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An ontology for interoperability assessment: a systemic approach

Gabriel da Silva Serapião Leal [1,2], Wided Guédria [1,2], Hervé Panetto[2]

[1]Luxembourg Institute of Science and Technologie (LIST), 5, Avenue des Hauts-Fourneaux, L-4362 Esch-sur-Alzette, Luxembourg ; (gabriel.leal@list.lu), (wided.guedria@list.lu)

[2]Université de Lorraine, CNRS, CRAN, Nancy, France ; (herve.panetto@univ-lorraine.fr)

Abstract. Enterprise Interoperability is a requirement for ensuring an effective collaboration within a network of enterprises. Therefore, interoperability should be continuously assessed and improved for avoiding collaboration issues. To do so, an interoperability assessment can be performed by the concerned enterprises. Such an assessment provides an overview of the enterprise systems' strengths and weaknesses regarding interoperability. A plethora of assessment approaches are proposed in the literature. The majority of them focus on one single aspect of interoperability. In general, to have a holistic view of the assessed systems, i.e. consider different aspects, enterprises have to apply different approaches. However, the application of multiple approaches may cause redundancy and confusion when assessing the same system using different metrics and viewpoints. Therefore, this article is to propose an ontology for interoperability assessment. The main objective of such an ontology is to provide a sound description of all relevant concepts and relationships regarding an interoperability assessment. Inference rules are also provided for reasoning on interoperability problems. A case study based on a real enterprise in presented to evaluate the proposed ontology.

Keywords. *Enterprise interoperability; interoperability assessment; ontology; system engineering*

1. Introduction

In the fast-changing environment that we are living in, enterprises need to work in a collaborative manner with other companies in order to remain competitive and survive disruptive changes. The enterprises that are progressively collaborating with others are becoming the so-called collaborative networked enterprises [1], [2]. This collaborative economy is growing rapidly around the world, as it provides new opportunities for citizens and innovative entrepreneurs to co-create value [3]. According to an assessment performed by PricewaterhouseCoopers (PwC) on behalf of the European Commission [4], the gross revenue in the European Union from collaborative platforms was estimated to be €28 billion in 2015. In order to ensure an effective collaboration, enterprises should share their core competencies and improve the interoperability of their process and data. Enterprise interoperability is the ability to exchange and share resources (e.g. information, devices, etc.) and use them in a meaningful manner [5], [6], [7]. Therefore, it can be seen as a requirement for ensuring an effective collaboration among enterprises within a network [5], [8], [9], [10].

In many cases, enterprises have to plan coherent transformations of their enterprise models, both organisational and technical, to develop and implement effective interoperations, while working seamlessly [11]. These interoperability-related transformations are stages that an enterprise should follow to achieve their targeted objectives, as well as the collaboration goals of the network in which it participates [12]. In order to plan transformation to improve such ability, Interoperability Assessment (INAS) can be performed [13], [14], [15], [16]. Such an assessment aims at determining, quantitatively or qualitatively, the state of a system, regarding its ability to interoperate [17]. The outputs of this assessment can serve for identifying potential interoperability problems and can support decision makers in deciding upon improvements for avoiding, reducing and solving the identified problems.

When carefully investigating the existing related work [18], [14], [19], [15], we observe that few INAS approaches address multiple interoperability aspects at the same time. Indeed, the use of multiple approaches can cause redundancy when assessing the same system [14]. In addition, few approaches address the interdependencies among and between interoperability aspects.

Acknowledging the different dependencies among and between them supports the identification of impacts on the overall system. Moreover, we also observed that there is a lack of a common understanding of Interoperability Assessment concepts.

Therefore, the objective of this paper is to propose the so-called Ontology for Interoperability Assessment (OIA). The OIA aims to provide a sound description of the relevant concepts, relationships, and logic rules related to interoperability assessment. Indeed, they have the capability to reserve semantic meaning of knowledge through a formal representation of knowledge as a set of concepts within a domain of discourse, and the relationships between those concepts [20], [21]. In addition, the formalisation of the knowledge is useful for providing a conceptual perspective and awareness of the interoperability assessment domain. This formalisation also supports the digitalisation of such knowledge, allowing the design of machine-readable knowledge models that can be exploited in decision support systems [22], [23], [24].

In order to design and develop such an ontology, we follow a design science research methodology [25] and a system engineering approach [26], [27]. Indeed, Interoperability is a systemic concept by nature: *it is about systems that interact* [28], [29], [30]. In addition, having a systemic view is very important and widely used in enterprise modelling because it provides a component-oriented view, which reflects closely the reality of enterprise systems' functioning [31], [32], [33].

The structure of the paper is as follows: the research methodology is first presented and detailed in section 2. It is followed by a review of the related work in the section 3. Next, the section 4 elaborates and defines the concepts and relations of the OIA. The proposed contribution is evaluated through a case study based on a real business scenario from Luxembourg in the section 5. Finally, in section 6, the conclusion is brought forward and the future work discussed.

2. Research methodology

The research methodology adopted for achieving our objective, is based on the Design Science Research Methodology [34], [25], the 7-steps methodology for developing ontologies defined in [35] and the practical guide to building ontologies using the ontology web language (OWL) [36]. The methodology four phases and the fulfilment of each one of them are described hereinafter.

Phase 1 - Determine the domain and scope. This phase refers to the scope definition (step 1 from [35]). Based on the discussed INAS approaches limitations, we propose the Ontology for Interoperability Assessment. The objective envisioned is twofold: (i) to provide a sound description of all relevant concepts, relationships, and reasoning rules related to interoperability assessment; and (ii) to enable information sharing and reusability, regarding interoperability issues.

Phase 2 - Gather information and knowledge. This phase corresponds to the investigation of the related domains (system engineering and interoperability assessment), in order to identify relevant concepts to be taken into account while assessing interoperability (step 2 from the [35] defined methodology). To do so, we perform literature reviews for identifying and selecting existing ontologies, models and standards from the defined domains that can be useful for the construction of the ontology.

Phase 3 - Develop Ontology. Based on the gathered information, we enumerate the relevant terms (step 3) that can be used for designing the ontology's concepts, relationships and data properties (steps 4 to 6). Therefore, once concepts are chosen, we design an Assessment MetaModel, which contains the general concepts of a system assessment. Next, we design an Interoperability Assessment MetaModel, which contains the specific concepts related to an Interoperability Assessment. To implement the ontology, we adopt the Ontology Web Language (OWL) [36] as it is an open standard for semantic knowledge representation. The tool used for modelling and building the OIA is the Protégé 5.2 [37]. We adopt the Semantic Web Rule Language (SWRL) [38] for expressing the inference rules included in the ontology. Such rules are used for automatically reasoning the stored knowledge against the information provided by the assessors. Reasoning in this context means the use of existing knowledge of a system and rules to infer new knowledge or to make reliable predictions about the systems future state or behaviour [36], [38].

Phase 4 – Evaluate the ontology. In this phase, we illustrate with a concrete use case the ontological formalisations of an interoperability assessment. Such use case is based on a real business scenario from an enterprise located in Luxembourg. To perform such an evaluation we create instances for the proposed ontology (step 7 from [35]).

3. Determining the scope and domain

First, considering an enterprise as a social-technical system and consequently a business network as a systems of systems (SoS) [39], [40], we study the definition and main characteristics of such systems. Next, we highlight the importance of interoperability assessment within a business network.

3.1. System Engineering

Systems Engineering is an interdisciplinary approach enabling the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem [27]. In the next subsection, we characterise the "system" and present techniques for designing such systems.

