hierarchies" OR "knowledge representation" OR "body of knowledge")

3.4 Inclusion and Exclusion Criteria

The primary studies recovered from digital libraries were analyzed considering the inclusion and exclusion criteria. At first, the application of selection criteria was limited to primary studies' metadata (title, abstract, and keywords). The metadata of each study were read in pair by the reviewers, who also discussed the application of the inclusion and exclusion criteria. In the case of any discordance, the reviewers discussed together about the study until reaching an agreement.

At a second stage, the selection criteria also considered the content of the introduction and conclusion of the studies. As a result, we obtained the set of primary studies contributing to answer the RQs of this SLR. The inclusion and exclusion criteria used in this SLR are presented below.

3.4.1 Inclusion Criteria

Primary studies addressing any of the topics listed below were included:

IC1: The study discusses knowledge representation in the SoS field.

IC2: The study addresses the representation of a SoS, application domain, problem, or activity related to SoSE using a knowledge representation approach.

IC3: The study discusses a space of use for a knowledge representation approach such as: Communication between people and organizations; Interoperability between systems; Support to SoSE; Other uses.

IC4: The study lists or describes a set of terms related to SoS using any knowledge representation approach.

3.4.2 Exclusion Criteria

Primary studies addressing any of the exclusion criteria listed below were excluded:

EC1: The study is not related to SoS.

EC2: The study does not discuss any knowledge representation approach.

EC3: Knowledge representation for SoS is not the main focus of the study.

EC4: The study is categorized as "gray literature", e.g. technical reports, manuals, tutorials or electronic books.

EC5: The study is an editorial, keynote, opinion, tutorial, poster or panel.

EC6: The study is duplicated, such as a same article of a conference in a proceedings. The newest one will be included.

EC7: There is a newer or a more complete study about the same research.

EC8: The primary study is not written in English. Since English is the main language used in international forums, this is the only language considered in this SLR.

EC9: The full study is not available.

3.5 Data Extraction

The final set of included studies was fully read to identify and extract all relevant information for this SLR. Each reviewer received half of the total of studies to read and extract the data. The following items were extracted from the selected studies:

- Title
- Country of the authors
- Knowledge representation approach
  - Glossary
  - Hierarchy
  - Dictionary
  - Thesaurus
  - Taxonomy
  - Ontology
  - Vocabulary
  - Frame
- Degree of formality

- Informal
- Semi-formal
- Formal

- Main motivation for using the knowledge representation approach
- Application domain
- Is the approach applied to a real case study / system or a toy example?
- Space of use of the knowledge representation approach
  - Communication
  - Interoperability
  - Support to SoSE
- List of relevant terms covered by the knowledge representation approach

3.6 Quality Assessment

In this SLR, we also assessed the quality of the primary studies selected. To do so, we based our analysis in the quality criteria as described in [24] [37] and [25]. The quality criteria and the specified scores for this SLR are shown in Table 1. The possible scores depends on the quality criterion. If the primary study fully matches a quality criteria, we gave 2 as score, 0 otherwise. In some cases the criterion was partially matched; in this case, we defined intermediate scores.

The final score of the quality assessment (QA) for each primary study was calculated using the following formula:

$$QA = \left(\frac{sum\ of\ scores}{maximum\ score}\right) * 100$$

Table 1: Quality assessment criteria and possible scores.

Quality Criteria (QC)	Scores
QC1: Do the authors clearly state the aims of the research?	0 - No. 1 - Yes, but partially. 2 - Yes, totally clear.
QC2: Do the authors discuss the limitations of their study?	0 - No. 1 - Yes, but partially. 2 - Yes, clearly discussed.
QC3: Do the authors state the findings clearly?	0 - No. 1 - Yes, but partially. 2 - Yes, fully matched the criterion.
QC4: Is there evidence that the findings of the study can be used by other researchers / practitioners?	0 - No. 1 - Yes, but partially 2 - Yes, totally reusable.
QC5: Does the study body fully meet issues provided in its abstract?	0 - No. 1 - Yes, but partially. 2 - Yes, fully matched the criterion.
QC6: Do the described methods were empirically evaluated?	0 - No. 1 - Yes, but partially. 2 - Yes, fully matched the criterion.
QC7: What kind of subjects / projects were used for empirical evaluation?	0 - None. 0.5 - Own / toy. 1 - Students. 1.5 - Researchers / experts. 2 - Open source / industrial project.
QC8: Are there any ideas for further investigation presented?	0 - No. 2 - Yes.

3.7 Support Tools

The following software tools were used to support the execution of this SLR.

- StArt: The StArt[1] is a software to support the execution of SLR [17]. In this SLR, it was used to organize all the studies found using the search string, to guide the reading prioritization, to apply the inclusion and exclusion criteria, and to perform the data extraction.
- Google Drive: Google Drive[2] was used to enable the collaborative work of the authors on the extracted data. The spreadsheet generated by the StArt tool was uploaded to Google Drive.
- Mendeley Desktop: Mendeley[3] was used to enable the reviewers to share the studies selected, make annotations, and support the extraction of relevant information.

4 Results and Discussions

In this section we present and discuss all the results of this SLR. First, we present the results obtained through the search string performed in the digital libraries. Next, we discuss the inclusion and exclusion process followed by a big picture of the selected studies. The extracted data are presented while answers for each research questions are discussed.

4.1 Search Results

The search string shown in the Section 3.3 was adapted for each database (Section 3.2) and the results were collected in the format of BibTeX files. The search strings used on each database can be found in the appendix A.

The databases considered in this SLR were included in the StArt protocol and search sessions were created for each search string. Some of the search strings were broken in parts due to search engine peculiarities.

The identification of duplicated studies was fully supported by the StArt tool, as it has a feature that calculates the similarity between studies using the metadata fields. Right

[1] http://lapes.dc.ufscar.br/tools/start_tool
[2] http://drive.google.com
[3] http://mendeley.com

during the load of a new BibTeX file, if a study with 100% of similarity is detected, the tool automatically tag it as duplicated, otherwise the similarity % can still be used later to sort the studies. As shown in the Figure 4, the search strings returned a total of 576 studies, where the majority was from Scopus, followed by IEEE.

