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Support à la décision pour l'analyse de l'interopérabilité des systèmes dans un contexte d'entreprises en réseau

THÈSE

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par

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Preface

This PhD thesis is the outcome of the collaboration between the Luxembourg Institute of Science and Technology (LIST) and the Research Centre for Automatic Control (CRAN) UMR 7039, Joint Research Unit of the University of Lorraine and the French National Centre for Scientific Research (CNRS) in the frame of the INTEROP Grande-Région Scientific Interrest Group[1].

This thesis is part of the PLATINE project (PLAnning Transformation Interoperability in Networked Enterprises), which is financed by the National Fund of Research of the Grand Duchy of Luxembourg (FNR), under the grant C14/IS/8329172/R2. The objective of this project is to help enterprises plan their interoperability transformations, preventing collaboration issues before they occur.

The involvement of The Factory Group, the project's industrial partner, not only helps reinforcing the comprehensive understanding of the context of networked enterprises and the planning of enterprise interoperability transformations, but it also assists in building a realistic scenario for the validation of PLATINE and this PhD thesis' results.

[1] The SIG INTEROP Grande-Région is one of the research pole of the INTEROP Vlab (international virtual laboratory on enterprises interoperability) – http://www.interop-vlab.eu

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Acronyms

BPMN	Business Process Modelling Notation
DSR	Design Science Research
EA	Enterprise Architecture
EIF	European Interoperability Framework
FEI	Framework of Enterprise Interoperability
IEC	Interoperability Evaluation Criterion
INAS	Interoperability Assessment
IR	Interoperability Requirement
ISO	International Organization for Standardization
IT	Information Technologies
KBS	Knowledge-Based System
MMEI	Maturity Model for Enterprise Interoperability
NE	Networked Enterprise
OIA	Ontology for Interoperability Assessment
OoEI	Ontology for Enterprise Interoperability
OWL	Ontology Web Language
RE	Requirement Engineering
SEMD	System Engineering Model-Driven pattern
SLR	Systematic Literature Review
SoS	System of Systems
SysML	System Modelling Language
SWRL	Semantic Web Rule Language
UML	Unified Modelling Language

General Introduction

Research context and motivation

Contemporary enterprises face a variety of challenges such as globalisation, new technologies and the increasing personalised customer demands in the dynamic socio-economic environment where they evolve. To face such challenges, some enterprises are adapting themselves and collaborating with other companies in networked enterprises (Chung et al., 2004), (Camarinha-Matos and Afsarmanesh, 2005), (Basole et al., 2011), (Proper, 2014). For example, Renault, Nissan and Mitsubishi formed a strategic partnership aiming to improve their production performance and investing in new products such as electric cars[2]. Another recent phenomenon is the increase of collaborative platforms (e.g. AirBnB[3]). Indeed, such platforms enable individuals and other actors such as micro-entrepreneurs and businesses to offer their services (European Commission, 2016a). For instance, an analysis commissioned by the European Commission and performed by PricewaterhouseCoopers (PwC) estimates that the collaborative economy facilitated €28 billions of transactions and generated revenues of nearly €4billons in Europe in 2015 (Vaughan and Daverio, 2016).

In this collaborative context, enterprise interoperability is a prerequisite for ensuring collaboration (Chen, Dassisti, Elvesaeter et al., 2007), (Panetto et al., 2016). Predominantly, it refers to the ability of systems to exchange information and use the information that has been exchanged (IEEE, 1991).

When this ability is not achieved, it becomes a problem that should be solved. In general, interoperability problems raise when interoperability barriers exist. The term ‘barrier’ means an ‘incompatibility’ or ‘mismatch’ which obstructs the sharing and exchanging of information (D. Chen et al., 2007). Three main categories of barriers are identified: *conceptual*, *technological* and *organisational* (D. Chen et al., 2007), (Vernadat, 2010). Consequently, these barriers should be removed to prevent interoperability problems.

Indeed, the lack of interoperability can influence drastically the performance and the outcomes of enterprises and networks. For instance, the U.S. Department of Commerce Technology Administration estimates a cost of U$15.8 billions related to the inadequate interoperability between systems in the U.S. Capital Facilities Industry (Gallaher et al., 2004). The West Health Institute estimates a potential of U$ 30 billions addressable waste per year related to the lack of interoperability across segments of health care in the U.S. (West Health Institute, 2013).

When enterprises encounter interoperability related problems, they should plan coherent transformations of their enterprise systems, to improve interoperability and solve the identified problems, while working seamlessly. To do so, decision-makers have to know what they need to change (Kasunic and Anderson, 2004). In other words, enterprises should be aware of their strengths and weaknesses concerning interoperability, to develop such ability between systems. Hence, enterprises

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[2] alliance-2022.com/

[3] airbnb.com

should perform an INteroperability ASsessment (INAS) as it has the objective to analyse the interoperability, before, during or after any collaboration between enterprise systems for identifying interoperability problems and associated solutions (Chen, Dassisti, Elvesaeter et al., 2007), (Ford et al., 2007a), (Panetto et al., 2016). Indeed, such an assessment determines the enterprise *as-is* state, and provides a roadmap toward the *to-be* state.

When assessing systems in terms of their interoperability, a certain number of interoperability requirements should be verified, i.e. should be considered as evaluation criteria during an INAS (Ford et al., 2007a), (Panetto et al., 2016), (Leal et al., 2017a). These requirements define the needs of stakeholders regarding interoperability and describe what systems must comply with to be considered as interoperable (Chen, Dassisti, Elvesaeter et al., 2007), (Daclin et al., 2016b). However, based on a literature review such as (Ford et al., 2007b), (Guédria et al., 2008), (Cestari et al., 2013), (Rezaei et al., 2013) and (Leal et al., 2019), we observed that few INAS approaches are considering interoperability requirements related to different interoperability barriers and enterprise levels at the same time. We argue that the use of multiple approaches to cover a holistic view of enterprise interoperability might cause: a) redundancy and confusion when more than one INAS approach is considered for the same barrier or enterprise level; and b) difficulties on relating evaluation results as in general the approaches use different measurement mechanism. In addition, no INAS approach explicitly addresses the interdependences between interoperability requirements, which hinder the identification of impacts caused by non-fulfilled requirements on the overall system.

Based on the research context, this thesis aims at addressing the following research problems, seen as necessities and priorities to consider:

- The lack of interoperability requirement formalisation within INAS approaches.
- The lack of INAS approaches explicitly addressing the interdependences between their considered interoperability requirements.

Research questions and the contribution of this thesis

Taking into account the identified research problems, we propose as the main contribution of this thesis:

"A holistic interoperability assessment approach based on interoperability requirements interdependencies"

We argue that such an approach can identify potential impacts of non-fulfilled requirements on other requirements and their associated enterprise systems. Subsequently, the concerned enterprises can have a global view of their systems and the negative impacts caused by non-fulfilled requirements along with the impacts that might be caused by any change for satisfying at least one requirement. Therefore, the enterprises can identify potential and existing interoperability problems and take preventive and corrective measures for avoiding and solving the identified problems, while ensuring the alignment between their enterprise systems.

In order to define and develop this assessment approach, we formulate the following research questions for guiding our research.

"(RQ1) What are the existing interoperability requirements, their interdependencies and their potential impacts on the overall system?"

Indeed, one of the first steps in our research is to investigate and define the different interoperability requirements and their interdependencies. Next, we intend to combine the defined knowledge of interoperability requirements and related interoperability problems and solutions for developing our proposed assessment approach. Hence, we need to link the different concepts related to an interoperability assessment for ensuring a common understanding and avoiding misinterpretation. Therefore, we raise the following question:

"(RQ2) How to formally represent the knowledge related to the interoperability assessment, including interoperability requirements and their interdependencies?"

Indeed, 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 (Power, 2004), (Turban et al., 2004). Regarding the exploitation and implementation of the defined interoperability assessment knowledge, we raised the following and last research question:

"(RQ3) How to assess the interoperability coherently, considering the multiplicity of interoperability requirements, for supporting decision-making regarding interoperability development?"

To answer the first question, we conducted a systematic literature review of the INAS literature aiming at identifying and studying appropriate assessment approaches. The review identifies 37 relevant INAS approaches. From them, we selected the Maturity Model for Enterprise Interoperability (MMEI) (Guédria et al., 2015), (ISO 11354-2, 2015) and its evaluation criteria as a reference assessment model as it adopts a systemic approach and provides a holistic view considering the different interoperability barriers and enterprise levels. However, MMEI does not define relationships between their evaluation criteria. Furthermore, using a Requirement Engineering approach based on the ISO/IEC 29148 (ISO/IEC 29148, 2011) and the requirement formalisation process described in (Peres et al., 2012), we propose an approach for determining interoperability requirements interdependencies.

The strategic alignment domain through the Enterprise Architecture (EA) literature (Lankhorst, 2013), (Proper, 2014), (TOG, 2018) is also considered, for supporting the requirements interdependencies definition. Indeed, an EA supports the visualisation and understanding of requirements and constraints from different levels of an enterprise (TOG, 2018).

For addressing the second question, we develop the Ontology of Interoperability Assessment (OIA) for formalising the knowledge about INAS. An ontology is an explicit formal specifications of the terms in the concerned domain and relations among them (Gruber, 1993). The OIA aims to provide a sound description of the relevant concepts, relationships, and logic rules related to interoperability assessment; and to represent and formalise knowledge concerning interoperability requirements. Indeed, the formal conceptualisation of the INAS knowledge, including the requirements interdepednecies can allow an automated reasoning for identifying positive and negative impacts between requirements.

To do so, we explore existing ontologies, models and standards such as: The ISO 9000 (ISO 9000, 2015), the ISO 33001 (ISO/IEC 33001, 2015) and the Capability Maturity Model Integration (CMMI) framework (CMMI Product Team, 2010a, 2010b, 2010c). The Model-Based System Engineering (INCOSE, 2015) domain is also explored to identify relevant system modelling techniques for organising and designing the concepts and relations of the OIA.

To deal with the third question, we define our holistic interoperability assessment approach by enhancing the MMEI with the determined interoperability requirements interdependencies. We also develop a Knowledge-Based System (KBS) (Power, 2004), (Turban et al., 2004) to support the proposed assessment approach. A KBS is a software application with specialised problem-solving expertise, where "expertise" consists of knowledge about a particular domain (e.g. interoperability) (Power, 2004). Indeed such a KBS can enhance a stakeholder's ability to analyse the system's current state and to make improvement decisions (Krivograd and Fettke, 2012). The designed OIA is used as the KBS's knowledge model as it describes the meaning in a machine-readable way, i.e. besides specifying a precise vocabulary, it also include the means to formally define it for supporting automated reasoning (Gruber, 2009), (Grambow and Oberhauser, 2010), (Alalwan and Thomas, 2012). In summary, the research objectives are to:

1) Provide a holistic view of the interoperability requirements relations, including their interdependencies and association with interoperability problems and solutions;
2) Formalise the knowledge regarding interoperability assessment, including interoperability requirements;
3) Provide a holistic interoperability assessment approach based on the identified requirements interdependencies;
4) Provide a Knowledge-Based System for supporting the proposed INAS approach.

In order to realise the proposed contribution, the Design Science Research (DSR) methodology (Hevner et al., 2004), (Peffers et al., 2007) is adopted. Such methodology aims at providing an artefact (e.g. model, methodology, software system, hardware systems, etc.) as a solution to a specific problem through rigorous research. It is particularly suitable for research on the interoperability assessment discipline, being practice-based, since "*DSR should not only try to understand how the world is, but also how to change it* (Carlsson et al., 2011). Indeed, such a research methodology allows us to establish a balance between academic rigour and industry relevance while representing the artefact as a relevant outcome of a DSR (Hevner et al., 2004), (Gregor and Hevner, 2013).

During the Design and Development activity, an agile and iterative method is used for developing both the Ontology of Interoperability Assessment and the Knowledge-Based System. The adapted DSR methodology has six iterative activities as illustrated in Fig. 1.

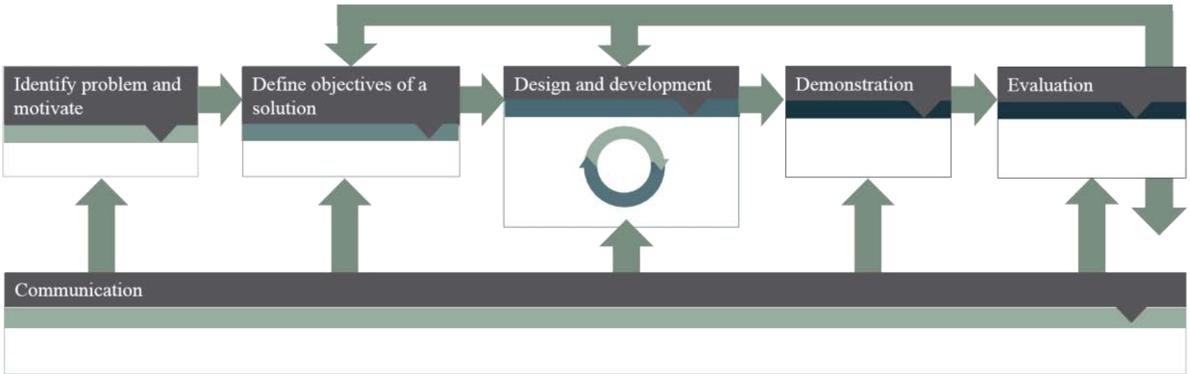

Fig. 1. The research methodology. Adapted from (Peffers et al., 2007)

The structure of this manuscript

Chapter 1 gives an overview of the research context. First, we explore the basic definitions related to a networked enterprise, the different topologies of collaborative relationships and the importance of the alignment between systems. Second, we study the Interoperability domain. We review the main interoperability frameworks, which are proposed for organising and describing knowledge about interoperability. Relevant work regarding interoperability development is also investigated. Finally, the importance and the different properties of an Interoperability Assessment are presented.

In **Chapter 2,** the results of the comparative analysis based on the INAS systemic literature review are brought forward. This comparative analysis aims at showing the evolution of INAS approaches' propositions over the years and the different properties taken into account. Comparison of the types of measurement mechanisms and the addressed interoperability barriers are also explored. The identified limitations are discussed. The thesis contribution is then proposed based on the research context presented in Chapter 1 and the identified limitations in Chapter 2.

Chapter 3 aims at studying the System Requirement Engineering and its related techniques for characterising and designing systems, for elicitating, formalising and modelling requirements. As a result, a Requirement Engineering approach is proposed for identifying, formalising and interrelating interoperability requirements. **Chapter 4** aims at specifying the knowledge found in Chapter 3 by proposing the Ontology of Interoperability Assessment. Moreover, the development of the prototype of the KBS based on the ontology is described. The prototype has the objective to ease the assessment process by providing automatic steps such as the requirement rate aggregation and the evaluation report generation. **Chapter 5** has the objective to demonstrate the proposed contribution in practice through a real case study. The evaluation of the thesis contribution is also performed. Finally, the **Conclusion** aims at discussing the research findings and concludes the research conducted in this dissertation. It also presents the research perspectives derived from this thesis.

Fig. 2 illustrates the instantiation of the DSR methodology to this thesis. It also shows the relations of each chapter of this document.

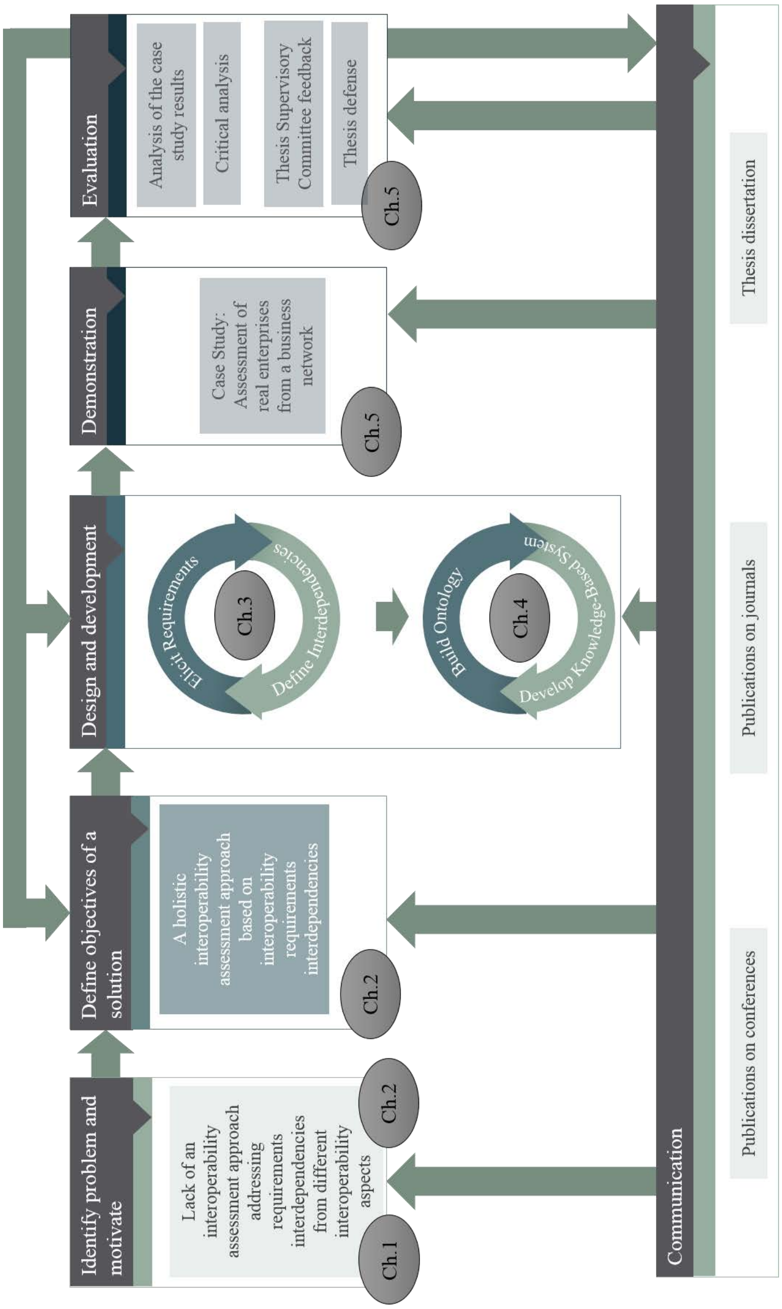

Fig. 2. The research methodology instantiated to this thesis. Adapted from (Peffers et al., 2007)

Chapter 1

Enterprise Interoperability within Networked Enterprises

Introduction

"*As a basic rule, in order to support rapid formation of collaborative networks, it is necessary that potential partners are ready in advance and prepared to participate in such collaboration*" (Camarinha-Matos et al., 2009). Readiness for collaboration means the capability from leadership to supporting collaborative activities, to allocating/assigning resources (money, staff, technology and information) across organisational boundaries, and attaching to a common ground for fruitful collaboration (e.g. universal operating principles, interoperable infrastructures, and cooperation agreements) (Romero et al., 2009). In this context, two of the main difficulties network members may face are the alignment of their enterprise systems (including their strategies and infrastructure) (Katzy et al., 2016) and the development of interoperability among those systems (Chen, Dassisti, Elvesaeter et al., 2007), (Panetto et al., 2016).

In this chapter, we outline the main concepts related to the networked enterprise and interoperability domains. First, a description of the networked enterprise domain is presented in section 1.1. In addition, the different typologies of collaboration within networks are brought forward. In section 1.2, interoperability is highlighted as one of the crucial requirements to be fulfilled in order to achieve an effective collaboration within the networked enterprise. Therefore, an overview of the interoperability research domain is presented. Section 1.3 explores the different phases for developing interoperability within enterprises. Finally, a summary is given in the Discussion.

1.1 The Networked Enterprise

The notion of "networked enterprise" is ubiquitous, but hard to understand due to the variety of definitions and interpretations provided in the literature. This term is commonly interchangeable with *Collaborative Network* (Camarinha-Matos and Afsarmanesh, 2006), (Romero and Molina, 2011), *Enterprise Networks* (Jagdev and Thoben, 2001), (Thoben and Jagdev, 2001), (Basole et al., 2011) and *Value Network* (Allee, 2008).

Although, these terms and associated definitions are based on different contexts and have varied points of view (e.g. technological, manufacturing, marketing, etc.), we can notice that some similar characteristics are considered among them. For instance, the necessity of a networked enterprise to be composed of at least two **autonomous enterprises** and the **ability to collaborate** to achieve a **shared objective** (Leal et al., 2016b).

In the following subsections, we explore basic definitions regarding such networks and their different typologies and relationships.

1.1.1 Basic definitions

Before exploring the anatomy and characteristics of a networked enterprise, we look into some terms related to **enterprise** and **collaboration** for avoiding ambiguity.

The term **enterprise** comes from the French word "*entreprendre",* meaning "something undertaken"[4]. It is the pursuit of something or someone to reach a goal. In this thesis, we adopt the generic definition proposed in the standard (ISO 15704, 2000), where an enterprise is seen as "*one or more organisations sharing a definite mission, goals and objectives to offer an output such as a product or a service*". Where, an *organisation* is composed of people, machines, processes, etc.; *Services* can be for example public services (e.g. citizenship registration, drive license delivery) provided by public administrations, or customised services (e.g. website development, urban mobility) provided by private companies; *Products* are anything that are manufactured or refined through a specific process. Therefore, the term **enterprise**, here, subsumes the notion of business firms, government, non-profit organisations, and hospitals and so on.

The concept of **collaboration** comes from the Latin word *collaborare,* which means, "to work together"[5]. However, such generic notion of "sharing the work" may lead researchers and practitioners to use terms such as cooperation, coordination and networking interchangeably, which can cause confusion. In order to avoid misinterpretation, we consider the following definitions proposed by (Camarinha-Matos and Afsarmanesh, 2006), (Camarinha-Matos et al., 2009):

- **Networking**: It involves communication and information exchange for mutual benefit. Enterprises can all benefit from the information made available, but there is not necessarily any common goal or structure influencing the form and timing of individual contributions, and consequently there is no value of co-creation.
- **Coordination**: In addition to exchanging information, it involves aligning activities so that more efficient results are achieved. Coordination is one of the main components of collaboration. Nevertheless, each entity might have a different goal and use its own resources and methods of impact creation; values are mostly created at an individual level.
- **Cooperation**: It involves not only information exchange and adjustments of activities, but also sharing resources for achieving compatible goals. Cooperation is achieved by division of some labour among participants. In this case, the aggregated value is the result of the addition of individual "components" of value generated by the various participants in a quasi-independent manner.
- **Collaboration**: A process in which entities share information, resources and responsibilities to jointly plan, implement, and evaluate a program of activities to achieve a common goal.

[4] https://en.oxforddictionaries.com/definition/enterprise
[5] https://en.oxforddictionaries.com/definition/collaboration

Collaboration involves mutual engagement of participants to solve a problem together, which implies mutual trust and thus takes time, effort, and dedication.

1.1.2 The Networked Enterprise typology

The way in which bilateral relations are put in place in a networked enterprise influences the functioning, information flow and governance of the overall network. (Thoben and Jagdev, 2001) define three types of collaborations based on how bilateral relationships are implemented: *Supply Chain*, *Extended Enterprise* and *Virtual Enterprise*. In addition to these three types, (Camarinha-Matos et al., 2009) define nine other categories of collaborative networks. This includes the *Virtual Laboratories, Virtual Organisations, Dynamic Virtual Organisations, Virtual Governments, Virtual Teams, Virtual Organisation Breeding Environments, Professional Virtual Communities* and *Disaster Rescue Networks*. Each "manifestation" depends on the term of collaboration (e.g. long-term, medium-term or short-term collaboration), the resources distribution, etc.

In this research, we consider that four categories encompass the main types of collaboration: *Supply Chain, Extended Enterprise, Virtual Enterprise* and *Generalised Networked Enterprise*. Indeed, the other "manifestioins" can be considered as a subclass of these four categories. They differences consis mainly on their purposes. For example, *Virtual Laboratories* has a similar structure as the *Virtual Enterprise*, but they focus on sharing and producing research. Each category is described next.

- **Supply Chain**: a stable long-term network of enterprises each having clear roles in the manufacturing value chain, covering all steps from initial product design and the procurement of raw materials, through production, shipping, distribution, and warehousing until a finished product is delivered to a customer (Camarinha-Matos and Afsarmanesh, 2006). It can be represented as a chain-type network, where requested products flow in one direction.
- **Extended Enterprise**: enterprises which have chosen to concentrate on their core-competencies and wish to extend their activities into other enterprises to increase their competitiveness by achieving cost-, time- or quality-related advantages regarding their respective offerings. Extending the activities implies that an enterprise is enhancing its existing capabilities or adding additional facilities, by outsourcing, which has not been at its disposal so far (Jagdev and Thoben, 2001). This typology can be represented by a star-type network where the communication between any two peripheral nodes will always be conducted through the central node. Therefore, the central node is considered as the "extended node" or a "controlling node" of the network.
- **Virtual Enterprise**: a network of at least two independent enterprises jointly form an entity committed to provide a product or service by sharing skills, core competencies and resources. From the customer's perspective and for all practical and operational purposes, these independent organisations are virtually acting as a single entity/enterprise (Jagdev and Thoben, 2001), (Camarinha-Matos and Afsarmanesh, 2006). The virtual enterprise can be represented as a ring-type

network, where there is no unique direction of the flow of information or products. It can take any path. Therefore, all nodes are hierarchically equal and any two can communicate directly.

- **Generalised Networked Enterprise:** a network of autonomous enterprises collaborating in different levels for reaching individual and common goals. A generalised network subsumes all members and their sub-networks of enterprises. It can be a combination of supply chains, extended and virtual enterprises. The networks' dynamic and complexity are greater. Such network can be represented by the generalised network type that is a complex inter-relationship among several nodes. The connections between the nodes and the issues of controlling node cannot be predefined and they are situation and case dependent.

Fig. 3 illustrates a simplified view of the main typologies. Table 1 summarises the similarities and differences between the networked enterprise typologies

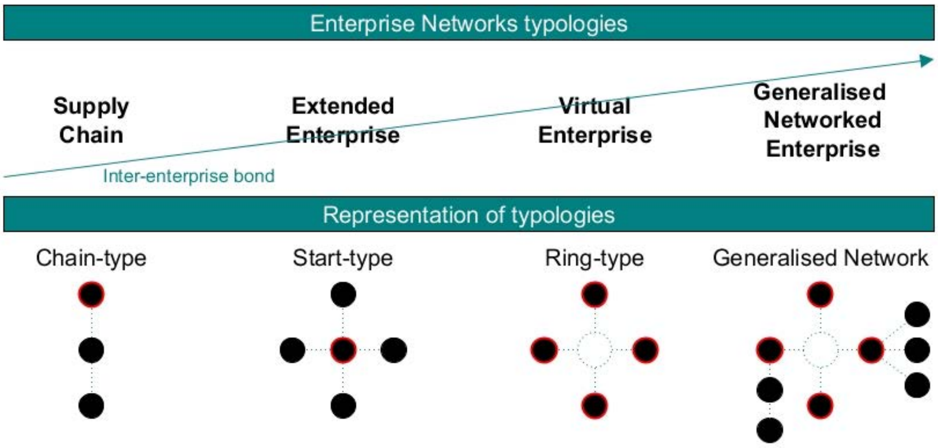

Fig. 3. Spectrum of the Networked Enterprise. Based on (Jagdev and Thoben, 2001)

Table 1. The similarities and differences between the NE typologies

Item	Supply Chain	Extended Enterprise	Virtual Enterprise	Generalised Networked Enterprise
Duration of the Collaboration	Long-term	Long term	Temporary	Short and long term
Type of relationship	Non hirarchical	Hierarchical	Non hirarchical	Non hierarchical and hierarchical
Members sizes (In general)	Small, Medieum and Big enterprises	The controlling node is a big enterprise	Small, Medieum and Big enterprises	Small, Medieum and Big enterprises
Organisational structe	Generally defined the node in the end of the chain; Predominantly vertical relationships	Generally defined by the controlling node; Predominantly vertical relationships;	Self-organisation; Mainly horizontal relationships; Mutual adjustment processes;	Self-organisation; Mainly horizontal relationships; Mutual adjustment processes;
Customer Relationship	The node in the end of the chain is responsible for the final customer relationship	The controlling node manages customer relationships	All enterprises manages custumor relationships	The product/service integrator manages customer relationships
Product type	Semi standardised to standardised product with options and variants	Semi standardised to standardised product with options and variants	Costumized	Customised to semi standardised product with options and variants
Knowledge and Resources management	Shared for specific purposes	The controlling node manages the exchange and share of resources	All shared	Shared according to project

1.2 Enterprise Interoperability

In this section, we describe the basic definitions related to the Interoperability domain. We also investigate the current interoperability frameworks and models describing the Enterprise Interoperability. Finally, we discuss how to assess such an ability.

1.2.1 Interoperability characterisation

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 (Chen, Dassisti, Elvesaeter et al., 2007). The word "interoperate" implies that one system performs an operation for another system. However, it does not have a particular objective of collaboration and does not imply a partnership relation. 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 (Chen, Dassisti, Elvesaeter et al., 2007).

In addition, it is also important to distinguish between other different concepts that can be related to interoperability for avoiding any misinterpretation and ambiguity (Panetto, 2007).

- **Compatibility** means that systems do not interfere with the functioning of each other. Nevertheless, it does not imply the ability to exchange information and services. For that reason, it is something less than interoperability. To realize the power of networking through robust information exchange, one must go beyond compatibility (Kasunic and Anderson, 2004), (Panetto, 2007).
- **Interchangeability** is concerned with the ability to replace a system or component to provide the same service with an equivalent behaviour (ex. response time). The concept of interoperability refers to the ability to exchange services without the necessity of having the same behaviour (Chen, Dassisti, Elvesaeter et al., 2007).
- **Portability** is the ability of data or system to be moved, while interoperability is the ability of software or systems to understand and use information coming from other software or systems (Chen, Dassisti, Elvesaeter et al., 2007).
- **Integration** is considered to go beyond mere "interoperability" to involve some degree of functional dependence (e.g. tightly coupled systems). An integrated system loses significant functionality if the flow of information and services is interrupted. An integrated family of systems must, out of necessity, be interoperable, but interoperable systems need not be integrated (Kasunic and Anderson, 2004), (Panetto, 2007).

1.2.2 Enterprise Interoperability domain description

In the past years, various projects have been proposed for studying the interoperability domain. Many of them had the objective to design a roadmap concerning the interoperability issues and to propose solutions for avoiding and removing interoperability problems. Table 2 presents the main European initiatives dealing with the Interoperability domain.

Table 2. Europeans projects related to Interoperability

Project	Acronym	Start-End	Reference
Interoperability Development for Enterprise Applications and Software – Roadmaps	IDEAS	2002-2003	(IDEAS Working Group, 2003)
Interoperability Research for networked Enterprises Applications and Software	INTEROP	2003-2007	(Chen, Dassisti, Elvesaeter et al., 2007)
Advanced Technologies for Interoperability of Heterogeneous Enterprise Networks and their Application	ATHENA	2004-2007	(ATHENA Working Group, 2007)
Application Bus for InteroperabiLITy In enlarged Europe SMEs	ABILITIES	2006-2008	(ABILITIES Working Group, 2008)
Enterprise Application Interoperability via Internet-Integration for SMEs, Governmental Organisations and Intermediaries in the New European Union	GENESIS	2006-2008	(GENESIS Working Group, 2008)
Community-based Interoperability Utility for SMEs	COMMIUS	2008-2011	(COMMIUS Working Group, 2011)
Collaboration and interoperability for networked enterprises	COIN	2008-2011	(COIN Working Group, 2011)
Envisioning, Supporting and Promoting Future Internet Enterprise Systems Research through Scientific Collaboration	ENSEMBLE	2010-2012	(ENSEMBLE Working Group, 2012)
Networked Enterprise transFormation and resource management in Future internet enabled Innovation CloudS	NEFFICS	2010-2013	(NEFFICS Working Group, 2013)

Besides the mentioned projects, many researchers have also proposed frameworks for describing Interoperability. The main purpose of an interoperability framework is to provide an organising mechanism so that concepts, problems and knowledge on Interoperability can be represented in a more structured way (Chen, Dassisti, Elvesaeter et al., 2007).

In order to identify the existing frameworks, we conduct a literature review using the search string "**Interoperability Framework**". The objective of this review is not to provide an exhaustive analysis of the existing frameworks, but rather to highlight the evolution of frameworks development, the main interoperability issues addressed and to identify which of them are the most appropriate to our work. We query five digital libraries (ScienceDirect, IEEE Xplore, ACM DL, Springer Link and Web of Science). As an additional search strategy we apply the snowballing technique (Wohlin, 2014). Such a technique refers to using the reference list of a paper or the citations to the paper to identify additional papers. It also cinsiders papers that are recommended by experts within the personal network of the authors (Wohlin, 2014), (Petersen et al., 2015).

The criteria for considering a paper are papers published after 2000; papers written in English; papers having the search string on its title, abstract or keywords, and papers proposing and describing an interoperability framework. The exclusion criteria is duplicated papers and other literature reviews.

The review based on the search string and snowballing uncovers 356 papers addressing to Interoperability Frameworks. By applying the exclusion and inclusion criteria, we identify 148 papers.

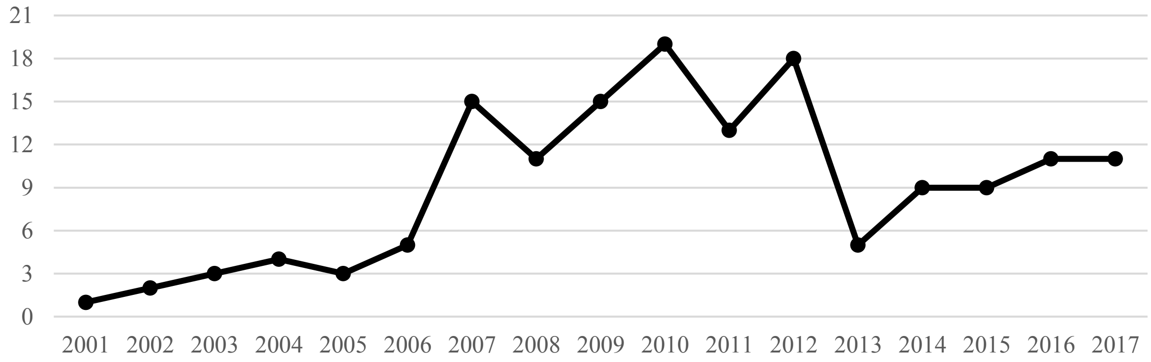

Fig. 4. Evolution of the interoperability frameworks proposition.

The most well-known and cited frameworks are for instance, the IDEAS interoperability framework (IDEAS Working Group, 2003), the ATHENA Interoperability Framework (AIF) (ATHENA Working Group, 2007), the Framework for Enterprise Interoperability (FEI) (Chen, Dassisti, Elvesaeter et al., 2007), (ISO 11354-1, 2011) defined in The INTEROP Network of Excellence (INTEROP NoE) project and the European Interoperability Framework (EIF) (EIF, 2017).

The IDEAS interoperability framework defines three levels of interoperability: Business, knowledge and ICT systems (IDEAS Working Group, 2003). The AIF provides an associated reference architecture for capturing the research elements and solutions to interoperability issues that holistically address the problem by inter-relating relevant information from different perspectives of the enterprise (ATHENA Working Group, 2007). The FEI highlights the different interoperability barriers associated with interoperability concerns, and approaches to be adopted in order to remove the identified barriers (Chen, Dassisti, Elvesaeter et al., 2007). Finally, the EIF describes interoperability layers and focuses on the interoperability between public entities from various European governments (EIF, 2017).

New interoperability frameworks have also been proposed in recent years. However, they are context-specific such as the Internet of Things based interoperability framework (Backman et al., 2016) for fleet management, the Smart City Interoperability Framework (Ahn et al., 2016), the Interoperability Framework for software as service systems in cloud (Rezaei et al., 2014b), the International Image Interoperability Framework (Snydman et al., 2015) and the Conceptual Interoperability Framework for Large-Scale Systems (Selway et al., 2017), focusing on industrial products.

For the purpose of our research, we consider the Framework for Enterprise Interoperability and European Interoperability Framework as they act as generic frameworks covering multiple dimensions of interoperability. More specifically, we choose the EIF because it is an European standard proposed by the European Commission, which is more and more adopted by public administration around Europe (Gatti et al., 2016). The clear definition of interoperability layers and the provision of improvement recommendations have also been considered as relevant assets for considering such framework. The choice of FEI is made mainly for two reasons: (1) FEI adopts a systemic approach allowing the study of interoperability in a broader sense. It means that such framework can be used not only to address public administration systems, but also different domains as manufacturing, health, and so on.; (2) It provides three explicitly defined interoperability dimensions (barriers, concerns and approach) to allow defining interoperability research domain.

The next two sections describe these two selected frameworks.

The European Interoperability Framework

The purposes of the EIF are to: (1) inspire European public administrations in their efforts to design and deliver seamless European public services to other public administrations, citizens and businesses which are to the degree possible, digital-by-default, cross-border-by-default and open-by-default; (2) provide guidance to public administrations on the design and update of national interoperability frameworks, or national policies, strategies and guidelines promoting interoperability; (3) contribute to the establishment of the digital single market by fostering cross-border and cross-sectoral interoperability for the delivery of European public services.

EIF provides a model to be applicable to all digital public services. It is composed of four layers of interoperability (legal, organisational, semantic and technical), a crosscutting component of the four layers (integrated public service governance) and a background layer, which is the 'interoperability governance'. Each component is described hereinafter. Fig. 5 illustrates the EIF model.

- **Legal interoperability** is about ensuring that organisations operating under different legal frameworks, policies and strategies are able to work together. This might require that legislation does not block the establishment of European public services within and between Member States and that there are clear agreements about how to deal with differences in legislation across borders, including the option of putting in place new legislation.
- **Organisational interoperability** refers to the way in which public administrations align their business processes, responsibilities and expectations to achieve commonly agreed and mutually beneficial goals.
- **Semantic interoperability** ensures that the precise format and meaning of exchanged data and information is preserved and understood throughout exchanges between parties.
- **Technical interoperability** covers the applications and infrastructures linking systems and services. Aspects of technical interoperability include interface specifications, interconnection services, data integration services, data presentation and exchange, and secure communication protocols.
- **Interoperability governance** refers to decisions on interoperability frameworks, institutional arrangements, organisational structures, roles and responsibilities, policies, agreements and other aspects of ensuring and monitoring interoperability at national and EU levels.

- **Integrated public service governance** covers all layers: legal, organisational, semantic and technical. Ensuring interoperability when preparing legal instruments, organisation business processes, information exchange, services and components that support European public services is a continuous task, as interoperability is regularly disrupted by changes to the environment.

Fig. 5 illustrates the interoperability model.

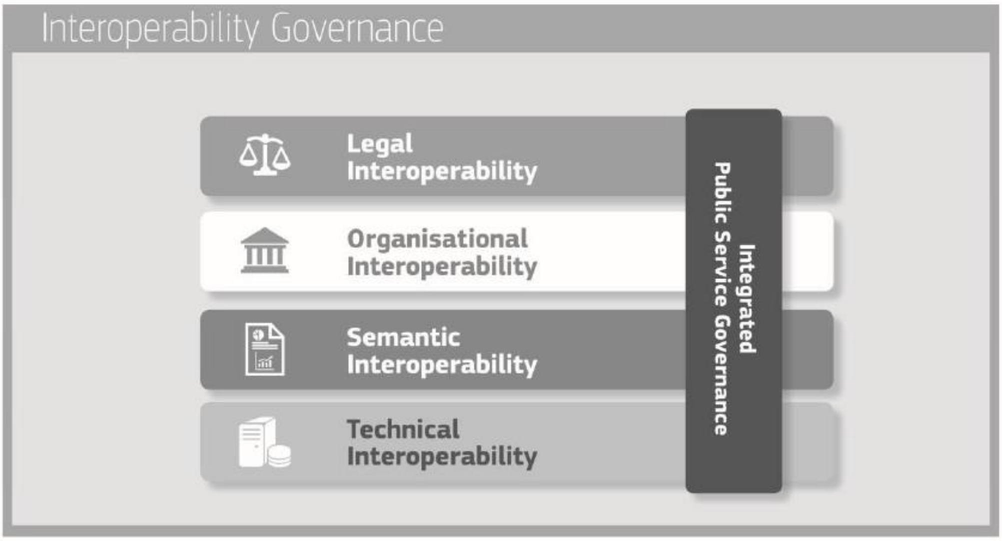

Fig. 5. The EIF Interoperability model. Extracted from (EIF, 2017)

The EIF also gives guidance, through a set of 47 recommendations, to public administrations on how to improve governance of their interoperability activities, establish cross-organisational relationships, streamline processes supporting end-to-end digital services, and ensure that existing and new legislation do not compromise interoperability efforts. The recommendations can be found in (EIF, 2017).

The Framework for Enterprise Interoperability

The FEI aims at structuring the concepts of the Enterprise Interoperability domain. The framework has three basic dimensions: interoperability concerns, interoperability barriers and interoperability approaches (Chen, Dassisti, Elvesaeter et al., 2007). The interoperability barriers refer to incompatibilities between systems. Interoperability concerns regard enterprise levels such as processes and services where interoperation can take place. Finally, interoperability approaches refer to the ways for applying solutions and thus, removing interoperability barriers. These three dimensions are described as follows:

Interoperability barriers

According to FEI, there are three major interoperability barriers: Conceptual, Technological and Organisational. These barriers are ‘incompatibilities’ or ‘mismatches’ which obstruct the sharing and exchanging of information (Chen, Dassisti, Elvesaeter et al., 2007). The interoperability barriers are described below.

- The **conceptual** barriers are concerned with the modelling at the high level of abstraction such as the models of a company, as well as the degree of the programming.
- The **technological** barriers are concerned with the lack of a set of compatible standards to allow using heterogeneous computing techniques for sharing and exchanging data between two or more systems.
- The **organisational** barriers are concerned with the incompatibilities of organisation structure and management techniques implemented in two enterprises.

Interoperability concerns

Hereinafter, the four main Enterprise Interoperability Concerns are described. Although the definitions are mainly given from a point of view of IT based applications, they apply to non-computerised systems as well (Chen, Dassisti, Elvesaeter et al., 2007).

- The interoperability of **business** referring to work in a harmonised way at the levels of organisation and company despite the different modes of decision-making, methods of work, legislation, the culture of the company and commercial approaches.
- The interoperability of **process** concern aims at making various processes work together. It is meant by linking different process descriptions to form collaborative processes and perform verification, simulation and execution.
- The Interoperability of **services** concerns with identifying, composing, and operating together various applications by solving the syntactic and semantic incompatibilities as well as finding the connections to the various heterogeneous databases.
- The interoperability of **data** is concerned with finding and sharing information coming from different databases, and which can furthermore reside on different devices with different operating systems and databases management systems.

Interoperability approaches

The FEI defines three approaches, i.e. three ways in which a solution may removes an interoperability barrier (Chen, Dassisti, Elvesaeter et al., 2007).

- A **federated** approach is established while the interoperation is in progress. It means that there is no common format defined, and nothing is forced by one system or another. Involved systems are required to distinguish and adjust to requirements "on the fly."
- A **unified** approach is characterized by a standard format that describes the systems' interactions on a meta-level. This model provides a mean for semantic equivalence to allow mapping between diverse models and systems. This approach may encounter some loss of data, as the systems' individual needs are not prepared to be reproduced instantly. This approach is fit for improving interoperability for collaborative or networked enterprises.

- An **integrated** approach is distinguished by a standard format that is used by all constituents' parties. This format is not fundamentally a standard but must be agreed by all participants to develop models and build systems. This approach is appropriate when creating and implementing new systems rather than re-engineering existing systems for interoperability.

Fig. 6 illustrates the three interoperability dimensions.

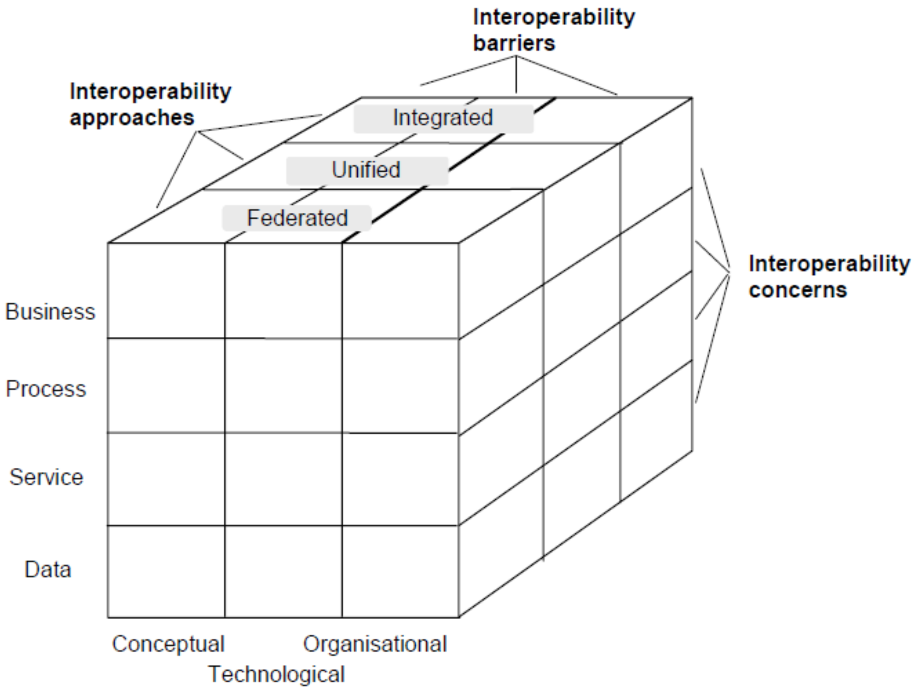

Fig. 6. The dimensions of the FEI. Extracted from (Chen, Dassisti, Elvesaeter et al., 2007)

1.2.3 Enterprise Interoperability conceptualisation

One of the first attempts to formally conceptualise the interoperability domain was made by (Rosener et al., 2004) in the INTEROP NoE project. The resulting conceptualisation is called Ontology of Interoperability (OoI). This ontology had been enhanced during the INTEROP NoE project by (Rosener et al., 2005), (Ruokolainen et al., 2007). The OoI final version had been documented in the INTEROP NoE project's derivable DO.2 (Paul Johannesson et al., 2007).

In the following years, the OoI had been integrated with concepts from FEI (Chen, Dassisti, Elvesaeter et al., 2007) 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) (Naudet et al., 2010), (Guédria and Naudet, 2014). The OoEI is a meta model, which formally describes the system's concepts and their relations, regarding interoperability. Hereinafter, we describe the main concepts of the OoEI.

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. Regarding the systematic core, the ontology considers that an enterprise is a *System* that has a *Structure*, which materialises the organisation of the system's elements and their relationships at a given time. A *Relation* is a link between two things, whatever the nature of this link. A *System* also has *Objectives* (the system's goals at a given time) and *Functions* that are sets of actions the *System* can execute in its *Environment*, in order to realise its *Objectives*. The *Behaviour* of a *System* can be defined as the manifestation of function in the course of time. The *Interfaces* are used to establish a connection between the concerned *System* and its *Environment*. Finally, the decisional model conceptualises the relationships between *Problems* and *Solutions*, regarding a *System*. The *ExistenceCondition* concept represents the source of a given *Problem* and specific *Indicators* define it.

In addition, OoEI implements the *Interoperability* concept as a subclass of the *Problem* concept. *Problems* of interoperability exist when there is a *Relation* between incompatible *Systems* in a super-system that belong to it. The *Incompatibility* concept is a subclass of a more generic *ExistenceCondition* class aiming at explicitly formalising the fact that *Incompatibility* is the source of interoperability problems. For representing the Enterprise Interoperability domain, the three interoperability dimensions from the FEI are considered. They are the concepts *Interoperability Barrier*, *Interoperability Concern* and *Interoperability Approach.* Fig. 7 illustrates the main concepts of the OoEI.

Further, the OoEI also integrates with Enterprise-as-a-System (EaaS) concepts. It allows in particular to have a general view of the enterprise and to have a model that stays valid whatever the kind of studied enterprise. This ontology extension was based on the enterprise sub-systems (decisional, physical and information systems) defined on the GRAI Integrated Methodology (Chen et al., 1997). The integrated concepts are described hereinafter and illustrated in Fig. 8.

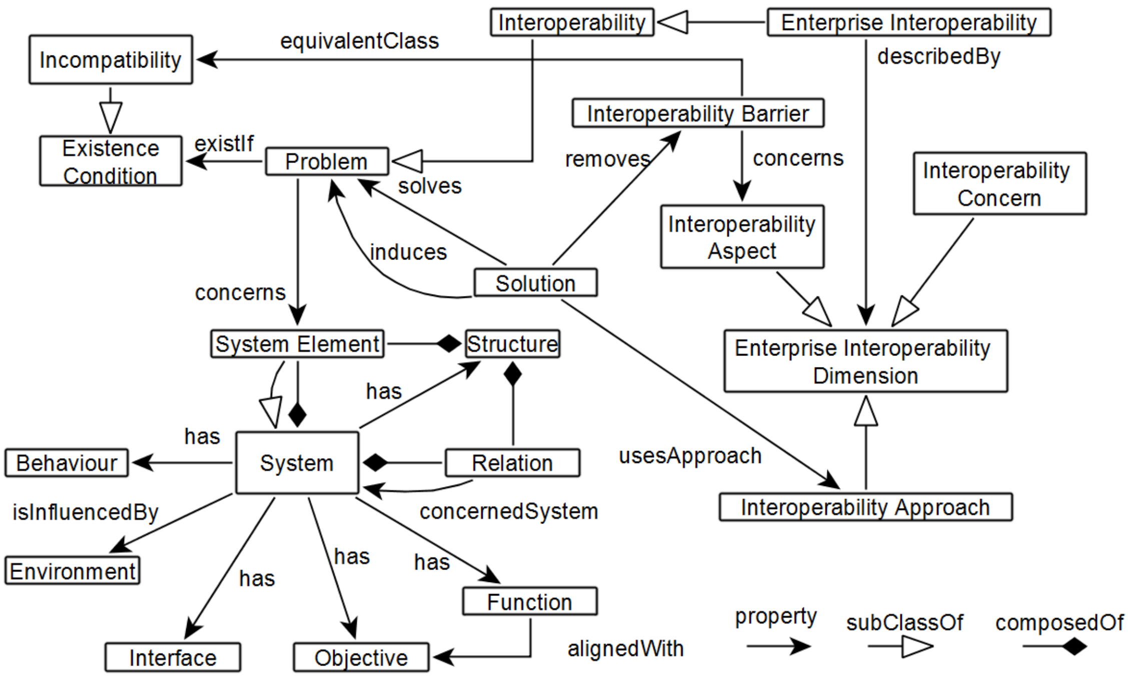

Fig. 7. An overview of the OoEI. Adapted from (Naudet et al., 2010).

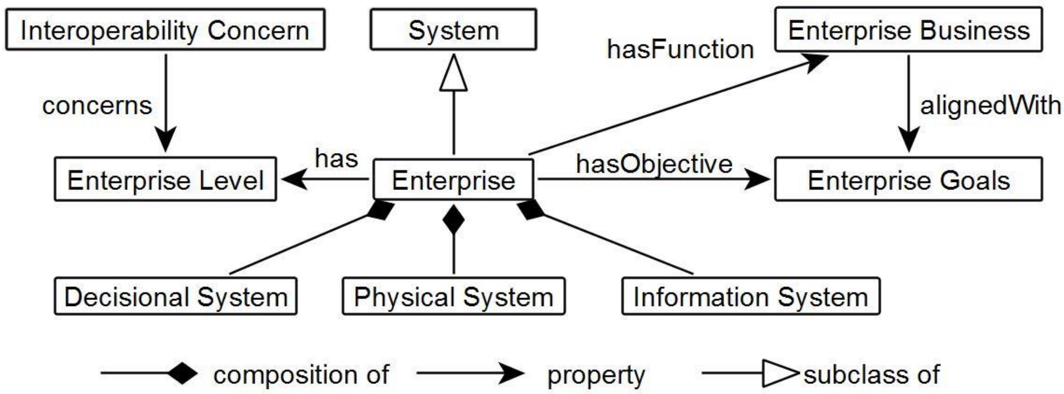

Fig. 8. OoEI with EaaS concepts. Adapted from (Guédria and Naudet, 2014).

The concept of *Enterprise Level* represents the layers of the enterprise in general. The *Enterprise Business* concept is used to denote the enterprise *Function* such as delivery of products and services to customers. The *Decisional System* ensures the overall objectives of the enterprise taking them as inputs to send orders to the *Physical System*. To determine how to control the operating system in order to achieve the system goals and objectives, the *Decisional System* communicates with the environment relating to the system's goals, accepting orders, making commitments and exchanging any other information with the environment that is necessary.

The *Decisional System* relies on models of the *Physical System* to make its decisions. However, for these models to reflect reality to a sufficient degree, the *Decisional System* must receive information, or feedback, from the *Physical System*. Therefore, the *Information System* is critical for the propagation of decisions to the lower levels of the *Decisional System* and the *Physical System*.

1.3 Enterprise Interoperability development

To achieve a higher quality of interoperability, a certain number of Interoperability Requirements (IRs) should be satisfied (Chen, Dassisti, Elvesaeter et al., 2007), (Daclin et al., 2016b). These requirements define the needs of stakeholders regarding interoperability and describe what systems must comply for being considered as interoperable. As soon as IRs 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 (Panetto et al., 2016). Therefore, enterprises should benefit from the use of interoperability assessment approaches for determining their systems' strengths and weaknesses regarding interoperability.

When improving the system's interoperability for avoiding or solving interoperability problems, changes may be necessary (Guédria et al., 2015), (Agostinho et al., 2016). For example, when there is a need for including or excluding particular enterprise systems function; for adding or eliminating processes' connections among companies; or even for restructuring data storage devices. However, such changes at the enterprise systems level embody an immediate evolution and present a disturbance to the networked enterprise (Agostinho et al., 2016). Hence, the alignment between enterprises systems should also be taken into account when assessing and improving systems' interoperability.

In the subsection 1.3.1, we give more details regarding the Interoperability Requirements related work. It is followed by the main characteristics of an interoperability assessment in subsection 1.3.2. In the subsection 1.3.3, the importance of strategic alignment between systems is investigated and brought forward. Finally, in subsection 1.3.4, we present relevant work addressing the study and the relations between enterprise interoperability and strategic alignment through the enterprise architectures techniques.

1.3.1 Interoperability Requirements

In the past years, much research has been dedicated to studying and defining interoperability requirements. For example, based on the FEI, EIF, AIF frameworks and the ISO 15504 standard (ISO/IEC 15504-1, 2004), the Quality Model for Interoperability (QMI) was proposed by (Jochem and Knothe, 2007). QMI contains sets of interoperability requirements according to the type of collaboration (i.e. Virtual Enterprise, Supply Chain, Joint Venture, and Strategic Alliance). (Chituc et al., 2009) defines 12 IRs for a collaborative–competitive economic networked environment. Based on the IRs, the authors propose a collaborative interoperability framework for identifying the main actors and their activities regarding interoperability. (Alemany et al., 2010) defines 26 IRs regarding a collaborative planning process.

(Zutshi et al., 2012) proposes an interoperability measurement model where eight major parameters representing the different levels of interactions in which collaborating entities can engage. (Mallek et al., 2012), (Daclin et al., 2016b) formulate 86 IRs concerning a collaborative process between two enterprises, based on a literature review and an industrial survey. The proposed requirements are classified into four categories (compatibility, interoperation, autonomy and reversibility) and organised based on the FEI interoperability barriers and concerns.

1.3.2 Interoperability Assessment

An interoperability assessment can be classified into three distinct types (Chen, Dassisti, Elvesaeter et al., 2007): The **potentiality** assessment which assesses the interoperability of a system towards its environment. The objective of this analysis is to evaluate the potentiality (also called maturity) of a system to adapt and to accommodate dynamically to overcome possible barriers when interacting with a potential partner. It means that this type of assessment is performed before knowing the interoperation partner(s).

The **compatibility** assessment evaluates the interoperability between two known systems before or after any interoperation. The most crucial task is to analyse the current state of both concerned systems in order to identify the incompatibilities that cause or may cause problems. Finally, the **performance** assessment, which assesses the cost (defined by the costs induced by removing of the barriers and the modification of the systems to obtain a satisfying time and quality of interoperation), delay (corresponds to the duration between the date at which an information is requested and the date at which the requested information is used) and quality (takes in consideration the quality of exchange, the quality of use and, the quality of conformity) of the interoperations during the collaboration.

There are two types of structures that an approach can adopt: The **Levelling structures** are designed to assess the quality (i.e. competency, maturity, capability, level of sophistication) of a selected domain based on a more or less comprehensive set of criteria (De Bruin et al., 2005). The approaches that adopt this kind of structure are called Maturity Models. There are two main types of maturity models: The "fixed-level maturity models" distinguishing a fixed number, usually around five, of generic maturity levels. A maturity level is state description regarding the defined criteria (Mettler, 2011). Each maturity level is associated with a number of processes (also called practices) that have to be implemented. The so-called "focus area maturity model" which are based on the concept of a number of focus areas that have to be developed to achieve maturity in a functional domain (van Steenbergen et al., 2010). The **Non-Levelling structured** approaches are a much more diverse group. Its majority is based on quantitative measures for specific types of systems or interoperability (Ford et al., 2009). The outputs of such methods are not levels of maturity but rather a single numeric or linguistic value for representing the quality of the assessed type of interoperability.

Regarding the measurement mechanisms, there are two main types (Yahia, 2011), (Guédria et al., 2015). The **Qualitative** measures are for the most part subjective and are constructed by general evaluation criteria by attaching a level of quality to a specific type of interoperability. In most cases, this kind of measure uses a rating scale composed of linguistic variables (e.g. "Good", "Optimized" and "Adaptive") for qualifying a system. It is mostly used by the Maturity Model based approaches.

The **Quantitative** measures define numeric values to characterise the interoperations. In general, the rating scale is from 0 to 100%. For example, some approaches use equations to determine the interoperability based on the "real / expected" ratio, the interoperation performance indicators etc. It is commonly used by the non-levelling structured approaches. However, a combination of both measures is possible. For example, some maturity models define quantitative measures for justifying the attributed quality of assessed criteria. In addition, some non-levelling approaches uses qualitative measures for assigning a meaning to quantitative results.

Table 3 summarises these three interoperability assessment dimensions.

Table 3. Interoperability assessment dimensions

Type of assessment	**Potentiality** : assesses the interoperability of a system towards its environment
	Compatibility : evaluates the interoperability between two known systems before or after any interoperation
	Performance : assesses the cost, delay and quality of the interoperations during the collaboration
Type of Structure	**Levelling**: defines a set of maturity level for classifying the assessment results
	Non-Leveling: does not defines levels of maturity but rather a single numeric or linguistic value for representin
Type of measurement meachanims	**Qualitative**: defines evaluation criteria and linguistic variables to charactersise qualitatively interperations
	Quantitative: defines numeric values to characterise quantitatively the interoperations

1.3.3 Strategic Alignment

Strategic alignment focuses on the activities that management performs to achieve cohesive goals across the Information Technology (IT) and other functional organisations (e.g., finance, marketing, manufacturing) (Luftman, 2003). Alignment is considered important because organisations with more consistent technology, structure and strategy have been found to perform better (Pollalis, 2003). Note that the strategic alignment's importance has been well known and well documented through the years (Henderson and Venkatraman, 1993), (Pollalis, 2003), (Solaimani and Bouwman, 2012), (Castellanos and Correal, 2013), (Wu et al., 2015) and (Goepp and Avila, 2015), (Gerow et al., 2015), (Aversano et al., 2012).

One of the most well-known work in this field is the Strategic Alignment Model (SAM) (Henderson and Venkatraman, 1993), where the authors assume that economic performance is directly related to their administrative and technological structures. In the past years, other models and frameworks for systems' alignment have been proposed in the literature. For example, (Walsh et al., 2013) proposes the Translated Strategic Alignment Model (TSAM) which focuses on the negotiation among three levels: the main actants (business infrastructure and strategy, information system infrastructure and strategy, users' tasks and users' diverse IT cultures), the main actants' needs and the delegates (technicians, analysts, managers and the actual utilization of the system by users). The authors in (Goepp and Avila, 2015), propose the Extended-Strategic Alignment Model (E-SAM) focusing on a tactical and operational point of view in the design of enterprise information systems, rather than a strategic viewpoint as SAM.

Regarding the networked enterprise context, the strategic alignment can be seen as an adjusted relationship between the performance achieved by enterprise members and the network strategy considering that each enterprise must contribute with self-operation efficiency in order to reach network alignment (da Piedade Francisco et al., 2012), (Katzy et al., 2016). Such an alignment is paramount when considering trans-sectors enterprises collaboration. Indeed, this involves the interaction and information exchange between different actors, while these interactions are described by diverging business process from the different interacting companies (Solaimani and Bouwman, 2012).

For example, (Solaimani and Bouwman, 2012) and (Solaimani et al., 2015) propose a framework for the alignment of business model and business processes, focusing on trans-sector companies. This framework includes three interdependent domains: value exchange, information exchange and business processes. Based on the SAM, (Katzy et al., 2016) proposes the Inter-Organisational Strategic Alignment Model (IOSAM) that distinguishes between the alignment of information systems with the network strategy and the multiple concurrent business strategies pursued by the collaborating firms.

1.3.4 Enterprise Interoperability and Enterprise Architecture

Form a general point of view, an architecture is *a description of the basic arrangement and connectivity of parts of a system (either a physical or a conceptual object or entity)* (ISO 15704, 2000). In the enterprise context, an Enterprise Architecture (EA) *is a formal description of a system or a detailed plan of the system at component level, to guide its implementation and the structure of components, their interrelationships and the principles and guidelines governing their design and evolution over time* (TOG, 2018). Indeed, EA enables the company to be represented in a holistic and integrated perspective, to facilitate decision-making while ensuring alignment between business and IT (Tamm and Shanks, 2011), (Vargas et al., 2016).

Since the concept of "Enterprise Architecture" has emerged in late 80's, many EA frameworks have been proposed. These frameworks intend to aid architects by providing a conceptual model, which uses different abstraction levels to map all kinds of information needed. Some examples of the most well-known frameworks are: The Zachman Framework (Zachman, 1987), the Department of Defence Architecture Framework (DoDAF) 2.0 (U.S. Department of Defense, 2010), The Open Group's Architecture Framework (TOGAF) (TOG, 2018), the Reference model for Collaborative Networks (ARCON) (Camarinha-Matos and Afsarmanesh, 2008) and the European Interoperability Reference Architecture (EIRA) (European Commission, 2018a).

Regarding the EIRA, it is an architecture content meta model defining the most relevant architectural building blocks needed to build interoperable e-Government systems (European Commission, 2017). This reference architecture provides a common terminology for IT architects and facilitates the development of digital public services across borders and sectors. It is defined based on the EIF (EIF, 2017) and TOGAF (TOG, 2018). The modelling language used by EIRA is the ArchiMate (TOG, 2013). Fig. 9 illustrates the Interoperability Specification viewpoint defined by EIRA.