3.1.1. Characterising systems and systems of systems

Ludwig von Bertalanffy, one of the founders of the General System Theory (GST), defines a system as "*a set of interconnected parts, having properties that are richer than the sum of the parts' properties*" [26]. Based on the GST, various works were proposed for characterising, modelling, developing a system. Table 1 shows a non-exhaustive list of system's definitions.

Table 1. System definitions

Reference	Definition
(von Bertalanffy, 1968) [26]	A set of interconnected parts, having properties that are richer than the sum of the parts' properties
(Ackoff, 1971) [41]	A set of interrelated elements.
(ISO 15704, 2000) [42]	A collection of real-world items organised for a given purpose.
(ISO 9000, 2015) [43]	Set of interrelated or interacting elements.
(INCOSE, 2015) [27]	An integrated set of elements, subsystems, or assemblies that accomplish a defined objective.
(ISO/IEC/IEEE 15288, 2015) [44]	Combination of interacting elements organized to achieve one or more stated purposes.

Considering the cited definitions, we remark that all of them agree that a system can be seen as *a set of interrelated elements*. However, when considering the system of systems concepts, there is still not a consensus. Various researchers and practitioners tried to define a system of systems in the past fifth years. Table 2 presents some of the proposed definitions of a SoS.

Table 2. System of systems definitions

Reference	Definition
(Maier, 1998)[45]	An assemblage of components, which individually may be regarded as systems.
(Krygiel, 1999) [46]	A set of different systems so connected or related as to produce results unachievable by the individual systems alone
(DeLaurentis and Callaway, 2004) [47]	Combination of a set of different systems forms a larger "system-of-systems" that performs a function not performable by a single system alone.
(Boardman and Sauser, 2006) [48]	A SoS is much than a system because its parts, acting as autonomous systems, forming their own connections and rejoicing in their diversity, lead to enhanced emergence, something that fulfils capability demands that set a SoS apart.
(INCOSE, 2015) [27]	A system of interest whose system elements are themselves systems; typically, these entail large-scale interdisciplinary problems with multiple, heterogeneous, distributed systems

Furthermore, the main characteristics of a SoS found in the literature [45], [47], [48], [49] can be summarised in Table 3.

Table 3. Main characteristics of a SoS

Characteristic	Description
Autonomy	Exercised by component systems to achieve the purpose of the SoS.
Evolution	The SoS adapts to fulfil its mission as a whole as the underlying technologies evolve with time.
Emergence	The SoS creates an emergence capability climate that supports the early detection and elimination of bad behaviours of its constituents.
Connectivity	Dynamically provided by component systems with each possibility of multiple connections between systems, through a net-centric architecture, or by interoperability processes, to enhance SoS capability
Diversity	Increased diversity in SoS capability achieved by released autonomy, committed belonging, and open connectivity
Belonging	Components systems choose to belong on a cost/benefits basis; also to cause more significant fulfilment of their purposes, and because of confidence in the SoS purpose

3.1.2. Model-Based System Engineering approaches

In general, a model can be seen as "*an abstraction or representation of a system*" [42]. There are many purposes for modelling systems e.g. the characterisation of the state of an existing system, the design of a future system, the verification and testing of system's requirements, etc.[33], [27]. Thus, the model must be scoped to address its intended purpose [27].

Therefore, the Model-Based System Engineering is the "*formalised application of modelling to support system requirements design, analysis, verification, and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases*" [27]. Various Model-Based System Engineering methodologies have been proposed in the literature. For instances, the methodology based on state analysis proposed by the Jet Propulsion Laboratory [50], the Object-process methodology (OPM) defined by (Dori 2011), the Model-Driven Architecture methodology from Object Management Group (OMG) [51] and the System Engineering ModelDriven (SEMD) pattern defined by [32]. Moreover, some research focuses on the interoperability domain specifically. For example, [52] proposes an interoperability framework for a model-driven development of software systems, [53] defines a model-based interoperability engineering process for System of Systems focusing on the civil aviation, and [54] proposes a model-driven approach to design collaborative information system.

Among them, we adopt the SEMD pattern [32] as it proposes a pattern for the system of enterprisesystems design in a higher level of abstraction. The defined concepts facilitate the modelling and instantiation of systems and SoS in the enterprise context. Figure 1 depicts an extract of the SEMD meta-model. The description of the meta-model is given hereinafter.

In Figure 1, a SoS is seen as a Loosely coupled System, which is an emergence resulting from a temporal aggregation of at least two other Loosely coupled Systems. Such systems are engineered following a System Engineering approach, based on the Initial Requirements provided by the Client. In the following, the Engineering System is the system "to be built" based on System Engineering practices. However, the Engineered System is the "built" system. The System of Systems Engineering (SoSE) refers to the practices for defining such SoS.

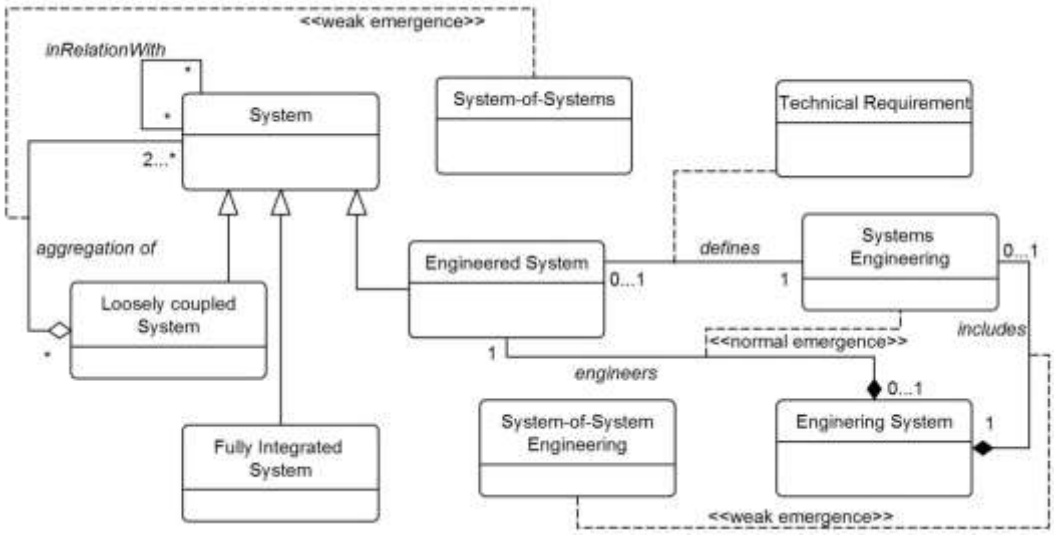

Figure 1 – The System Engineering Model-Driven pattern. Adapted from [32]

3.2. Enterprise Interoperability Assessment

It is important to note that the concept of **interoperability** is different from the concept of **collaboration**. Generally speaking, interoperability is the ability or the aptitude of two systems that have to understand one another and to function together [5]. Two interoperable enterprises do not necessarily collaborate in a joint project; two companies that collaborate can have serious problems of interoperability. Therefore, Interoperability is a **prerequisite** for collaboration [5].

To achieve a higher quality of interoperability, a certain number of interoperability requirements should be satisfied [5], [55]. These requirements define the needs of stakeholders regarding interoperability and describe what systems must comply for being considered as interoperable. As soon as requirements are not fulfilled, interoperability problems can appear and hinder interoperation between partners. Consequently, this becomes a problem that must be solved.

Assessing the enterprises' ability to interoperate is frequently the initial step toward the identification of interoperability problems and the proposition of interoperability improvements [17]. Therefore, enterprises should benefit from the use of interoperability assessment approaches for determining their systems' strengths and weaknesses regarding interoperability.