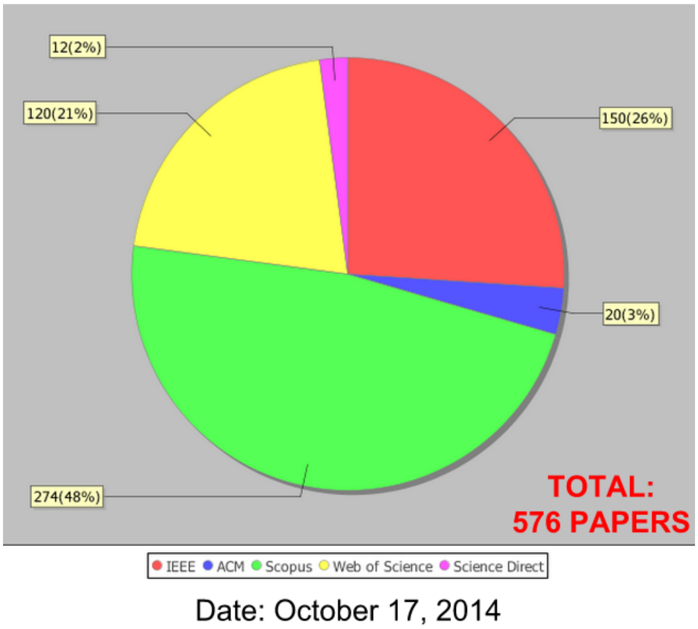


Figure 4: Studies found using the search string

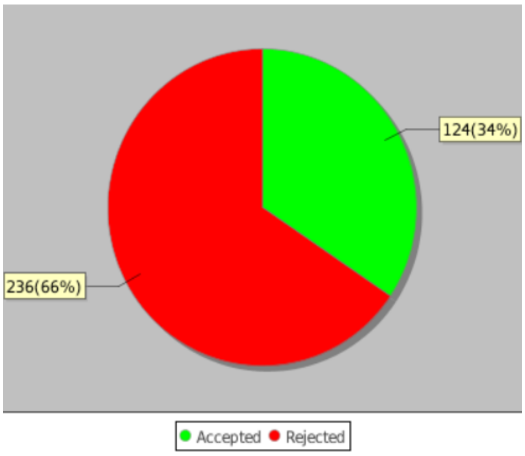
After this step, we applied the first step of our inclusion and exclusion criteria, which is discussed in the next section.

4.1.1 First Inclusion and Exclusion Phase

After removing all the duplicated studies using StArt, the Title, Abstract and Keywords (TAK) of each study were pair-read by the reviewers in order to decide by its inclusion or exclusion, mainly in case of divergent opinions.

The reading was prioritized considering the Score that the tool StArt defines for each study, based on the occurrence of keywords in the TAK. A reading priority was defined for each study considering the categories: *Very High, High, Low, Very Low*. This step was performed manually. Both score and reading parameters were used to guide the later reading process, prioritizing those with higher priority and higher score.

At the end of the TAK analysis, 236 studies were rejected and 124 were accepted. The charts presenting the accepted and rejected studies with their reading priority can be seen in the Figure 5.



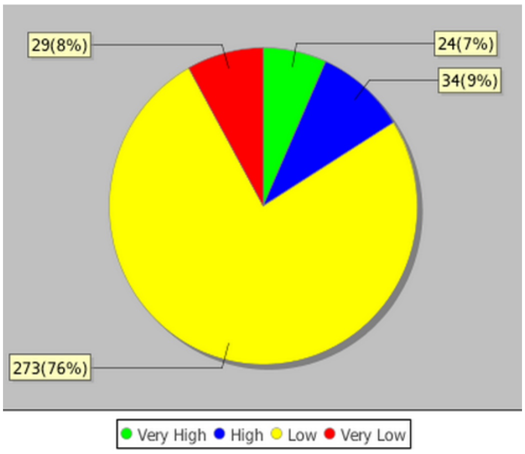


Figure 5: First Inclusion/Exclusion Results (Left) and Reading Priority (Right)

4.1.2 Second Inclusion and Exclusion Phase

In the second stage of the inclusion and exclusion process, the introduction and conclusion of all 124 studies were read. As well as in the first phase, the reading process was prioritized considering the reading priority and the StArt score. After this stage, 31 studies were accepted, one study was identified as duplicated and 92 studies were rejected. The result of this phase is shown in the Figure 6.

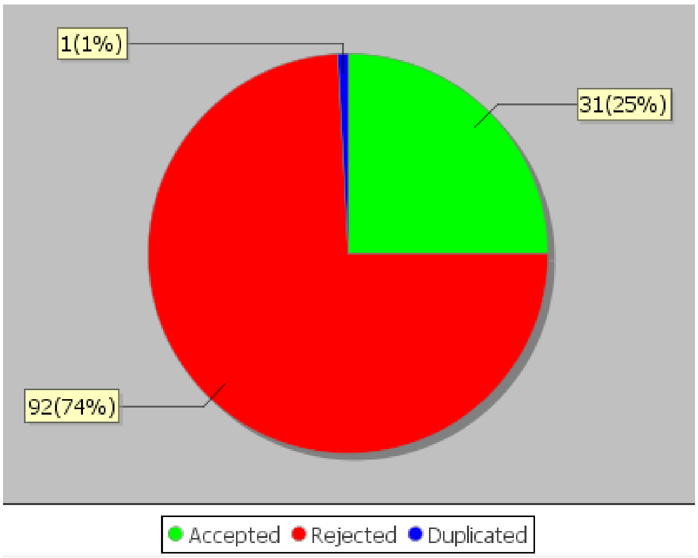


Figure 6: Second Inclusion/Exclusion

4.2 Selected Studies

The 31 selected studies were fully read and the information defined in the Section 3.5 was extracted from each one. A picture of the number of studies published per year can be seen in the Figure 7. There is an increasing tendency of studies published, mainly from the year 2010 to nowadays. It suggests that there are more people publishing studies related to this research field, and the interest on it seems to be growing.

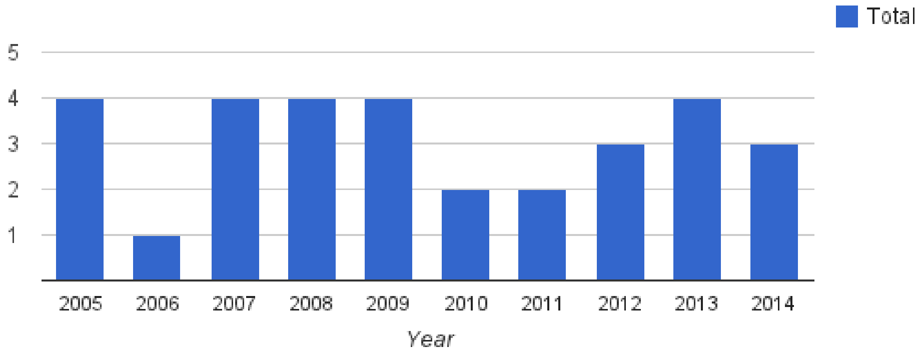


Figure 7: Studies per year

The country of the authors' institution was also extracted to show us the scenario of research in SoS and Knowledge Representation around the world. Here we considered the countries of all authors per study. A chart and a world map presenting the amount of studies per country are shown in the Figure 8 and Figure 9, respectively. Considering the distribution of studies per country, we see that USA, United Kingdom, and France are the uppermost publishers in this research field.

