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A semi-automated system for interoperability assessment: an ontology-based approach

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Abstract: A plethora of approaches to assess the ability of companies to interoperate can be found in the literature. Nevertheless, most of the current assessment approaches are following manual-conducted processes, which can be laborious, time-consuming and costly. Therefore, this paper aims at developing a knowledge-based system for supporting an interoperability assessment process using an ontology as its knowledge model. The resulting system allows identifying potential interoperability problems and related solutions based on the knowledge model including information of the assessed enterprise(s). A real business case is presented for evaluating the proposed approach.

Keywords: enterprise interoperability; interoperability assessment; knowledge-based system; ontology; ontology-based system

Introduction

Enterprise Interoperability is a multidimensional issue that can concern different levels of the enterprise (Vernadat 2010), (Jardim-Goncalves et al. 2013). In the past years, the development of interoperability has been considered as a scientific challenge of significant importance because of the increasing diversity of the socio-economic environment in which enterprises are collaborating with another one (Panetto et al. 2016), (Khisro and Sundberg 2018). Therefore, such ability is a crucial requirement that should be continuously assessed and improved by enterprises that have the need to

collaborate (Chen, Dassisti, Elvesaeter et al., 2007), (Ford et al. 2007), (Naudet et al. 2010), (Leal 2019). Indeed, assessing the enterprises' systems ability to interoperate is frequently the initial step toward a new collaboration development or an improvement program. This kind of assessment has the objective to determine the systems' strengths and weaknesses regarding their future collaboration (Chen, Dassisti, Elvesaeter et al., 2007), (Panetto et al. 2016), (Daclin, Chen, and Vallespir 2016).

Based on literature reviews regarding Interoperability Assessment (INAS) approaches (Rezaei et al. 2014), (Leal, Guédria, and Panetto 2019a), we observed that the majority of the existing INAS approaches are manually conducted. Indeed, such approaches follow a laborious and time-consuming process and usually relies on experts (Alalwan and Thomas 2012), (Krivograd and Fettke 2012), (Grambow, Oberhauser, and Reichert 2013). Few of the approaches studied propose computer-mediated tools to support their assessment processes. Such tools can support analysing the current state of the assessed systems and proposing improvement measures. These tools need to incorporate the knowledge that resides in human experts for having realistic decisions. The tool that integrates such knowledge is called a knowledge-based system (KBS) (Dhaliwal and Benbasat 1996), (Turban, Aronson, and Liang 2004). By evaluating the current situation of the concerned system, the KBS can identify opportunities for change and support decision-making by recommending appropriate knowledge for the deployment of solutions (Power 2004) to achieve a desired situation.

Knowledge model is an essential component of such systems. Each knowledge model is committed, explicitly or implicitly, to some conceptualisation. A conceptualisation is "*an abstract, simplified view of the world that we wish to represent for some purpose*" (T. R. Gruber 1995). Numerous KBS have been empowered as a knowledge model by computer - readable ontologies in recent years. An ontology is an

explicit conceptualization specification (T. R. Gruber 1993). According to the literature (Darai, Singh, and Biswas 2010), (Li, Xie, and Xu 2011), (Alalwan and Thomas 2012), (Tarhan and Giray 2017) the benefits of using an ontological approach to knowledge model development are as follows: It sets a common basis for sharing contextual knowledge across different users, facilitates common understanding of the domain and provides users with more accurate, accurate and comprehensive knowledge. The KBS using ontology for formalising knowledge and reasoning on it is called ontology-based system.

The aim of this paper is therefore to design and develop a knowledge-based system to support interoperability assessment. For the purpose of this research work, we use the Ontology for Interoperability Assessment (OIA) (Leal, Guédria and Panetto 2019b). Such ontology contains the knowledge regarding interoperability assessment, including the different requirements that should be fulfilled to improve and implement interoperability. A preliminary result of this work was presented on (Leal et al. 2017). The knowledge-based system presented in this paper can exploit knowledge about interoperability issues and information from the *as-is* situation of the assessed systems for identifying potential interoperability problems and improvements.

Moreover, we use the Maturity Model for Enterprise Interoperability (MMEI) (Guédria, Naudet, and Chen 2015) as reference model for instantiating the OIA. The reasons of choosing MMEI is because follows a systemic approach (i.e. can be applied to different types of systems such as businesses, hospitals, public administration, etc) and provides a set of best practices related to its evaluation criteria. A more detailed discussion regarding the selection of MMEI is given on the section dedicated to the literature review.

The structure of the paper is as follows: the **Research methodology** describes the steps followed to develop the proposed contribution. Next, the **State of the art** section gives an overview of the interoperability assessment and KBS domains. It also presents a review of the existing systems supporting an interoperability assessment. An overview of the Ontology for Interoperability Assessment is also presented in this section. The **Prototyping the knowledge-based system for interoperability assessment** section, which describes the development of the KBS prototype, follows it**.** The proposed contribution is evaluated through a case study based on a real business scenario from Luxembourg in the section **Evaluating the knowledge-based system**. The **Discussion** section, we compare and highlight the improvements of the proposed KBS against its previous version presented on (Leal et al. 2017). Finally, the **Conclusion** is brought forward and the future work discussed.

Research methodology

The research methodology adopted for achieving our objective, is based on the Design Science Research Methodology (Hevner et al. 2004), (Peffers et al. 2007). The four phases of the methodology and the fulfilment of each of them are described below.

Phase 1 - Determine the domain and scope. This phase refers to the scope definition. Based on the identified INAS approaches limitation, we propose a knowledge-based system for the interoperability assessment. The objectives envisioned is to provide the ability to infer potential problems and transformations that an enterprise can face, based on interoperability requirements analysis.

Phase 2 - Gather information and knowledge. This phase corresponds to the investigation of the related domains. To do so, we perform literature reviews for identifying and studying the existing computer-mediated systems and ontologies supporting an interoperability assessment.

Phase 3 - Prototyping the knowledge-based system. This phase is divided in three steps: (i) Definition of the prototype functionalities; (ii) Design of the prototype architecture for ensuring the defined functionalities; and (iii) Definition of the assessment process based on the prototype. For developing the prototype, we consider the requirements defined by (Krivograd and Fettke 2012) (See Table 1).

Table 1. Overview of the assessment approaches providing computer-mediated tools.

Domain focus		**Description**
Functional	Create and delete user and client	The system is able to manage multiple clients and users
	Create, edit and delete objectives	The system is designed in such a way that changes of the questions can be done fast and easily
	Create, edit and delete answer options	The system is designed in such a way that changes of the answer options that can be done fast and easily
	Create, edit and delete model results	The system is designed in such a way that changes of the model results that can be done fast and easily
	Weight answer options	The system is able to weight different answer options independently.
	Evaluate an assessment automatically	The system is able to automatically determine the maturity level on the basis of the responses
	Generate reports	The system is able to generate result reports on the basis of the assessments
	Compare assessments	The system supports the automatic comparisons of assessments from different time points.
Non-Functional	Genericity	The system's life cycle is adapted by introducing a separate configuration-time for the implementation of specific customer demands
	Support of multiple maturity models	The system is able to work with various maturity models
	Support of different scale levels	The system is able to work with different scale levels
	Extensibility	The system is designed in such a way that it can be easily adapted and extended to work with more maturity models.
	Connectivity	The system has an interface to connect to external applications.
	Simplicity	The system is able to quickly and easily support regular assessments
	Ease of use	The system is designed in such a way that users with only basic training can intuitively perform an assessment

Phase 4 – Evaluating the knowledge-based systems. In this phase, we apply the proposed KBS for supporting an interoperability assessment of a real enterprise located in Luxembourg.

State of the art

In this section, we present the Interoperability Assessment domain. Further, we investigate the KBS domain as one of the alternatives for supporting INAS. We focus on the study of KBS based on ontologies as it encapsulates the knowledge of domain experts. Next, we present a review of computer-mediated systems supporting assessment processes. Finally, an overview of the Ontology for Interoperability Assessment is presented.

Enterprise Interoperability Assessment

In order to support enterprises to better interoperate with their partners, the interoperability between their systems requires being assessed and continuously improved.