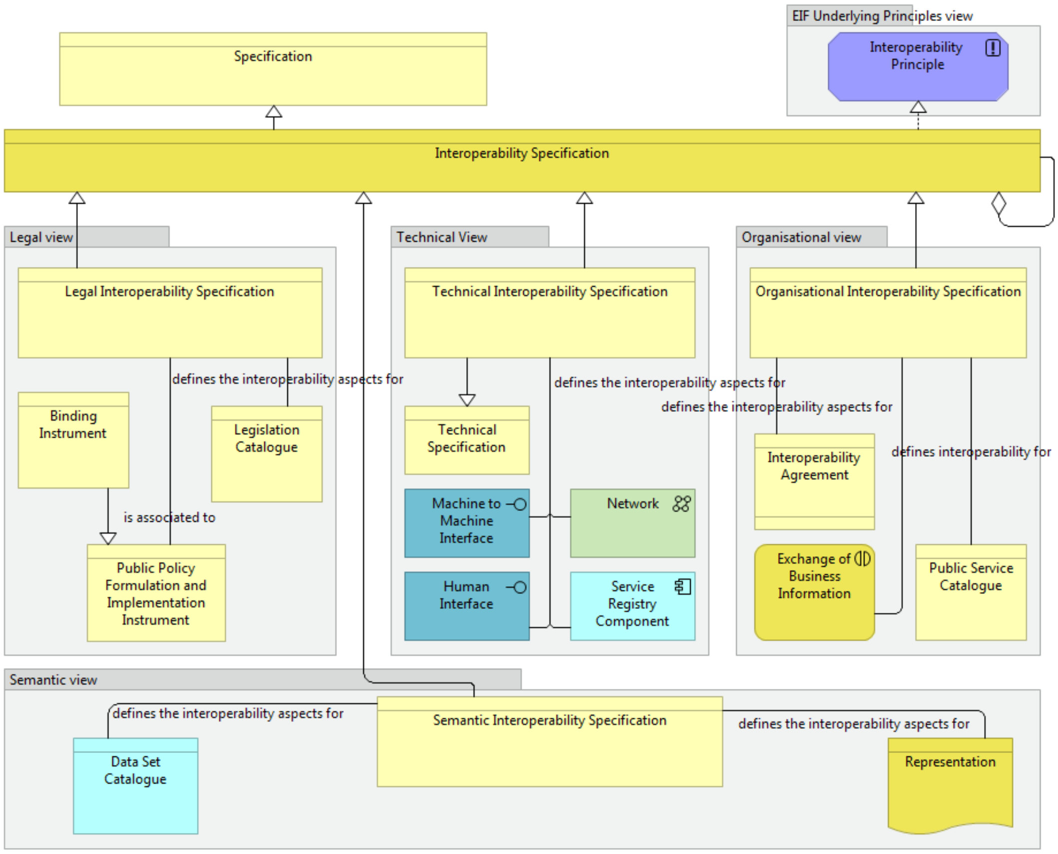

Fig. 9. Interoperability specification view of EIRA. Adapted from (European Commission 2017b)

Discussion

In this chapter, we explored the networked enterprise and interoperability domains. We have observed that networked enterprises emerge when at least two autonomous enterprises join forces and collaborate to achieve a shared objective. The development of interoperability and the strategic alignment between enterprise systems were identified as two of the many challenges faced by such collaborative networks. We highlighted the importance of the assessment and improvement of interoperability in order to achieve an effective collaboration. We also have described the underlining relations between interoperability and strategic alignment through the Enterprise Architecture domain.

The next chapter presents a detailed literature review of the existing interoperability assessment approaches. This review allow us to identify if the existing approaches are considering a holistic view of the interoperability domain (i.e. covering multiple interoperability layers/barriers and concerns) and if they are considering the alignment between the assessed enterprise systems and their associated interoperability requirements. Based on the review results, we position ourselves regarding the interoperability assessment domain.

Chapter 2

Enterprise interoperability assessment: state of the art

Introduction

We acknowledge that many surveys and reviews for studying INteropereability Assessment (INAS) approaches have been conducted in the literature such as (Ford et al., 2007b), (Panetto, 2007), (Guédria et al., 2008), (Yahia, 2011), (Cestari et al., 2013), (Rezaei et al., 2014c) and (Guédria et al., 2015). However, these existing surveys do not consider a holistic view of the INAS. They only focus on a few aspects at once. For instance, (Cestari et al., 2013) focuses on maturity models for the public administration domain. The authors also do not discuss the measurement mechanisms nor the interoperability layers and concerns covered by the reviewed models. (Guédria et al., 2015) addresses different INAS application domains (e.g. health, military, etc.) but focuses only on interoperability maturity models. (Ford et al., 2007b) considers both levelling and non-levelling methods but does not explicitly differentiate the types of assessment that are being adopted by the reviewed approaches.

Therefore, in this chapter, we perform an exhaustive literature review of the INAS domain. The aim of this review is to identify papers that are proposing INAS approaches and to conduct a comparative analysis upon the selected approaches for evaluating the current INAS literature.

Thus, in section 2.1, we conduct a Systematic Literature Review (SLR) based on the guidelines defined in (Kitchenham, 2004). Next, in section 2.2, the identified papers from the SLR are analysed against a set of comparison criteria. Based on the comparative analysis results, the Maturity Model for Enterprise Interoperability (MMEI) (Guédria et al., 2015) is chosen as a reference assessment model. For that reason, this model is described in detail. Considering the presented research context and the identified limitation from the INAS literature, we bring forward in section 2.3 this thesis contribution and the positioning according to the INAS domain.

2.1 Systematic literature review

The SLR is a review undertaken following a predefined search strategy and presents evidence concerning the data sources, the papers' selection and analysis criteria. The procedure of this SLR is the following: First, we define the process to select relevant papers. To do so, we determine the digital libraries to be queried, the keywords to be used and the selection criteria. Second, we present the selected papers. Information regarding the year of publication, the type of publication (e.g. conference proceedings and journal papers) and the domain addressed by the selected papers are presented.

2.1.1 Paper selection process

First, we define questions for supporting and directing the papers selection. The questions are: What are the papers proposing approaches for assessing interoperability and identifying potential barriers or negative impacts within a network of systems? Where these papers are published (e.g. journals, conferences)? What are the addressed domains (e.g. manufacturing, healthcare)? When such papers have been proposed?

Next, we perform the papers sampling by identifying potential papers from the related literature. To do so, we search for papers by querying four digital libraries: ScienceDirect, Taylor & Francis Online, Springer and Web of Science. The keywords are defined based on an iterative process, which is described as follows. First, we query the digital libraries with the keyword "*Interoperability Assessment*". 135 papers are identified. From these papers, we extract the most used keywords considering the following paper's fields: Title, Abstract and Keywords. To do so, we used the VOSviewer software (van Eck and Waltman, 2010) to construct and visualise the co-occurrence networks of words extracted from the metadata. Based on the co-occurrence analysis, we select the keywords that were repeated more than ten times and that are related to the act of assessment. Thus, two keywords are identified: *Interoperability Maturity Model* and *Interoperability Evaluation*.

In the next step, we query the four digital libraries again with these two new keywords. We identify 88 and 81 papers related to *Interoperability Maturity Model* and *Interoperability Evaluation*, respectively. Further, we extract the metadata from these new 169 papers. Before performing another co-occurrence analysis, we exclude the metadata from the redundant papers. Consequently, the new analysis considers 263 papers, i.e. the 135 from the previous analysis and 128 papers specifically related to the two new keywords. From the second co-occurrence analysis, we identify four more keywords, which are *Interoperability Measurement, Interoperability Analysis, Interoperability Methodology* and *Interoperability Performance Evaluation*. Further, querying the digital libraries, we identify 56 papers related to *Interoperability Measurement*, 134 papers associated with *Interoperability Analysis,* 57 papers to *Interoperability Methodology* and 8 papers related to *Interoperability Performance Evaluation.* Finally, we perform the last co-occurrence analysis considering the total of non-redundant papers, which is **418**. Fig. 10. presents the most occurred keywords from the identified papers.

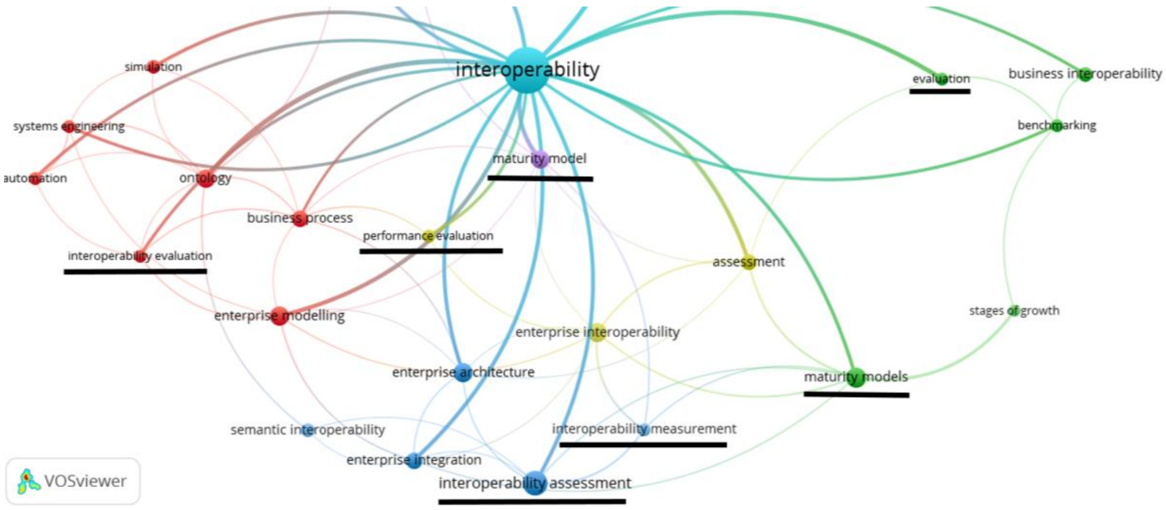

Fig. 10. The most used keywords among the identified papers

Fig. 11. illustrates the described steps and the number of papers identified regarding a specific keyword.

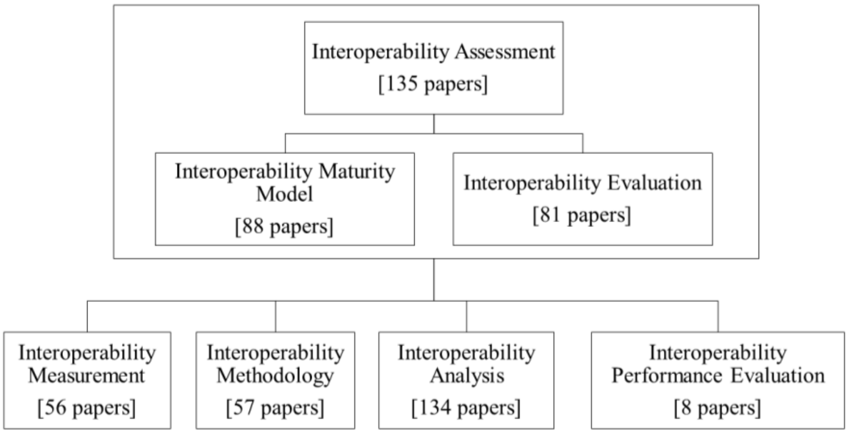

Fig. 11. The identified keywords and their respectively number of associated papers.

As additional search strategy, we also include 29 papers using the "snowball sampling" technique (Wohlin, 2014) whereby we consider the referrals of assessment approaches made by experts, as well as the most cited papers in the existing INAS surveys and reviews. A total of 447 publications are identified at the end of this sampling phase.

Furthermore, the selection of the papers to be analysed and compared is done in two steps. In the first one, we apply for each one of the papers, the inclusion and exclusion criteria corresponding to the step St1 as described in Table 4. In this step, we only consider the metadata of the papers.

Table 4. The Inclusion and exclusion criteria for step 1

Step	Inclusion criteria	Exclusion criteria
St1	Paper written in English	Paper not written in English
	Paper that we have access to the full text	Paper without access to the full text
	Primary study	Other literature reviews
	Paper establishing a link between "assessment" (and the variants terms) and interoperability	

The second step includes the reading of the full-text of the selected papers. To select which papers are considered, we apply the criteria related to the step St2 as described in Table 5.

Table 5. The Inclusion and exclusion criteria for step 2

Step	Inclusion criteria	Exclusion criteria
St2	In the case where the paper does not include the term "interoperability", it should addresses the interaction and connectivity among systems, focusing on the exchange and sharing of information	Paper presenting at least one of the key concepts (interoperability, enterprise interoperability, etc.), but not considering the term "assessment" (and its variants)
	Paper proposing a methodology, a method or model for assessing interoperability and also proposing measurement mechanism	

Once the papers are selected, we classify them by year, the type of publication (e.g. journal article, conference proceedings, etc.) and the addressed domain (e.g. military, industry, etc.). This process is depicted in Fig. 12.

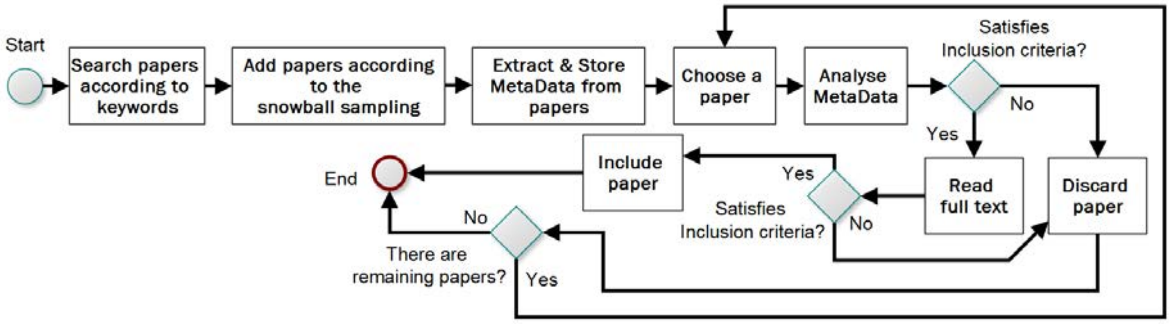

Fig. 12. Paper selection process

2.1.2 Paper selection results

The initial search reveals 418 references from the digital libraries, and 29 papers based on the snowball sampling. From the 447 considered papers, we apply the inclusion and exclusion criteria from Step St1, as described in Table 2. Therefore, we first exclude those papers that are not available, not written in English and papers that are reviews, surveys and comparative analysis of existing INAS approaches. The resulting number of considered papers are 419 in this phase.

Moving forward, we analyse the rest of the papers, considering their title, abstract and keywords. The number of considered papers drop to 139 in total. Moreover, after reading and analysing the full text of the remaining papers, we select 71 of them. Table 6 shows the results from different phases of the selection process.

Table 6. The paper selection phases

Phase	TOTAL
Total number of paper from digital libraries	418
N° of papers after snowballing sampling	447
N° of papers after exclusion based on the paper access, language and type of research (reviews and surveys have been excluded)	419
N° of papers after exclusion based on title, abstract and keywords	139
N° of papers after exclusion based on full text = N° of included papers	71

Fig. 13 illustrates the number of papers that are published per year, from 1996 to 2018. We observe that the number of papers proposing INAS approaches increased in 2009 and 2016.

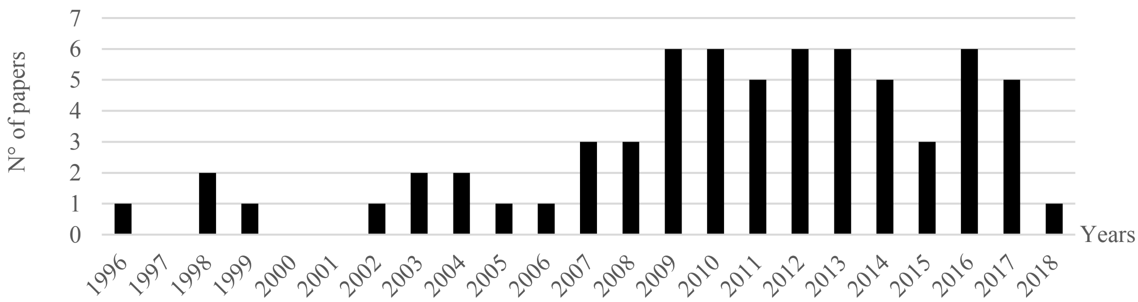

Fig. 13. Number of papers published per year

The analysis shows that the publications are divided as journal papers (35%) and conference proceedings (52%). The remaining 13% represents technical reports. The main conferences and journals are cited below:

- **Journals**: Computers in Industry (5 papers) and Enterprise Information Systems (3 papers)
- **Conferences**: International Conference on Interoperability for Enterprise Software and Applications (3 papers) and International Command and Control Research and Technology Symposium (3 papers)

Considering the domains addressed by the analysed papers, 40 of them focus on the Industry domain (including manufacturing supply chains, service providers, etc.), 16 consider the Military domain and 6 papers address Information Technology (IT) systems without considering a specific domain. Finally, 9 papers cover other domains such as health, public administration, crisis management and smart grid. Table 7 shows the domains addressed by the identified papers.

Table 7. Selected papers and their associated domains.

Domain	Reference
Military	(Tolk and Muguira, 2003), (Hamilton Jr. et al., 2002), (Wang et al., 2009), (Tolk et al., 2013), (Clark and Jones, 1999), (Fewell and Clark, 2003), (Fewell et al., 2004), (Kingston et al., 2005), (C4ISR, 1998), (Ford et al., 2007a), (Ford et al., 2008), (Ford et al., 2009), (Leite, 1998), (Amanowicz and Gajewski, 1996), (LaVean, 1980), (Mensh et al., 1989)
Industry	(Chalyvidis et al., 2016), (Camara et al., 2010), (Guédria et al., 2015), (Cornu et al., 2012a), (Yahia et al., 2012a), (Neghab et al., 2015), (Camara et al., 2014), (Daclin et al., 2016b), (Guédria et al., 2009), (Guédria et al., 2011a), (Guédria et al., 2011b), (Guédria et al., 2011c), (SCAMPI Upgrade Team, 2011), (CMMI Product Team, 2010b), (CMMI Product Team, 2010a), (CMMI Product Team, 2010c), (Chapurlat and Roque, 2010), (Mallek et al., 2011), (Mallek et al., 2012), (Mallek et al., 2015), (Yahia et al., 2012b), (Fang et al., 2004), (Chen and Daclin, 2007), (Daclin et al., 2008), (Daclin et al., 2016a), (Chalyvidis et al., 2013), (Maheshwari and Janssen, 2014), (de Soria et al., 2009), (Alonso et al., 2010), (Cuenca et al., 2013), (Camara et al., 2012), (Campos et al., 2013), (Cornu et al., 2012b), (Li et al., 2013), (Sseggujja and Selamat, 2015), (Daclin et al., 2006)
IT System (No specific domain)	(Rezaei et al., 2014a), (Rings et al., 2014), (Bhuta and Boehm, 2007), (Basson et al., 2016), (Vito and Rapuano, 2010), (Saturno et al., 2017)
Others (e.g. Public Administration, Crisis Management, e-Health)	(Riz et al., 2017), (Bharambe et al., 2016), (MEASURE Evaluation Team, 2017a), (MEASURE Evaluation Team, 2017b), (Knight et al., 2013); (da Silva Avanzi et al., 2017), (Gottschalk, 2009), (European Commission, 2016b), (European Commission, 2018b)

2.2 Comparative analysis

In this section, we first define the comparison criteria. It is followed by the selection and analysis of the relevant INAS approaches. Finally, the comparative analysis is performed and the results are discussed.

2.2.1 Defining the comparison criteria

The first criterion that we consider in this analysis is the ***application of the INAS approach***. It supports identifying which type of systems are assessed and in which cases the approaches can be applied. Hence, we classify an approach based on two types of assessed system: *Non-Human Resources* subsuming hardware and software (e.g. Manufacturing Executing Systems (MES) and Healthcare Information Systems (HIS)) and *Entities* including all human and non-human resources (e.g. enterprises, hospitals and governmental departments). We also identify if the approach can be of *General Use* (i.e. any type of entity or non-human resource can be considered) or is for *Specific Use* (i.e. only a certain type of system can be considered e.g. only government entities or only HISs). Next, we highlight if the INAS approach is demonstrated using a *Real Scenario* (i.e. based on real-world entities and resources) or based on abstract and *Illustrative Examples*.

The second criterion regards the ***type of structure***. This criterion identifies if the concerned INAS approach is a levelling approhc (a maturity model) or a non-leveling approach. The third criterion is the ***type of assessment***. This criterion is selected for identifying the types of assessment addressed by the INAS approaches. Therefore, we classify and compare the selected INAS approaches according to the three types of assessment described in section 1.2.4: *Potentiality*, *Compatibility* and *Performance*. Besides comparing the current state of the art regarding this criterion, this analysis provides us an insight into the evolution and importance given for each one of the considered type of assessment.

The fourth criterion refers to the ***coverage of interoperability layers/barriers***. This criterion is essential as it supports the verification of INAS approaches dealing with one or more layers and associated barriers of interoperability. To our best knowledge, almost all of the previous literature reviews explore this criterion on INAS. However, it is worth noting that this criterion is not always defined based on the same nomenclature. For example, in (Ford et al., 2007b), the authors consider seven interoperability layers (or “types”): the technical, conceptual, coalition, programmatic, operational, constructive and non-technical interoperability. The authors in (Panetto, 2007) and (Yahia, 2011) consider the three layers defined in EIF: technical, semantic and organisational interoperability. The reviews (Cornu et al., 2012a), (Cestari et al., 2013) and (Guédria et al., 2015) address the three interoperability barriers defined in FEI: technological, conceptual and organisational. The review presented in (Rezaei et al., 2014c) discuss four layers of interoperability (technical, syntactic, semantic and organisational). For the purpose of this review, we adopt the barriers defined in the FEI (Chen, Dassisti, Elvesaeter et al., 2007), which are the *Conceptual* (including the semantic and syntactic barriers), the *Technological* (including the IT infrastructure and application barriers) and the *Organisational* barriers (subsuming the organisation structure and legal barriers). We argue that if an interoperability barrier is addressed, the related interoperability layer is also considered (explicitly or implicitly).

The coverage of the ***enterprise interoperability concerns*** is the fifth criterion considered in our comparative analysis. The considered concerns are the *Business*, *Process*, *Service* and *Data* concerns as defined in FEI. This criterion is relevant for studying the systems and their relations regarding different enterprise levels. It is also useful for identifying if the concerned INAS approaches are also considering the alignment of their addressed enterprise levels.

The sixth comparison criterion concerns the type of ***measurement mechanism*** used by the INAS approaches. Such criterion helps us to classify the approaches whether they are using *Qualitative*, *Quantitative* mechanism or both of them. It supports the understanding of how approaches are rating evaluation criteria and how to interpret the results. The seventh criterion refers to ***the provision of best practices***. *Best practices* are proven guidelines, recommendations or processes that have been successfully used by multiple enterprises (ISO/IEC 33001, 2015). These practices do not describe "which" solutions or "how" to implement solutions, but rather "what" should be done, in broad terms, to improve the system's interoperability (Guédria et al., 2015).

The eighth comparison criterion is ***the provision of a computer-mediated tool***, whether the tool being automated or semi-automated. In general, *Computer-Mediated Tools* support different processes (including an assessment) by automatizing certain activities (e.g. rating calculation, data storage, etc.), consequently reducing time and improving the process performance (Krivograd et al., 2014), (Alalwan and Thomas, 2012). Therefore, this criterion is relevant for classifying the INAS approaches as manual-conducted or computer-mediated approaches.

Table 8 summarises the eight comparitions criteria and their considered attriubutes.

Table 8. The comparision cirteria

Criteria	Attributes
Application of the INAS approach	*Types of assessed system (Non-Human Resources; Entities); Type of use (General Use; Specific Use);*
Type of assessment	*Pontentiality; Compatibility;Performance;*
Type of structure	*Levelling (Maturity Model); Non-Leveling*
Coverage of interoperability layers/barriers	*Conceptual;Technological;Organisational;*
Enterprise interoperability concerns	*Business; Process; Service; Data;*
Measurement mechanism	*Qualitative;Quantitative;*
Provision of best practices	*Yes; No*
Provision of a computer-mediated tool	*Automated or semi automated; No tool*

2.2.2 Analysing the interoperability assessment approaches

While studying the selected papers from section 2.1.2, we observe that some of them are addressing the same approach. Considering this, we identify 37 assessment approaches based on the 68 considered papers. For conducting the comparative analysis, we select only the ones that are demonstrated or evaluated through a real or illustrative application. Indeed, these approaches provide more information about its applicability, usefulness and effectiveness. From the 37 identified INAS approaches, 21 of them have at least one associated publication where the approach is applied to a real case.

Hereinafter, the 21 selected INAS approaches are described with a focus on the defined comparison criteria. An ID is also given for each one of these approaches for facilitating their identification during the comparative analysis. First, we present the INAS approaches addressing only the potentiality type of assessment. It is followed by the approaches covering the compatibility and performance assessment, respectively. Finally, the approaches covering multiple types of assessment are presented.

The results of the comparative analysis are presented in the following section 2.2.3.

Approaches covering the compatibility assessment

Approach A1: The levels of conceptual interoperability model

The Levels of Conceptual Interoperability Model (LCIM) (Tolk and Muguira, 2003), (Wang et al., 2009), (Tolk et al., 2013) is a maturity model assessing the semantic and syntactic divergences between systems. In other words, LCIM assesses the *Compatibility* of two E*ntities* targeting the *Conceptual* barriers within the *Data* interoperability concern.

LCIM provides descriptions of each of their seven defined maturity levels and the requirements that should be satisfied to achieving a given level. The assessment is mainly done based on the assessors' expertise and judgement using a *Qualitative* measurement mechanism. It can also be seen as a guidance model to prescribe and guide the interoperability design and implementation for the concerned systems (Wang et al., 2009). This model proposes a set of prescriptive requirements that can be seen as *Recommendations* for achieving the desired maturity level. It also suggests engineering approaches for reaching the defined recommendations.

This maturity model can be applied to different situations (i.e. *General Use*). An *Illustrative Example* of the assessment of one system using the High Level Architecture (HLA) standard (IEEE 1516.2, 2000) and other system using the Base Object Models (BOM) standard (SISO-STD-003, 2006) is given in (Wang et al., 2009).

Approach A2: Assessing interoperability of access equipment for broadband networks

The approach defined in (Vito and Rapuano, 2010) proposes a Remote Testing Board (RTB), designed and realized to carry out off-line interoperability tests in smart office devices (e.g. telephones) within a broadband network (e.g. office telephone network). This approach deals with the *Compatibility* assessment of two *Non-Human Resources* focusing only on the *Technical* barriers and the *Data* concern.

Indeed, the interoperability assessment is done by connecting the concerned smart office devices in the RTB. With the help of a *Computer-Mediated Tool*, the assessor(s) verifies if the devices can identify each other and if data exchange is possible. For example, the RTB simulates combinations of phone calls directed to and from the telephone line through the office telephone network. A traffic generator is also implemented for customising and testing different phone lines and device communications. The conclusions are given according to the observations, experience of the tester and the defined objectives. This approach is defined for the specific assessment of broadband networks and their connected devices. A complete application description is given in (Vito and Rapuano, 2010).

Approach A3: A generic interoperability testing framework

The generic interoperability testing framework defined in (Rings et al., 2014) enables automated interoperability testing between at least two *Non-Human Resources*. It is mainly based on message checks, which assess the compliance of messages exchanged between the considered systems. In other words, it focuses on the *Compatibility* assessment of two systems regarding the *Data* concern. It evaluates the *Technological* (by verifying if the systems are connected and capable to exchange data) and the *Conceptual* interoperability (by verifying if the format of the message is compatible).

In order to assess the concerned systems, the framework defines a “Test Coordinator” architecture. This architecture provides the guidelines to connect the considered system and guidelines to design the functions for the message checks. This generic interoperability-testing framework can be applied to different systems that can be connected through a communication path (e.g. internet and local architecture network). This framework has been demonstrated in a *Real Scenario* focusing on Internet Protocol Multimedia Subsystems. The details of this scenario are given in (Rings et al., 2014).

Approach A4: A Framework for Identification and Resolution of Interoperability Mismatches in COTS-Based Systems

The authors in (Bhuta and Boehm, 2007) propose an attribute-based framework for performing an automated assessment of the interoperability between at least two Commercial-Of-The-Shelf (COTS) products. In other words, it deals with the *Compatibility* assessment *Non-Human Resources*. The assessment covers the *Conceptual* and *Technological* barriers of interoperability and the *Service* and *Data* concerns.

This approach develops and provides a *Computer-Mediated Tool* based on the defined COTS interoperability framework. Such tool is composed of a COTS definition repository (storing generic COTS architectures), an interoperability rules repository (every rule has a set of pre-conditions, which if true for the given architecture and components, identifies an architectural mismatch.) and the interoperability analysis component. For obtaining the analysis results, the assessor enters the considered COTS’s information. The tool then uses the COTS definitions and the interoperability rules for identifying potential incompatibilities that the considered COTS may face.

This approach is demonstrated in *Real Scenario* based on multiple software systems requested by a real-world client. The authors of the approach argue that it is not limited to a single type of COTS and that it can be used for assessing different systems.

Approach A5: Performance evaluation of collaboration in the design process: Using interoperability measurement

(Neghab et al., 2015) proposes a *Computer-Mediated* methodology for assessing the *Conceptual* interoperability between systems that have to collaborate in business/design *Processes*. It deals with the *Compatibility* type of assessment.

This methodology is divided in two main phases: The first one refers to the process modelling, including all *Entities* and activities assigned to the concerned process. The second phase is the interoperability assessment. A *Quantitative* measurement mechanism subsuming two measures is defined for evaluating the semantic and syntax of the data to be exchanged. A *Qualitative* mechanism is also in place for defining the measures threshold (i.e. what is considered as semantically interoperable). The mathematic development and notation are described in (Neghab et al., 2015).

Regarding the computer-mediated tool, it is developed based on the Eclipse Modelling Framework (EMF). The authors use three components of EMF: the *ECORE* for metamodeling the processes to be analysed, the *Object Constraint Language* for performing the syntax check and the *EMF compare* for the semantic check. This methodology can be used to assess different collaborative processes (i.e. General Use). The application of this methodology in a *Real Scenario* regarding a design process of a mechanical coupling between a propeller and a diesel engine is presented in (Neghab et al., 2015).

Approach A6: Evaluation of Interoperability between Automation Systems using Multi-criteria Methods

The authors in (Saturno et al., 2017) propose a maturity model to evaluate the potential interoperability among systems within an existing automation platform in the Industry 4.0 context. It addresses the *Compatibility* assessment of *Non-Human Resources*, focusing on the *Technological* and *Conceptual* barriers that can influence the *Service* and *Data* interoperability concerns.

This model defines three levels considering automation and information technological requirements, in terms of interoperability. The definition of the requirements has its basis in concepts of Industry 4.0 with orientation to the concept of interoperability between systems. These requirements are instantiated in an AHP matrix (Saaty, 2004) using the Super Decisions software.

The AHP architecture is designed as follows: The first layer in this architecture presents the objective of evaluation. The second and the third layers represent the requirements and interoperability barriers related to the subject of this evaluation (i.e. the assessed systems). The fourth layer represents the interoperability maturity levels. The maturity level is determined based on the requirements pairwise comparisons.

This model had been developed for assessing interoperability of automated systems in the Industry 4.0 context. An *Illustrative Example* of the application of this maturity model is detailed in (Saturno et al., 2017).

Approach A7: Formal measures for semantic interoperability assessment in cooperative enterprise information systems

The formal measures for semantic interoperability proposed by (Yahia et al., 2012b), (Yahia et al., 2012a) focus on the assessment between two cooperative information systems (i.e. *Compatibility* assessment). This approach provides a *Quantitative* measurement mechanism for evaluating the *Conceptual* interoperability of two *Non-Human Resources*, regarding the *Data* concern.

For calculating the interoperability between two information systems, this approach defines three main activities. First, one has to identify every concept (mandatory or not) from the two systems' conceptual models. Second, one has to identify the mandatory and non-mandatory semantic relationships with the help a domain expert. These mandatory relationships are those that if not satisfied, interoperability is not fully achieved. The third activity is to calculate the Maximum Potential Interoperability (MPI) and the Minimal Effective Interoperability (MEI).

MPI is reached when all the concepts of one system (even the non-mandatory ones) are instantiated in the other. MEI is reached when only the mandatory concepts of one system are instantiated in the second system. Table 9 describes the formal measures and the meaning of their results. It is worth noting that this approach considers interoperability as non-bidirectional i.e. given two systems A and B and measuring their interoperability level I(x,y) it is structurally coherent to find $I(A,B) \neq I(B,A)$.

Table 9. Interoperability conclusions following the values of MPI and MEI. Adapted from (Yahia et al., 2012a)

Type of evaluation	Interoperability measure	Value	Conclusion
$MPI_{(A,B)}$	$v_{A \to B} = \frac{All\ identified\ semantic\ relationships\ from\ A\ to\ B}{All\ mandatory\ concepts\ from\ A\ that\ should\ be\ instantiated\ in\ B}$	=0	A is not interoperable with B
		<100%	A is partially interoperable with B
		=100%	A is fully interoperable with B
$MEI_{(A,B)}$	$v^e_{A \to B} = \frac{All\ identified\ mandatory\ semantic\ relationships}{All\ mandatory\ concepts\ from\ A\ that\ should\ be\ instantiated\ in\ B}$	=0	A is not interoperable with B
		<100%	A is partially interoperable with B but this interoperability is effective.
		=100%	A is fully interoperable with B and this interoperability is effective.

This approach can be applied to different situations (i.e. *General Use*). It is illustrated in (Yahia et al., 2012b) through an *Illustrative Example* dealing with a business to manufacturing scenario between an Enterprise Resource Planning (ERP) system and a Manufacturing Execution System (MES) application.

Approach A8: The organisational interoperability maturity model

The organisational interoperability maturity model (OIMM) (Clark and Jones, 1999), (Fewell and Clark, 2003), (Fewell et al., 2004), (Kingston et al., 2005) defines five maturity levels describing the ability of organisations to interoperate. OIMM aims at assessing the *Compatibility* of at least two *Entities*, regarding the *Organisational* and *Conceptual* barriers, with a focus on the *Business* concern.

OIMM provides descriptions of each of their five maturity levels. Sets of questions are defined and associated with each of these levels for assessing them. Based on their expertise and judgement, assessors qualify the entities interoperability and determine their maturity level. This maturity model was initially proposed to be used on the assessment of military organisations. However, OIMM's authors argued that such a model could be applied to different contexts (i.e. *General Use*). A *Real Scenario* based on the International Force East Timor military coalition focusing on the interaction between the United States Joint Forces Command and Australia is presented in (Fewell and Clark, 2003).

Approach A9: Maturity model for the structural elements of coordination mechanisms in the collaborative planning process

The Structural Elements Of Coordination Mechanisms Maturity Model SECM-MM (Cuenca et al., 2013) focuses on the maturity of the coordination mechanisms in the collaborative planning process within a business network. It defines five levels of maturity for assessing nine structural elements (e.g. number of coordination mechanisms, information exchanged, information processing) of a given process. Indeed, SECM-MM deals with the *Compatibility* assessment of two *Entities*, in terms of the *Business* and *Process* interoperability concerns and the related *Organisational* barriers.

Based on interviews, each structural element is individually assessed by an assessor to determine the level of maturity. When many assessors are involved, the team's assessments are discussed and then a final level is given to each element. The SECM-MM also includes the *Best Practices* to be carried out on collaborative planning that must be implemented to reach the highest maturity level in the defined structural elements. This maturity model can be applied to different entities (i.e. *General Use*). (Cuenca et al., 2013) presents the application of SECM-MM in a *Real Scenario* based on a ceramic tile company.

Approach A10: The Interoperability Score

The Interoperability Score (*i-Score*) (Chalyvidis et al., 2016), (Ford et al., 2007a), (Ford et al., 2008), (Ford et al., 2009), (Chalyvidis et al., 2013) focuses on measuring the interoperability of complex non-homogeneous system networks. It deals with the *Compatibility* assessment of collaborative *Processes* established between at least two *Entities*. The assessment approach considers the *Conceptual*, *Technological* and *Organisational* barriers of interoperability.

This assessment approach proposes a system resemblance matrix for calculating the systems' interoperability. The coefficients in the resemblance matrix represent measures of similarity between systems, based upon system attributes pertinent to interoperability. The cardinal rule to follow is that only functional system interoperability attributes describing *what systems do to each other* should be used to instantiate systems within the matrix. Their particular mathematic development requires extensive notation and are detailed in (Ford et al., 2008) and (Chalyvidis et al., 2016). The calculated interoperability between two systems is equal to a positive real number ranging from 0 to 1, where a score of zero indicates no interoperability and a score of one indicates perfect interoperability.

This approach can be applied to different process from different entities (i.e. *General Use*). *Illustrative Examples* based on fictional Suppression of Enemy Air Defences (SEAD) systems are presented in (Ford et al., 2007a), (Ford et al., 2008), (Ford et al., 2009).

Approaches covering the potentiality assessment

Approach A11: Reconceptualising measuring, benchmarking for improving interoperability in smart ecosystems

The authors in (Maheshwari and Janssen, 2014) define a process for measuring and benchmarking for improving interoperability in the smart governments. It focuses on the *Potentiality* assessment of a single *Entity*, considering all three interoperability barriers and the four interoperability concerns.

More precisely, this approach defines ten aspects to be considered during the assessment: Semantic, Syntactical, Data linking, Physical, Policy, Enterprise architecture, Business process, Judicial, Governance, and Economical. From these ten aspects, twenty-three evaluation criteria are derived and described. For measuring the potential interoperability, the approach provides *Qualitative* measurement mechanisms.

For instance, considering the entity to be assessed and the assessment objectives, a questionnaire based on the evaluation criteria should be defined. However, this approach does not provide a standard questionnaire. Therefore, assessors should build their own questionnaires based on their experience and the concerned context. Once the questionnaires are defined, assessors ask the selected employee to categorically specify a numeric value for each of the related questions from zero (lowest) to nine (highest). In the end, the interoperability degree is equal to the set of the mean of each criterion.

This approach can be used for different entities and contexts. A *Real Scenario* regarding the Population Welfare Department (PWD) Government of Sindh in Pakistan is presented in (Maheshwari and Janssen, 2014).

Approach A12: The ultra large scale systems interoperability maturity model

The Ultra Large Scale Systems Interoperability Maturity Model (ULSSIMM) (Rezaei et al., 2014a) defines five maturity levels for assessing the *potential* interoperability of ultra large scale systems (e.g. health information systems and hospitals itself). This maturity model covers all interoperability barriers (*Conceptual, Technological* and *Organisational*) and the four interoperability concerns (*Data, Service, Process* and *Business*). Forty-one criteria are defined and related to the maturity levels.

The ULSSIMM proposes a *Quantitative* measurement mechanism using colours. For instance, a score between zero and one is given for each evaluated criteria. One colour (grey, red, yellow and green) is allocated to each level of interoperability according to the mean of its related criteria (grey [=0], red [<0.4], yellow [>=0.4 and <0.7] and green [>=0.7]). A maturity level is achieved when the allocated colour is green.

This maturity model also provides a solution framework containing *Best Practices* for improving interoperability. For each maturity level and for each interoperability barrier a set of potential solutions and technologies are suggested for removing the concerned barrier. The ULSSIMM can be applied to different situations (i.e. *General Use*). A *Real Scenario* regarding the assessment of the Malaysian Healthcare system is detailed in (Rezaei et al., 2014a).

Approach A13: Maturity Model for Interoperability Potential Measurement

The maturity model proposed in (Campos et al., 2013) is composed of a methodology and a reference set of evaluation criteria to measure interoperability *Potential*. It focuses on evaluating the capability of an *Entity* to interoperate with an unknown partner. The three interoperability barriers and the four interoperability concerns are considered in six enterprise views: Business, Process Management, Knowledge, Human Resources, Information and Communication Technology, and Semantic views.

For each view, a description is provided and a set of evaluation criteria is defined. According to the fulfilment of evaluation criteria, one of the five proposed maturity levels (Isolated, Initial, Executable, Connectable and Interoperable) can be assigned to the concerned view. In order to perform the interoperability assessment, the proposed methodology provides five phases. The Project Planning aims at defining the conceptual aspects of the enterprise in regards to interoperability, taking into account the strategic and cultural goals of the assessed enterprise. The second phase is the classification of collaborations. It aims at studying the organizational structure of the company and the identification of the collaborations that exist between each department for each of the enterprise's processes.

The third phase consists of the measurement and collection of results. The objective of this phase is twofold: first, the design of questionnaires for conducting the assessment is developed. The questions are defined by the assessor(s) according to the defined evaluation criteria for each view and based on the enterprise's current situation studied in the first phase. The second objective of this phase is to assess each identified collaboration identified in the second phase using the defined questionnaires. To complete the questionnaires, *Qualitative* measurement mechanism (e.g. interviews and group discussions) should be used. In the fourth phase, a *Quantitative* measurement mechanism is used for quantifying and aggregating the information gathered through the questionnaires. It allows the analysis and determination of the enterprise's interoperability potential. However, this measurement mechanism is not completely described in (Campos et al., 2013). Finally, the last phase refers to the proposal of improvements based on the assessment results. However, this approach does not specify the improvement proposals to be adopted. This maturity model can be applied to different situations (i.e. *General Use*). A *Real Scenario* based on a large textile enterprise from Spain is used to demonstrate the maturity model application.

Approach A14: A framework for interoperability assessment in crisis management

The authors in (da Silva Avanzi et al., 2017) propose the Disaster Response Management System (DRMS) development cycle framework, which is centred in the Disaster Interoperability Assessment Model (DIAM). DIAM focuses on the *Potentiality* assessment of a public/private *Entities* or localities.

The concerned assessment model defines three maturity levels that an entity can achieve: Basic, Intermediary and Advanced. For determining the maturity level, a set of functional and non-functional requirements for crisis management defined in DIAM should be verified. These requirements are related to all interoperability barriers (*Conceptual*, *Technological* and *Organisational*) and concerns (*Business*, *Process*, *Service* and *Data*).

DIAM 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 (including *Qualitative* and *Quantitative* measurement mechanisms). The AHP architecture is designed as follows: The first layer corresponds to the goal of the interoperability assessment. The second and third layers represent the interoperability concerns and barriers, respectively. These layers are related to the fourth layer, which represents the functional requirements. The fifth and final layer represents the potential interoperability levels. This approach uses the open source *Software* called Super Decisions[6] for implementing their AHP matrix. Interviews based on the defined requirements should be 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 concerns and barriers to be addressed. It also identifies how well a requirement is being fulfilled in comparison with the others and to determine the maturity level. In the end, the software automatically generates graphs showing the calculated maturity levels.

In (da Silva Avanzi et al., 2017), a *Real Scenario* based on the company responsible for the municipal technology sector of Curitiba (Brazil) is described. Application to other entities e.g. civil defence, firefighters, traffic engineering are also planned.

Approaches covering the performance assessment

Approach A15: Methodology for Interoperability Evaluation and Improvement

(Camara et al., 2010), (Camara et al., 2012), (Camara et al., 2014) propose an approach for the evaluation of interoperability improvements in a networked enterprise based on collaborating *Entities Performance* assessment. This approach includes an interoperability evaluation framework and an evaluation methodology.

The interoperability framework is composed of three layers. The interoperability investment layer aims to analyse the relationships between elements located in the physical system of networked enterprise. These elements include the interoperability concerns (*Process*, *Service* and *Data*), the *Technological* interoperability barriers and related solutions. The operational interoperability impact layer subsumes the key performance indicators (KPI) related to the concerned collaborative process (i.e. indicators related to the cost, time and failure reduction in processes). Finally, the tactical and

[6] superdecisions.com

strategic impact layer uses the KPIs related to the enterprises' strategies to evaluate the impact of interoperability on high-level business' objectives. The KPIs from the different layers are defined based on the specific context of the networked enterprise and based on the strategic decisions of the concerned stakeholders.

The evaluation methodology describes the main steps to support the INAS as well as explains how to use the defined interoperability evaluation framework. Three blocks of steps are determined: the Configuration Management aiming at modelling the *as-is* and *to-be* states of the concerned enterprises and their interactions; the Interface Management aiming to identify interoperability barriers in the *as-is* state and to propose solutions to remove these barriers; and the Decision Analysis aiming to provide the basis for evaluating and selecting alternatives when decisions need to be made. According to the authors of this assessment approach, it can be applied to any type of collaborative processes from networked enterprises from different sectors of activity. An *Illustrative Example* of the application of such approach in a goods entry process between three entities is presented in (Camara et al., 2014).

Approaches covering the multiple types of assessment

Approach 16: Maturity levels for interoperability in digital government

(Gottschalk, 2009) defines five maturity levels for assessing the interoperability in digital governments. This model addresses the *Potentiality* and *Compatibility* assessments of governmental *Entities*, covering all the three interoperability barriers (*Conceptual, Technological* and *Organisational*) and three interoperability concerns (*Business, Process* and *Data*).

Descriptions of each maturity level is given. Assessors are free to use their judgement for *qualifying* the interoperability and for determining the entities' maturity level. It also provides *Recommendations* for public administrations to improve their potential interoperability and discusses the relevance of two public entities to achieve together a higher level of maturity. This maturity model can be applied mainly to public administration entities (i.e. *Specific Use*). An *Illustrative Example* of the application of the model is presented based on the Norwegian Police and Customs departments.

Approach A17: Levels of Information System Interoperability

The Levels of Information System Interoperability (LISI) (C4ISR, 1998) defines an interoperability LISI maturity model, which considers five increasing levels of sophistication regarding system interaction and the ability of the system to exchange and share information and services. This model can be used for comparing a single system to the LISI reference system model as well as for comparing the desired state of a pair of systems against the LISI reference system model.

In other words, LISI deals with the *Potentiality* and *Compatibility* assessment of *Entities,* focusing on the exchanging and sharing of *Data* and *Services* between systems. The proposed model deals with the *Technological* barriers, but *Conceptual* issues such as semantics are also considered. For determining the "degree of interoperability" attained by or between systems, a *Quantitative* measurement mechanism is proposed. It is derived using the Interoperability Questionnaire as the data source and the LISI maturity model as the measurement template. Consequently, the LISI Interoperability Questionnaire forms the bridge between the LISI maturity model and the LISI assessment process. The LISI identifies for each level of interoperability, a common suite of capabilities across procedures, applications, infrastructure, and data that must be incorporated (i.e. *Best Practices*) by system developers in order to have a "common-ground" basis for interoperability assurance. A *Computer-Mediated Tool* is proposed for implementing the interoperability questionnaires and to automatically generate the assessment results (i.e. maturity level determinations and recommendations).

The LISI can be applied to different situations (i.e. *General Use*). Five *Illustrative Examples* of LISI application are detailed in (C4ISR, 1998).

Approach A18: The maturity model for enterprise interoperability

The Maturity Model For Enterprise Interoperability (MMEI) (Guédria et al., 2009), (Guédria et al., 2011a), (Guédria et al., 2011b), (Guédria et al., 2011c), (Guédria et al., 2015) focuses mainly on the *Potentiality* assessment of an single *Entity*. As it is defined based on a systemic approach, the authors argue that it can also be used for the *Compatibility* assessment. This model describes five levels of maturity. Each maturity level is an instantiation of the main elements of interoperability with an evolution of the elements regarding the development of the level. Based on the FEI dimensions, it defines twelve areas of interoperability. Those areas represent the crossing between the interoperability barriers and concerns. Each one of the interoperability areas contain the evaluation criteria that should be verified when assessing the maturity level of an enterprise. These areas are named after their associated barrier and concern, e.g. Business-Conceptual and Service-Technological.

Table 10 shows the criteria from each area regarding the maturity level three.

Table 10. The areas of interoperability and their evaluation criteria. Adapted from (Guédria et al., 2015)

	Conceptual	Technological	Organisational
Business	Business models for multi partnership and collaborative enterprise	Open IT infrastructure	Flexible organisation structure
Process	Meta-modelling for multiple model mappings	Platforms and tools for collaborative execution of processes	Cross-enterprise collaborative Processes management
Service	Meta-modelling for multiple model mappings	Automated services discovery and composition, shared applications	Collaborative services and application management
Data	Meta-modelling for multiple model mappings	Remote access to databases possible for applications, shared data	Personalised data management for different partners

The MMEI proposes one criterion for each interoperability area for each maturity level, totalising forty-eight interoperability criteria. For rating these criteria, the model adopts a *Qualitative* measurement mechanism. It means that, the assessor can rate each criterion using four linguistic variables: Not Achieved (NA), Partially Achieved (PA), Largely Achieved (LA) and Fully Achieved (FA). When there is more than one assessor, the final rating of a criterion is calculated by aggregating the ratings provided by all involved assessors. A *Quantitative* measurement mechanism, based on the fuzzy sets theory and the Ordered Weighted Average (OWA) aggregation operator (Yager, 1988) is provided for translating the linguistic values into numeric values in order to compute, aggregate and calculate the final ratings and maturity levels criteria.

Moreover, MMEI proposes 126 *Best Practices*. Each practice is associated with an interoperability barrier, concerns and maturity level. These best practices describe "what" should be done to improve a current situation in terms of interoperability. This maturity model can be applied to different situations (i.e. *General Use*). A *Real Scenario* based on a company specialised in automobile manufactures with modern wiring harness systems, exclusive interiors and electrical components is detailed in (Guédria et al., 2015).

Approach A19: Customizable interoperability assessment methodology to support technical processes deployment in large companies

The authors in (Cornu et al., 2012a), (Cornu et al., 2012b) propose a methodology for INAS regarding the deployment of collaborative processes. This methodology allows the concerned enterprises to select between the *Potentiality* and *Compatibility* assessment for evaluating the interoperability between two *Entities*. A set of fourteen questionnaires are based on eighty-eight interoperability requirements defined in (Cornu, 2012). Each question is related to at least one of the interoperability barriers (*Conceptual*, *Technological* and *Organisational*). Besides the *Process* being the main interoperability concern addressed, the *Business*, *Service* and *Data* concerns are also covered by the proposed questionnaires. These defined questions are yes or no questions, where the "yes" value means that the assessed system fulfils the related requirement(s). At least one *Recommendation* for improving interoperability is associated to each question.

There are two measurement mechanisms proposed in this methodology. The first one is a *Qualitative* one, referring to the answer of each question. Indeed, the assessors answer a question based on their experience and best judgment regarding the current situation of the assessed system. Second, a *Quantitative* measurement mechanism is put in place for "translating" the yes/no answers on numeric values or calculating the result of the assessment. Their mathematic development requires extensive notation and is detailed in (Cornu et al., 2012a). The proposed questionnaires were implemented in a Computer-Mediated Tool for ease of use. The tool was designed and developed by the authors. To use the tool, the assessor enters information about the system to be assessed and the answers to the defined questions. The tool computes automatically the assessment results, including the provision of recommendations to the questions that had negative answers. An *Illustrative Example* of a large company in the field of aeronautics is presented in (Cornu et al., 2012a).

Approach 20: Writing and verifying interoperability requirements

In the publications (Chapurlat and Roque, 2010), (Mallek et al., 2011), (Mallek et al., 2012), (Mallek et al., 2015), (Daclin et al., 2016b), the authors propose and develop an approach for defining and verifying interoperability requirements. Such an approach focuses on the verification of requirement that two *Entities* should comply before interoperating. It also considers the verification of requirements related to the performance of the interaction between entities. In other words, it is an approach addressing the *Compatibility* and *Performance* types of assessment. The forty-five interoperability requirements defined for the compatibility assessment are related to one of the interoperability barriers (*Conceptual, Organizational*, and *Technological*) and one interoperability concern (*Data, Services, Processes*, and *Business*). The twenty-six interoperability requirements defined for the performance assessment are related to three main factors: the time, quality and cost of interoperations.

In order to verify the interoperability requirements (independent of the type of assessment) a computer-mediated tool is proposed. The requirement verifications is mainly based on model checkers. For evaluating a-temporal requirements (i.e. requirements that are independent of time), they first transform the requirements into conceptual graphs. Next, they use the COGITANT (Conceptual Graphs Integrated Tools Allowing Nested Typed graphs) tool[7] for performing the requirement verification. For evaluating the temporal requirements (i.e. verifiable only at certain stages of the collaboration), they first model the requirements using the Networks of Timed Automata (a behavioural modelling language). Next, they use UPPAAL model checker (Behrmann et al., 2004) for performing the requirement s verification. Both model checkers are implemented in the computer-mediated tool developed by the authors. For identifying if requirements are achieved, *qualitative* rules are instantiated in the tool.

This approach can be used for different entities and contexts. An *Illustrative Example* regarding a vehicle design and production collaborative process is presented in the paper (Mallek et al., 2012), and another example focuses on the assessment of a drug circulation collaborative process is also described in the paper (Daclin et al., 2016b).

Approach A21: A methodology to implement and improve interoperability

The methodology to implement and improve interoperability (Daclin et al., 2006), (Chen and Daclin, 2007), (Daclin et al., 2008), (Daclin et al., 2016a) focuses on the interoperability development of enterprises (i.e. it addresses *Entities*). This methodology is the only one dealing with the three types of assessment: *Potentiality*, *Compatibility* and *Performance*.

Regarding the potentiality assessment, a maturity model containing five levels is defined. The model defines the evaluation of an enterprise potentiality according to the three interoperability barriers defined by FEI that impact the development of interoperability and the levels where interoperability takes place, which is *Business*, *Process*, *Service* and *Data*. This assessment is based on *Qualitative* measurement mechanism for determining the enterprise maturity level.

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[7] https://cogitant.sourceforge.io/

Considering the *Compatibility* assessment, it proposes a matrix of incompatibilities. Such a matrix has four rows corresponding the interoperability concerns (*Business*, *Process*, *Service* and *Data*) and six columns based on the three interoperability barriers (*Conceptual*, *Technological* and *Organisational*). These columns are *Syntactic, Semantic, Platform application, Communication, Authorities' responsibilities* and *Organisation*. If at least one incompatibility is detected, the coefficient 1 is assigned to the interoperating level and the problem that is considered. Conversely, the coefficient 0 will be applied either when no incompatibility is detected or when the view is not concerned.

The set of questions to detect incompatibilities is defined according to the needs expressed by partners. The assessors evaluate *Qualitatively* the defined questions based on their experience and judgment. The total degree of interoperability is given by the sum of the matrix's cells. A compatibility degree equal to 24 is the worst situation, as it means that there is at least one incompatibility in each cell. Moreover, *Quantitative* criteria related to the cost, delay and quality of interoperation is defined by conducting a *Performance* assessment. The criteria are described in Table 11.

Table 11. Interoperability performance criteria. Adapted from (Daclin et al., 2016a)

Type of evaluation	Details	Formula
Cost of data exchange (C_{ex})	It represents the difference between the initial cost allocated to exchange (C_{iniex}) and the real cost of exchange (C_{effex})	$C_{ex} = C_{iniex} - C_{effex}$
Cost of operation (C_{op})	It represents the difference between the initial cost allocated to operation (C_{iniop}) and the real cost of operation (C_{effop})	$C_{op} = C_{iniop} - C_{effop}$
Duration of data exchange (T_{ex})	It represents the time measurement between the date of the emission of information (partner 1) (T_{em1}) and the date of reception of the information (partner 2) (T_{rec2}).	$T_{ex} = T_{rec2} - T_{em1}$
Duration of operation (T_{op})	It represents the time measurement between the date of the reception of information (T_{rec2}) and the date of operation (T_{op2})	$T_{op} = T_{op2} - T_{rec2}$
Quality of exchange (Q_{ex})	It represents the difference between the total number of sendings (N_{eff}) and the number of successful sendings (N_{succ})	$Q_{ex} = N_{eff} - N_{succ}$
Quality of operation (Q_{op})	It represents the difference between the number of requests (N_{req}) and the number of receptions (N_{rec})	$Q_{op} = N_{req} - N_{rec}$
Conformity (Q_{conf})	It represents the difference between the total number of receptions (N_{rec}) and the number of conform receptions (N_{conf})	$Q_{conf} = N_{rec} - N_{conf}$

According to the authors, this methodology can be applied to any kind of entities. This methodology has been applied in two *Real Scenarios*. The scenario regarding a telecommunication company and its dealers is detailed in (Daclin et al., 2016a). The second scenario detailed in (Daclin et al., 2008) corresponds to a carrier and shipper company.

2.2.3 Comparing and discussing the interoperability assessment approaches

The literature review reveals 68 candidate papers, of which 46 are retained. The selected papers propose or improve 21 INAS approaches that are analysed and compared based on seven criteria: the type of application, the type of assessment, the coverage of interoperability layers, and the coverage of enterprise interoperability concerns, the measurement mechanism, and the provision of best practices and the provision of a computer-mediated tool for supporting the assessment process. In this section, we provide first a summary of the analysed approaches considering the comparison criteria. Further, we elaborate on the identified limitations and research perspectives.

Summary

Table 12 presents a summary of the INAS approaches regarding the comparison criteria. The main findings and limitation are discussed hereinafter. The column “approach” identifies the considered INAS approach according to their given ID, i.e. “Approach A1: The levels of conceptual interoperability model” is identified as A1.

Table 12. Summary of the comparative analysis

ID	Type of system	Type of application	Type of structure	Type of assessment			Measurement mechanism		Best practice	Supporting tool
				Pot	Com	Per	Qual	Quant		
A1	Non-Human Resources	General Use	Leveling	-	+	-	+	-	+	-
A2	Non-Human Resources	Specific Use	Non-Leveling	-	+	-	+	-	-	+
A3	Non-Human Resources	General Use	Non-Leveling	-	+	-	+	+	-	+
A4	Non-Human Resources	General Use	Non-Leveling	-	+	-	+	-	-	+
A5	Non-Human Resources	General Use	Non-Leveling	-	+	-	-	+	-	+
A6	Non-Human Resources	Specific Use	Leveling	-	+	-	+	+	-	+
A7	Non-Human Resources	General Use	Non-Leveling	-	+	-	+	+	-	-
A8	Entity	General Use	Leveling	-	+	-	+	-	-	-
A9	Entity	General Use	Leveling	-	+	-	+	-	+	-
A10	Entity	General Use	Non-Leveling	-	+	-	-	+	-	-
A11	Entity	General Use	Non-Leveling	+	-	-	-	+	-	-
A12	Entity	General Use	Leveling	+	-	-	+	+	+	-
A13	Entity	General Use	Leveling	+	-	-	+	-	-	-
A14	Entity	General Use	Non-Leveling	+	-	-	+	+	-	+
A15	Entity	General Use	Non-Leveling	-	-	+	-	+	-	-
A16	Entity	Specific Use	Leveling	+	+	-	+	-	-	-
A17	Entity	General Use	Leveling	+	+	-	+	-	+	-
A18	Entity	General Use	Leveling	+	+	-	+	+	+	-
A19	Entity	General Use	Non-Leveling	+	+	-	+	+	+	+
A20	Entity	General Use	Non-Leveling	-	+	+	+	-	-	+
A21	Entity	General Use	Leveling only for Pot	+	+	+	+	+	+	-

Pot = Potential; Com = Compatibility; Per = Performance; Qual: Qualitative; Quan = Quantitative; + = addresses; - = does not address

Regarding the types of assessment, we outline that the *Compatibility* assessment is the most addressed in the sixteen approaches. It reflects the relevance of understanding thoroughly both systems that need to interoperate. It is related to the fact that most of the enterprises already have a list of primary partners or a desired one. The nine INAS approaches addressing the *Potentiality* assessment are more diversified comparing the other types. For instance, four of them are specifically addressing information systems but they are being applied in different domains. Further, the others are dealing with a broader assessment by considering multiple barriers, concerns and domains. The *Performance* assessment is the lesser addressed with only three approaches.

Moreover, the number of approaches using *Qualitative* measurement mechanisms is equal to seventeen. The number of approaches proposing *Quantitative* measurement mechanisms is equal to twelve. Among them, eight approaches are combining both types of mechanisms. Seven INAS approaches are providing *Best Practices* or guidelines for improving systems interoperability. Indeed, best practices are useful for decision makers in order to design the *to-be* situation of the system(s) of interest and to implement interoperability solutions. Finally, the results of this review indicate that the majority of the approaches do not have a *Computer-Mediated Tool*. Only eight approaches propose computer-mediated tools for supporting the assessment process.

Next, we analyse and discuss the coverage of interoperability barriers and concerns by the INAS approaches. This allows us to identify which are the INAS approaches addressing most of the barriers and concerns. Table 13 presents a matrix considering the cross section between the interoperability barriers and concerns. The approach ID is put into a corresponding cell when dealing with the considered barrier and concern.

Table 13. Classification regarding the addressed interoperability areas: layer/barrier x concern

		Interoperability Layers / Barriers		
		Conceptual	Technological	Organisational
Enterprise Interoperability concerns	Business	(A8), (A14), (A13), (A16), (A18), (A20), (A21)	(A13), (A14), (A18), (A20), (A21)	(A8), (A9), (A11), (A13), (A14), (A18), (A19), (A20), (A21)
	Process	(A5), (A10), (A12), (A13), (A14), (A16), (A18), (A20), (A21)	(A10), (A13), (A14), (A15), (A18), (A20), (A21)	(A9), (A10), (A11), (A12), (A13), (A14), (A16), (A18), (A19), (A20), (A21)
	Service	(A4), (A5), (A6), (A17), (A12), (A14), (A18), (A19) (A20), (A21)	(A4), (A6), (A11), (A12), (A13), (A14), (A15), (A17), (A18), (A19), (A20), (A21)	(A12), (A14), (A18), (A19) (A20), (A21)
	Data	(A1), (A3), (A4), (A5), (A7), (A11), (A13), (A14), (A16), (A17), (A18), (A19), (A20), (A21)	(A1), (A2), (A3), (A4), (A6), (A11), (A12), (A13), (A14), (A15), (A16), (A17), (A18), (A19), (A20), (A21)	(A11), (A12), (A14), (A18), (A19), (A20), (A21)

Among the twenty-one approaches, we identify seventeen addressing the *Technological* barriers, eighteen dealing with the *Conceptual* barriers, twelve approaches assessing the *Organisational* barriers, and ten of the studied approaches are addressing all three barriers. Regarding the interoperability concerns, we identify eleven INAS approaches dealing with the *Business* concern, thirteen with the *Process* concern, thirteen with the *Service* concern, and eighteen addressing the *Data* concern.

As shown in Table 13, the Technological-Data cross-section is the most addressed with sixteen approaches. It is closely followed by the Conceptual-Data cross-section with fourteen approaches. The Technological-Business cross-section is the less addressed, with five approaches. However, note that only four of the studied approaches are addressing all barriers and all concerns, which are: the approach for interoperability requirements specification and verification (Mallek et al., 2012), the MMEI (Guédria et al., 2015), the methodology to implement and improve interoperability (Daclin et al., 2016a) and the framework for interoperability assessment in crisis management (da Silva Avanzi et al., 2017).

Limitations

Based on the comparative analysis, we discuss the identified limitations as well as research perspectives.

Limitation 1. We identified that few INAS approaches addresses multiple interoperability barriers and concerns at the same time. We argue that the application of various approaches may cause redundancy and confusion when assessing the same barriers using different metrics and viewpoints (Leal et al., 2016a), (Leal et al., 2019). Consequently, few approaches - implicitly - address the interdependencies among and between interoperability barriers and concerns, but none explicitly defines interoperability requirements interdepednecies. For instance, the approach proposed in (Cornu et al., 2012a) associate some of their defined questions for evaluating interoepability requirements to two interoperability barriers (e.g. the question *"Is it possible to make the non-human resource accept a new data format?"* is related to both Conceptual and Technological barriers). However, the authors do not explicitly explain which the related requirement is and why the question concerns to both barriers. Further, the Maturity Model for Enterprise Interoeprability determines that all evaluation criteria related to all interoperability barriers and concerns regarding a maturity level should be fulfilled to the concerned level to be considered as achiecved. However, the order and the impacts of the criteria fulfillement are not explicitly defined. Next, in (Yahia et al., 2012a), the authors highlights that the assessed systems must have compatible interfaces (i.e. technacly interoperable). Dispite the authors not precising what are the technological interoeprability requirements are, we observe that the semantic measures (which are related to the conceptual layer) are dependent the technological layer. Acknowledging the different dependencies among and between them supports the identification of impacts on the overall system (Leal et al., 2017b). For example, when implementing a new software application, the enterprise should: verify if the current data format available on their servers are compatible with the new application; verify if employees have the competence and authorisation to use the application; verify if the existing internal and external applications are compatible and connectable with the new one.

Limitation 2. We observed that the majority of INAS 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 (Alalwan and Thomas, 2012), (Krivograd and Fettke, 2012). Few of the studied approaches are proposing computer-mediated tools for supporting the assessment and decision-making processes. Indeed, computer-mediated systems for supporting assessment processes enhance a stakeholder's ability to analyse the system's current state and to make improvements (Krivograd and Fettke, 2012).

Limitation 3. We remarked that only seven INAS approaches are conveying any information or guidance to improve interoperability based on their assessment results. Indeed, the provision of best practices can support stakeholders making informed decisions for solving or at least reducing interoperability problems.

2.3 Contribution positioning

Based on the research context and found limitations, we propose, "***A holistic interoperability assessment approach based on interoperability requirements interdependencies***".