4.3 Research Questions

4.3.1 RQ1: Which knowledge representation approaches have been applied to SoS?

Considering the approaches we included in the search string, we did not find any study explicitly mentioning *glossary*, *hierarchy*, *dictionary*, or *frame*. The major amount of approaches used in the selected studies are ontologies [20] [42] [29] [21] [59] [13] [14] [35] [40] [31] [47] [60] [30] [48] [36] [9] [16] [46] [7] [53] [58]. Here an ontology is seen as a heavyweight ontology, that is, an ontology with a high level of formality and semantics. We also found taxonomies used to address SoS issues [11] [10] [26] [34] [33] [38] [2]. Only two studies dis-

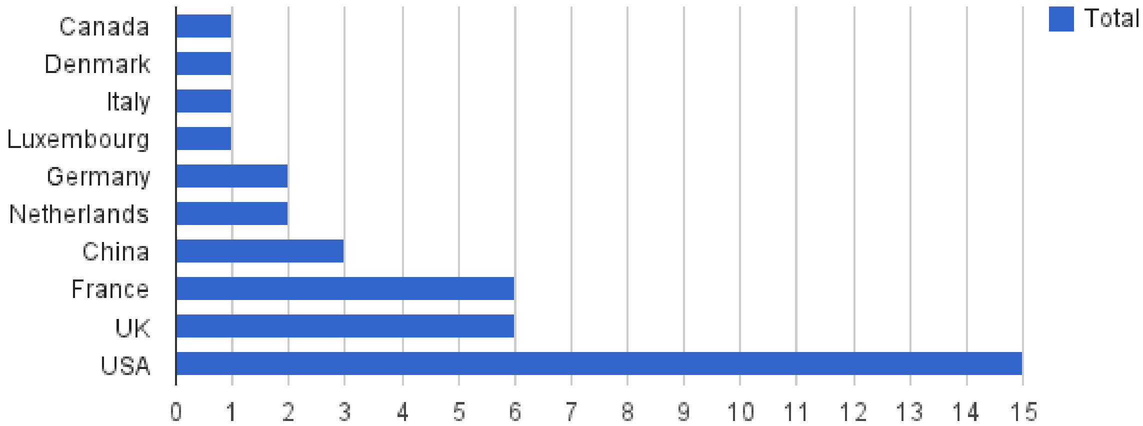


Figure 8: Studies and Countries - Chart

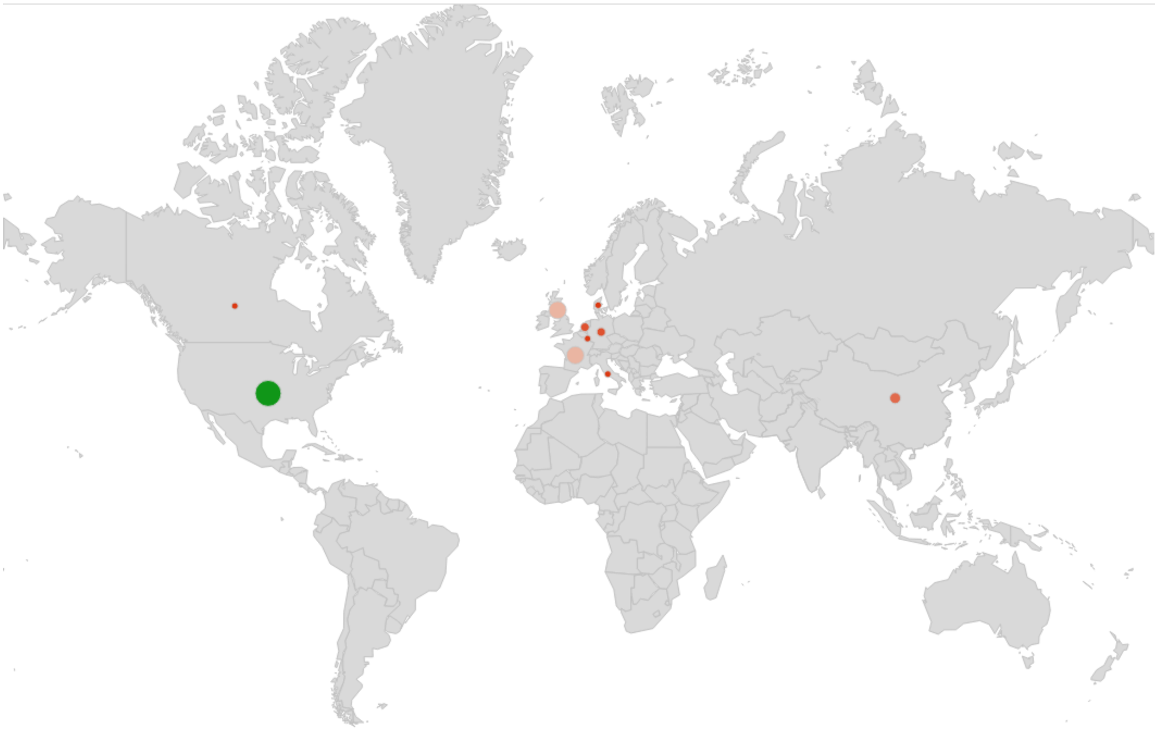


Figure 9: Studies and Countries - World Map

cussed the use of thesaurus [12] [5], which was not implemented yet according to the study. There was another study referring to the same research, but with a different perspective, so we decided to keep both on our SLR. The other most used approach was vocabulary [19], which we found only one study discussing it. The number of approaches used in the studies is summarized in the Figure 10.

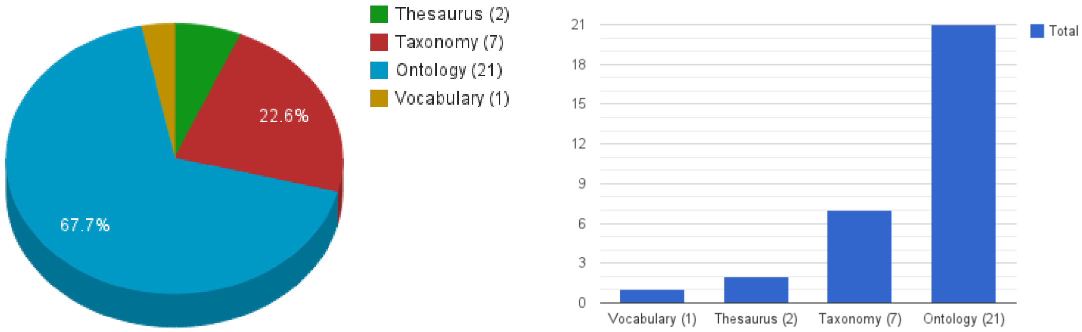


Figure 10: Knowledge representation approaches

4.3.2 RQ1.1: What is the degree of formality of the approach?

From the data extracted related to the degree of formality, we could see that most of the studies selected in our SLR take advantage of formal ontologies, with a total of 10 studies [46] [9] [7] [13] [16] [36] [47] [48] [58] [60]. Semi-formal [59] [30] [29] [31] [21] [2] [5] [12] and informal [20] [14] [34] [10] [26] [33] [11] [19] share the second and third place, with a total of 8 studies each. There was also a subset of studies we could not identify the degree of formality due to limited information, or even because it was still undefined [40] [35] [38] [42] [53] . In a certain way, we could say that the amount of studies discussing each degree of formality (informal, formal and semi-formal) considered in this study is approximately equal. Figure 11 presents the charts with the number of studies grouped by degree of formality.