According to (Ford et al. 2007), (Yahia et al. 2012), (Guédria et al. 2015), interoperability assessment approaches can be classified mainly based on two properties:

(i) The type of assessment: the Potentiality assessment which relates to the potential of a system to be interoperable with a possible future partner whose identity is not known at the moment of evaluation. The Compatibility assessment concerning the analysis and identification of interoperability barriers two know systems. The Performance measurement is to be done during the test or operation phase of two interoperating systems.

(ii) The Measurement Mechanism: Qualitative (defined by their qualitative criteria) or Quantitative (defined by their numeric values metric applied to characterise the interoperations) mechanism.

Numerous methods have been proposed in the literature regarding interoperability assessment. We present in Table 2 a non-exhaustive comparison between assessment approaches. This analysis is based on the work of (Ford et al. 2007), (Rezaei et al. 2014), (Leal, Guédria, and Panetto 2019a). The compared approaches are those that were applied on real case studies and that are covering a large spectrum of the interoperability dimensions such as business and process concerns and semantical and organisational aspects.

Table 2. Summary of the comparative analysis. Adapted from (Leal, Guédria, and Panetto 2019)

Approach	**Use (Focus)**	**Type of assessment**		**Measurement mechanism**		**Best practice**	**Supporting tool**
		Potential	*Compatibility*	*Qualitative*	*Quantitative*		
(Daclin et al., 2016a)	General use	-	+	+	-	-	+
(Guédria et al., 2015)	General use	+	+	+	+	+	-
(da Silva Avanzi et al., 2017)	Crisis Management	+	-	+	+	-	+
(Campos et al., 2013)	Business	+	-	+	-	-	-
(Cornu et al., 2012)	Business	+	+	+	+	+	+
(Cestari et al. 2018), (Cestari et al. 2019)	Public administration	+	-	+	+	+	+

Regarding the type of assessment, we observe that the majority is focusing on the evaluation the interoperability potential of a given enterprise. We also can highlight that all of them are providing qualitative measures for expressing the assessment results.

Based on the presented comparison and the analyses provided on (Ford et al. 2007), (Rezaei et al. 2014), (Leal, Guédria, and Panetto 2019a), three INAS approaches limitations were identified:

1) Few approaches are addressing the multiple interoperability aspects (Technical, Semantical and Organisational) and concerns (Business, Process,

Service and Data). Besides, fewer approaches - explicitly or implicitly - address the interdependencies among and between interoperability aspects and concerns.

2) Few approaches providing guidance for interoperability improvement. The provision of best practices can support stakeholders making informed decisions for solving or at least reducing interoperability problems.
3) Few approaches providing computer-mediated tools. The majority of approaches is manual-conducted, which is a laborious and time-consuming process and in many times depends on the "subjective" knowledge of experts which can be expensive in time and money when hiring external consultants.

In this research work, we focus on the third limitation i.e. the lack of INAS approaches providing supporting tools for conduction their assessment processes. We argue that computer-mediated systems can enhance the stakeholder's ability to analyse the system's current state and to make improvements.

For tackling this issue, we study in the next subsections the literature regarding automatic assessment from other domains as well as Knowledge-Based System (KBS) architectures that can be a potential solution for building INAS systems.

Knowledge-based systems and ontologies

A knowledge-based system (KBS) differentiates from other computer-mediated systems as it has specific knowledge derived from human expertise stored in their knowledge models (Dhaliwal and Benbasat 1996), (Power 2004), (Turban, Aronson, and Liang 2004).

Such knowledge can be reasoned and inferred for arriving at specific conclusions. Table 3 presents two comparisons: first between KBS and a human expert and second between a KBS and a non-KBS.

The architecture of a KBS is composed of three main components (Dhaliwal and Benbasat 1996), (Turban, Aronson, and Liang 2004): a knowledge model (e.g. an ontology or relational database), an inference engine for reasoning the stored knowledge, and user interfaces.

(Chandrasekaran, Josephson, and Benjamins 1999) presents a comparison between ontologies and relational databases on the potential technologies to be adopted to build the knowledge model. The authors conclude that specialization and integration procedures are required for relational databases, and they are single-oriented-purpose, and ontologies provide a restriction-free framework for representing a reality. In (Tarhan and Giray 2017), a review of the software tools for process evaluation identified the following benefits from ontologies: reduction in time, cost, and effort for software process data collection, validation, process attribute rating, and reporting.

Table 3. Comparisons between Human experts, KBS and non-KBS. Adapted from (Turban, Aronson, and Liang 2004)

KBS	**Human Expert**
Knowledge is storage and preserved without limit of time	May retire or leave the enterprise
Knowledge transfer is easy	Knowledge transfer is hard
Knowledge documentation is easy	Knowledge documentation is hard
Decision consistency is high	Decision consistency is low (can be biased)
Knowledge scope is narrow (in general, specific to a domain)	Knowledge scope is broad
Has no creativity	Has creativity and common sense

KBS	**Non-KBS**
Knowledge base is clearly separated from the processing mechanism	Information and its processing are usually combined in one sequential program.
Do not require all initial facts. Typically can arrive at reasonable conclusions with missing facts	Require all input data. May not function properly with missing data unless planned for.
Changes in the rules are easy to make	Changes in the program are tedious
The system can operate with only a few rules	The system operates only when it is completed
Easily deal with qualitative data	Easily deal with quantitative data

An ontology in computer science specifies the concepts, relationships and other distinctions relevant to the modelling of a domain (T. Gruber 2009). Therefore, an ontology which is developed as a knowledge model to a KBS should also include the means to formally define it for supporting automated reasoning (T. Gruber 2009).

In KBS, two types of ontology specification can be identified (Chandrasekaran, Josephson, and Benjamins 1999): (i) Domain factual knowledge that provides knowledge of objective realities in the field of interest and (ii) Problem-solving knowledge of how to achieve different goals.

As a result of considering the work associated with the study, we can summarize that the benefits of using ontologies as knowledge models are: avoiding semantic problems (T. Gruber 2009); establishing a common foundation for sharing contextual knowledge (Alalwan and Thomas 2012), (Li, Xie, and Xu 2011); enabling formal domain knowledge representation in a computer - readable manner (T. Gruber 2009). Therefore, the combination of ontological approach and computer - mediated application becomes relevant as it makes the use of complex knowledge management easier by (semi) automatizing specific activities such as knowledge storage, inference and querying.

Reviewing existing computer-mediated systems for assessment

A literature review focusing on the existing KBS and ontology-based systems did not uncover any ontological approach for supporting interoperability assessment explicitly. Nonetheless, we identify some (i) computer-mediated systems that are supporting the interoperability assessment and (ii) computer-mediated systems supporting the assessment process in different domains. The identified research works are presented in the next two sections.

Computer-mediated systems supporting interoperability assessment

We identified four approaches proving a computer-mediated tool. The Interoperability Maturity Assessment of a Public Service (IMAPS) (Interoperability Unit 2018b) approach provides an online survey[1] based on the IMAPS maturity model. Each question on the survey is linked specifically to an area of interoperability: service delivery, service consumption and service management. Moreover, based on the rating of each question, the interoperability maturity is determined as well as recommendations are provided for achieving the next maturity level.

The Interoperability Quick Assessment Toolkit (Interoperability Unit 2018a) is a questionnaire implemented in Excel that allows software solution owners to assess the potential interoperability of their software solutions supporting public services. This approach divided solution's interoperability into four areas: interoperability governance, software architecture, machine-to-human and machine-to-machine interfaces. Considering the assessor's answers, the tool determines for each defined area, its maturity level. However, no best practices for improving the interoperability is provided.

The authors in (Cornu et al. 2012) propose a set of questionnaires that are implemented in a computer-mediated tool for easing their use. These questionnaires are defined based on interoperability requirements regarding the different interoperating systems (e.g. between machine-machine and machine-human interactions), the interoperability layers (conceptual, technological and organisational) and the type of assessment. The questions on the questionnaires are "Yes/No" questions. The interoperability degree is determined based on the sum of correctly answered questions.

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[1] https://ec.europa.eu/eusurvey/runner/IMAPS

The authors defined the correct answers before implementing the tool. Moreover, if a question is wrong (i.e. the answer does not correspond to the ideal state of an interoperable system), the tool provides a specific recommendation.

In the papers (Mallek, Daclin, and Chapurlat 2012), (Daclin et al. 2016) the authors propose a requirement verification based on model checkers. The interoperability requirements are defined, modelled and divided into two categories: temporal and a-temporal. However, the approach does not recommend any solution based on the assessment results.