In order to formalise the knowledge of INAS, we develop the Ontology of Interoperability Assessment. In Computer Science, an ontology specifies the concepts, relationships, and other distinctions that are relevant for modelling a domain, where the specification takes the form of the definitions of representational vocabulary, which provide meanings for the vocabulary and formal constraints on its consistent use [56].

4. Gathering information and knowledge

In this section, we introduce the related work serving as basis for the development of the OIA. Further, we investigate well-known international standards that provide information regarding assessment processes. Finally, we review ontologies and models supporting the INAS. Note that, the objective of this section is not to present an exhaustive review but to identify relevant work for this research.

4.1. Ontologies and models for interoperability

A review regarding INAS domain does not disclose any ontology defining explicitly the INAS. Nonetheless, we found various approaches for describing the interoperability domain and models for supporting INAS.

Indeed, in the past years, various projects have been proposed for studying the interoperability domain. The most well-known and cited frameworks are for instances, the IDEAS interoperability framework [57], the ATHENA Interoperability Framework (AIF) [58], the Framework for Enterprise Interoperability (FEI) [5], [59] defined in The INTEROP Network of Excellence (INTEROP NoE) project and the European Interoperability Framework (EIF) [60].

Regarding the interoperability assessment, the most well-know approaches are: the Levels of Information System Interoperability (LISI) maturity model[61], the Organisational Interoperability Maturity Model (OIMM)[62], the Levels of Conceptual Interoperability Model (LCIM) [63], the Enterprise Interoperability Maturity Model (EIMM) [64] and the Maturity Model for Enterprise Interoperability (MMEI) [14]. A complete systematic literature review regarding interoperability assessment approaches can be found in [15].

Among them, we adopt the Ontology of Enterprise Interoperability (OoEI) [28] that is a metamodel, which formally describes the system's concepts and their relations, regarding interoperability. Regarding specifically the INAS domain, we adopt the standard namely Maturity Model for Enterprise Interoperability [14], [65]. The reasons of choosing MMEI as reference model, is because: it explicitly defines a process for performing an interoperability assessment, it follows a systemic approach based on OoEI, it covers all three interoperability layers and provides a set of best practices relating to its evaluation criteria. It was also taken into account the fact that OoEI and MMEI are rooted in the same standard, which is the FEI [5], [59]. Both of them are presented below.

4.1.1. The Ontology of Enterprise Interoperability

One of the first attempts to formally conceptualise the interoperability domain was made by [66], [67] in the INTEROP NoE project. The OoI final version had been documented in the INTEROP NoE project's derivable DO.2 [68].

In the following years, the OoI had been integrated with concepts from Framework for Enterprise Interoperability [5] and Enterprise-as-a-System concepts for adding a specific vocabulary to the enterprise domain. The resulting ontology is called the Ontology of Enterprise Interoperability (OoEI) [28], [30]. The OoEI is a meta-model, which formally describes the system's concepts and their relations, regarding interoperability. The OoEI includes a systemic model centred on the notion of the system and its properties, and a decisional model that constitutes the basis to build a decision-support system for enterprise interoperability. A detailed description of this ontology can be found in [28].

4.1.2. The ISO 11354-2: Maturity Model for Enterprise Interoperability

The MMEI focus on the potentiality assessment i.e. evaluates the maturity of an enterprise towards its environment. It defines five maturity levels of interoperability: Unprepared, Defined, Aligned, Organised and Adaptive. MMEI organises its evaluation criteria in twelve areas of interoperability, which are based on the cross-section of the interoperability barriers (Technological, Organisational and Conceptual) and concerns (Data, Service, Process and Business) defined on FEI [5].

The model current version provides a six-steps process inspired on the ISO 15504. The first step consists on defining the purpose of the assessment, its scope and any complementary information that needs to be gathered. Further, the step 2 refers to the information gathering. In this step, assessors collect information through a series of interviews and from documents analysis. At step 3, the gathered information is synthesise and validated through feedback sessions.

Having validated the information, assessors move forward to step 4, i.e. the system evaluation. This step is based on two phases: first, each assessor gives his own evaluation, while in the second phase; the assessing team needs to aggregate the individual evaluations and reach a compromise about the assigned rate for each assessed criterion. Finally, the maturity level is determined based on defined rules (Step 5). At step 6, best practices are proposed to facilitate the migration from the determined maturity level to a higher one.

4.2. Assessment standards

Among the reviewed literature, we chose relevant work to use as basis for this research work, such as: the SEMD pattern [32], the OoEI [28] the MMEI [14].

However, in order to have a closer look into the assessment domain, despite the applied context, we study in more detail four well-known and industry applicable standards: The ISO 9000 [43] family of standards, which is produced to help enterprises to evaluate the quality of systems; The ISO/IEC 33000 [69] family (the predecessor of the ISO 15504 family [70]) provides overall information of the employment of process assessment for evaluating the achievement of process quality characteristics; The Capability Maturity Model Integration (CMMI) framework [71–73], which provides a set of practices for developing processes, resulting in a performance improvement system that covers the way for better operations and performance; and the Control Objectives for Information and related Technology 5 (COBIT 5) [74] which is a business framework for the governance and management of enterprise information technology.

Among the studied standards, we consider the ISO 9000 and the ISO 33001, as they are more general (i.e. can be applied to any kind of domain or sector of activity). Another reason to disregards COBIT 5 and CMMI is the fact that both are defined based on the ISO 15504. We argue that considering the ISO 33000 family, which substitute the ISO 15504 family, it is enough for understanding the principles of a process assessment. Both ISO 9000 and ISO 33001 standards are described as follows.

The ISO 9000 describes fundamentals of quality management systems and specifies the terminology for quality management systems [43]. It provides a definite vocabulary for describing concepts related to system's requirements and association with an audit. The term "audit" provided by the standard is considered the equivalent to the term "assessment" in this paper. The definition of an audit provided is the following: "*an audit is a systematic, independent and documented process for obtaining audit evidence and evaluating it objectively to determine the extent to which audit criteria are fulfilled"* [43].

According to ISO 33001, the purpose of the process assessment process is to determine the extent to which the organization's standard processes contribute to the achievement of its business goals and to help the organization focus on the need for continuous process improvement [69]. This standard describes the main elements of a process assessment processes such as the assessment framework (including the measurement mechanisms, the assessment requirements etc.).

5. Developing the Ontology of Interoperability Assessment

The INAS can be seen as a process for determining the interoperability quality of a system (e.g., a software application or organisation unit) or of a relation between systems (e.g., two enterprises). Such process can be triggered, for example, when an interoperability problem appears or transformations are planned. For improving/transforming the concerned systems, decisions are made considering the assessment results. Based on this assumption and the gathered information, we propose an architecture for modelling the concepts and relations of an INAS process. This modelling corresponds to the third phase of our methodology, which includes the steps 3 to 6 from [35]: enumerate terms, define concepts, establish relationships and define concepts' data properties.

Applying a Model-Based System Engineering approach, define three layers for describing the proposed architecture: the Assessment MetaModel, the Interoperability Assessment MetaModel and the Implementation. The Assessment MetaModel contains the general concepts of an assessment. As this model defines a general representation of an assessment, it can be used for instantiating different types of assessment, e.g. security assessment, sustainability assessment and agility assessment, and so on. The Interoperability Assessment MetaModel is an instantiation of the Assessment MetaModel, based on the interoperability assessment. Therefore, this model contains specific concepts of an INAS. Finally, the Implementation is the instantiation of the real world. The Assessment MetaModel and Interoperability Assessment MetaModel are designed by using UML class-diagrams [75].