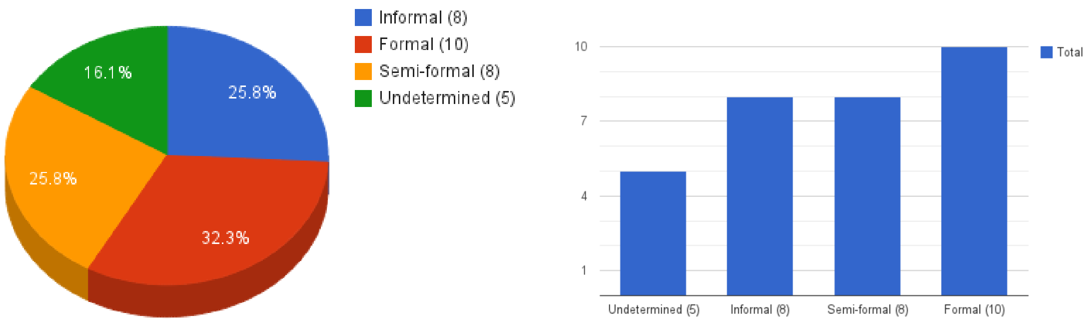


Figure 11: Degree of Formality

4.3.3 RQ2: What is the main motivation for using knowledge representation in SoS?

Among the motivations for using knowledge representation approaches in SoS that we identified in the studies, we could organize them in four major groups:

- Terminology standardization and knowledge sharing;
- SoS Integration;
- SoSE Activities; and
- SoS Management.

These groups can be related to the space of uses presented in the Section 2.2. Considering these results, we can say that there is a correspondence between the motivation to use knowledge representation itself, regarding space of use, and issues in the SoS field, regarding their challenging problems compared to monolithic systems [22] [39].

The complete list of main motivations for the usage of knowlege representation in SoS can be found in the Appendix E.

4.3.4 RQ3: What application domains the knowledge representation approaches of SoS have been applied to?

The RQ3 aimed to help us to identify the application domain the knowledge representation approaches had been applied to. Our results show that the majority of the studies developed focuses on general domains (10 studies) [20] [7] [40] [26] [33] [19] [42] [5] [12] [35], followed by the military (six studies) [59] [47] [34] [29] [53] [60] and crisis management (four studies) [9] [38] [48] [21]. By "general domain" we mean the study did not address a specific application domain, so we assumed the approach can be applied to any application domain. The data collected for this RQ are shown in the Figure 12.

4.3.5 RQ 3.1: Is the approach applied to a real case study / system?

Regarding the subjects of study, most of the studies considered industrial scenarios (11 studies) [9] [38] [48] [59] [2] [21] [60] [36] [11] [46] [10] and own / toy examples (10 studies) [31] [7] [26] [16] [47] [34] [29] [53] [13] [58]. There were studies without any evaluation process

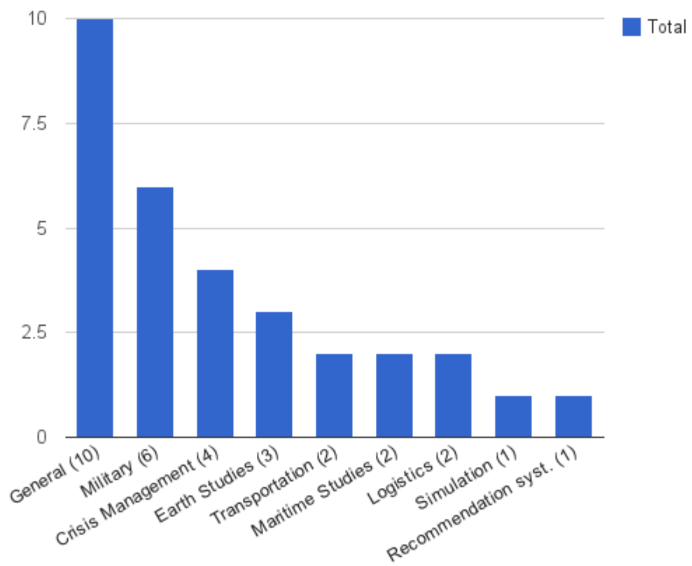


Figure 12: Application Domain

(eight studies) [20] [40] [33] [19] [42] [35] [30]. There were also two other studies evaluating the proposes based on experts or specialists' opinion [5] [12]. The results of this RQ are shown in the Figure 13.

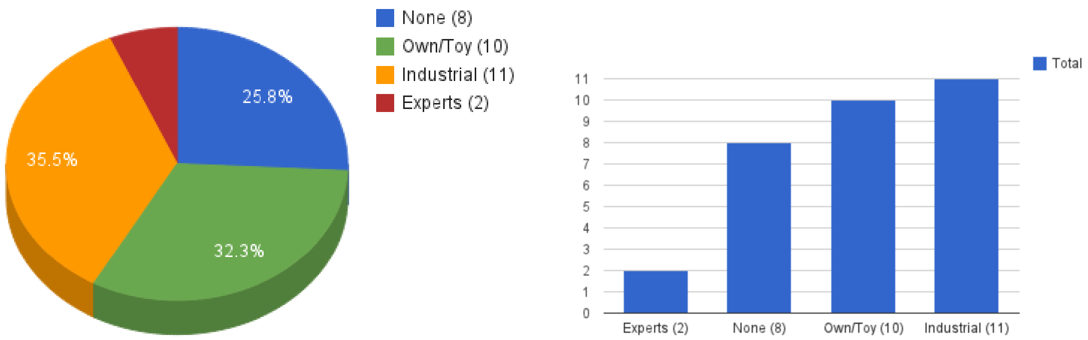


Figure 13: Subjects of Study

4.3.6 RQ 3.2: For what purposes the studies found were conducted?

Within the domain of problems solved by the approaches, our results show that most of the studies were addressing interoperability of SoS (16 studies) [9] [46] [53] [48] [2] [60] [36] [14] [35] [30] [31] [7] [16] [47] [13] [58]. Communication was in second place (10 studies) [19] [40] [53] [46] [38] [12] [5] [42] [26] [9], followed by Support to SoSE (10 studies) [40] [19] [59] [21] [10] [11] [20] [33] [34] [29], both with the same number of occurrences. In this RQ, there were studies addressing more than one space of use, so we included them in two categories.

The results of this RQ are shown in the Figure 14.

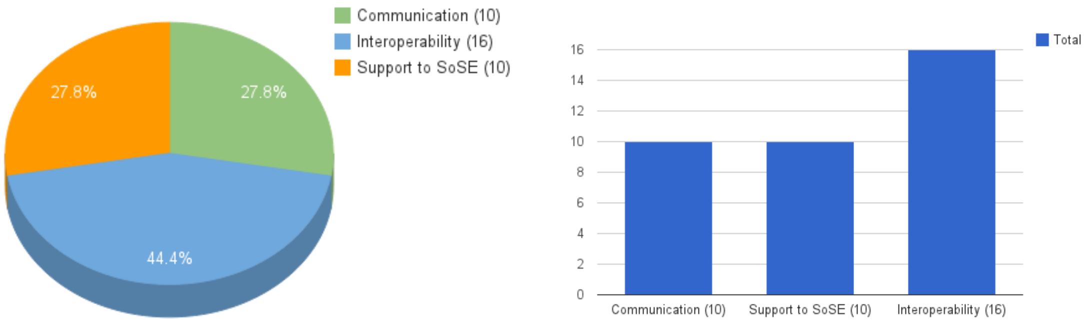


Figure 14: Space of Use

4.3.7 RQ4: What are the terms covered by knowledge representation approaches in SoS?

We faced some problems while identifying the terms used in the approaches due many studies did not present explicitly any terms or concepts. In these cases, the list of terms was marked as *N/A* (not available). Also, we highlight that our search was limited to the information described in the studies and no secondary source was considered.

