A Systematic Review about Requirements Engineering Processes for Multi-Agent Systems

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Abstract: Requirements engineering is a crucial phase for the software development process, including multi-agent systems. This particular kind of software is composed by agents, autonomous and pro-active entities which can collaborate among themselves to achieve a given goal. However, multi-agent systems have some particular requirements that are not normally found in other software. Taking this into consideration, this paper aims to determine the actual state of the development processes which support requirements engineering for multi-agent systems by means of a systematic review, highlighting the requirements engineering coverage and its support to the BDI model.

1 INTRODUCTION

Agents technology is a software paradigm that provides agents abstractions for distribute and heterogeneous open systems development (Gan et al., 2020). An agent is an autonomous, flexible, and pro-active process (Vicari and Gluz, 2007) that can act in its environment without being commanded by external entities (Wooldridge and Jennings, 1995). Thus, software agents are characterized as being autonomous, having social skills, reactivity and pro-activity (Hajduk et al., 2018). Moreover, agents can collaborate to achieve their goals (Deloach and Wood, 2000).

Multi-agent systems (MAS) are composed by a number of agents interacting among themselves (Wooldridge, 2009). This kind of system has received great attention from scholars in several areas, including computer science and civil engineering, as a way to solve complex problems, by dividing them into smaller tasks (Labba et al., 2015) (Dorri et al., 2018). The use of MAS is present in several applications, such as complex systems modelling, intelligent networks, and computer networks (Dorri et al., 2018).

Adopting an agent-oriented world view demonstrates that most problems demand or involve multiple agents, because they represent multiple perspectives, because its application defines a decentralized nature of the problem, or because there are multiple areas of actuation in the system (Jennings, 1999).

However, developing this kind of system brought challenges to the software engineering. Thus, a new area arose mixing features from both software engineering and artificial intelligence areas, called AOSE - Agent-Oriented Software Engineering. The goals of AOSE include producing methodologies, processes, techniques, modeling languages, and tools for MAS development (Cervenka and Trencansky, 2007) (Slhoub et al., 2019), in order to increase the chances of success in MAS development (Slhoub et al., 2019).

AOSE is also concerned in adapting requirements engineering (RE) – an area of software engineering focused on eliciting, analysing, specifying, and validating software requirements to ensure the correct understanding of what needs to be developed (Fuentes-Fernández et al., 2009). RE performs a crucial function to the development of any software, since, if the software needs are not correctly understood, the project will not satisfy those for whom it is intended.

According to (Dorri et al., 2018) software engineering on MAS demands the specification of those agent behaviors needed to provide documented requirements to the project and implementation phases. Rodriguez in (Rodriguez et al., 2011) also states that the requirements modeling in MAS requires abstractions, techniques, and notations that had been particularly adapted for this kind of domain.

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Taking this in consideration, we are concerned in how RE was specifically adapted to the development of this kind of system. We are particularly interested in how the RE was adapted to focus on requirements relative to the BDI model (Bratman et al., 1987), a model for programming intelligent agents that is based on the beliefs, desires, and intentions of each agent and that, according to (Singh et al., 2016) has been widely used in MAS development.

Thus we performed a systematic review to determine the state-of-art of RE for MAS. In this review, we retrieved studies that propose process/methodologies (or extensions of them) for MAS development that involves RE in somehow. We intend with this review to understand how RE is supported by the existing processes and to determine its gaps, in such a way to serve as a basis for future works.

This paper is organized as follows. Section 2 contains the background. Section 3 contains related works. The research method is described in Section 4. In Section 5, the results are presented and discussed. Threats to the validity were described in Section 6 and, in Section 7, we present the conclusion and future works.

2 BACKGROUND

2.1 Requirements Engineering

According to (Berenbach et al., 2009), the RE goals are: (I) to identify software requirements, (II) to analyse requirements in order to classify them and to derive additional requirements, as well as to solve conflicts among them (III) to document requirements, and (IV) to validate the documented requirements.

In SWEBOK (Bourque et al., 2014) - a reference book in the area - is stated that the RE process cover four main subareas: (I) Requirements Elicitation; (II) Requirements Analysis; (III) Requirements Specification; and (IV) Requirements Validation.

Requirements elicitation investigates how to extract requirements and which are its origins. Requirements analysis aims to detect and solve conflicts among the requirements, to discover the system boundaries. Requirements specification, by its turn, produce requirements documents that can be systematically reviewed, evaluated, and approved. Finally, requirements validation evaluates requirements documents to ensure that the requirements be understandable, consistent, and complete.