Nonetheless, we decided to take the Maturity Model for Enterprise Interoperability (A18) (Guédria et al., 2015) as a reference model as it: (1) Defines a framework for assessing and measuring potential interoperability maturity, while providing information for how far along an enterprise is regarding targeted maturity levels; (2) Adopts a systemic approach and 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); (3) Is an international standard under the number 11354-2 (ISO 11354-2, 2015). Table 14 presents the contribution positioning regarding the INAS domain.

Table 14. The contribution positioning

Assessment Characteristics	**Positioning**	**Description**
Type of assessment	Potentiality and Compatibility	We focus on these two types of assessments, 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.
Structure of assessment	Levelling	We apply a levelling structure for organising the interoperability requirements. A meaning is given for each maturity level containing the defined interoperability requirements.
Measurement mechanism	A combination of qualitative and quantitative measures	Qualitative measures are used for attributing a linguistic value to each concerned requirement by assessors. Quantitative measurement mechanisms are used for computing and aggregating multiple requirement ratings.
Interoperability coverage	All twelve interoperability areas based on MMEI	We chose to cover all areas for providing a holistic view of the assessed system
Requirements interdependencies	Yes	The requirements' interdependencies from the different interoperability areas are explicitly defined and considered.
Computer-mediated support	Yes	A Knowledge-Based System is proposed for supporting the implementation of the requirements dependencies as well as to support the assessment process.
Best practices	Yes	Best practices based on international standards are encoded within the proposed system.

We formulate the following objectives for realising our contribution:

— Investigate and define the relationships between interoperability requirements.

- Formalise INAS knowledge, including the relations between interoperability requirements, problems and solutions.
- Contribute to INAS domain by improving MMEI (Guédria et al., 2015) based on the interoperability requirements interdependencies
- Provide a Knowledge-Based System for supporting the overall INAS process.

In order to address the research solution proposal, we propose three artefacts.

The set of interoperability requirements and their interdependencies (SO1):

Due to the MMEI being adopted as the reference interoperability model, we consider it as a starting point for extracting interoperability requirements from its defined interoperability areas. The System Requirement Engineering domain (Loucopoulos and Karakostas, 1995), (ISO/IEC 29148, 2011), (INCOSE, 2015) is used for providing techniques such requirement elicitation and requirement formalisation.

In order to establish explicit links among interoperability requirements, the literature from both Enterprise Architecture and Strategic Alignment domains are explored. The latter focuses on aligning enterprise systems for achieving cohesive goals across the IT and other functional organisations (e.g. marketing and human resources units). In addition, the literature of Enterprise Architecture (EA) is also relevant for gathering insights as an EA can provide a coherent and comprehensive view of the relationships of **enterprise systems** (e.g. machines, human resources, organisation units, etc.) according to the defined business strategy (Op't Land et al., 2009), (TOG, 2018). Therefore, it supports the visualisation and understanding of requirements and constraints from different layers of the enterprise. Once the interoperability requirements interdependencies are defined, they are integrated into the MMEI, thus enriching this assessment model.

The Ontology of Interoperability Assessment (SO2):

In order to formalise the knowledge of INAS, we develop the Ontology of Interoperability Assessment (OIA). 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 (Gruber, 2009).

The aims of OIA are: (i) provide a sound description of the relevant concepts, relationships, and reasoning rules related to interoperability assessment; (ii) represent and formalise knowledge concerning interoperability requirements; (iii) enables information sharing and reusability, regarding interoperability issues.

Further, the OIA will also be used as knowledge model of a decision support system for interoperability assessment. Indeed, an ontology can provide formal descriptions to the interoperability requirements, and use reasoning functions to assist in the analysis of the concerned systems. Therefore, OIA will provide the ability to infer potential problems and transformations that an enterprise can face, based on requirements interdependencies.

To develop the OIA, we follow the Noy and McGuinness's ontology development methodology (Noy and McGuinness, 2001) and (Horridge et al., 2004). For defining the OIA concepts and relations, we apply a Model-Based System Engineering approach (INCOSE, 2015).

The knowledge-based system for interoperability assessment (SO3):

The current version of MMEI can be characterised as a manual-conducted approach. This kind of approach is, in general, laborious and time-consuming and in many times depends on the subjective knowledge of experts (Grambow and Oberhauser, 2010), (Alalwan and Thomas, 2012), (Krivograd and Fettke, 2012). Therefore, we propose a Knowledge-Based System (KBS) for supporting the assessment process. Indeed, a KBS is a software application with specialised problem-solving expertise, where "expertise" consists of knowledge about a particular domain (e.g. interoperability) (Power, 2004). In general, this "expertise" is stored in a knowledge model (e.g. Ontologies). Hence, our proposed KBS will recommend actions based on the knowledge that has been stored in the OIA. Indeed, the use of an ontology as a knowledge model provides the following advantages: It establishes a common foundation for sharing contextual knowledge across various users, facilitates common domain understanding and offers users more accurate, proper and comprehensive knowledge (Chandrasekaran et al., 1999), (Li et al., 2011), (Alalwan and Thomas, 2012), (Tarhan and Giray, 2017), (Leal et al., 2017c).

Next, for implementing the OIA in the KBS, we adopted the Ontology Web Language (OWL) (Horridge et al., 2004) as it is an open standard for semantic knowledge representation. The tool used for modelling and building it was the Protégé 5.2 (Musen, 2015). We adopted the Semantic Web Rule Language (SWRL) (Horrocks et al., 2014) for expressing the semantic rules. Such rules are used for reasoning the stored knowledge against the information provided by the assessors. The architecture of the KBS is defined based on the work proposed by (Krivograd and Fettke, 2012). It is worth noting that KBS is not fully automated. We argue that the insights and expertise of concerned persons (e.g. assessment team) are valuable to the assessment (Leal et al., 2017c). For example, lead assessors use their expertise to validate or not the proposed results of the KBS.

Fig. 14 illustrates the three artefacts and their relations as well as the research questions that they are addressing.

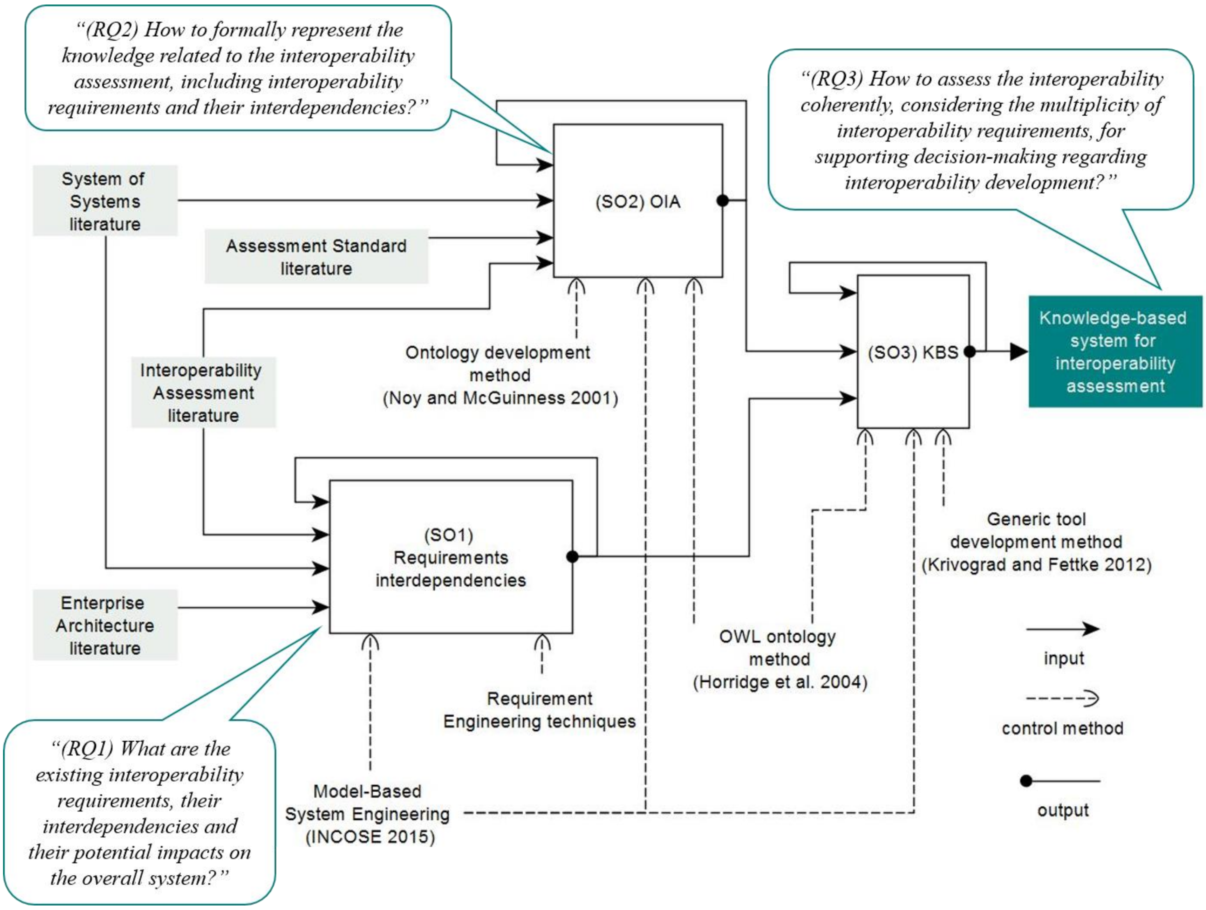


Fig. 14. The thesis artefacts

Chapter 3

System Requirement Engineering for Enterprise Interoperability

Introduction

Assessing the enterprise's ability to interoperate is frequently the initial step toward the identification of interoperability problems and the proposition of interoperability improvements (Ford et al., 2007a), (Chalmeta and Pazos, 2015), (Guédria et al., 2015). When improving the system's interoperability for avoiding or solving interoperability problems, changes may be necessary. However, such changes at the enterprise systems' level embodies an immediate evolution and presents a disturbance to the networked enterprise (Jardim-Goncalves et al., 2012), (Agostinho et al., 2016). For that reason, the alignment between enterprise's systems as well as their Interoperability Requirements (IRs) relationships should be taken into account when assessing and improving systems' interoperability.

However, we observed that none of the INAS related work studied in Chapter 2 is explicitly defining the relationships between IRs. Indeed, having an understanding of the relationships between the requirements of different enterprise levels supports the identification of impacts on the overall system (Leal et al., 2017b). It also helps identify any changes that can cause potential misalignment between enterprise systems.

Therefore, the objective of this chapter is to investigate the relations between IRs and enterprise systems and define the interdependencies between IRs to ensure a global view of the current state of the assessed systems. In order to address the hereinabove objective, in the first part of this chapter, we study the different processes of the Requirement Engineering (RE). Where RE is concerned with discovering, eliciting, developing, analysing, validating, communicating, documenting, and managing requirements (ISO/IEC 29148, 2011). We also investigate RE techniques such as requirement elicitation, formalisation and modelling. The output of this part is the proposition of a RE approach for the definition of the IRs interdependencies.

Finally, in the second part of the chapter, we define the IRs interdependencies. Here, we assert that a manner for defining requirements relationships is to identify what enterprise systems are being addressed by the same requirements and by considering the composition of the concerned requirements. Hence, taking into consideration the proposed set of identified IRs, we elaborate and define the IRs interdependencies.

3.1 System Requirement Engineering

Requirement Engineering can be defined as the systematic process of developing requirements through an iterative combining process of examining the problem, documenting the resulting observations, and verifying the accuracy of the obtained knowledge (Loucopoulos and Karakostas, 1995). Indeed, the set of requirements obtained through a RE approach enables an agreed understanding between stakeholders and provides a basis for verifying designs and accepting system solutions (ISO/IEC 29148, 2011).

Many frameworks have been proposed in the literature to describe the general processes of a RE (Loucopoulos and Karakostas, 1995), (Dick et al., 2017), (ISO/IEC 29148, 2011). Relevant techniques for supporting the overall RE process have been also identified, such as the requirements elicitation (van Lamsweerde, 2001), (Sutcliffe, 2003), (Pacheco and Garcia, 2012) requirements formalisation (Peres et al., 2012), (Szejka et al., 2015), (Z. Y. Chen et al., 2007) and system requirements modelling (Amyot and Mussbacher, 2011), (Panetto et al., 2004), (OMG, 2017a).

In the following, we review some relevant work that defines RE processes and techniques. Note that the objective here is not to conduct an exhaustive review, but rather to present the main aspects of the RE processes that are relevant to this research.

3.1.1 Requirement engineering processes

(Loucopoulos and Karakostas, 1995) proposes a framework containing three RE processes focusing on the development of software systems: (1) the first process refers to the elicitation of the requirements based on the stakeholders' needs and on the knowledge extracted from the concerned domain. The purpose of this process is to gain knowledge relevant to the problem, which can be used to produce a formal specification of the software needed to solve the problem. (2) The second process corresponds to the requirements specification. This process produces formal software requirements models, which have two main objectives: to serve as an agreement between stakeholders and developers, and to serve as a blueprint for the development of the software system. (3) The third and last process refers to the validation of requirements. Such process aims at certifying that the requirements' model is consistent with stakeholders' intentions and needs.

(Dick et al., 2017) describes a generic system development process grounded in the RE. Such a generic process subsumes three sub-processes. The first one is responsible for transforming the stakeholders' needs into a set of stakeholders' requirements. The second sub-process is responsible for translating the set produced by the first one into a set of system requirements. Finally, the third sub-process refers to the design of the system based on the system requirements defined in the second sub-process. Its main output is the system's architecture.

The international standard ISO 29148 (ISO/IEC 29148, 2011) describes three processes: the Stakeholder Requirements Definition process, the Requirements Analysis process and The Architectural Design process. The Stakeholder Requirements Definition process aims to determine the system's requirements that can provide the functions needed by users and other stakeholders in a defined environment. The purpose of the Requirements Analysis process is to transform the stakeholder, requirement-driven view of desired functions into a technical view of a required system that could deliver those functions. These first two processes result in a set of requirements, which flow into the Architectural Design process where the requirements are allocated, decomposed and traced to system elements. In some instances, additional requirement statements should be created to define relationships between the architectural elements of the system, to provide necessary clarity in the context of the lower levels of abstraction of the system elements (ISO/IEC 29148, 2011).

Note that all the three processes are related to enterprise or an enterprise system to be built or transformed.

3.1.2 Requirement elicitation

Requirement elicitation refers to the process of acquiring all the relevant knowledge needed (e.g. context, needs and constraints) to produce a requirement model of a problem domain (Loucopoulos and Karakostas, 1995). It is considered as one of the main phases of the overall RE processes. Poor execution of elicitation will almost certainly guarantee that the final project is a complete failure (Pacheco and Garcia, 2012).

Many techniques and approaches for eliciting requirements have been proposed in the literature. For instances, the goal-oriented analysis approach intending on relating the purpose and functions of the concerned system to its environment (van Lamsweerde, 2001); the scenario-based approach, in which users participate by executing scenarios based on real cases and in such a way that their expertise are elicited (Sutcliffe, 2003); the data-intensive approach, which is based on documents' analysis, data mining and natural language processing (Castro-Herrera et al., 2008); and finally, the direct acquisition of knowledge from the application domain users through interviews and brainstorming (Loucopoulos and Karakostas, 1995). More techniques can be found in (Pacheco and Garcia, 2012).

3.1.3 Requirement formalisation

In general, requirements have a set of varied information that are typically defined by specialists using documents written in a natural language (Eriksson et al., 2009). However, natural languages can usually cause ambiguity and misinterpretation and they cannot serve as inputs for automated verification techniques (Peres et al., 2012). To cope with these issues, numerous methods have been developed over the years to formalise requirements.

For example, in (Szejka et al., 2015), the authors propose a conceptual methodology to structure the formalisation of product requirements written in natural language to formal logic requirements. This method is structured in two parts: (1) a conceptual data model, which is responsible for conceptual modelling requirements, extracting the main facts from each sentence and establishing the links between these facts; and (2) a logical model, which is responsible for transforming these modelled requirements to formal logical requirements.

In (Z. Y. Chen et al., 2007) a formalisation process is proposed to transform a design problem described in natural language into a formal specification. This is based on two mathematical theorems of product requirements derived using the axiomatic theory of design modelling. Finally, in (Peres et al., 2012), the proposed formalisation process follows a top-down approach: it starts from the high-level requirements and ends with directly formalised requirements.

3.1.4 System requirements modelling

One of the main objectives of system design is to identify which requirements should be allocated to which system elements. In some instances, additional requirements should be created to define relationships between the architectural elements of the system and to provide necessary clarity in the context of the deeper granularity of the system (ISO/IEC 29148, 2011). To do so, many modelling languages have been proposed in the literature with a focus on system and requirement modelling or a combination of both. For instances, the Goal-oriented Requirement Language (GRL) (Amyot and Mussbacher, 2011), (Amyot et al., 2010) is a visual modelling notation for intentions, business goals, and non-functional requirements of many stakeholders. The Unified Enterprise Modelling Language (UEML) (Panetto et al., 2004) is a language for providing standardised mechanisms for sharing and exchanging models among projects, overcoming tool dependencies. The Object Management Group (OMG) Systems Modelling Language (SysML) (OMG, 2017a) which is a general-purpose modelling language for systems engineering. It is particularly effective in specifying requirements, structure, behaviour, allocations, and constraints on system properties.

Finally, the ArchiMate (TOG, 2013), which is a language to express the architecture of enterprises. Concepts in the ArchiMate language cover the Business, Application, Technology layers of an enterprise and provide two extended layers that represent the Motivation and Implementation. The Motivational concepts are used to model the motivations, or reasons, that underlie the design or change of some enterprise architecture. These concepts are *Goals, Principles, Requirements*, and *Constraints.* In this modelling language, the concept *Requirements* model the properties of the enterprise elements (e.g. information systems, business process, etc.) that are needed to achieve the "ends" that are modelled by the enterprise' goals. In this respect, requirements represent the "means" to realize goals.

3.2 Definition of the interoperability requirement interdependencies

This section investigates and defines the interoperability requirement interdependencies.

3.2.1 Interoperability requirements interdependencies: a requirement engineering approach

Based on the work of (Loucopoulos and Karakostas, 1995) and (ISO/IEC 29148, 2011), we propose a RE approach subsuming four steps for identifying and determining the IRs interdependencies as described hereinafter.

1. **Requirement Elicitation**: The requirements can be extracted from the IR related literature (Chituc et al., 2009), (Alemany et al., 2010), (Daclin et al., 2016b) and from INAS approaches such those studied in Chapter 2. Information gathered from interviews with system architects, and enterprise

stakeholders are relevant for defining systems requirements. In our case, we observe that none of the reviewed work (see Chapter 1 for IR literature and Chapter 2 for the INAS literature) is explicitly defining the interdependencies of IRs. Nonetheless, we adopt the Maturity Model for Enterprise Interoperability (MMEI) (Guédria et al., 2015) as the reference assessment model as it provides a holistic view of the INAS defining twelve interoperability areas based on the interoperability barriers and concerns from the Framework for Enterprise Interoperability (Chen, Dassisti, Elvesaeter et al., 2007). Each interoperability area contains a set of criteria and related best practices describing what should be evaluated and done for improving interoperability, respectively. Therefore, these evaluation criteria and best practices are used for defining IRs.

2. **Requirement Decomposition and Formalisation**: The decomposition and formalisation are done in order to formalise requirements from the natural language form. For this purpose, we adopt the formal framework for the formalization of informal requirements defined in (Peres et al., 2012). One of the main advantages of this framework is that it provides an iterative process supported by a formal structure: the Pseudo-Requirement Graph, which consists in two types of nodes (refinements and pseudo-requirements).
3. **Requirement Architectural Design**: According to (ISO/IEC 29148, 2011), it is crucial to define requirement statements at more detailed levels of abstraction than just the overall system. This is accomplished by allocating the system requirements to the system elements. For the purpose of this research, we follow a similar approach adopted by the European Commission for modelling enterprise elements and their associated requirements in the European Interoperability Reference Architecture (EIRA) (European Commission, 2018a). Regarding the modelling language, we adopt the System Modelling Language (SysML) (OMG, 2017a) as it is a well-known standard and can be used to model any kind of system e.g. enterprises, networked enterprises, software applications, etc.
4. **Requirement Interdependencies Identification**: Based on the requirements and enterprises elements relationships, we define the requirements interdependencies.

As illustrated in Fig. 15, we first extract the evaluation criteria from MMEI. Next, we formalise the extracted criteria using the iterative methodology proposed in (Peres et al., 2012). Having the requirements formalised, we relate them with the concerned enterprise elements (e.g. data storage systems, conceptual models, etc.). Finally, based on the determined relationships, we infer the requirement interdependencies. For example, we define that the Requirements R1 and R2 are interdependent as both of them are related to the same Enterprise Element 1, as illustrated in Fig. 15.

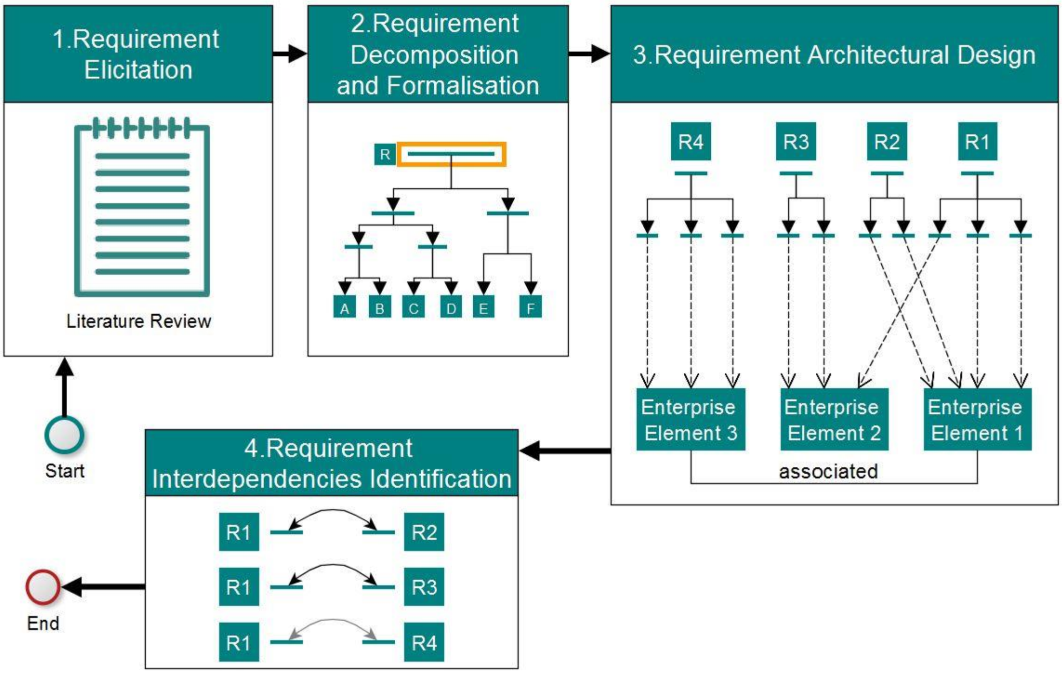


Fig. 15. Approach for defining interoperability requirements interdependencies

3.2.2 Interoperability requirement elicitation

The first step of our RE approach is the IRs elicitation. As mentioned before, we adopt the forty-eight interoperability evaluation criteria defined on the MMEI (Guédria, 2012), (Guédria et al., 2015) as IRs. To write the interoperability requirements based on the evaluation criteria, we follow the (ISO/IEC 29148, 2011) recommendations for construction of a requirement. It means that, we re-wrote the proposed criteria on the current version of MMEI for clearly and precisely expressing requirements and in a form convenient for further analysis.

According to the (ISO/IEC 29148, 2011), requirements should state what is needed for the concerned system and not include design decisions for it. However, as interoperability requirements are allocated and decomposed through the levels of the system, the solution architectures will be defined at a higher level, when defining best practices. Regarding the requirement construct, superlative, subjective language, comparative phrases and ambiguous adverbs should be avoided. As requirements are binding provisions, the use of '*shall'* when describing the actions of the concerned subject (i.e system) is mandatory. A value can be also allocated to a requirement as a support for the requirement verification. Fig. 16 illustrates the requirement construct.

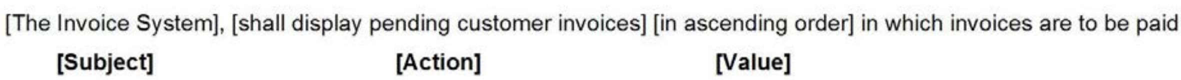


Fig. 16. Requirement construct example.

Therefore, when applying these guidelines to the MMEI evaluation criteria we have the following as illustrated in Fig. 17. Note that as no value is defined in the requirement form, we consider that the requirement will be true when it achieves the maximum value established by the concerned assessment model.

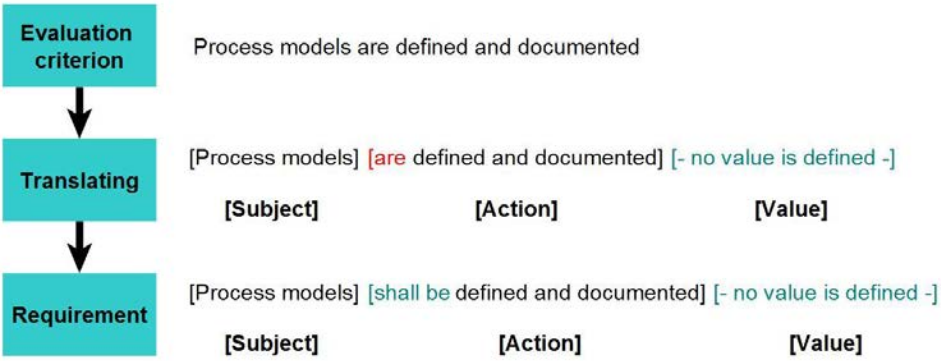


Fig. 17. Switching from interoperability evaluation criteria to interoperability requirement.

Table 15 to Table 18 present the requirements. They are organised according to the interoperability areas defined in MMEI. Each area represents the cross-section between an Interoperability Barrier (*Conceptual*, *Technological* and *Organisational*) and an Interoperability Concern (*Business*, *Process*, *Service* and *Data*). 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 **B**usiness concern and the **C**onceptual barrier from the maturity level **1**.

Table 15. Interoperability Requirements relate to the Business concern (Guédria, 2012)

ID	Conceptual / Business	ID	Technological / Business	ID	Organisational / Business
BCR1	Business models shall be defined and documented	BTR1	Basic IT infrastructure shall be in place	BOR1	Organization structure shall be defined and in place
BCR2	Standards shall be used for alignment with other business models	BTR2	Standard and configurable IT infrastructures shall be used	BOR2	Human resources shall be trained for interoperability
BCR3	Business models shall be designed for multi partnership and collaborative enterprise	BTR3	IT infrastructure shall be open	BOR3	Organization structure shall be flexible
BCR4	Business model shall be adaptive	BTR4	IT infrastructure shall be adaptive	BOR4	Organization shall be agile for on-demand business

Table 16. Interoperability Requirements relate to the Process concern (Guédria, 2012)

ID	Conceptual / Process	ID	Technological / Process	ID	Organisational / Process
PCR1	Process models shall be defined and documented	PTR1	IT devices shall support processes and ad hoc exchange of process information shall be possible	POR1	Processes responsibilities and authorities shall be defined and put in place
PCR2	Standards shall be used for alignment with other process models	PTR2	Standard process tools and platforms shall be available	POR2	Procedures for processes interoperability shall be in place
PCR3	Meta-modelling shall be done for multiple process model mappings	PTR3	Platform(s) and tool(s) for collaborative execution of processes shall be available	POR3	Cross-enterprise collaborative processes management shall be in place
PCR4	Process modelling shall be done for dynamic re-engineering	PTR4	Dynamic and adaptive tool(s) and engines for processes shall be available	POR4	Real-time monitoring of processes, adaptive procedures shall be in place

Table 17. Interoperability Requirements relate to the Service concern (Guédria, 2012)

ID	Conceptual / Service	ID	Technological / Service	ID	Organisational / Service
SCR1	Service models shall be defined and documented	STR1	Applications/services shall be connectable and ad hoc information exchange shall be possible	SOR1	Service responsibilities and authorities shall be defined and put in place
SCR2	Standards shall be used for alignment with other service models	STR2	Standardise and configurable service architecture(s) and interface(s) shall be available	SOR2	Procedures for services interoperability shall be in place
SCR3	Meta-modelling shall be done for multiple service model mappings	STR3	Automated services discovery and composition shall be possible and shared applications shall be in place	SOR3	Collaborative services and application management shall be in place
SCR4	Service modelling shall be adaptive	STR4	Dynamically composable services and networked applications shall be in place	SOR4	Dynamic service and application management rules and methods shall be in place

Table 18. Interoperability Requirements relate to the Data concern (Guédria, 2012)

ID	Conceptual / Data	ID	Technological / Data	ID	Organisational / Data
DCR1	Data models shall be defined and documented	DTR1	Data storage devices shall be connectable and simple electronic exchange shall be possible	DOR1	Responsibilities and authorities shall be defined and in place
DCR2	Standards shall be used for alignment with other data models	DTR2	Automated access to data based on standard protocols shall be in place	DOR2	Rules and methods for data management shall be in place
DCR3	Meta-modelling shall be done for multiple data model mappings	DTR3	Remote access to databases shall be possible for applications and shared data shall be available	DOR3	Personalized data management for different partners shall be in place
DCR4	Data models shall be adaptive (considering both syntax and semantics)	DTR4	Direct database exchanges capability and full data conversion tool(s) shall be in place	DOR4	Adaptive data management rules and methods shall be in place

3.2.3 Interoperability requirement decomposition and formalisation

In the following subsections, we first describe the methodology for requirement decomposition and formalisation proposed by (Peres et al., 2012). Next, we present the formalisation of the requirements from the *Process* Interoperability Concern regarding the maturity level 1.

The decomposition and formalisation process

To address the IRs decomposition and formalisation, we adopt the formal framework for requirement formalisation proposed in (Peres et al., 2012), as it provides an iterative methodology for decomposing and formalising informal requirements (i.e. natural language written requirements).

This methodology follows a top-down approach starting from the high-level requirements (i.e. requirements directly taken from the requirements' document) and ends with the formalised requirements. The methodology is illustrated in Fig. 18 and described hereinafter.

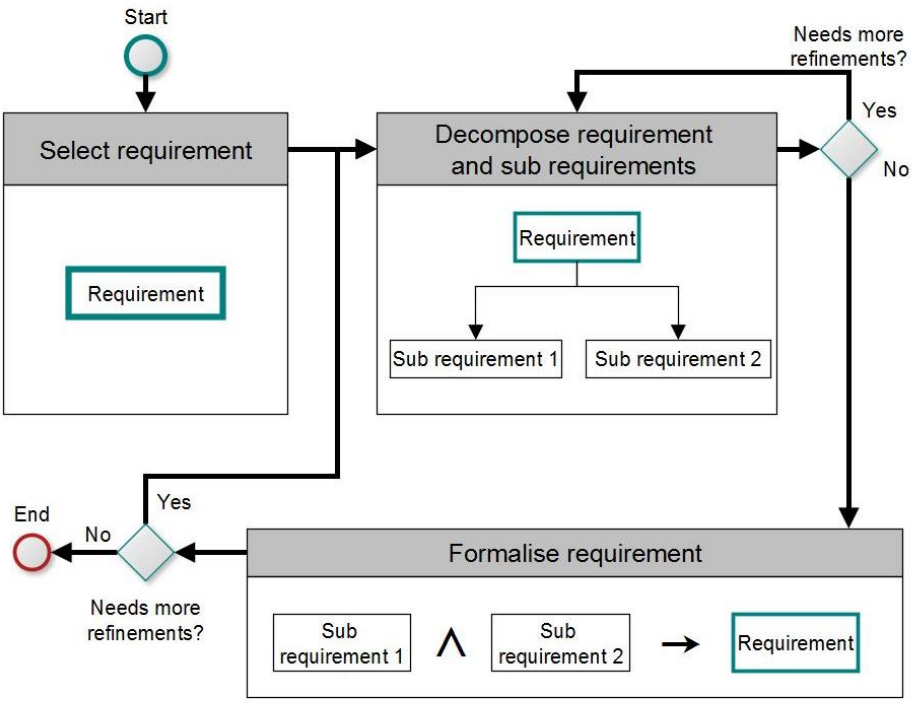


Fig. 18. The three main steps of the decomposition and formalisation methodology. Adapted from (Peres et al., 2012)

The first step consists on selecting a requirement from the considered document of reference. In our case, the IRs are those defined in the subsection 3.2.1. Therefore, for each requirement, we apply the three steps of this methodology.

The second step is the decomposition of the selected requirement. It is supported by a formal graph structure called the Pseudo-Requirement Graph. Such graph has three main elements:

- **Pseudo-requirement**, which is a requirement, a sub requirement, or an atomic requirement.
- **Atomic requirements** are equivalent to the atomic statements defined in logic, which is a statement that cannot be broken down into smaller statements.
- **Refinements**, which are the paths from the high-level requirement until the atomic requirements. The type of refinement must be chosen and specified. We adopt four categories, which are: (a) Precision: when a pseudo-requirement must be disambiguated; (b) Abstraction: when a pseudo-requirement is described in too much details regarding the system which is being studied (in other words, when a part is out of scope); (c) Correction: when the pseudo-requirement is incorrect; (d) Decomposition: when the pseudo-requirement can be decomposed in several pseudo-requirement

In the case of a refinement, its category should be chosen and applied. The outcome is one or multiple pseudo-requirements, which are linked with the refined requirement. The refinements are done until all the atomic-requirements are defined, and no other modification is needed. We argue that the atomic-requirements are defined based on the desired granularity level, the awareness of the environment in which the requirement is applied and the related context (e.g. interoperability).

Further, four elements are related to the refinement: ***What*** (identifies the concerned pseudo-requirement), ***Why*** (explains why the refinement is helpful), ***How*** (describes the result of modifying what is pointed out by the ***What*** according to what is explained by the ***Why***), and finally, the ***Link*** (describes how the refined pseudo-requirement is related to the pseudo-requirement(s) resulting from the refinement). Fig. 20 illustrates an example of a requirement decomposition using the Pseudo-Requirement Graph.

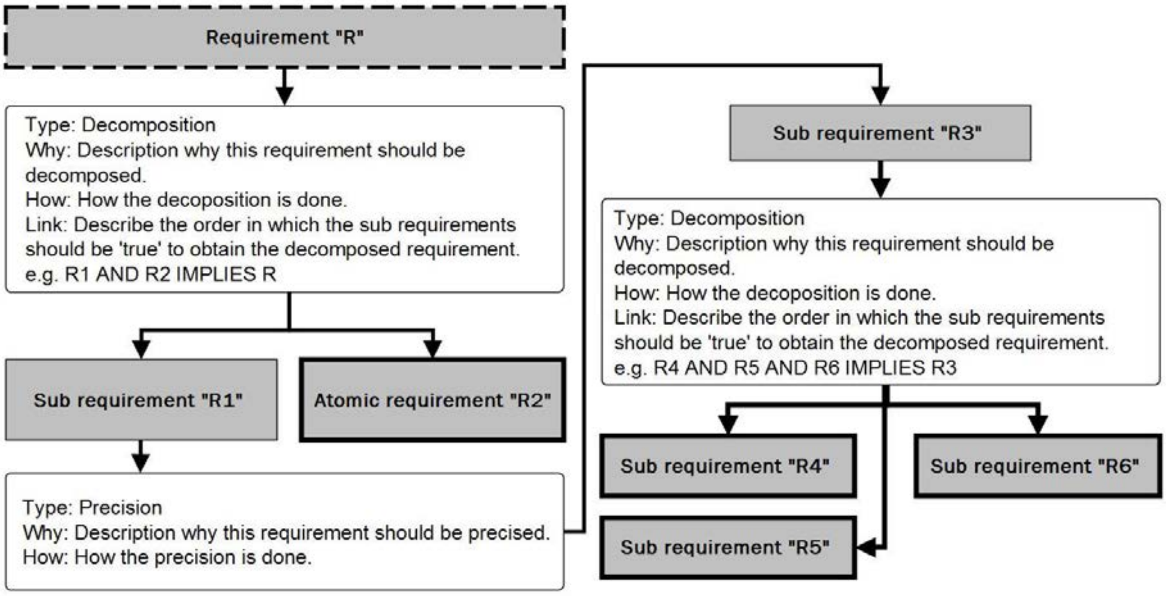


Fig. 19. Example of a requirement decomposition using the Pseudo-Requirement Graph.

In Fig. 19, the dashed rectangle represents the requirement extracted directly from the document of reference. The rounded rectangles represent the types of refinement. It includes an explanation of why the refinement is helpful, how the refinement is done and what are the links of the resulting refinement. The ordinary rectangles represent the pseudo requirements resulting from the refinements. The rectangles with thick lines represent the atomic requirements.

Finally, the third step refers to the formalisation of the decomposed requirement, based on the identified ***Links***. The formal language used is the same as defined in (Peres et al., 2012). It is a combination of the usual logical connectors from the first-order logic (Nienhuys-Cheng and Wolf, 1997), and the $\mathbf{U}$ temporal connector from the CTL* (Computer Tree Logic) (Emerson and Halpern, 1986). The $\mathbf{U}$ temporal connector is useful for formalising temporal conditions. For example, let us take the requirement "*BCR1: Business models shall be defined and documented*" and two of its sub requirements "*BCR1.1: Business models shall be defined*" and "*BCR1.2: Business models shall be documented*". Adopting only the first order logic connectors, one can write the following: $BCR1.1 \wedge BCR1.2 \rightarrow BCR1$. This statement means that *BCR1* is true if both *BCR1.1* and *BCR1.2* are true at the same time. It formalises the dependency of *BCR1* from *BCR1.1* and *BCR1.2*. In this logic, the order in which *BCR1.1* and *BCR1.2* are achieved does not matter for the implication of *BCR1*. In other words, if *BCR1.2* is true in a given time *t0* and *BCR1.1* is true in *t1* (i.e. after *t0*), *BCR1* is considered true.

However, it is not possible to document a business model (*BCR1.2*) before it is defined (*BCR1.1*). Therefore, it is paramount to include the notion of time for formalising this kind of situation. For instance, the connector **U** means, "hold until" and implies the notion of temporal dependency between two variables. Let us consider the same example using the requirement *BCR1*. The statement $BCR1.1 \cup BCR1.2 \rightarrow BCR1$ means that *BCR1.1* holds until *BCR1.2* happens. In other words, *BCR1.2* can be only considered true when *BCR1.1* is already true and is sustained as true.

The decomposition and formalisation of the IR from the Process Interoperability Concern

For demonstrating the decomposition and formalisation of the interoperability requirements, we applied the described methodology to three requirements from the Process Interoperability Concern regarding the maturity level 1. These requirements are *"PCR1: Process models shall be defined and documented"*; *"POR1: Process responsibilities and authorities shall be defined and in place"*; and *"PTR1: IT support for processes shall be in place and Ad hoc exchange of information shall be possible"*. Fig. 19 illustrates the decomposition of the requirement *PCR1* using the Pseudo-Requirement Graph. Table 19 shows the decomposition and formalisation of this same requirement.

Further, Table 21 and Table 20 show the decomposition and formalisation of the requirements *POR1* and *PTR1,* respectively. A simplified view of the Pseudo-Requirement Graphs from both *POR1* and *PTR1* are also presented in Table 21 and Table 20, respectively. The complete list of the formalised requirements and their atomic-requirements can be found in Annexe A.

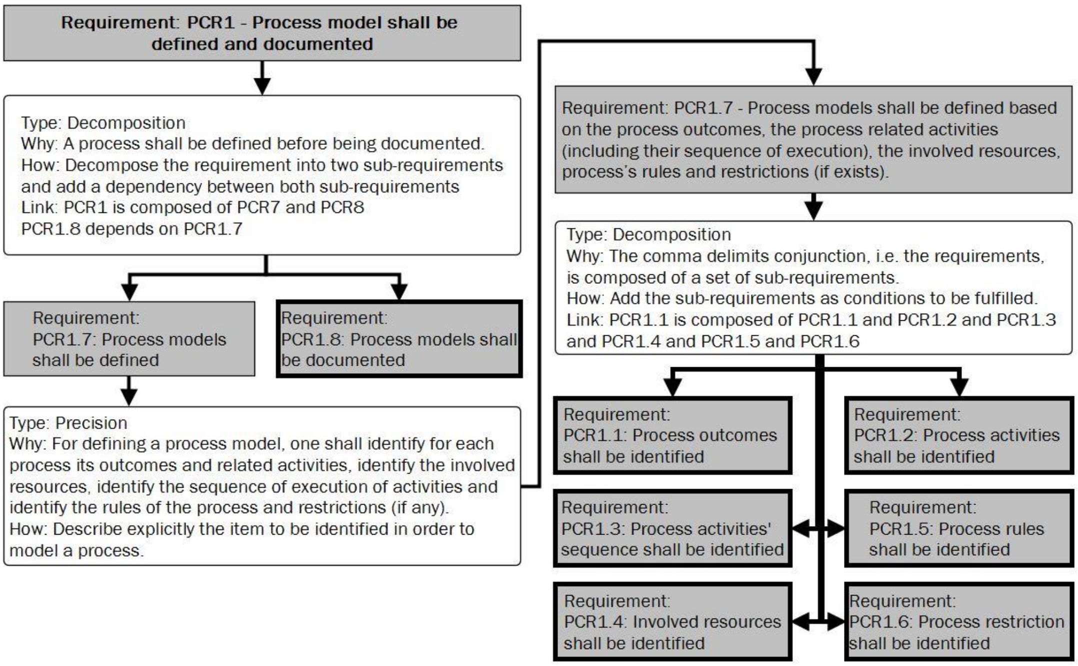


Fig. 20. Decomposition of the requirement PCR1

Table 19. Requirement PCR1

IR	PCR1: Process models shall be defined and documented
Interop. Area	Process-Conceptual
Maturity Level	Level 1 - Defined
Decomposition	PCR1.1: Process outcomes shall be identified PCR1.2: Process activities shall be identified PCR1.3: Process activities' sequence shall be identified PCR1.4: Involved resources shall be identified PCR1.5: Process rules shall be identified PCR1.6: Process restriction shall be identified PCR1.7: Process models shall be defined PCR1.8: Process models shall be documented
Formalisation	(((PCR1.1 ∧ (PCR1.2 ∪ PCR1.3) ∧ PCR1.4 ∧ PCR1.5) ∪ PCR1.6) ∪ PCR1.8) → PCR1

Table 20. Requirement POR1

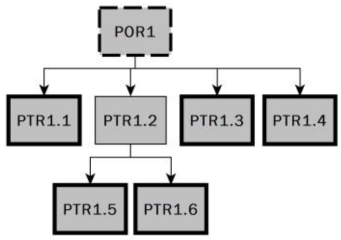
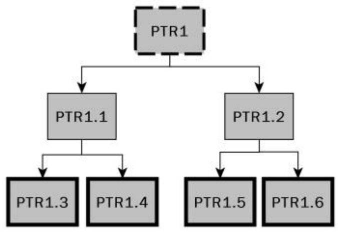
IR	POR1: Process responsibilities and authorities shall be defined and in place	**Simplified Pseudo-Requirement Graph**
Interop. Area	Process-Organisational	
Maturity Level	Level 1 - Defined	
Decomposition	POR1.1: Process responsibilities/authorities shall be defined POR1.2: Process responsibilities/authorities shall be in place POR1.3: Process responsibilities/authorities shall be assigned to actors (e.g. business unit and employee) POR1.4: Procedure for monitoring if responsibilities and authorities are being performed shall be defined POR1.5: Process management rules shall be defined POR1.6: Procedure for monitoring if process rules are being respected shall be defined	
Formalisation	(POR1.1 ∪ (POR1.5 ∪ POR1.6) ∧ (POR1.3 ∧ POR1.4)) → POR1	

Table 21. Requirement PTR1

IR	PTR1: IT devices supporting processes shall be in place and ad hoc exchange of information shall be possible	**Simplified Pseudo-Requirement Graph**
Interop. Area	Process-Technological	
Maturity Level	Level 1 - Defined	
Decomposition	PTR1.1: IT devices supporting processes shall be in place PTR1.2: Exchange of process information shall be possible PTR1.3: IT devices supporting processes shall be identified PTR1.4: IT devices supporting processes shall be implemented PTR1.5: IT devices supporting processes shall be connectable PTR1.6: Communication protocols between the IT devices supporting processes shall be defined	
Formalisation	((PTR1.3 ∪ PTR1.4) ∪ (PTR1.5 ∧ PTR1.6)) → PTR1	

3.2.4 Interoperability requirement architectural design

In the previous section, we identified the dependencies of IRs regarding their sub-requirements. Nevertheless, to identify and represent interdependencies between requirements from different interoperability areas, it is important to establish a sound and common understanding of the requirements relations to concerned enterprise elements (e.g. process models, information systems, etc.). For that reason, we investigate and identify these relations in this section.

To do so, we design a conceptual model as illustrated in Fig. 21 using the SysML notation (OMG, 2017a). The "*Enterprise*" class can be instantiated to any business organisation, hospitals, public administration, etc. The "*Enterprise Element*" is a class that can be generalised to any element that is relevant to the enterprise, e.g. an *Actor*, a *Software application*, a *Process*, a *Document*, etc. These generalisations are distinguished by two related powertypes: tangible and intangible elements. The "*Requirement*" is a class that can be instantiated to any *Interoperability Requirement*. To represent the relationships between requirement and a design element (e.g. enterprise system), we use the "satisfy" relationship to describe how a design or implementation model satisfies one or more requirements.

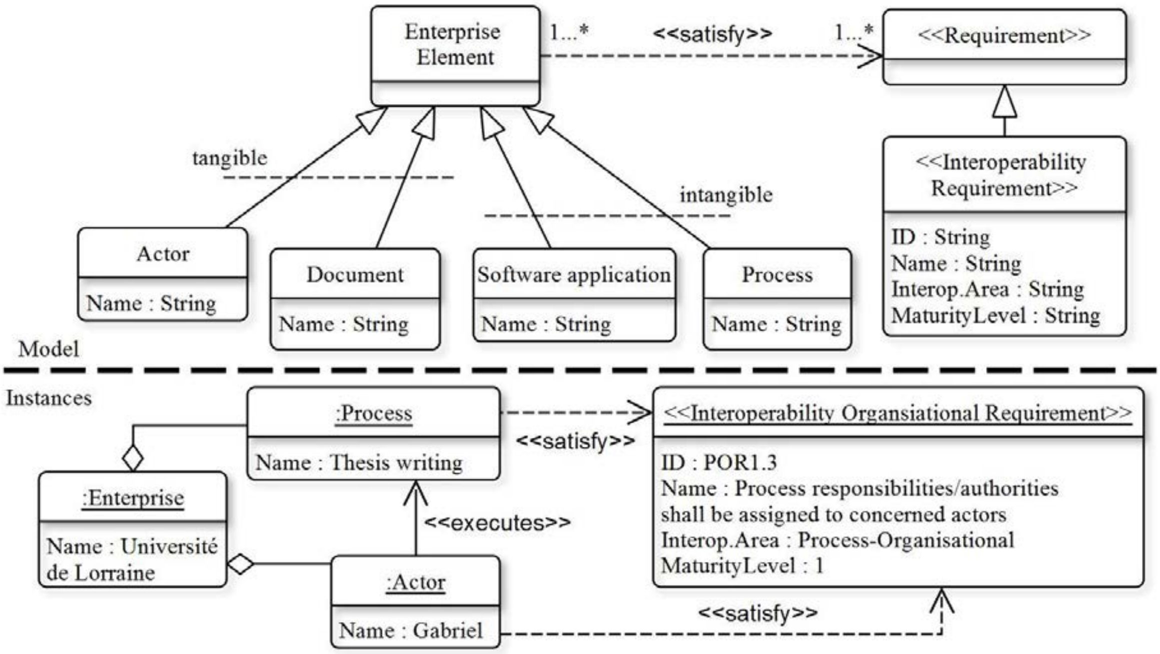


Fig. 21. Modelling IRs and enterprise elements relations

Fig. 21 also illustrates an instantiation example, considering the *Interoperability Requirement POR1.3: Process responsibilities/authorities shall be assigned to actors*, and the *Enterprise Elements* "*Gabriel*" as an *Actor* and "*Thesis writing*" as a *Process*. For relating an IR to enterprise elements, we follow the process described in Fig. 22.

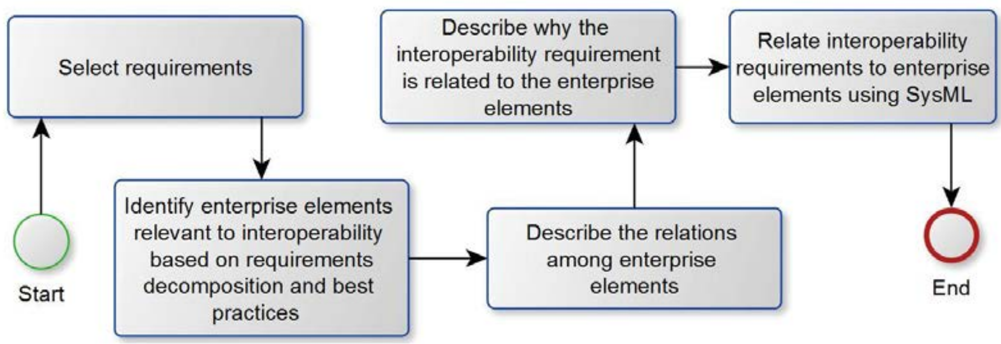


Fig. 22. The architectureal desing process

In the following, we elaborate on how we related the IRs from the Business-Conceptual and Business-Organisational interoperability areas to relevant enterprise elements.

Associating Business-Conceptual IRs to enterprise elements

Four IRs are associated to the Business-Conceptual interoperability area as shown in the Table 22.

Table 22. The IRs from the Business-Conceptual interoperability area

Interoperability Requirement	Decomposition	Best practices
BCR1: Business models shall be defined and documented	BCR1.1: Business model shall be defined BCR1.2: Business model shall be documented BCR1.3: Business' objectives shall be defined BCR1.4: Business strategy shall be defined BCR1.5: Business processes shall be defined BCR1.6: Business services shall be defined BCR1.7: Business rules shall be defined BCR1.8: Business hierarchy shall be defined BCR1.9: Business partners are defined BCR1.10: Clients shall be identified	1.1. Define business models Describe the business of the enterprise: patterns of the business activities, including its functions, objectives, services, main processes, politic, main partners 1.2. Document Business Model Add notes and descriptions to business model in order to be understood by any person using the model.
BCR2: Standards shall be used for alignment with other business models	BCR2.1: Standards used in the enterprise environment shall be identified BCR2.2: Standards shall be selected and used for modelling business	2.1. Identify relevant standards for interoperability Identify the frequently used standards and de facto standards in the enterprise environment (including partners, providers, clients, etc.). BC2.2. Use relevant standards for interoperability Relevant standards are used to facilitate alignment with other business models
BCR3: Business Models shall be designed for collaboration	BCR3.1 Core business subject to potential collaboration shall be identified BCR3.2: Preferred partners shall be identified BCR3.3: Potential collaborations shall be included in the defined business model BCR3.4: The documented business model shall be updated	3.1. Identify core business of the enterprise and the business that can be subject of collaboration 3.2. Identify preferred possible partners that enterprise can collaborate with, based on its requirement, the market and its past experiences
BCR4: Business models shall be adaptive	BCR4.1: Periodic review procedure shall be defined to adapt business model BCR4.2: Periodic review procedure shall be implemented to adapt business model BCR4.3: A reuse-centric strategy shall be adopted BCR4.4: Actors shall be aware of the adopted strategy BCR4.5:The reusable components in the company shall be identified	4.1. Define and implement periodic review procedure to adapt the business model to changing external environment. 4.2. Adopt a reuse-centric strategy and make the concerned actors aware of its importance 4.3. Identify the reusable components (e.g. a procedure, a model, a process, a service) in the company.

As we can observe based on the requirements in Table 22, the purpose of this interoperability area is to ensure main aspects of the concerned business models such as business goals, visions and strategies are defined documented and shared. It also ensures that business models are designed for collaboration with multiple partners and are adaptive regarding its environment. Indeed, a business model "*describes the manner that a business embodies a strategic vision and uses it to create and capture value from the service (or product). It can be associated to a logic or method that explains how an enterprise intends to create value for its customers*" (Solaimani and Bouwman, 2012). MMEI (Guédria et al., 2015) enumerates the following components of a business model that are relevant to the interoperability assessment: ***information*** *about strategy, politic, rules, hierarchy, objective, functions, services, processes* and *partners of the enterprise*. Hence, to ensure business interoperability, these components should be defined.

Moreover, the business model can be only understood by the person defining it i.e. the meaning of the business model is in the mind of the person who defines it, which leads to work on the tacit knowledge (Lezoche et al., 2012), (Guédria et al., 2015). To make information accessible, a business model should be documented and shared among the concerned stakeholders (e.g. enterprises, employees, etc.). A business model can be documented in many forms e.g. an electronic version in PDF, a printed document, etc. For ensuring semantic interoperability, one has to maximise the amount of explicit semantics in the represented models (Obrst, 2003). Besides, standards can be used in order to facilitate the semantic and syntactic alignment with other models in the case of interoperations with multiple partners. For ensuring and sustaining business interoperability, business models should be designed considering the enterprise environment and the potential internal and external collaborations. For that reason, existing and possible interactions with partners should be highlighted and explicitly defined in the considered business model for ensuring the business alignment (Solaimani et al., 2015). Considerations from all stakeholders shall be integrated a priori engaging collaborations.

Nevertheless, when collaborations are already happening, and new partners are involved, such business models should be adapted. An adaptive business model means that it can be modified without negatively affecting the business performance (Chesbrough, 2007), (Ricciardi et al., 2016). These modifications should be based on informed decisions (Proper, 2014). Therefore, periodic review procedures for monitoring the performance and evolution of business should be defined and in place. Such reviews allow to identify any difficulties and changes "on the fly", despite being internal to the enterprise or regarding the interactions between partners (Guédria et al., 2015). Fig. 23 illustrates the instantiation of some interoperability requirements and their relations to enterprise elements, based on the defined conceptual model in Fig. 21.

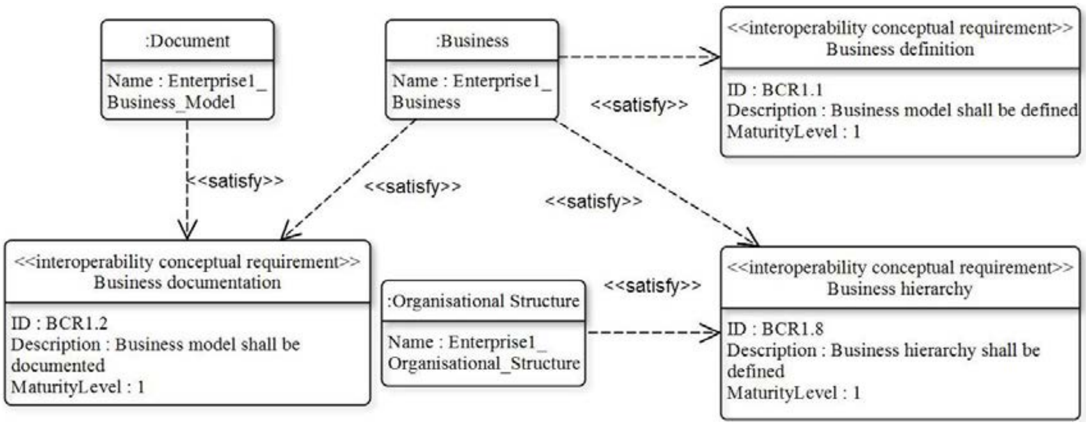


Fig. 23. A simplified view of Interoperability Requirements and their relations to Enterprise Elements: Requirements from the Business-Conceptual interoperability area

In Fig. 23 three instances of IRs are illustrated. These instances are *BCR1.1: Business model shall be defined*, *BCR1.2: Business model shall be documented* and *BCR1.8: Business hierarchy shall be defined*. These instances have also their attributes depicted. These attributes correspond to the requirement *ID*, the requirement *Description* and the associated *Maturity Level*. We also observe that each one of these requirements is related to an *Enterprise Element* trough an association "satisfy". The generalisations of the class *Enterprise Element* that are considered are: *Business*, *Document* and *Organisational Structure*. For clarity sake, we do not illustrate the element *Enterprise1*, which is an instantiation of the class *Enterprise*. Nevertheless, note that *Enterprise1_Business, Enterprise1_Business_Model* and *Enterprise1_Organisational_Structure* are elements that aggregate *Enterprise1*. Further, the requirement *BCR1.1* is related to the *Enterprise1_Business,* which is an instance of the class *Business*. The requirement *BCR1.8* is related to the *Enterprise1_Business* and to the *Enterprise1_Organisational_Structure.* Indeed, the organisational structure definition (or at least the main roles) is an essential part of a business. Finally, the requirement *BCR1.2* is related to the *Enterprise1_Business* and to a document called *Enterprise1_Business_Model*.

Associating Business-Organisational IRs to enterprise elements

Four IRs are associated to the Business-Organisational area as shown in the Table 23.

Table 23. The IRs from the Business-Organisational interoperability area

Interoperability Requirement	Decomposition	Best practices
BOR1: Organization structure shall be defined and in place	BOR1.1: The actors shall be identified BOR1.2: The actors have their responsibilities defined BOR1.3: The actors have their authorities defined BOR1.4: The relations between actors shall be defined BOR1.5: The structure shall be documented BOR1.6: Organization structure shall be put in place	1.1. Define organization structure: Define the different entities within the enterprise and relations between them. This includes Policies, contracts that bind two or more entities, roles played by each entity within the enterprise, etc. 1.2. Put in place the organization structure: The organization structure should be put in place: the defined departments exist, the relations between them are defined, the authorities that relies each one of them, etc.
BOR2: Human resources shall be trained for interoperability	BOR2.1: Training needs shall be identified BOR2.2: Trainings shall be offered to employees BOR2.3 Problematic situations shall be identified BOR2.4 Concerned employees shall be identified and trained BOR2.5 Employees shall be informed about problematic situation	2.1. Organize training sessions for interoperability 2.2. Anticipate problematic situations and inform employees what to do in case of problems.
BOR3: Organisation structure shall be flexible	BOR3.1: Delegation for main responsibilities shall be defined BOR3.2: Shall have more than one manager for a main responsibility BOR3.3: Employees shall be trained for polyvalence BOR3.4: Replacements shall be identified BOR3.5: Competence shall be managed	3.1. Define delegation for main responsibilities: Identify more than one manager for one responsibility (in case of absence); Trainings for polyvalence 3.2. Manage employees' competence: Identify who replaces each employee in case of departure; In case of a departure of an employee, the enterprise should manage this and the absence of this employee should not influence the enterprise business.
BOR4: Organisation structure shall be agile	BOR4.1: Methods for business agility shall be defined BOR4.2: Responsiveness to a new event shall be short BOR4.3: Business procedures shall be clear and simple	4.1. Define methods facilitating enterprise business agility: Describe what to do in case of business interoperability problems, how to react in case of introduction of a new partner, a new service, a new product, etc.; This includes also internal new events where the management of the human resources competences has to be ensured. 4.2. Shorten the delay of reaction to a new event 4.3. Make enterprise business procedures clearer and simpler

As we can see based on the requirements in Table 23, the purpose of the Business-Organisational is to ensure that the organisational structure is defined, put in place, flexible and agile. It also concerns ensuring that human resources are well trained for performing interoperations.

Hence, the organisational structure including the different actors (e.g. departments, person, etc.) and their relations are the object of evaluation when considering the interoperability assessment. This structure is represented and accessible through an Organisational chart, where at least the key actors are expressed. Legal agreements shall also be defined and agreed between concerned actors. For instance, contracts for formally describing roles (e.g. project manager, software developer) in order to preventing misinterpretations and explicating precisely what are the responsibilities and authorities of a role, thus of an actor. In the context of networked enterprises, legal agreements regarding the interaction between partners and intellectual property rights are necessary.

Each actor has one or multiple assigned roles, which should be fulfilled for ensuring the enterprise or network business performance. A business role is composed of all responsibilities and authorities concerning the enterprise business that an actor should respect. Competencies are also part of a business role as they are essential for executing correctly the defined business's services and processes.

Moreover, work methods including interoperability guidelines are also important to be defined and documented for dealing with anticipated and unanticipated events, which may cause interoperability problems. Therefore, the organisational structure should be agile. Agility here means the ability to rapidly perceive potential problems and opportunities in the considered environment, and act upon them without disturbing the business and collaboration performance. Fig. 24 illustrates the instantiation of some IRs and their relations to enterprise elements, based on the defined conceptual model in Fig. 21.

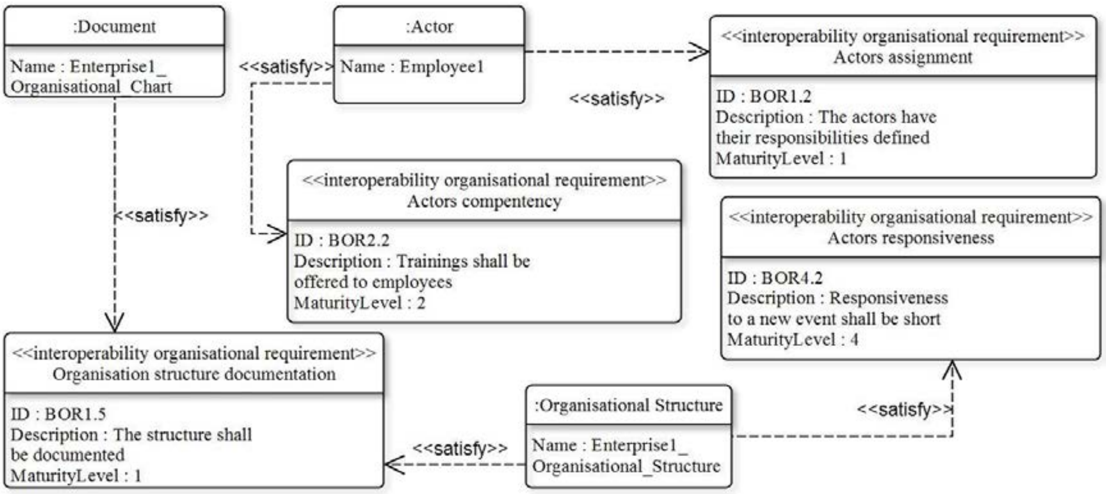


Fig. 24. A simplified view of Interoperability Requirements and their relations to Enterprise Elements: Requirements from the Business-Organisational interoperability area

In Fig. 24, four instances of IRs are illustrated. These instances are *BOR1.2: The actors have their responsibilities defined, BOR1.5: The structure shall be documented, BOR2.2: Training shall be offered to employees* and *BOR4.2: Responsiveness to a new event shall be short.* These instances have also their attributes depicted. These attributes correspond to the requirement *ID*, the requirement *Description* and the associated *Maturity Level*. The generalisations of the class *Enterprise Element* that are considered are: *Actor*, *Document* and *Organisational Structure*.

For instance, the requirement *BOR1.2* is related to the *Employee1*, an *Actor* of the Enterprise1. Note that this requirement should be related to all *Actors* of the Enterprise1. Indeed, responsibilities should be explicitly defined and shared (if possible). The requirement *BOR2.2* is also related to *Employee1*. This requirement ensures that *Actors* as *Employee1* receive appropriate training. Next, the requirement *BOR1.5* is related to both *Enterprise1_Organisational_Structure* and *Enterprise1_Organisational_Chart*, where the fulfilment of such a requirement guarantees that the *Organisational Structure* of the *Enterprise1* is defined and documented. Finally, *BOR4.2* is related to the *Enterprise1_Organisational_Structure* in order to ensure that such an organisational structure can be rapidly and smoothly changed, while businesses are conducted seamlessly.

3.2.5 Interoperability requirement interdependencies identification

Having the requirements decomposed and allocated to enterprise elements, we can identify the same or similar atomic requirements that are used by different requirements and addressed to the same enterprise elements. Based on these relationships, we define the IRs interdependencies. In addition, the formalised form of the requirements is also considered, especially those requirements that contains the U temporal connector (Emerson and Halpern, 1986) (see section 3.2.3). As an example, we describe hereinafter the interdependences focusing on the Business Interoperability Concern.

When considering the collaborative context, business models should be defined accordingly to the collaboration goals and semantic alignment across the network for avoiding misinterpretation (See IR *BCR3*). Besides, changes in business models can lead to changes in different enterprise elements, in a single enterprise or on multiple network partners.