5.1. The Assessment MetaModel

We divide the model into two cores: the systemic core, which allows the design of systems to be assessed, and the assessment core that describes the concepts related to an assessment allowing the design of different kinds of assessment. This model is based on concepts from the OoEI [28], and enriched with concepts from the SEMD [32], ISO 9000 [43], the MMEI [14], and the ISO/IEC 33001 [69]. The model's concepts are selected on their relevance to an interoperability assessment process. Indeed, we start by defining the object of the assessment, which in our case is a system, and the main relevant concepts related to such an assessment. After many iterations of modelling, simulation with the Protégé tool (see Section 5.3) and discussions with the main stakeholders, we defined the concepts presented in Table 4.

Table 4. Definitions related to a System

Terms	Based on	Definition
System	SEMD, OoEI, ISO 9000	A system is a bounded set of inter-connected elements forming a whole that functions for a specific finality in an environment, from which it is dissociable and with which it exchanges through interfaces. Note that a system defined based on Requirements through Systems Engineering practices can be called as Engineered System [32]
Quality	ISO 9000	Degree to which a set of inherent Quality characteristics fulfils Requirements [43]
Quality Characteristic	ISO 9000	Measurable inherent characteristic of the Object of Assessment; Collection of attributes that are significant to the Object of Assessment [43]
Quality Attribute	ISO/IEC 33001	Measurable attribute of a Quality Characteristic [69]
Requirement	SEMD, ISO 9000	Need or expectation that is stated, generally implied or obligatory [43], [32]
Assessment Process	ISO 9000, ISO/IEC 33001, MMEI	A systematic, independent and documented Process for obtaining Evidence regarding the defined Evaluation Criteria and evaluating it objectively against a standard or set of guidelines to determine the Quality of the concerned Quality Characteristic from the assessed Object of Assessment. [43], [14]
Assessment Scope	ISO/IEC 33001	Definition of the boundaries of the Assessment, provided as part of the assessment Input [69]
Object of Assessment	ISO/IEC 33001, MMEI	Something or someone that are concerned by the Assessment.
Evaluation Criteria	ISO/IEC 33001, MMEI	Measurable requirement of a Quality Attribute [14], [69]
Problem	OoEI	A situation, person, or thing that needs attention and needs to be dealt with or solved
Solution	OoEI	The answer to a problem

Figure 2 illustrates systemic and assessment cores.

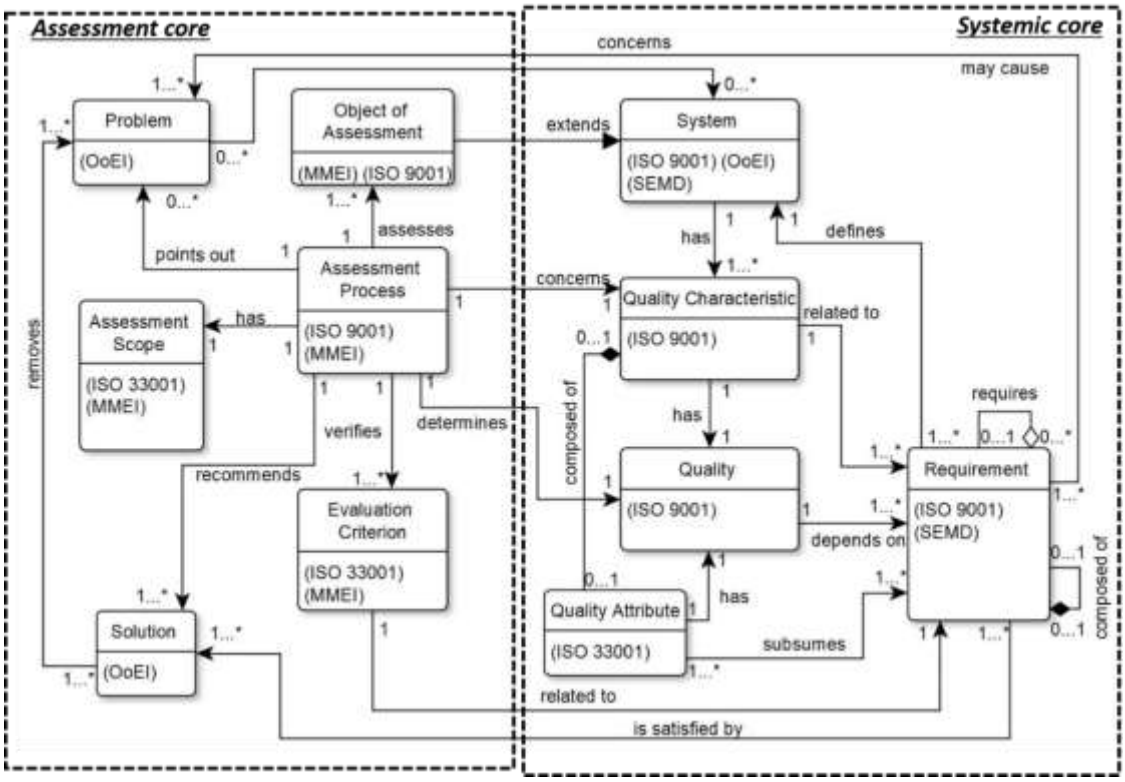

Figure 2 – The conceptual model for the interoperability assessment

On the right side of the Figure 2, we find the systemic core of the model where the *System* is defined based on *Requirements* through systems engineering practices. In general, *Requirements* may be composed of other *Requirements* and some *Requirements* may require other *Requirements*. Several characteristics can characterise a *System*.

Such characteristics can be inherent to a *System* or assigned to it. Inherent characteristics are those existing in a *System*, and the assigned ones are those given by someone or something (e.g. the price of a product) [43]. A *Quality Characteristic* is an inherent characteristic of a *System*, which is related to a set of *Requirements*. A *Quality Characteristic* is composed of a set of *Quality Attributes* that are measurable properties of such characteristic.

In the INAS context, these attributes represent the different interoperability areas. Moreover, *Requirements* are organised according to their relevance to a *Quality Attribute*. The *Quality* concept represents the degree in which a *Quality Characteristic* or a *Quality Attribute* fulfils the related *Requirements*.

On the left side of the Figure 2, we find the assessment core of the model. An *Assessment Process* has a purpose, which can be defined as the statement defining the reasons (i.e. the Why and What) for performing the assessment [69]. For example, a business network needs a new partner from a specific sector for fulfilling a role in the network's new business model (the Why). Therefore, the network compares candidates and selects one (the What). Aligned with the purpose, the *Assessment Scope* defines the boundaries of the assessment, i.e. it defines the *Quality Attributes* to be considered, the type of assessment etc. Regarding the inputs of an *Assessment Process*, the *Object of Assessment* represents anything that is evaluated.

The concerned *Evaluation Criteria* is verified by the *Assessment Process*. Each *Evaluation Criterion* is related to a *Requirement*. To determine the *Quality*, during the *Assessment Process*, rates are determined for each verified *Evaluation Criterion*. The rate is a data property of the *Evaluation Criterion, which* is related to the scale defined in the adopted measurement mechanism. A rating scale can range from a set of values (e.g. "0 to 100"). Based on the *Evaluation Criteria* rating and the determined *Quality*, the *Assessment Process* points out identified *Problems* and recommends related *Solutions*. In general, *Solutions* are best practices prescribed in domain specific standards or in the adopted assessment framework.