2.2 Belief-Desire-Intention Model

The Belief-Desire-Intention (BDI) model is a software model developed to programming intelligent agents. It includes beliefs, desires, and intentions in the agent architecture (Bratman et al., 1987).

Beliefs represent the information state the agent owns, i. e., what he believes to be true about the environment, about itself, and about other agents. Desires represent the agents motivational state. They represent the goals or situations the agent would like to achieve. Finally, the intentions represent desires the agent believes he can achieve and take actions to achieve them (Rao and Georgeff, 1995).

This model allows to the agents a more complex behavior than the reactive models, without the computational overload of the cognitive architectures. Moreover, it is easier to specify knowledge by means of this model (Larsen, 2018).

According (Herzig et al., 2017), concepts of belief and goal perform a central role in the conception and implementation of autonomous agents. The concept of BDI, consider mental attitudes to be fundamental to the agents, where the beliefs are adapted to the environment truths, while in the intentions, the agents try to make the environment to correspond to its goals.

3 RELATED WORKS

We discovered some studies that aimed to identify and to evaluate methodologies/processes in the AOSE area. However, these studies do not follow a systematic vision, they are informal literature reviews with subjective comparison criteria.

The study of (Henderson-Sellers and Gorton, 2002) discusses the state of AOSE methodologies and how to turn them into acceptable products for the industry. This study also present a methodology classification, dividing them in (I) independent of goal-oriented methodologies and (II) extensions of goal-oriented methodologies to give support to the agent concepts. The study of (Sudeikat et al., 2004) evaluates agent-oriented software methodologies. The work proposes a comparison frame with four selection groups: concepts, notations, process, and pragmatics. This proposal was evaluated comparing the methodology adequation and its development capacity. For this comparison were used three methodologies, MaSE (an old version of O-MaSE), Tropos, and Prometheus. Finally, the work of (Cernuzzi et al., 2005) investigates the AOSE methodologies coverage regarding software engineering concepts. However, besides this work not following a systematic vision, it does not present several methodologies and does not have a wide coverage of requirements engineering.

Regarding systematic reviews, we found the study of (Blanes et al., 2009a) that developed a review about requirements engineering in multi-agent systems development. However, this study tried to verify which modeling techniques were applied in the requirements engineering for MAS. On the other hand, our work has as its goal to identify the coverage of the requirements engineering process regarding the SWEBOK stages and its adequation to the BDI model.

4 RESEARCH METHOD

A systematic literature review (SLR) is a research technique whose purpose is identifying, selecting, evaluating, interpreting, and summarizing the available studies considered relevant to the research theme or phenomenon of interest (Kitchenham and Charters, 2007). This technique searches for primary studies related to the theme and provides a deeper synthesis about the data obtained from these studies (Kitchenham and Brereton, 2013).

A SLR has as its basis a protocol previously defined, that formalizes its execution, beginning by the stipulation of the research questions, passing by establishing the studies inclusion and exclusion criteria, selecting the digital basis for the extraction of works related with the keywords applied during the search in these basis, and concluding with the definition of how the results will be presented (Biolchini et al., 2005).

Our review had as its goal to establish the state-of-art of the process/methodologies for MAS development that support in somehow requirements engineering for this kind of system. Our main interest is about how these processes identify and specify the BDI model features in the requirements engineering phase.

4.1 The Research Questions

We defined four research questions to this review. The first research question (RQ1) aims to identify which methodologies/processes support RE for MAS.

The second research question (RQ2) was defined to identify the coverage of the RE by these methodologies. We believe that with this question we can discover possible gaps in the area and that this will allow for future research.

The third research question (RQ3) aims to verify which methodologies support the BDI model. As we stated before, this is a consolidated model in the MAS development and we believe it aggregates better reliability in using the methodologies that support it.

Finally, the fourth question (RQ4) has as its goal to show a wider view of the area needs and to focus on the points that can be approached in future works.

The four research questions are listed below:

- **RQ1:** Which methodologies for the MAS development support a specific requirements engineering (RE) life cycle to this kind of system?
- **RQ2:** Which is the coverage of the requirements engineering by these methodologies taking as a basis the subareas defined by SWEBOK (Bourque et al., 2014)?
- **RQ3:** Which of these methodologies focus on the BDI model during the requirements engineering?
- **RQ4:** Which are the existing gaps in the methodologies that support RE for MAS?