An illustrative example could be a networked enterprise composed of three bookstores that want to improve their book delivery delays in order to increase their sales and client satisfaction. To do so, the enterprise responsible for the delivery decides to implement a new customer data processing system, focusing on the customer location information. It would imply the change of existing information systems and their interfaces, leading to the questions: Can the existing databases communicate with the new processing system? Can the information systems already in place in the other stores exchange information with the new system? Can employees learn easily and smoothly to operate the new system? Moreover, what will be the changes to the overall book delivery process? Hence, we can observe that such models have relations with the process and service concerns as they should be aligned with the business goals that are stated on the concerned business model.

When considering the agility and dynamicity of such model, i.e. how fast changes can be made and how flexible they are, various enterprise elements should be taken into account. For example, stakeholders desire to improve their performance in their market by seizing a collaboration opportunity.

However, for capturing and running such opportunities, enterprises should verify if their business supports collaboration as well as if their structures (be organisational or technological) are open to changes. In other words, in order to fulfil the requirements *BCR3: Business Models shall be designed for collaboration* and *BCR4: Business models shall be adaptive*, requirements from the Business-Organisational and Business-Technological interoperability areas should be considered.

Some of the identified interdependencies are depicted in Fig. 25. Note that we use the SysML notation (OMG, 2017a) to represent the relationships among requirements and relations between requirement and a design element (e.g. enterprise system). For instance, we use the "satisfy" relationship to describe how a design or implementation model satisfies one or more requirements. Further, for representing the dependencies between the requirements, we use the "deriveReqt" relationship defined a dependency between two requirements in which a client requirement can be derived from the supplier requirement. For example, a system requirement may be derived from a business need, or lower-level requirements may be derived from a system requirement. As with other dependencies, the arrow direction points from the derived requirement to the requirement from which it is derived. Finally, for representing the requirements' decomposition, we use the "containment" relationship, which enables a complex requirement to be decomposed into its containing child requirements (i.e. decomposed in their atomic-requirements) (OMG, 2017a).

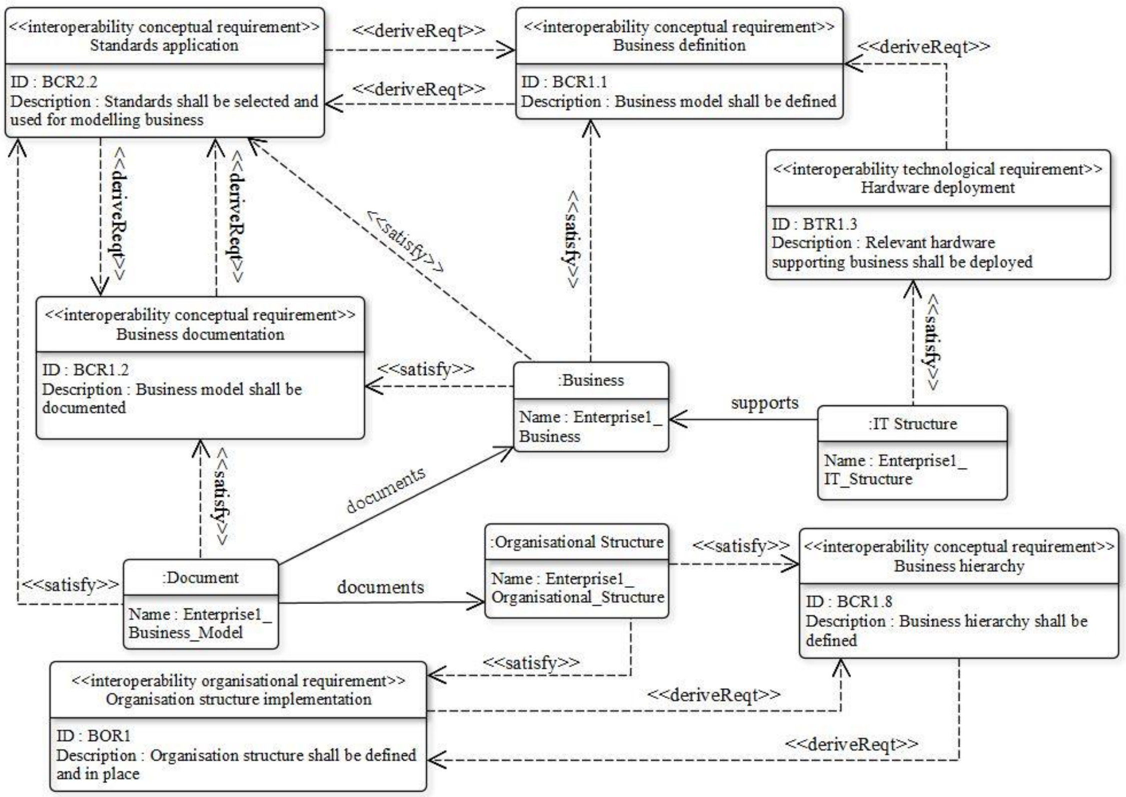


Fig. 25. The IRs interdependences using the SysML notation (OMG, 2017a)

In Fig. 25, we observe that *BCT1.8: Business hierarchy shall be defined* and *BOR1: Organisational structure shall be defined and put in place* are both related to the same *Enterprise Element*, which is the concerned *Organisational Structure*. From this relationship, we infer that these requirements are interdependent as both states that the organisational structure should be defined. The dependencies between these two requirements show that there is indeed at least one interdependency between Business-Conceptual and Business-Organisational interoperability areas. Further, we argue that the requirement *BCR1.1* shall be satisfied before deploying relevant hardware for supporting business (*BT1.3*). Thus, there is a dependency between *BTR1.3* and *BCR1.1*, which represents a relationship between the Business-Conceptual and Business-Technological areas.

Finally, we identify an interdependency among the requirements *BCR1.1*, *BCR1.2* and *BCR2.2*. Indeed, when the *BCR2.2* requirement should be considered while defining and documenting a business model. Nevertheless, a business model can still be defined and documented without a standard, but the potential to interoperability problems to occur is higher. Note that not all interdependencies regarding the illustrated IRs are depicted. For example, the dependency between *BCR1.2: Business models shall be documented* towards *BCR1.1: Business models shall be defined* is not explicitly illustrated.

Fig. 26 and Fig. 27 illustrate the requirements interdependencies based on requirements decomposition and formalisation done in Chapter 3.

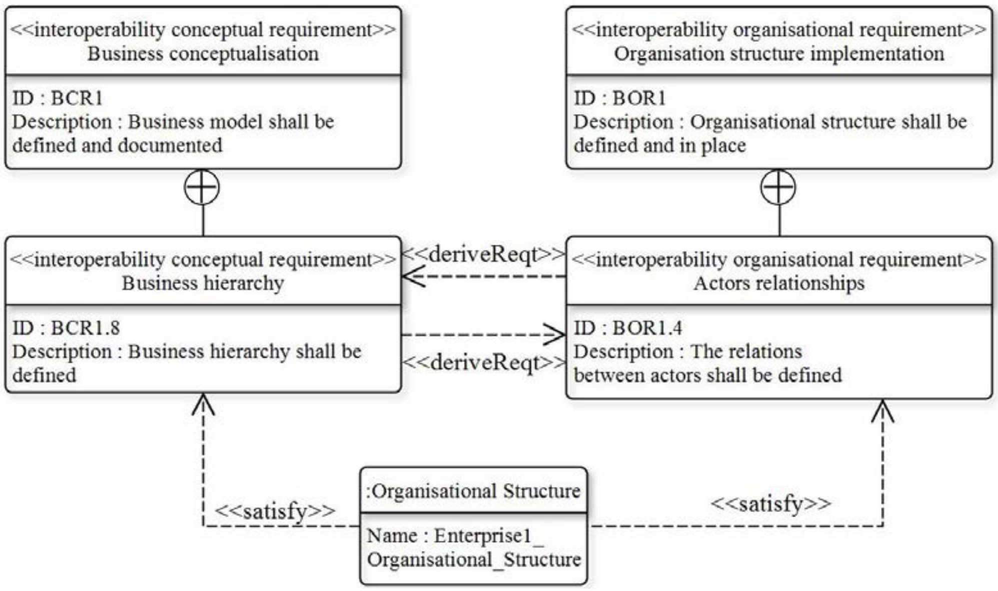


Fig. 26. The IRs interdependences based on the atomic requirements using the SysML notation (OMG, 2017a)

In Fig. 26, we observe that the atomic requirements *BCR1.8: Business hierarchy shall be defined* and the *BOR1.4: The relations between actors shall be defined* are related to the same enterprise element, which is the *Enterprise1_Organisational_Structure*. Based on their descriptions, we argue that they are similar to each other. Therefore, both atomic requirements are interdependent. This interdependency can be write as an AND (^) when writing using the first order logic.

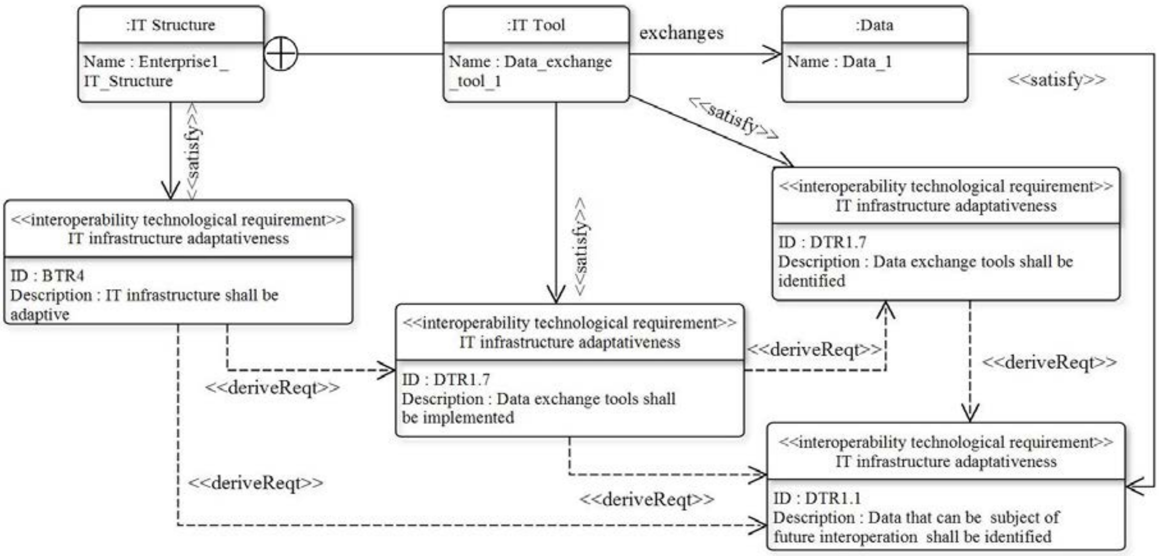


Fig. 27. The IRs interdependences based on the U logical connector using SysML notation (OMG, 2017a)

In Fig. 27, we observe that the requirement *BTR4: IT infrastructure shall be adaptive* requires that the atomic requirement *DTR1.7: Data exchange tools shall be implemented* is fulfilled. Taking into account the temporal dependencies (defined with the U connector) from the atomic requirement *DTR1.7*, we can argue that *BTR4* also requires the atomic requirement *DTR1.1: Data that can be subject of future interoperation shall be identified*.

As an example, Table 26 to Table 29 present the IRs from the *Business* Interoperability Concern from the maturity level 1. These tables presents the decomposition the concerned IR, the requirements that are required by the concerned IR and the requirements that require the concerned IR. In Annexe A, all of the IRs are listed.

Table 24. Requirement BTR1

IR	BTR1: Basic IT infrastructure shall be in place
Interoperability Area	Business-Technological
Maturity Level	Level 1 - Defined
Decomposition	BTR1.1: Relevant hardware supporting business shall be identified BTR1.2: Relevant software supporting business shall be identified BTR1.3: Relevant hardware supporting business shall be deployed BTR1.4: Relevant software supporting business shall be deployed
Requires	BCR1.3: Business strategy shall be defined BCR1.5: Business processes shall be defined BCR1.6: Business services shall be defined DCR1.1 Tools for handling data models shall be identified
Is required by	BTR2: Standard-based and configurable IT infrastructure shall be used BTR3: IT infrastructure shall be open BTR4: IT infrastructure shall be adaptive

Table 25. Requirement BOR1

IR	BOR1: Organization structure shall be defined and in place
Interoperability Area	Business-Organisational
Maturity Level	Level 1 - Defined
Decomposition	BOR1.1: The actors shall be identified BOR1.2: The actors have their responsibilities defined BOR1.3: The actors have their authorities defined BOR1.4: The relations between actors shall be defined BOR1.5: The structure shall be documented BOR1.6: Organization structure shall be put in place
Requires	BCR1.4: Business hierarchy shall be defined BCR1.5: Business processes shall be defined BCR1.6: Business services shall be defined POR1.2: Process responsibilities/authorities shall be defined SOR1: Service responsibilities and authorities defined and put in place DOR1: Responsibilities and authorities shall be defined and in place
Is required by	BCR4: Business models shall be adaptive BCR1: Business models shall be defined and documented BOR2: Human resources shall be trained for interoperability BOR3: Organisation structure shall be flexible BTR3: IT infrastructure shall be open POR1: Process responsibilities and authorities shall be defined and in place

Table 26. Requirement BCR1

IR	BCR1: Business models shall be defined and documented
Interoperability Area	Business-Conceptual
Maturity Level	Level 1 - Defined
Decomposition	BCR1.1: Business model shall be defined BCR1.2: Business model shall be documented BCR1.3: Business' objectives shall be defined BCR1.4: Business strategy shall be defined BCR1.5: Business processes shall be defined BCR1.6: Business services shall be defined BCR1.7: Business rules shall be defined BCR1.8: Business hierarchy shall be defined BCR1.9: Business partners are defined BCR1.10: Clients shall be identified
Requires	BOR1.1 Organisation structure shall be defined
Is required by	BOR1: Organization structure shall be defined and in place BCR2: Standards shall be used for alignment with other business models BCR3: Business Models shall be designed for collaboration BTR1: Basic IT infrastructure shall be in place BTR2: Standard-based and configurable IT infrastructure shall be used PTR2: Standard-based IT tools shall be used BOR2: Human resources shall be trained for interoperability BCR4: Business models shall be adaptive DCR3:Meta-modeling for multiple data model mappings DCR2:Use of standards for alignment with other data models DTR2: Automated access to data based on standard protocols PCR1: Process models shall be defined and documented SCR1: Service models shall be defined and documented

Table 27. The requirement PTR1

IR	PTR1: IT support for processes shall be in place and Ad hoc exchange of information shall be possible
Interoperability Area	Process-Technological
Maturity Level	Level 1 - Defined
Decomposition	PTR1.1: Process IT tools shall be identified PTR1.2: Process IT tools shall be implemented PTR1.2: Exchange of process information shall be possible
Requires	BTR1: Basic IT infrastructure shall be in place DTR1.4: Data storage tools shall be implemented DTR1.7: Data exchange tools shall be implemented
Is required by	PTR2: Standard-based IT tools shall be used PTR3: Platforms and tools for collaborative processes shall be in place

Table 28. The requirement PCR1

IR	PCR1: Process models shall be defined and documented
Interoperability Area	Process-Conceptual
Maturity Level	Level 1 - Defined
Decomposition	PCR1.1: Process outcomes shall be identified PCR1.2: Process activities shall be identified PCR1.3: Process activities' sequence shall be identified PCR1.4: Involved resources shall be identified PCR1.5: Process rules shall be identified PCR1.6: Process restriction shall be identified PCR1.7: Process models shall be defined PCR1.8: Process models shall be documented
Requires	BTR1: Basic IT infrastructure shall be in place BOR1.1: The actors shall be identified PTR1.1: Process IT tools shall be identified BCR1.5: Business processes shall be defined DCR1.12 Semantics of each concept and attribute shall be defined POR1: Process responsibilities and authorities shall be defined and in place SCR1: Service models shall be defined and documented
Is required by	PCR2: Standards shall be used for alignment with other process models PCR3: Meta-Models for multiple process mapping shall be defined PCR4: Process modelling supports dynamic re-engineering POR2: Procedures for process interoperability shall be in place POR4: Process shall be monitored and procedures shall be adaptive

Table 29. The requirement POR1

IR	POR1: Process responsibilities and authorities shall be defined and in place
Interoperability Area	Process-Organisational
Maturity Level	Level 1 - Defined
Decomposition	POR1.1: Process responsibilities/authorities shall be defined POR1.2: Process responsibilities/authorities shall be in place POR1.3: Process responsibilities/authorities shall be assigned to actors (e.g. business unit and employee) POR1.4: Procedure for monitoring if responsibilities and authorities are being performed shall be defined POR1.5: Process management rules shall be defined POR1.6: Procedure for monitoring if process rules are being respected shall be defined
Requires	PTR1.1: Process IT tools shall be identified BOR1.1: The actors shall be identified PCR1.4: Involved resources shall be identified DOR1: Responsibilities and authorities shall be defined and in place SOR1: Service responsibilities and authorities defined and put in place
Is required by	POR2: Procedures for process interoperability shall be in place POR3: Cross-Enterprise collaborative management is put in place POR4: Process shall be monitored and procedures shall be adaptive

3.3 Discussion on how to improve the Maturity Model for Enterprise Interoperability

Besides the advantages of using the relationships of IRs interdependencies for identifying impacts on the overall system, the defined IRs, their atomic-requirements and relations are also useful for improving other parts of the INAS process. Therefore, in this section, we discuss the preparation of questionnaires to be used during the information-gathering phase. It will be followed by a discussion on how to use the MMEI in the compatibility assessment.

3.3.1 Preparing questionnaires

Once the scope of the assessment is defined, the questionnaires used during interviews can be designed. We assert that the defined atomic-requirements can support the design of such questionnaires. For instance, based on the chosen layers and concerns to be considered, a set of related IRs is identified, which are used as Interoperability Evaluation Criterion (IEC). The atomic-requirements composing the considered IR can be used as the basis for formulating the relevant questions to be inserted in the questionnaires.

Note that the number of questions does not need to be equal to the number of atomic-requirements, i.e. a question can cover multiple atomic-requirements, or various questions can cover the same atomic-requirement. In this way, the design of the questionnaire is more flexible, allowing the adaption of the questions regarding the enterprise environment, the assessor expertise, the purpose of the assessment and so on.

Fig. 28 illustrates the relations between questions and atomic-requirements, and Table 30 presents an example of the questions related to the process concern.

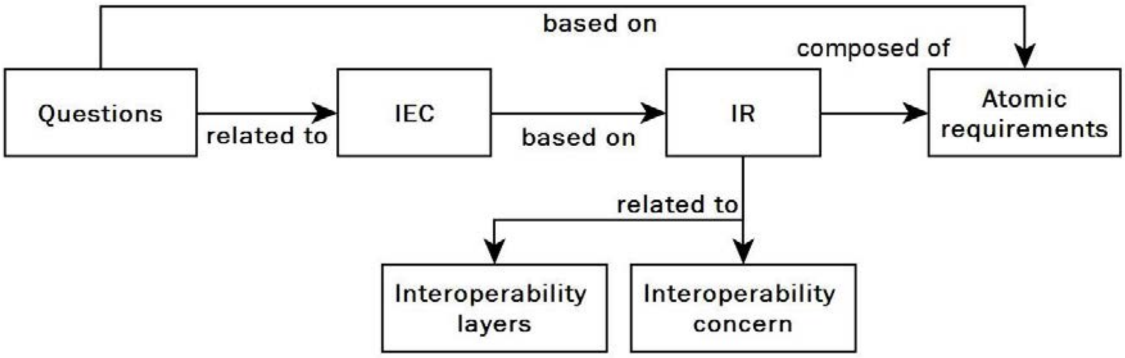


Fig. 28. Relating questions to atomic-requirements

Table 30. Example of questions

Question	Related IEC	Based on atomic-requirements
What are the key resources required to perform the concerned process?	Process models are defined and documented	PCR1.4: Involved resources shall be identified
Is the information regarding resources documented?	Process models are defined and documented	PCR1.8: Process models shall be documented
Who has access to this document?	Process responsibilities and authorities are defined and in place	POR1.1: Process responsibilities/authorities shall be defined POR1.3: Process responsibilities/authorities shall be assigned to actors
Are the responsibilities of each employee well defined regarding the process execution?	Process responsibilities and authorities are defined and in place	POR1.1: Process responsibilities/authorities shall be defined POR1.3: Process responsibilities/authorities shall be assigned to actors
Are the authorities of each employee well defined regarding the process execution?	Process responsibilities and authorities are defined and in place	POR1.1: Process responsibilities/authorities shall be defined POR1.3: Process responsibilities/authorities shall be assigned to actors

3.3.2 Using MMEI for the compatibility assessment

As the MMEI is defined based on a systemic approach, we argue that such a model can also be used during a compatibility assessment. For instance, when defining the assessment scope and the used questionnaires, the concerned business network should be considered as the object of assessment. For example, the question *"Are the responsibilities of each employee well defined regarding the process execution?"* will refer to all employees involved in the concerned collaborative processes, despite their enterprise of origin. Even if the majority of the involved enterprises have a well-defined organisational structure but one of the partners does not (e.g. no point of contact is explicitly defined), the interoperation within the network will be difficult. Consequently, the related IR is not fulfilled.

Note that these compatibility verifications can be done regarding all types of interoperability barriers and concerns. For example, let us take the IR "*PCR1: Process models shall be defined and documented*". Considering that all involved enterprises have defined and documented their processes, but using different modelling languages (e.g. BPMN and UML), the interoperation between processes will also be difficult. However, if they have an IT application that serves as a mediator for translating each process model to a correspondent language (relate to the IR "*PTR3: Platforms and tools for collaborative processes shall be in place"*) or if they are using meta-models for mapping their existing process model (related to the IR "*PCR3: Meta-Models for multiple process mapping are defined"*), the interoperability between them can be ensured.

Therefore, when performing a compatibility assessment, assessors should consider the whole business network as the object of assessment and take into account the relationships between the IRs. The compatibility assessment *per se* is done by checking if the IR fulfilled individually during the potentiality assessment, is met in the same or similar way by the concerned enterprises. Table 31 depicts an example of assessment indicators for both potentiality and compatibility assessments regarding the same requirement "*DCR1: Data models shall be defined and documented*".

Table 31. An example of an interoperability requirement and its assessment indicators.

Interoperability Area	Data-Conceptual
IR	DCR1: Data models shall be defined and documented
Potentiality Indicator	Assessors have to verify to which extent data models are defined and documented. For that, they have to see the documents defining data models, information exchanged, etc. If yes, look at (a) the formalism level of the models (depending on the modelling language used, if any); and (b) level of detail and understandable of models description and explanations.
Compatibility Indicator	Assessors have to verify to which extent data models are defined, compatible and documented. For that they have to see if: (a) the data used by enterprise systems to perform services/applications and processes to ensure collaborative business are defined; (b) the data semantics are agreed to avoid differences in terminologies with regard to the business area that enterprise systems share, so that differing terms in different systems do not create operational difficulties; and (c) the data models are documented (e.g. Reference Models, Dictionaries, Glossaries, Taxonomies, Ontology, UML, etc.) using similar or compatible formats.

Having verified all the concerned IRs, the degree of interoperability between the considered systems depends on their IRs compatibility. For example, let us consider that enterprise E1 has achieved the maturity level 3 and enterprise E2 has achieved maturity level 4. The solutions implemented from both enterprises for achieving all the IRs from level two are compatible. However, the requirement "*PTR3: Platforms and tools for collaborative processes shall be in place*" is fulfilled differently by the considered enterprises, e.g. their process management systems does not support information exchange among them. Hence, both enterprises "failed" to achieve the maturity level 3 together. It means that the considered maturity level is two. In the case where more than two enterprises are considered, the maturity level will be the lower identified level. Fig. 29 illustrates the example described hereinabove.

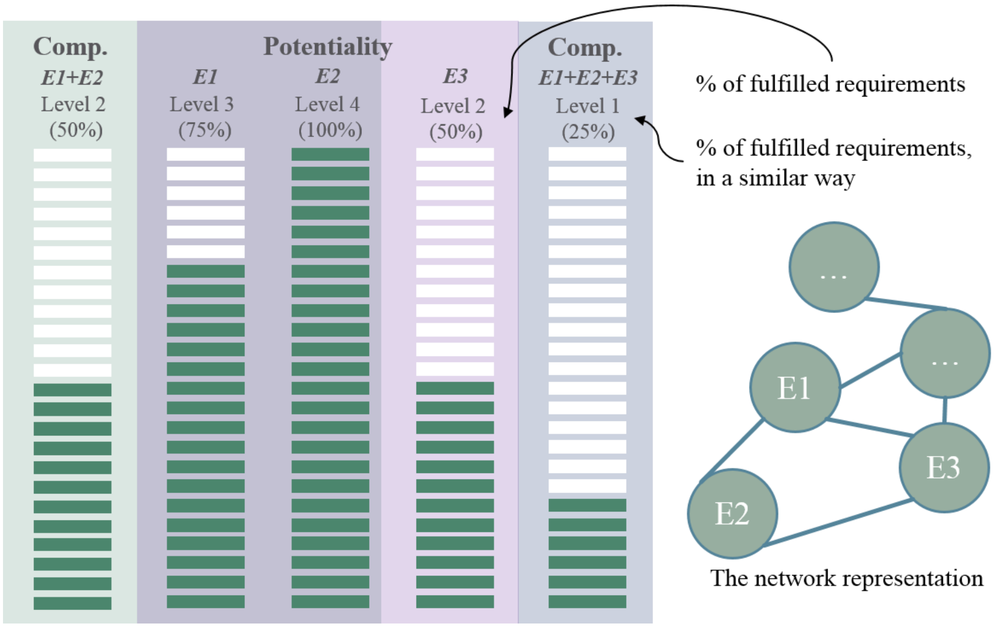


Fig. 29. Examples of the maturity level determination in the compatibility assessment

Chapter 4

Towards an ontology-based system for interoperability assessment

Introduction

When carefully investigating the existing related Interoperability Assessment (INAS) literature (see Chapter 2), we identified that the majority of the INAS approaches is manually-conducted, which is a laborious and time-consuming process and in many cases depends on the "subjective" knowledge of experts (Alalwan and Thomas, 2012), (Krivograd and Fettke, 2012). Few of the studied approaches propose computer-mediated tools for supporting the assessment and decision-making processes.

Indeed, computer-mediated systems for supporting assessment processes enhance a stakeholder's ability to analyse the system's current state and to make improvement decisions (Krivograd and Fettke, 2012), (Leal et al., 2017c). In some instances, it is necessary to incorporate the knowledge that resides in human experts when developing these systems. The system that integrates such knowledge is called Knowledge-Based System (KBS) (Dhaliwal and Benbasat, 1996), (Turban et al., 2004), (Phillips-Wren et al., 2009).

Indeed, a KBS can identify change opportunities and support decision making, based on a knowledge model, by recommending the appropriate knowledge for the deployment of solutions for a given problem (Power, 2004). An essential component of such systems is its knowledge model, which is committed to some conceptualisation, explicitly or implicitly. A conceptualisation is an abstract, simplified view of the world that we wish to represent for some purpose (Gruber, 1995).

In recent years, numerous KBS are empowered by computer readable ontologies (which are an explicit specification of a conceptualisation (Gruber, 2009)) as a knowledge model. According to the literature, the advantages of using an ontological approach for developing a knowledge model are the following: It establishes a common foundation for sharing contextual knowledge across various users, facilitates common domain understanding and offers users more accurate, proper and comprehensive knowledge (Chandrasekaran et al., 1999), (Li et al., 2011), (Giovannini et al., 2012), (Alalwan and Thomas, 2012), (Tarhan and Giray, 2017), (Leal et al., 2017c).

Therefore, in this chapter, we design and develop a KBS based on an ontology for supporting the INAS process. In the first part of this chapter, we study the KBS domain, focusing on the ontology-based systems. Furthermore, we define an approach for developing such a KBS and the ontology based on the development methodologies proposed by (Noy and McGuinness, 2001), (Horridge et al., 2004) and (Krivograd and Fettke, 2012). In the second part, we design and implement the Ontology of Interoperability Assessment (OIA). This ontology formally conceptualises the knowledge of INAS. It includes the interoperability requirements and their interdependencies as well as interoperability problems and related solutions. Finally, in the third part, we present the prototyping of the proposed KBS using OIA as its knowledge model. The KBS's architecture and its functionalities are also described. The resulting system is able to exploit knowledge about interoperability issues and information from the current state of the assessed enterprises for identifying potential problems and improvements.

4.1 Knowledge-Based Systems and ontologies

A "Knowledge-Based System" 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 et al., 2004). Such knowledge can be reasoned and inferred for arriving at specific conclusions. Table 32 presents two comparisons for highlighting the advantages of a KBS. The first comparison is done between KBS and a human expert, and the second between a KBS and a non-KBS.

Table 32. Comparisons between Human experts, KBS and non-KBS. Adapted from (Turban et al., 2004)

KBS	Human Expert
Knowledge is stored 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 it.
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

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

Regarding the potential technologies to be adopted for building the knowledge model, a comparison between ontologies and relational databases are presented by (Chandrasekaran et al., 1999). The authors conclude that relational databases require specialisation and integration procedures, and they are single-oriented-purpose, and ontologies provide a restriction-free framework to represent a machine-readable reality. In (Tarhan and Giray, 2017), a review focusing on process assessment software tools identified the following benefits from using ontologies: reduction in time, cost, and effort for software process data collection, validation, process attribute rating, and reporting.

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 (Gruber, 2009). Therefore, an ontology which is developed as a knowledge model to a

KBS must describe meaning in a machine-readable way, i.e. besides specifying a precise vocabulary, it should also include the means to formally define it for supporting automated reasoning (Gruber, 2009).

In KBS, two types of ontology specification can be identified (Chandrasekaran et al., 1999): (i) Domain factual knowledge providing knowledge about the objective realities in the domain of interest and (ii) Problem-solving knowledge providing knowledge about how to achieve various goals. A piece of this knowledge might be in the form of a problem-solving procedure (e.g.; best practices) specifying (in a domain-independent manner) how to achieve a class of objectives.

As a result of considering the studied related work, we can summarise that the advantages of using ontologies as knowledge models are: preventing semantical problems (Gruber, 2009); establishing a common foundation for sharing contextual knowledge (Alalwan and Thomas, 2012), (Li et al., 2011); enabling the formal representation of a domain knowledge in a computer-readable way (Gruber, 2009).

4.2 An approach for developing a KBS using an ontology as knowledge model

The KBS development approach used in this research is defined based on the ontology development methodologies proposed by (Noy and McGuinness, 2001) and (Horridge et al., 2004) and the tool development requirements defined by (Krivograd and Fettke, 2012).

(Noy and McGuinness, 2001) proposes a seven steps guide for designing ontologies: (1) Determine the domain and scope of the ontology; (2) Consider reusing existing ontologies; (3) Enumerate important terms in the ontology; (4) Define the classes and the class hierarchy; (5) Define the properties of classes and datatypes; (6) Define the facets of the datatypes; and (7) Create instances. (Horridge et al., 2004) provides an extensive guide on how design and implement an ontology using the Ontology Web Language (OWL) in the Protégé tool (Musen, 2015). Finally, (Krivograd and Fettke, 2012) defines 15 requirements for developing a generic computer-mediated assessment system as described in Table 33 and Table 34.

Table 33. Requirements for developing a generic computer-mediated assessment system

Requirement		Description
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

Table 34. Requirements for developing a generic computer-mediated assessment system (Continued)

	Requirement	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.

Based on these methodologies, we define an iterative approach having four phases. These phases and the fulfilment of each one of them are described hereinabove and illustrated in Fig. 30.

Phase 1 - Determine the domain and scope. This phase refers to the scope definition. Based on the discussed INAS approaches limitations, we propose a KBS concerning the interoperability assessment in the context of the networked enterprises. The objectives envisioned are: (i) to provide a sound description of all relevant concepts, relationships, and reasoning rules related to interoperability assessment, (ii) to provide the ability to infer potential problems and transformations that an enterprise can face, based on interoperability requirements interdependencies checking, and (iii) 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 (interoperability, system requirement engineering and assessment), in order to identify relevant concepts to be taken into account while assessing interoperability. 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. The INAS approaches reviewed in Chapter 2 are also taken into account.

Phase 3 - Develop Ontology. Based on the gathered information, we design a Assessment MetaModel, which contains the general concepts of a system assessment. Next, we design the Interoperability Assessment Model, which contains the specific concepts related to an Interoperability Assessment. To implement the ontology, we adopt the OWL (Horridge et al., 2004) as it is an open standard for semantic knowledge representation. The tool used for modelling and building the OIA is the Protégé 5.2 (Musen, 2015). We adopt the Semantic Web Rule Language (SWRL) (Horrocks et al., 2014) for expressing the inference rules included in the ontology. Such rules are used for reasoning the stored knowledge against the information provided by the assessors.

Phase 4 - Prototype the KBS. This phase is divided in three steps: (i) Definition of the KBS functionalities; (ii) Design of the KBS prototype architecture for ensuring the defined functionalities;

and (iii) Definition of the assessment process based on the KBS. For developing the KBS, we consider the requirements defined by (Krivograd and Fettke, 2012).

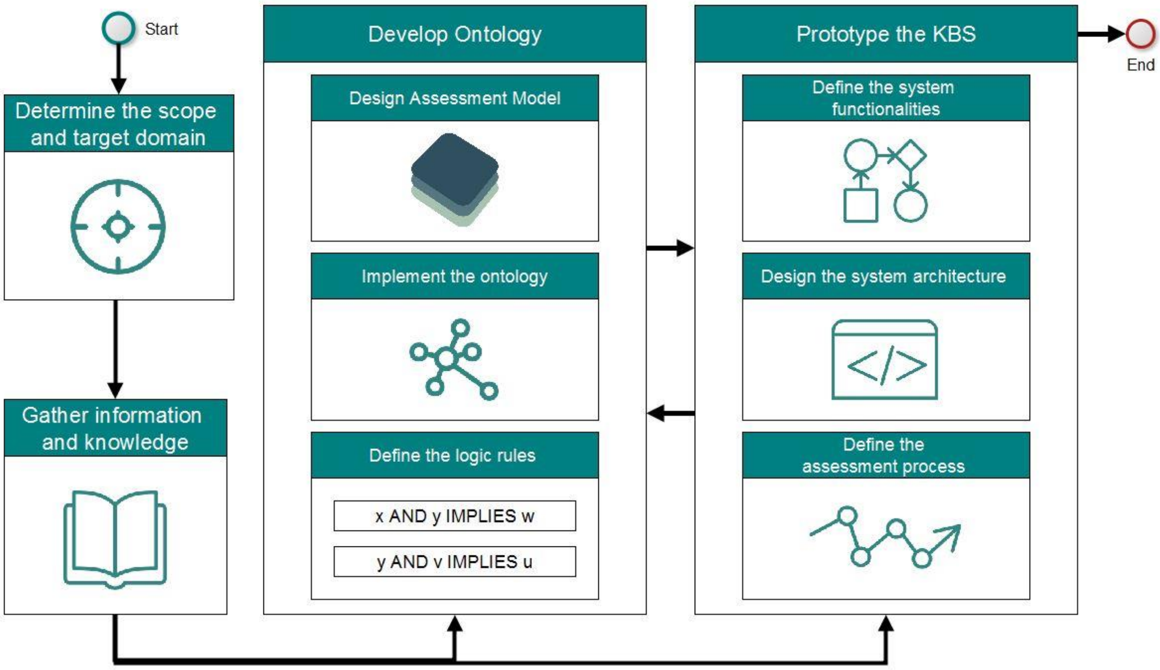


Fig. 30. The approach for developing a KBS based on an ontology

Note that phase 1 is already carried out in both Chapters 1 and 2. Therefore, the next three following sections covers the information gathering (phase 2), the development of the OIA (phase 3) and the prototyping of the KBS (phase 4).

4.3 Gathering information and knowledge

4.3.1 Investigating and selecting concepts related to a system

In this section, we explore the basic definitions of a system and we investigate the existing Model-Based System Engineering (INCOSE, 2015) techniques for modelling systems.

System and System of Systems: basic definitions and characteristics

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*" (von Bertalanffy, 1968). Based on the GST and research advancements, various works and standards were proposed for characterising, modelling, developing a system. For instance, Table 35 shows a non-exhaustive list of system's definitions.

Table 35. System definitions

Reference	Definition
(von Bertalanffy, 1968)	A set of interconnected parts, having properties that are richer than the sum of the parts' properties.
(Ackoff, 1971)	A set of interrelated elements.
(ISO 15704, 2000)	A collection of real-world items organised for a given purpose.
(ISO 9000, 2015)	A set of interrelated or interacting elements.
(INCOSE, 2015)	An integrated set of elements, subsystems, or assemblies that accomplish a defined objective.

Considering these definitions, we note that all of them agree that a system can be seen as a set of interrelated elements. However, when considering a System of Systems (SoS), there is still not a consensus. Various researchers and practitioners tried to characterise a SoS in the past years. Table 36 presents some of the proposed definitions of a SoS.

Table 36. System of Systems definitions

Reference	Definition
(Maier, 1998)	An assemblage of components that individually may be regarded as systems.
(Krygiel, 1999)	A set of different systems so connected or related as to produce results unachievable by the individual systems alone
(DeLaurentis and Callaway, 2004)	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)	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)	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 characterises of a SoS found in the literature (Maier, 1998), (DeLaurentis and Callaway, 2004), (Boardman and Sauser, 2006), (Auzelle, 2009) can be summarised as:

- **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.

Model-Based System Engineering approaches

In general, a model can be seen as "*an abstraction or representation of a system*" (ISO 15704, 2000). 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. Thus, the model must be scoped to address its intended purpose (INCOSE, 2015).

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*" (INCOSE, 2015). 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 (Kordon et al., 2007), the Object-process methodology (OPM) defined by (Dori 2011), the Model-Driven Architecture methodology from Object Management Group (OMG) (OMG, 2014a) and the System Engineering Model-Driven (SEMD) pattern defined by (Morel et al., 2007).

Moreover, some research focuses on the interoperability domain specifically. For example, (Elvesæter et al., 2006) proposes an interoperability framework for a model-driven development of software systems, (Mordecai et al., 2018) defines a model-based interoperability engineering process for System of Systems focusing on the civil aviation, and (Touzi et al., 2007) proposes a model-driven approach to design collaborative information system.

Among them, we adopt the SEMD pattern (Morel et al., 2007) as it proposes a pattern for the system of enterprise-systems design in a higher level of abstraction. The defined concepts facilitate the modelling and instantiation of systems and SoS in the enterprise context. **Fig. 31** depicts an extract of the SEMD meta-model. The description of the meta-model is given hereinafter.

In Fig. 31, 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*. The *Engineering System* is to derive the composite pattern and to instantiate generic models for a specific project. The *Engineered System* as result of an *Engineering System* is emerging from a contextual whole, which is the atomic relationship between the environment and the desired finality. Such *Engineering System* produces a desired system (i.e. *Engineered System*) by putting in place *Systems Engineering* practices to transform *Initial Requirements* to Technical ones. The System of Systems Engineering (*SoSE*) refers to the practices for defining such *SoS*.

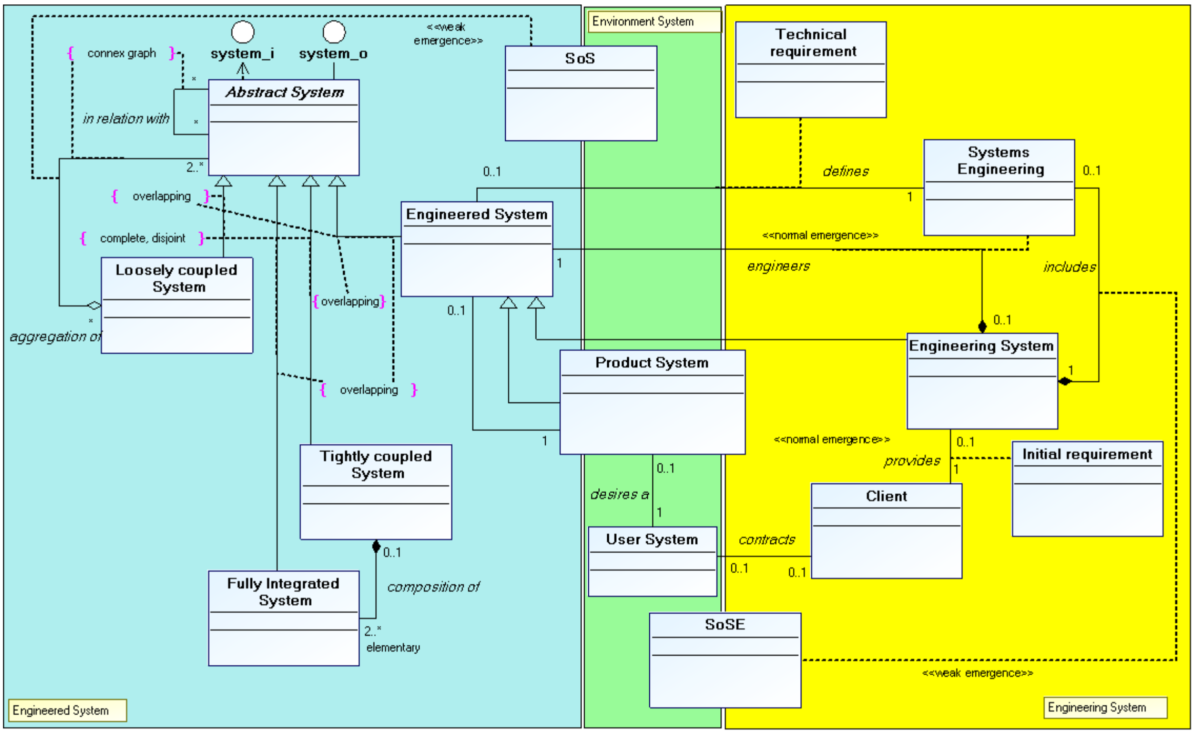


Fig. 31. The System Engineering Model-Driven pattern (Morel et al., 2007)

4.3.2 Investigating and selecting concepts related to an assessment process

Among the reviewed literature, we chose relevant work to use as basis for this research work, such as: the SEMD pattern (Morel et al., 2007) as it provides a meta model containing the main concepts related to a system and a SoS; the OoEI (Naudet et al., 2010) as it formally describes the system's concepts and their relations, regarding interoperability; and the MMEI (Guédria et al., 2015) as it explicitly defines evaluation criteria and a process for performing an INAS. It was also taken into account the fact that both OoEI and MMEI are rooted in the same interoperability framework and standard, which is the FEI (ISO 11354-1, 2011) (Chen, Dassisti, Elvesaeter et al., 2007).

We look in this section in more detail on four well-known and industry applicable standards regarding an assessment process, that are: The ISO 9000 (ISO 9000, 2015) family of standards, which is produced to help enterprises to evaluate the quality of systems; The ISO/IEC 33000 (ISO/IEC 33001, 2015) family (the predecessor of the ISO 15504 family (ISO/IEC 15504-1, 2004)) provides overall information of the employment of process assessment for evaluating the achievement of process quality characteristics; The Capability Maturity Model Integration (CMMI) framework (CMMI Product Team, 2010a, 2010b, 2010c), 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) (ISACA, 2012) 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 (ISO 9000, 2015). 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 thesis. 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"* (ISO 9000, 2015). Fig. 32 depicts the main concepts relating to an audit and their definitions.

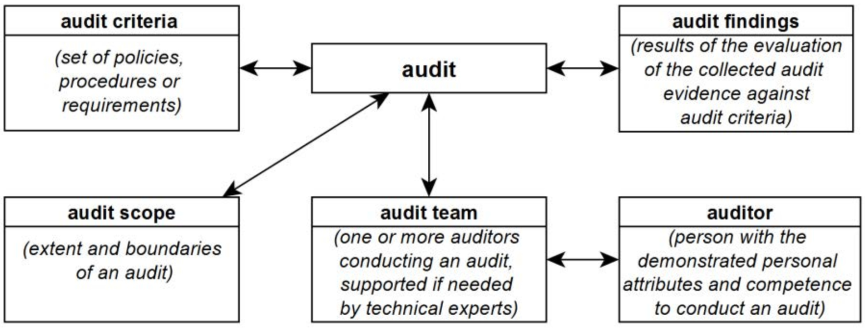


Fig. 32. Audit related concepts. Adapted from (ISO 9000, 2015)

Besides the concepts related to an audit, this standard provides definitions considering the quality characteristics and requirements of a system as illustrated in Fig. 33.

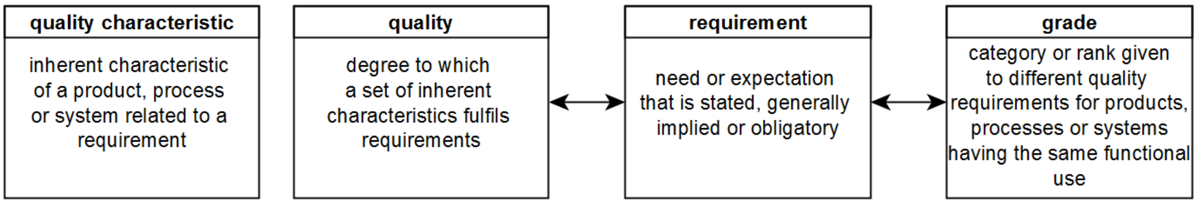


Fig. 33. Requirement related concepts. Adapted from (ISO 9000, 2015)

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 (ISO/IEC 33001, 2015).

This standard describes the main elements of a process assessment processes such as the assessment framework (including the measurement mechanisms, the assessment requirements etc.). Fig. 34 illustrates the main elements of such process and their relations.

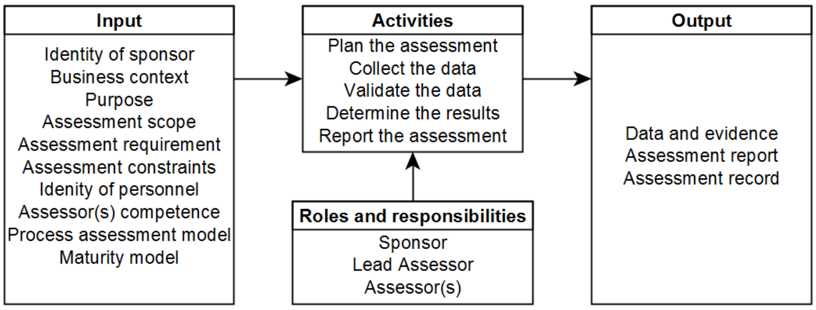


Fig. 34. Elements of the process assessment process. Adapted from (ISO/IEC 33001, 2015)

Table 37 summarises the most relevant concepts for this thesis from both ISO 9000 and ISO/IEC 33001. We also observe that the perspective regarding an assessment/audit is very similar between these two standards. Indeed, eight of the fifteen identified concepts are present in both standards.

Table 37. Synthesising the similarities between ISO 9000 and ISO/IEC 33001

ISO 9000: 2015		ISO 33001: 2015	
Concept	**Description**	**Concept**	**Description**
System	Set of interrelated or interacting elements	-	-
Requirement	Need or expectation that is stated, generally implied or obligatory	-	-
Audit Criteria	Set of policies, procedures or requirements	-	-
Audit	Systematic, independent and documented process for obtaining audit evidence and evaluating it objectively to determine the extent to which audit criteria are fulfilled	Process Assessment	Disciplined evaluation of an organizational unit's processes against a process assessment model
-	-	Assessment Purpose	Statement provided as part of the assessment input, which defines the reasons for performing the assessment
Audit Scope	Extent and boundaries of an audit	Assessment Scope	Definition of the boundaries of the assessment, provided as part of the assessment input, encompassing the boundaries of the organizational unit for the assessment, the processes to be included, the quality level for each process to be assessed, and the context within which the processes operate
Audit Evidence	Records, statements of fact or other information which are relevant to the audit criteria and verifiable	Assessment Indicator	Sources of objective evidence used to support the assessor's judgment in rating process attributes
Audit Findings	Results of the evaluation of the collected audit evidence against audit criteria	Assessment Output	All of the tangible results from an assessment
Auditor	Person with the demonstrated personal attributes and competence to conduct an audit	Assessor	Individual who participates in the rating of process attributes
-	-	Lead Assessor	Assessor who has demonstrated the competencies to conduct an assessment and to monitor and verify the conformance of a process assessment
Quality	Degree to which a set of inherent characteristics fulfils requirements	Process Quality	Ability of a process to satisfy stated and implied stakeholder needs when used in a specified context
Process	Set of interrelated or interacting activities which transforms inputs into outputs	Process (Same As ISO 9000)	Set of interrelated or interacting activities which transforms inputs into outputs
Quality Characteristic	Inherent characteristic of a product, process or system related to a requirement	Process Quality Characteristic	Measurable aspect of process quality; category of process attributes that are significant to process quality
-	-	Process Quality Attribute	Measurable property of a process quality characteristic
-	-	Base Practice	Activity that, when consistently performed, contributes to achieving a specific process purpose

4.4 Developing the Ontology of Interoperability Assessment

In this thesis we consider an interoperability assessment a process for determining the interoperability degree of a system or of a relation between systems (Panetto et al., 2016), (Guédria et al., 2015). Such process can be triggered, for example, when an interoperability problem appears or improvements are planned. For improving/transforming the concerned systems and relations, decisions are made considering the assessment results. Based on this assumption and the gathered information, we propose a conceptual model for illustrating the concepts and relations of the OIA. This model serves as the basis for implementing the ontology using Protégé.

4.4.1 Designing the Ontology of Interoperability Assessment

In order to organise the relevant concepts and to define their relationships, we propose an architecture containing a meta-model and a conceptual model, following a Model-Based System Engineering approach for modelling the concepts and relations of an assessment process.

We 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, i.e. it represents the real assessed system and the applied assessment model.

The Assessment MetaModel and Interoperability Assessment MetaModel are designed by using UML class-diagrams (OMG, 2017b).

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 (Naudet et al., 2010), and enriched with concepts from the SEMD (Morel et al., 2007), ISO 9000 (ISO 9000, 2015), the MMEI (Guédria et al., 2015), and the ISO/IEC 33001 (ISO/IEC 33001, 2015). Table 38 presents the adopted concepts and their definitions.

Table 38. The Assessment MetaModel concepts

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 (Morel et al., 2007)
Quality	ISO 9000	Degree to which a set of inherent Quality characteristics fulfils Requirements (ISO 9000, 2015)
Quality Characteristic	ISO 9000	Measurable inherent characteristic of the Object of Assessment; Collection of attributes that are significant to the Object of Assessment (ISO 9000, 2015)
Quality Attribute	ISO/IEC 33001	Measurable attribute of a Quality Characteristic (ISO/IEC 33001, 2015)
Requirement	SEMD, ISO 9000	Need or expectation that is stated, generally implied or obligatory (ISO 9000, 2015), (Morel et al., 2007)
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. (ISO 9000, 2015), (Guédria et al., 2015)
Assessment Scope	ISO/IEC 33001	Definition of the boundaries of the Assessment, provided as part of the assessment Input (ISO/IEC 33001, 2015)
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 (Guédria et al., 2015), (ISO/IEC 33001, 2015)
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

Fig. 35 illustrates both systemic and assessment cores.

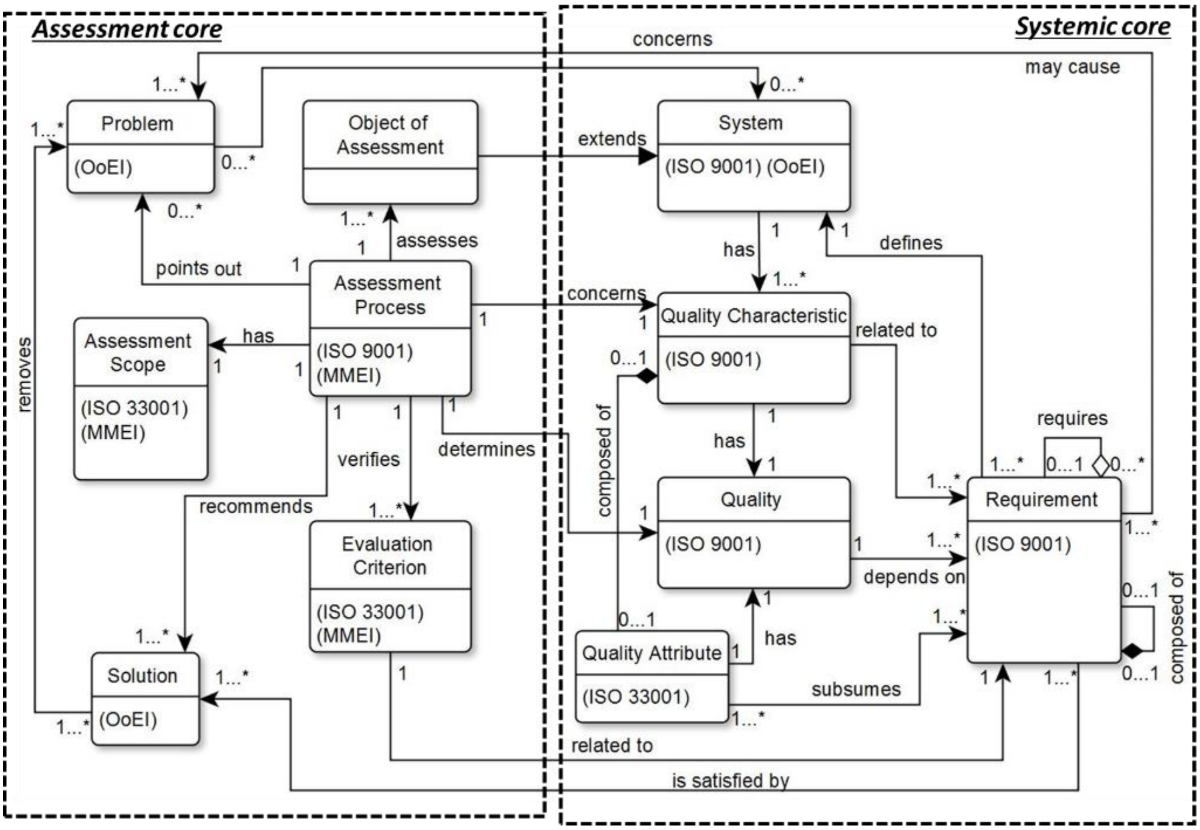


Fig. 35. The Assessment MetaModel using the UML notation (OMG, 2017b)

On the right side of the **Fig. 35**, 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) (ISO 9000, 2015). A *Quality Characteristic* is an inherent characteristic of a *System*, which are 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 **Fig. 35**, 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 (ISO/IEC 33001, 2015). 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.

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 (Guédria et al., 2015). Having established these conditions, we use them to instantiate the Assessment MetaModel. Note that the Assessment MetaModel 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 (Naudet et al., 2010), and enriched witch concepts from SEMD (Morel et al., 2007), ISO 9000 (ISO 9000, 2015), the MMEI (Guédria et al., 2015), and the ISO 33001 (ISO/IEC 33001, 2015). Table 39 present the adopted concepts. Fig. 36 illustrates the Interoperability Assessment Model. The rationales are presented in the following.

Table 39. The concepts from the Interoperability Assessment Model

Concept	Instance of […] from Assessment MetaModel	Based on
Interoperability Assessment Process	Assessment Process	MMEI
Interoperability Assessment Scope	Assessment Scope	MMEI, ISO/IEC 33001
Interoperability Evaluation Criterion	Evaluation Criteria	MMEI
Best Practice	Solution	MMEI
Interoperability Barrier	Problem	OoEI
Enterprise	System; Object of Assessment	OoEI
Networked Enterprise	System; Object of Assessment	-
Interoperability	Quality Characteristic	OoEI
Interoperability Area	Quality Attribute	MMEI
Interoperability Requirement	Requirement	-
Maturity Level	Quality	MMEI, ISO/IEC 33001

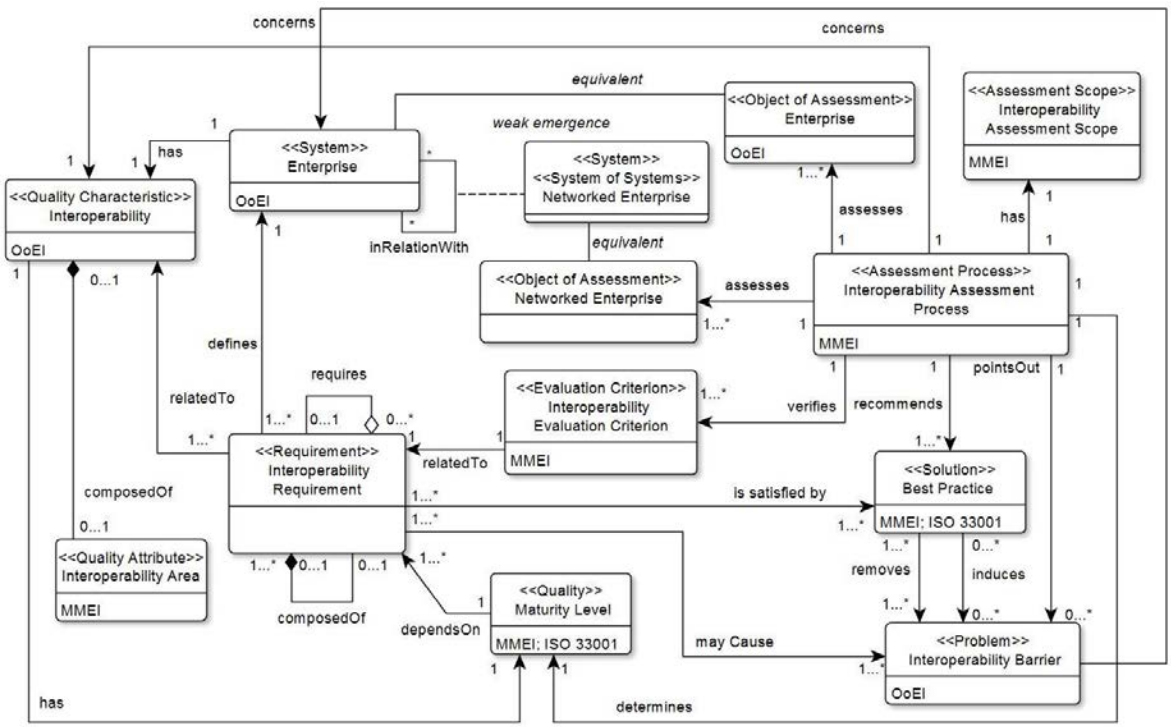


Fig. 36. The Interoperability Assessment MetaModel using the UML notation (OMG, 2017b)

In Fig. 36, 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*. A *Maturity Level* specialises the *Quality* concept. It 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*).

4.4.2 Implementing the Ontology of Interoperability Assessment

Here, we implement the model previously defined using the Protégé 5.2 (Musen, 2015). To implement it, we use the concepts from the defined MetaModels as Classes from the T-Box and the instances from the Implementation as individuals of A-Box. Fig. 37 illustrates the relation between the conceptual model and the proposed Ontology of Interoperability Assessment.

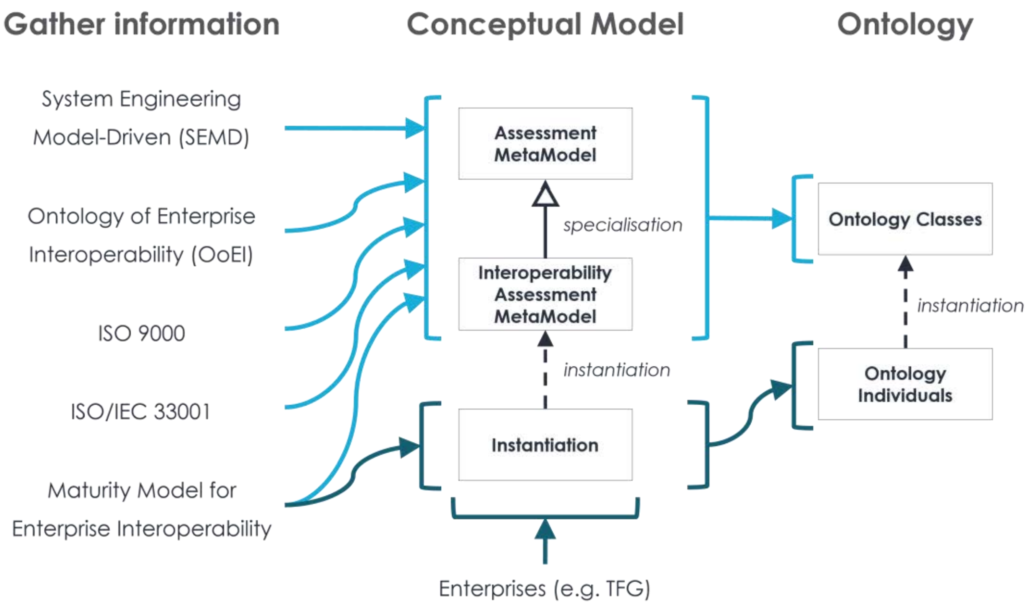


Fig. 37. The relations between the conceptual model and OIA

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.

Fig. 38 illustrates an overview of the implemented ontology. Note that the classes with a yellow circle are based on the cncepts from the Assessment MetaModel, the classes with a grey circle are based on the Interoeprability Aseessment MetaModel and the ontology individuals are represented by a purple diamond.

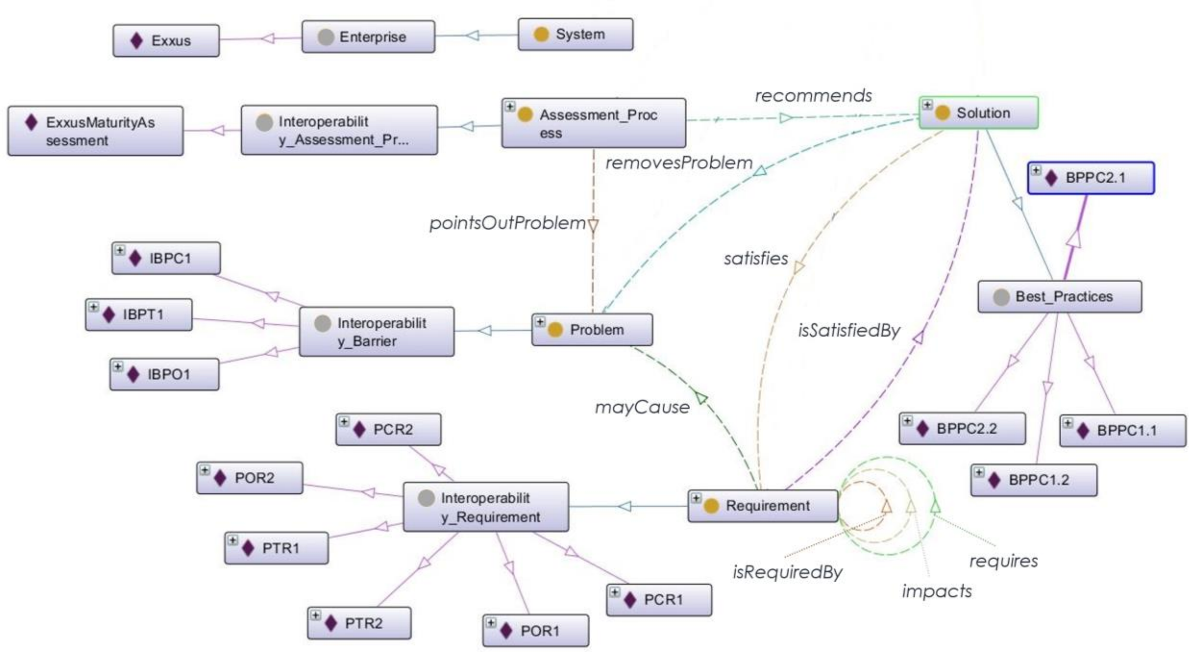


Fig. 38. The Ontology of Interoperability Assessment

After defining the concepts, we populate the ontology with the fixed instances, i.e. individuals that are already instantiated on the OIA and that will not change during the assessment. These instantiations includes the following concepts:

- ***Requirement*** with the set of interoperability requirements and their interdependencies defined in Chapter 3.
- ***Problem*** with the interoperability barriers described in the Framework for Enterprise Interoperability (Chen, Dassisti, Elvesaeter et al., 2007)
- ***Solution*** with the 126 best practices defined in MMEI (Guédria, 2012), (ISO 11354-2, 2015).
- ***Quality Attribute*** with the twelve interoperability areas (*Business-Conceptual, Business-Technological, Business-Organisational, Process-Conceptual, Process-Technological, Process-Organisational, Service-Conceptual, Service-Technological, Service-Organisational, Data-Conceptual, Data-Technological* and *Data-Organisational*) defined in MMEI.