From the terms we extracted, we could see no obvious relationship among each other. Moreover, there were not so many repeated terms, which means there is a lack of consistency on the terminology in the SoS field.

However, we were able to group them according to the SoS characteristics (Section 2.1) and space of use for ontologies (Section 2.2). Examples of terms extracted are *stakeholder context*, *collaborative process*, *integration resources*, *location*, and *mitigation strategy*, which may be related to the SoS characteristics. Other terms, such as *negotiation, goal, requirement, interface, orchestration, and services*, may also be linked to the spaces of use for knowledge representation approaches.

The complete list of the terms extracted can be found in the Appendix D.

5 Threats to Validity

In this SLR we only considered the digital libraries mentioned in Section 3.2 and we did not search for studies in other specific sources, such as journals, conferences, or workshops related to knowledge representation or SoS. Thus, journals or events not indexed by those databases are out of the scope of this SLR.

Moreover, we only considered studies written in English. If there are important results in studies written in other languages they are out of this SLR.

For the definition of our search string, we considered the spectrum of ontology kinds shown in Figure 2. We did not consider some terms of the spectrum to reduce the number of false positives, such as *XML*. In this case, our search string may not be covering all the most appropriate terms.

In the first filtering phase, there may be problems in interpreting the abstract of the studies due to some intrinsic characteristics, such as authors not explicitly mentioning information relevant to our SLR.

In order to mitigate bias during the data extraction, the reviewers split the studies and, when any doubts extracting the data arose, the reviewers met to resolve them.

The degree of formality extracted from the studies were limited only to the information available in the study. So if the studies did not properly detail the implementation of the knowledge representation approach, we may have classified it incorrectly.

With respect to the subject of study, we classified it based on what was the most adequate according to our understanding. For instance, some toy scenarios were designed based on industrial standards. However, to the best of our knowledge, they are still a toy scenario.

There may be inconsistencies related to the terminology presented in the studies. For instance, an study may be referring an approach as taxonomy instead of hierarchy. This way we limited our analysis only considering the terminology used in the study without infering anything about the approach.

Lastly, inconsistencies in the search engine of the digital libraries might have affected our results.

6 Conclusions

In this SLR we explored the use of knowledge representation approaches in the SoS field. After removing duplicated studies, we reached a total of 360 studies. We filtered the results by the abstract in a first stage and then, after applying our inclusion and exclusion criteria in a second stage, we finally selected 31 primary studies for data extraction.

Our results show that the most used approach in the SoS field are formal ontologies. We did not find studies addressing the use of glossaries, dictionaries, hierarchies, or frames.

The majority of the selected studies do not address issues of a specific application domain, which were classified as *general* in this SLR. However, when we could identify the domain, military was predominant, followed by crisis management.

Regarding the space of use, we noticed that interoperability is the major concern when using the knowledge representation approaches in SoS. We identified that all the studies classified as using formal ontologies are also addressing interoperability issues.

Only two studies classified as formal ontologies addressed communication, besides interoperability. We did not find any study using a formal ontology specifically dealing with communication in SoS. Additionally, these same studies do not concern with SoS concepts or terminology formalization. Thus, this can be seen as a research gap to be explored in the future.

7 Acknowledgements

Carlos Diego N. Damasceno's research is supported by the National Council for Scientific and Technological Development (CNPq), process number 132249/2011-6.

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A Databases Search Strings

IEEE Xplore	(“system of system” OR “systems of systems” OR “system-of-systems” OR “systems-of-systems”) AND (“glossary” OR “glossaries” OR “classification” OR “dictionary” OR “dictionaries” OR “thesaurus” OR “thesauri” OR “taxonomy” OR “taxonomies”)
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	(“system of systems” OR “system-of-system”) AND (“glossary” OR “glossaries” OR “classification” OR “dictionary” OR “dictionaries” OR “thesaurus” OR “thesauri” OR “taxonomy” OR “taxonomies”)
	(“system of systems” OR “system-of-system”) AND (“ontology” OR “ontologies” OR “vocabulary” OR “vocabularies” OR “schema” OR “frame” OR “hierarchy” OR “hierarchies” OR “knowledge representation” OR “body of knowledge”)
ACM Digital Library	Title:((“system of systems” OR “systems of systems” OR “system of system” OR “system-of-systems” OR “systems-of-systems” OR “system-of-system”) AND (“glossary” OR “glossaries” OR “classification” OR “dictionary” OR “dictionaries” OR “thesaurus” OR “thesauri” OR “taxonomy” OR “taxonomies” OR “ontology” OR “ontologies” OR “vocabulary” OR “vocabularies” OR “schema” OR “frame” OR “hierarchy” OR “hierarchies” OR “knowledge representation” OR “body of knowledge”))
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	(Abstract:(“system of systems” OR “systems of systems” OR “system of system” OR “system-of-systems” OR “systems-of-systems” OR “system-of-system”) AND Keywords:(“glossary” OR “glossaries” OR “classification” OR “dictionary” OR “dictionaries” OR “thesaurus” OR “thesauri” OR “taxonomy” OR “taxonomies” OR “ontology” OR “ontologies” OR “vocabulary” OR “vocabularies” OR “schema” OR “frame” OR “hierarchy” OR “hierarchies” OR “knowledge representation” OR “body of knowledge”))

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	(Keywords:("system of systems" OR "systems of systems" OR "system of system" OR "system-of-systems" OR "systems-of-systems" OR "system-of-system") AND Title:("glossary" OR "glossaries" OR "classification" OR "dictionary" OR "dictionaries" OR "thesaurus" OR "thesauri" OR "taxonomy" OR "taxonomies" OR "ontology" OR "ontologies" OR "vocabulary" OR "vocabularies" OR "schema" OR "frame" OR "hierarchy" OR "hierarchies" OR "knowledge representation" OR "body of knowledge"))
	(Keywords:("system of systems" OR "systems of systems" OR "system of system" OR "system-of-systems" OR "systems-of-systems" OR "system-of-system") AND Abstract:("glossary" OR "glossaries" OR "classification" OR "dictionary" OR "dictionaries" OR "thesaurus" OR "thesauri" OR "taxonomy" OR "taxonomies" OR "ontology" OR "ontologies" OR "vocabulary" OR "vocabularies" OR "schema" OR "frame" OR "hierarchy" OR "hierarchies" OR "knowledge representation" OR "body of knowledge"))