The Disaster Interoperability Assessment Model (DIAM) (da Silva Avanzi et al., 2017) provides an Analytic Hierarchy Process (AHP) (Saaty, 2004) to calculate the maturity level of a given entity. An AHP is a multi-criteria decision analysis technique. This approach uses the open source Software called *Super Decisions*[2] for implementing their AHP matrix. Interviews based on defined requirements are conducted for gathering relevant information of the assessed entity. From the collected data, pairwise comparisons are conducted in each layer of the AHP matrix using the Super Decisions software. These comparisons intend to identify what are the most relevant interoperability concerns and barriers to be addressed.

The Public Administration Interoperability Capability Model (PAICM) (Cestari el al. 2019) is an assessment approach focusing on the interoperability of public administration. One of its preliminaries version was presented on (Cestari et al. 2018). The PAICM is composed of attributes, guidelines and capability levels, describing the intervals of the capability degree of certain measurable attributes related to the interoperability domain. This INAS also base its interoperability evaluation on an AHP

[2] superdecisions.com

matrix. As DIAM (da Silva Avanzi et al., 2017), PAICM also is supported by the software *Super Decisions.*

Computer- mediated systems supporting an assessment process

Moreover, we also identified computer-mediated tools for supporting assessment and decision-making processes in other domains as summarised in Table 4.

Table 4. Overview of the assessment approaches providing computer-mediated tools.

Reference	**Domain focus**	**Ontology-based**
(Steel et al. 2016), (Shrestha, Cater-Steel, and Toleman 2016)	Process assessment	No
(Krivograd, Fettke, and Loos 2014)	Business processes assessment	No
(Alalwan and Thomas 2012)	Electronic records management	Yes
(Grambow, Oberhauser, and Reichert 2013)	Process assessment	Yes
(Giovannini et al. 2012)	Sustainable manufacturing	Yes
(Barafort et al. 2018)	Software process assessment	No
(Wen, Chen, and Chen 2008)	Enterprise performance assessment	No

The SMPA approach (Steel et al. 2016), (Shrestha, Cater-Steel, and Toleman 2016) is a standards-based process assessment method by which organisations can self-assess their processes transparently and efficiently using a decision support system. (Krivograd, Fettke, and Loos 2014) describes the development of an Intelligent Maturity Model-Tool for supporting the analysis of the business processes management (BPM) systems. Alalwan and Thomas (Alalwan and Thomas 2012) developed a record's management assessment tool centred on a proposed electronic records management ontology. The authors assert that the use of such system raises the effectiveness of the evaluation process and aid sharing and communication of evaluation results.

The authors in (Grambow, Oberhauser, and Reichert 2013) propose an ontology-based approach for enhancing the degree of automation in current process assessment. According to the authors, such approach is capable of supporting different assessment

models (e.g. CMMI[3] and ISO 9000 family (ISO 9000 2015)). (Giovannini et al. 2012) developed a KBS for sustainable manufacturing that is able to automatically identify change opportunities and to propose alternatives.

In (Wen, Chen, and Chen 2008), Wen et al. propose a KBS for measuring enterprise performance, which provides not only company's various financial data query, but also enterprise performance based on knowledge reasoning. A cloud-based software-as-a-service (SaaS) tool is proposed in (Barafort et al. 2018) for automating and supporting the assessment of processes as well as for the storage of assessment data for benchmarking and analysis. For the interested readers, more computer-mediated approaches focusing on software processes are analysed in (Tarhan and Giray 2017).

The ontology for interoperability assessment

The OIA is a meta model, which formally describes the system and assessment's concepts and their relations, regarding interoperability) (Leal, Guédria and Panetto 2019b). This ontology is defined based on the Ontology of Enterprise Interoperability (OoEI) (Naudet et al. 2010), the System Engineering Model-Driven (SEMD) pattern (Morel et al. 2007) and the Maturity Model for Enterprise Interoperability (MMEI) (Guédria, Naudet, and Chen 2015).

The OIA includes a systemic model centred on the notion of the system and its requirements, and an assessment core that constitutes the general concepts related to an interoperability assessment and its inputs and outputs. Figure 1 presents an extract of the OIA meta model.

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[3] http://cmmiinstitute.com/capability-maturity-model-integration

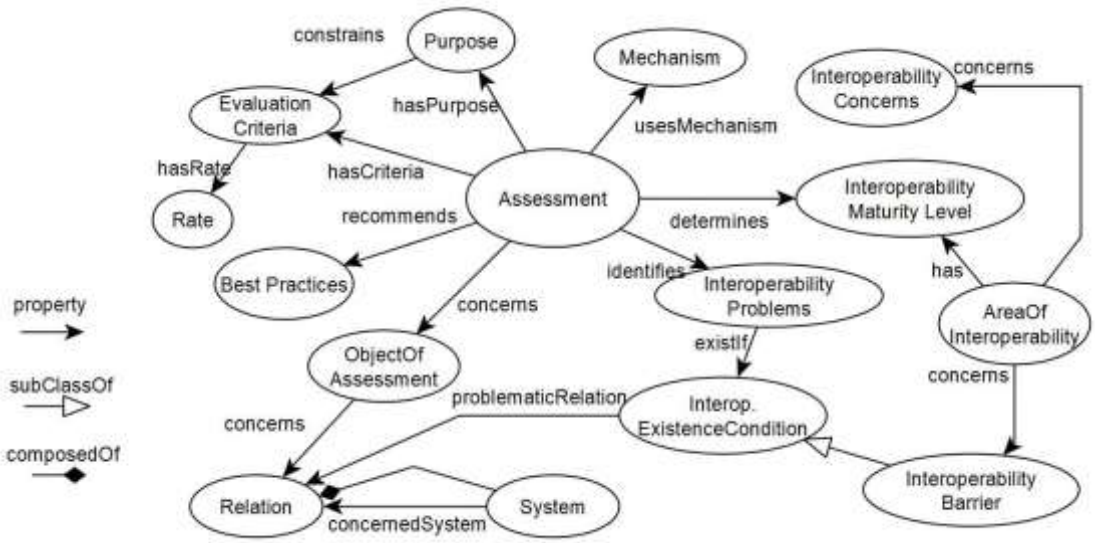

Figure 1 – An extract of the ontology for interoperability assessment. Adapted from (Leal et al. 2017)

In Figure 1, the *Object Of Assessment* concerned by an *Assessment* can be a *System*(s) or *Relations* between *Systems*. The *Assessment* uses *Mechanisms* for measuring *Evaluation Criteria* and for determining *Interoperability Maturity Level*. The *Evaluation Criteria* is one of the most relevant concepts in OIA. Each *Evaluation Criteria* has a *Rate*, which characterise the achievement of the concerned criterion. In addition, the *Evaluation Criteria* is related to the *Area Of Interoperability*. An *Area of Interoperability* regards to the *Interoperability Concerns* (e.g. processes, services and data) and to an *Interoperability Barrier* (e.g. Conceptual and Organisational). An *Interoperability Barrier* is the existence condition of *Interoperability Problems*. For removing the identified *Interoperability Problems*, the *Assessment* recommends *Best Practices*. A detailed description of this ontology can be found in) (Leal, Guédria and Panetto 2019b).

Our positioning

Based on the research context and found limitations, we propose a knowledge-based system for supporting the interoperability assessment.

We focus on both potentiality and compatibility types of assessment, as we are interested in detecting and preventing interoperability problems before they occur. Hence, the performance assessment, which evaluates data from the running time, is out of scope.

We decided to take the MMEI (Guédria et al., 2015) as a reference model as it: (1) Defines a framework for assessing and measuring interoperability maturity, while providing information for how far along an enterprise is regarding targeted maturity levels; (2) Adopts a systemic approach (i.e. can be applied to different types of systems such as businesses, hospitals, public administration, etc); (3) Provides a holistic view considering the different barriers and concerns of interoperability based on the Framework of Enterprise Interoperability (Chen, Dassisti, Elvesaeter et al., 2007); (4) Is an international standard under the number 11354-2 (ISO 11354-2, 2015).

The proposed knowledge-based system is presented on the next section.

Prototyping the knowledge-based system for interoperability assessment

The proposed KBS prototype architecture, its features and the users concerned are presented in this section. Ideally, users follow the defined evaluation process and use the OIA - embedded system prototype to support specific activities. An overview of the users, assessment process and prototype relations is illustrated in Figure 2.