5.2. The Interoperability Assessment MetaModel

In order to design the Interoperability Assessment Model, we first define the assessment conditions. Such conditions correspond to the selection of a *Quality Characteristic* to be assessed, the selection of an assessment framework and so on. In our case, we instantiate *Quality Characteristic* as *Interoperability*, the *Object of Assessment* as *Enterprises* and *Networked Enterprises*. The adopted assessment framework is the MMEI [14].

Having established these conditions, we use them to instantiate the Assessment MetaModel. Note that the meta-model defined in the previous section could be instantiated based on another quality characteristic (e.g. sustainability), system and another assessment framework.

The resulting Interoperability Assessment MetaModel is based on concepts from the OoEI [28], and enriched with concepts from SEMD [32], ISO 9000 [43], the MMEI [14], and the ISO 33001 [69]. Figure 3 illustrates the Interoperability Assessment MetaModel. The rationales are presented in the following.

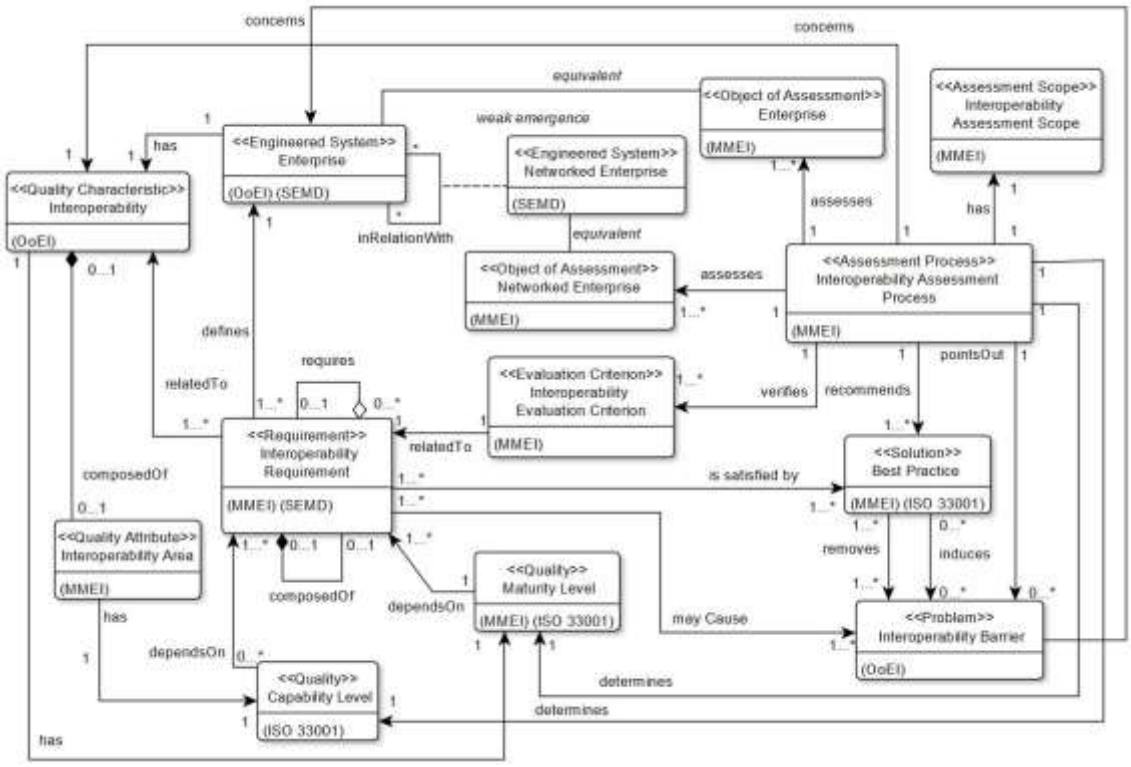

Figure 3 – The Interoperability Assessment MetaModel

In Figure 3, an *Interoperability Assessment Process* is an instance of an *Assessment Process*. It concerns the *Interoperability* (a *Quality Characteristic*). The *Interoperability Assessment Scope* is associated with the *Interoperability Areas* to be considered and INAS type (i.e. potentiality, compatibility and performance). An *Enterprise* and a *Networked Enterprise* are the *Object of Assessment* of this kind of assessment. Note that both *Networked Enterprise* and *Enterprise* are also instances of the *System* concept. Moreover, the *Interoperability Areas* are considered as *Quality Attributes* of the *Interoperability*.

It is related to the interoperability barriers and interoperability concerns. Each area is related to a set of *Interoperability Requirements*. Hence, the *Interoperability Evaluation Criteria* are related to the *Interoperability Requirements*. The adopted assessment framework describes the *Interoperability Evaluation Criteria*, the *Interoperability Requirements* and the measurement mechanisms.

The determination of the *Interoperability Quality* depends on the fulfilment of the *Interoperability Requirements*. There are two types of *Interoperability Quality*: the *Maturity Level* and the *Capability Level*. A *Maturity Level* represents how well the *Object of Assessment* is fulfilling all the

Interoperability Requirements. The *Capability Level* represents how well the *Object of Assessment* is respecting the *Interoperability Requirements* related to a specific *Interoperability Area*. Moreover, considering the rating of the *Interoperability Evaluation Criteria*, the *Interoperability Assessment Process* points out the potential *Interoperability Problem* and related *Best Practices* (i.e. *Solution*).

5.3. Implementing the Ontology for Interoperability Assessment

Here, we implement the conceptual model previously defined using Protégé. For implementing it, we use the concepts from the Assessment MetaModel as Classes from the T-Box and the instances from the Implementation as individuals of A-Box. Figure 4 illustrates the three layers of the architecture and its relations with the proposed OIA.

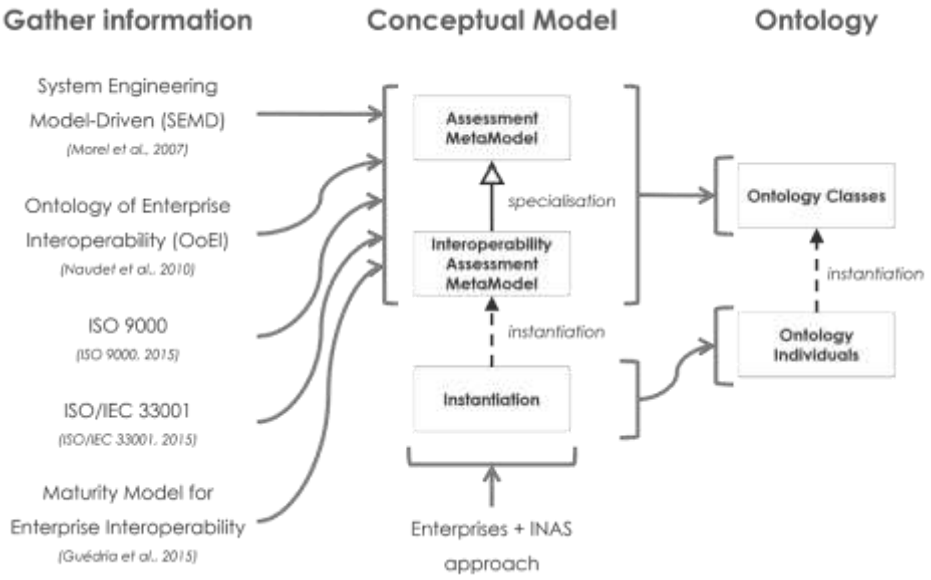

Figure 4 – The conceptual model architecture for developing the OIA

Furthermore, we define the Object Properties (link individuals to individuals) and Datatype properties (link individuals to data values). The latter is additional information concerning the attributes of an instance of a concept (e.g. the Name, and the rate of a criterion). The former is defined based on the concepts relationships. Figure 5 illustrates an overview of the ontology.