4.2 Identifying and Selecting Primary Studies

To recover relevant works for this study, we built a String containing a set of keywords based on the research questions. This String was adapted to the particularities of each bibliographic basis.

To perform this review, we used bibliographic bases which (I) have a search mechanism based on web; (II) have a mechanism able to use keywords; (III) contain documents from the computer science area; and (IV) their data bases are updated regularly. It is important to highlight that we do not limited the period in which the studies were published

In addition, we have included a book (Cossentino et al., 2014) about methodologies for MAS, as well as other classical and known studies. These studies were manually selected by a specialist in the area because we considered that they would not be selected in the search String as they do not present in its title, abstract, and keywords topics related to the requirements engineering, since they are not processes focused on RE, though their life cycles encompass the RE area.

In Table 1 we show the generic String used in the basis. In addition to the search String, we used manual filters in the bibliographic bases. We considered necessary to apply these manual filters because, in some bases, the results obtained were high and many of the studies returned were outside the scope.

For ACM library it was used the filter “Title/Abstract/keywords”; for Engineering Village, “Subject/Title/Abstract”; for IEEE Xplore, All metadata, filters suggested by the base software “agents and multi-agent systems"; for Science Direct, "Subject/Title/Abstract" and "Title/Abstract/keywords" and commands "multiagent OR multi-agent OR agent-based"; for Scopus, "Title/Abstract/keywords"; and for Springer Link it were applied the filters "Filter of the area: Computer science", "Filter of the subarea: Software Engineering and Artificial intelligence".

Table 1: String generic.

String	Conector
("multiagent" OR "multi-agent" OR "multi agent" OR "agent-based" OR "agent society"	AND
("methodology" OR "method" OR "process")	AND
("requirements engineering" OR "requirements elicitation" OR "requirements modeling" OR "requirements analysis" OR "requirements specification")	

4.3 Inclusion and Exclusion Criteria

The selection criteria have as its goal to identify the primary studies that provide contents to answer the research questions. Thus, firstly the studies were analysed with basis on the title, abstract, and keywords. If there were still doubts about the final classification of a study in relation to the inclusion or exclusion criteria, a specialist would be consulted. These criteria are described in the Table 2.

Table 2: Inclusion and Exclusion Criteria.

Criterion	ID	Description
Inclusion	IC1	Does the study presents a methodology or an extension of a methodology for multi-agent systems that contemplates at least one of the requirements engineering subareas defined in the SWEBOK?
Exclusion	EC1	Studies that cover a methodology already included in more recent work.
	EC2	Studies that are not a paper or a chapter of book.
	EC3	Studies with less than 6 pages.
	EC4	Studies that boils down to a case study or methodology evaluation.
	EC5	Studies that boils down to a comparison of methodologies.
	EC6	Studies that do not present a methodology (or extension of a methodology) for multi-agent systems that contemplate at least one of requirements engineering subareas from SWEBOK.
	EC7	Studies that concentrate in other areas of Software Engineering.
	EC8	Studies that boils down to the development of a system.
	EC9	Studies that present a methodology or extension of a methodology created only to a kind of specific application.

4.4 Studies Quality Assessment

We defined two quality criteria to evaluate the relevance of the studies to the scope of this research. These criteria were not used to the exclusion of studies, only for the ranking of studies more relevant. Next we described the two qualitative criteria and the score attributed for each criterion defined.

1. **QC1:** The work supports the BDI model?
   Yes (Y): the work fully supports the BDI model;
   Partly (P): the work supports at least one of the features of the BDI model;
   Not (N): the work does not support the BDI model.
2. **QC2:** the work applies some empirical study (experiment, case study, etc.)?
   Yes (Y): the study applies some empirical study;
   Not (N): the study does not apply some empirical study.

To establish a quality general index of the selected studies, we attributed scores to each criterion defined, where Yes (Y) corresponds to 1 score, Partly (P) 0.5 score and Not (N) 0 score.

The Table 3, shows the score of each selected study. We noticed that only three studies ((Jo and Einhorn, 2005), (Mylopoulos et al., 2013), and (Morreale et al., 2006)) reached the maximum ranking of 2 scores.

On the other hand, some studies got 0 score ((Alonso et al., 2004), (Hajer et al., 2009), (Bokma et al., 1994), and (González-Moreno et al., 2014)), though these studies did not achieve any score, they were kept because the qualitative criteria were used only for ranking the studies, not for eliminate them.