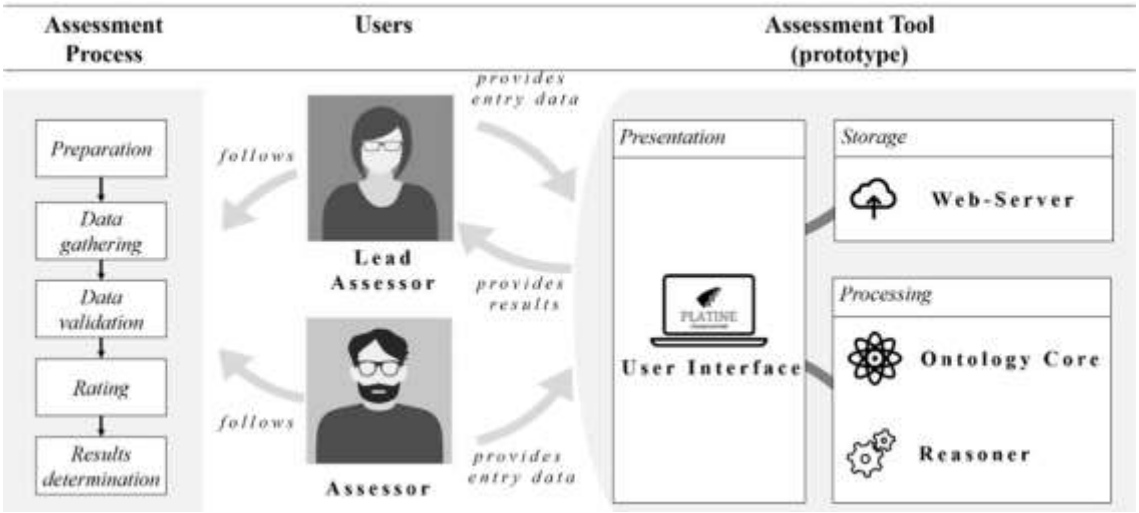

Figure 2 – The relations between users, the assessment process and the knowledge-based system.

Defining the knowledge-based system functionalities

We consider three roles for interacting with the proposed KBS: The Lead assessor is required to have a clear understanding of the evaluation workflow and manages the system to aid the entire assessment. He is accountable for creating and editing assessments as well as generating the reports. Such a report contains the determined system's maturity level, the final rating of each evaluation criteria, the identified problems and associated solutions. The assessors are responsible for completing and editing their assigned assessment by entering their evaluations and comments according to the defined criteria. Finally, the administrator is responsible for updating the raw ontology file, the assessment framework and the measurement mechanism used by the system.

The KBS functionalities are directly related to these roles as illustrated in Figure 3.

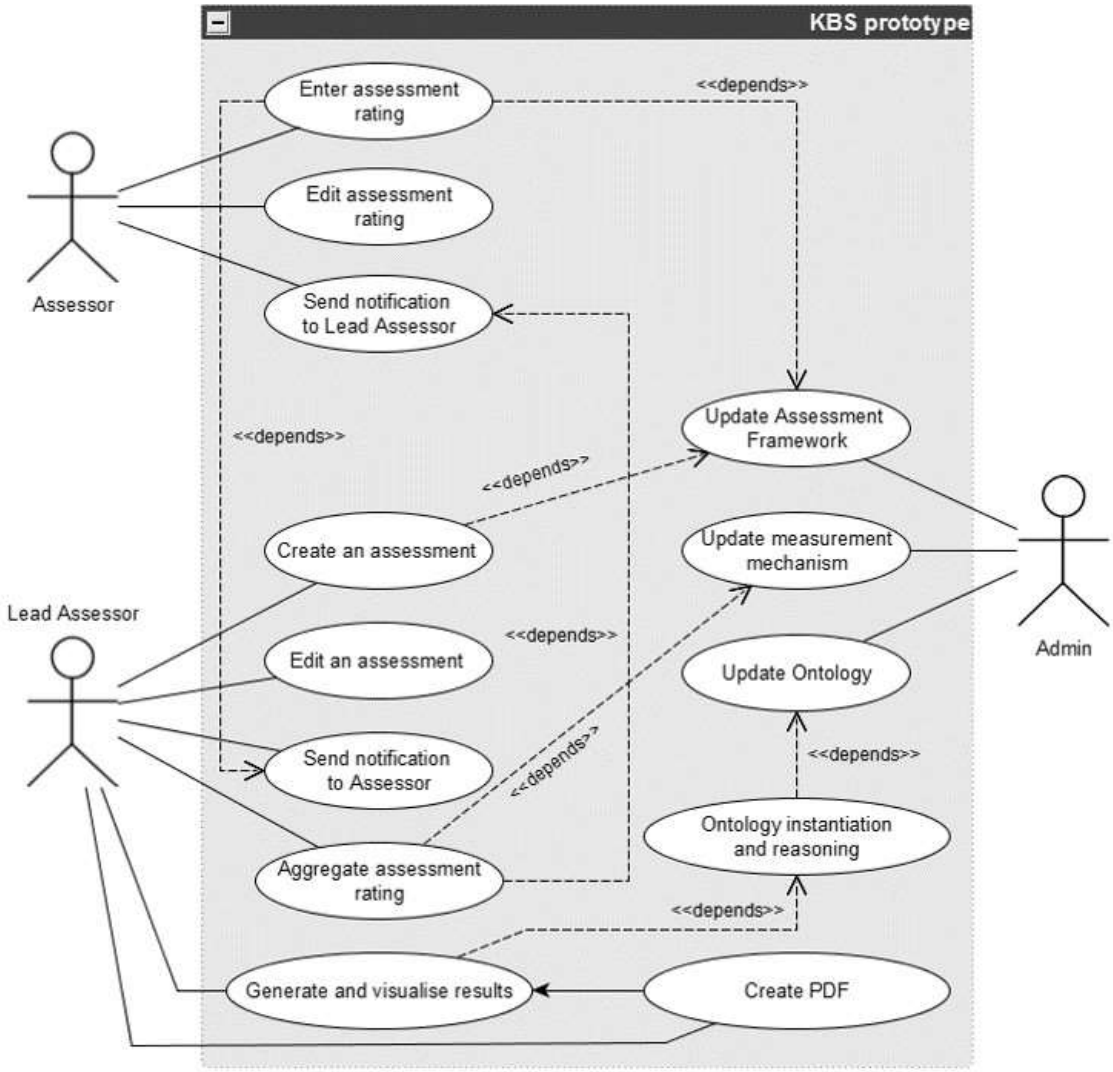

Figure 3 – The Use Diagram of the prototype

Designing the knowledge-based system prototype architecture

In order to accommodate different components, the system prototype architecture distinguishes three layers. The Presentation Layer includes the components of the data collector and data viewer. The Data Collector is responsible for collecting all relevant data that is entered by the lead assessor and assessors, such as the assessment information and criteria rating. The Data Viewer is responsible for organizing and presenting users with relevant data, such as the rating summary and the evaluation

results. The user interfaces are designed using the NetBeans IDE 8.1[4] and the Java[5] language.

The Storage layer includes the component of the database and the files of ontology and evaluation reports generated. The Database is responsible for storing, for example, the assessment of general information, the information concerning the users, the rating provided by the assessors, and the results generated by the Processing layer.

Finally, the Processing layer contains six components: The Assessment Manager is responsible for managing the prototype data input and output and for calling and managing the other components if necessary. The Data Access Object component is responsible for connecting the prototype to the database. The Measurement Mechanism contains the algorithms for aggregating evaluation criteria and calculating the maturity of interoperability. These mechanisms are based on the MMEI (Guédria, Naudet, and Chen 2015).

The Ontology Manager is responsible for instantiating the raw ontology file (in the .owl format) and to querying the inferred results. The OIA is instantiated based on the MMEI approach (Guédria, Naudet, and Chen 2015) and interoperability evaluation criteria interdependencies defined on (Leal, Guédria, and Panetto 2017).

The Inference Engine is responsible for reasoning the instantiated ontology and providing new knowledge about the current state of the evaluated system. OWL API[6] provides the implemented Inference Engine. The architecture is depicted in Figure 4.