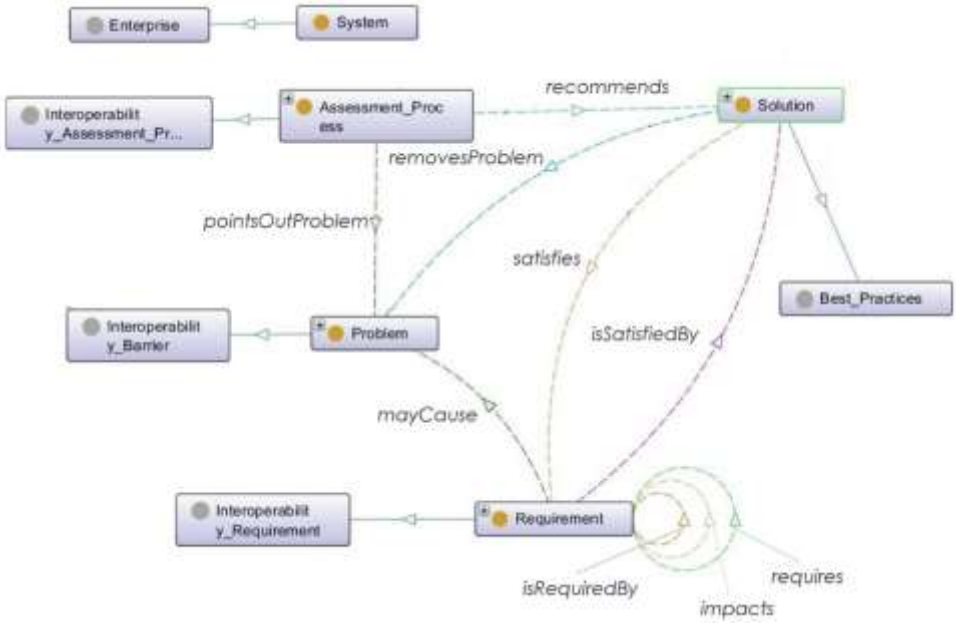

Figure 5 – Extract of the Ontology for Interoperability Assessment

Moreover, five inference rules, defined with SWRL, are used to infer knowledge concerning the assessment process and the requirements' achievements. The rules are mainly used for identifying the interoperability barriers that a non-fulfilled requirement may cause and the best practices related to them. Impacts of non-satisfied requirement on other requirements are also inferred using these rules. The Drools engine (a plug-in for Protégé) is used for inserting the defined rules within the ontology. The rules are described in Table 5 to Table 9.

Table 5. Rule: Attributing requirement to an assessment

Language	Description (Formula)
Natural Language:	The interoperability assessment process verifies those interoperability requirements that are related to the interoperability areas and the assessment type defined by the assessment scope.
SWRL Language:	`Assessment_Process(?iap) ^ Quality_Attribute(?ia) ^ hasScope(?iap, ?ap) ^ Assessment_Scope(?ap) ^ relatedToAttribute(?ir, ?ia) ^ definesAttribute(?ap, ?ia) ^ Requirement(?ir) -> verifiesCriterion(?iap, ?ir)`

Table 6. Rule: Identifying negative impacts

Language	Description (Formula)
Natural Language	If a specific requirement *R1* that is verified by the assessment has a lower rate than the one stipulated as "minimum" and the same requirement *R1* is required by another verified requirement *R2*, requirement *R1* influences negatively the requirement *R2*.
SWRL Language	`hasMin(FA, ?miv) ^ requiresRequirement(?irR1, ?irR2) ^ hasRate(?irR2, ?raR2) ^ swrlb:lessThan(?raR2, ?miv) ^ Assessment_Process(?a) ^ Evaluation_Criterion(?irR2) ^ Evaluation_Criterion(?irR1) ^ verifiesCriterion(?iap, ?irR2) ^ verifiesCriterion(?iap, ?irR1) -> impactsRequirement(?irR2, ?irR1)`

Table 7. Rule: Pointing out barriers and recommending best practices

Language	Description (Formula)
Natural Language	If a specific requirement that is verified by the assessment has a lower rate than the one stipulated as "minimum", the assessment points out the interoperability barrier(s) and recommends the best practice(s) that are related to the concerned requirement.
SWRL Language	`satisfiesRequirement(?bp, ?ir) ^ Assessment_Process(?iap) ^ hasMin(FA, ?miv) ^ Solution(?bp) ^ relatedToCondition (?ir, ?ib) ^ swrlb:lessThan(?ra, ?miv) ^ Existence_Condition(?ib) ^ Evaluation_Criterion(?ir) ^ verifiesCriterion(?iap, ?ir) ^ hasRate(?ir, ?ra) -> pointsOutCondition (?iap, ?ib) ^ hasCause(?ib, ?ir) ^ recommends(?iap, ?bp)`

Table 8. Rule: Verifying level non-satisfaction

Language	Description (Formula)
Natural Language	If a considered requirement has a rate less than the stipulated minimum, the concerned requirement does not satisfy the related level.
SWRL Language	`hasMin(FA, ?miv) ^ Quality(?il) ^ swrlb:lessThan(?ra, ?miv) ^ dependsOnRequirement(?il, ?ir) ^ Evaluation_Criterion(?ir) ^ hasRate(?ir, ?ra) -> doesNotSatisfy(?ir, ?il)`

Table 9. Rule: Verifying level satisfaction

Language	Description (Formula)
Natural Language	If a considered requirement has a rate less than the stipulated minimum, the concerned requirement satisfies the related level.
SWRL Language	`hasMin(FA, ?miv) ^ Quality(?il) ^ dependsOnRequirement(?il, ?ir) ^ Evaluation_Criterion(?ir) ^ hasRate(?ir, ?ra) ^ swrlb:greaterThan(?ra, ?miv) -> satisfiesLevel(?ir, ?il)`

Once the reasoning is completed, a query using SPARQL [36], [37] can be used in Protégé environment for querying if all the related requirements are satisfied (based on the Rule: Verifying level satisfaction). Indeed, based on the results of the query, that indicates if an assessed requirement satisfies

a related level or not, the maturity level of the system can be determined by verifying if all the requirements of the considered level are satisfied.

6. Evaluating the ontology

In this section, the evaluation of the proposed contribution is presented (Phase 4 of our research methodology). According to [34] the evaluation of artefacts (e.g. prototypes, methodologies, etc.) is an activity that provides feedback information and a better understanding of the addressed problem in order to improve both the quality of the contribution and the design process. Indeed, an evaluation means to observe and measure how well the artefact supports a solution to the problem [25]. This activity involves comparing the objectives of a solution to actual observed results from use of the artefact.

Therefore, we apply the proposed ontology for interoperability assessment, using a real case study based on an IT service provider in Luxembourg. For confidentiality reasons, we omit the name of the enterprise, and we refer to it as **ITECH**. The case concerns the interoperability maturity assessment of ITECH, i.e. how mature is the ability to interoperate from ITECH towards its environment.

For illustrating this assessment, we used the Maturity Model for Enterprise Interoperability [14], as the INAS approach. Note that, the OIA can be instantiated to any INAS approach and enterprise or to a network of enterprises.

First, the ontology is instantiated based on the adopted INAS approach and the concerned enterprise (step 7 from the adopted methodology [35]). The instantiation in this case is the responsibility of the lead assessor, which is responsible for the entire assessment process. The leas assessor is expected to have a clear understanding of the assessment workflow and to facilitate the entire assessment [14]. Next, the instantiated OIA is used to support the ITECH assessment.