— ***Quality*** with the five maturity levels (*Unprepared, Defined, Aligned, Organised* and *Adaptive*) defined in MMEI.

Only the KBS administrator may edit such instances. Table 40 presents some of the information that is instantiated regarding the requirement "*BCR1: Business models shall be defined and documented*". Fig. 39 and Fig. 40 show the relationships and details of this requirement.

Table 40. Interoperability Requirement BCR1 relations

Requirement	BCR1: Business models shall be defined and documented
Interoperability Area	Business-Conceptual
Maturity Level	Level 1 - Defined
Requires	BOR1: Organization structure shall be defined and in place
Is required by	BCR2: Standards shall be used for alignment with other business models BCR3: Business Models shall be designed for collaboration BCR4: Business models shall be adaptive BOR1: Organization structure shall be defined and in place BOR2: Human resources shall be trained for interoperability BTR1: Basic IT infrastructure shall be in place BTR2: Standard-based and configurable IT infrastructure shall be used DCR3: Meta-modelling shall be done for multiple data model mappings DCR2: Standards shall be used for alignment with other data models DTR2: Automated access to data based on standard protocols shall be in place PTR2: Standard process tools and platforms shall be available
Best Practices	BPBC1.1. Define business models BPBC1.2. Document Business Model
Interoperability Barrier	IBBC1: Business Content IBBC2: Business syntax IBBC3: Business semantics

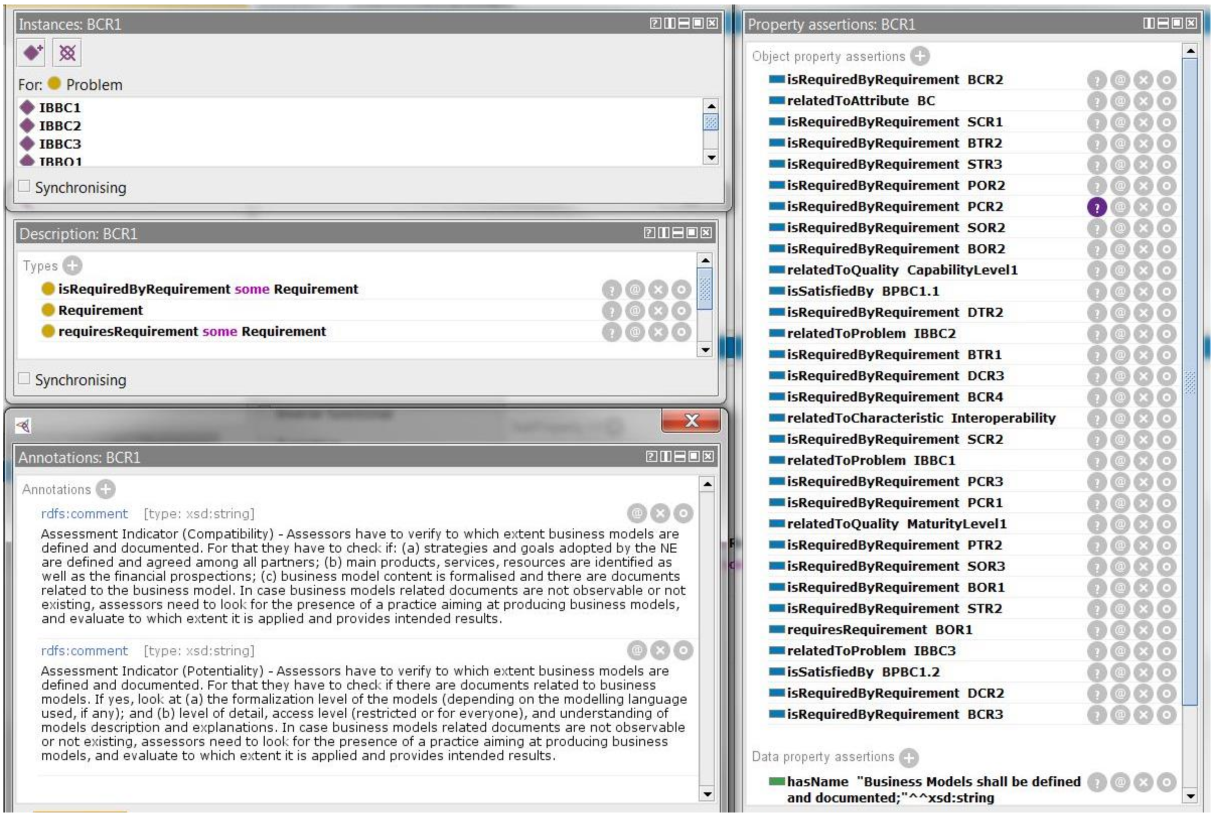
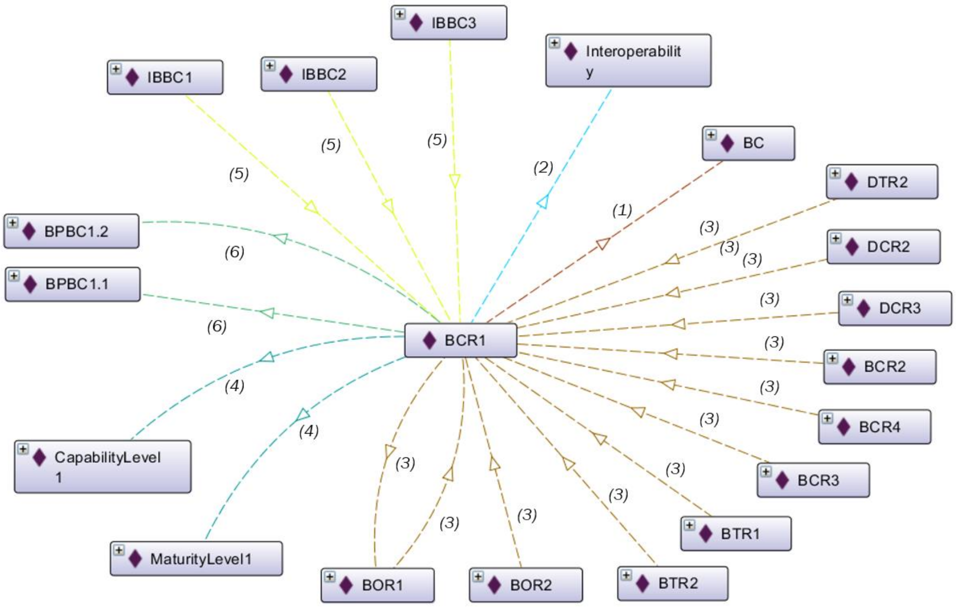


Fig. 39. BCR1 requirement details



(1) relatedToAttribute
(2) relatedToCharacteristic
(3) requiresRequirement
(4) relatedToQuality
(5) relatedToProblem
(6) isSatisfiedBy

Fig. 40. The relationships of the BCR1 requirement

Moreover, 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. These rules are described in Table 41 to Table 45.

Table 41. 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 42. 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 43. 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 44. 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 45. Rule: Verifying level satisfaction

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

4.5 Prototyping the Knowledge-Based System for Interoperability Assessment

In this section, the KBS prototype architecture, its functionalities and the concerned users are presented. Ideally, the users follow the defined assessment process and use the KBS prototype (embedded with the OIA) for supporting specific activities. An overview of the users, assessment process and KBS prototype relations is illustrated in Fig. 37.

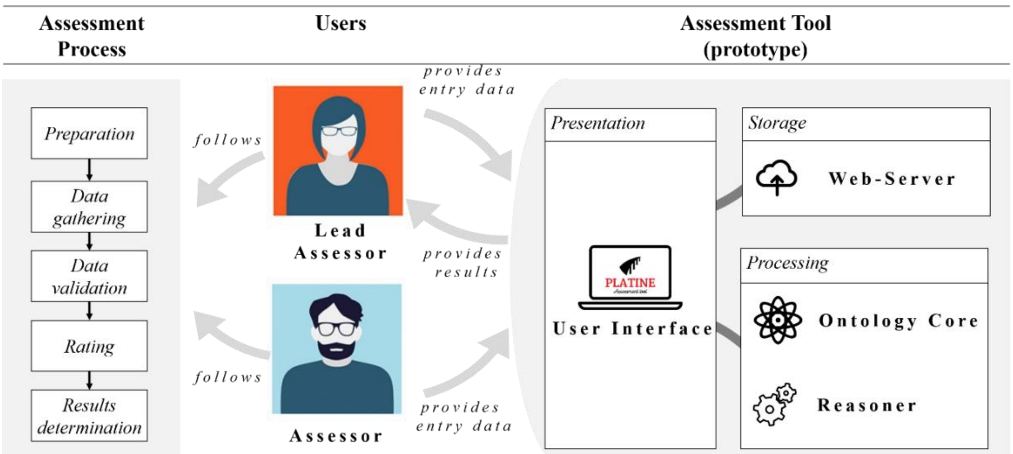


Fig. 41. The overview of the Knowledge-Based System for Interoperability Assessment

4.5.1 Defining the KBS functionalities

We consider three roles for interacting with the KBS: The Lead Assessor is expected to have a clear understanding of the assessment workflow and operates the KBS prototype to facilitate the entire assessment. He is responsible for creating and editing assessments as well as generating the assessment 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 KBS. The prototype functionalities are directly related to these roles as illustrated in Fig. 42.

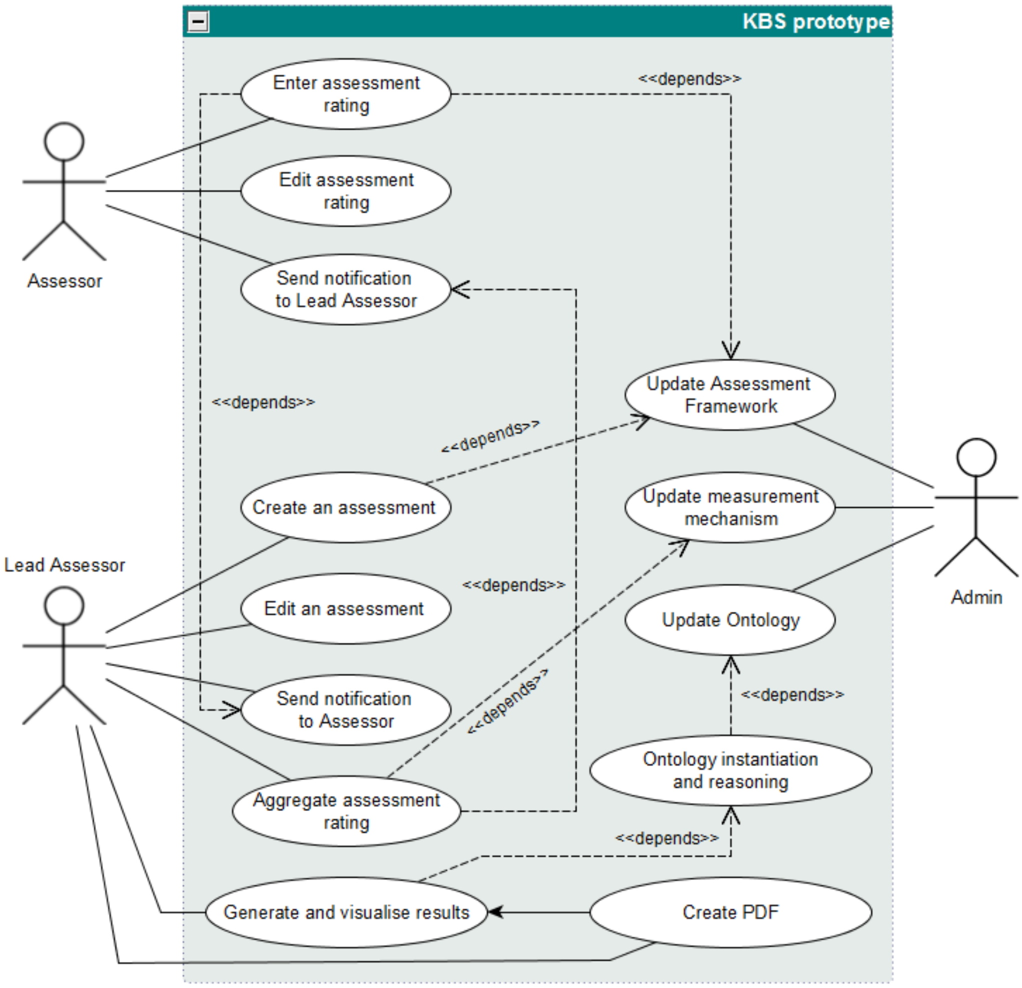


Fig. 42. The Use Case Diagram of the KBS prototype using UML notation (OMG, 2017b)

4.5.2 Designing the KBS prototype architecture

The KBS prototype architecture distinguishes three layers for accommodating different components. The Presentation layer includes the *Data Collector* and *Data Viewer* components. The *Data Collector* is responsible for collecting all relevant data that is entered by the Lead Assessor and Assessors, such as the information for creating an assessment and the evaluation criteria rating.

The *Data Viewer* is responsible for organising and presenting relevant data to the users, such as the rating summary and the assessment results. The user interfaces are designed using the NetBeans IDE 8.1 and the Java language. The Storage layer includes the *Database* component and the generated ontology and assessment reports files. 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 data input and output from the prototype and for calling and managing the other components when needed. The *Data Access Object* component is responsible for establishing a connection between the prototype and the *Database*. The *Measurement Mechanism* contains the algorithms for aggregating evaluation criteria ratings and for calculating the interoperability maturity. The Annexe B describes in the detail the mathematics of the measurement mechanism. The *Ontology Manager* is responsible for instantiating the raw ontology file and to querying the inferred results. The *Inference Engine* is responsible for reasoning the instantiated ontology and inferring new knowledge about the assessed system's current state. OWL API[8] provides the implemented *Inference Engine*. The architecture is depicted in Fig. 43.

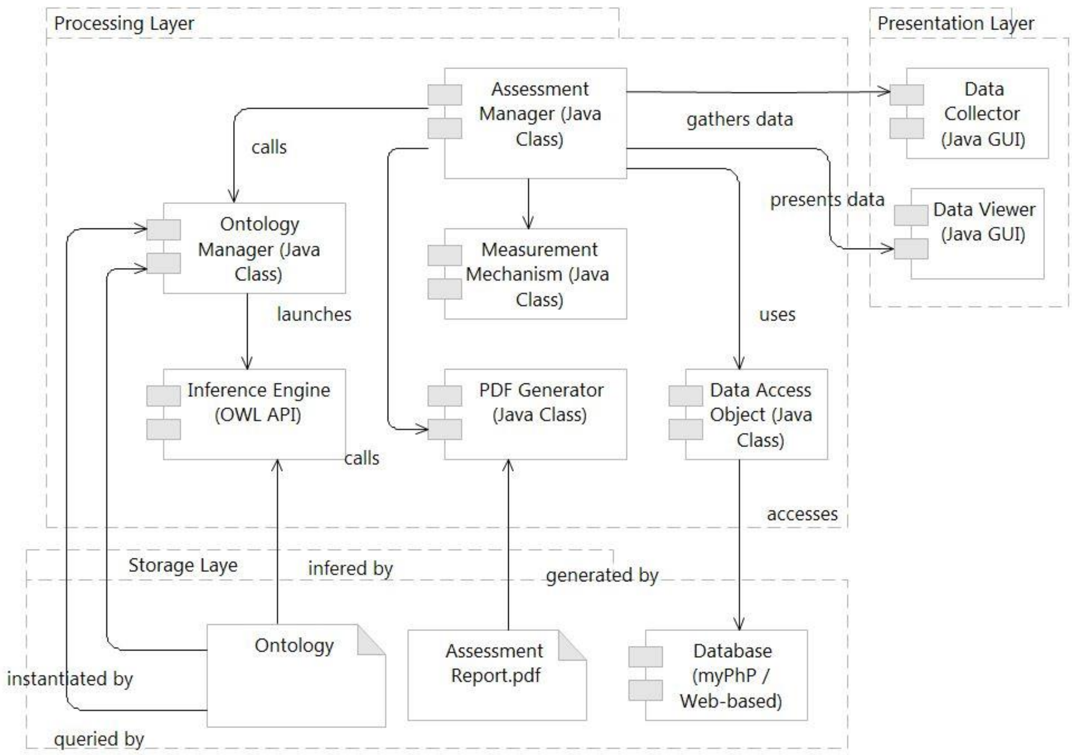


Fig. 43. The architecture of the KBS prototype using the UML notation (OMG, 2017b)

[8] github.com/owlcs/owlapi

4.5.3 Defining the assessment process for the KBS prototype

Considering the assessment process, we adopt the five stages proposed in the MMEI: Preparation, Data gathering, Data validation, Rating and Results determination. Some adaptations have been made to include the proposed KBS.

The first step when conducting an assessment process is to define the purpose of the assessment, its scope, under which constraints it is done (i.e. the context) and any additional information that needs to be gathered. Having defined the assessment scope, the lead assessor enters the specified information about the assessment (e.g. the name of the assessment, the systems to be assessed, the interoperability areas to be considered, etc.). Next, he selects the assessors and sends a message to notify them.

Moreover, assessors need to collect information through a series of interviews. After holding feedback sessions to validate the gathered information, the assessors analyse the approved data and enters into the KBS prototype the evidence (e.g. commentaries and documents) and rating of each concerned evaluation criteria. The rates and pieces of evidence are stored on the *Database*, and a notification is sent to the lead assessor. If there are multiple assessors, the lead assessor aggregates the assessments provided by them. To do so, he launches the aggregation mechanism implemented into the KBS prototype (in our case, the Ordered Weighted Average (Yager, 1988), (Guédria et al., 2015) technique is implemented within the KBS). The prototype then provides the resulting aggregation that can be modified by the lead assessor.

The evidence uploaded by the assessors are helpful for the lead assessor when aggregating and validating the final rating. Next, the lead assessor launches the ontology instantiation through the KBS. Having the ontology duly instantiated, the KBS prototype launches its *Inference Engine*.

Moreover, the *Inference Engine* infers the ontology to identify interoperability problems. The reasoned facts (i.e. the outcome of the rules execution) are stored in the *Database*. Based on the inferred ontology and the identified non-fulfilled criteria, the prototype proposes the related best practices and points out the potential influences behind the non-fulfilment of 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 Fig. 44, using the BPMN standard (OMG, 2014b)[9]. The grey coloured activities are those supported by the KBS.

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[9] 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.

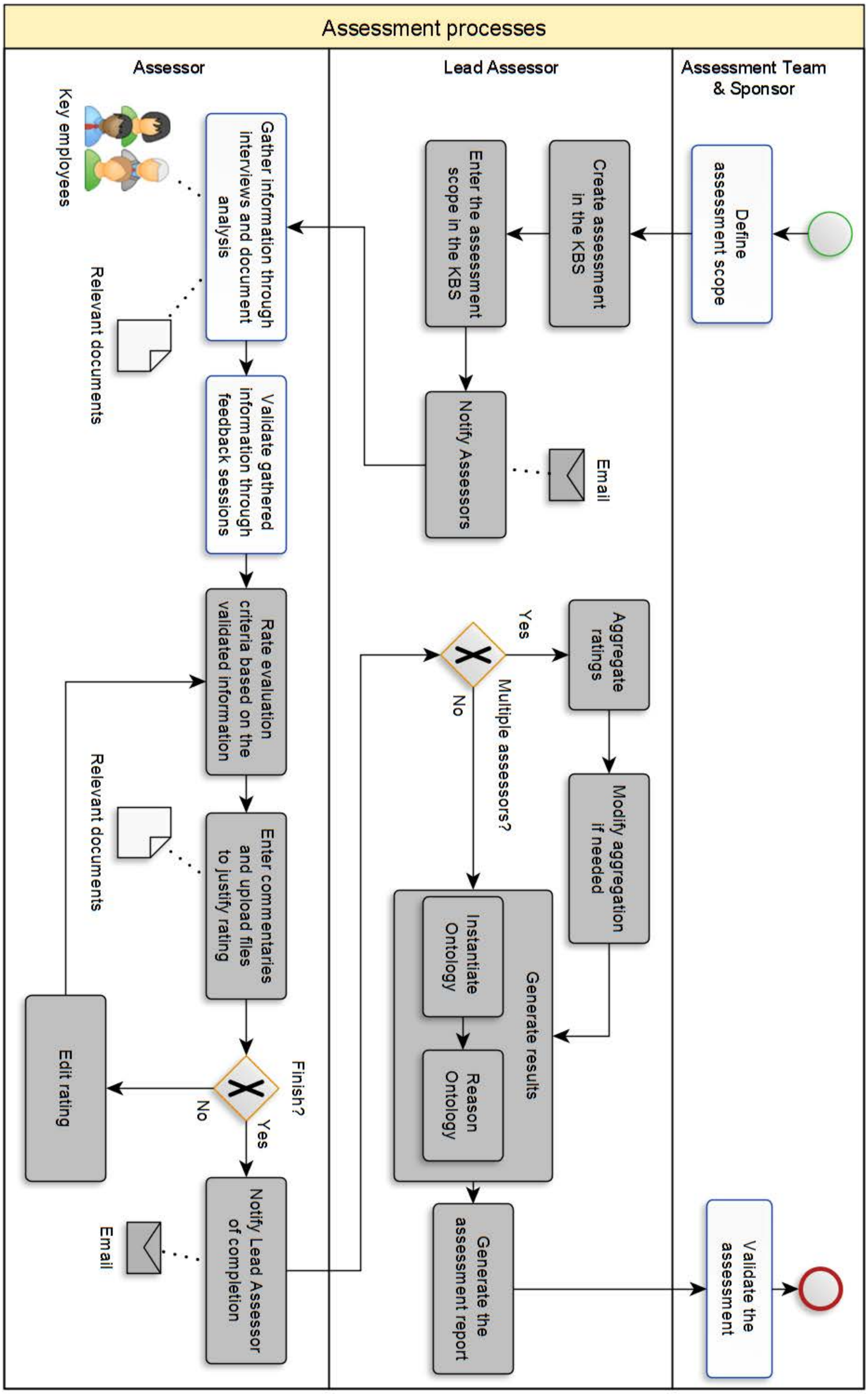

Fig. 44. The assessment process using the Business Process Model Notation

4.6 Discussion

In this chapter, we presented the design and development of both the Ontology of Interoperability Assessment and the Knowledge-Based system for supporting our interoperability assessment approach.

As our proposed INAS approach is covering both potentiality and compatibility assessment, we compared it to the other existing approaches covering these same types of assessment. Table 46 shows the comparison between the INAS approaches using the following criteria: *Type of Assessment, Type of Measurement Mechanism, Provision of Best Practices, Provision of Computer-Mediated Tool, Coverage of Barriers and Concerns of Interoperability* and *Definition of Interoperability Requirements Interdependencies*. For more details regarding the comparison criteria see Section 2.2.1, and for more details regarding the existing assessment approaches, please see Section 2.2.2.

Table 46. Comparision with existing INAS approaches

Approach	Type of assessment			Measurement mechanism		Best practice	Supporting tool	Covers all barriers/ concerns	Req. Inter.
	Pot	Com	Per	Qual	Quant				
A16 (Gottschalk, 2009)	✓	✓	✗	✓	✗	✗	✗	✗	✗
A17 (C4ISR, 1998)	✓	✓	✗	✓	✗	✓	✗	✗	✗
A18 (Guédria et al., 2015)	✓	✓	✗	✓	✓	✓	✗	✓	✗
A19 (Cornu et al., 2012a)	✓	✓	✗	✓	✓	✓	✓	✗	✗
A21 (Daclin et al., 2016a)	✓	✓	✓	✓	✓	✓	✗	✓	✗
Thesis contribution	✓	✓	✗	✓	✓	✓	✓	✓	✓

Pot = Potential; Com = Compatibility; Per = Performance; Req. Inter. = Requirements Interdependencies

Regarding the comparison, we observe that besides our INAS approach only the "Contumazible Interoperability Assessment Methodology" (Cornu et al., 2012a) is providing a computer-mediated tool for supporting its assessment process. Further, our proposed approach with the "Maturity Model for Enterprise Interoperability" (Guédria et al., 2015) and the "Methodology to Implement and Improve Interoperability" (Daclin et al., 2016a), are the only ones covering all three interoperability barriers and four concerns. Finally, only our assessment approach is defining interoperability requirements interdependencies.

Chapter 5

Evaluation of the thesis contribution

Introduction

In this chapter, we present the evaluation of the proposed thesis's contribution. According to (Hevner et al., 2004) 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 (Peffers et al., 2007). This activity involves comparing the objectives of a solution to actual observed results from use of the artefact.

In the first part of this chapter, we apply the proposed artefacts, namely the interoperability assessment approach and the Knowledge-Based System (KBS) prototype, using the case study of The Factory Group (TFG)[10]. This allows us to observe how the proposed interoperability assessment can be applied in a real-world business scenario.

In the second part of this chapter, we evaluate the proposed contribution based on the observations and analysis made in the TFG case study. We first verify whether our KBS prototype is complaint with the requirements needed to develop a computer-mediated tool (i.e. functional and non-functional), as defined in Section 4.2. The coherence and consistency of the designed Ontology of Interoperability Assessment (OIA) is also checked using the debugger implemented within the Protégé. Next, we evaluate the performance of the proposed contribution using time and cost indicators.

5.1 The Factory Group case study

The case study described here presents the collaboration and interoperation between the enterprises members of The Factory Group. TFG is a group of specialized and complementary agencies with more than 40 communication specialists. It is the first and only group of agencies and economic actors in Luxembourg covering all areas of marketing and communication[11]. The TFG aims at creating sustainable customer value by the complementarity of its members' competencies and resources. The initiative to create TFG, in early 2007, reflects the desire to consolidate more than 15 years of experience and presence in market segments such as business, marketing and communication. This network is located in Luxembourg and is composed by four independent and autonomous enterprises, which are:

- ***Exxus*** is an innovation and strategy-consulting agency located in Luxembourg. The company provides the following services: Innovation Consulting, think tank, feasibility study, business modelling, partner pooling, funding, project management and user experience design. The agency has a small team of five specialists in business innovation management. Exxus main objective is to

[10] http://www.thefactorygroup.com/
[11] http://interact.lu/about/

ensure their service delivery in order to attain a high level of client’s satisfaction. Consequently, improving its brand image and capturing new businesses.

- ***Concept Factory*** is a marketing and communication agency located in Luxembourg. The enterprise provides services such marketing strategy, communication strategy, branding strategy and brand conceptualisation and development. The agency counts with more than fifteen employees. The main objective of the company is to become a reference in the field of communications services, providing integrated solutions
- ***Sustain*** is the leader in sustainable development consulting and social responsibility in Luxembourg. The enterprise offers services such as smart city consulting, smart mobility, smart energy, smart buildings, etc. With five employees, the goal of the agency is to be recognised as an expert in the field of sustainable development in Europe.
- ***Interact*** is the first « digital native » agency in Luxembourg. The enterprise provides services such as big data analysis, data mining, ergonomics and software -engineering architecture and design. The objective of the company is to become a technological centre providing IT solutions and IT consulting for all the different areas of marketing. To reach its objective, Interact counts with more than fifteen employees.

5.1.1 The business scenario

Here, we chose to describe a particular business scenario based on a recent experience between TFG and a customer. The name of the client remains confidential for security reasons. Subsequently we use the term “ClientX” for addressing the concerned client.

The main participants were Exxus and Concept Factory as service providers and the ClientX as the customer. The data collection have been done based on workshops with key employees, concerning the structure and businesses of the network. Documents sent by network members have also been used to complement our analysis. During the workshops, we discussed the adopted strategy, their service proposals, the different relations between the network partners, and existing and potential problems regarding collaborations. In the following, we present the relations between the concerned enterprises and the main elements from the Exxus and Concept Factory’s architectures.

The relationships between the concerned enterprises

ClientX business’s objective is to improve their brand image by following a sound business and marketing strategy. However, they did not know the steps to follow in developing their brand (business) image. Therefore, ClientX requested the TFG services. Their goal was twofold: first to be informed concerning what is required to develop their business image and second, for the network to handle all of their brand development processes, once a contract is agreed.

As a results, in this case, the relationship between ClientX and TFG (including both Exxus and Concept Factory) have been characterised as a Consumer-Provider relationship. To offer any combination of the specific services that the network's members can supply, TFG promised a single point of contact at the group level for ClientX. It implies that one of the members, in this case Exxus, assumes the role of the Mediator between the ClientX and the rest of the network. The mediator is responsible for the external customer relationships and the internal partners' relationships. Internally, Exxus and Concept Factory should discuss and validate any service delivery before sending to the customer. It implies that the relationship between Exxus and Concept Factory has been characterised as a business collaboration.

However, it is not what ended up occurring in this specific case study. Exxus had not completely fulfilled its tasks as Mediator. For instance, after contacting the client, Exxus requested Concept Factory for their services and put them in direct contact with the ClientX. This happened mainly because Exxus had a small team and a large workload. The agency therefore passed the client's contact to Concept Factory and expected the latter to handle the new client. Hence, there was no collaboration *per se*, but it was rather a cooperation where service providers worked on their own deliverables (see section 1.1 for the collaboration and cooperation disambiguation). In this particular case, the ClientX had been communicating in German with Exxus, and Concept Factory employees were not proficient in this language, thus, the communication language has been shifted to English. Furthermore, Concept Factory kept touch with the ClientX during the development until the delivery of their services. Hence, also assuming a Consumer-Provider relationship with ClientX.

The perceived problem in this current configuration is that information was dispersed among the different members and enterprise systems, along with the fact members did not have "one voice" when handling customer relationships. Three potential reasons for these problems are the lack of linguistic skills from the Concept Factory side; the lack of human resources from the Exxus side; and the lack of a defined collaborative processes and interoperability guidelines from TFG as a whole.

The Exxus and Concept Factory's architectures in the considered scenario

In the following sections, information about the participants' architectures are presented. These pieces of information helped us to design the *as-is* situation of the TFG and identify issues regarding the network interoperations.

IT infrastructure

The main TFG's IT components are described as follows: The **Basecamp**[12] is a web-based project management tool. It is used for file sharing (documents, images, etc.) between members of a project team. All employees have access to this tool, but notifications for a project are sent only to the concerned

[12] basecamp.com

employees. This tool offers the following features: (a) multiple "basecamps" (i.e. project folders), (b) instant messaging, (c) dashboard, (d) to do list, and (e) the ability to define deadlines for various project tasks.

The **FileMaker** is an IT platform used to store and manage administrative information from projects such as customer contacts, billing, type of project (e.g. website creation, brand consulting, etc.) and services associated with a project. However, the version used within TFG limits the access to its database to one person at a time (the number of employees who have access is also limited). Another limitation is the fact that the MacBook do not have direct access to the platform server, therefore a "virtual" machine is needed to access it. The **Harvest**[13] is a web-based time tracking tool. All employees within the network (except the CEOs) must enter their worked hours to each project in which they are enrolled. However, this tool is not automatically linked to the badging system of enterprises. Hence, employees must enter the worked hours manually to each pre-defined project task.

The **Microsoft Office tools** are particularly used for bureaucratic activities. For example, schedules are stored on Excel spreadsheets; invoices are written in Word and presentations (internal or external) are made with PowerPoint. According to respondents, it does not necessarily exist a template for each type of documents.

The **ViaNeo**[14] **tools** are used for supporting the Business Concepts Analysis service. There are two main web-based tools: The ViaNeo-Select for submitting, assessing and selecting projects online and the ViaNeo-Strategy guiding the market strategy through a systemic method and helping to track projects' situation and evolution thanks to a dashboard.

Regarding the data storage, a shared server (**TFG Server**) is installed within the group, and each company has a dedicated folder. Access rights are defined to each one of the folders. Hence, only concerned employees can access the different folders. At Concept Factory, two other servers are set up:

(a) A server is dedicated to the Creative and Production departments. It serves to store all sketches, draws, concepts, etc. according to a concerned project.

(b) The second server is dedicated to the project managers. It serves to store briefings, project general information, planning, etc. It is worth noting that both servers do not 'communicate' with one another. Hence, the information concerning a particular project (draws, general information, etc.) is decentralised.

Fig. 45 illustrates the TGF's IT infractructure.

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[13] https://www.getharvest.com/
[14] https://www.vianeo.io/fr/

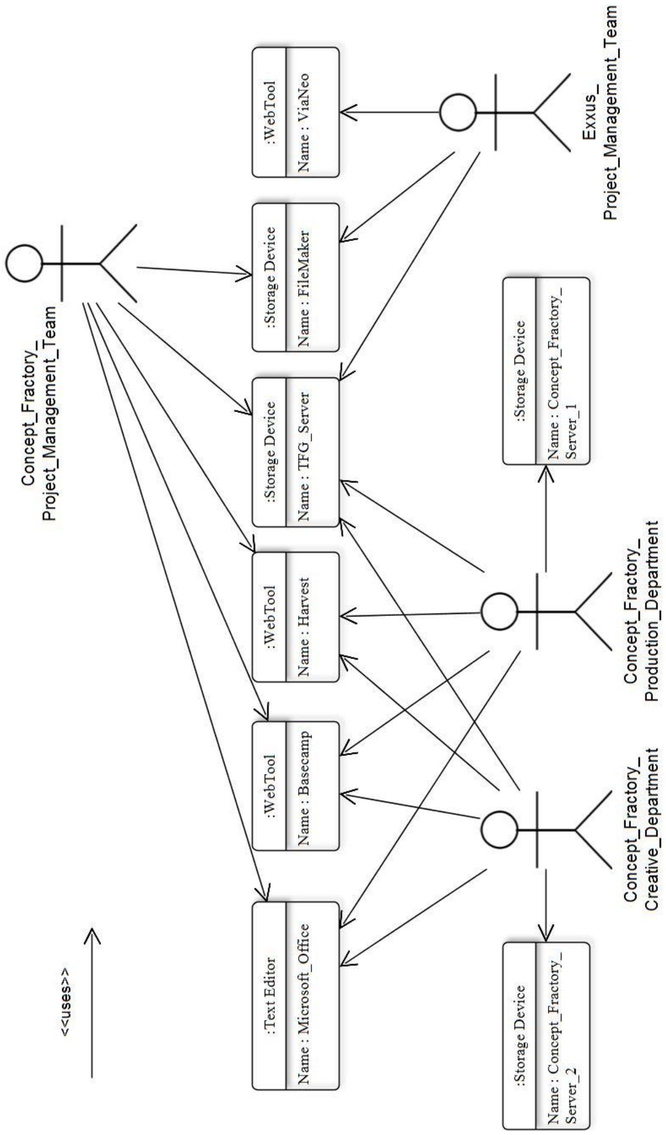


Fig. 45. The IT infrastructure form The Factory Group

Processes and services

For this case, we identified three services and six main processes, which are described in Table 48 and Table 47, respectively.

Table 47. The specific TFG services for this business scenario

Process	Description
Business concept analysis	The service refers to the result of the analysis of the client's project is done through the ISMA360→ methodology based on the ViaNeo tools. This methodology will validate the substance and strategy of the customer's approach. It helps to analyse the ecosystem by identifying the missing or winning elements in the market approach. Exxus provide this service.
Marketing plan development	The service refers to the delivery of the marketing plan. Concept Factory provides this service.
Business plan development	The service refers to the delivery of the pitch deck, the business model and the marketing strategy plan to the Client. Exxus provide this service.

Table 48. The specific TFG processes for this business scenario

Process	Description
Handle a client request	Following the client's request, all client's information and requirements are gathered and registered. The leading enterprise debriefs about the client's request with the rest of the concerned partners. Here, a first project team is selected, and the affected employees make the prototype (e.g. a first website, a first logo, a first pitch deck, etc.). If the request is rejected by the TFG or by the client, a rejection notification is generated. Otherwise, the client's request is validated, and validation notification is generated. The TFG and client negotiate constraints, deadlines, costs, etc. based on the prototype. The responsible for this process are the members of the board of directors.
Plan tasks	First, the project managers organise all the accomplished and remain activities from each project that they are in charge. After that, they must send this information using an Excel spreadsheet to the Account Director from Concept Factory. Having gathered the information from all projects, the Account Director organises them in a single spreadsheet and schedule a meeting. During this meeting, the planning is shared with all project managers. The first planning version can be negotiated and modified. At the end of the meeting, The Account Director and project managers validate the planning and share it with the concerned employees.
Create a project	When a new project is started, the project manager responsible should follow some steps that are: Create a project number in the Filemaker platform. This number will be used as references in all process and stages of the project. As TFG and Exxus do not have an integrated project management tool, the project manager should perform different activities to register and manage the project in the various IT applications. For instance, having the project number, the manager should: a) Enter all necessary information about the project in the Filemaker platform; b) Create a project space in the Basecamp web application and select the employees who compose the project team; c) Add a project line into the Harvest web application and associated concerned employees to allow them to save their related worked hours; d) Create a folder in the dedicated servers.
Create pitch deck	The process produces the pitch deck, which is written in English and is a brief presentation of 10 to 20 PPT slides containing the critical information about the enterprise. Companies usually use the pitch deck during face-to-face or online meetings to convince or engage emotionally potential investors, customers, partners, and co-founders.
Create marketing plan	The process produces the marketing plan, which is a comprehensive document that outlines the company's advertising and marketing efforts for the coming year(s). It describes business activities involved in accomplishing specific marketing objectives within a set time frame.

The overall collaborative process is illustrated in Fig. 46.

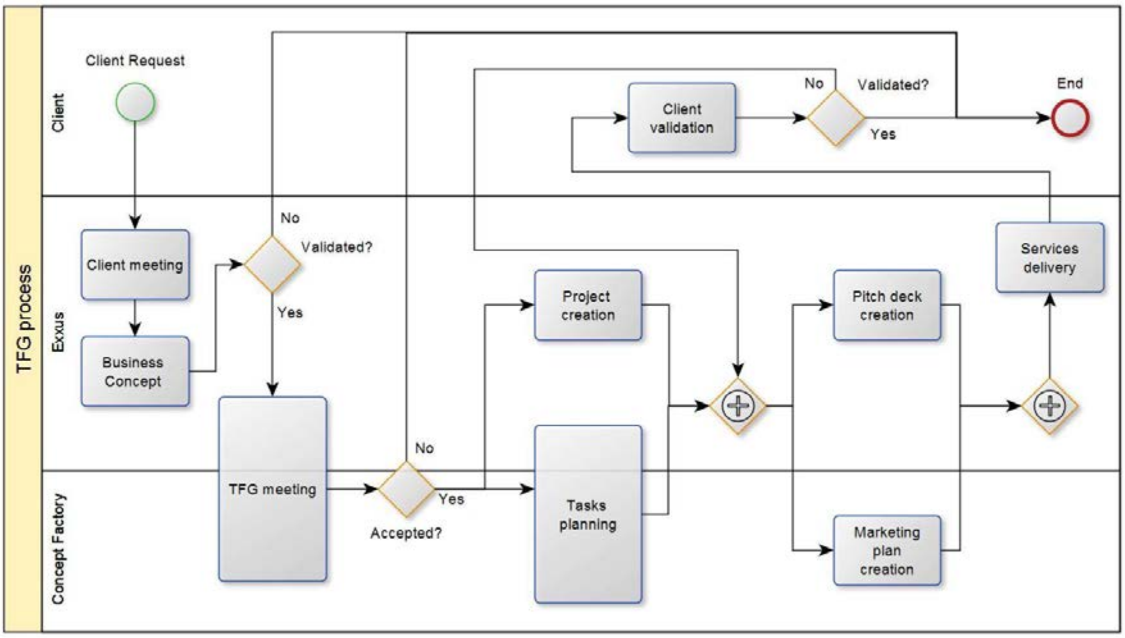


Fig. 46. The TFG overall collaborative process

5.1.2 Interoperability assessments regarding the considered business scenario

In the following sections, we present the maturity assessment of both Concept Factory and Exxus. We focus on showing the interoperability requirements interdependencies in the Exxus Assessment section and testing the proposed KBS in the Concept Factory Assessment section.

Concept Factory assessment focusing on the usability of the KBS

First, the scope of the Concept Factory assessment was defined. The type of assessment chosen was the potentiality assessment, which aimed at determining the maturity level of the Concept Factory current state. The assessment framework was the MMEI (Guédria et al., 2015) enriched with the defined interoperability requirements and their interdependencies (see Chapter 3).

In the following step, two assessors gathered information by interviewing the Chief Executive Officer (CEO) and the Account Manager of Concept Factory. The questionnaire used in the interviews was semi-structured, and the questions have been used to initiate discussion on identified issues. During the meetings, the strategy adopted by the network has been discussed, along with their services proposals, the different relations between the network partners and existing and potential problems regarding collaborations.

Table 49 presents some of the questions used for starting relevant discussions. These questions were asked for grasping the points of view of the interviewees regarding their enterprise and the entire TFG. The complete questionnaire is presented in detail in the Annexe C.

Table 49. The questions used during the interoperability assessment

Question	Description
What are the main objectives of the ENTERPRISE / The Factory Group?	This question allows the interviewer to understand the enterprise primary motivations.
What are the key resources required to reach its objectives? Who manages resources? Is the information documented? (If yes) Who has access to this document? (The same question for The Factory Group)	This question allows the interviewer to understand what the primary resources the enterprise needs are. It allows determining which one is more important, human resource (knowledge), technology (ICT), etc.
Are the authorities and responsibilities of each employee well defined in ENTERPRISE? (If yes) Is the information documented? Who has access to this document?	This question allows the interviewer to understand its organization and to see if the company is transparent considering its structure.
Is there a common file format used by the ENTERPRISE / the group? (e.g. PDF and Word for text, Excel for spreadsheet, PowerPoint for presentation, etc.). (If not) Is the ENTERPRISE / the group capable of using different formats?	This question allows the interviewer to see if the enterprise can handle different file formats. It helps to identify if the enterprise has different IT applications at its disposal.
How do the employees communicate within the ENTERPRISE / the Group? (Which means do they use?)	This question allows the interviewer to identify the communication fluidity. It helps to identify if the enterprise uses a digital channel (email, Messenger, etc.) of communication or it still uses traditional ways (phone calls, printed-paper, etc.)

Analyses of provided documents have been also conducted to identify relevant data. Once feedback sessions have been performed for validating the synthesis of the gathered information, the requirement rating could start. Thus, one of the assessors assumed the role of lead assessor. Then, the lead assessor logged in the proposed KBS prototype, where he entered the information about the assessment scope. The lead assessor gave a name to the assessment (ConceptFactoryMaturity), described the purpose of the assessment, and selected the potentiality assessment type and MMEI as the assessment framework. For having a holistic view of the assessed enterprise, the lead assessors selected all Interoperability Layers and Concerns as illustrated in Fig. 47.

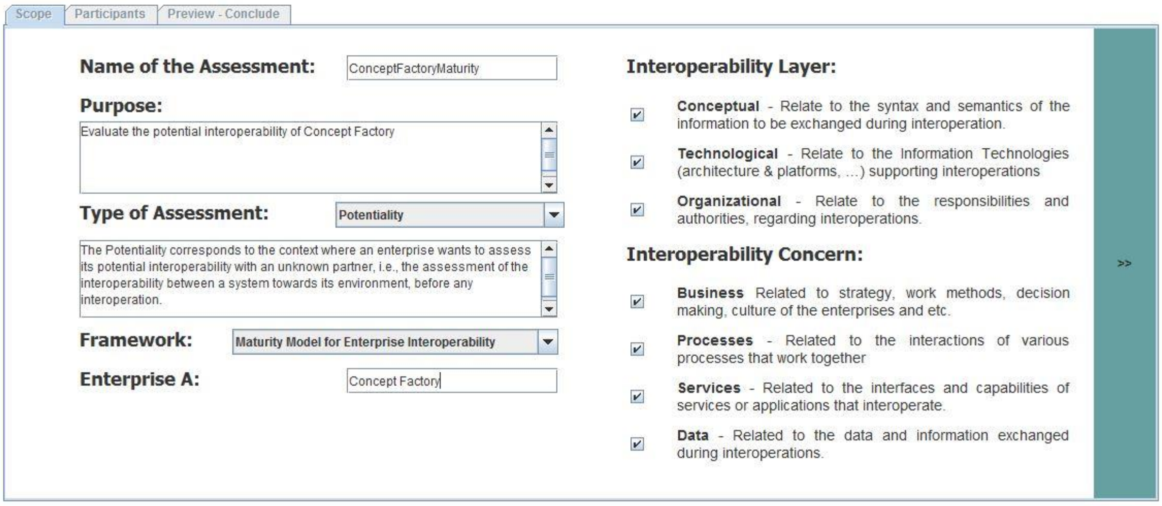


Fig. 47. Screenshot of the Concept Factory assessment scope

Having created this assessment, the lead assessor sent a notification for the concerned assessors. The assessors, then, logged in their accounts and completed the concerned ConceptFactoryMaturity assessment (see Fig. 48).

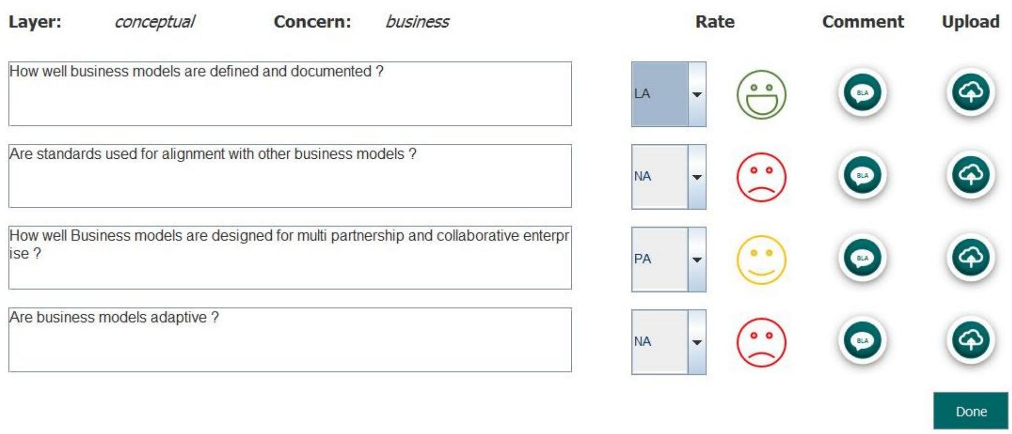


Fig. 48. Screenshot of the Concept Factory assessment: Requirement rating

In Fig. 48, an extract of the requirement rating is illustrated. In this particular interface of the KBS, the assessors rate the concerned requirements using the linguistic variables established on MMEI: “Not Achieved (NA)”, “Partially Achieved (PA)”, “Largely Achieved (LA)” and “Fully Achieved (FA)”. For providing a more user-friendly interface, these requirements were written in the form of questions (see section 3.3 to see how to do it). Note that, the requirements to be assessed have been automatically selected according to defined scope. Comments for justifying their rating should also be given. Evidence (e.g. documents, images, etc.) for complementing their justification can also be uploaded.

Once both assessors have completed their assessments, they sent a notification to the lead assessor. The latter, then, aggregated the requirement ratings provided by the two assessors. Comments and Evidence help the lead assessor to validate the requirement aggregation automatically generated by the KBS. Fig. 49 illustrates the summary concerning the rates related to requirement from the Process concern.

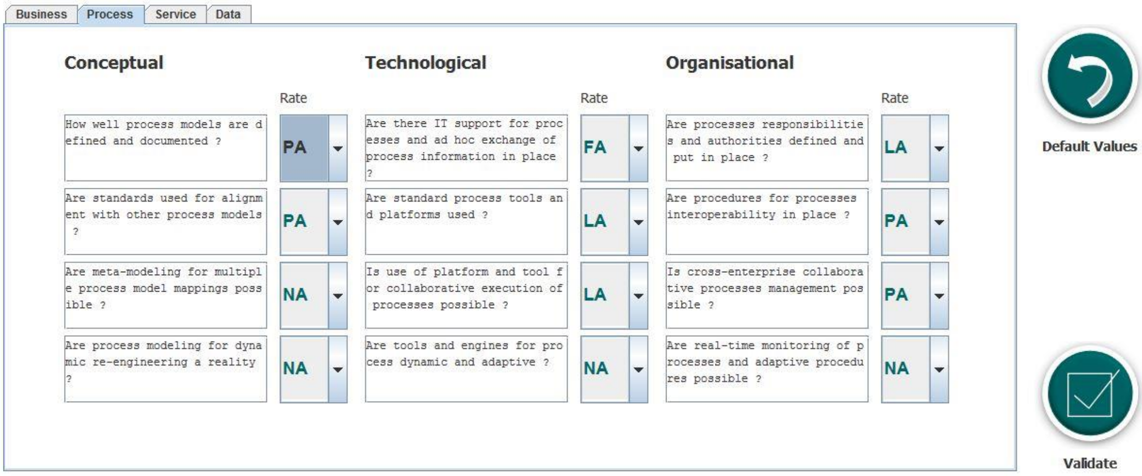


Fig. 49. Screenshot of the Concept Factory assessment summary

In the next step, the lead assessor launched the "generate results" function. Thus, the KBS instantiated automatically the embedded ontology and launched the reasoning engine.

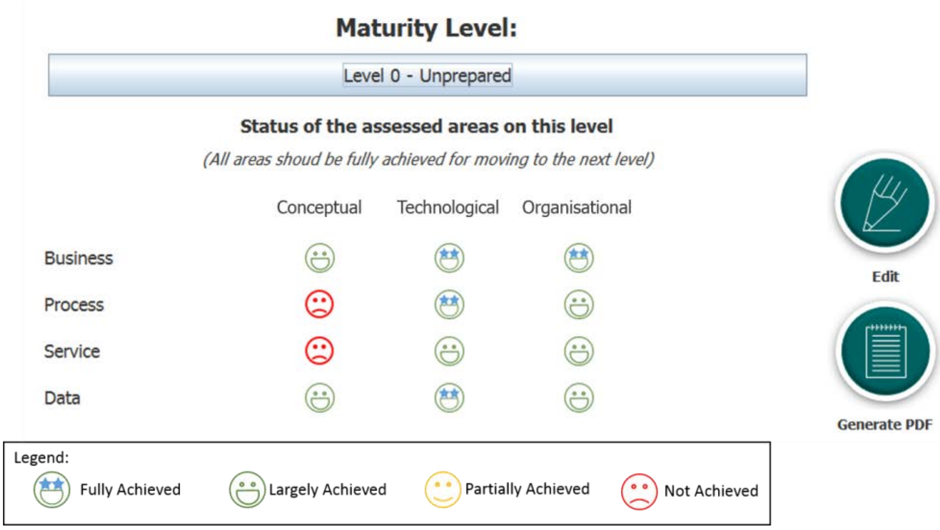
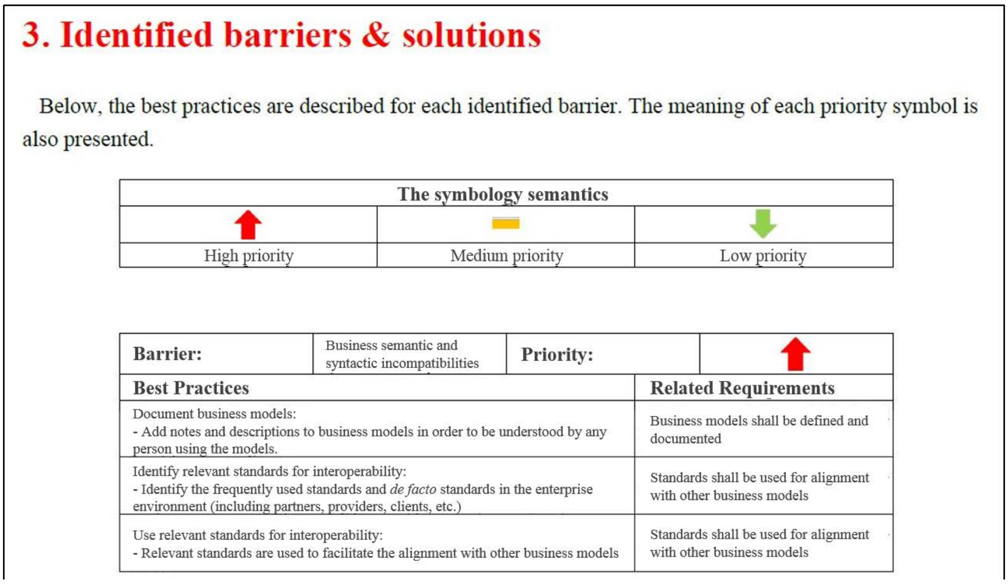


Fig. 50. Screenshot of the Concept Factory assessment results

Considering the MMEI measurement mechanism (Guédria et al., 2015), (see Annexe B for more details), Concept Factory 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; its enterprise systems run stand-alone and are not prepared for interoperation. Enterprise modelling is not done or done in an ad-hoc and* *inconsistent manner. Information exchange with external systems is mainly performed manually. No formal framework is in place, and the existing infrastructure frequently fails or does not support effective communication.* For achieving the next level, the concerned enterprise should focus on improving the conceptual requirements related to the process and services concerns. A list of best practices based on the maturity level and criteria evaluation was generated and presented in the "Assessment Report". Fig. 51 illustrates the best practices proposed in the generated report.



3. Identified barriers & solutions

Below, the best practices are described for each identified barrier. The meaning of each priority symbol is also presented.

The symbology semantics		
High priority	Medium priority	Low priority

Barrier:	Business semantic and syntactic incompatibilities	Priority:	
Best Practices		**Related Requirements**	
Document business models: - Add notes and descriptions to business models in order to be understood by any person using the models.		Business models shall be defined and documented	
Identify relevant standards for interoperability: - Identify the frequently used standards and *de facto* standards in the enterprise environment (including partners, providers, clients, etc.)		Standards shall be used for alignment with other business models	
Use relevant standards for interoperability: - Relevant standards are used to facilitate the alignment with other business models		Standards shall be used for alignment with other business models	

Fig. 51. Extract of an assessment report: Examples of best practices

Exxus assessment focusing on the interoperability requirement interdependencies

The Exxus assessment followed the same steps as described in the Concept Factory Assessment. However, here we focus on the identified interoperability barriers.

First, the scope of the assessment was defined. The type of assessment chosen was also the potentiality assessment. The assessment framework was the MMEI (Guédria et al., 2015) enriched with the defined interoperability requirements and their interdependencies (see Chapter 3).

In the following step, the same two assessors gathered information by interviewing the CEO and the Chief Operation Officer (COO) of Exxus. They used the same questionnaire applied in the Concept Factory assessment for initiating discussions with the interviewees. Documents provided by Exxus have been also analysed to identify relevant data.

Once the interviews and analysis have been completed, one of the assessors also assumed the role of lead assessor. Then, the lead assessor logged in the proposed KBS prototype, where he entered the information about the assessment scope. The lead assessor gave a name to the assessment (ExxusMaturity), described the purpose of the assessment, and selected the potentiality assessment type and MMEI as the assessment framework. For having a holistic view of the assessed enterprise, the lead assessors selected all Interoperability Layers and Concerns. Fig. 52 illustrates the scope of the Exxus maturity assessment.

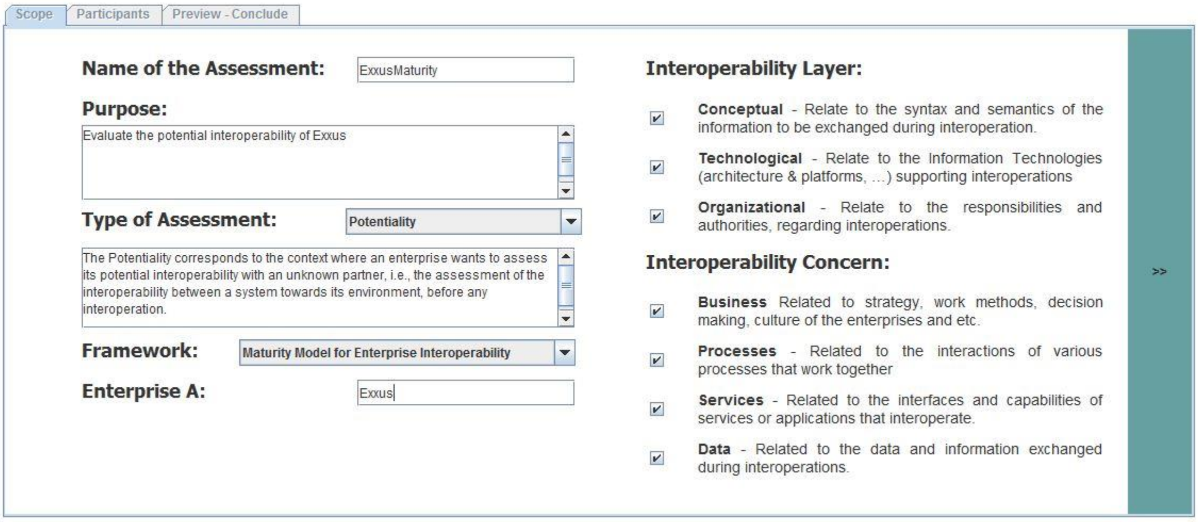


Fig. 52. Screenshot of the Exxus assessment: Scope definition scope

Having created this assessment, the lead assessors sent a notification for the concerned assessors. The assessors, then, logged in their accounts and completed the concerned ExxusMaturity assessment. Next, the assessors sent a notification through the KBS to the lead assessor. The latter then aggregated the ratings in order to obtain the final score for each interoperability requirement. Table 50 depicts the summary of the ExxusMaturity assessment considering each interoperability area: Business-Conceptual (BC), Business- Technological (BT), Business-Organisational (BO), Process-Conceptual (PC), Process-Technological (PT), Process-Organisational (PO), Service-Conceptual (SC), Service-Technological (ST), Service-Organisational (SO), Data-Conceptual (DC), Data- Technological (DT) and Data-Organisational (DO).

Table 50. Exxus assessment: the evaluation criteria rating

Area	ID	Rate	Area	ID	Rate	Area	ID	Rate	Area	ID	Rate
BC	BCR1	PA	PC	PCR1	LA	SC	SCR1	LA	DC	DCR1	LA
	BCR2	NA		PCR2	NA		SCR2	NA		DCR2	NA
	BCR3	PA		PCR3	NA		SCR3	NA		DCR3	NA
	BCR4	NA		PCR4	NA		SCR4	NA		DCR4	NA
BT	BTR1	LA	PT	PTR1	FA	ST	STR1	PA	DT	DTR1	FA
	BTR2	LA		PTR2	PA		STR2	PA		DTR2	NA
	BTR3	NA		PTR3	PA		STR3	NA		DTR3	NA
	BTR4	NA		PTR4	NA		STR4	NA		DTR4	NA
BO	BOR1	LA	PO	POR1	FA	SO	SOR1	FA	DO	DOR1	LA
	BOR2	PA		POR2	PA		SOR2	NA		DOR2	LA
	BOR3	NA		POR3	PA		SOR3	NA		DOR3	PA
	BOR4	NA		POR4	NA		SOR4	NA		DOR4	NA

In the next step, the lead assessor launched the automatic assessment results generation. Therefore, the KBS instantiated the embedded knowledge model, i.e. the OIA, with the validated assessment information (i.e. the requirements rating, the type of assessment, etc.). It was followed by the reasoning and inference of knowledge considering the assessment information. Fig. 53 shows the instantiated ontology. Note that the term “EntA”, in Fig. 53, is applied for identifying the assessed enterprise, i.e. Exxus.

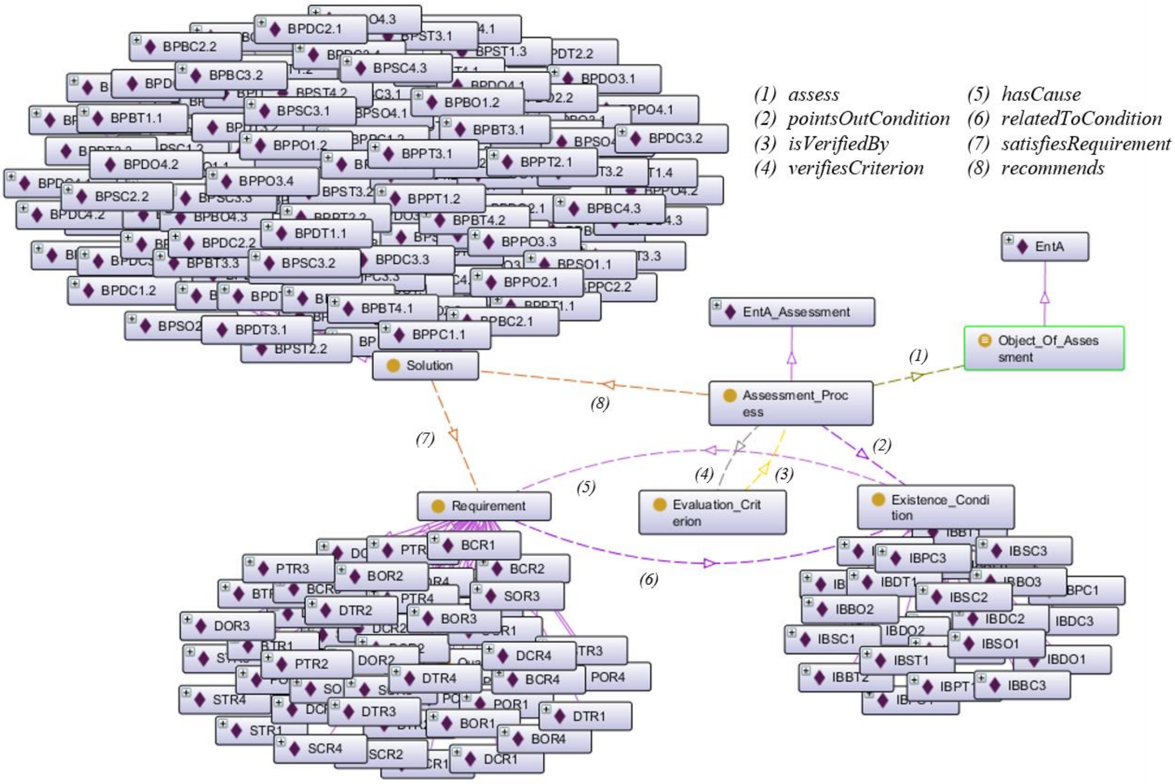


Fig. 53. The instantiated ontology visualisation using Protégé

Finally, the results were generated and available to be downloaded as a PDF document. Considering the MMEI measurement mechanism (Guédria et al., 2015), (see Annexe B for more details), Exxus obtained a maturity equal to "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; its enterprise systems run stand-alone and are not prepared for interoperation. Enterprise modelling is not done or done in an ad-hoc and inconsistent manner. Information exchange with external systems is mainly performed manually. No formal framework is in place, and the existing infrastructure frequently fails or does not support efficient communication.

It is important to note that a lower interoperability maturity for a company does not systematically mean a dysfunction at all levels and for all functions of the company. The maturity is only evaluated from the interoperability point of view and cannot be applied for another purpose (e.g. product quality or financial performance). Table 51 summarises the encountered interoperability barriers.

Table 51. Interoperability barriers from Exxus

Concern	Barrier	Description
Data, Service, Process	Semantic incompatibilities	Different languages are used in the project execution. There are no formalised documents describing the overall services. The collaborative services and processes are performed based on experience, oral agreements, and based on memory.
Data, Service, Process, Business	Syntax incompatibilities	Concerning data models, different document formats are used. As there are no documents describing services and processes, they are expressed in different forms (e.g. the services can be defined in various languages with varying levels of formalism as the information about them are in the employees' minds).
Data	Lack of guidelines for data management	Data is manipulated without any restriction. It can be observed in all the processes.
Process	Incompatible business process behaviour	The sequences of processes' activities in the business scenarios are defined on the fly.
Service	Interface incompatibilities	Most of the interfaces are human-based, and the involved actors do not master all the necessary languages. In addition, the software application used in the collaborative processes are from different providers, and not always compatible.
Service	Lack of resource control	Incompatibility of the allocated resources with the needed service.
Business	IT structure fails to support all network business activities	There is no integrated project management application supporting the project follow-up.
Business	Organisational structure incompatibilities	In an operational view, the enterprise adopts a flat structure. Each project manager is autonomous to perform processes and services. However, there is no explicit specification of relationships within the organisation structure. The responsibilities and authorities are written in the employee job description but not shared with the whole organisation.