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[4] https://netbeans.apache.org/

[5] https://www.java.com/

[6] github.com/owlcs/owlapi

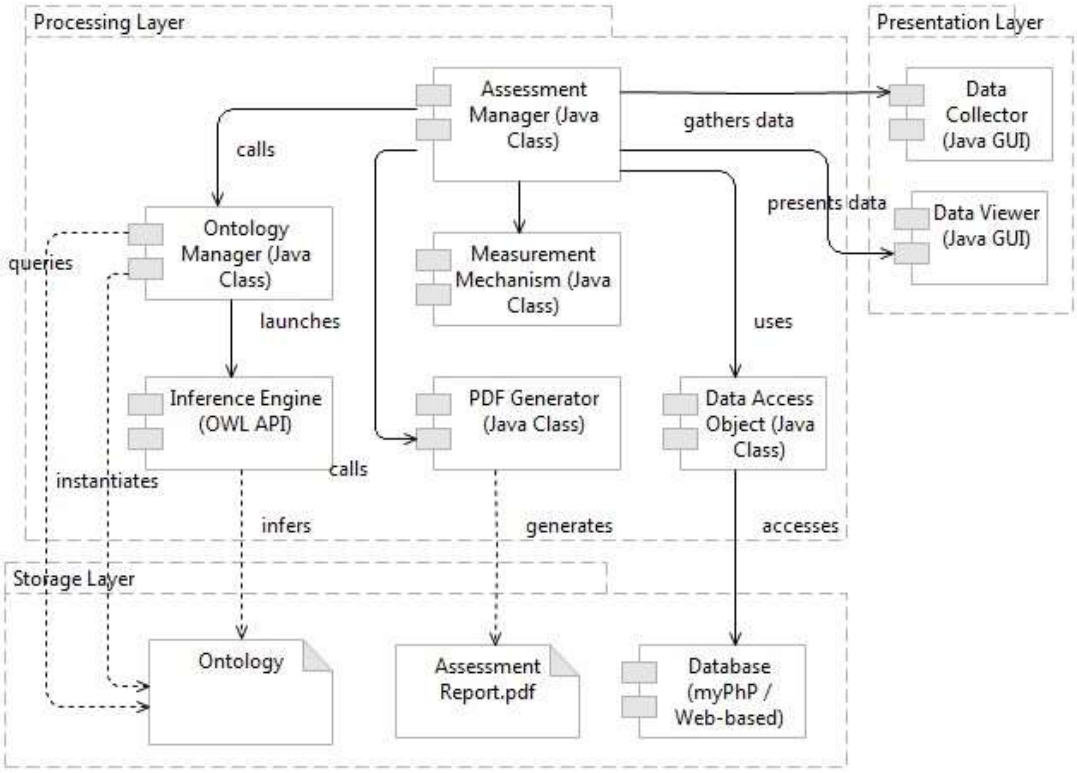

Figure 4 – The architecture of the prototype

Defining the assessment process for the knowledge-based system prototype

Considering the assessment process, we adopt the following five stages: Preparation, Data gathering, Data validation, Rating and Results determination. These steps are defined based on the MMEI approach. Some adaptations have been made to include the proposed system.

The first step when performing an assessment is to define its purpose, its scope, and any additional information that needs to be gathered. After determining the scope of the evaluation, the lead assessor enters into the KBS the detailed information about the assessment (e.g. the system(s) to be analysed, the interoperability layers to be taken into account, etc.). Next, he selects the assessors and sends a message to notify them.

The second step is the information gathering, which is performed by the concerned assessors. It can be done through a series of interviews and document analysis. Following feedback sessions to validate the information gathered (step 3), the assessors analyse the verified data and enter the evidence and rating of each criterion into the prototype (step 4). The rates and evidence will be stored in the Database, and a notification will be sent to the lead assessor. If there is more than one assessor, the lead assessor aggregates the evaluations they provide. To do so, he launches the prototype's aggregation mechanism (the Ordered Weighted Average (Yager 1988), (Guédria, Naudet, and Chen 2015) technique is implemented within the KBS). Then the prototype provides the resulting aggregation that the lead assessor can modify. The evidence uploaded by the assessors is useful to the lead assessor when the final rating is aggregated and validated.

The last step is the Results determination. Through the KBS, the lead assessor starts the ontology instantiation. Moreover, the ontology is inferred by the Inference Engine in order to identify interoperability problems and the non-fulfilled requirements. Considering these results, the KBS proposes best practices and highlights the potential impacts that can be cause by the failure to fulfil requirements.

Finally, the lead assessor may generate an assessment report in the PDF format. Such a report contains the current state of the assessed system, the criteria ratings, and the recommended best practices that the system needs to follow. The adapted assessment process is depicted in Figure 5, using the BPMN standard (OMG 2014)[7]. The grey coloured activities are those supported by the KBS.

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[7] BPMN stands for Business Process Model Notation. It is a standard managed by the Open Management Group. It objective is to provide a framework and a modelling language for designing business processes.

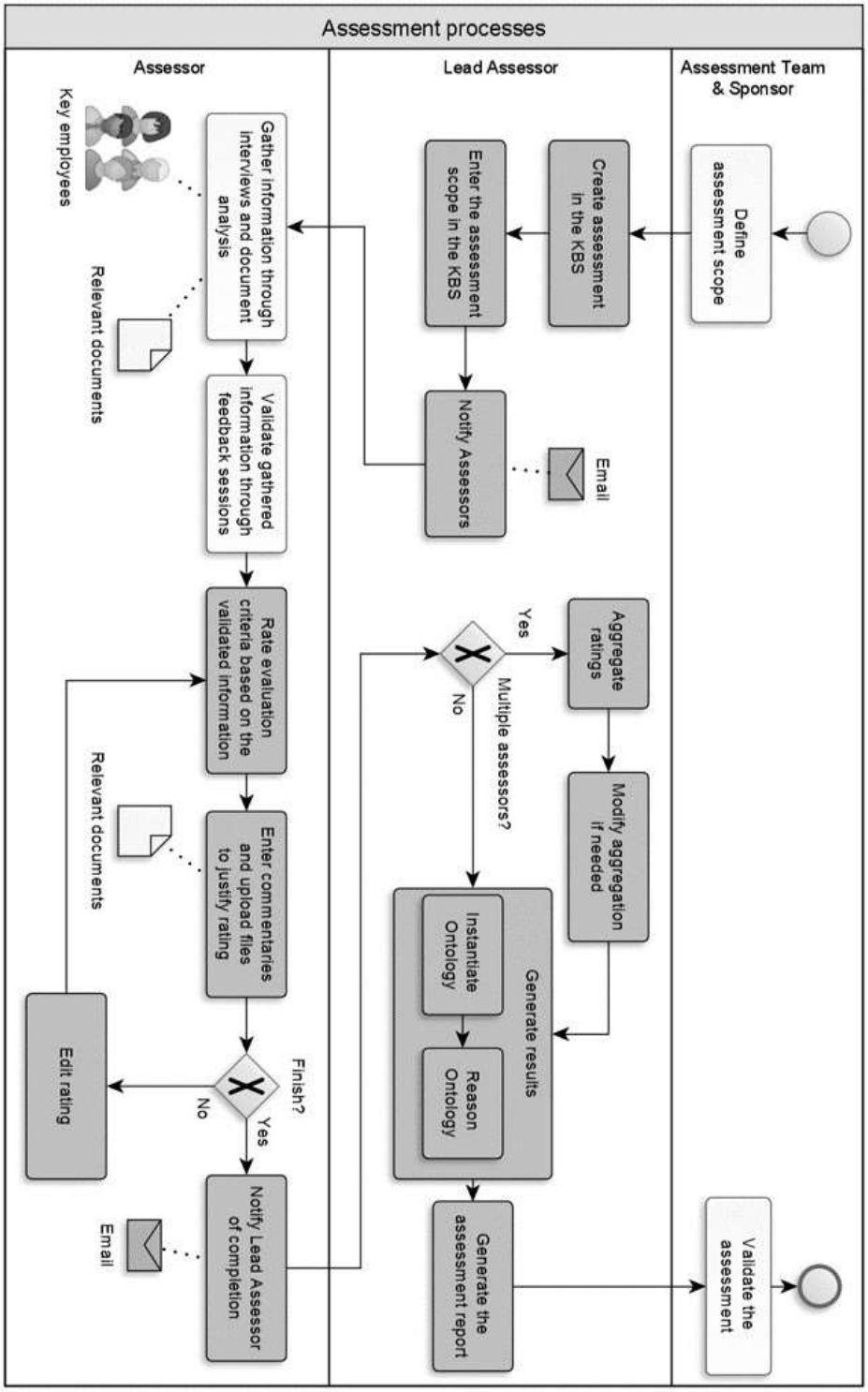

Figure 5 – The assessment process BPMN

Evaluating the knowledge-based system for interoperability assessment

We present the evaluation of the proposed contribution in this section. According to (Hevner et al. 2004) such an evaluation is an activity that provides feedback and a better

understanding of the problem addressed in order to improve both the quality of the contribution and the design process. This activity involves comparing a solution's objectives with actual observed contribution results.