4.5 Data Extraction Strategy

When the studies selection process was concluded, the basic information of each paper was registered for data extraction. The extraction was performed using the Google Spreadsheet to capture all the information of each work included, allowing the posterior synthesis. The data extracted from the included works were analysed in order to answer the research questions. In Section 5, these results were exposed and discussed.

Table 3: Quality Indexes of the Studies.

Study	*QC1*	*QC2*	*Total*
(Ulfat-Bunyadi et al., 2018)	0.50	0.00	0.50
(Abushark et al., 2016)	0.50	1.00	1.50
(Ribino et al., 2013)	1.00	0.00	1.00
(Liu et al., 2011)	0.00	1.00	1.00
(Argente et al., 2011)	0.50	0.00	0.50
(Sen and Hemachandran, 2010)	0.50	1.00	1.50
(Blanes et al., 2009b)	0.50	1.00	1.50
(Huiying and Zhi, 2009)	0.50	0.00	0.50
(Fuentes-Fernández et al., 2009)	0.50	1.00	1.50
(Rodriguez et al., 2009)	0.50	1.00	1.50
(Bryl et al., 2008)	0.50	0.00	0.50
(Lee and Lee, 2008)	0.50	1.00	1.50
(Ranjan and Misra, 2006)	0.50	0.00	0.50
(Lindoso and Girardi, 2006)	0.50	0.00	0.50
(Shen et al., 2005)	0.50	0.00	0.50
(Alonso et al., 2004)	0.00	0.00	0.00
(Jo and Einhorn, 2005)	1.00	1.00	2.00
(Mylopoulos et al., 2013)	1.00	1.00	2.00
(Marcio Cysneiros and Yu, 2003)	1.00	0.00	1.00
(Chiung-Hui Leon Lee and Liu, 2002)	0.50	0.00	0.50
(Banach, 2010)	0.50	0.00	0.50
(Morreale et al., 2006)	1.00	1.00	2.00
(Murray, 2004)	0.00	1.00	1.00
(Cossentino et al., 2010)	0.50	0.00	0.50
(Bresciani and Donzelli, 2003)	0.50	1.00	1.50
(Sen and Jain, 2007b)	0.50	1.00	1.50
(Hsieh et al., 2008)	0.00	1.00	1.00
(Sutcliffe, 2001)	0.50	1.00	0.00
(Sen and Jain, 2007a)	0.50	1.00	1.50
(Haumer et al., 1999)	0.50	1.00	1.50
(Longbing Cao et al., 2004)	0.50	1.00	1.50
(Wilmann and Sterling, 2005)	0.50	0.00	0.50
(Wu et al., 2010)	0.50	1.00	1.50
(Liu and Li, 2015)	0.00	1.00	1.00
(Hajer et al., 2009)	0.00	0.00	0.00
(Ashamalla et al., 2017)	0.50	1.00	1.50
(Bokma et al., 1994)	0.00	0.00	0.00
(Hilaire et al., 2012)	0.50	0.00	0.50
(Gaur and Soni, 2012)	0.50	1.00	1.50
(Passos et al., 2015)	0.50	1.00	1.50
(Wang et al., 2013)	0.50	1.00	1.50
(Ronald et al., 2012)	0.50	1.00	1.50
(Domann et al., 2014)	0.00	1.00	1.00
(Cernuzzi et al., 2014)	0.50	0.00	0.50
(Cossentino and Seidita, 2014)	0.00	1.00	1.00
(González-Moreno et al., 2014)	0.00	0.00	0.00
(Bonjean et al., 2014)	0.00	1.00	1.00
(DeLoach and Garcia-Ojeda, 2014)	0.50	0.00	0.50
(Padgham et al., 2014)	1.00	0.00	1.00
(Caire et al., 2004)	0.50	1.00	1.50
(Cao, 2015)	0.50	0.00	0.50
(Glaser, 1997)	1.00	0.00	1.00
(Iglesias et al., 1998)	1.00	0.00	1.00
(Lind, 2001)	0.00	1.00	1.00

4.6 Conducting the Review

The conduction of this systematic review was performed between the months of February and May of 2020. We defined four stages for the studies selection: (I) executing the search String in the bibliographic bases; (II) removing the duplicated studies; (III) applying the inclusion and exclusion criteria to the works; and (IV) reading and extracting the information of the remaining studies of the Stage (III). The studies were read by two reviewers in consultation with a specialist in the area.