For illustrating the identified barriers, Fig. 54 presents the interoperability requirements related to enterprise elements (processes, information systems, etc.) from Exxus. A red lightening represents the identified potential interoperability problems.

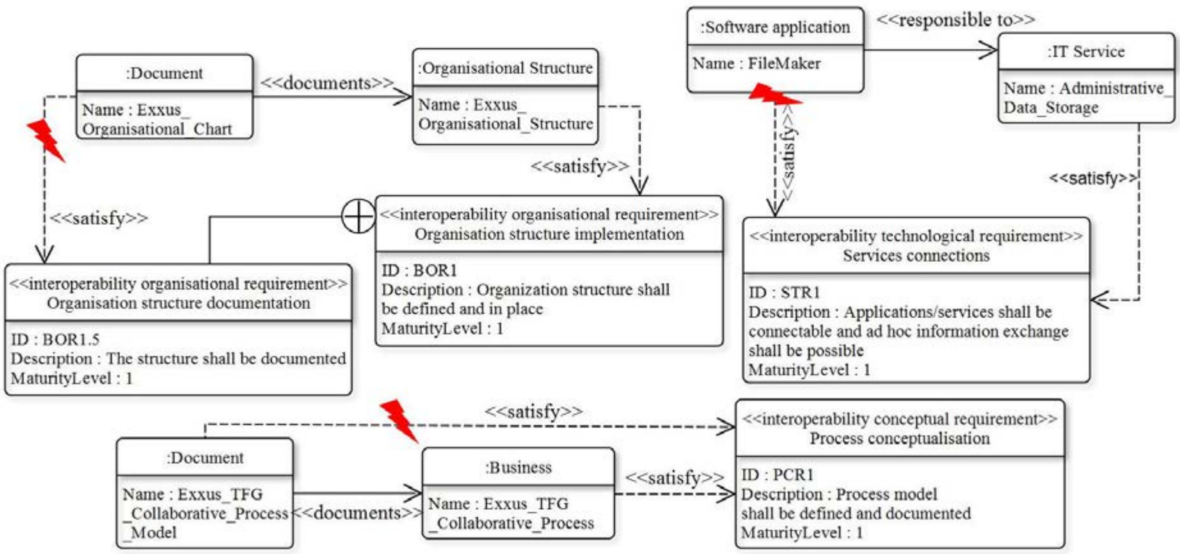


Fig. 54. Exxus Assessment: Identification of potential interoperability barriers

Indeed as illustrated in Fig. 54, a potential barrier to interoperability can occur, as the Exxus_TFG_Collaborative_Process_Model is not documented. Note that it does not means that the Exxus_TFG_Collaborative_Process is underperforming, but that misalignment with potential partners can happen within a collaboration as process information are not documented.

An organisational barrier can emerge as concerning the responsibilities and authorities of concerned employees (e.g. those working in collaborative processes). It is due to the lack of an organisational chart describing the relations between the different actors of Exxus. This barrier does not immediately influence the current state of Exxus, as they are five employees.

However, it should be taken into account when expanding and hiring new employees. Finally, we also identified a potential technological barrier regarding the storage of administrative data. It is because the access to the software application FileMaker is difficult. Indeed, Exxus employees should request the installation of a virtual machine in their computers or otherwise ask the information directly to the concerned employee or unit. The latter can cause disturbances in the defined information flow. It can also be difficult to ensure information robustness within the enterprise and partners if the information is dispersed in different databases.

Based on these results, a list of best practices have been provided for removing or at least reducing the negative impacts of the identified interoperability barriers. Table 52 describes, as an example, the best practices related to the requirement *PCR1. Process models shall be defined and documented*.

Table 52. 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

5.2 Evaluating the proposed contribution based on the TFG case study

5.2.1 The verification of the requirements for developing computer-mediated tools

In this section, we verify the needed requirements to develop our KBS prototype based on the defined requirements in Section 4.2. There are two kinds of requirements: **Functional** regarding the basic functionalities that a computer-mediated tool should have, and **Non-Functional** referring to the characteristics that a computer-mediated assessment tool must satisfy. Table 53 focuses on the evaluation regarding the Non-Functional Requirements and Table 54 focuses on the Functional Requirements. An observation for each requirement is also given.

Table 53. Evaluation of Non-Functional Requirements for developing computer-mediated tools

Requirement		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.
	Extensibility	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.
	Support of different scale levels	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.

Table 54. Evaluation of Functional Requirements for developing computer-mediated tools

Requirement		Verification	Observation
Functional	Create and delete user	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, pre-defined 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.

Regarding the consistency of the proposed Ontology of Interoperability Assessment, we used the debugger implement within the Protégé tool. Fig. 55 presents the Protégé screenshot showing the results of the debugging.

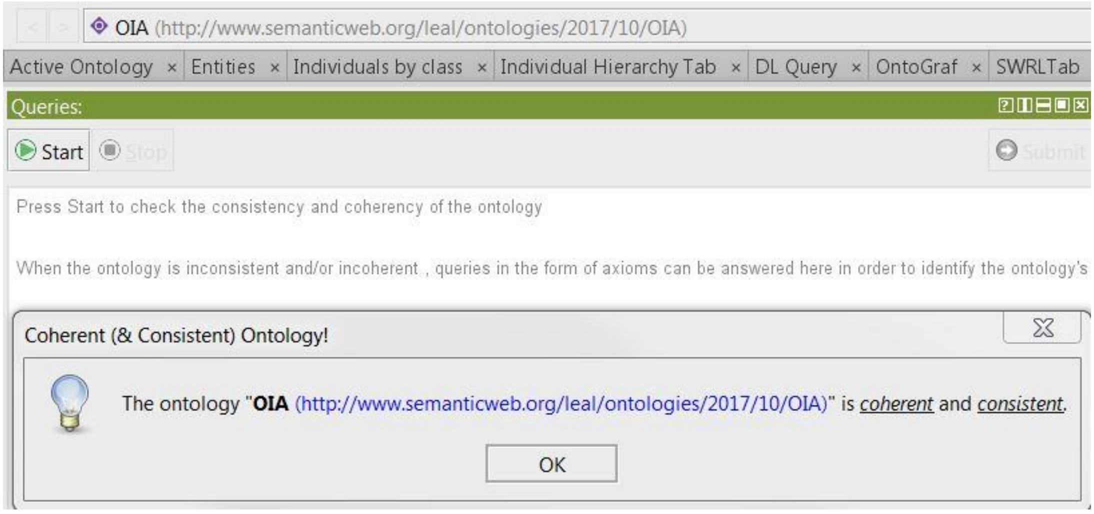


Fig. 55. Screenshot illustrating the OIA debugging through the Protégé tool.

5.2.2 The performance evaluation

For evaluating the performance of the proposed contribution, we conducted the entire assessment of Exxus twice. As for performance indicators, we considered the quality, time and cost of the assessments. Regarding the quality, we consider the completeness of the assessment results, i.e. if the interoperability requirements interdependencies were considered. For calculating the total cost, we consider that the salary of an Assessor in Luxembourg is about 19€ per hour. Note that this cost represents only the time spent by the Assessors for performing the assessment. It does not consider the travel expenses of the Assessors nor the time spent by the CEO, COO and the other employees involved in the assessment process. The time indicator refers to the time spent to perform each activity.

We first performed a traditional manually conducted assessment using MMEI without considering the defined requirements interdependencies. Next, we conducted the assessment using the proposed INAS approach and the KBS prototype. It allowed us to compare the efficiency of both assessments and identify the advantages and limitations of our contribution. The manually conducted and computer-mediated assessments are presented next and followed by a discussion summarising the differences between the assessments.

For the ***manually conducted assessment (without requirements interdependencies)***; first, the assessment scope was defined by the Lead Assessor together with the CEO and the COO of Exxus. Having the scope defined, the assessment team composed of three Assessors was defined. This step was concluded in a three hours meeting. Next, the information gathering and analysis was performed. The Assessors prepared their questionnaires considering the defined scope, which took an average of 2 hours per Assessor.

Further, they conducted semi-structured interviews with the CEO and COO, individually. Each interview took 3 hours, representing a total of 18 hours for the six interviews. The meetings were fixed over a month according to the CEO and COO's availability. In parallel of the interviews, the Assessors also analysed documents provided by Exxus. This analysis plus the summary of the interviews took about 16 hours per Assessor. Feedback sessions were also organised for validation. These sessions were conducted over two weeks. Each one of them took 2 hours on average per Assessor.

Once the information was validated, each Assessor gave a rating to the concerned evaluation criteria. This work was done individually, and each Assessor spent about 8 hours. For obtaining the final rating of each evaluation criteria, the Lead Assessor aggregated the ratings provided by the other Assessors. The Lead Assessors spent 15h for aggregating and verifying the ratings. Finally, the Lead Assessor took 8 hours for determining the maturity level and identifying the interoperability problems and related solutions. The generation of the assessment report took another 5 hours as the Lead Assessor had to synthesise the scope of the assessment, the ratings and comments from the Assessors, the final rating, the determined maturity level as well as the identified problems and proposed solutions. The total time spent on conducting this manual-conducted assessment, from the assessment scope definition to the report generation, was equal to 139 hours.

For ***the computer-mediated assessment***, we followed the assessment process defined in section 5.3, for evaluating the interoperability of Exxus. The assessment preparation (including the scope and team assessment definition) only took 2 hours. This was due to the following: (1) the KBS created the assessment and stored its information automatically, which avoided the manual description of the scope. (2) Notifications to Assessors were sent automatically once the assessment was created. It was also easier for the Assessors to prepare the questionnaire, because the KBS offered a set of predefined criteria, respecting the defined scope. Hence, this took 30 minutes per Assessor, instead of 2 hours. The rest of the information gathering and analysis activities took the same as the manual-conducted assessment, i.e. 78 hours.

An improvement regarding the criteria rating was also observed. Indeed, during this step, each Assessor spent an average of 1 hour as the KBS allowed entering the rating, comments and documents and saved them automatically. Once all Assessors completed the assessment, the Lead Assessor launched the aggregation function. The KBS calculated the final rating of each criterion in 1 second. For generating the final results (including the defined maturity level, and the identified problems and solutions), the KBS took 31 seconds. Finally, for generating the assessment, the KBS took only 11 seconds, since the report's structure was predefined and the information was filled automatically by the PDF generator component. Fig. 56 shows an extract of the runtime output of the KBS. This extract is from the NetBeans "runtime output" module. The code was adapted for showing the time at which the steps started and finished.

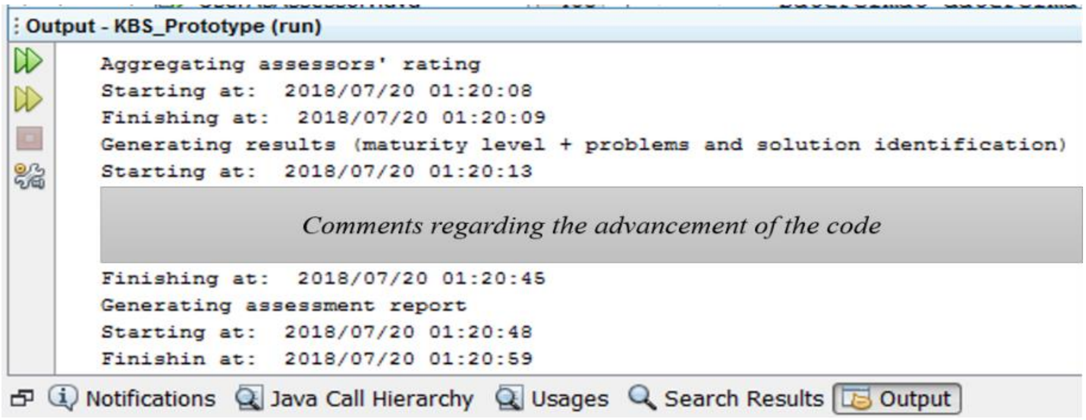


Fig. 56. Time spent by aggregating ratings, generating results and the assessment report.

The total time spent in hours for conducting the computer-mediated assessment, from the assessment scope definition to the report generation, was equal to 84 hours 30 minutes and 43 seconds. In summary, the application of the manual and computer-mediated assessments, allowed us to compare their performance in terms of time, quality and cost. Fig. 57 illustrates the time spent on each activity and summarises the performance indicators.

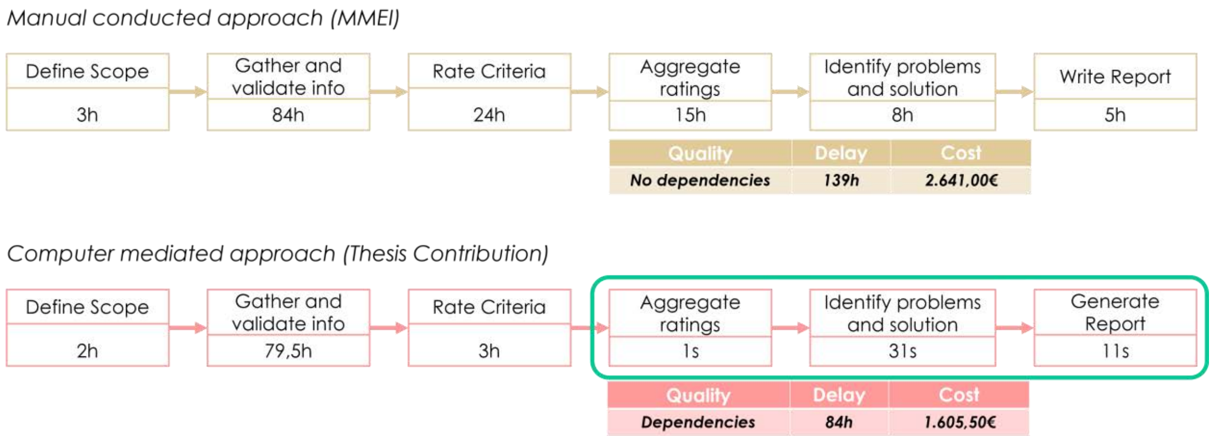


Fig. 57. Difference between the manual-conducted and the semi-automated assessments

Hence, taking into account both assessments, we observe a reduction of 55 hours when using the KBS for conducting the assessment, meaning a reduction of 39% of the total cost of the manual-conducted assessment.

General conclusion

Introduction

This thesis contributes to the INteroperability ASsessment (INAS) domain by proposing a holistic INAS approach supported by a Knowledge-Based System (KBS). The proposed approach and the related KBS can evaluate a plethora of Interoperability Requirements (IRs) and identify the potential problems due to their non-compliance along with the potential solutions for solving the identified problems. While other INAS approaches available in the literature have been already providing coverage to multiple interoperability barriers and related requirements, the interdependencies between them were still unexplored. To the best of our knowledge, the contribution proposed in this thesis is the first approach that covers various IRs and their interdependencies.

The developed approach subsumes three distinguished artefacts: the set of the identified IRs and their defined interdependencies; the Ontology of Interoperability Assessment (OIA), which formally conceptualise the knowledge of an INAS (subsuming the relations between IRs, interoperability problems and interoperability solutions); and the KBS for semi-automating activities from the INAS process, such as the interoperability barriers identification and the assessment report generation. The KBS uses the proposed OIA as the knowledge model and the Maturity Model for Enterprise Interoperability (MMEI) (Guédria et al., 2015) as the instantiated assessment model. For the development of the overall contribution, we followed the Design Science Research methodology defined by (Peffers et al., 2007). This methodology provided the necessary steps for the identification of the objectives, motivation, development and evaluation of the thesis contribution.

The rest of this chapter presents a summary of the contribution and brings forward some perspectives. First, we revisit the research problem, the state-of-the-art limitations as well as an overview of our contribution. After that, we identify directions for future research.

Summary of the thesis

In Chapter 1, we discussed the importance of interoperability within networked enterprises. We asserted that in certain cases to deal with challenges (e.g. new technologies and globalisation); enterprises are progressively collaborating with other companies and participating in collaborative networks. Taking into account this context, we argued that a significant issue faced by the business networks is the improvement of the interoperability between their enterprise systems (e.g. software applications, organisational units, etc.) while ensuring the alignment between those systems.

Hence, to achieve a higher quality of interoperability and ensure effective collaboration, a certain number of requirements should be satisfied. Such requirements are called Interoperability Requirements. We also described the importance of the alignment between these requirements. Indeed, the non-fulfilment or changes in requirements can cause negative impacts on the overall system. Therefore, as soon as these IRs are not achieved, interoperability becomes a problem that must be solved. Hence, enterprises can benefit from the application of INAS approaches for identifying their strengths and weaknesses regarding interoperability (i.e. the IRs compliance) and for predicting potential problems before they occur.

For investigating the INAS state-of-the art, we conducted a systematic literature review in Chapter 2. It allowed us to identify relevant assessment approaches regarding interoperability. Based on the review results, we identified two significant limitations, which can be highlighted as: (1) the interdependencies between IRs are not explicitly defined nor formalised. Indeed, their interdependencies should be considered as they can support the identification of impacts on the overall system; (2) the majority of the approaches are manually-conducted, which is a laborious and time-consuming process and in many cases depends on the knowledge of experts which can be expensive in both time and hourly-rate when hiring external consultants.

Taking into account the limitations, we proposed the following research contribution:

"A holistic interoperability assessment approach based on interoperability requirements interdependencies"

For ensuring the pertinence and the development of the research contribution, we considered the following hypothesis:

"A networked enterprise can be seen as a System of Systems composed of at least two autonomous systems (enterprises) that collaborate and interoperate during a period of time to reach a shared objective that cannot be reached by an individual alone"

In order to address the identified limitations and develop our contribution, we formulated three research questions:

"(RQ1) What are the existing interoperability requirements, their interdependencies and their potential impacts on the overall system?"

"(RQ2) How to formally represent the knowledge related to the interoperability assessment, including interoperability requirements and their interdependencies?"

"(RQ3) How to assess the interoperability coherently, considering the multiplicity of interoperability requirements, for supporting decision-making regarding interoperability development?"

Chapter 3 addressed the first question. We studied the literature related to systems' requirements and the current work regarding INAS. Based on the Requirement Engineering (RE) domain, we proposed a RE approach for identifying and formalising the IRs interdependencies. This iterative process subsumes four main activities as described hereinafter:

- *Interoperability Requirement Elicitation*, which is based on a systematic literature review of existing INAS approaches. Existing INAS approaches were also studied for identifying evaluation criteria that can be seen as requirements;

- *Interoperability Requirement Decomposition and Formalisation* done based on the adapted formalisation method proposed in (Peres et al., 2012);
- *Interoperability Requirement Architecture Design*, which followed a similar design approach as the one used by the European Commission on developing the European Interoperability Reference Architecture (EIRA) (European Commission, 2018a); Thus, we model the relations between each interoperability requirement to an enterprise element (e.g. actor, software application) using the UML notation (OMG, 2017b).
- *Interoperability Requirement Interdependencies Identification,* which is based on the Strategic Alignment through Enterprise Architecture (EA) literature. Based on the relationships among enterprise systems defined in the third activity and EA research, we inferred the relationships between IRs.

To answer the second question, we developed the OIA in Chapter 4. The aims of this ontology are: (i) to provide a sound description of the relevant concepts, relationships, and reasoning rules related to INAS, (ii) to represent and formalise knowledge concerning IRs, (iii) to provide the ability to infer potential problems and transformations that an enterprise can face, based on IRs interdependencies, and (iv) to enable information sharing and reusability, regarding interoperability issues.

We followed the guidelines for ontology design proposed by both (Horridge et al., 2004) and (Noy and McGuinness, 2001) for developing the OIA. The latter guidelines provide generic steps to be followed for identifying relevant concepts and their relationships to be considered in the concerned ontology. The former is useful for implementing the designed ontology in the Protégé tool, using the Web Ontology Language (OWL). Note that the Model-Based System Engineering (INCOSE, 2015) was also used for organising and conceptually modelling the selected concepts and relationships, before implementing the ontology in Protégé.

To address the third question, we first proposed to improve the current version of the MMEI with the identified IRs. We organised the IRs on the MMEI levels of maturity according to their related areas and the established interdependencies among the requirements. Besides, we argued that the development of a KBS empowered by the proposed OIA, as the knowledge model is useful for supporting the INAS process. We followed the approach defined by (Krivograd and Fettke, 2012) for developing the KBS. Such an approach aims at determining functional and non-functional requirements for the development of a generic tool for the application of maturity models.

Finally, in Chapter 5, we evaluated our contribution trough a case study based on a real networked enterprise: The Factory Group. Furthermore, analyses considering the case study findings and a more technical evaluation were done. The latter focus on: evaluating the functional and non-functional requirements proposed by (Krivograd and Fettke, 2012) regarding the development of a KBS; and analysing the coherence and consistency of the proposed OIA. The former evaluation focused on how well the proposed computer-mediated approach performs, regarding execution time and cost. More details can be found in Chapter 5.

Perspectives for future research work

The work presented in this thesis induces several other research paths and questions that can be considered in the future:

- The gathering of information is done mainly through interviews and workshops. Therefore, 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.
- The implementation of a component for supporting the prioritisation of solutions. The current version of the KBS provides a list of best practices for avoiding potential barriers and removing those already existing. 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

Besides the perspectives that are derived from our contribution, we can also point out some relevant research directions such as:

- The interoperability performance assessment approaches can consider interoperability barriers. Based on the conducted INAS literature review in Chapter 2, we observed that the current performance assessment approaches are not explicitly considering interoperability barriers and their interdependencies. Therefore, an investigation for identifying Key Performance Indicators (KPI) interdependencies regarding interoperability barriers can help the identification of indicators' correlations. The correlations can support the performance assessment, as they can highlight potential influences considering different layers of interoperability. The literature regarding Performance Measurement Systems (PMS) (Camara et al., 2014), (Neely et al., 2000) and collaboration performance frameworks and metrics (Camarinha-Matos and Abreu, 2007), (Westphal et al., 2007), (Ramanathan et al., 2011) can be assets for designing interoperability performance frameworks and for identifying relevant Key Performance Indicators for interoperability. A more detailed discussion regarding the association of PMS and the INAS can be found in (da Costa Castro et al., 2017). For example, generic KPI for the conceptual layer could be (1) the percentage of information lost during the exchange between two information systems; (2) the time for exchanging information between two systems; (3) the time for translating the requested information (in the case of the considered system are using different data semantics). Referring to the technological layer, the following KPI could be considered: (1) the percentage of failed connections between two systems; (2) the time for translating the requested information (in the case of the considered system using different data syntax). Finally, considering the organisational layer: (1) the percentage of the times when the absence of an employee caused any delay in the interoperations; (2) the percentage of the times when interoperations failed because resources (human and non-human) were not allocated. However, it is important to note that KPI should reflect the reality of the considered context and sectors of activity (e.g. healthcare, manufacturing and financial sectors).

- The improvement of measurement mechanisms. From the early propositions of INAS approaches to late early 2010, we remarked that few of them were proposing a combination of qualitative and quantitative measures. Indeed, many of the proposed maturity models do not define a threshold for delineating the different proposed maturity levels, which can cause ambiguity and misinterpretation when multiple experts are assessing the same system. Furthermore, some INAS approaches based on quantitative measures do not explicitly define the meaning of their numeric results. Therefore, we argue that new contributions should keep proposing this combination of measures for attributing rates in an objective and meaningful manner, i.e. combining both quantitative and qualitative measures. For that reason, techniques such as the AHP/ANP method (Saaty, 2004) and the fuzzy logic methods (Lee, 1990), (Zadeh, 1996) are assets for improving the measurement mechanisms.

Glossary

Glossary based on the definitions from the Framework for Enterprise Interoeprability (Chen, Dassisti, Elvesaeter et al., 2007) and the European Interoperability Framework (EIF, 2017)

Interoperability	The ability for two (or more) systems or components to exchange information and to use the information that has been exchanged
Interoperation	The effective exchange and use of information between two systems. Requires Interoperability.
Interoperate	The act to realize interoperations.
Interoperable	A system that can interoperate with another systems without its self-degradation.
Enterprise interoperability	Ability of interaction between enterprises (or part of it).
Interoperability layer	Describes the different aspect of interoperability, such as the conceptual, technological an organisational.
Interoperability barrier	Incompatibility of various natures between two parts (system, data, application, etc.) There are three types of barriers: conceptual, technological, organisational
Interoperability concern	Content or view of interoperation between two parts. There are four concerns: data, service, process, business.
Interoperability approach	Way in which a solution removes an interoperability barrier. There are three basic approaches: integrated, unified, and federated

Views of interoperability	Way in which interoperability is defined: It can be seen as a problem when two incompatible systems interact, as a goal to be reach by a system and as a requirement inside a systems and a requirement to be met when two systems interact.
Interoperability problem	Phenomena or manifestation observed when there is a non-interoperability. Interoperability problem is caused by one or several interoperability barriers.
Interoperability solution	Method/ process of solving an interoperability problem by removing an interoperability barrier. There are two types of solution: conceptual (independent of a technology) and technological
Interoperability measure	Act consisting in evaluating interoperability. There are three types of measure: potentiality, compatibility and performance
Interoperability degree	Result of an interoperability measure allowing to characterise the level (or importance) of interoperability
Interoperability knowledge	What is known (fact, information, skill…) in the interoperability domain.
Interoperability issue	A subject of discussion related to any combination of interoperability problem, solution and concept in the domain
Interoperability requirement	A statement that specifies a function, ability or characteristic, related to the ability of a partner to ensure its partnership in terms of compatibility, interoperation, autonomy, and reversibility, that it must satisfy''.
Networked Enterprise	a System of Systems composed of at least two autonomous systems (enterprises) that are collaborating during a period of time to reach a shared objective
Enterprise	a complex adaptive system, which is stimulated by extensive and resilient sensorial capabilities that can detect physical and virtual stimulus, recognising the context of specific situations and responding and reacting accordingly
Collaborative Enterprise System	represents the enterprise systems that collaborate with systems from other enterprises within the NE

Bibliography

ABILITIES Working Group, 2008. Application bus for Interoperability in enlarged Europe SMEs (ABILITIES) [WWW Document]. URL https://cordis.europa.eu/project/rcn/79358_en.html (accessed 7.30.18).

Ackoff, R.L., 1971. Towards a System of Systems Concepts. Management Science 17, 661–671. https://doi.org/10.1287/mnsc.17.11.661

Agostinho, C., Ducq, Y., Zacharewicz, G., Sarraipa, J., Lampathaki, F., Poler, R., Jardim-Goncalves, R., 2016. Towards a sustainable interoperability in networked enterprise information systems: Trends of knowledge and model-driven technology. Computers in Industry 79, 64–76. https://doi.org/https://doi.org/10.1016/j.compind.2015.07.001

Ahn, J., Lee, J.S., Kim, H.J., Hwang, D.J., 2016. Smart city interoperability framework based on city infrastructure model and service prioritization, in: 2016 Eighth International Conference on Ubiquitous and Future Networks (ICUFN). IEEE, Vienna, Austria, pp. 337–342. https://doi.org/10.1109/ICUFN.2016.7537044

Alalwan, J., Thomas, M., 2012. An Ontology-based Approach to Assessing Records Management Systems. e-Service Journal 8, 24. https://doi.org/10.2979/eservicej.8.3.24

Alemany, M.M.E., Alarcón, F., Lario, F.C., Poler, R., 2010. Conceptual Framework for the Interoperability Requirements of Collaborative Planning Process, in: Popplewell, K., Harding, J., Poler, R., Chalmeta, R. (Eds.), Enterprise Interoperability IV: Making the Internet of the Future for the Future of Enterprise. Proceedings of I-ESA 2010. Springer London, Coventry, UK, pp. 25–34. https://doi.org/10.1007/978-1-84996-257-5_3

Allee, V., 2008. Value network analysis and value conversion of tangible and intangible assets. Journal of Intellectual Capital 9, 5–24. https://doi.org/10.1108/14691930810845777

Alonso, J., de Soria, I., Orue-Echevarria, L., Vergara, M., 2010. Enterprise Collaboration Maturity Model (ECMM): Preliminary Definition and Future Challenges, in: Popplewell, K., Harding, J., Poler, R., Chalmeta, R. (Eds.), Enterprise Interoperability IV: Making the Internet of the Future for the Future of Enterprise, Proceedings of I-ESA 2010. Springer London, Coventry, UK, pp.

429–438. https://doi.org/10.1007/978-1-84996-257-5_40

Amanowicz, M., Gajewski, P., 1996. Military communications and information systems interoperability, in: Proceedings of MILCOM '96 IEEE Military Communications Conference. IEEE, McLean, VA, USA, pp. 280–283 vol.1. https://doi.org/10.1109/MILCOM.1996.568629

Amyot, D., Ghanavati, S., Horkoff, J., Mussbacher, G., Peyton, L., Yu, E., 2010. Evaluating goal models within the goal-oriented requirement language. International Journal of Intelligent Systems 25, 841–877. https://doi.org/10.1002/int.20433

Amyot, D., Mussbacher, G., 2011. User Requirements Notation: The First Ten Years, The Next Ten Years (Invited Paper). Journal of Software 6. https://doi.org/10.4304/jsw.6.5.747-768

ATHENA Working Group, 2007. D.A4.2: Specification of Interoperability Framework and Profiles, Guidelines and Best Practices.

Auzelle, J.-P., 2009. Proposition d'un cadre de modélisation multi-échelles d'un système d'information en entreprise centré sur le produit. Université Henri Poincaré.

Aversano, L., Grasso, C., Tortorella, M., 2012. A Literature Review of Business/IT Alignment Strategies. Procedia Technology 5, 462–474. https://doi.org/10.1016/j.protcy.2012.09.051

Backman, J., Väre, J., Främling, K., Madhikermi, M., Nykänen, O., 2016. IoT-based interoperability framework for asset and fleet management, in: 2016 IEEE 21st International Conference on Emerging Technologies and Factory Automation (ETFA). IEEE, Berlin, Germany, pp. 1–4. https://doi.org/10.1109/ETFA.2016.7733680

Basole, R.C., Rouse, W.B., McGinnis, L.F., Bodner, D.A., Kessler, W.C., 2011. Models of Complex Enterprise Networks. Journal of Enterprise Transformation 1, 208–230. https://doi.org/10.1080/19488289.2011.601397

Basson, H., Bouneffa, M., Matsuda, M., Ahmad, A., Chung, D., Arai, E., 2016. Qualitative Evaluation of Manufacturing Software Units Interoperability Using ISO 25000 Quality Model, in: Mertins, K., Jardim-Gonçalves, R., Popplewell, K., Mendonça, J.P. (Eds.), Enterprise Interoperability VII: Enterprise Interoperability in the Digitized and Networked Factory of the Future, Proceedings of the I-ESA Conferences. Springer, Cham, Guimarães, Portugal, pp. 199–209. https://doi.org/10.1007/978-3-319-30957-6_16

Behrmann, G., David, A., Larsen, K.G., 2004. A Tutorial on Uppaal, in: Bernardo, M., Corradini, F. (Eds.), Formal Methods for the Design of Real-Time Systems: International School on Formal Methods for the Design of Computer, Communication, and Software Systems, Bertinora, Italy, September 13-18, 2004, Revised Lectures. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 200–236. https://doi.org/10.1007/978-3-540-30080-9_7

Bharambe, U., Durbha, S.S., King, R.L., Younan, N.H., Kurte, K., 2016. Use of geo-ontology matching to measure the degree of interoperability, in: 2016 IEEE International Geoscience and Remote Sensing Symposium (IGARSS). IEEE, Beijing, China, pp. 7601–7604.

https://doi.org/10.1109/IGARSS.2016.7730982

Bhuta, J., Boehm, B., 2007. A Framework for Identification and Resolution of Interoperability Mismatches in COTS-Based Systems, in: IWICSS ’07 Proceedings of the Second International Workshop on Incorporating COTS Software into Software Systems: Tools and Techniques. IEEE Computer Society Washington, DC, Minneapolis, MN, USA, p. 2. https://doi.org/10.1109/IWICSS.2007.1

Boardman, J., Sauser, B., 2006. System of Systems - the meaning of of, in: 2006 IEEE/SMC International Conference on System of Systems Engineering. IEEE, Los Angeles, CA, USA, pp. 118–123. https://doi.org/10.1109/SYSOSE.2006.1652284

C4ISR, 1998. Levels of Information System Interoperability (LISI). Washington, DC, USA.

Camara, M., Ducq, Y., Dupas, R., 2012. A Methodology for Interoperability Evaluation in Supply Chains based on Causal Performance Measurement Models, in: Poler, R., Doumeingts, G., Katzy, B., Chalmeta, R. (Eds.), Enterprise Interoperability V. Proceedings of the I-ESA Conferences. Springer London, Valencia, Spain, pp. 3–13. https://doi.org/10.1007/978-1-4471-2819-9_1

Camara, M., Ducq, Y., Dupas, R., 2010. Methodology for Prior Evaluation of Interoperability, in: Camarinha-Matos, L.M., Boucher, X., Afsarmanesh, H. (Eds.), Collaborative Networks for a Sustainable World: 11th IFIP WG 5.5 Working Conference on Virtual Enterprises, PRO-VE 2010. Springer Berlin Heidelberg, St. Etienne, France, pp. 697–704. https://doi.org/10.1007/978-3-642-15961-9_82

Camara, M.S., Ducq, Y., Dupas, R., 2014. A methodology for the evaluation of interoperability improvements in inter-enterprises collaboration based on causal performance measurement models. International Journal of Computer Integrated Manufacturing 27, 103–119. https://doi.org/10.1080/0951192X.2013.800235

Camarinha-Matos, L.M., Abreu, A., 2007. Performance indicators for collaborative networks based on collaboration benefits. Production Planning & Control 18, 592–609. https://doi.org/10.1080/09537280701546880

Camarinha-Matos, L.M., Afsarmanesh, H., 2008. The ARCON modeling framework, in: Camarinha-Matos, L.M., Afsarmanesh, H. (Eds.), Collaborative Networks: Reference Modeling. Springer US, Boston, MA, pp. 67–82. https://doi.org/10.1007/978-0-387-79426-6_7

Camarinha-Matos, L.M., Afsarmanesh, H., 2006. Collaborative Networks: Value creation in a knowledge society, in: Wang, K., Kovács, G.L., Wozny, M.J., Fang, M. (Eds.), Knowledge Enterprise: Intelligent Strategies in Product Design, Manufacturing, and Management. Proceedings of PROLAMAT 2006, IFIP TC5 International Conference. Springer Boston, MA, Shanghai, China, pp. 26–40. https://doi.org/10.1007/0-387-34403-9_4

Camarinha-Matos, L.M., Afsarmanesh, H., 2005. Collaborative networks: a new scientific discipline. Journal of Intelligent Manufacturing 16, 439–452. https://doi.org/10.1007/s10845-005-1656-3

Camarinha-Matos, L.M., Afsarmanesh, H., Galeano, N., Molina, A., 2009. Collaborative networked organizations – Concepts and practice in manufacturing enterprises. Computers & Industrial Engineering 57, 46–60. https://doi.org/10.1016/j.cie.2008.11.024

Campos, C., Chalmeta, R., Grangel, R., Poler, R., 2013. Maturity Model for Interoperability Potential Measurement. Information Systems Management 30, 218–234. https://doi.org/10.1080/10580530.2013.794630

Carlsson, S.A., Henningsson, S., Hrastinski, S., Keller, C., 2011. Socio-technical IS design science research: developing design theory for IS integration management. Information Systems and e-Business Management 9, 109–131. https://doi.org/10.1007/s10257-010-0140-6

Castellanos, C., Correal, D., 2013. A Framework for Alignment of Data and Processes Architectures Applied in a Government Institution. Journal on Data Semantics 2, 61–74. https://doi.org/10.1007/s13740-013-0021-5

Castro-Herrera, C., Duan, C., Cleland-Huang, J., Mobasher, B., 2008. Using Data Mining and Recommender Systems to Facilitate Large-Scale, Open, and Inclusive Requirements Elicitation Processes, in: 2008 16th IEEE International Requirements Engineering Conference. IEEE, Catalunya, Spain, pp. 165–168. https://doi.org/10.1109/RE.2008.47

Cestari, J.M.A.P., Loures, E.R., Santos, E.A.P., 2013. Interoperability Assessment Approaches for Enterprise and Public Administration, in: Demey, Y.T., Panetto, H. (Eds.), On the Move to Meaningful Internet Systems: OTM 2013 Workshops: Confederated International Workshops: OTM Academy, OTM Industry Case Studies Program, ACM, EI2N, ISDE, META4eS, ORM, SeDeS, SINCOM, SMS, and SOMOCO 2013. Springer Berlin Heidelberg, Graz, Austria, pp. 78–85. https://doi.org/10.1007/978-3-642-41033-8_13

Chalmeta, R., Pazos, V., 2015. A step-by-step methodology for enterprise interoperability projects. Enterprise Information Systems 9, 436–464. https://doi.org/10.1080/17517575.2013.879212

Chalyvidis, C.E., Ogden, J.A., Johnson, A.W., 2013. Using Supply Chain Interoperability as a Measure of Supply Chain Performance. Supply Chain Forum: An International Journal 14, 52–73. https://doi.org/10.1080/16258312.2013.11517321

Chalyvidis, C.E., Ogden, J.A., Johnson, A.W., Colombi, J.M., Ford, T.C., 2016. A method for measuring supply chain interoperability. Supply Chain Forum: An International Journal 17, 246–258. https://doi.org/10.1080/16258312.2016.1247655

Chandrasekaran, B., Josephson, J.R., Benjamins, V.R., 1999. What are ontologies, and why do we need them? IEEE Intelligent Systems 14, 20–26. https://doi.org/10.1109/5254.747902

Chapurlat, V., Roque, M., 2010. Interoperability Constraints and Requirements Formal Modelling and Checking Framework, in: Vallespir, B., Alix, T. (Eds.), Advances in Production Management Systems. New Challenges, New Approaches. APMS 2009. IFIP Advances in Information and Communication Technology. Springer, Berlin, Heidelberg, Bordeaux, France, pp. 219–226.

https://doi.org/10.1007/978-3-642-16358-6_28

Chen, D., Daclin, N., 2007. Barriers Driven Methodology for Enterprise Interoperability, in: Camarinha-Matos, L.M., Afsarmanesh, H., Novais, P., Analide, C. (Eds.), Establishing the Foundation of Collaborative Networks. PRO-VE 2007. IFIP — The International Federation for Information Processing. Springer, Boston, MA, Guimarães, Portugal, pp. 453–460. https://doi.org/10.1007/978-0-387-73798-0_48

Chen, D., Dassisti, M., Elvesaeter, B., Panetto, H., Daclin, N., Jaekel, F.-W., Knothe, T., Solberg, A., Anaya, V., Gisbert, R.S., Kalampoukas, K., Pantelopoulos, S., Kalaboukas, K., Bertoni, M., Bor, M., Assogna, P., 2007. DI.3: Enterprise Interoperability-Framework and knowledge corpus-Advanced report Deliverable DI.3, INTEROP NoE (Network of Excellence on Interoperability research for Networked Enterprise).

Chen, D., Vallespir, B., Doumeingts, G., 1997. GRAI integrated methodology and its mapping onto generic enterprise reference architecture and methodology. Computers in Industry 33, 387–394. https://doi.org/10.1016/S0166-3615(97)00043-2

Chen, Z.Y., Yao, S., Lin, J.Q., Zeng, Y., Eberlein, A., 2007. Formalisation of product requirements: from natural language descriptions to formal specifications. International Journal of Manufacturing Research 2, 362. https://doi.org/10.1504/IJMR.2007.014730

Chesbrough, H., 2007. Business model innovation: it's not just about technology anymore. Strategy & Leadership 35, 12–17. https://doi.org/10.1108/10878570710833714

Chituc, C.-M., Azevedo, A., Toscano, C., 2009. A framework proposal for seamless interoperability in a collaborative networked environment. Computers in Industry 60, 317–338. https://doi.org/10.1016/j.compind.2009.01.009

Chung, W.W.C., Yam, A.Y.K., Chan, M.F.S., 2004. Networked enterprise: A new business model for global sourcing. International Journal of Production Economics 87, 267–280. https://doi.org/https://doi.org/10.1016/S0925-5273(03)00222-6

Clark, T., Jones, R., 1999. Organisational Interoperability Maturity Model for C2, in: '1999 Command and Control Research Technology Symposium. Command and Control Research Program (U.S.), Newport, Rhode Island.

CMMI Product Team, 2010a. Capability Maturity Model® Integration for Acquisition, Version 1.3. Pittsburgh, PA.

CMMI Product Team, 2010b. Capability Maturity Model® Integration for Services, Version 1.3. Pittsburgh, PA.

CMMI Product Team, 2010c. Capability Maturity Model® Integration for Development, Version 1.3. Pittsburgh, PA.

COIN Working Group, 2011. Collaboration and interoperability for networked enterprises project [WWW Document]. URL http://interop-vlab.eu/coin/

COMMIUS Working Group, 2011. Community-based Interoperability Utility for SMEs project [WWW Document]. URL http://interop-vlab.eu/commius-2/ (accessed 7.30.18).

Cornu, C., 2012. Contribution à la prise en compte de l'interopérabilité pour le déploiement de processus complexes dans une grande entreprise: proposition d'un guide méthodologique outillé pour les processus d'Ingénierie Système. Ecole Nationale Supérieure des Mines de Paris.

Cornu, C., Chapurlat, V., Quiot, J.-M., Irigoin, F., 2012a. Customizable Interoperability Assessment Methodology to support technical processes deployment in large companies. Annual Reviews in Control 36, 300–308. https://doi.org/http://dx.doi.org/10.1016/j.arcontrol.2012.09.011

Cornu, C., Chapurlat, V., Quiot, J.-M., Irigoin, F., 2012b. Interoperability Assessment in the Deployment of Technical Processes in Industry. IFAC Proceedings Volumes 45, 1246–1251. https://doi.org/https://doi.org/10.3182/20120523-3-RO-2023.00348

Cuenca, L., Boza, A., Alemany, M.M.E., Trienekens, J.J.M., 2013. Structural elements of coordination mechanisms in collaborative planning processes and their assessment through maturity models: Application to a ceramic tile company, in: Computers in Industry. pp. 898–911. https://doi.org/10.1016/j.compind.2013.06.019

da Costa Castro, A., Cestari, J.M.A., Loures, E.R., de Lima, E.P., Santos, E.A.P., 2017. Performance Measurement Systems for Designing and Managing Interoperability Performance Measures: A Literature Analysis, in: Amorim, M., Ferreira, C., Vieira Junior, M., Prado, C. (Eds.), Engineering Systems and Networks: The Way Ahead for Industrial Engineering and Operations Management. Springer International Publishing, Cham, pp. 307–315. https://doi.org/10.1007/978-3-319-45748-2_33

da Piedade Francisco, R., Azevedo, A., Almeida, A., 2012. Alignment prediction in collaborative networks. Journal of Manufacturing Technology Management 23, 1038–1056. https://doi.org/10.1108/17410381211276862

da Silva Avanzi, D., Foggiatto, A., dos Santos, V.A., Deschamps, F., de Freitas Rocha Loures, E., 2017. A framework for interoperability assessment in crisis management. Journal of Industrial Information Integration 5, 26–38. https://doi.org/https://doi.org/10.1016/j.jii.2017.02.004

Daclin, N., Chen, D., Vallespir, B., 2016a. Developing enterprise collaboration: a methodology to implement and improve interoperability. Enterprise Information Systems 10, 467–504. https://doi.org/10.1080/17517575.2014.932013

Daclin, N., Chen, D., Vallespir, B., 2008. Methodology for Enterprise Interoperability. IFAC Proceedings Volumes 41, 12873–12878. https://doi.org/https://doi.org/10.3182/20080706-5-KR-1001.02177

Daclin, N., Chen, D., Vallespir, B., 2006. Enterprise interoperability measurement - Basic concepts, in: Missikoff, M., Nicola, A. De, D'Antonio, F. (Eds.), EMOI - INTEROP'06, Enterprise Modelling and Ontologies for Interoperability, Proceedings of the Open Interop Workshop on Enterprise

Modelling and Ontologies for Interoperability, Co-Located with CAiSE'06 Conference, Luxembourg, 5th-6th June 2006. CEUR, Luxembourg, Luxembourg.

Daclin, N., Daclin, S.M., Chapurlat, V., Vallespir, B., 2016b. Writing and verifying interoperability requirements: Application to collaborative processes. Computers in Industry 82, 1–18. https://doi.org/https://doi.org/10.1016/j.compind.2016.04.001

De Bruin, T., Freeze, R., Kaulkarni, U., Rosemann, M., 2005. Understanding the Main Phases of Developing a Maturity Assessment Model, in: Campbell, B., Underwood, J., Bunker, D. (Eds.), Australasian Conference on Information Systems (ACIS). Australasian Chapter of the Association for Information Systems, Sydney, New South Wales, Australia, pp. 8–19.

de Soria, I.M., Alonso, J., Orue-Echevarria, L., Vergara, M., 2009. Developing an enterprise collaboration maturity model: Research challenges and future directions, in: 2009 IEEE International Technology Management Conference (ICE). IEEE, Leiden, Netherlands, pp. 1–8. https://doi.org/10.1109/ITMC.2009.7461411

DeLaurentis, D., Callaway, R.K. "CAB," 2004. A System-of-Systems Perspective for Public Policy Decisions. Review of Policy Research 21, 829–837. https://doi.org/10.1111/j.1541-1338.2004.00111.x

Dhaliwal, J.S., Benbasat, I., 1996. The Use and Effects of Knowledge-Based System Explanations: Theoretical Foundations and a Framework for Empirical Evaluation. Information Systems Research 7, 342–362. https://doi.org/10.1287/isre.7.3.342

Dick, J., Hull, E., Jackson, K., 2017. Requirements Engineering, 4th Ed. ed. Springer International Publishing. https://doi.org/10.1007/978-3-319-61073-3

EIF, 2017. European Interoperability Framework - Implementation Strategy. Annex II of to the communication from the commission to the European parliament, the council, the European economic and social committee and the committee of the regions. Brussels.

Elvesæter, B., Hahn, A., Berre, A.-J., Neple, T., 2006. Towards an Interoperability Framework for Model-Driven Development of Software Systems, in: Konstantas, D., Bourrières, J.-P., Léonard, M., Boudjlida, N. (Eds.), Interoperability of Enterprise Software and Applications. Springer London, London, pp. 409–420. https://doi.org/10.1007/1-84628-152-0_36

Emerson, E.A., Halpern, J.Y., 1986. "Sometimes" and "not never" revisited: on branching versus linear time temporal logic. Journal of the ACM 33, 151–178. https://doi.org/10.1145/4904.4999

ENSEMBLE Working Group, 2012. Envisioning, Supporting and Promoting Future Internet Enterprise Systems Research through Scientific Collaboration project [WWW Document]. URL http://interop-vlab.eu/ensemble/ (accessed 7.30.18).

Eriksson, M., Börstler, J., Borg, K., 2009. Managing requirements specifications for product lines – An approach and industry case study. Journal of Systems and Software 82, 435–447. https://doi.org/10.1016/j.jss.2008.07.046

European Commission, 2018a. An introduction to the European Interoperability Reference Architecture (EIRA©) v2.1.0.

European Commission, 2018b. Interoperability Maturity Assessment of a Public Service: IMAPS v1.1.1 User Guide.

European Commission, 2017. How does the EIRA support interoperability? - EIRA Support Series.

European Commission, 2016a. European agenda for the collaborative economy - supporting analysis, in the Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Brussels.

European Commission, 2016b. Interoperability Maturity Model Guideline.

Fang, J., Hu, S., Han, Y., 2004. A service interoperability assessment model for service composition, in: IEEE International Conference OnServices Computing, 2004. (SCC 2004). Proceedings. 2004. Shanghai, China, pp. 153–158. https://doi.org/10.1109/SCC.2004.1358002

Fewell, S., Clark, T., 2003. Organisational Interoperability: Evaluation and Further Development of the OIM Model, in: Proceedings of the 8th International Command and Control Research and Technology Symposium (ICCRTS). Washington, D.C, USA.

Fewell, S., Richer, W., Clark, T., Warne, L., Kingston, G., 2004. Evaluation of Organisational Interoperabiity in a Network Centric Warfare Environment, in: 9th International Command and Control Research and Technology Symposium. Copenhagen, Denmark.

Ford, T.C., Colombi, J., Graham, S., Jacques, D., 2007a. The Interoperability Score, in: 5th Annual Conference on Systems Engineering Research (CSER). Hoboken, NJ, USA.

Ford, T.C., Colombi, J., Graham, S.R., Jacques, D., 2008. Measuring system interoperability, in: 6th Annual Conference on Systems Engineering Research (CSER). Los Angeles, California USA.

Ford, T.C., Colombi, J.M., Graham, S.R., Jacques, D.R., 2007b. A survey on interoperability measurement, in: International Command and Control Research and Technology Symposium (ICCRTS). Air Force Inst. of Tech. Wright-Patterson AFB OH, Rhode, Greece.

Ford, T.C., Colombi, J.M., Jacques, D.R., Graham, S.R., 2009. A General Method of Measuring Interoperability and Describing Its Impact on Operational Effectiveness. The Journal of Defense Modeling and Simulation: Applications, Methodology, Technology 6, 17–32. https://doi.org/10.1177/1548512909342079

Gallaher, M.P., O'Connor, A.C., Dettbarn Jr., J.L., Gilday, L.T., 2004. Cost analysis of inadequate interoperability in the US capital facilities industry.

Gatti, R., Carbone, L., Mezzapesa, V., 2016. State of Play of Interoperability in Europe - The National Interoperability Framework observatory (NIFO) Report 2016. Luxembourg, Luxembourg. https://doi.org/10.2799/969314

GENESIS Working Group, 2008. Enterprise Application Interoperability via Internet-Integration for SMEs, Governmental Organisations and Intermediaries in the New European Union project

[WWW Document]. URL http://interop-vlab.eu/genesis/ (accessed 7.30.18).

Gerow, J.E., Thatcher, J.B., Grover, V., 2015. Six types of IT-business strategic alignment: an investigation of the constructs and their measurement. European Journal of Information Systems 24, 465–491. https://doi.org/10.1057/ejis.2014.6

Giovannini, A., Aubry, A., Panetto, H., Dassisti, M., Haouzi, H. El, 2012. Ontology-based system for supporting manufacturing sustainability. Annual Reviews in Control 36, 309–317. https://doi.org/http://dx.doi.org/10.1016/j.arcontrol.2012.09.012

Goepp, V., Avila, O., 2015. An Extended-Strategic Alignment Model for technical information system alignment. International Journal of Computer Integrated Manufacturing 28, 1275–1290. https://doi.org/10.1080/0951192X.2014.964774

Gottschalk, P., 2009. Maturity levels for interoperability in digital government. Government Information Quarterly 26, 75–81. https://doi.org/https://doi.org/10.1016/j.giq.2008.03.003

Grambow, G., Oberhauser, R., 2010. Towards Automated Context-Aware Software Quality Management, in: 2010 Fifth International Conference on Software Engineering Advances. IEEE, Nice, France, pp. 347–352. https://doi.org/10.1109/ICSEA.2010.59

Gregor, S., Hevner, A.R., 2013. Positioning and Presenting Design Science Research for Maximum Impact. MIS Quarterly 37, 337–355. https://doi.org/10.25300/MISQ/2013/37.2.01

Gruber, T., 2009. Ontology, in: Liu, L., Özsu, M.T. (Eds.), Encyclopedia of Database Systems. Springer US, Boston, MA, pp. 1963–1965. https://doi.org/10.1007/978-0-387-39940-9_1318

Gruber, T.R., 1995. Toward principles for the design of ontologies used for knowledge sharing? International Journal of Human-Computer Studies 43, 907–928. https://doi.org/10.1006/ijhc.1995.1081

Gruber, T.R., 1993. A translation approach to portable ontology specifications. Knowledge Acquisition 5, 199–220. https://doi.org/10.1006/knac.1993.1008

Guédria, W., 2012. A contribution to enterprise interoperability maturity assessment. Thesis manuscript. Bordeaux 1.

Guédria, W., Chen, D., Naudet, Y., 2009. A Maturity Model for Enterprise Interoperability, in: Meersman, R., Herrero, P., Dillon, T. (Eds.), On the Move to Meaningful Internet Systems: OTM 2009 Workshops: Confederated International Workshops and Posters, ADI, CAMS, EI2N, ISDE, IWSSA, MONET, OnToContent, ODIS, ORM, OTM Academy, SWWS, SEMELS, Beyond SAWSDL, and COMBEK 2009, Vilamoura, Portugal,. Springer Berlin Heidelberg, Vilamoura, Portugal, pp. 216–225. https://doi.org/10.1007/978-3-642-05290-3_32

Guédria, W., Naudet, Y., 2014. Extending the Ontology of Enterprise Interoperability (OoEI) Using Enterprise-as-System Concepts, in: Mertins, K., Bénaben, F., Poler, R., Bourrières, J.-P. (Eds.), Enterprise Interoperability VI - Part of the Proceedings of the I-ESA 2014 Conference. Springer, pp. 393–403. https://doi.org/10.1007/978-3-319-04948-9_33

Guédria, W., Naudet, Y., Chen, D., 2015. Maturity model for enterprise interoperability. Enterprise Information Systems 9, 1–28. https://doi.org/10.1080/17517575.2013.805246

Guédria, W., Naudet, Y., Chen, D., 2011a. A Maturity Model Assessing Interoperability Potential, in: Halpin, T., Nurcan, S., Krogstie, J., Soffer, P., Proper, E., Schmidt, R., Bider, I. (Eds.), Enterprise, Business-Process and Information Systems Modeling: 12th International Conference, BPMDS 2011, and 16th International Conference, EMMSAD 2011, Held at CAiSE 2011, London, UK, June 20-21, 2011. Proceedings. Springer Berlin Heidelberg, London, UK, pp. 276–283. https://doi.org/10.1007/978-3-642-21759-3_20

Guédria, W., Naudet, Y., Chen, D., 2011b. Enterprise Interoperability Maturity: A Model Using Fuzzy Metrics, in: Salinesi, C., Pastor, O. (Eds.), Advanced Information Systems Engineering Workshops: CAiSE 2011 International Workshops, London, UK, June 20-24, 2011. Proceedings. Springer Berlin Heidelberg, London, UK, pp. 69–80. https://doi.org/10.1007/978-3-642-22056-2_8

Guédria, W., Naudet, Y., Chen, D., 2011c. Maturity Model as Decision Support for Enterprise Interoperability, in: Meersman, R., Dillon, T., Herrero, P. (Eds.), On the Move to Meaningful Internet Systems: OTM 2011 Workshops: Confederated International Workshops and Posters: EI2N+NSF ICE, ICSP+INBAST, ISDE, ORM, OTMA, SWWS+MONET+SeDeS, and VADER 2011. Springer Berlin Heidelberg, Hersonissos, Crete, Greece, pp. 604–608. https://doi.org/10.1007/978-3-642-25126-9_73

Guédria, W., Naudet, Y., Chen, D., 2008. Interoperability Maturity Models -- Survey and Comparison --, in: Meersman, R., Tari, Z., Herrero, P. (Eds.), On the Move to Meaningful Internet Systems: OTM 2008 Workshops: OTM Confederated International Workshops and Posters, ADI, AWeSoMe, COMBEK, EI2N, IWSSA, MONET, OnToContent + QSI, ORM, PerSys, RDDS, SEMELS, and SWWS 2008, Monterrey, Mexico, November 9-14,. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 273–282. https://doi.org/10.1007/978-3-540-88875-8_48

Hamilton Jr., J.A., Rosen, J.D., Summers, P.A., 2002. An Interoperability Roadmap for C4ISR Legacy Systems. Acquisition Review Quarterly 9, 17.

Henderson, J.C., Venkatraman, H., 1993. Strategic alignment: Leveraging information technology for transforming organizations. IBM Systems Journal 32, 472–484. https://doi.org/10.1147/sj.382.0472

Hevner, March, Park, Ram, 2004. Design Science in Information Systems Research. MIS Quarterly 28, 75. https://doi.org/10.2307/25148625

Horridge, M., Knublauch, H., Rector, A., Stevens, R., Wroe, C., 2004. A Practical Guide To Building OWL Ontologies Using The Protege-OWL Plugin and CO-ODE Tools.

Horrocks, I., Patel-Schneider, P.F., Boley, H., Tabet, S., Grosof, B., Dean, M., 2014. SWRL: A Semantic Web Rule Language Combining OWL and RuleML [WWW Document]. W3C Member

Submission. URL https://www.w3.org/Submission/2004/SUBM-SWRL-20040521/ (accessed 7.25.18).

IDEAS Working Group, 2003. Interoperability Developments for Enterprise Application and Software (IDEAS) - roadmaps [WWW Document]. URL http://interop-vlab.eu/ideas/ (accessed 7.30.18).

IEEE, 1991. IEEE Standard Computer Dictionary: A Compilation of IEEE Standard Computer Glossaries, IEEE Std 610. https://doi.org/10.1109/IEEESTD.1991.106963

IEEE 1516.2, 2000. IEEE 1516.2-2000 - Standard for Modeling and Simulation (M&S) High Level Architecture (HLA) - HLA Object Model Template (OMT) Specification.

INCOSE, 2015. INCOSE Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities, 4th Editio. ed. Wiley.

ISACA, 2012. COBIT 5: A Business Framework for the Governance and Management of Enterprise IT. ISACA, Rolling Meadows, USA.

ISO/IEC 15504-1, 2004. ISO/IEC 15504-1:2004 Information technology -- Process assessment -- Part 1: Concepts and vocabulary. ISO/IEC JTC 1/SC 7.

ISO/IEC 29148, 2011. ISO/IEC 29148: System and software engineering – Life cycle processes – Requirements Engineering. ISO/IEC JTC 1/SC 7. Geneva.

ISO/IEC 33001, 2015. ISO/IEC 33001:2015 Information technology -- Process assessment -- Concepts and terminology. ISO/IEC JTC 1/SC 7.

ISO 11354-1, 2011. ISO 11354-1:2011 Advanced automation technologies and their applications -- Requirements for establishing manufacturing enterprise process interoperability -- Part 1: Framework for enterprise interoperability. ISO/TC 184/SC 5.

ISO 11354-2, 2015. ISO 11354-2:2015 - Advanced automation technologies and their applications -- Requirements for establishing manufacturing enterprise process interoperability -- Part 2: Maturity model for assessing enterprise interoperability. ISO/TC 184/SC 5.

ISO 15704, 2000. ISO 15704:2000 Industrial automation systems -- Requirements for enterprise-reference architectures and methodologies. ISO/TC 184/SC 5. Geneva.

ISO 9000, 2015. ISO 9000:2015 - Quality management systems -- Fundamentals and vocabulary. ISO/TC 176/SC 1.

Jagdev, H.S., Thoben, K.-D., 2001. Anatomy of enterprise collaborations. Production Planning & Control 12, 437–451. https://doi.org/10.1080/09537280110042675

Jardim-Goncalves, R., Agostinho, C., Steiger-Garcao, A., 2012. A reference model for sustainable interoperability in networked enterprises: towards the foundation of EI science base. International Journal of Computer Integrated Manufacturing 25, 855–873. https://doi.org/10.1080/0951192X.2011.653831

Jochem, R., Knothe, T., 2007. Interoperability Requirements derived from Interoperability Dimensions, in: Gonçalves, R.J., Müller, J.P., Mertins, K., Zelm, M. (Eds.), Enterprise Interoperability II - New

Challenges and Industrial Approaches, Proceedings of the 3th International Conference on Interoperability for Enterprise Software and Applications, IESA. Springer London, Funchal, Madeira Island, Portugal, pp. 39–50. https://doi.org/10.1007/978-1-84628-858-6_4

Kasunic, M., Anderson, W., 2004. Measuring Systems Interoperability: Challenges and Opportunities (CMU/SEI-2004-TN-003). Pittsburgh, PA.

Katzy, B.R., Sung, G., Crowston, K., 2016. Alignment in an inter-organisational network: the case of ARC transistance. European Journal of Information Systems 25, 553–568. https://doi.org/10.1057/ejis.2016.9

Kingston, G., Fewell, S., Richer, W., 2005. An Organisational Interoperability Agility Model, in: 10th International Command and Control Research and Technology Symposium (ICCRTS). Command and Control Research Program (U.S.), McLean, VA.

Kitchenham, B., 2004. Procedures for Performing Systematic Reviews. Department of Computer Science, Keele University, UK.

Knight, M., Widergren, S., Mater, J., Montgomery, A., 2013. Maturity model for advancing smart grid interoperability, in: 2013 IEEE PES Innovative Smart Grid Technologies Conference (ISGT). IEEE, Washington, DC, USA, pp. 1–6. https://doi.org/10.1109/ISGT.2013.6497915

Kordon, M., Wall, S., Stone, H., Blume, W., Skipper, J., Ingham, M., Neelon, J., Chase, J., Baalke, R., Hanks, D., Salcedo, J., Solish, B., Postma, M., Machuzak, R., 2007. Model-Based Engineering Design Pilots at JPL, in: 2007 IEEE Aerospace Conference. IEEE, Big Sky, MT, USA, pp. 1–20. https://doi.org/10.1109/AERO.2007.353021

Krivograd, N., Fettke, P., 2012. Development of a Generic Tool for the Application of Maturity Models--Results from a Design Science Approach, in: 2012 45th Hawaii International Conference on System Sciences. IEEE, Maui, HI, USA, pp. 4326–4335. https://doi.org/10.1109/HICSS.2012.213

Krivograd, N., Fettke, P., Loos, P., 2014. Development of an Intelligent Maturity Model-Tool for Business Process Management, in: Sprague Jr., R.H. (Ed.), 2014 47th Hawaii International Conference on System Sciences. IEEE, Waikoloa, HI, USA, pp. 3878–3887. https://doi.org/10.1109/HICSS.2014.481

Krygiel, A.J., 1999. Behind the Wizard's curtain : an integration environment for a system of systems. Publication Directorate of the Institute for National Strategic Studies.

Lankhorst, M., 2013. Enterprise Architecture at Work, 3rd Editio. ed, The Enterprise Engineering Series. Springer Berlin Heidelberg, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-29651-2

LaVean, G., 1980. Interoperability in Defense Communications. IEEE Transactions on Communications 28, 1445–1455. https://doi.org/10.1109/TCOM.1980.1094832

Leal, G.S.S., Guédria, W., Panetto, H., 2017a. Assessing Interoperability Requirements in Networked

Enterprises: A Model-Based System Engineering Approach. INSIGHT 20, 15–18. https://doi.org/10.1002/inst.12174

Leal, G.S.S., Guédria, W., Panetto, H., 2019. Interoperability Assessment: A Systematic Literature Review. Computers in Industry (In Press). https://doi.org/10.1016/j.compind.2019.01.002

Leal, G.S.S., Guedria, W., Panetto, H., Lezoche, M., 2016a. Towards a Comparative Analysis of Interoperability Assessment Approaches for Collaborative Enterprise Systems, in: Borsato, M., Wognum, N., Peruzzini, M., Stjepandic, J. and Verhagen, W.J.C. (Ed.), Transdisciplinary Engineering: Crossing Boundaries, Advances in Transdisciplinary Engineering. pp. 45–54. https://doi.org/10.3233/978-1-61499-703-0-45

Leal, G.S.S., Guédria, W., Panetto, H., Proper, E., 2017b. An approach for interoperability assessment in networked enterprises, in: 20th IFAC World Congress, IFAC 2017. Toulouse, France.

Leal, G.S.S., Guédria, W., Panetto, H., Proper, E., 2017c. Towards a Semi-automated Tool for Interoperability Assessment: An Ontology-Based Approach, in: Mas, A., Mesquida, A., O'Connor, R. V, Rout, T., Dorling, A. (Eds.), Software Process Improvement and Capability Determination: 17th International Conference, SPICE 2017. Springer International Publishing, Palma de Mallorca, Spain, pp. 241–254. https://doi.org/10.1007/978-3-319-67383-7_18

Leal, G.S.S., Guédria, W., Panetto, H., Proper, E., 2016b. Towards a Meta-Model for Networked Enterprise, in: Schmidt, R., Guédria, W., Bider, I., Guerreiro, S. (Eds.), Enterprise, Business-Process and Information Systems Modeling: 17th International Conference, BPMDS 2016, 21st International Conference, EMMSAD 2016, Held at CAiSE 2016. Springer International Publishing, Ljubljana, Slovenia, pp. 417–431. https://doi.org/10.1007/978-3-319-39429-9_26

Lee, C.C., 1990. Fuzzy logic in control systems: fuzzy logic controller. I. IEEE Transactions on Systems, Man, and Cybernetics 20, 404–418. https://doi.org/10.1109/21.52551

Leite, M.J., 1998. Interoperability Assessment, in: 66th Military Operations Research Society Symposium. Monterey, California, USA.