Therefore, we apply the proposed KBS prototype in a real case study. The case concerns a marketing and communication agency in Luxembourg. For reasons of confidentiality, we omit the company name and refer to it as COMMUNIC. Further, we conduct the same assessment using the traditional manual approach. This allowed us to verify the results obtained by the system prototype, compare the efficiency of both assessments and identify the advantages and limitations of our contribution.

Applying the computer-mediated assessment

First, the scope of the COMMUNIC assessment was defined. The type of assessment chosen was the potentiality assessment, which aimed at determining the maturity level of the COMMUNIC current state. The assessment framework was the MMEI (Guédria, Naudet, and Chen 2015).

In the following step, two assessors gathered information by interviewing the Chief Executive Officer (CEO) and the Chief Operations Officer of COMMUNIC. During the interviews, the questionnaire applied was semi - structured and the questions were used to initiate discussion. The strategy adopted by the network was discussed during the meetings, along with its services proposals. The different relationships between the network partners and the existing and potential collaborative problems were also highlighted. To identify relevant data, analyses of the documents provided were also conducted. Once feedback sessions were conducted to validate the synthesis of the information collected, the requirement rating could begin.

One of the assessors assumed the role of lead assessor, which logged in to the proposed system prototype. There he gave a name to the assessment

(COMMUNIC_Maturity), described the purpose of the assessment, and selected the potentiality assessment type and MMEI as the assessment framework. The lead assessors selected all Interoperability Layers and Concerns of them to have a holistic view of the company evaluated as illustrated in Figure 6.

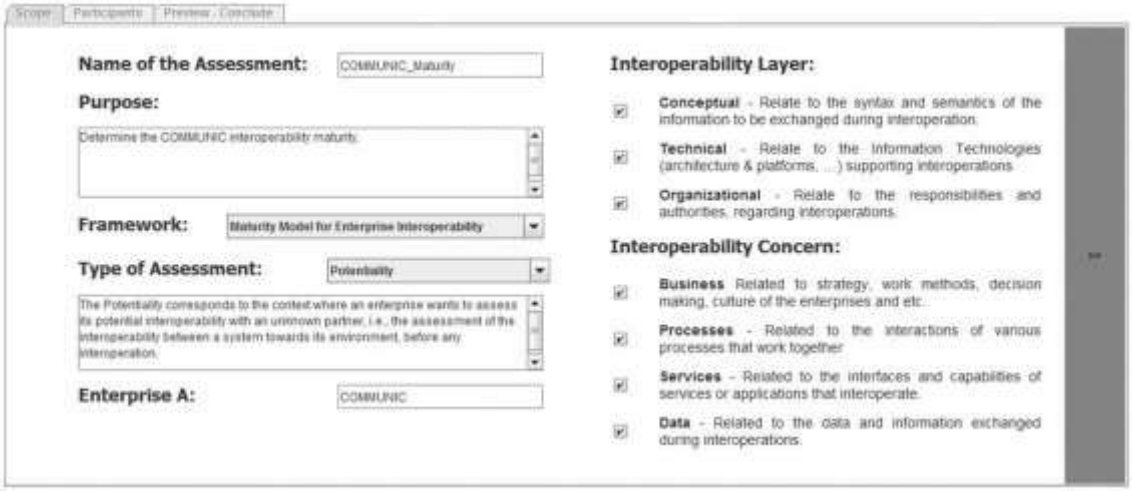

Figure 6 – The COMMUNIC assessment scope

The lead assessor sent a notification to the assessors concerned after creating this assessment. The assessors then logged in to their accounts and completed the COMMUNIC Maturity evaluation in question (see Figure 7).

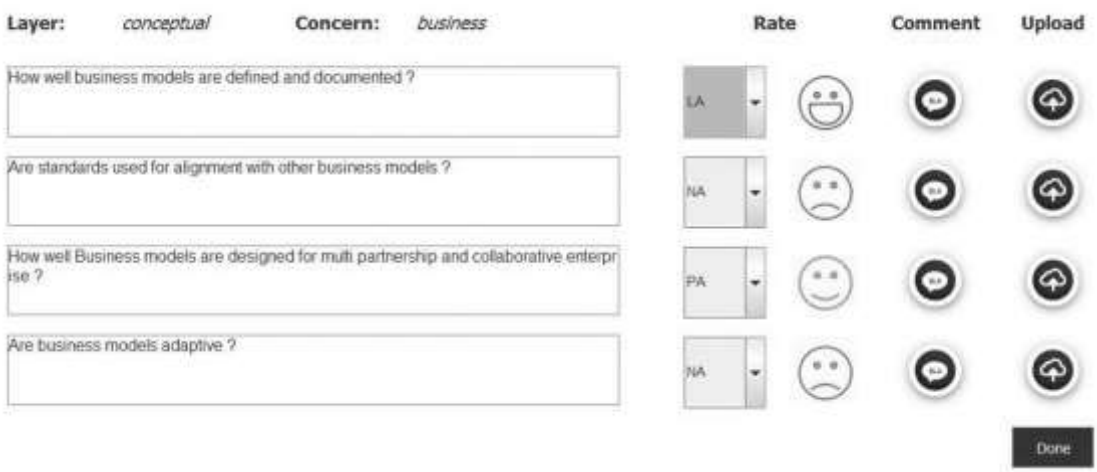

Figure 7 – Screenshot of the COMMUNIC assessment: Requirement rating

In Figure 7, the requirement rating extract is shown. The assessors gave a rate to each requirement in the illustrated interface using the linguistic variables established on MMEI: “Not Achieved (NA)”, “Partially Achieved (PA)”, “Largely Achieved (LA)” and “Fully Achieved (FA)”. These requirements have been written in the form of questions to provide a more user - friendly interface. Note that the requirements to be evaluated were selected automatically by defined scope. Comments should also be given to justify their rating. Evidence (e.g. documents, pictures, etc.) can also be uploaded to complement their justification.

They sent a notification to the lead assessor once both assessors have completed their assessments. The prototype then aggregates the requirements of the two assessors. Comments and evidence help the lead assessor validate the system prototype's automatic requirement aggregation. Figure 8 illustrates the summary concerning the rates related to requirement from the Process concern.

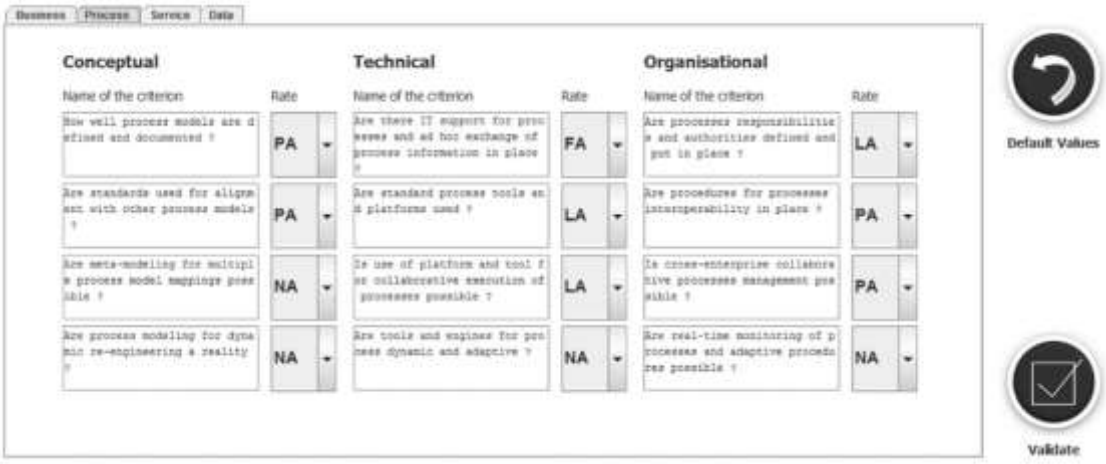

Figure 8 – The COMMUNIC assessment summary

The lead assessor launched the function "generate results" in the next step. The KBS instantiated the embedded ontology automatically and launched the reasoning engine. Figure 9 depicts the results obtained. Note that the term “EntA” is applied for identifying the assessed enterprise, i.e. COMMUNIC.