In Stage 1, the search String was executed in the bibliographic bases selected for this review. The overview of this stage can be observed in Figure 1. The conduction began analysing the 1060 works imported from the selected bibliographic bases.

In Stage 2, a total of 247 duplicated studies were removed. In Stage 3, there were applied the inclusion and exclusion criteria based on the reading of the title, abstract, and keywords, resulting in the selection of 53 studies considered promising.

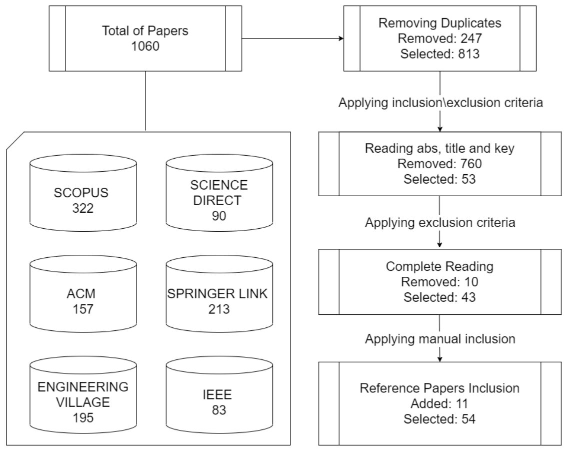

Figure 1: Search process.

To avoid the selection of works that are not fitted in the scope of this review, the 53 studies, selected in the third stage, were completely read, what resulted in the exclusion of 10 works, totalling 43 selected works. The rejected works in this stage were inside of two exclusion criteria:

1. Works that concentrate in other Software Engineering areas: the works excluded that were inside on this criterion were methodologies that worked with MAS only in posterior stages to the requirements engineering. The requirements engineering was performed in a traditional way, not focusing on any particular feature of MAS.
2. Works that cover a methodology already included in a work: for this criterion we selected the most recent work in such a way we can understand the current state of the methodology.

At the end of the conduction Stage, the manually selected studies ((Cernuzzi et al., 2014), (Cossentino and Seidita, 2014), (González-Moreno et al., 2014), (Bonjean et al., 2014), (DeLoach and Garcia-Ojeda, 2014), (Padgham et al., 2014), (Caire et al., 2004), (Cao, 2015), (Glaser, 1997), (Iglesias et al., 1998), (Lind, 2001)) were added to the set of papers searched in the bases, according with defined in Section 4.2. This resulted in a total of 54 accepted studies.

4.7 Data Extraction

For data extracting in the accepted works, we read them all and tried to identify which SWEBOK RE subareas each work covers, whether the methodology proposed in the study has a well-defined life cycle, whether the RE presented in the study is adequate for MAS, and whether the study supports the BDI model.

The conduction of this stage was performed in pairs, where each researcher read the paper and extracted the information about the issues cited previously. The conflicts between the researchers were decided by a specialist in the area.

5 RESULTS

The relevant information of the selected studies was obtained using the data extraction spreadsheet. The evidence found about each research question are discussed in the next subsections.

5.1 Analysis of the Research Questions

In this section we answered the research questions of this study and we discussed the results achieved.

Research Question 1: To answer this question, we found 54 methodologies which approached RE for MAS. These studies can be observed in Table 4.

Research Question 2: From the 54 selected studies we observed that all of them present Requirements Engineering fit for multi-agent systems. Thus, we extracted which RE sub-areas defined in SWEBOK (Bourque et al., 2014) are supported by these studies.

Table 4 shows the 54 studies and the sub-areas that they support. Great part of these studies, 46 in the total, support the sub-area of requirements analysis. While 31 of them support the sub-area of requirements specification.

The sub-area of requirements elicitation, by its turn, is supported by 16 studies. Finally, the sub-area of requirements validation has the lower number of studies, with only 3 of the total.

We also observed that, from these studies, only the ADELFE methodology (Bonjean et al., 2014) supports the four RE sub-areas (elicitation, analysis, specification, and validation).Moreover, the elicitation in the ADELFE methodology is not suitable for MAS, being applied a traditional elicitation. The features suitable for a MAS began to be presented in the analysis stage. However, this stage does not present the means for validating the documents specific for MAS. ADELFE validates only documents present in a traditional requirements engineering.

Another important fact that we noticed in the extraction is that only 30 studies presented some empirical experiments for the validation of the methodology.