Web of Science	TS=((“system of systems” OR “systems of systems” OR “system of system” OR “system-of-systems” OR “systems-of-systems” OR “system-of-system”) AND (“glossary” OR “glossaries” OR “classification” OR “dictionary” OR “dictionaries” OR “thesaurus” OR “thesauri” OR “taxonomy” OR “taxonomies” OR “ontology” OR “ontologies” OR “vocabulary” OR “vocabularies” OR “schema“ OR ”frame“ OR ”hierarchy“ OR ”hierarchies“ OR ”knowledge representation“ OR ”body of knowledge“)) OR TI=((”system of systems“ OR ”systems of systems“ OR ”system-of-systems“ OR “systems-of-systems”) AND (“glossary” OR “glossaries” OR “classification” OR “dictionary” OR “dictionaries” OR “thesaurus” OR “thesauri” OR “taxonomy” OR “taxonomies” OR “ontology” OR “ontologies” OR “vocabulary” OR “vocabularies” OR “schema” OR “frame” OR “hierarchy” OR “hierarchies” OR “knowledge representation” OR “body of knowledge”))
Scopus	TITLE-ABS-KEY ((“system of systems” OR “systems of systems” OR “system of system” OR “system-of-systems” OR “systems-of-systems” OR “system-of-system”) AND (“glossary” OR “glossaries” OR “classification” OR “dictionary” OR “dictionaries” OR “thesaurus” OR “thesauri” OR “taxonomy” OR “taxonomies” OR “ontology” OR “ontologies” OR “vocabulary” OR “vocabularies” OR “schema” OR “frame” OR “hierarchy” OR “hierarchies” OR “knowledge representation” OR “body of knowledge”))
Science Direct	tak((“system of systems” OR “systems of systems” OR “system of system” OR “system-of-systems” OR “systems-of-systems” OR “system-of-system”) AND (“glossary” OR “glossaries” OR “classification” OR “dictionary” OR “dictionaries” OR “thesaurus” OR “thesauri” OR “taxonomy” OR “taxonomies” OR “ontology” OR “ontologies” OR “vocabulary” OR “vocabularies” OR “schema” OR “frame” OR “hierarchy” OR “hierarchies” OR “knowledge representation” OR “body of knowledge”))

B Studies Selected

ID	Title	Authors	Year	Journal
S1	A taxonomy of geospatial services for global service discovery and interoperability	Yuqi Bai and Liping Di and Yaxing Wei	2009	Computers & Geosciences
S2	An ontological approach to simulate critical infrastructures	Alberto Tofani and Elisa Castorini and Paolo Palazzari and Andrij Usov and Cesaire Beyel and Erich Rome and Paolo Servillo	2010	Journal of Computational Science
S3	A Model-Based Approach for Requirements Engineering for Systems of Systems	Holt, J. and Perry, S. and Payne, R. and Bryans, J. and Hallerstede, S. and Hansen, F.O.	2014	IEEE Systems Journal
S4	Model-based failure management for distributed reactive systems	Ermagan, V. and Krüger, I. and Menarini, M.	2007	Lecture Notes in Computer Science
S5	The Role of Ontologies in Emergent Middleware: Supporting Interoperability in Complex Distributed Systems	Blair, G. S. and Bennaceur, A. and Georgantas, N. and Grace, P. and Issarny, V. and Nundloll, V. and Paolucci, M.	2011	Middleware 2011

S6	A semantic security framework for systems of systems	Trivellato, D. and Zannone, N. and Glaundrup, M. and Skowronek, J. and Etalle, S.	2013	International Journal of Cooperative Information Systems
S7	A metamodel and its ontology to guide crisis characterization and its collaborative management	Bénaben, F. and Hanachi, C. and Lauras, M. and Couget, P. and Chapurlat, V.	2008	5th International Conference on Information Systems for Crisis Response and Management (ISCRAM 2008)
S8	Collaborative process design for mediation information system engineering	Truptil, S. and Bénaben, F. and Pingaud, H.	2009	6th International Conference on Information Systems for Crisis Response and Management: Boundary Spanning Initiatives and New Perspectives (ISCRAM 2009)
S9	A service-oriented method for system-of-systems requirements analysis and architecture design	Zhang, Y. and Liu, X. and Wang, Z. and Chen, L.	2012	Journal of Software
S10	Based on ontology methodology to model and evaluate System of Systems (SoS)	He Yan and Zhang Jing and Yue Li-qun and Li Ze-min and Tang Li-jian	2014	9th International Conference on System of Systems Engineering (SoSE 2014)

S11	General taxonomy of system[ic] approaches for analysis and design	Kovacic, S.F.	2005	IEEE International Conference on Systems, Man and Cybernetics
S12	Design of a web-based thesaurus for Systems of Systems Engineering	Barot, V. and Henshaw, M. and Siemieniuch, C. and Dogan, H.	2013	8th International Conference on System of Systems Engineering (SoSE 2013)
S13	A taxonomy-based perspective for systems of systems design methods	DeLaurentis, D.A.	2005	IEEE International Conference on Systems, Man and Cybernetics
S14	On the Use of Description Logic for Semantic Interoperability of Enterprise Systems	Yahia, E. and Yang, J. and Aubry, A. and Panetto, H.	2009	On the Move to Meaningful Internet Systems: Otm 2009 Workshops
S15	Formalisation and mapping of terminologies for Systems of Systems Engineering thesaurus	Dogan, H. and Barot, V. and Henshaw, M. and Siemieniuch, C.	2013	8th International Conference on System of Systems Engineering (SoSE 2013)
S16	A systemic approach to interoperability formalization	Naudet, Y. and Latour, T. and Chen, D.	2008	IFAC Proceedings Volumes (IFAC-PapersOnline)
S17	Collective Intelligence: Toward Classifying Systems of Systems	Ramsbotham,Jr., Alan J.	2009	9th Workshop on Performance Metrics for Intelligent Systems
S18	Developing Systems Engineering Ontologies	Sarder, B. and Ferreira, S.	2007	IEEE International Conference on System of Systems Engineering (SoSE '07)

S19	An Information Semantics Approach for Knowledge Management and Interoperability for the Global Earth Observation System of Systems	Durbha, S.S. and King, R.L. and Younan, N.H.	2008	IEEE Systems Journal
S20	Ontology approach for the interoperability of networked enterprises in supply Chain environment	Lu, Y.a and Panetto, H.a and Gu, X.b	2010	Lecture Notes in Computer Science
S21	A semantic mediation framework for architecting federated ubiquitous systems	Moschoglou, G. and Eveleigh, T. and Holzer, T. and Sarkani, S.	2012	7th International Conference on System of Systems Engineering (SoSE 2012)
S22	Ontology-based active requirements engineering framework	Lee, S.W. and Gandhi, R.A.	2005	12th Asia-Pacific Software Engineering Conference (APSEC '05)
S23	Appropriate modeling and analysis for systems of systems: Case study synopses using a taxonomy	DeLaurentis, D.A.	2008	IEEE International Conference on System of Systems Engineering (SoSE '08)
S24	A taxonomy of perturbations: Determining the ways that systems lose value	Mekdeci, B. and Ross, A.M. and Rhodes, D.H. and Hastings, D.E.	2012	IEEE International Systems Conference (SysCon)
S25	Towards a common system of systems vocabulary	Henrie, M. and Delaney, E.E.	2005	IEEE International Conference on Systems, Man and Cybernetics