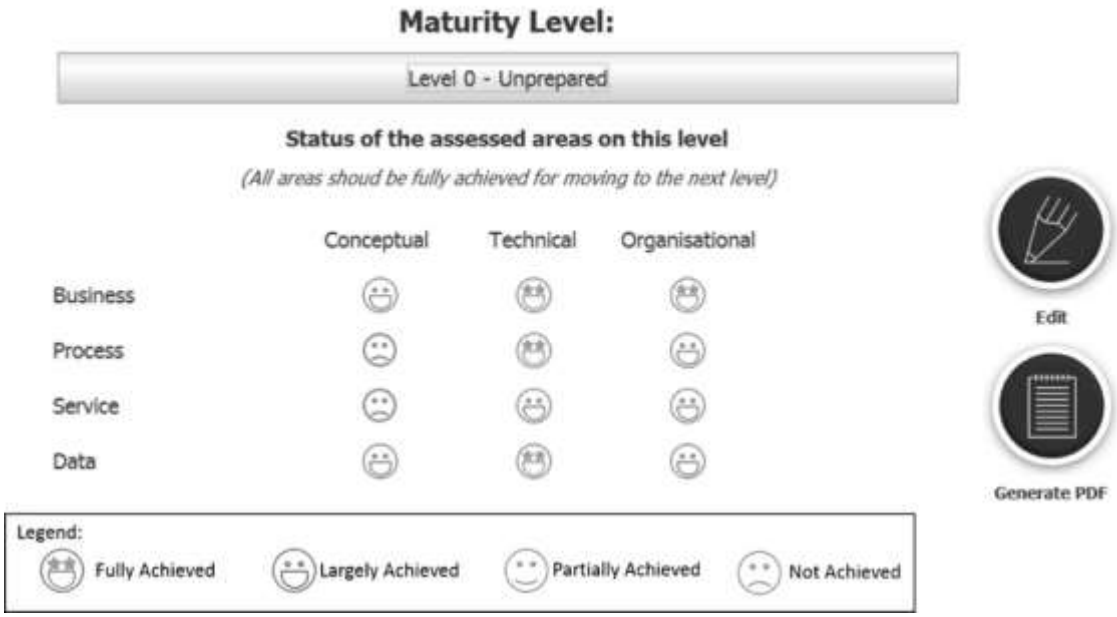

Figure 9 – The COMMUNIC assessment results

Considering the MMEI measurement mechanism (Guédria, Naudet, and Chen 2015), COMMUNIC obtained a global maturity level 0 – Unprepared. This level is characterised by the following statement: *At the unprepared level, the enterprise does not have an appropriate environment for developing and maintaining interoperability*. The company concerned should focus on improving the conceptual requirements related to the process and services concerns in order to achieve the next level. A list of best practices was generated and presented in the "Assessment Report" based on the maturity level and evaluation of criteria.

Comparing the computer-mediated and manual-conducted assessments

The cost on money and time from both manually conducted and computer-mediated assessments are presented hereinafter. This is followed by a discussion summarising the differences between both assessment approaches.

For the **manually conducted assessment**; first, the lead assessor together with the CEO and the COO of COMMUNIC defined the assessment scope. The evaluation team composed of two assessors was defined with the scope defined. This step was

concluded in a meeting lasting three hours. Next, the collection and analysis of information was carried out. Considering the defined scope, which took an average of two hours per assessor, the assessors prepared their questionnaires.

In addition, semi-structured interviews were conducted individually with the CEO and COO. Each interview took three hours, representing a total of eighteen hours. The meetings were arranged over a month, depending on the availability of the CEO and COO. The assessors also analysed documents provided by COMMUNIC in parallel to the interviews. This analysis plus the interview summary took approximately sixteen hours per assessor. Feedback sessions for validation were also organised. These sessions took place over a period of two weeks. Each of them took an average of two hours per assessor.

Once the information was validated, the evaluation criteria concerned were given a rating by each assessor. This work was done individually and spent about eight hours each assessor. The lead assessor aggregated the ratings provided by the other assessors to obtain the final rating of each evaluation criterion. The ratings were aggregated and verified by the lead assessors for fifteen hours. Finally, it took the lead assessor eight hours to determine the level of maturity and to identify the problems of interoperability and related solutions. It took another five hours to generate the evaluation report as the lead assessor had to synthesize the evaluation scope, the evaluators ' ratings and comments, the final rating, the determined maturity level, as well as the identified issues and proposed solutions. The total time spent on this manual evaluation, from the definition of the evaluation scope to the generation of reports, was equal to one hundred and thirty nine hours.

Concerning the **computer-mediated assessment**, we followed the assessment process defined, for evaluating the interoperability of COMMUNIC. The preparation

for the assessment (including the definition of scope and team) took only two hours. This was due to the following: (1) the proposed system created the evaluation and automatically stored its information, thus avoiding the scope's manual description. (2) Notifications were sent automatically to the assessors after the evaluation was established. It was also easier for the assessors to prepare the questionnaire because the system offered a set of predefined criteria in accordance with the defined scope. This, therefore, took thirty minutes per assessor, rather than two hours. The remainder of the information collection and analysis activities took the same time as the manual evaluation, i.e. seventy eight hours.

There was also an improvement in the criteria rating. Each assessor spent an average of one hour during this step as the KBS allowed and automatically saved the rating, comments and documents. The lead assessor launched the aggregation function once all assessors completed the assessment. The system calculated each criterion's final rating in a second. The KBS took thirty-one seconds to generate the final results. Finally, the proposed system took only eleven seconds to generate the assessment, as the structure of the report was predefined and the PDF generator component filled the information automatically. Figure 10 shows an extract of the runtime output of the prototype.

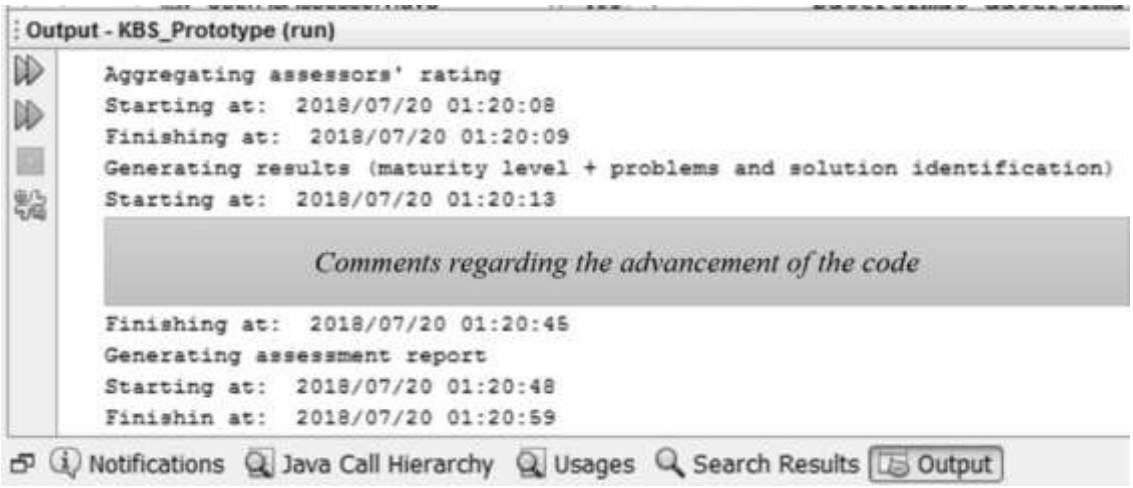

Figure 10 – Time spent by aggregating ratings, generating results and the assessment report

The time spent in hours for realising the computer-mediated assessment, from the definition of the assessment scope to report generation, was equal to eighty-four hours thirty minutes and forty-three seconds. In summary, both manual and computer-mediated approaches have enabled us to compare their performance in terms of time and cost spent. Figure 11 illustrates the time spent and cost of each assessment process.