6.1. Instantiating the ontology

First, the lead assessor populates the ontology with the individuals that are from the adopted INAS approach (i.e. MMEI). We also considered the interdependencies of the interoperability requirements defined on [40]. The instantiation is done using the Protégé tool. The instantiated classes are presented in Table 10.

Table 10. Ontology's instantiations

Class	Instantiation
Requirement	The set of interoperability requirements. To facilitate the requirements' identification we attribute an ID, which it is composed of the first letter of the related Interoperability Concern, the first letter of the related Interoperability Barrier. These are followed by the letter "R", meaning that it is a requirement. The related maturity level follows it. For example, the ID "BCR1" represents the requirement related to the Business concern and the Conceptual barrier from the maturity level 1.
Problem	The interoperability barriers described in the Framework for Enterprise Interoperability (Chen, Dassisti, Elvesaeter et al., 2007)
Solution	The 126 best practices defined in MMEI [14], [65]
Quality Attribute	The twelve interoperability areas (*Business-Conceptual, Business-Technological, Business-Organisational, Process-Conceptual, Process-Technological, Process-Organisational, ServiceConceptual, Service-Technological, Service-Organisational, Data-Conceptual, Data-Technological* and *Data-Organisational*) defined in MMEI.
Quality	The five maturity levels (*Unprepared, Defined, Aligned, Organised* and *Adaptive*) defined in MMEI

Table 11 presents some of the information that is instantiated regarding the requirement "*BCR1: Business models shall be defined and documented*".

Table 11. Interoperability Requirement BCR1 relations

Interoperability Requirement	*BCR1: Business models are defined and documented*

Interoperability Area	*Business-Conceptual*
Maturity Level	*Level 1 - Defined*
Requires	*BOR1: Organization structure is defined and in place*
Is required by	*BCR2: Standards are used for alignment with other business models* *BTR2: Standard-based and configurable IT infrastructure are used* *BCR3: Business Models are designed for collaboration mappings* *DCR3:Meta-modeling for multiple data model mappings* *BCR4: Business models are adaptive* *DCR2:Use of standards for alignment with other data models* *BOR1: Organization structure is defined and in place* *DTR2: Automated access to data based on interoperability* *BOR2: Human resources are trained for standard protocols* *PTR2: Standard-based IT tools are used BTR1: Basic IT infrastructure is in place*
Best Practices	*BP_DT1.1. Identify data that can be subject of future interoperation* *BP_DT1.2. Configure data storage devices so that they are connectable* *BP_DT1.3. Put in place technical assets supporting data exchange within the enterprise* *BP_DT1.4. Define protocols that can be used for data exchange interoperability*
Interoperability Barrier	*IBBC1: Business Content* *IBBC2: Business syntax* *IBBC3: Business semantics*

Figure 6 shows the relationships and details of the BCR1 requirement.

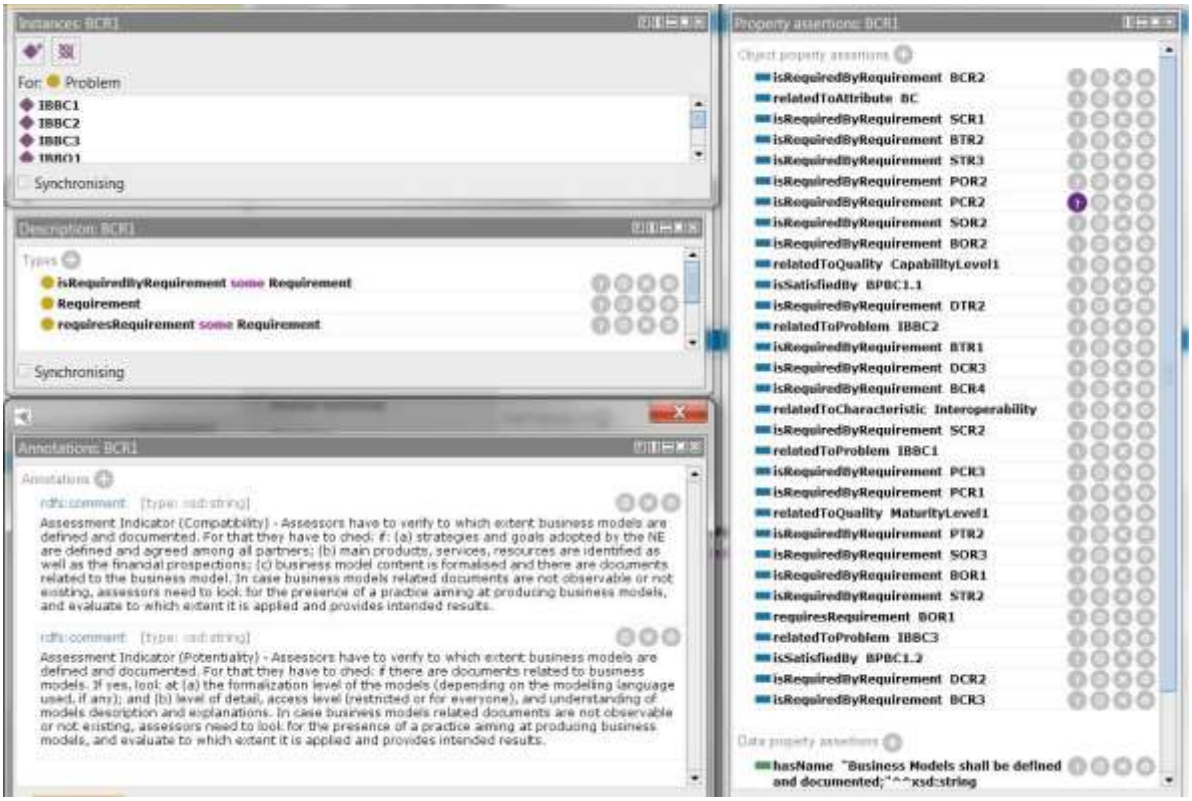

Figure 6. BCR1 requirement details

Further, new instances are added based on the considered enterprise and its context. It is done according to the defined assessment scope. The scope definition is part of the Assessment Preparation phase, which is detailed in the next section.

6.2. Conducting an interoperability assessment using OIA

The next two phases were followed for performing the ITECH assessments. The first one was the Assessment Preparation in which the objective is to define the purpose of the assessment, its scope (e.g. the name of the assessment, the systems to be assessed, the interoperability areas to be considered, etc.), under which constraints it is done (i.e. the context) and any additional information that needs to be gathered. As stated before, the Assessment Preparation phase also supports the instantiation of OIA regarding the conducted assessment.

The second phase was the Assessment itself. In this specific case, two assessors (one being the lead assessor) evaluated the ITECH interoperability maturity by applying the MMEI. The assessment data collection was done based on interviews with key employees. Two workshops were also conducted. Documents sent by ITECH were also used to complement the assessors' analysis. The questionnaire used on the interviews was semi-structured and the questions were used to initiate discussion on identified issues.

Once the data collected and validated by the key employees, the assessors rate the evaluation criteria related to the considered interoperability areas. Further, the lead assessor aggregated the rating from the evaluated criteria using the aggregation mechanism defined in [14]. Having all the needed information and ratings, the lead assessor instantiated the OIA using the Protégé tool. Once it was done, the lead assessor started the reasoner plugin from Protégé, which inferred the ontology. Figure 7 illustrates the assessment process using OIA.