Research Question 3: We tried to identify which methodologies support the BDI model. We observed that most part of the studies, 35 in the total, support partially the BDI model, i. e., they identify at least one of the features of this model.

These features are: agent beliefs; agent goals/desires; and agent intentions. However, it is necessary to state that the majority of these works do not cite explicitly the BDI model, most of them are goal-oriented methodologies, i. e., they focus on just in one feature of the BDI model and they do not necessarily use this model, but the fact that these studies identify one of the features is useful for our research.

Agents goals were the most identified feature, in most cases in isolation. There are studies that identify intentions, however we noticed that beliefs and intentions are not identified in isolation, they are always accompanied by the identification of their goals.

Another issue to be highlighted is that 11 studies do not present support to the BDI model and only 8 present support for all these features in at least one stage of their requirements engineering. Table 5 presents the methodologies coverage regarding their support to the BDI model.

Research Question 4: We noticed that only three studies cover the validation sub-area in their RE cycle. It demonstrates that the majority of the methodologies do not care with this phase that is so important to the systems quality.

We also noticed that just one study covers the four sub-areas of RE in its cycle (Bonjean et al., 2014). On the other hand, this study does not support the BDI model, what demonstrates a gap and the need of the proposition of a methodology containing a requirements engineering phase that supports the BDI model.

Regarding the BDI model coverage, we understand that the support to just 8 studies from a total of 54 is a low number. Moreover, just two methodologies have as their focus to cover this model ((Jo and Einhorn, 2005), (Ribino et al., 2013)) and none of them cover elicitation and validation, what highlights a gap in the RE for MAS area.

Other point that we could identify as a neglect is that, among the methodologies that support BDI, only the Tropos methodology (Mylopoulos et al., 2013) covers the requirements elicitation and just the methodology proposed by Cysneiros (Marcio Cysneiros and Yu, 2003) includes requirements validation. It demonstrates that most of the methodologies that support BDI focus on the requirements analysis and specification and that, besides these areas, there is space to be explored in the elicitation and validation areas.

Table 4: Methodologies/Processes that support RE for MAS and its coverage with relation to the SWEBOK subareas.

Methodology	Elicitation	Analysis	Specification	Validation
KAOS Extension (Ulfat-Bunyadi et al., 2018)		✓	✓	
JAAMAS (Abushark et al., 2016)			✓	
Patrizia Ribino (Ribino et al., 2013)			✓	
AGSIRA (Liu et al., 2011)		✓	✓	
GORMAS (Argente et al., 2011)		✓	✓	
ATABGE (Sen and Hemachandran, 2010)	✓			
RE4Gaia (Blanes et al., 2009b)		✓		
Xu Huiying (Huiying and Zhi, 2009)		✓	✓	
REG for AOSE (Fuentes-Fernández et al., 2009)	✓	✓		
Extension GAIA (Rodriguez et al., 2009)		✓		
B-Tropos (Bryl et al., 2008)	✓	✓	✓	
JONGWON LEE (Lee and Lee, 2008)		✓		
Prabhat Ranjan (Ranjan and Misra, 2006)	✓	✓	✓	
SRAMO (Lindoso and Girardi, 2006)		✓		
Zhiqi Shen (Shen et al., 2005)		✓		
SONIA (Alonso et al., 2004)		✓	✓	
BDI ASP (Jo and Einhorn, 2005)		✓		
Tropos (Mylopoulos et al., 2013)	✓	✓	✓	
Cysneiros (Marcio Cysneiros and Yu, 2003)		✓	✓	✓
Chiung-Hui (Chiung-Hui Leon Lee and Liu, 2002)	✓	✓		
KAOS (Banach, 2010)		✓	✓	
PRACTIONIST (Morreale et al., 2006)		✓	✓	
Murray (Murray, 2004)			✓	
ASPECS (Cossentino et al., 2010)		✓	✓	
REF (Bresciani and Donzelli, 2003)		✓	✓	
Sen and Jain (Sen and Jain, 2007b)	✓			
Hsieh et al. (Hsieh et al., 2008)		✓	✓	
Sutcliffe (Sutcliffe, 2001)		✓	✓	
Agile Sen and Jain (Sen and Jain, 2007a)	✓			
CREWS-EVE (Haumer et al., 1999)	✓		✓	✓
Cao et al. (Longbing Cao et al., 2004)		✓	✓	
HOMER (Wilmann and Sterling, 2005)	✓			
Wu et al. (Wu et al., 2010)	✓			
Liu and Li (Liu and Li, 2015)		✓		
Mahmoud et al. (Hajer et al., 2009)		✓		
Ashamalla et al. (Ashamalla et al., 2017)	✓	✓		
Consensus (Bokma et al., 1994)		✓	✓	
Hilaire et al. (Hilaire et al., 2012)		✓		
Gaur and Soni (Gaur and Soni, 2012)		✓		
Passos et al. (Passos et al., 2015)	✓	✓		
PLANT (Wang et al., 2013)		✓	✓	
Ronald et al. (Ronald et al., 2012)		✓	✓	
aMIAC (Domann et al., 2014)		✓	✓	
GAIA (Cernuzzi et al., 2014)		✓	✓	
PASSI (Cossentino and Seidita, 2014)	✓	✓	✓	
INGENIAS-SCRUM (González-Moreno et al., 2014)	✓	✓	✓	
ADELFE (Bonjean et al., 2014)	✓	✓	✓	✓
O-MaSE (DeLoach and Garcia-Ojeda, 2014)		✓	✓	
PROMETHEUS (Padgham et al., 2014)		✓		
MESSAGE (Caire et al., 2004)		✓	✓	
OSOAD (Cao, 2015)		✓		
COMOMAS (Glaser, 1997)		✓		
MAS-COMMONKADS (Iglesias et al., 1998)		✓	✓	
MASSIVE (Lind, 2001)	✓	✓	✓	
Total	16	46	31	3