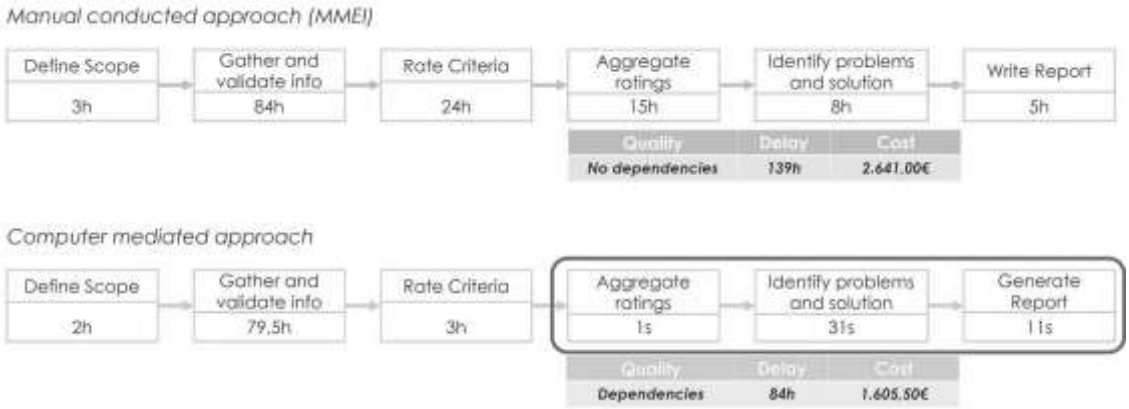

Figure 11 – Difference between the manual-conducted and the computer-mediated assessments

Therefore, taking into account both assessment, we observe a reduction of fifty-five hours when using the proposed KBS, which means a reduction of thirty-nine percept regarding the total cost of the manual approach.

Discussion

The application of the proposed knowledge-based system prototype in the COMMUNIC case illustrates the usefulness of the KBS for improving the interoperability assessment. Indeed, the use of a KBS (or an automated tool) for supporting an assessment process can reduce the cost of time and resources.

The proposed KBS tackles mainly the third limitation raised on section State of the Art: "*Few interoperability assessment approaches are providing computer-mediated tools*". The combination of the Ontology for Interoperability Assessment (Leal, Guédria and Panetto 2019) as the knowledge model and the KBS prototype proved useful as shown in the COMMUNIC case study.

Besides, the other two limitations are also considered as we chose the Maturity Model for Enterprise Interoperability (MMEI) (Guédria, Naudet, and Chen 2015) as the assessment reference model. MMEI addresses the technological, conceptual and organisational aspects of interoperability and business, process, service, and data concerns. The interdependencies among those aspects and concerns – as well as the derived evaluation criteria - are tackle by adopting the approach proposed in (Leal, Guédria and Panetto 2017). The MMEI also provides a set of 126 best practices which are implemented within the KBS prototype.

Tables 5 and 6 provide how we tackle the Functional and Non-Functional requirements provided by (Krivograd and Fettke 2012) for developing a tool for the application of maturity models.

Table 5. Fulfilment of the Functional requirements

Domain focus		Verification	Observation
Functional	Create and delete user and client	Yes	The proposed system can manage multiple Lead Assessors and Assessors.
	Create, edit and delete objectives	Yes	The proposed system is designed in such a way that changes of the questions can be done fast and easily. For instance, predefined questions are printed on the assessor's screen, and the same can be modified, or the Administrator can add new ones.
	Create, edit and delete answer options	Yes	The proposed system is designed in such a way that changes of the answer options (i.e. the values available for rating a criterion) can be done, but only by the system's Administrator. The answers are instantiated in the ontology and the tool. Consequently, the Administrator must modify the ontology file using the Protégé tool* and modify the source code. This change should be agreed between the final users (i.e. assessors) and following the measurement mechanism adopted for the concerned assessment.
	Create, edit and delete model results	Yes	The proposed system is designed in such a way that changes of the interoperability solutions' descriptions can be done, but only by the system's administrator. The results are instantiated in the ontology. Consequently, the administrator must modify the ontology file using the Protégé tool.
	Weight answer options	No	The proposed system does not allow to weight different answer options. Each option has the same weight and they are arranged in specific sets regarding their related interoperability areas.
	Evaluate an assessment automatically	Yes	The proposed system can automatically determine the maturity level from the responses. The potential interoperability problems and related solutions are also provided automatically based on the assessment results;
	Generate reports	Yes	The proposed system can generate result reports from the assessments.
	Compare assessments	Partially	The proposed system does not support the automatic comparisons of assessments from different time points. However, Lead Assessors can create a new compatibility assessment and enter the information of the concerned enterprise in instant of time t1 and t2 for determining what have changed.

*Protégé is a tool for designing ontologies (Musen, 2015)

Table 6. Fulfilment of the Non-Functional requirements

Domain focus		Verification	Observation
Non-Functional	Genericity	Yes	The proposed system's life cycle is adapted by introducing a separate configuration-time for the implementation of specific customer demands.
	Support of multiple maturity models	No	The proposed system is defined for supporting the Maturity Model for Enterprise Interoperability.
	Support of different scale levels	Yes	We argue that any assessment model can be instantiated in the proposed system. Nonetheless, domain experts will be required to enter their expertise regarding the assessment model to be instantiated.
	Extensibility	Yes	The proposed system is implemented using multiple measurement mechanisms. The ones used for determining values of achievement of requirements and maturity levels are defined based on the same scales described in ISO 15504, ISO 33001 and MMEI. However, these scales can be modified by the system administrator in the source code and the Ontology File.
	Connectivity	No	The system has no interface to connect to external applications. This is future work. New interfaces will be designed for capturing information and data directly from enterprise information systems and for launching solution prioritisation methods.
	Simplicity	Yes	The proposed system can easily support regular assessments. New assessment can be created with a few clicks of the Lead Assessor.
	Ease of use	Yes	The proposed system provides intuitive and straightforward interfaces allowing a smooth interaction between the assessors and the system.

The KBS presented in this paper differs from its preliminary results shown in (Leal et al. 2017). As a matter of fact, four main functionalities were implemented in the system presented that were missing on the preliminary one. These functionalities are:

1- Automated notification: Assessors are notified by mail once they are assigned to an assessment and; Lead Assessors are notified once all Assessors have finished their assessments.
2- Automated ontology installations: In the preliminary system, the instantiation was done manually using the Protégé tool. The KBS presented here done it automatically by launching the Ontology Manager component (cf. section Designing the knowledge-based system prototype architecture)
3- Automated retrieval of information from the inferred ontology: The assessment results are retrieved automatically by the Ontology Manager component once the Inference Engine component finishes the reasoning of the instantiated ontology.
4- Generates automatically the assessment report: The KBS generates a report containing the assessment scope and results, including the recommendation of best practices and their potential influences in the overall system.

Conclusion

In this paper, we discussed the relevance of collaborative enterprise systems' interoperability. The development of interoperability had come once again under the spotlight considering the challenges faced by enterprises such as globalisation, collaborative economies, and new business models. In this context, the assessment of interoperability is one of the first steps in a collaboration project. However, there are some limitations with the current interoperability assessment approaches.

To cover the identified limitations, we have proposed a knowledge-based system for interoperability assessment implementing an ontology as knowledge model. The ontology allows the reasoning of assessment information and the inference of the potential barriers and solutions related to the non-fulfilled evaluation criteria. The proposed system provides user interfaces for entering and retrieving information concerning the assessment. A methodology for conducting an interoperability assessment process using the proposed system is also described. Finally, a case study based on a real business network is presented for validating the proposed system.

Two major perspectives from this work are perceived: First, should be the implementation of a component for supporting the prioritisation of solutions. The current version of the knowledge-based system provides a list of best practices for avoiding potential and removing existing barriers. However, the selection of the recommended practices depends on the objectives of the enterprises and the expertise of decision makers. Hence, an application-programming interface (API) based on a multi-criteria technique should be a great asset. Second, the gathering of information is done mainly through interviews and workshops. Thus, an improvement could be the development of an API for gathering information automatically from enterprise information systems such as Enterprise Resource Planning (ERP), Manufacturing Execution Systems (MES) and project management applications.

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