Lezoche, M., Yahia, E., Aubry, A., Panetto, H., Zdravković, M., 2012. Conceptualising and structuring semantics in cooperative enterprise information systems models. Computers in Industry 63, 775–787. https://doi.org/https://doi.org/10.1016/j.compind.2012.08.006

Li, B.M., Xie, S.Q., Xu, X., 2011. Recent development of knowledge-based systems, methods and tools for One-of-a-Kind Production. Knowledge-Based Systems 24, 1108–1119. https://doi.org/10.1016/j.knosys.2011.05.005

Li, Z., Liang, P., Zhao, Y., He, K., 2013. MFI Based Interoperability Measurement of Business Models in Service-Based Enterprises, in: 2013 Ninth International Conference on Computational Intelligence and Security. IEEE, Leshan, China, pp. 358–362. https://doi.org/10.1109/CIS.2013.82

Loucopoulos, P., Karakostas, V., 1995. System Requirements Engineering, McGraw-Hil. ed. McGraw-

Hill, New York, NY, USA.

Luftman, J., 2003. Assessing It/Business Alignment. Information Systems Management 20, 9–15. https://doi.org/10.1201/1078/43647.20.4.20030901/77287.2

Maheshwari, D., Janssen, M., 2014. Reconceptualizing measuring, benchmarking for improving interoperability in smart ecosystems: The effect of ubiquitous data and crowdsourcing. Government Information Quarterly 31, S84–S92. https://doi.org/https://doi.org/10.1016/j.giq.2014.01.009

Maier, M.W., 1998. Architecting principles for systems-of-systems. Systems Engineering 1, 267–284. https://doi.org/10.1002/(SICI)1520-6858(1998)1:4<267::AID-SYS3>3.0.CO;2-D

Mallek, S., Daclin, N., Chapurlat, V., 2012. The application of interoperability requirement specification and verification to collaborative processes in industry. Computers in Industry 63, 643–658. https://doi.org/https://doi.org/10.1016/j.compind.2012.03.002

Mallek, S., Daclin, N., Chapurlat, V., 2011. An Approach for Interoperability Requirements Specification and Verification, in: van Sinderen, M., Johnson, P. (Eds.), Enterprise Interoperability: Third International IFIP Working Conference, IWEI 2011, Stockholm, Sweden, March 23-24, 2011, Part of the Lecture Notes in Business Information Processing (LNBIP) Book Series. Springer Berlin Heidelberg, Stockholm, Sweden, pp. 89–102. https://doi.org/10.1007/978-3-642-19680-5_9

Mallek, S., Daclin, N., Chapurlat, V., Vallespir, B., 2015. Enabling model checking for collaborative process analysis: from BPMN to 'Network of Timed Automata.' Enterprise Information Systems 9, 279–299. https://doi.org/10.1080/17517575.2013.879211

MEASURE Evaluation Team, 2017a. Health Information Systems Interoperability Maturity Toolkit: Users' Guide.

MEASURE Evaluation Team, 2017b. Health Information Systems Interoperability Maturity Toolkit: Assessment Tool.

Mensh, D.R., Kite, R.S., Darby, P.H., 1989. The Quantification of Interoperability. Naval Engineers Journal 101, 251–259. https://doi.org/10.1111/j.1559-3584.1989.tb02204.x

Mettler, T., 2011. Maturity assessment models: a design science research approach. International Journal of Society Systems Science 3, 81. https://doi.org/10.1504/IJSSS.2011.038934

Mordecai, Y., Orhof, O., Dori, D., 2018. Model-Based Interoperability Engineering in Systems-of-Systems and Civil Aviation. IEEE Transactions on Systems, Man, and Cybernetics: Systems 48, 637–648. https://doi.org/10.1109/TSMC.2016.2602543

Morel, G., Panetto, H., Mayer, F., Auzelle, J.-P., 2007. System of Enterprise-Systems Integration Issues: an Engineering Perspective, in: IFAC. IFAC Conference on Cost Effective Automation in Networked Product Development and Manufacturing, IFAC-CEA'07. Elsevier, Monterrey, Mexico.

Musen, M.A., 2015. The protégé project. AI Matters 1, 4–12. https://doi.org/10.1145/2757001.2757003

Naudet, Y., Latour, T., Guedria, W., Chen, D., 2010. Towards a systemic formalisation of interoperability. Computers in Industry 61, 176–185. https://doi.org/http://dx.doi.org/10.1016/j.compind.2009.10.014

Neely, A., Mills, J., Platts, K., Richards, H., Gregory, M., Bourne, M., Kennerley, M., 2000. Performance measurement system design: developing and testing a process-based approach. International Journal of Operations & Production Management 20, 1119–1145. https://doi.org/10.1108/01443570010343708

NEFFICS Working Group, 2013. Networked Enterprise transFormation and resource management in Future internet enabled Innovation CloudS project [WWW Document]. URL http://interop-vlab.eu/neffics/

Neghab, A.P., Etienne, A., Kleiner, M., Roucoules, L., 2015. Performance evaluation of collaboration in the design process: Using interoperability measurement. Computers in Industry 72, 14–26. https://doi.org/https://doi.org/10.1016/j.compind.2015.03.011

Nienhuys-Cheng, S.-H., Wolf, R., 1997. Foundations of Inductive Logic Programming, Lecture Notes in Computer Science. Springer Berlin Heidelberg, Berlin, Heidelberg. https://doi.org/10.1007/3-540-62927-0

Noy, N.F., McGuinness, D.L., 2001. Ontology development 101: A guide to creating your first ontology. Stanford, CA,.

Obrst, L., 2003. Ontologies for semantically interoperable systems, in: Proceedings of the Twelfth International Conference on Information and Knowledge Management - CIKM ’03. ACM Press, New York, New York, USA, p. 366. https://doi.org/10.1145/956863.956932

OMG, 2017a. OMG System Modeling Language (SysML), Version 1.5.

OMG, 2017b. Unified Modeling Language - Version: 2.5.1. Needham, USA.

OMG, 2014a. Model Driven Architecture (MDA), Guide rev. 2.0. Boston.

OMG, 2014b. Business Process Model And Notation - Version: 2.0.2.

Op’t Land, M., Proper, E., Waage, M., Cloo, J., Steghuis, C., 2009. Enterprise Architecture: Creating Value by Informed Governance. Springer Berlin Heidelberg, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-85232-2

Pacheco, C., Garcia, I., 2012. A systematic literature review of stakeholder identification methods in requirements elicitation. Journal of Systems and Software 85, 2171–2181. https://doi.org/10.1016/j.jss.2012.04.075

Panetto, H., 2007. Towards a classification framework for interoperability of enterprise applications. International Journal of Computer Integrated Manufacturing, Taylor & Francis 20, 727–740. https://doi.org/10.1080/09511920600996419

Panetto, H., Berio, G., Benali, K., Boudjlida, N., Petit, M., 2004. A Unified Enterprise Modelling

Language for Enhanced Interoperability of Enterprise Models. IFAC Proceedings Volumes 37, 605–610. https://doi.org/10.1016/S1474-6670(17)36181-5

Panetto, H., Zdravkovic, M., Jardim-Goncalves, R., Romero, D., Cecil, J., Mezgár, I., 2016. New perspectives for the future interoperable enterprise systems. Computers in Industry 79, 47–63. https://doi.org/http://dx.doi.org/10.1016/j.compind.2015.08.001

Paul Johannesson, Harzallah, M., Huza, M., Weigand, H., Bergholtz, M., Naudet, Y., Latour, T., Hausmann, K., Abels, S., Andersson, B., Edirisuriya, A., Llayperma, T., Gordijn, J., Grégoire, B., Schmitt, M., Dubois, E., Hahn, A., Wangler, B., Castano, S., Montanelli, S., Ferrara, A., Antonellis, V. De, Bianchini, D., Franconi, E., Jeusfeld, M., Hoppenbrouwers, J., 2007. INTEROP NoE - Deliverable DO.2: Ontology-based methods for Interoperability.

Peffers, K., Tuunanen, T., Rothenberger, M.A., Chatterjee, S., 2007. A Design Science Research Methodology for Information Systems Research. Journal of Management Information Systems 24, 45–77. https://doi.org/10.2753/MIS0742-1222240302

Peres, F., Yang, J., Ghazel, M., 2012. A Formal Framework for the Formalization of Informal Requirements. International Journal of Soft Computing and Software Engineering 2, 14–27. https://doi.org/10.7321/jscse.v2.n8.2

Petersen, K., Vakkalanka, S., Kuzniarz, L., 2015. Guidelines for conducting systematic mapping studies in software engineering: An update. Information and Software Technology 64, 1–18. https://doi.org/10.1016/j.infsof.2015.03.007

Phillips-Wren, G., Mora, M., Forgionne, G.A., Gupta, J.N.D., 2009. An integrative evaluation framework for intelligent decision support systems. European Journal of Operational Research 195, 642–652. https://doi.org/10.1016/j.ejor.2007.11.001

Pollalis, Y.A., 2003. Patterns of co-alignment in information-intensive organizations: business performance through integration strategies. International Journal of Information Management 23, 469–492. https://doi.org/10.1016/S0268-4012(03)00063-X

Power, D.J., 2004. Specifying an Expanded Framework for Classifying and Describing Decision Support Systems. The Communications of the Association for Information Systems 13.

Proper, H.A., 2014. Enterprise Architecture: Informed Steering of Enterprises in Motion, in: Hammoudi, S., Cordeiro, J., Maciaszek, L., Filipe, J. (Eds.), Enterprise Information Systems. ICEIS 2013. Lecture Notes in Business Information Processing, Vol 190. Springer, Cham, Angers, France, pp. 16–34. https://doi.org/10.1007/978-3-319-09492-2_2

Ramanathan, U., Gunasekaran, A., Subramanian, N., 2011. Supply chain collaboration performance metrics: a conceptual framework. Benchmarking: An International Journal 18, 856–872. https://doi.org/10.1108/14635771111180734

Rezaei, R., Chiew, T., Lee, S., 2013. A review of interoperability assessment models. Journal of Zhejiang University SCIENCE C 14, 663–681. https://doi.org/10.1631/jzus.C1300013

Rezaei, R., Chiew, T.K., Lee, S.P., 2014a. An interoperability model for ultra large scale systems. Advances in Engineering Software 67, 22–46. https://doi.org/https://doi.org/10.1016/j.advengsoft.2013.07.003

Rezaei, R., Chiew, T.K., Lee, S.P., Aliee, Z.S., 2014b. A semantic interoperability framework for software as a service systems in cloud computing environments. Expert Systems with Applications 41, 5751–5770. https://doi.org/https://doi.org/10.1016/j.eswa.2014.03.020

Rezaei, R., Chiew, T.K., Lee, S.P., Aliee, Z.S., 2014c. Interoperability evaluation models: A systematic review. Computers in Industry 65, 1–23. https://doi.org/https://doi.org/10.1016/j.compind.2013.09.001

Ricciardi, F., Zardini, A., Rossignoli, C., 2016. Organizational dynamism and adaptive business model innovation: The triple paradox configuration. Journal of Business Research 69, 5487–5493. https://doi.org/10.1016/j.jbusres.2016.04.154

Rings, T., Poglitsch, P., Schulz, S., Serazio, L., Vassiliou-Gioles, T., 2014. A generic interoperability testing framework and a systematic development process for automated interoperability testing. International Journal on Software Tools for Technology Transfer 16, 295–313. https://doi.org/10.1007/s10009-013-0281-2

Riz, G., Santos, E.A.P., de Freitas Rocha Loures, E., 2017. Interoperability Assessment in Health Systems Based on Process Mining and MCDA Methods, in: Rocha, Á., Correia, A.M., Adeli, H., Reis, L.P., Costanzo, S. (Eds.), Recent Advances in Information Systems and Technologies. WorldCIST 2017. Advances in Intelligent Systems and Computing. Springer, Cham, Porto Santo Island, Madeira, Portugal, pp. 436–445. https://doi.org/10.1007/978-3-319-56535-4_44

Romero, D., Galeano, N., Molina, A., 2009. Mechanisms for assessing and enhancing organisations' readiness for collaboration in collaborative networks. International Journal of Production Research 47, 4691–4710. https://doi.org/10.1080/00207540902847280

Romero, D., Molina, A., 2011. Collaborative networked organisations and customer communities: value co-creation and co-innovation in the networking era. Production Planning & Control 22, 447–472. https://doi.org/10.1080/09537287.2010.536619

Rosener, V., Latour, T., Dubois, E., 2004. A Model-based Ontology of the Software Interoperability Problem: Preliminary Results, in: Enterprise Modelling and Ontologies for Interoperability, Proceedings of the Open Interop Workshop on Enterprise Modelling and Ontologies for Interoperability, Co-Located with CAiSE'04 Conference. Riga, Latvia, pp. 241–252.

Rosener, V., Naudet, Y., Latour, T., 2005. A Model Proposal of the Interoperability Problem, in: Enterprise Modelling and Ontologies for Interoperability, Proceedings of the Open Interop Workshop on Enterprise Modelling and Ontologies for Interoperability, Co-Located with CAiSE'05 Conference.

Ruokolainen, T., Naudet, Y., Latour, T., 2007. An Ontology of Interoperability in Inter-Enterprise

Communities, in: Gonçalves, R.J., Müller, J.P., Mertins, K., Zelm, M. (Eds.), Enterprise Interoperability II: New Challenges and Approaches. Springer London, London, pp. 159–170. https://doi.org/10.1007/978-1-84628-858-6_17

Saaty, T.L., 2004. Decision making — the Analytic Hierarchy and Network Processes (AHP/ANP). Journal of Systems Science and Systems Engineering 13, 1–35. https://doi.org/10.1007/s11518-006-0151-5

Saturno, M., Ramos, L.F.P., Polato, F., Deschamps, F., de Freitas Rocha Loures, E., 2017. Evaluation of Interoperability between Automation Systems using Multi-criteria Methods. Procedia Manufacturing 11, 1837–1845. https://doi.org/https://doi.org/10.1016/j.promfg.2017.07.321

SCAMPI Upgrade Team, 2011. Standard CMMI® Appraisal Method for Process Improvement (SCAMPISM) A, Version 1.3: Method Definition Document. Software Engineering Institute.

Selway, M., Stumptner, M., Mayer, W., Jordan, A., Grossmann, G., Schrefl, M., 2017. A conceptual framework for large-scale ecosystem interoperability and industrial product lifecycles. Data & Knowledge Engineering 109, 85–111. https://doi.org/10.1016/j.datak.2017.03.006

SISO-STD-003, 2006. SISO-STD-003-2006: Standard for Base Object Model (BOM) Template Specification.

Snydman, S., Sanderson, R., Cramer, T., 2015. The International Image Interoperability Framework (IIIF): A community & technology approach for web-based images, in: IS&T (Digital) Archiving Conference, Archiving 2015 Final Program and Proceedings, Color and Imaging Conference Final Program and Proceedings. Society for Imaging Science and Technology, Angeles, California, pp. 16–21.

Solaimani, S., Bouwman, H., 2012. A framework for the alignment of business model and business processes. Business Process Management Journal 18, 655–679. https://doi.org/10.1108/14637151211253783

Solaimani, S., Bouwman, H., Itälä, T., 2015. Networked enterprise business model alignment: A case study on smart living. Information Systems Frontiers 17, 871–887. https://doi.org/10.1007/s10796-013-9474-1

Sseggujja, H., Selamat, A., 2015. Towards Domain Ontology Interoperability Measurement, in: Fujita, H., Selamat, A. (Eds.), Intelligent Software Methodologies, Tools and Techniques: 13th International Conference, SoMeT 2014, Langkawi, Malaysia, September 22-24, 2014. Revised Selected Papers. Springer, Cham, Langkawi, Malaysia, pp. 282–296. https://doi.org/10.1007/978-3-319-17530-0_20

Sutcliffe, A., 2003. Scenario-based requirements engineering, in: Journal of Lightwave Technology. IEEE Comput. Soc, Monterey Bay, CA, USA, pp. 320–329. https://doi.org/10.1109/ICRE.2003.1232776

Szejka, A.L., Aubry, A., Panetto, H., Canciglieri, O., Rocha Loures, E., 2015. A Method for

Formalizing Requirements Interoperation in Complex Systems Engineering. INSIGHT 18, 28–30. https://doi.org/10.1002/inst.12058

Tamm, T., Shanks, G., 2011. How Does Enterprise Architecture Add Value to Organisations? Communications of the Association for Information Systems 28. https://doi.org/10.17705/1CAIS.02810

Tarhan, A., Giray, G., 2017. On the Use of Ontologies in Software Process Assessment, in: Proceedings of the 21st International Conference on Evaluation and Assessment in Software Engineering - EASE'17. ACM Press, New York, New York, USA, pp. 2–11. https://doi.org/10.1145/3084226.3084261

Thoben, K.-D., Jagdev, H.S., 2001. Typological issues in enterprise networks. Production Planning & Control 12, 421–436. https://doi.org/10.1080/09537280110042666

TOG, 2018. The TOGAF® Standard, Version 9.2.

TOG, 2013. ArchiMate® 2.1 Specification.

Tolk, A., Bair, L.J., Diallo, S.Y., 2013. Supporting Network Enabled Capability by extending the Levels of Conceptual Interoperability Model to an interoperability maturity model. The Journal of Defense Modeling and Simulation: Applications, Methodology, Technology 10, 145–160. https://doi.org/10.1177/1548512911428457

Tolk, A., Muguira, J.A., 2003. The Levels of Conceptual Interoperability Model, in: Proceedings of the 2003 Fall Simulation Interoperability Workshop. Orlando, Florida, USA, pp. 1–11. https://doi.org/10.1.1.196.1923

Touzi, J., Lorré, J.-P., Bénaben, F., Pingaud, H., 2007. Interoperability through Model-based Generation: The Case of the Collaborative Information System (CIS), in: Doumeingts, G., Müller, J., Morel, G., Vallespir, B. (Eds.), Enterprise Interoperability, New Challenges and Approaches, Proceedings of the 2nd International Conference on Interoperability for Enterprise Software and Applications, I-ESA 2006. Springer London, Bordeaux, France, pp. 407–416. https://doi.org/10.1007/978-1-84628-714-5_38

Turban, E., Aronson, J.E., Liang, T.-P., 2004. Decision Support Systems and Intelligent Systems, 7th Editio. ed. Prentice-Hall, Inc., Upper Saddle River, NJ, USA.

U.S. Department of Defense, 2010. The DoDAF Architecture Framework Version 2.02 [WWW Document]. URL https://dodcio.defense.gov/Library/DoD-Architecture-Framework/ (accessed 7.30.18).

van Eck, N.J., Waltman, L., 2010. Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics 84, 523–538. https://doi.org/10.1007/s11192-009-0146-3

van Lamsweerde, A., 2001. Goal-oriented requirements engineering: a guided tour, in: Proceedings Fifth IEEE International Symposium on Requirements Engineering. IEEE Comput. Soc, Toronto, Ontario, Canada, pp. 249–262. https://doi.org/10.1109/ISRE.2001.948567 van Steenbergen, M., Bos, R., Brinkkemper, S., van de Weerd, I., Bekkers, W., 2010. The Design of Focus Area Maturity Models, in: Winter, R., Zhao, J.L., Aier, S. (Eds.), Global Perspectives on Design Science Research 5th International Conference, DESRIST 2010. Springer, Berlin, Heidelberg, St. Gallen, Switzerland, pp. 317–332. https://doi.org/10.1007/978-3-642-13335-0_22

Vargas, A., Boza, A., Patel, S., Patel, D., Cuenca, L., Ortiz, A., 2016. Inter-enterprise architecture as a tool to empower decision-making in hierarchical collaborative production planning. Data and Knowledge Engineering 105, 5–22. https://doi.org/10.1016/j.datak.2015.10.002

Vaughan, R., Daverio, R., 2016. Assessing the size and presence of the collaborative economy in Europe - PwC UK Report.

Vernadat, F.B., 2010. Technical, semantic and organizational issues of enterprise interoperability and networking. Annual Reviews in Control 34, 139–144. https://doi.org/https://doi.org/10.1016/j.arcontrol.2010.02.009

Vito, L. De, Rapuano, S., 2010. Assessing interoperability of access equipment for broadband networks. Measurement 43, 320–328. https://doi.org/https://doi.org/10.1016/j.measurement.2009.11.004

von Bertalanffy, L., 1968. General System Theory: Foundations, Development, Applications. George Braziller Inc, New York.

Walsh, I., Renaud, A., Kalika, M., 2013. The Translated Strategic Alignment Model: A Practice-Based Perspective. Systèmes d'information & management 18, 37. https://doi.org/10.3917/sim.132.0037

Wang, W., Tolk, A., Wang, W., 2009. The Levels of Conceptual Interoperability Model: Applying Systems Engineering Principles to M&S, in: Proceedings of the 2009 Spring Simulation Multiconference, SpringSim '09. Society for Computer Simulation International, San Diego, CA, USA, p. 168:1--168:9.

West Health Institute, 2013. The value of medical device interoperability. San Diego, California.

Westphal, I., Thoben, K.-D., Seifert, M., 2007. Measuring Collaboration Performance in Virtual Organizations, in: Establishing the Foundation of Collaborative Networks. Springer US, Boston, MA, pp. 33–42. https://doi.org/10.1007/978-0-387-73798-0_4

Wohlin, C., 2014. Guidelines for snowballing in systematic literature studies and a replication in software engineering, in: In 8th International Conference on Evaluation and Assessment in Software Engineering (EASE 2014). ACM, London, England, United Kingdom, pp. 321–330.

Wu, S.P.-J., Straub, D.W., Liang, T.-P., 2015. How Information Technology Governance Mechanisms and Strategic Alignment Influence Organizational Performance: Insights from a Matched Survey of Business and IT Managers. MIS Quarterly 39, 497–518. https://doi.org/10.25300/MISQ/2015/39.2.10

Yager, R.R., 1988. On ordered weighted averaging aggregation operators in multicriteria decisionmaking. IEEE Transactions on Systems, Man, and Cybernetics 18, 183–190. https://doi.org/10.1109/21.87068

Yahia, E., 2011. Contribution à l'évaluation de l'interopérabilité sémantique entre systèmes d'information d'entreprise: Application aux systèmes d'information de pilotage de la production. Université Henri Poincaré - Nancy I.

Yahia, E., Aubry, A., Panetto, H., 2012a. Formal measures for semantic interoperability assessment in cooperative enterprise information systems. Computers in Industry 63, 443–457. https://doi.org/https://doi.org/10.1016/j.compind.2012.01.010

Yahia, E., Lezoche, M., Aubry, A., Panetto, H., 2012b. Semantics enactment for interoperability assessment in enterprise information systems. Annual Reviews in Control 36, 101–117. https://doi.org/http://dx.doi.org/10.1016/j.arcontrol.2012.03.008

Zachman, J.A., 1987. A framework for information systems architecture. IBM Systems Journal 26, 276–292. https://doi.org/10.1147/sj.263.0276

Zadeh, L.A., 1996. Soft Computing and Fuzzy Logic, in: Fuzzy Sets, Fuzzy Logic, and Fuzzy Systems. pp. 796–804. https://doi.org/10.1142/9789814261302_0042

Zutshi, A., Grilo, A., Jardim-Goncalves, R., 2012. The Business Interoperability Quotient Measurement Model. Computers in Industry 63, 389–404. https://doi.org/https://doi.org/10.1016/j.compind.2012.01.002

Annexe A – The Interoperability Requirements Interdependencies

Requirements related to the Business concern

Table A1. BCR1: Business models shall be defined and documented

IR	BCR1: Business models shall be defined and documented
Interoperability Area	Business-Conceptual
Maturity Level	Level 1 - Defined
Decomposition	BCR1.1: Business model shall be defined BCR1.2: Business model shall be documented BCR1.3: Business' objectives shall be defined BCR1.4: Business strategy shall be defined BCR1.5: Business processes shall be defined BCR1.6: Business services shall be defined BCR1.7: Business rules shall be defined BCR1.8: Business hierarchy shall be defined BCR1.9: Business partners are defined BCR1.10: Clients shall be identified
Requires	BOR1.1 Organisation structure shall be defined
Is required by	BOR1: Organization structure shall be defined and in place BCR2: Standards shall be used for alignment with other business models BCR3: Business Models shall be designed for collaboration BTR1: Basic IT infrastructure shall be in place BTR2: Standard-based and configurable IT infrastructure shall be used PTR2: Standard-based IT tools shall be used BOR2: Human resources shall be trained for interoperability BCR4: Business models shall be adaptive DCR3:Meta-modeling for multiple data model mappings DCR2:Use of standards for alignment with other data models DTR2: Automated access to data based on standard protocols PCR1: Process models shall be defined and documented SCR1: Service models shall be defined and documented
Best Practices	BPBC1.1. Define business models BPBC1.2. Document Business Model
Related Barrier	IBBC1. Business context IBBC2. Business Syntax IBBC3. Business Semantics

Table A2. BCR2: Standards shall be used for alignment with other business models

IR	BCR2: Standards shall be used for alignment with other business models
Interoperability Area	Business-Conceptual
Maturity Level	Level 2 - Aligned
Decomposition	BCR2.1: Standards used in the enterprise environment shall be identified BCR2.2: Standards used by reg. Institutions shall be identified BCR2.3: Standards used by partners shall be identified BCR2.4: Standards used by clients shall be identified BCR2.5: Standards shall be selected and used within the enterprise
Requires	BCR1.8: Business partners shall be defined BCR1.9: Clients shall be identified BCR1.10: Reg. Institutions shall be identified
Is required by	PTR2: Standard-based IT tools shall be used
Best Practices	BPBC2.1. Identify relevant standards for interoperability BPBC2.2. Use relevant standards for interoperability
Related Barrier	IBBC2. Business Syntax IBBC3. Business Semantics

Table A3. BCR3: Business Models shall be designed for collaboration

IR	BCR3: Business Models shall be designed for collaboration
Interoperability Area	Business-Conceptual
Maturity Level	Level 3 - Organized
Decomposition	BCR3.1 Core business subject to potential collaboration shall be identified BCR3.2: Preferred partners shall be identified
Requires	BCR1.3: Business strategy shall be defined BCR1.5: Business processes shall be defined BCR1.8: Business partners shall be defined BOR1: Organization structure shall be defined and in place BOR2: Human resources shall be trained for interoperability
Is required by	PCR3: Meta-Models for multiple process mapping shall be defined
Best Practices	BPBC3.1. Identify core business of the enterprise and the business that can be subject of collaboration BPBC3.2. Identify preferred possible partners that enterprise can collaborate with, based on its requirement, the market and its past experiences
Related Barrier	IBBC2. Business Syntax IBBC3. Business Semantics

Table A4. BCR4: Business models shall be adaptive

IR	BCR4: Business models shall be adaptive
Interoperability Area	Business-Conceptual
Maturity Level	Level 4 - Adapted
Decomposition	BCR4.1: Periodic review procedure shall be defined to adapt business model BCR4.2: Periodic review procedure shall be implemented to adapt business model BCR4.3: A reuse-centric strategy shall be adopted BCR4.4: Actors shall be shall be of the adopted strategy BCR4.5:The reusable components in the company shall be identified
Requires	BCR1.1: Business model shall be defined BOR1.1 The actors shall be identified PCR4.1:The reusable process components shall be identified BTR4.1:The reusable components in the company shall be identified SCR4: Adaptive service modelling DCR4: Adaptive data models (both syntax and semantics) BOR4: Organisation structure shall be agile
Is required by	SCR4: Adaptive service modelling
Best Practices	BPBC4.1. Define and implement periodic review procedure to adapt the business model to changing external environment. BPBC4.2. Adopt a reuse-centric strategy and make the concerned actors aware of its importance BPBC4.3. Identify the reusable components in the company
Related Barrier	IBBC2. Business Syntax IBBC3. Business Semantics

Table A5. BOR1: Organization structure shall be defined and in place

IR	BOR1: Organization structure shall be defined and in place
Interoperability Area	Business-Organisational
Maturity Level	Level 1 - Defined
Decomposition	BOR1.1: The actors shall be identified BOR1.2: The actors have their responsibilities defined BOR1.3: The actors have their authorities defined BOR1.4: The relations between actors shall be defined BOR1.5: The structure shall be documented BOR1.6: Organization structure shall be put in place
Requires	BCR1.4: Business hierarchy shall be defined BCR1.5: Business processes shall be defined BCR1.6: Business services shall be defined POR1.2: Process responsibilities/authorities shall be defined SOR1: Service responsibilities and authorities defined and put in place DOR1: Responsibilities and authorities shall be defined and in place
Is required by	BCR4: Business models shall be adaptive BCR1: Business models shall be defined and documented BOR2: Human resources shall be trained for interoperability BOR3: Organisation structure shall be flexible BTR3: IT infrastructure shall be open POR1: Process responsibilities and authorities shall be defined and in place
Best Practices	BPBO1.1. Define organization structure BPBO1.2. Put in place the organization structure
Related Barrier	IBBO1. Legislation IBBO2. Organisational Structure IBBO3. Methods of work

Table A6. BOR2: Human resources shall be trained for interoperability

IR	BOR2: Human resources shall be trained for interoperability
Interoperability Area	Business-Organisational
Maturity Level	Level 2 - Aligned
Decomposition	BOR2.1: Training needs shall be identified BOR2.2: Trainings shall be offered BOR2.3 Problematic situations shall be identified BOR2.4 Concerned employees shall be identified BOR2.5 Employees shall be informed about problematic situations
Requires	BCR1.3: Business strategy shall be defined BCR1.5: Business processes shall be defined BCR1.6: Business services shall be defined BOR1.1: The actors shall be identified BOR1.2: The actors have their responsibilities defined BOR1.3: The actors have their authorities defined
Is required by	BOR3: Organisation structure shall be flexible BOR4: Organisation structure shall be agile
Best Practices	BPBO2.1. Organize training sessions for interoperability BPBO2.2. Anticipate problematic situations and inform employees what to do in case of problems.
Related Barrier	IBBO2. Organisational Structure IBBO3. Methods of work

Table A7. BOR3: Organisation structure shall be flexible

IR	BOR3: Organisation structure shall be flexible
Interoperability Area	Business-Organisational
Maturity Level	Level 3 - Organized
Decomposition	BOR3.1: Delegation for main responsibilities shall be defined BOR3.2: Shall have more than one manager for a main responsibility BOR3.3: Employees shall be trained for polyvalence BOR3.4: Replacements shall be identified BOR3.5: Competence shall be managed
Requires	BOR1.1: The actors shall be identified BOR1.2: The actors have their responsibilities defined BOR2.2: Trainings shall be offered BOR1.4: The relations between actors shall be defined
Is required by	BOR4: Organisation structure shall be agile
Best Practices	BPBO3.1. Define delegation for main responsibilities. BPBO3.2. Manage employees competence
Related Barrier	IBBO2. Organisational Structure IBBO3. Methods of work

Table A8. BOR4: Organisation structure shall be agile

IR	BOR4: Organisation structure shall be agile
Interoperability Area	Business-Organisational
Maturity Level	Level 4 - Adapted
Decomposition	BOR4.1: Methods for business agility shall be defined BOR4.2: Responsiveness to a new event shall be short BOR4.3: Business procedures shall be clear and simple
Requires	BOR3.1: Delegation for main responsibilities shall be defined BOR3.5: Competence shall be managed BOR2: Human resources shall be trained for interoperability DOR2: Rules and Methods for data management shall be in place PCR1: Process models shall be defined and documented SCR1: Service models shall be defined and documented SOR2: Procedures for service interoperability shall be in place POR2: Procedures for process interoperability shall be in place
Is required by	
Best Practices	BPBO4.1. Define methods facilitating enterprise business agility BPBO4.2. Shorten the delay of reaction to a new event (quickly decision-making procedure, delegation of responsibility in case of absence BPBO4.3. Make enterprise business procedures clearer and simpler
Related Barrier	IBBO2. Organisational Structure IBBO3. Methods of work

Table A9. BTR1: Basic IT infrastructure shall be in place

IR	BTR1: Basic IT infrastructure shall be in place
Interoperability Area	Business-Technological
Maturity Level	Level 1 - Defined
Decomposition	BTR1.1: Relevant hardware supporting business shall be identified BTR1.2: Relevant software supporting business shall be identified BTR1.3: Relevant hardware supporting business shall be deployed BTR1.4: Relevant software supporting business shall be deployed
Requires	BCR1.3: Business strategy shall be defined BCR1.5: Business processes shall be defined BCR1.6: Business services shall be defined DCR1.1 Tools for handling data models shall be identified
Is required by	BTR2: Standard-based and configurable IT infrastructure shall be used BTR3: IT infrastructure shall be open BTR4: IT infrastructure shall be adaptive
Best Practices	BPBT1.1. Identify core IT elements supporting enterprise business BPBT1.2. Deploy identified elements
Related Barrier	IBBT1. Degree of computerisation IBBT2. IT requirement fulfilment

Table A10. BTR2: Standard-based and configurable IT infrastructure shall be used

IR	BTR2: Standard-based and configurable IT infrastructure shall be used
Interoperability Area	Business-Technological
Maturity Level	Level 2 - Aligned
Decomposition	BTR2.1: Relevant standards shall be identified BTR2.2: Standards shall be selected and used BTR2.3: Configurable IT devices shall be identified BTR2.4: IT devices shall be configured for interoperability
Requires	BCR1.8: Business partners shall be defined BCR1.9: Clients shall be identified BCR1.10: Reg. Institutions shall be identified BTR1: Basic IT infrastructure shall be in place
Is required by	BTR3: IT infrastructure shall be open
Best Practices	BPBT2.1. Put in place a standard-based IT infrastructure BPBT2.2. Identify IT elements and parameters that are expected to be configurable BPBT2.3. Configure identified IT elements
Related Barrier	IBBT1. Degree of computerisation IBBT2. IT requirement fulfilment

Table A11. BTR3: IT infrastructure shall be open

IR	BTR3: IT infrastructure shall be open
Interoperability Area	Business-Technological
Maturity Level	Level 3 - Organized
Decomposition	BTR3.1: Modification in the IT elements' structure shall be possible BTR3.2: IT elements supports new components BTR3.3: IT element's parameters shall be modifiable BTR3.4: Rules of access shall be modifiable
Requires	BTR1: Basic IT infrastructure shall be in place BTR2.3: Configurable parameters shall be identified BOR1.2: The actors have their responsibilities defined DOR1.4: Data rules shall be defined STR2: Standardise and configurable service architecture(s) and interface(s) shall be available
Is required by	BTR4: IT infrastructure shall be adaptive
Best Practices	BPBT3.1. Put in place standard technical assets supporting enterprise business BPBT3.2. Identify the technical elements that are configurable BPBT3.3. Put in place configurable technical elements if they don't exist
Related Barrier	IBBT1. Degree of computerisation IBBT2. IT requirement fulfilment

Table A12. BTR4: IT infrastructure shall be adaptive

IR	BTR4: IT infrastructure shall be adaptive
Interoperability Area	Business-Technological
Maturity Level	Level 4 - Adapted
Decomposition	BTR4.1: ITR elements that can be reused shall be identified BTR4.2: IT elements that can be rearranged shall be identified BT4.3: New IT elements can be added
Requires	BTR1: Basic IT infrastructure shall be in place BTR3.1: Modification in the IT elements' structure shall be possible BTR3.2: IT elements supports new components PTR1.12 IT tools supporting processes shall be implemented STR1.12 IT tools supporting services shall be implemented DTR1.7: Data exchange tools shall be implemented DTR1.4: Data storage tools shall be implemented
Is required by	
Best Practices	BPBT4.1. Identify reusable components that can be turned around quickly for any new application development. BPBT4.2. Perform necessary re-engineering of existing IT infrastructure to make it reconfigurable
Related Barrier	IBBT1. Degree of computerisation IBBT2. IT requirement fulfilment

Requirements related to the Process concern

Table A13. PCR1: Process models shall be defined and documented

IR	PCR1: Process models shall be defined and documented
Interoperability Area	Process-Conceptual
Maturity Level	Level 1 - Defined
Decomposition	PCR1.1: Process outcomes shall be identified PCR1.2: Process activities shall be identified PCR1.3: Process activities' sequence shall be identified PCR1.4: Involved resources shall be identified PCR1.5: Process rules shall be identified PCR1.6: Process restriction shall be identified PCR1.7: Process models shall be defined PCR1.8: Process models shall be documented
Requires	BTR1: Basic IT infrastructure shall be in place BOR1.1: The actors shall be identified PTR1.1: Process IT tools shall be identified BCR1.5: Business processes shall be defined DCR1.12 Semantics of each concept and attribute shall be defined POR1: Process responsibilities and authorities shall be defined and in place SCR1: Service models shall be defined and documented
Is required by	PCR2: Standards shall be used for alignment with other process models PCR3: Meta-Models for multiple process mapping shall be defined PCR4: Process modelling supports dynamic re-engineering POR2: Procedures for process interoperability shall be in place POR4: Process shall be monitored and procedures shall be adaptive
Best Practices	BPPC1.1. Define Process models BPPC1.2. Document Process model
Related Barrier	IBPC1. Process content IBPC2. Process syntax IBPC3. Process semantics

Table A14. PCR2: Standards shall be used for alignment with other process models

IR	PCR2: Standards shall be used for alignment with other process models
Interoperability Area	Process-Conceptual
Maturity Level	Level 2 - Aligned
Decomposition	PCR2.1: Standards used in the enterprise environment shall be identified PCR2.2: Standards used by reg. Institutions shall be identified PCR2.3: Standards used by partners shall be identified PCR2.4: Standards used by clients shall be identified PCR2.5: Standards shall be selected and used within the enterprise
Requires	PCR1.7: Process models shall be defined BCR1.8: Business partners shall be defined BCR1.9: Clients shall be identified BCR1.10: Reg. Institutions shall be identified
Is required by	PCR4: Process modelling supports dynamic re-engineering
Best Practices	BPPC2.1. Identify relevant standards for interoperability BPPC2.1. Use relevant standards for interoperability
Related Barrier	IBPC1. Process content IBPC2. Process syntax IBPC3. Process semantics

Table A15. PCR3: Meta-Models for multiple process mapping shall be defined

IR	PCR3: Meta-Models for multiple process mapping shall be defined
Interoperability Area	Process-Conceptual
Maturity Level	Level 3 - Organized
Decomposition	PCR3.1: Collaborative processes shall be identified PCR3.2: Meta-Models shall be defined based on the identified concepts subject to interoperability PCR3.3: Concepts used by partners shall be identified PCR3.4: Concepts subject to interoperability shall be identified PCR3.5: Problematic concepts shall be identified PCR3.6: Meta-Models shall be used for defining process
Requires	DCR1.12 Each data model concept and attribute shall be defined PCR1.7: Process models shall be defined BCR1.8: Business partners shall be defined BCR3: Business Models shall be designed for collaboration
Is required by	PCR4: Process modelling supports dynamic re-engineering PTR3: Platforms and tools for collaborative processes shall be in place PTR4: IT tools shall be dynamic and adaptive
Best Practices	BPPC3.1. Define meta models for existing process models BPPC3.2. Identify concepts that are used by the main partners (past or future ones) BPPC3.3. Use meta models for the process models definition
Related Barrier	IBPC1. Process content IBPC2. Process syntax IBPC3. Process semantics

Table A16. PCR4: Process modelling supports dynamic re-engineering

IR	PCR4: Process modelling supports dynamic re-engineering
Interoperability Area	Process-Conceptual
Maturity Level	Level 4 - Adapted
Decomposition	PCR4.1: Process models shall be reusable PCR4.2: Process models shall be adaptable PCR4.3: Model-Driven engineering shall be adopted
Requires	PCR1.7: Process models shall be defined PCR3.5: Meta-Models shall be defined PCR2.5: Standards shall be selected and used within the enterprise PTR4: IT tools shall be dynamic and adaptive
Is required by	PTR4: IT tools shall be dynamic and adaptive
Best Practices	BPPC4.1. Identify reusable processes components BPPC4.2. Adopt a model driven engineering approach
Related Barrier	IBPC1. Process content IBPC2. Process syntax IBPC3. Process semantics

Table A17. POR1: Process responsibilities and authorities shall be defined and in place

IR	POR1: Process responsibilities and authorities shall be defined and in place
Interoperability Area	Process-Organisational
Maturity Level	Level 1 - Defined
Decomposition	POR1.1: Process responsibilities/authorities shall be defined POR1.2: Process responsibilities/authorities shall be in place POR1.3: Process responsibilities/authorities shall be assigned to actors (e.g. business unit and employee) POR1.4: Procedure for monitoring if responsibilities and authorities are being performed shall be defined POR1.5: Process management rules shall be defined POR1.6: Procedure for monitoring if process rules are being respected shall be defined
Requires	PTR1.1: Process IT tools shall be identified BOR1.1: The actors shall be identified PCR1.4: Involved resources shall be identified DOR1: Responsibilities and authorities shall be defined and in place SOR1: Service responsibilities and authorities defined and put in place
Is required by	POR2: Procedures for process interoperability shall be in place POR3: Cross-Enterprise collaborative management is put in place POR4: Process shall be monitored and procedures shall be adaptive
Best Practices	BPPO1.1. Define process responsibilities and authorities BPPO1.2. Put in place processes responsibilities/authorities
Related Barrier	IBPO1. Business process behaviour IBBO3. Methods of work

Table A18. POR2: Procedures for process interoperability shall be in place

IR	POR2: Procedures for process interoperability shall be in place
Interoperability Area	Process-Organisational
Maturity Level	Level 2 - Aligned
Decomposition	POR2.1: Concerned process shall be identified POR2.2: Requirements for process interop. shall be specified POR2.3: Restrictions shall be specified POR2.4: Set policy, guidelines and oversight
Requires	BCR1.5: Business processes shall be defined PCR1.7: Process models shall be defined POR1.4: Process rules shall be defined
Is required by	POR3: Cross-Enterprise collaborative management shall be put in place POR4: Process shall be monitored and procedures shall be adaptive
Best Practices	BPPO2.1. Specify requirements for process interoperability BPPO2.2. Specify conditions and restrictions for process interoperability BPPO2.3. Define procedures for process interoperability BPPO2.4. Set policy, guidance and oversight to ensure that relevant processes are interoperable with other systems, internal and external to the enterprise.
Related Barrier	IBPO1. Business process behaviour IBBO3. Methods of work

Table A19. POR3: Cross-Enterprise collaborative management shall be put in place

IR	POR3: Cross-Enterprise collaborative management shall be put in place
Interoperability Area	Process-Organisational
Maturity Level	Level 3 - Organized
Decomposition	POR3.1: Constraints for collaborative processes shall be identified POR3.2: Rules for collaborative processes shall be defined POR3.3: Procedure for collaborative processes shall be defined POR3.4: Control procedures for collaborative processes shall be defined POR3.5: Procedures and rules shall be executed
Requires	POR2.1: Concerned process shall be identified POR1.2: Process responsibilities/authorities shall be defined BCR3: Business Models shall be designed for collaboration PTR3: Platforms and tools for collaborative processes shall be in place
Is required by	POR4: Process shall be monitored and procedures shall be adaptive
Best Practices	BPPO3.1. Identify requirements for networked collaborative process management BPPO3.2. Define rules and responsibilities to manage networked collaborative processes for present and future collaboration BPPO3.3. Identify relevant tools for collaborative process management BPPO3.4. Implement defined rules, responsibilities and tools in the company for collaborative process management
Related Barrier	IBPO1. Business process behaviour IBBO3. Methods of work

Table A20. POR4: Process shall be monitored and procedures shall be adaptive

IR	POR4: Process shall be monitored and procedures shall be adaptive
Interoperability Area	Process-Organisational
Maturity Level	Level 4 - Adapted
Decomposition	PO4.1: Key processes to be monitored shall be identified PO4.2: Responsibilities and authorities referring to the process monitoring shall be defined PO4.3: Responsibilities and authorities referring to the process monitoring shall be assigned PO4.4: Procedures components that can be modified shall be identified PO4.5: Rules for changing procedures shall be defined
Requires	POR3.4: Procedures, rules and tools for collaborative processes shall be implemented POR2.1: Concerned process shall be identified PCR1.7: Process models shall be defined PCR1.4: Involved resources shall be identified
Is required by	BOR4: Organisation structure shall be agile
Best Practices	BPPO4.1. Identify key processes to be monitored BPPO4.2. Define explicitly responsibility for process monitoring and assign appropriate persons. BPPO4.3. Separate parts of procedures that cannot be modified from those that can be changed. BPPO4.4. Define conditions or rules under which a part of procedure change shall be possible
Related Barrier	IBPO1. Business process behaviour IBBO3. Methods of work

Table A21. PTR1: IT support for processes shall be in place and Ad hoc exchange of information shall be possible

IR	PTR1: IT support for processes shall be in place and Ad hoc exchange of information shall be possible
Interoperability Area	Process-Technological
Maturity Level	Level 1 - Defined
Decomposition	PTR1.1: Process IT tools shall be identified PTR1.2: Process IT tools shall be implemented PTR1.2: Exchange of process information shall be possible
Requires	BTR1: Basic IT infrastructure shall be in place DTR1.4: Data storage tools shall be implemented DTR1.7: Data exchange tools shall be implemented
Is required by	PTR2: Standard-based IT tools shall be used PTR3: Platforms and tools for collaborative processes shall be in place
Best Practices	BPPT1.1. Put in place technical assets supporting enterprise processes BPPT1.2. Verify that exchange of process information is possible
Related Barrier	IBBT1. Degree of computerisation IBBT2. IT requirement fulfilment IBPT.1 Process behaviour

Table A22. PTR2: Standard-based IT tools shall be used

IR	PTR2: Standard-based IT tools shall be used
Interoperability Area	Process-Technological
Maturity Level	Level 2 - Aligned
Decomposition	PTR2.1: Relevant standards shall be identified PTR2.2: Standards shall be selected and used
Requires	BCR1.8: Business partners shall be defined BCR1.9: Clients shall be identified BCR1.10: Reg. Institutions shall be identified PTR1.1: Process IT tools shall be identified
Is required by	PTR3: Platforms and tools for collaborative processes shall be in place
Best Practices	BPPT2.1. Identify processes tools and platforms that are needed BPPT2.2. Use standard process tools and platforms
Related Barrier	IBBT1. Degree of computerisation IBBT2. IT requirement fulfilment IBPT.1 Process behaviour

Table A23. PTR3: Platforms and tools for collaborative processes shall be in place

IR	PTR3: Platforms and tools for collaborative processes shall be in place
Interoperability Area	Process-Technological
Maturity Level	Level 3 - Organized
Decomposition	PTR3.1: Tools that support collaborative processes shall be available PTR3.2: Tools that support collaborative processes shall be compatible PTR3.3: Interfaces from the tools supporting collaborative processes shall be connectable PTR3.4: Communication protocols between the tools supporting collaborative processes shall be defined
Requires	PCR3.1: Collaborative processes shall be identified PTR1.1: Process IT tools shall be identified PTR1.2: Process IT tools shall be implemented PTR2.2: Standards shall be selected and used POR3: Cross-Enterprise collaborative management shall be put in place STR1: Applications/services shall be connectable and Ad hoc information exchange shall be possible
Is required by	PTR4: IT tools shall be dynamic and adaptive
Best Practices	BPPT3.1. Identify collaborative processes BPPT3.2. Identify technical assets to support collaborative processes BPPT3.3. Define the execution steps of the identified collaborating processes BPPT3.4. Make sure that execution of the collaborative processes is ensured
Related Barrier	IBBT1. Degree of computerisation IBBT2. IT requirement fulfilment IBPT.1 Process behaviour

Table A24. PTR4: IT tools shall be dynamic and adaptive

IR	PTR4: IT tools shall be dynamic and adaptive
Interoperability Area	Process-Technological
Maturity Level	Level 4 - Adapted
Decomposition	PTR4.1: IT tools supporting processes support changes in real-time PTR4.2: IT tools adopts a model-driven approach
Requires	PCR4: Process modelling supports dynamic re-engineering PTR3.1: Tools for collaborative management shall be identified PTR1: IT support for processes shall be in place and Ad hoc exchange of information shall be possible
Is required by	
Best Practices	BPPT.4.1. Make sure that existing IT tools support rapid process model changes. If this is not the case: Acquire new suitable tools. BPPT.4.2. Acquire necessary tools to support model driven engineering approaches.
Related Barrier	IBBT1. Degree of computerisation IBBT2. IT requirement fulfilment IBPT.1 Process behaviour

Requirements related to the Service concern

Table A25. SCR1: Service models shall be defined and documented

IR	SCR1: Service models shall be defined and documented
Interoperability Area	Service-Conceptual
Maturity Level	Level 1 - Defined
Decomposition	SCR1.1: Service outcomes shall be identified SCR1.2: Service users shall be identified SCR1.3: Service execution's sequence shall be defined SCR1.4: Service rules shall be identified SCR1.5: Service restriction shall be identified SCR1.6: Service models shall be defined SCR1.7: Service information that can be reusable shall be identified SCR1.8: Service models shall be documented
Requires	BOR1.1: The actors shall be identified BTR1: Basic IT infrastructure shall be in place BCR1.6: Business services shall be defined STR1.1: Service information that can be reusable shall be identified SOR1: Service responsibilities and authorities defined and put in place
Is required by	BOR4: Organisation structure shall be agile
Best Practices	BPSC.1.1. Define Service models BPSC.1.2. Document Service model
Related Barrier	IBSC1. Service content IBSC2. Service Syntax IBSC3. Service Semantics

Table A26. SCR2: Standards shall be used for alignment with other service models

IR	SCR2: Standards shall be used for alignment with other service models
Interoperability Area	Service-Conceptual
Maturity Level	Level 2 - Aligned
Decomposition	SCR2.1: Standards used in the enterprise environment shall be identified SCR2.2: Standards used by reg. Institutions shall be identified SCR2.3: Standards used by partners shall be identified SCR2.4: Standards used by clients shall be identified SCR2.5: Standards shall be selected and used within the enterprise
Requires	BCR1.6: Business services shall be defined BCR1.8: Business partners shall be defined BCR1.9: Clients shall be identified BCR1.10: Reg. Institutions shall be identified
Is required by	SCR4: Adaptive service modelling
Best Practices	BPSC2.1. Identify relevant standards for interoperability BPSC2.1. Use relevant standards for interoperability
Related Barrier	IBSC1. Service content IBSC2. Service Syntax IBSC3. Service Semantics

Table A27. SCR3: Meta-Models for multiple service mapping shall be defined

IR	SCR3: Meta-Models for multiple service mapping shall be defined
Interoperability Area	Service-Conceptual
Maturity Level	Level 3 - Organized
Decomposition	SC3.1: Concepts used by partners shall be identified SC3.2: Concepts subject to interoperability shall be identified SC3.3: Problematic concepts shall be identified SC3.4: Meta-Models shall be defined SC3.5: Meta-Models shall be used for defining service
Requires	SCR1.6: Service models shall be defined DC1.12 Each data model concept and attribute shall be defined
Is required by	
Best Practices	BPSC3.1. Define meta models for existing services models BPSC3.2. Identify concepts that are used by the main partners (past or future ones) BPSC3.3. Use meta models for the services models definition
Related Barrier	IBSC1. Service content IBSC2. Service Syntax IBSC3. Service Semantics

Table A28. SCR4: Adaptive service modelling

IR	SCR4: Adaptive service modelling
Interoperability Area	Service-Conceptual
Maturity Level	Level 4 - Adapted
Decomposition	SCR4.1: Modelling methods supporting service decomposition shall be used SCR4.2: Reusable service components shall be modelled SCR4.3: A model-driven engineering approach shall be adopted
Requires	SCR1.1: Service information that can be reusable shall be identified SCR3: Meta-Models for multiple service mapping shall be defined DCR4:Adaptive data models (both syntax and semantics)
Is required by	
Best Practices	BPSC4.1. Identify modelling methods that supports services decomposition and composition BPSC4.2. Model basic reusable enterprise services components BPSC4.3. Adopt a model driven engineering approach
Related Barrier	IBSC1. Service content IBSC2. Service Syntax IBSC3. Service Semantics

Table A29. SOR1: Service responsibilities and authorities defined and put in place

IR	SOR1: Service responsibilities and authorities defined and put in place
Interoperability Area	Service-Organisational
Maturity Level	Level 1 - Defined
Decomposition	SOR1.11: Involved resources shall be identified SOR1.12: Service responsibilities/authorities shall be defined SOR1.13: Responsibilities/ authorities shall be assigned SOR1.14: Service rules shall be defined SOR1.2: Service responsibilities and authorities shall be put in place
Requires	BTR1: Basic IT infrastructure shall be in place BOR1: Organization structure shall be defined and in place SCR1: Service models shall be defined and documented DOR1: Responsibilities and authorities shall be defined and in place
Is required by	SCR1: Service models shall be defined and documented
Best Practices	BPSO1.1. Define Service responsibilities and authorities BPSO1.2. Put in place service responsibilities/authorities
Related Barrier	IBSO1. Service management

Table A30. SOR2: Procedures for services interoperability shall be in place

IR	SOR2: Procedures for services interoperability shall be in place
Interoperability Area	Service-Organisational
Maturity Level	Level 2 - Aligned
Decomposition	SOR2.1: Concerned services shall be identified SOR2.2: Requirements for service interop. shall be specified SOR2.3: Restrictions shall be specified SOR2.4: Set policy, guidelines and oversight
Requires	SOR1: Service responsibilities and authorities defined and put in place BCR1: Business models shall be defined and documented SCR1: Service models shall be defined and documented
Is required by	BOR4: Organisation structure shall be agile
Best Practices	BPSO2.1. Specify services interoperability requirements BPSO2.2. Define Services interoperability procedures
Related Barrier	IBSO1. Service management

Table A31. SOR3: Collaborative services and application management

IR	SOR3: Collaborative services and application management
Interoperability Area	Service-Organisational
Maturity Level	Level 3 - Organized
Decomposition	SO3.1: Collaborative services shall be identified SO3.2: Rules for collaborative services shall be defined SO3.3: Tools for collaborative management shall be identified SO3.4: Implement rules and tools
Requires	SOR1: Service responsibilities and authorities defined and put in place SOR2: Procedures for services interoperability shall be in place BCR1: Business models shall be defined and documented ST1.2: Technical assets supporting services shall be put in place BCR3: Business Models shall be designed for collaboration
Is required by	
Best Practices	BPSO3.1. Identify collaborative services and applications BPSO3.2. Define procedures, rules and guidelines for collaborative services
Related Barrier	IBSO1. Service management

Table A32. SOR4: Dynamic service and application management rules and methods

IR	SOR4: Dynamic service and application management rules and methods
Interoperability Area	Service-Organisational
Maturity Level	Level 4 - Adapted
Decomposition	SOR4.1: Key services involved in collaborations shall be identified SOR4.2: Rules and methods for dynamic management shall be defined SOR4.3: An agile organisational structure shall be in place
Requires	SCR1: Service models shall be defined and documented SOR2: Procedures for services interoperability shall be in place BOR4: Organisation structure shall be agile
Is required by	
Best Practices	BPSO4.1. Identify key services and applications that are directly involved in inter-enterprise interoperability. BPSO4.2. Define rules, methods and procedures that are needed for dynamic service interoperability management. BPSO4.3. Put in place the needed agile organization structure (responsibilities, authorization…) so that service interoperability can be established dynamically ‘on the fly’.
Related Barrier	IBSO1. Service management

Table A33. STR1: Applications/services shall be connectable and Ad hoc information exchange shall be possible

IR	STR1: Applications/services shall be connectable and Ad hoc information exchange shall be possible
Interoperability Area	Service-Technological
Maturity Level	Level 1 - Defined
Decomposition	STR1.1: Service information that can be reusable shall be identified STR1.21: IT tools shall be identified STR1.22: IT tools shall be implemented STR1.23: Services shall be connectable STR1.2: Technical assets supporting services shall be put in place STR1.3: Exchange of process information shall be possible
Requires	DTR1:Data storage devices connectable, simple electronic exchange possible DCR1:Data models defined and documented
Is required by	BTR1: Basic IT infrastructure shall be in place
Best Practices	BPST1.1. Identify possibilities of information extraction from services/applications and their reusability by other applications. BPST1.2. Identify technical assets supporting interconnection between services BPST1.3. Make sure that an information exchange of applications/services is possible
Related Barrier	IBBT1. Degree of computerisation IBBT2. IT requirement fulfilment IBST1. Service granularity

Table A34. STR2: Standardise and configurable service architecture(s) and interface(s) shall be available

IR	STR2: Standardise and configurable service architecture(s) and interface(s) shall be available
Interoperability Area	Service-Technological
Maturity Level	Level 2 - Aligned
Decomposition	STR2.1: Relevant standards shall be identified STR2.2: Standards shall be selected and used STR2.3: Service parameters that shall be expected to be configurable shall be identified STR2.4: Parameters shall be configured
Requires	BCR1.8: Business partners shall be defined BCR1.9: Clients shall be identified BCR1.10: Reg. Institutions shall be identified STR1: Applications/services shall be connectable and Ad hoc information exchange shall be possible
Is required by	
Best Practices	BPST2.1. Put in place standard technical assets supporting services BPST2.2. Define parameters to configure for enterprise services BPST2.3. Make sure that tools supporting services are configurable
Related Barrier	IBBT1. Degree of computerisation IBBT2. IT requirement fulfilment IBST1. Service granularity

Table A35. STR3: Automated services discovery and composition, shared applications

IR	STR3: Automated services discovery and composition, shared applications
Interoperability Area	Service-Technological
Maturity Level	Level 3 - Organized
Decomposition	STR3.11: IT tools for supporting service discovery shall be identified STR3.12: IT tools for supporting service decomposition shall be identified STR3.13: IT tools for supporting service discovery shall be implemented STR3.14: IT tools for supporting service decomposition shall be implemented STR3.2: Services shall be decomposed STR3.5: Services can be shared with partners STR3.3: Interoperability between two basic services shall be ensured STR3.4: Functions and semantics shall be defined
Requires	BCR1: Business models shall be defined and documented BCR3: Business Models shall be designed for collaboration BTR1: Basic IT infrastructure shall be in place SCR1: Service models shall be defined and documented STR1: Applications/services shall be connectable and Ad hoc information exchange shall be possible STR2: Standardise and configurable service architecture(s) and interface(s) shall be available DCR1:Data models defined and documented
Is required by	
Best Practices	BPST3.1. Put in place technical assets supporting enterprise services discovery and composition BPST3.2. Decompose service/application in basic ones BPST3.3. Ensure interoperability between basic services and applications. ST3.4. Clearly define its functions and semantics BPST3.5. Make sure that services and applications can be shared by partners
Related Barrier	IBBT1. Degree of computerisation IBBT2. IT requirement fulfilment IBST1. Service granularity

Table A36. STR4: Dynamically composable services, networked applications

IR	STR4: Dynamically composable services, networked applications
Interoperability Area	Service-Technological
Maturity Level	Level 4 - Adapted
Decomposition	STR4.1: Dynamic service engineering tools shall be identified STR4.2: Dynamic service engineering tools shall be implemented STR4.3: Services can be managed by different teams
Requires	STR1: Applications/services shall be connectable and Ad hoc information exchange shall be possible SOR4: Dynamic service and application management rules and methods STR3: Automated services discovery and composition, shared applications
Is required by	
Best Practices	BPST4.1. Identify tools and platforms that support dynamic services engineering BPST4.2. Decompose services into manageable and composable elements
Related Barrier	IBBT1. Degree of computerisation IBBT2. IT requirement fulfilment IBST1. Service granularity

Requirements related to the Data concern

Table A37. DCR1: Data models defined and documented

IR	DCR1:Data models defined and documented
Interoperability Area	Data-Conceptual
Maturity Level	Level 1 - Defined
Decomposition	DCR1.11 Tools for handling data models shall be identified DCR1.12 Semantics of each concept and attribute shall be defined DCR1.1: Data models shall be defined DCR1.2 Data models shall be documented
Requires	BTR1: Basic IT infrastructure shall be in place DTR1:Data storage devices connectable, simple electronic exchange possible
Is required by	BTR1: Basic IT infrastructure shall be in place
Best Practices	BPDC1.1. Define Data models BPDC1.2. Document Data model
Related Barrier	IBDC1. Data content IBDC2. Data Syntax IBDC3. Data semantics

Table A38. DCR2: Use of standards for alignment with other data models

IR	DCR2:Use of standards for alignment with other data models
Interoperability Area	Data-Conceptual
Maturity Level	Level 2 - Aligned
Decomposition	DCR2.11 Standards used by reg. Institutions shall be identified DCR2.12 Standards used by partners shall be identified DCR2.13 Standards used by clients shall be identified DCR2.2 Standards shall be selected and used
Requires	BCR1.8: Business partners shall be defined BCR1.9: Clients shall be identified BCR1.10: Reg. Institutions shall be identified DCR1:Data models defined and documented
Is required by	
Best Practices	BPDC2.1. Identify relevant standards for interoperability BPDC2.1. Use relevant standards for interoperability
Related Barrier	IBDC1. Data content IBDC2. Data Syntax IBDC3. Data semantics

Table A39. DCR3: Meta-modelling for multiple data model mappings

IR	DCR3:Meta-modeling for multiple data model mappings
Interoperability Area	Data-Conceptual
Maturity Level	Level 3 - Organized
Decomposition	DCR3.1: Concepts used by partners shall be identified DCR3.21: Concepts subject to interoperability shall be identified DCR3.22: Problematic concepts shall be identified DCR3.2: Meta-Models shall be defined DCR3.3: Meta-Models shall be used for defining data models DCR3.41: Syntactic correspondences shall be defined DCR3.42: Semantic correspondences shall be defined
Requires	DCR1:Data models defined and documented DCR2:Use of standards for alignment with other data models
Is required by	
Best Practices	BPDC3.1. Identify concepts that are used by the main partners (past or future ones) BPDC3.2. Define meta models for existing data models BPDC3.3. Use meta models for the data models definition BPDC3.4. Define possible mappings, semantic and syntactic correspondences for schema matching.
Related Barrier	IBDC1. Data content IBDC2. Data Syntax IBDC3. Data semantics

Table A40. DCR4: Adaptive data models (both syntax and semantics)

IR	DCR4:Adaptive data models (both syntax and semantics)
Interoperability Area	Data-Conceptual
Maturity Level	Level 4 - Adapted
Decomposition	DCR4.1: Modifiable elements of data models shall be identified DCR4.2: Non-modifiable elements of data models shall be identified DCR4.3: Potential modifications for enhancing collaboration shall be identified
Requires	DCR1:Data models defined and documented DCR2:Use of standards for alignment with other data models
Is required by	
Best Practices	BPDC4.1. Define data models elements that can be modified BPDC4.2. Identify data model elements that cannot be modified BPDC4.3 Identify the main changes that can be undertaken for the identified elements to collaborate with future partners.
Related Barrier	IBDC1. Data content IBDC2. Data Syntax IBDC3. Data semantics

Table A41. DOR1: Responsibilities and authorities shall be defined and in place

IR	DOR1: Responsibilities and authorities shall be defined and in place
Interoperability Area	Data-Organisational
Maturity Level	Level 1 - Defined
Decomposition	DOR1.1: Involved resources shall be identified DOR1.2: Data responsibilities/authorities shall be defined DOR1.3: Responsibilities/ authorities shall be assigned DOR1.4: Data rules shall be defined DOR1.5: Data responsibilities and authorities shall be put in place
Requires	BOR1: Organization structure shall be defined and in place DTR1:Data storage devices connectable, simple electronic exchange possible BTR1: Basic IT infrastructure shall be in place SOR1: Service responsibilities and authorities defined and put in place
Is required by	
Best Practices	BPDO1.1. Define data responsibilities and authorities BPDO1.2. Put data responsibilities/authorities in place and in everyday use.
Related Barrier	IBDO1. Information ownership IBDO2. Classified information

Table A42. DOR2: Rules and methods for data management shall be in place

IR	DOR2: Rules and methods for data management shall be in place
Interoperability Area	Data-Organisational
Maturity Level	Level 2 - Aligned
Decomposition	DOR2.1: Private data shall be identified DOR2.2: Set policy, guidelines and procedures DOR2.3: Rules and Methods shall be used
Requires	DCR1:Data models defined and documented DTR1:Data storage devices connectable, simple electronic exchange possible DTR2: Automated access to data based on standard protocols
Is required by	PTR2: Standard-based IT tools shall be used STR2: Standardise and configurable service architecture(s) and interface(s) shall be available
Best Practices	BPDO2.1. Define data management rules BPDO2.2. Identify private data BPDO2.3. Set data management rules in place
Related Barrier	IBDO1. Information ownership IBDO2. Classified information

Table A43. DOR3: Personalized data management for different partners

IR	DOR3: Personalized data management for different partners
Interoperability Area	Data-Organisational
Maturity Level	Level 3 - Organized
Decomposition	DOR3.1: Restrictions shall be defined DOR3.2: Procedures to personalised data shall be defined DOR3.3: Part of data that can be personalised shall be identified
Requires	DCR1:Data models defined and documented BCR3: Business Models shall be designed for collaboration DOR2: Rules and methods for data management shall be in place
Is required by	
Best Practices	BPDO3.1. Define personalization data management rules BPDO3.2. Identify parts of data that can be personalized
Related Barrier	IBDO1. Information ownership IBDO2. Classified information

Table A44. DOR4: Adaptive data management rules and methods

IR	DOR4: Adaptive data management rules and methods
Interoperability Area	Data-Organisational
Maturity Level	Level 4 - Adapted
Decomposition	DOR4.1: Rules and methods that support dynamic adaptation of data models shall be defined DOR4.2: Data elements that shall be subject of potential adaptation and accommodation shall be identified DOR4.3: Responsible for managing data changes shall be identified
Requires	DOR1: Responsibilities and authorities shall be defined and in place DOR2: Rules and methods for data management shall be in place DOR3: Personalized data management for different partners DCR4:Adaptive data models (both syntax and semantics) DCR1:Data models shall be defined and documented
Is required by	
Best Practices	BPDO4.1. Define data rules and methods that support dynamic adaptation of data models. BPDO4.2. Identify data elements that are subject of potential adaptation and accommodation BPDO4.3. Identify responsible persons to manage the change and define what to do in case of problems. BPDO4.4. Identify and define the main actions to undertake for data model dynamic adaptation.
Related Barrier	IBDO1. Information ownership IBDO2. Classified information

Table A45. DTR1: Data storage devices connectable, simple electronic exchange possible

IR	DTR1:Data storage devices shall be connectable and simple electronic exchange shall be possible
Interoperability Area	Data-Technological
Maturity Level	Level 1 - Defined
Decomposition	DTR1.1: Data that can be subject of future interoperation shall be identified DTR1.2: Data storage tools shall be connectable DTR1.3: Data storage tools shall be identified DTR1.4: Data storage tools shall be implemented DTR1.5: Technical assets supporting data exchange shall be in place DTR1.6: Data exchange tools shall be identified DTR1.7: Data exchange tools shall be implemented DTR1.8: Protocols regarding data storage and exchange shall be defined DTR1.9: Protocols related to data exchange shall be defined DTR1.10: Protocols related to data storage shall be defined
Requires	DCR1:Data models shall be defined and documented BTR1: Basic IT infrastructure shall be in place
Is required by	DTR2: Automated access to data shall be based on standard protocols DTR3: Remote access to databases shall be possible for applications and shared data shall be available DOR1: Responsibilities and authorities shall be defined and in place DOR2: Rules and methods for data management shall be in place STR1: Applications/services shall be connectable and ad hoc information exchange shall be possible PTR1: IT support shall support processes and ad hoc exchange of process information shall be possible BTR1: Basic IT infrastructure shall be in place
Best Practices	BPDT1.1. Identify data that can be subject of future interoperation BPDT1.2. Configure data storage devices so that they are connectable BPDT1.3. Put in place technical assets supporting data exchange within the enterprise BPDT1.4. Define protocols that can be used for data exchange interoperability
Related Barrier	IBBT1. Degree of computerisation IBBT2. IT requirement fulfilment IBDT1. Exchange format

Table A46. DTR2: Automated access to data based on standard protocols

IR	DTR2: Automated access to data shall be based on standard protocols
Interoperability Area	Data-Technological
Maturity Level	Level 2 - Aligned
Decomposition	DTR2.1: Relevant standards shall be identified DTR2.2: Standards shall be selected and used DTR2.3: Parameters that shall be expected to be configurable shall be identified DTR2.4: Parameters shall be configured
Requires	BCR1.8: Business partners shall be defined BCR1.9: Clients shall be identified BCR1.10: Reg. Institutions shall be identified DTR1:Data storage devices connectable, simple electronic exchange possible
Is required by	
Best Practices	BPDT2.1. Parameter data storage devices in order to ensure automated access to data BPDT2.2. Use standard data transmission protocol
Related Barrier	IBBT1. Degree of computerisation IBBT2. IT requirement fulfilment IBDT1. Exchange format

Table A47. DTR3: Remote access to databases possible for applications, shared data

IR	DTR3: Remote access to databases possible for applications, shared data
Interoperability Area	Data-Technological
Maturity Level	Level 3 - Organized
Decomposition	DT3.1: IT tools that need remote access to databases shall be identified DT3.2: Remote accesses shall be secured DT3.3: Data exchange shall be ensured
Requires	BCR3: Business Models shall be designed for collaboration BTR1: Basic IT infrastructure shall be in place DTR1:Data storage devices connectable, simple electronic exchange possible DTR2: Automated access to data based on standard protocols DOR1: Responsibilities and authorities shall be defined and in place DOR2: Rules and methods for data management shall be in place DOR3: Personalized data management for different partners
Is required by	
Best Practices	BPDT3.1. Identify applications that need a remote access to databases BPDT3.2. Secure the remote access to databases BPDT3.3. Make sure that data can be shared among applications
Related Barrier	IBBT1. Degree of computerisation IBBT2. IT requirement fulfilment IBDT1. Exchange format

Table A48. DTR4: Direct database exchanges capability and full data conversion tool.