Table 5: Coverage of methodologies/Processes regarding the BDI model support.

Methodology	Belief	Desire (Goal)	Intention	Not support
KAOS Extension (Ulfat-Bunyadi et al., 2018)		✓	✓	
JAAMAS (Abushark et al., 2016)		✓		
Patrizia Ribino (Ribino et al., 2013)	✓	✓	✓	
AGSIRA (Liu et al., 2011)		✓		
GORMAS (Argente et al., 2011)		✓		
ATABGE (Sen and Hemachandran, 2010)		✓		
RE4Gaia (Blanes et al., 2009b)		✓		
Xu Huiying (Huiying and Zhi, 2009)		✓	✓	
REG for AOSE (Fuentes-Fernández et al., 2009)		✓		
Extension GAIA (Rodriguez et al., 2009)		✓		
B-Tropos (Bryl et al., 2008)		✓		
JONGWON LEE (Lee and Lee, 2008)		✓		
Prabhat Ranjan (Ranjan and Misra, 2006)		✓		
SRAMO (Lindoso and Girardi, 2006)		✓		
Zhiqi Shen (Shen et al., 2005)		✓		
SONIA (Alonso et al., 2004)				✓
BDI ASP (Jo and Einhorn, 2005)	✓	✓	✓	
Tropos (Mylopoulos et al., 2013)	✓	✓	✓	
Cysneiros (Marcio Cysneiros and Yu, 2003)	✓	✓	✓	
Chiung-Hui (Chiung-Hui Leon Lee and Liu, 2002)		✓		
KAOS (Banach, 2010)		✓		
PRACTIONIST (Morreale et al., 2006)	✓	✓	✓	
Murray (Murray, 2004)				✓
ASPECS (Cossentino et al., 2010)		✓		
REF (Bresciani and Donzelli, 2003)		✓		
Sen and Jain (Sen and Jain, 2007b)		✓		
Hsieh et al. (Hsieh et al., 2008)				✓
Sutcliffe (Sutcliffe, 2001)		✓		
Agile Sen and Jain (Sen and Jain, 2007a)		✓		
CREWS-EVE (Haumer et al., 1999)		✓		
Cao et al. (Longbing Cao et al., 2004)		✓		
HOMER (Wilmann and Sterling, 2005)		✓		
Wu et al. (Wu et al., 2010)		✓		
Liu and Li (Liu and Li, 2015)				✓
Mahmoud et al. (Hajer et al., 2009)				✓
Ashamalla et al. (Ashamalla et al., 2017)		✓		
Consensus (Bokma et al., 1994)				✓
Hilaire et al. (Hilaire et al., 2012)		✓		
Gaur and Soni (Gaur and Soni, 2012)		✓		
Passos et al. (Passos et al., 2015)		✓		
PLANT (Wang et al., 2013)		✓		
Ronald et al. (Ronald et al., 2012)		✓		
aMIAC (Domann et al., 2014)				✓
GAIA (Cernuzzi et al., 2014)		✓		
PASSI (Cossentino and Seidita, 2014)				✓
INGENIAS-SCRUM (González-Moreno et al., 2014)				✓
ADELFE (Bonjean et al., 2014)				✓
O-MaSE (DeLoach and Garcia-Ojeda, 2014)		✓	✓	
PROMETHEUS (Padgham et al., 2014)	✓	✓	✓	
MESSAGE (Caire et al., 2004)		✓		
OSOAD (Cao, 2015)		✓		
COMOMAS (Glaser, 1997)	✓	✓	✓	
MAS-COMMONKADS (Iglesias et al., 1998)	✓	✓	✓	
MASSIVE (Lind, 2001)				✓
Total	8	43	11	11