S26	Examining survivability of systems of systems	Mekdeci, B. and Ross, A.M. and Rhodes, D.H. and Hastings, D.E.	2011	21st Annual International Symposium of the International Council on Systems Engineering (INCOSE 2011)
S27	Data Fusion Enabled Networks	Vila, V. and Ieee	2007	10th International Conference on Information Fusion,
S28	System of systems integration: Key considerations and challenges	Madni, A.M.a and Sievers, M.b	2014	Systems Engineering
S29	Information systems for crisis response and management	Nieuwenhuis, K.	2007	Lecture Notes in Computer Science
S30	Semantics-Enabled Knowledge Management for Global Earth Observation System of Systems	Durbha, S.S. and King, R.L. and Shah, V.P. and Younan, N.H.	2006	IEEE International Conference on Geoscience and Remote Sensing Symposium (IGARSS 2006)
S31	A Framework for Characterising Complex Systems and System of Systems	Hessami, A.	2013	IEEE International Conference on Systems, Man, and Cybernetics (SMC)

C Data Extracted

ID	Type of publication	KR Approach	Formality	Application domain	Subject of Study	Space of Use
S1	Journal	Taxonomy	Semi-formal	Earth observation	Industrial	Interoperability
S2	Journal	Ontology	Formal	Software Simulation	Industrial	Communication, Interoperability
S3	Journal	Ontology	Semi-formal	Emergency services	Industrial	Support to SoSE
S4	Workshop	Ontology	Formal	Marine observation	Own/Toy	Interoperability
S5	Conference	Ontology	Formal	General	Own/Toy	Interoperability
S6	Journal	Ontology	Formal	Maritime safety and security	Own/Toy	Interoperability
S7	Conference	Ontology	Formal	Crisis management	Industrial	Communication, Interoperability
S8	Conference	Ontology	Formal	Crisis management	Industrial	Interoperability
S9	Journal	Ontology	Formal	Militar	Industrial	Interoperability

S10	Conference	Ontology	Semi-formal	Defense of air-intercept fight mission.	Industrial	Support to SoSE
S11	Conference	Taxonomy	Informal	General	Own/Toy	Communication
S12	Conference	Thesaurus	Semi-formal	General	Experts	Communication
S13	Conference	Taxonomy	Informal	Transportation	Industrial	Support to SoSE
S14	Workshop	Ontology	Formal	Product Data Management	Own/Toy	Interoperability
S15	Conference	Thesaurus	Semi-formal	General	Experts	Communication
S16	Conference	Ontology	Formal	Recommendation Systems	Industrial	Interoperability
S17	Workshop	Ontology	NA	General	None	Communication, Support to SoSE
S18	Conference	Ontology	NA	General	None	Communication
S19	Journal	Ontology	Informal	Earth observation	None	Interoperability
S20	Workshop	Ontology	Semi-formal	Supply Chain	None	Interoperability
S21	Conference	Ontology	NA	General / Smart systems	None	Interoperability
S22	Conference	Ontology	Semi-formal	Militar	Own/Toy	Support to SoSE

S23	Conference	Taxonomy	Informal	Shared-Autonomy in automotive transportation, space and air transportation.	Industrial	Support to SoSE
S24	Conference	Taxonomy	Informal	Maritime security system	Own/Toy	Support to SoSE
S25	Conference	Vocabulary	Informal	General	None	Communication, Support to SoSE
S26	Conference	Taxonomy	Informal	General	None	Support to SoSE
S27	Conference	Ontology	NA	Militar	Own/Toy	Communication, Interoperability
S28	Journal	Ontology	Semi-formal	Earth seismic studies	Own/Toy	Interoperability
S29	Workshop	Taxonomy	NA	Crisis management	Industrial	Communication
S30	Conference	Ontology	Formal	Ocean observing	Own/Toy	Interoperability
S31	Conference	Ontology	Informal	General	None	Support to SoSE

D List of Terms Extracted

ID	List of terms
S1	Service category; services standard; standard version; service binding; service profile; Uniform Resource Name (URN).
S2	N/A
S3	Rule; Source Element; Need; Goal; Capability; Requirement; Use Case; Scenario; Formal Scenario; Semi-formal Scenario; Context; System Context; Stakeholder Context; Constituent System; System of Systems; Virtual; Acknowledged; Collaborative; Directed; Validation View; Analysis Relationship; Context definition view; requirement context view; context interaction view; validation interaction view; requirement description view; definition rule set view; source element view; system of systems requirement process; system of systems requirement engineering process; system of systems requirement management process; SoS requirement development; verification and validation definition process; requirements elicitation process; context process; requirements change process; CS process analysis; requirement control process; requirements monitor process; traceability process
S4	Resend message; Replicate component; Failsafe mode; Architectural strategy; Runtime strategy; Ignore message; Mitigation strategy; Mitigator; Cause; Failure; Effect; Failure origin; Detector; Software Failure; Hardware Failure; Risk level; Harzadous; Potential harzadous; Non harzadous; Accident; Environment; Behavior type; Non occurence behavior; Unexpected behavior; Lost message; QoS; Power over-consumption; Exced bandwidth; Miss deadline; Repetition type; permanent; Transient
S5	N/A
S6	Event; Actor; Place; Time; EventType; ActorType; PlaceType; TimeType; Authority; Role; RoleType; Constraint; Core; View; Type; Temporary
S7	N/A

S8	SS Component; Goods; Natural Site; Civilian Society; People; Event; Risk; Characteristic; Gravity Factor; Complexity Factor; Consequence; Crisis; Actor; Human means; Material means; Resource; Service; Condition; Mediation IS; Service of Mediation; Service of Actor; Orchestrator; Collaborative process; partner lane; partner pool; SIM pool; SIM lane; message flow; data; sequence flow; message flow IN; message flow OUT; sequence flow IN; sequence flow OUT; Partner task; SIM task; start event; intermediate event; end event; gateway; task; sub process; SIM component
S9	Desired Effect, Capability, Location, Performer, Activity, Rule, Resource, Condition, Information, Service Description, Materiel, Service, Service Interface, Skill, Person, Organization, System
S10	History Data; Aim; Capability Index; Functional Characteristic; Non-functional characteristic; System; System Function; System Effectiveness; System Cost; System Quantity; System Relations
S11	Decomposed Solution Form; Undecomposed Solution Form; Simple Component/Entity; Complex Component/Entity; Loosely Bounded Entity Domain; Tightly Bounded Entity Domain
S12	N/A
S13	system type; system control (autonomy); system interaction (connectivity)
S14	N/A
S15	Enterprise Architecture; Systems of Systems; Family of Systems; Whole Systems
S16	Interoperability; Interoperability Existence Condition; Incompatibility; Heterogeneity; Misalignment; Negociation; Homogenization; Bridging; Compensation; Condition; Existence Condition; Indicator; Conformance Point; Anti Pattern; Problem; Solution; Apriori Solution; Aposteriori Solution; Application Condition; System Element; Relation; Structural Relation; Behavioral Relation; Communication; Message; Interface; System; Objective; Model; Metamodel; Representation; System to Build; Environment
S17	Leader-Follower; Swarming (simple); Swarming (complex) Loosely; Homogenous intelligent systems; Heterogeneous intelligent systems; Ad hoc intelligent adaptive systems
S18	N/A
S19	N/A
S20	N/A

S21	N/A
S22	N/A
S23	Resources; Stakeholders; Operations; Policies; Connectivity; System type; System Control
S24	N/A
S25	Complexity; Domain; Domain of interest; Nature of domain; Solution Form; Bounding; Environment
S26	Origin of disturbance; nature of disturbance; intent; disturbance duration; context change
S27	Fusion Information Consumer; fusion problems; knowledge; fusion algorithms
S28	Integration; Stakeholder viewpoint; Certification and accreditation; Structure; Integration resources; Tailoring and reuse; Stakeholders; Configuration management; V&V; Requirements and interface definitions; Risk management; External influences; Mechanisms; Integration Resources
S29	N/A
S30	N/A
S31	Architecture and Hierarchy; Composition and Complexity; Topology and Interfaces; Emergence; Criticality; Performance and Sustainability; Scale and Spread.