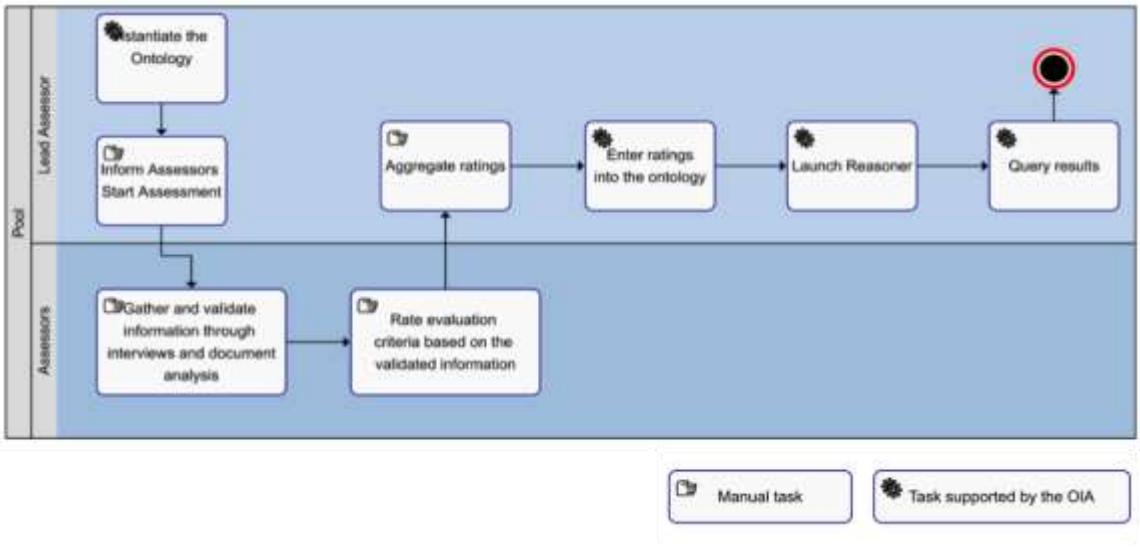

Figure 7. The assessment process using OIA

Figure 8 presents the OIA instantiated and inferred regarding the ITECH assessment.

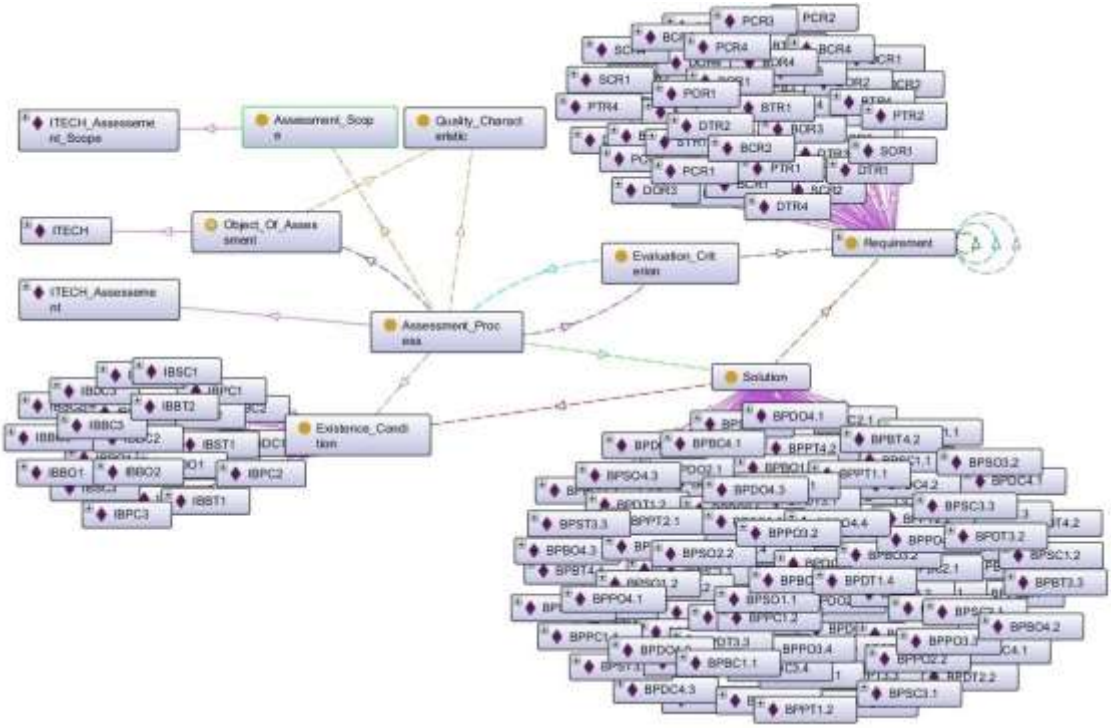

Figure 8. The OIA instantiation based on the ITECH case.

From the inferred ontology, the lead assessor could determine the maturity level together with a list of best practices for removing or reducing the negative impacts of the identified interoperability barriers. For retrieving the determined maturity level, the lead assessor queries the ontology using the protégé environment (SPARQL) functionality [36], [37].

Table 12 describes, as an example, the best practices related to the requirement *PCR1. Process models shall be defined and documented*.

Table 12. Best practices related to the PCR1 requirement

Related Requirement	PCR1. Process models shall be defined and documented
Requirements that are potentially impacting this requirement	"BCR1: Business models shall be defined and documented" is **PA** "DCR1: Data models shall be defined and documented" is **NA** "BOR1: Organization structure shall be defined and in place" is **PA**
Requirements that are potentially impacted by this requirement	PCR2: Standards shall be used for alignment with other process models PCR3: Meta-Models for multiple process mapping shall be defined PCR4: Process modelling shall support dynamic re-engineering POR2: Procedures for process interoperability shall be in place POR4: Process shall be monitored and procedures are adaptive
Best Practices (specific for PCR1)	Define Process models – Identify for each collaborative process its outcomes and related activities. – Identify the involved resource from both enterprises: human, material and immaterial resources – Identify the sequence of execution of activities – Identify the rules of the process and restrictions (if any) Document Process model – Add notes and descriptions to each process model in order to support understanding by any person using the model. – Make the collaborative process available

Finally, based on the assessment outcomes, the lead assessor then, produced the assessment report, summarising the assessment scope and outcomes.

7. 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 the Ontology for Interoperability Assessment. To do so, we followed a research methodology based on the design science research [25] and the methodologies for ontologies development defined in [35] and [36].

The proposed ontology is defined based on the principal concepts from the Ontology of Enterprise Interoperability, the System Engineering Model Driven pattern and international standards such as the ISO 9000, the ISO 33000 and Maturity Model for Enterprise Interoperability. The proposed ontology allows the reasoning of assessment information and the inference of the potential barriers and solutions related to the non-fulfilled evaluation criteria. Indeed, the advantage of the OIA is that it provides a sound understanding of the main concepts related to an interoperability assessment and that it can infer automatically the potential interoperability problems based on the chosen assessment reference model and the current state of the assessed system.

Note that in this paper we used the MMEI as reference assessment approach for building and instantiating the proposed ontology. One of the reasons in choosing this approach is that it considers multiple aspects of interoperability. Nonetheless, one may instantiate the OIA with a different assessment approach, as the ontology was not specifically built for MMEI.

Finally, a case study based on a real business network is presented for evaluating the proposed ontology. As future work, we intend to use the OIA as a knowledge model for developing a computermediated assessment system. Such system will help support assessment process by allowing, in an automated manner, the determination of the quality of interoperability, identification of non-compliant requirements and their negative influences and the automated generation of the assessment report.

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