6 THREATS TO VALIDITY

During the planning and execution of this review, some factors were characterized as threats to the research validity. The potential threats are discussed to orient the interpretation of this work:

1. **Construct Validity:** The reliability of the search string defined to select relevant works can be a threat to the construct. To minimize this threat the string was calibrated with the execution of several tests and the area expert was consulted about the most used terms.
2. **Internal Validity:** A possible threat could have arisen from the individual interpretation of each researcher, something that could have led to the exclusion of relevant studies. To minimize this threat, the protocol of this review was strictly followed, considering mainly the inclusion and exclusion criteria. When necessary, a researcher with experience in this area was consulted to reach a consensus about the acceptance of the identified studies.

3. **External Validity:** Another possible threat is that some studies could not have been found because it does not contain keywords defined in the search string. To minimize this threat, the book "Handbook on Agent-Oriented Design Processes" (Cossentino et al., 2014) was used as research source and some classical papers were manually selected by a specialist in the area. To complement the research we performed a manual search in the methodologies found aiming to ensure the use of studies with the most recent version.
4. **Coverage Validity:**
   Regarding the possible papers that were not captured by our String, we intend, as a future work, to apply the snowballing technique trying to find more relevant papers. Another issue is that the snowballing technique can allow us to find more papers about the analysed methodologies, since in this analysis we focused only on the last paper of each methodology and this practice may not fully guarantee a complete coverage of the methodology.
5. **Conclusion Validity:** In spite of following a systematic protocol, systematic reviews are subject to human error, especially in the data extraction from papers. To mitigate this threat, the data extraction was performed by two independent researchers following the strategy defined in subsection 4.7 and, in case of divergences, a specialist in the area was consulted.

7 CONCLUSIONS AND FUTURE WORK

In this systematic review, we answered the research questions about which methodologies for multi-agent systems support the requirements engineering life cycle, which is the coverage of requirements engineering in these methodologies, and which of them focused on the BDI model. This way, aiming to search and categorize the studies directly related to the theme and to support posteriorly the development of new scientific researches in the area.

This revision was carried out by two reviewers. A third specialist reviewer had as its function to decide about the conflicts. The review phases were composed by the protocol definition, conduction of the review, and studies extraction.

The initial search returned 1060 studies. The application of the inclusion and exclusion criteria resulted in the selection of a total of 43 studies. After the inclusion of the studies manually selected we obtained a total of 54 studies.

Regarding the requirements engineering life cycle, we identified 54 studies that support at least one of the requirements engineering subareas. From these studies, we observed that only 31 of the total present a well-defined RE life cycle.

The synthesis of the data guided us to some interesting observations. Among them, we noticed that only 3 studies support the requirements validation subarea ((Bonjean et al., 2014), (Marcio Cysneiros and Yu, 2003), (Haumer et al., 1999)). We also noticed that only the ADELFE methodology (Bonjean et al., 2014) covers the four requirements engineering sub-areas. And, finally, that only 8 methodologies support the BDI model.

We identified some gaps that demonstrate the need of specific studies to multi-agent systems. Among them, there is the need of proposing a methodology that covers the four requirements engineering subareas, considering that ADELFE methodology (Bonjean et al., 2014) is specific for adaptive MAS and that it does not support the BDI model. Another identified gap is the weak coverage of the validation sub-area, present in just three studies. We also noticed that none methodology covers the four requirements engineering sub-areas with support to the BDI model.

That said, as a future work, we will propose a requirements engineering process for multi-agents systems, supporting and containing guidelines for the four requirements engineering sub-areas and with support to the BDI model, as well. This work is already in an advanced stage. We also intend to extend this process in such a way that it encompasses all the development life cycle of multi-agent systems with focus on the BDI model.

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