E Motivation to Use KR Approaches

Terminology standardization and knowledge sharing
S11: Provide definition to the variety of fields that hold claim to the term systems, and to reduce this group into a set of meaningful related clusters.
S15: Ensure that SoS concepts and terms are consistently interpreted, and provide an artefact that will be of significant assistance to planners of future programmes in SoSE.
S12: A web-based thesaurus system is being designed and implemented by the authors to share expertise.
S18: Provide more consistent and clear terminology to be used in the discipline.
S25: Reduce the confusion around the use of these common SE terms, by presenting a set of terminology that may adequately provide meaning and understanding from a SoSE perspective.
S19: Better information sharing, more effective information management, more intelligent search methods, and smarter decision-making.
S22: Software-intensive systems require an essential way to build a common language that creates a shared understanding between stakeholders and promotes cohesiveness between the information gathered from diverse sources to guide software engineering processes.

SoS Integration
S5: Interoperability is a fundamental problem in distributed systems, and an increasingly difficult given the level of heterogeneity and dynamism exhibited by contemporary systems.
S30: Data exchange and modularization
S16: Interoperability formalization
S28: SoS integration
S1: Promote the global sharing of and interoperability among geospatial service instances.
S20: Interoperation between all enterprise applications involved in an extended supply chain.
S14: Evaluate and formalize interoperability in order to identify semantic gaps between information systems concepts and models.
S6: SoS paradigm has a strong impact on systems interoperability and on the security requirements of the collaborating parties.
S21: Enable automation of system capabilities discovery, selection, and composition between heterogeneous, autonomous and geographically dispersed ubiquitous computing systems. Existing SOA standards are not capable of dealing with web services at a semantic level of expressivity for properly representing and discovering service capabilities.

SoSE Activities
S10: Evaluate SoS.
S23: Traditional engineering methods are not suitable for designing SoS.
S13: Guide design method development and use of SoS by proposing a taxonomy to provide an interface between architecting approaches and design-oriented analysis.
S27: The eventual goal of this research is to develop design principles to guide system architects in recognizing and evaluating system design options to increase survivability / reliability / robustness.
S3: The operational and managerial independence of SoS and CS that can lead to competing and conflicting requirements must be properly controlled and the traditional Req. Engineering approaches, such as ACRE, are unsuitable for SoS field.
S17: Design and characterization of future SoS that exhibit collective intelligence
S9: SoS architecture frameworks usually provide a number of viewpoints with focus on what should be described rather than concrete modeling methods to model SoS architectures. Moreover, it is also often difficult to keep consistency between business concepts and and low level IT requirements. Furthermore, enterprise architecture proposals are often represented in different ways, making difficult to ensure and verify interoperability among models and in the architecture.

SoS Management
S4: An ontology guides the identification of failures and the activation of additional services that mitigate the effects of such failures.
S31: A framework describing a set of attributes that can be used as metrics to characterize SoS.
S26: SoS tend to be larger, more complex systems and operate under more varied context than monolithic systems then a broader definition of disturbance is needed.
S24: Disturbances and disruptions internal and external to systems are a major concern for system architects who are responsible for guarantee robustness and develop survivability design principles for prevention, mitigation and recovery from these issues.
S29: Improve the transfer of scientific results in multiple fields to a particular application domain: disaster and crisis management.
S7: In a crisis context, the notion of adaptability or flexibility of the MIS is an unavoidable requirement and it seems that ontology offers a strong basis to challenge this question.
S2: The understanding of system of critical infrastructures with all their interdependencies is still immature. The study of these complex infrastructure systems demands joint interdisciplinary efforts of researchers, industrial stakeholders and governmental organisations to overcome all the difficulties involved as availability of models and data for the single infrastructures, interoperable simulation of multiple infrastructures, testbeds and benchmarks for protection solutions. The various aspects of infrastructure networks present numerous theoretical and practical challenges in modelling, prediction, simulation and analysis of cause-and-effect relationships in coupled systems. In this context, the adoption of ontologies allow both an uniform modelling of heterogeneous infrastructures and the easy representation of inter-domain dependencies.
S8: Deducing the available services to the crisis response and the execution order of the selected services.

F Quality Assessment

ID	QC1	QC2	QC3	QC4	QC5	QC6	QC7	QC8	QA Result (%)
S1	2	2	2	2	2	2	2	2	100
S2	2	2	2	2	1	2	2	2	93.75
S3	2	2	2	2	1	2	2	2	93.75
S4	2	2	2	2	2	2	0.5	2	90.625
S5	2	2	2	2	2	2	0.5	2	90.625
S6	2	2	2	2	2	2	0.5	2	90.625
S7	2	1	2	1	2	2	2	2	87.5
S8	2	0	2	2	2	2	2	2	87.5
S9	2	1	2	2	2	1	2	2	87.5
S10	2	1	1	2	2	2	2	2	87.5
S11	2	2	2	2	2	1	0.5	2	84.375
S12	2	1	2	2	2	1	1.5	2	84.375
S13	2	1	2	2	2	2	2	0	81.25
S14	2	1	2	2	2	1	0.5	2	78.125
S15	2	1	1	2	2	1	1.5	2	78.125
S16	2	0	2	2	2	2	2	0	75
S17	2	2	2	2	1	0	0	2	68.75
S18	2	0	2	2	2	0	0	2	62.5
S19	2	1	1	2	2	0	0	2	62.5
S20	2	1	1	2	2	0	0	2	62.5
S21	2	0	2	2	2	0	0	2	62.5
S22	1	1	1	2	1	1	0.5	2	59.375
S23	1	1	1	2	1	1	0.5	2	59.375
S24	2	1	1	1	1	1	0.5	2	59.375
S25	2	0	2	1	2	0	0	2	56.25
S26	1	2	1	2	1	0	0	2	56.25
S27	1	1	1	1	1	1	0.5	2	53.125
S28	2	0	1	2	1	2	0.5	0	53.125
S29	2	1	1	1	1	0	0	2	50
S30	1	0	0	1	2	1	0.5	2	46.875
S31	2	1	1	0	1	0	0	2	43.75