IR	DTR4: Direct database exchanges capability and full data conversion tool.
Interoperability Area	Data-Technological
Maturity Level	Level 4 - Adapted
Decomposition	DTR4.1: Direct data exchange between heterogeneous databases shall be possible; DTR4.2: Data conversion tools shall be in place
Requires	DCR2:Use of standards for alignment with other data models DCR3:Meta-modeling for multiple data model mappings DOR4: Adaptive data management rules and methods DTR3: Remote access to databases possible for applications, shared data DTR2: Automated access to data based on standard protocols
Is required by	
Best Practices	BPDT4.1. Define and build a federation (through federated approach) of heterogeneous databases to ease interoperability. BPDT4.2. Develop or acquire full data conversion tools to support dynamic (on-the-fly) data conversion
Related Barrier	IBBT1. Degree of computerisation IBBT2. IT requirement fulfilment IBDT1. Exchange format

Annexe B – Rating the Interoperability Requirements

The adopted rating scale

A rating scale is an ordered set of values, continuous or discrete, to which the requirement fulfilment is mapped. We choose to keep the same four linguistics values that compose the rating scale from the current version of MMEI. These four values (Fully Achieved, Largely Achieved, Partially Achieved and Not Achieved) are defined based on the scale proposed by the ISO 15504 (ISO/IEC 15504-1, 2004), later revised into the ISO 33000 family (ISO/IEC 33001, 2015). This rating scale is widely used by international and de facto standard such as the COBIT 5 (ISACA, 2012) and the CMMI framework (CMMI Product Team, 2010b, 2010c, 2010a).

The linguistic values and their description are presented in Table B1. The numeric ranges, which represents each linguistic values, is presented in Table B2 with their Centre of Gravity.

Table B1. Description of each linguistic value

Linguistic value	Description
Not Achieved (NA)	There is little or no evidence of achievement of the defined attribute in the assessed requirement
Partially Achieved (PA)	There is some evidence of an approach to, and some achievement of, the defined attribute in the assessed requirement. Some aspects of achievement of the attribute may be unpredictable
Largely Achieved (LA)	There is evidence of a systemic approach to, and significant achievement of, the defined attribute in the assessed requirement. Some weakness related to this attribute may exist in the assessed requirement.
Fully Achieved (FA)	There is evidence of a complete and systematic approach to, and full achievement of, defined attribute in the assessed requirement. No significant weakness related to this attribute exist in the assessed requirement.

Table B2. Numeric values related to each linguistic value

Linguistic value	Numeric range	Centre of Gravity (COG)
Not Achieved (NA)	$0 \leq x \leq 15$	6,866
Partially Achieved (PA)	$15 < x \leq 50$	32,861
Largely Achieved (LA)	$50 < x \leq 85$	67,5
Fully Achieved (FA)	$85 < x \leq 100$	90,495

The linguistics values are used for rating each concerned interoperability requirement. The numeric value given by the Centre of Gravity (COG) (which are defined in details in (Guédria et al., 2015)) is useful for quantifying and computing (if necessary) the ratings. Such quantification is used for example by the aggregation methods (i.e. the method used for aggregating rating of the same requirement given by different assessors). The numeric range is useful for classifying the requirement values after an aggregation calculation takes place.

However, the assessors should be careful to not directly associate the numeric range described above with the numeric values obtained by other quantitative methods as, in general, the same numeric values provided by different methods have different meaning. Therefore, in the following sections, we discuss and propose rating methods for the interoperability requirements related to each interoperability aspects.

The rating method for the potentiality assessment

As the current version of the maturity model focus on the ***potentiality assessment***, the rating method is based only on the linguistic variables i.e. requirement can be: *Fully Achieved*, *Largely Achieved*, *Partially Achieved* and *Not Achieved*. It is mostly done because in the potentiality assessment the interoperation's partner is unknown. Thus, the evaluation concerns the maturity of the concerned enterprise towards its environment. Hence, it is hard to quantify whether an enterprise is potentially compatible with its environments, as the evaluation must consider all or the most of the potential partners, used standards and technologies in the enterprise environment. An overview of the method steps is illustrated on Fig. B1.

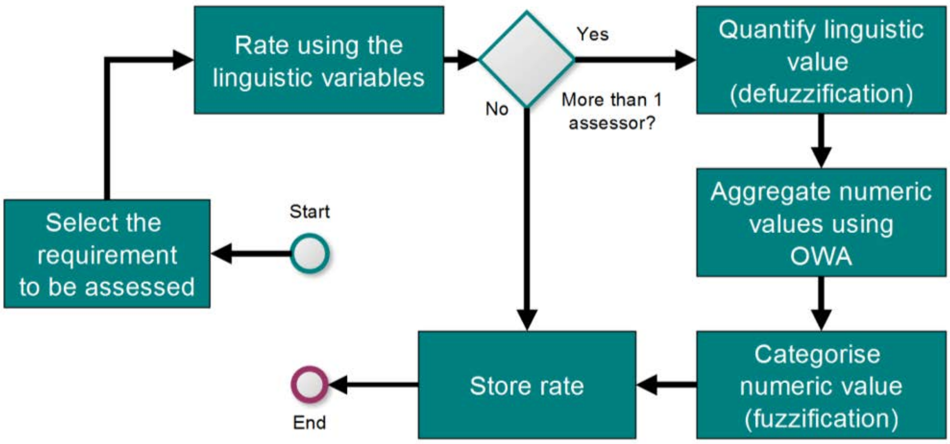


Fig. B1. The current rating method for the potentiality assessment

The "defuzzification" refers to the use of the respective COG value and the "fuzzification" refers to attribute a linguistic value based on the numeric range and the numeric value obtained by the aggregation method. The aggregation method is described below.

The aggregation method

When there are more than one assessor, the final rating is the aggregation of all assessors' individual assessments. It is calculated based on an Over Weight Average (OWA) operator (Yager, 1988). To this end, the following definitions are established:

Definition 1) an OWA operator of dimension "n" is a mapping OWA: $R^n \rightarrow R$ that has an associated vector w= (w_1, w_2, w_3, …, w_n), such as $w_1 \in [0,1], 1 \leq j \leq n$ and $\sum_{j=1}^{n} w_j = 1$d, furthermore:

$$OWA(a_1, a_2, \ldots, a_n) = \sum_{j=1}^{n} w_j \, b_j$$

Where b_j is the j-th largest element of the bag $(a_1, a_2, \ldots, a_n)$.

Definition 2) let $(a_1, a_2, \ldots, a_n)$ be a collection of arguments, and let M be the average value of these arguments:

$$M = \sum_{j=1}^{n} a_j$$

Then:

$$s(b_j, M) = 1 - \frac{|b_j - M|}{\sum_{j=1}^{n} |a_j - M|} \; ; j = 1,2, \ldots, n$$

Is called the similarity degree of the j-th largest argument $b_j$and the average value M.

Definition 3) let $w = (w_1, w_2, w_3, \ldots w_n)$ be the weight vector pf the OWA operator:

$$w_j = \frac{s(b_j, M)}{\sum_{j=1}^{n} s(b_j, M)} \; ; j = 1,2, \ldots, n.$$

The rating methods for the compatibility assessment

However, when one is applying a compatibility assessment, partners are already known, therefore, it is possible to compare quantitatively and qualitatively the concerned enterprises. Thus, assessor can follow the rating steps as illustrated on Fig. B2. This proposed rating method is similar to the used for the potentiality assessment but with two new steps (coloured in light green): calculate the formal measures and associate numeric values with linguistic ones.

This modification allows assessor to use different quantitative and formal measure for justifying their ratings. For example, when verifying if the partners have compatible and interpretable data model (e.g. ontologies, taxonomies, etc.), assessors may use quantitative methods for identifying the percentage of similar concepts semantics and the existing semantics relationships. It is important to note that the use of such quantitative methods is optional. They are a support for justifying the qualitative rates.

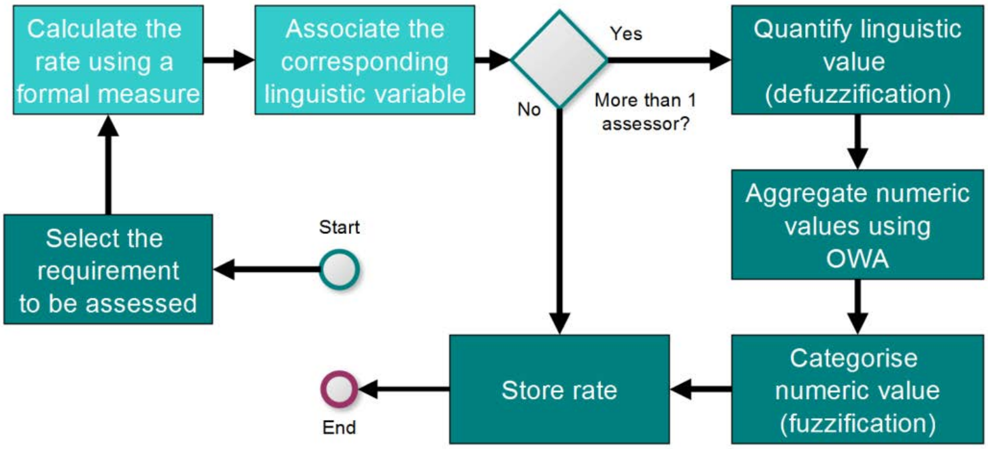


Fig. B2. The proposed rating method for the compatibility assessment

However, such quantitative methods may have distinct rate scales and as discussed in chapter 3, it can be difficult to interpret the obtained results. For example, let take the linguistics values and their numeric ranges proposed by the current version of MMEI (see Table B2) and the quantitative measures proposed by (Yahia et al., 2012a) regarding the semantic relationships.

When considering the rating of the requirement "data models are compatible", can we consider that a 75% of similar concepts represents is "translated" directly to the *Largely Achieved* value from MMEI? The answer, for us, for this question is NO. As observed during the conducted literature review, the existing methods that propose quantitative measures, are not applying the same rating scale and / or the same meaning for each numeric value. Therefore, assessors should base their rating considering the results from such quantitative methods and their experience. It is also important to note that not all requirements can be quantified, for instance, those requirements related to the organisation's culture.

The maturity level determination

The determination of the maturity level is based on the achievement of the interoperability requirements. Organisations may desire to have an insight regarding:

- A specific Interoperability Aspects (e.g. an IT manager wants to know what the current state of the implemented technological assets is, despite the enterprise layer);
- A specific Interoperability Concern (e.g. a project manager wants to identify improvement opportunities of a given process considering the conceptual, technological and organisational aspects of it);
- The Interoperability Maturity of the whole concerned system (e.g. an enterprise, a network, part of the network, etc.);

Fig. B3 illustrates the different form to obtain the maturity levels.

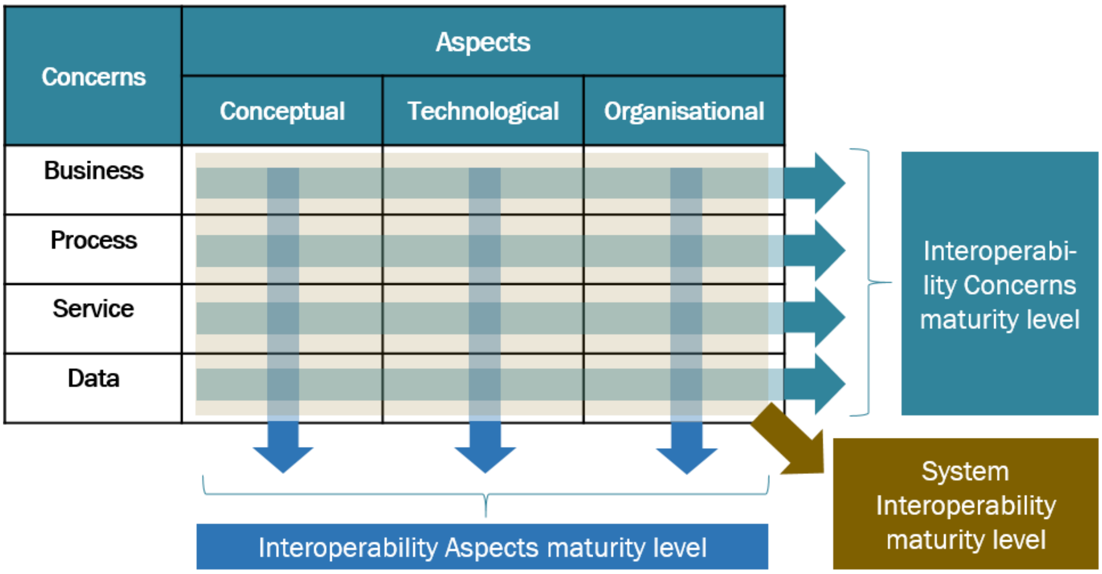


Fig. B3. The maturity level determination focuses

Therefore, we describe below, three maturity level determination methods: One for identifying the level of an Interoperability Aspect maturity; one for the Interoperability Concern maturity; and one for the System Interoperability maturity. The specificities of each method are described below.

The Interoperability Aspect maturity level determination

Let R_a be the set of fuzzy rules allowing to determining the rating of an EI Aspects at a level L based on the requirements fulfilment. The EI aspects: Conceptual, Technological and Organisational at level L are denote as C_L, T_L and O_L, respectively. Further, let R' be the set of rules r allowing calculating the final interoperability maturity level of each EI aspect and where final level of each aspect is represented as: C_E, T_E and O_E.

Definition 4) $R_a = \{r_C, r_T, r_O\}$ such as:

$r_x = \{r_x\}$: (BIa_L is λ_1) AND (PIa_L is λ_2) AND (SIa_L is λ_3) AND (dIa_L is λ_4) THEN (Ic_L is λ_c) (1)

With: x = Ia ϵ {C, T, O}, λ_i, λ_c ϵ {NA; PA; LA; FA}, L ϵ {1; 2; 3; 4}

Table B3 details some rules based on equation 1, where Ia = T, and L = 3.

Table B3. Example of fuzzy rules : r_x

Fuzzy rules – extract from R_a									
IF	BT3 is PA	AND	PT3 is PA	AND	ST3 is PA	AND	DT3 is PA	THEN	T_L is PA
IF	BT3 is PA	AND	PT3 is NA	AND	ST3 is NA	AND	DT3 is NA	THEN	T_L is NA
IF	BT3 is FA	AND	PT3 is FA	AND	ST3 is FA	AND	DT3 is LA	THEN	T_L is FA
IF	BT3 is FA	AND	PT3 is LA	AND	ST3 is LA	AND	DT3 is PA	THEN	T_L is LA

Based on the calculation of λ_c of the target EI aspect at the level L,

Definition 5) R' = {r'_C, r'_T, r'_O} such as:

$r'_x = \{r'_x\}$: (Ia1 is λ_{c1}) AND (Ia2 is λ_{c2}) AND (Ia3 is λ_{c3}) AND (Ia4 is λ_{c4}) THEN (Ia_E is L) (2)

With: x = Ia ϵ {C, T, O}, λ_{ci} ϵ {NA; PA; LA; FA}, L ϵ {1; 2; 3; 4}

Table B4 details some rules based on equation 1, where IC = B, and L = 2.

Table B4. Example of fuzzy rules : r'_x

Fuzzy rules – extract from R''									
IF	T1 is FA	AND	T2 is FA	AND	T3 is FA	AND	T4 is FA	THEN	T_E is 4
IF	T1 is FA	AND	T2 is FA	AND	T3 is FA	AND	T4 is PA	THEN	T_E is 3
IF	T1 is FA	AND	T2 is FA	AND	T3 is PA	AND	T4 is LA	THEN	T_E is 2
IF	T1 is FA	AND	T2 is FA	AND	T3 is PA	AND	T4 is NA	THEN	T_E is 2

Fig. B4 illustrates the rating steps.

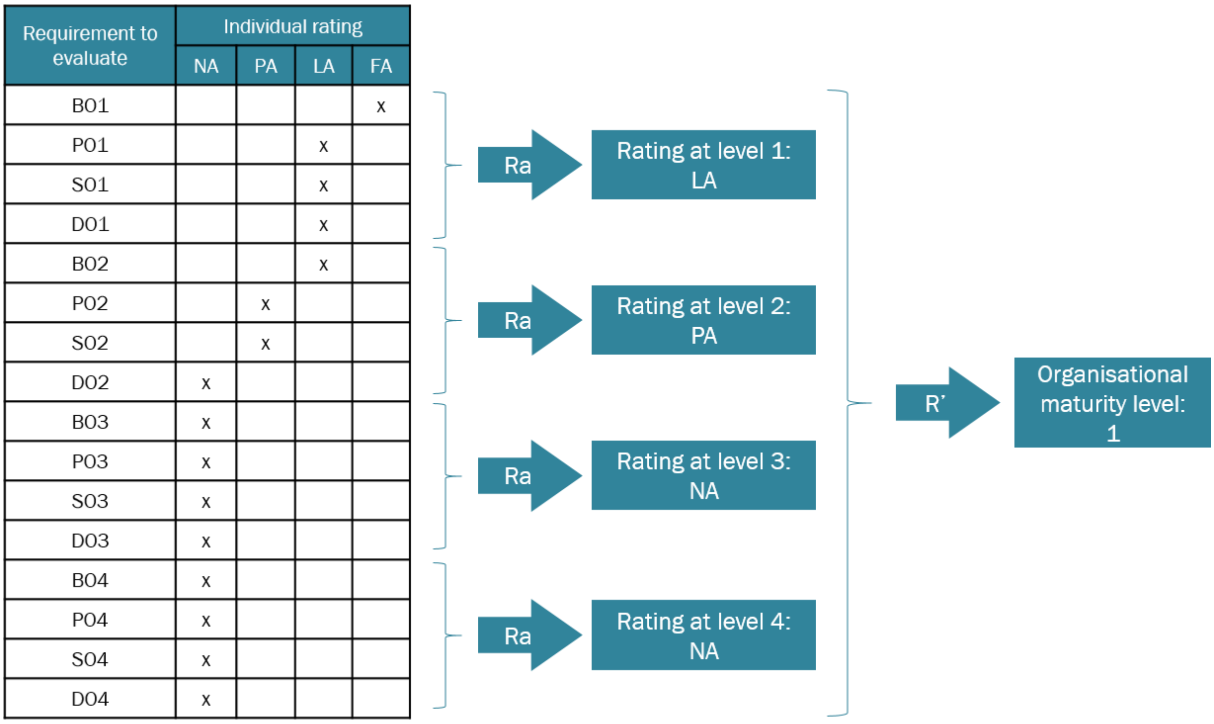


Fig. B4. Interoperability concern maturity level determination

The Interoperability Concern maturity level determination

Let R_c be the set of fuzzy rules allowing to determine the rating of an EI Concern at a level L based on the requirements fulfilment. The EI concerns: Business, Process, Service and Data at level L are denote as B_L, P_L, S_L and D_L, respectively. Let R'' be the set of rules r allowing to calculate the final interoperability maturity level of each EI concern and where final level of each concerns is represented as: B_E; P_E; S_E and D_E.

Definition 6) $R_c = \{r_B, r_P, r_S, r_D\}$ such as:

$$r_x = \{r_x\} : (IcC_L \text{ is } \lambda_1) \text{ AND } (IcT_L \text{ is } \lambda_2) \text{ AND } (IcO_L \text{ is } \lambda_3) \text{ THEN } (Ic_L \text{ is } \lambda_c) \qquad (3)$$

With: $x = Ic \in \{B, P, S, D\}$, λ_i, $\lambda_c \in \{NA; PA; LA; FA\}$, $L \in \{1; 2; 3; 4\}$

Table B5 details some rules based on equation 1, where IC = B, and L = 2.

Table B5. Example of fuzzy rules: r_x

Fuzzy rules – extract from R_c							
IF	BC2 is PA	AND	BT2 is NA	AND	BO2 is NA	THEN	B_L is NA
IF	BC2 is PA	AND	BT2 is NA	AND	BO2 is PA	THEN	B_L is PA
IF	BC2 is PA	AND	BT2 is PA	AND	BO2 is NA	THEN	B_L is PA
IF	BC2 is PA	AND	BT2 is PA	AND	BO2 is PA	THEN	B_L is PA

Based on the calculation of λ_c of the target EI concern at the level L,

Definition 7) R'' = {r'_B, r'_P, r'_S, r'_D} such as:

$r'_x = \{r'_x\}$: (Ic1 is λ_{c1}) AND (Ic2 is λ_{c2}) AND (Ic3 is λ_{c3}) AND (Ic4 is λ_{c4}) THEN (Ic_E is L) (4)

With: x = Ic ϵ {B, P, S, D}, λ_{ci} ϵ {NA; PA; LA; FA}, L ϵ {1; 2; 3; 4}

Table B6 details some rules based on equation 1, where Ic = B, and L = 2.

Table B6. Example of fuzzy rules : r'_x

Fuzzy rules – extract from R''									
IF	B1 is FA	AND	B2 is FA	AND	B3 is FA	AND	B4 is FA	THEN	B_E is 4
IF	B1 is FA	AND	B2 is FA	AND	B3 is FA	AND	B4 is PA	THEN	B_E is 3
IF	B1 is FA	AND	B2 is FA	AND	B3 is PA	AND	B4 is LA	THEN	B_E is 2
IF	B1 is FA	AND	B2 is FA	AND	B3 is PA	AND	B4 is NA	THEN	B_E is 2

Fig. B5 illustrates the rating steps.

Requirement to evaluate	Individual rating			
	NA	PA	LA	FA
PC1				X
PT1				X
PO1			X	
PC2			X	
PT2		X		
PO2			X	
PC3		X		
PT3		X		
PO3	X			
PC4	X			
PT4	X			
PO4	X			

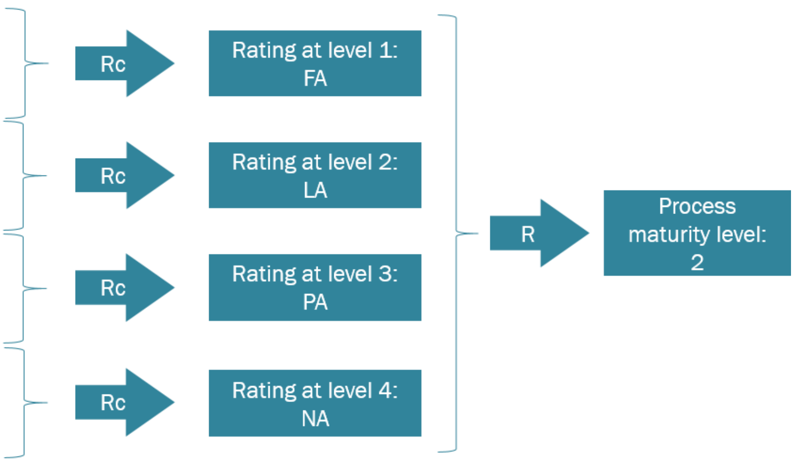


Fig. B5. Interoperability concern maturity level determination

The System maturity level determination

Let R_s be the set of fuzzy rules allowing determining the rating of the concerned system at a level L based on the requirements fulfilment. Further, let R''' be the set of rules r allowing to calculate the final interoperability maturity level of the concerned system. S_L denotes if the system achieved the concerned maturity level.

Definition 8) R_s = {r_s} such as:

$r_s = \{r_s\}$: (BC_L is λ_1) AND (BT_L is λ_2) AND (BO_L is λ_3) AND (PC_L is λ_4) AND (PT_L is λ_5) AND (PO_L is λ_6) AND (SC_L is λ_7) AND (ST_L is λ_8) AND (SO_L is λ_9) AND (DC_L is λ_{10}) AND (DT_L is λ_{11}) AND (DO_L is λ_{12}) THEN (S_L is λ_c) (5)

With: λ_i, $\lambda_c \in$ {NA; PA; LA; FA}, L $\in$ {1; 2; 3; 4}

Based on the calculation of λ_c,

Definition 9) R''' = {r'$_s$} such as:

$r'_s = \{r'_s\}$: (S1 is λ_{c1}) AND (S2 is λ_{c2}) AND (S3 is λ_{c3}) AND (S4 is λ_{c4}) THEN (S_E is L) (6)

With: $\lambda_{ci} \in$ {NA; PA; LA; FA}, L $\in$ {1; 2; 3; 4}

Fig. B7 illustrates the rating steps.

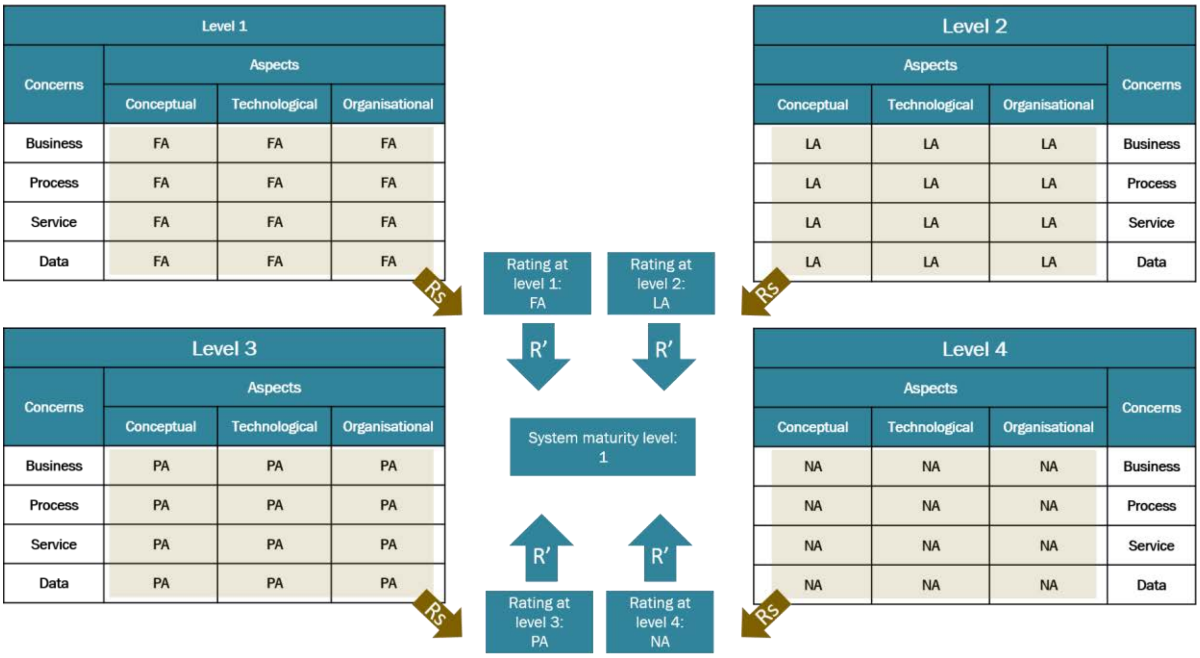


Fig. B7. System Interoperability maturity level determination

Annexe C – The questionnaire used for gathering informaiton

Question	Details
What does the ENTERPRISE name mean?	General Information
How many employees does the ENTERPRISE have?	This question allows the interviewer to determine the workforce (human resource) in each enterprise.
Is the ENTERPRISE present in different regions?	This question allows the interviewer to determine if the enterprise acting on a national or international scale. It helps to determine the enterprise boundaries.
How many nationalities are working in the ENTERPRISE? Is there an official language within the ENTERPRISE? (If yes) Which one?	This question allows the interviewer to determine if the enterprise is a global enterprise or not. Moreover if, the enterprise has a standard language to avoid communication problems.
Does the ENTERPRISE have any certificate? (If yes) Can you cite the main certificates?	This question allows the interviewer to determine if the enterprise follows any 'global' standard. e.g. ISO 9000, and others.
What are the main objectives of the ENTERPRISE / The Factory Group?	This question allows the interviewer to understand the enterprise primary motivations.
What are the key activities required to reach its objectives? Who defines activities? Is the information documented? (If yes) Who has access to this document? (The same question for The Factory Group)	This question allows the interviewer to evaluate if the enterprise knows how to achieve its objectives. (e.g. scenario 1: Concept Factory is too concerned to develop IT applications instead of creating designs and publication material. (Wrong), scenario 2: Concept Factory is focusing on developing new marketing projects and leaves the development of IT applications to Interact.)
What are the key resources required to reach its objectives? Who manages resources? Is the information documented? (If yes) Who has access to this document? (The same question for The Factory Group)	This question allows the interviewer to understand what are the primary resources the enterprise needs. It allows determining which one is more important, human resource (knowledge), technology (ICT), etc.
What are the products and services of the ENTERPRISE? How is this information presented to customers? Do you think that it is sufficiently visible to the clients? (If not) What do you think that needs to improve?	The first question allows the interviewer to know if the enterprise has determined its primary services. The second question allows the interviewer to better understand how the Enterprise delivers information about its services, and if it is efficient.
Exxus and Sustain -> why your website does not follow the same model off Interact and Concept Factory?	This question allows the interviewer to understand the enterprise marketing priorities, the enterprise influence, and importance within the FG.
What products and services is The Factory Group offering to customers? Is the client aware of the services that The Factory Group is offering? Do you think that it is sufficiently visible to the clients? (If not) What do you think that needs to improve? Do you think that the website presents a clear structure with a clear mission of each partner within The Factory Group? (If not) Why?	The first question allows the interviewer to know if the enterprise has determined its main services. If the enterprise knows the client needs. The second and third questions allow the interviewer to better understand how the Enterprise delivers information about its services, and if it is efficient. The fourth question allows the interviewer to see if all CEOs agree with its enterprise description and participation within the group.
Is there a well-defined organizational structure in ENTERPRISE / In the Factory Group? (If yes) Is there a representation (chart) that shows the structure? Is this representation documented? Who has access to this document?	This question allows the interviewer to understand how the hierarchy within the enterprise and the group works. It also allows determining if the company is implementing a vertical or horizontal structure. It helps to understand the relationship between employees.
Are the authorities and responsibilities of each employee well defined in ENTERPRISE? (If yes) Is the information documented? Who has access to this document?	This question allows the interviewer to understand its organization and to see if the company is transparent considering its structure.
Does the group structure influence the enterprise structure?	This question allows the interviewer to understand the different actors and its influence within the group.

Among the members of the group, do you think that a specific one has more influence than the others? (If yes) Why?	This question allows the interviewer to understand the various stakeholders and its influence within the group.
If an employee is absent, is it easy to "replace him"/to find someone to do the job? (If yes) Is this documented? Who has access to this information?	This question allows the interviewer to determine the flexibility within the enterprise. It also helps to see if the enterprise is prepared for casualties.
If an employee leaves the ENTERPRISE, is it easy to "replace him"/to find someone to do the job? (If yes) Is this documented? Who has access to this information?	This question allows the interviewer to determine the flexibility of the enterprise. It also helps to see if the enterprise is prepared for casualties.
Does the enterprise / the group organise group dynamics?	This question allows the interviewer to see if the enterprise offers opportunities to its employees know each other, and understand the different activities within the enterprise.
Is it easy to make changes in the organization structure?	This question allows the interviewer to determine the enterprise flexibility.
Are the main processes well defined within the ENTERPRISE / the Group? (e.g. business processes, project management processes, communication process, etc.) (If yes) Are the relations between processes well defined? Who are responsible for defining processes and its relations? Can we easily modify, add/delete a task/activity in a business process? Is there a standard for process definition? Do you have documents where the different processes are defined? (If not) How does the ENTERPRISE / the group handle with the different approaches and order of activities that employees can use to accomplish the same task?	This question allows the interviewer to see if the primary enterprise processes are structured and shared within the company. It helps to identify conflicts between activities. It allows determining the processes flexibility. If the answer to the first question is negative, we can understand how the enterprises deal with different ways of acting.
Are the work methods well defined? (e.g. The employee 'X' spends more time doing a task but he spends fewer resources. The employee 'Y' spends more resources then employee 'X', but he does the same task quickly. Which one is better?). (If yes) Who defines work methods? Is there a standard for the work methods definition? Do you have documents where the different work methods are described?	This question allows the interviewer to see if the particular enterprise methodologies are structured and shared within the company. It helps to identify conflicts between methods. If the answer to the first question is negative, we can understand how the enterprises deal with different ways of thinking.
Can you introduce a new work method if needed? (If yes) Do you think it would be an impact on the enterprise? And with the employees, would they accept it easily? Is there some organized training to get used to the new work methods?	
How do the employees communicate within the ENTERPRISE / the Group? (Which means do they use?)	This question allows the interviewer to identify the communication fluidity. It helps to identify if the enterprise uses a digital channel (email, Messenger, etc.) of communication or it still uses traditional ways (phone calls, printed paper, etc.)
How does managers communicate with employees? (Which means do they use?) Does the managers announce new projects, products, and partnerships to all employees within the ENTERPRISE / the group? (An exaggerated situation, for example, the employees discover by the external media that their enterprise is launching a new project).	This question allows the interviewer to identify the communication fluidity (concerning the management level). It helps to identify if the management uses a digital channel (email, Messenger, etc.) of communication or it still uses traditional ways (phone calls, printed paper, etc.)
How do you exchange documents within the ENTERPRISE / The Group? (Which means do you use?)	This question allows the interviewer to identify which are the main means of communications (email, servers, etc.)
All members of the group use the same communication means? (If not) Why not?	This question allows the interviewer to determine if the communication between the enterprises is homogeneous or heterogeneous.
Is there a collaborative space to share information within the ENTERPRISE / The Group? (e.g. Intranet, Enterprise Social Network, etc.)	This question allows the interviewer to see if the enterprise has a common place where all employees can share and access information.
Is there a standard for information sharing? (If yes) Is the standard presented to all employees?	This question allows the interviewer to see if the enterprise has standards and if they share with all employees (or with the concerned ones).
How are organized the meetings within the ENTERPRISE / The Group?	Communication / Collaboration
If an employee is not available, can he delegate another employee to participate?	This question allows the interviewer to see if the enterprise is flexible. To see if the enterprise is prepared for casualties.
The concerned employees can participate via Videoconference?	This question allows the interviewer to see if the enterprise is flexible. To see if the enterprise has IT means to support video conferences.
Is there a digital calendar where employees can check/access to their colleagues' availabilities and invite them to meetings?	This question allows the interviewer to see if the enterprise disposes of useful IT applications. To see if they have means to easy communication between employees.
How do the employees make decisions? Is there any decision support tool?	This question allows the interviewer to identify if the enterprise uses specifics methodologies and/or tool to support its decisions.
How often meetings between the employees from the five enterprises (as part of The Factory Group) happen?	This question allows the interviewer to see if the group members are communicating with each other. Moreover, if they are sharing relevant information that impact the whole group.

Are there digital minutes for the meeting? (If yes) Is the document communicated to all participants?	This question allows the interviewer to see if the enterprise disposes of useful IT applications. It helps to identify if the enterprise has a process to share information with its employees.
Are there organized kick-off meetings involving all members of a new project? Do the five enterprises (as part of The Factory Group) participate systematically in these meetings? (If not) Are the different members aware of the various projects of the Group?	This question allows the interviewer to identify management standards and processes. It also helps to identify if all the enterprises participate actively in the group decisions.
Is there a common file format used by the ENTERPRISE / the group? (e.g. PDF and Word for text, Excel for spreadsheet, PowerPoint for presentation, etc.). (If not) Is the ENTERPRISE / the group capable of using different formats? (e.g. Microsoft Office products and Apple products).	This question allows the interviewer to see if the enterprise can handle different file formats. It helps to identify if the enterprise has different IT applications at its disposal.
Is there a common database or a specific database for each enterprise? Is there a shared project database where we can find different information, the description, the members and the progress of any project? (If yes) Is it shared among the group?	This question allows the interviewer to see how much the enterprises are integrated.
Is it easy to find files in the database? Who can modify these databases? Who has access to these databases? Is the ENTERPRISE / the group classifying what is private and public information? How can an employee demand access? Is this information documented? Who has access to this information?	This question allows the interviewer to identify if the enterprise implemented rules to data access. It helps to see how flexible and accessible are the databases (IT applications).
Is there a common computer network or a particular computer network for each enterprise?	This question allows the interviewer to see how much the enterprises are integrated.
Does the ENTERPRISE / the group have a VPN (Virtual Private Network)?	This question allows the interviewer to see if the enterprise authorizes external access in the local network.
Does the ENTERPRISE use physical servers or cloud servers? Is the use of cloud servers encouraged? (e.g. Dropbox, Google Drive, etc.)	This question allows the interviewer to see if the enterprise follows technology trends.
How often does the enterprise update its servers? Are there server backups planned?	This question allows the interviewer to determine if the enterprise is cautious with it stored information. It helps to identify if a backup process is in place.
Does the ENTERPRISE / the group have an IT department? (If not) Does the ENTERPRISE / the group outsource this service?	This question allows the interviewer to see if the enterprise has control on its IT applications, systems, etc.
In case of a technical problem, can your IT department develop new applications or solutions quickly?	This question allows the interviewer to see if the enterprise can solve any IT problem rapidly.
Are the enterprise IT applications homemade?	This question allows the interviewer to see if the applications are specifically developed to the enterprise needs.
Do you think that your current IT applications are user-friendly?	This question allows the interviewer to determine if IT applications can be considerate as an issue to communication or collaboration. (e.g. The application's interface is too complicated that the employee spends more time trying to understand it than using it.)
Can you introduce a new IT application or service if needed? (New software, new communication service, etc.)? (If yes) Do you think it would be an impact on the IT system? And with the employees, would they accept it easily? Is there some organized training to get used to the new tools?	This question allows the interviewer to determine if the IT systems are flexible. It helps to see if the employees are willing to accept changes or not. It also helps to identify if the enterprise offers training and support to its employees.
How often does the ENTERPRISE / the group update its IT applications? (e.g. Windows 7 to Windows 10, etc.)	This question allows the interviewer to see if the application versions are compatible with its partners.
Is there training concerning the current IT applications for new employees?	This question allows the interviewer to see if the new employees are capable of using the enterprise IT applications.
Are there tutorials or help pages for each IT application? (If yes) Do you think that all employees have access to that? (If not) Who has access to this document?	This question allows the interviewer to see if the enterprise has materials to help in training.
Do you know how many projects are on-going within the group? Can you cite the main projects?	This question allows the interviewer to see if the CEOs are aware of the events in the group. It helps to see if he/she participates actively within the group.
Does the ENTERPRISE have a standard for project management? (If yes) Is this information documented? Who has access to this document?	This question allows the interviewer to identify standard and if they are followed. It also helps to see if the information is shared.
Are there sometimes delays in projects? (If yes) What can be the main reasons? Do you have a concrete example? (e.g. Do the employees have problems to send files? Do the employees have problems to reach others employees? Does the daily work interfere with the project activities? Does an employee have different tasks to accomplish to the same deadline? Does the employee have problems with hardware? Is it difficult to retrieve information from partners? Does the partners respect deadlines?)	This question allows the interviewer to identify a problem related to communication and collaboration in projects. It helps to see if the CEOs are aware of these problems and if they are acting to solve them.

Does the ENTERPRISE / the group organize training sessions for its employees? (If yes) Is there training dedicated to: How improve communication techniques? How to share information? Language classes?	This question allows the interviewer to see if the enterprise / the group is constantly renewing knowledge and improving competencies within the enterprise / the group. It helps to see if they offer specific training in communication and collaboration.
If an employee suggests an external training, does the enterprise accept automatically? Does it cover the costs? (If yes) Is there a knowledge transfer session after the training?	This question allows the interviewer to determine if the enterprise is flexible considering training. It also helps to identify if the enterprise is concerned to disseminate knowledge within the company.
Do you think that you have some problems with internal communication in the ENTERPRISE? In the Group? (If yes) What are they? e.g. Do the employees use simultaneously different emails to discuss the same subject? Are there sometimes delays in the minutes' meeting delivery? Is the Internet connection stable? Is the internal completion between employees / enterprises?	This question allows the interviewer to identify any communication or collaboration problem.
Which department/enterprise within the ENTEEPRISE / the group do you think frequently presents communication and collaboration problems? Why?	This question allows the interviewer to identify where communication and collaboration problems happen. It helps to identify where the ENTERPRISE / the group need to act first.
Who are the main important partners (Clients, suppliers, providers, etc.) for the enterprise/ the group? Where are they located?	This question allows the interviewer to identify if the CEO/manager knows with whom the group is working. It also helps to determine if the main partners are local or international.
If you have international partners: Has the group already faced legislation problems (E.g. to export or import, taxes, etc.)? Has the group already faced communication problems? How does the group deals with the different time zones? Any other problems related to the location?	This question allows the interviewer to identify what kind of problems they have, and if these problems are related mainly to communication and collaboration.
Has the group already faced problems with different work methodologies?	This question allows the interviewer to identify what kind of problems they have, and if these problems are related mainly to communication and collaboration.
Has the group already faced problems with project planning? (e.g. the group estimate X months to deliver a product, but it took X+1 months to deliver. Do the new aspects demanded by partners are taken in account when the project is already in progress or not? How does the group deal with the volatile of partners?)	Communication / Collaboration
Does the enterprise / the group outsource services? (If yes) Which kind of service?	Business / Collaboration
What are the main aspects to consider, before engaging in partnership?	This question allows the interviewer to identify what the enterprise / the group consider important in a relationship. It helps to see if they analyze the potential risks and if its systems are compatible, etc.
How does the ENTERPRISE / The group ensure communication with partners (Clients, suppliers, providers, etc.)?	Business / Communication / Collaboration
Do you have sometimes video-conference meetings with your partners? Do you think this kind of meeting is fruitful and practical? Or do you prefer physical meetings?	This question allows the interviewer to see the flexibility of the enterprise (e.g. VC could be a good option for communication with American partners). It helps to see if the enterprise is prepared for using this kind of technology.
How do you exchange documents with your partners (Clients, suppliers, providers, etc.)?	This question allows the interviewer to identify what means the enterprise has at its disposal. It helps to see if the enterprise communicates differently with its partners.
Is there a standard for document and information sharing? (If yes) Is this information well-known? Is this information documented? Who has access to this information?	This question allows the interviewer to determine if the enterprise and its partners agree with a common way to share information. It helps to see if the partnership documents its processes, and if these documents are available.
Have you ever had a problem with a partner? (If yes) What kind of problem? Do you have any foreseen alternatives in case of communication problems? What happens if a client/ a partner cancels a planned partnership/ a project, etc. (have you had this kind of problems?), etc.	This question allows the interviewer to identify what kind of problems and if they are related to communication and collaboration. It helps to see if the enterprise is ready to deals if these problems. It also helps to see if the enterprise is prepared for changes (expected or unexpected).
Will there be any problem if the enterprise is led to use new standards? Is this planned?	This question allows the interviewer to see if the enterprise is willing to change if necessary.

Résumé

Les entreprises sont actuellement confrontées à divers défis dans le contexte socio-économique dans lequel elles évoluent. Des défis tels que la mondialisation, les nouvelles technologies, les crises financières, la nécessité de réduire les coûts de production et augmenter la qualité de leurs produits sont des facteurs qui les amènent à planifier et conduire des transformations. Ces défis peuvent être liés à l'évolution rapide des technologies de l'information et de la communication (TIC) qui offrent, paradoxalement, des opportunités (ex. en facilitant les communications à longue distance) et des menaces (ex. des incompatibilités entre protocoles de communication). L'augmentation de la demande de produits personnalisés et intégrés est aussi un autre facteur important.

Dans certains cas, pour faire face à ces défis, les compétences ou les outils nécessaires peuvent ne pas être disponibles au sein d'une seule entreprise. Par conséquent, de nombreuses entreprises s'adaptent et collaborent avec d'autres organisations et forment un réseau d'entreprises. Cette collaboration (partage d'actifs, de connaissances et de compétences fondamentales) entre les parties prenantes permet la co-création de valeur et nourrit des idées novatrices. Par exemple, Renault, Nissan et Mitsubishi ont formé un partenariat stratégique visant à améliorer leurs performances de production et à investir dans de nouveaux produits tels que les voitures électriques.

Un autre phénomène récent est l'augmentation du nombre d'entreprises et de clients participant à l'économie collaborative via des plateformes collaboratives comme AirBnB. En effet, ces plateformes permettent aux particuliers et à d'autres acteurs tels que les micro-entrepreneurs et les entreprises d'offrir leurs services. Une analyse effectuée par la société PricewaterhouseCoopers (PwC) pour le compte de la Commission Européenne estime ainsi qu'au moins 275 plateformes d'économie collaborative ont été créées en Europe et que cette économie collaborative (centrée sur l'hébergement, les transports, la finance et les services professionnels) a facilité 28 milliards d'euros de transactions et généré un chiffre d'affaires de près de 4 milliards d'euros en Europe en 2015.

Dans ce contexte collaboratif, l'interopérabilité, i.e. la capacité des systèmes à échanger des informations et à utiliser les informations échangées, est une précondition nécessaire à remplir. En se concentrant sur le contexte de l'entreprise, on s'intéressera (dans cette thèse) à l'interopérabilité entre les unités organisationnelles ou les processus métier au sein d'une grande entreprise ou d'un réseau d'entreprises.

Pour obtenir une meilleure interopérabilité et assurer une collaboration efficace au sein des réseaux, un certain nombre d'exigences doivent être satisfaites. Ces exigences sont appelées Exigences d'Interopérabilité (EI). Les EI définissent les besoins des parties prenantes en matière d'interopérabilité et décrivent les spécifications auxquelles les systèmes doivent être conformes pour être considérés comme interopérables. En effet, l'ingénierie d'Exigences d'Interopérabilité est un facteur crucial pour la gestion, l'amélioration et le contrôle adéquat des capacités d'interopérabilité.

En général, les EI sont liés aux multiples couches d'interopérabilité (ex. organisationnelle, technologique et conceptuelle) et à différents niveaux de l'entreprise (ex. processus, services et données). Notez que dans cette thèse, nous utilisons le terme « zone d'interopérabilité » pour désigner la section transversale d'une couche d'interopérabilité et d'un niveau de l'entreprise. Par exemple, la zone « Processus-Organisationnel » fait référence à la couche Organisationnelle et au niveau du Processus et englobe les responsabilités et les autorisations des systèmes au sein d'un processus.

Dès que les EI ne sont pas remplies, des problèmes d'interopérabilité peuvent apparaître et entraver l'interopérabilité entre les partenaires. En effet, le manque d'interopérabilité peut avoir un impact considérable sur les performances et les résultats des réseaux d'entreprises et nécessite par conséquent, d'être résolu. Par exemple, le « West Health Institute » a estimé en 2013 un potentiel de 30 milliards de dollars de gaspillages par année liés à l'absence d'interopérabilité entre les secteurs des soins de santé aux États-Unis. Enfin, un rapport publié en 2015 par PwC, commandé par la « Global System for Mobile Communications Association (GSMA) », estime que la « Digital Health » pourrait permettre d'économiser 99 milliards d'euros de coûts de soins de santé sur le Produit Intérieur Brut (PIB) de l'Union Européenne. La GSMA indique aussi que le manque d'interopérabilité est souvent souligné comme l'un des obstacles à la réalisation de cet objectif.

Alors, lorsqu'un réseau d'entreprises rencontre des problèmes d'interopérabilité, ses entreprises doivent planifier des transformations cohérentes de leurs modèles techniques et organisationnelles afin d'améliorer son interopérabilité, tout en fonctionnant de manière transparente et performante. Ces transformations sont des étapes qu'une entreprise doit suivre pour atteindre ses propres objectifs, ainsi que ceux du réseau auquel elle participe. Pour ce faire, les décideurs doivent pouvoir mesurer ce qu'ils souhaitent changer et, les entreprises doivent connaître leurs forces et leurs faiblesses en matière d'interopérabilité pour développer cette capacité entre leurs systèmes.

Ainsi, les approches d'ANalyse de l'INteropérabilité (ANIN) doivent être envisagées car elles ont pour objectif d'analyser l'interopérabilité, avant, pendant ou après toute collaboration entre les systèmes d'entreprise afin d'identifier les problèmes d'interopérabilité et les solutions associées. Une telle évaluation détermine l'état actuel de l'entreprise, et fournit les lignes directrices vers l'état souhaité. En d'autres termes, un ANIN aide les entreprises à planifier des transformations personnalisées et à améliorer leurs situations.

Cependant, il convient de noter que la notion « d'Exigence d'Interopérabilité » dans ces approches d'évaluation est, en général, implicite et non formalisée. Néanmoins, ces approches représentent un apport important à partir duquel des EI peuvent être obtenues et fournissent des outils pertinents pour évaluer l'interopérabilité des systèmes. En effet, les Critères d'Evaluation de l'Interopérabilité (CEI) proposés par ANIN peuvent être considérés comme des EI car ils représentent un énoncé permettant d'évaluer et de juger les systèmes.

Selon la littérature, il existe trois principaux types d'évaluation de l'interopérabilité: Évaluation de la *potentialité* (évalue l'interopérabilité d'un système avec son environnement), de la *compatibilité* (évalue l'interopérabilité entre deux systèmes connus avant ou après toute interopération) et de la *performance* (évalue le coût, les retards et la qualité des interopérations lors de la collaboration).

Dans cette thèse, nous nous concentrons sur l'évaluation de la *potentialité* et de la *compatibilité*, dans la mesure où nous avons l'intention de prendre en charge la prévision des problèmes potentiels et des solutions associées, en tenant compte de l'environnement de l'entreprise et des partenaires existants. Compte tenu du contexte présenté, nous formulons l'objectif général de la thèse comme suit: « *Aider les entreprises à évaluer et à prévenir les problèmes d'interopérabilité potentiels et à planifier les transformations nécessaires pour améliorer leur état d'interopérabilité* ».

Pour examiner l'état de l'art du domaine de l'ANIN, nous avons procédé à une revue systématique de la littérature afin de déterminer les méthodes d'évaluation pertinentes en matière d'interopérabilité. Sur la base des résultats de la revue, nous avons identifié deux limitations importantes, qui peuvent être soulignées comme suit: (1) les interdépendances entre les EI ne sont pas explicitement définies ni formalisées. En effet, leurs interdépendances devraient être prises en compte car elles peuvent faciliter l'identification des impacts sur l'ensemble du système. (2) la majorité des approches sont manuelles, ce qui est un processus laborieux et chronophage qui dépend souvent de la connaissance « subjective » des experts, qui peut coûter cher en temps et en argent lors du recrutement de consultants externes.

Tenant compte du contexte de la recherche et des limites identifiées, nous avons formulé le problème de recherche suivant:

Problème. *Il n'existe pas d'approche d'évaluation prenant en compte plusieurs zones d'interopérabilité. Par conséquent, les dépendances des exigences liées à différentes zones d'interopérabilité ne sont pas explicitement définies. De plus, les entreprises ont peu de visibilité sur les impacts causés par le non-respect d'une exigence et par des changements visant à améliorer leur interopérabilité.*

Pour aborder le problème de recherche identifié, nous proposons la contribution suivante:

Contribution. *Une approche informatisée d'évaluation de l'interopérabilité prenant en compte les multiples domaines d'interopérabilité et les interdépendances de leurs exigences.*

Pour guider notre recherche et assurer le développement de la contribution à la recherche, nous considérons les hypothèses suivantes:

Hypothèse 1. *Une entreprise en réseau peut être perçue comme un Système de Systèmes (SoS) composé d'au moins deux systèmes autonomes (entreprises) qui collaborent et interopèrent au cours d'une période donnée pour atteindre un objectif commun difficile à atteindre par un seul individu.*

Afin de résoudre le problème identifié et de développer notre contribution, nous avons formulé trois questions de recherche (RQ):

RQ1. *Quelles sont les exigences d'interopérabilité existantes, leurs interdépendances et leurs impacts potentiels sur l'ensemble du système, à savoir l'entreprise en réseau?*

RQ2. *Comment représenter formellement les connaissances liées aux interdépendances des exigences d'interopérabilité ?*

RQ3. *Comment pouvons-nous évaluer l'interopérabilité, lorsque nous traitons avec différents zones d'interopérabilité et leurs exigences, dans le contexte d'entreprise en réseau?*

Les réponses à ces questions sont données ci-après.

RQ1. *Quelles sont les exigences d'interopérabilité existantes, leurs interdépendances et leurs impacts potentiels sur l'ensemble du système, à savoir l'entreprise en réseau?*

Pour répondre à cette question, nous avons étudié la littérature relative aux exigences des systèmes et aux travaux concernant l'ANIN. Le domaine de l'Ingénierie des Exigences est utilisé pour fournir des techniques telles que l'extraction des exigences (pour identifier les EI) et la formalisation des exigences (pour formaliser les exigences afin de permettre leur réutilisation et d'éviter les erreurs d'interprétation).

Les approches d'ANIN existantes ont également été étudiées afin d'identifier des critères d'évaluation pouvant être considérés comme des EI. En ce qui concerne les interdépendances, les littératures sur l'alignement stratégique et l'architecture d'entreprise ont été utilisée comme base pour l'attribution des EI aux systèmes d'entreprise concernés. Ainsi, sur la base des relations entre les systèmes d'entreprise, nous avons déduit les relations entre les EI.

RQ2. *Comment représenter formellement les connaissances liées aux interdépendances des exigences d'interopérabilité ?*

Pour représenter formellement la connaissance sur les EI, nous avons soutenu que le développement d'une ontologie était approprié. Par conséquent, nous avons proposé l'Ontologie de l'Analyse de l'Interopérabilité (OIA). Les objectifs de cette ontologie sont les suivants: (i) fournir une description solide des concepts, relations et règles de raisonnement pertinents liés à l'ANIN, (ii) représenter et formaliser la connaissance concernant les EI, (iii) permettre de déduire des problèmes et des transformations potentiels auxquels une entreprise peut faire face, en fonction des interdépendances des EI, et (iv) permettre le partage et la réutilisabilité des informations, en ce qui concerne les problèmes d'interopérabilité. Notez que l'Ingénierie Système Basée sur un Modèle a également été utilisée pour organiser et modéliser de manière conceptuelle les concepts et les relations sélectionnés, avant la mise en œuvre de l'ontologie dans le logiciel Protégé.

RQ3. *Comment pouvons-nous évaluer l'interopérabilité, lorsque nous traitons avec différents zones d'interopérabilité et leurs exigences, dans le contexte d'entreprise en réseau?*

Pour répondre à cette question, nous avons conçu et développé la contribution principale de cette thèse : *L'approche informatisée d'évaluation de l'interopérabilité prenant en compte les multiples domaines d'interopérabilité et les interdépendances de leurs exigences.* Nous avons d'abord proposé d'améliorer la version actuelle du Modèle de Maturité pour l'Interopérabilité d'Entreprises (MMEI) avec les EI identifiés. Ainsi, nous avons organisé les EI sur les niveaux de maturité MMEI en fonction de leurs zones d'interopérabilité et des interdépendances établies entre les exigences. En outre, nous avons proposé le développement d'un Système Basé sur la Connaissance (SBC), en utilisant l'OIA proposée en tant que modèle de connaissance, utile pour soutenir le processus d'ANIN. L'approche résultante identifie les problèmes d'interopérabilité existants et potentiels sur la base de l'évaluation des EI et recommande des actions en fonction des connaissances stockées à l'aide des règles sémantiques d'OIA.

Ces travaux de recherche sont présentés dans cette thèse de la manière suivante :

- L'Introduction décrit le contexte et la motivation des travaux de recherche menés dans cette thèse. L'objectif général, l'aperçu des limitations rencontrées (dans la pratique et dans la littérature), l'énoncé du problème de la recherche, les questions de recherche et une brève description de l'approche de recherche sont fournis.
- Le Chapitre 1 donne un aperçu des domaines « d'Interopérabilité » et de « Réseau et d'Entreprise ». Il explore les principales définitions des deux domaines et la manière dont ils sont connectés. Les propriétés d'une Analyse d'Interopérabilité sont également présentées.
- Le Chapitre 2 décrit l'apport de la thèse. La contribution proposée est basée sur les résultats d'une revue systématique de la littérature et d'une analyse comparative des approches d'ANIN existantes.
- Le Chapitre 3 explore des approches d'Ingénierie des Exigences d'un système. Sur la base de cette étude, une approche d'Ingénierie des Exigences d'Interopérabilité est définie pour étudier et définir les interdépendances des EI. Ainsi, les EI sont sélectionnés sur la base de la littérature d'ANIN. Enfin, les interdépendances des EI sont définies et décrites.
- Le Chapitre 4 vise à formaliser les connaissances conçues dans les Chapitres 4 en proposant une ontologie pour appuyer l'évaluation de l'interopérabilité. De plus, le développement du prototype d'un outil informatique d'analyse de l'interopérabilité basé sur l'ontologie est décrit. L'objectif du prototype est de faciliter le processus d'analyse en fournissant des étapes automatiques telles que le calcul de la maturité des entreprises et la génération du rapport d'évaluation.
- Le Chapitre 5 a pour objectif d'appliquer les artefacts proposés dans la pratique. Ainsi, le l'outil outil informatique d'analyse de l'interopérabilité et la méthodologie associée sont appliqués dans l'étude de cas concernant un réseau d'entreprises réel. Les résultats de cette étude visent également à évaluer la contribution globale de la recherche.

Enfin, la Conclusion vise à discuter les résultats de cette thèse. Une analyse critique de la manière dont les questions de recherche et les objectifs ont été abordés est présentée. Il conclut également les travaux de recherche menés dans le cadre de cette thèse et présente les perspectives de recherche.

Support à la décision pour l'analyse de l'interopérabilité des systèmes dans un contexte d'entreprises en réseau

Résumé. L'interopérabilité entre les systèmes a été identifiée comme un problème majeur auquel sont confrontées les entreprises lorsqu'ils ont le besoin de collaborer avec d'autres organisations et de participer au sein d'un réseau d'entreprises. Pour atteindre une qualité d'interopérabilité supérieure et garantir une collaboration efficace, un certain nombre d'Exigences d'Interopérabilité (EI) doivent être satisfaites. Ainsi, l'interopérabilité doit être vérifiée et continuellement améliorée. L'Analyse de l'Interopérabilité (ANIN) est une manière de vérifier l'interopérabilité des systèmes. Cependant, en général, la notion « d'exigence » est implicite et présentée sous forme de critères d'évaluation dans les approches ANIN. Il a également été identifié que les interdépendances entre les EI ne sont pas explicitement définies. En effet, leurs interdépendances doivent être prises en compte car elles peuvent aider à identifier les impacts sur l'ensemble du système. De plus, la majorité des approches ANIN sont manuelles, ce qui est un processus laborieux et long qui dépend souvent des connaissances « subjectives » des experts. Dans ce contexte, cette recherche propose un Système d'Analyse de l'Interopérabilité basé sur la Connaissance (SAIC) pour soutenir la prise de décision au sein des entreprises en réseau. Une méthodologie « Design Science Research » (DSR) a été adoptée pour mener à bien la contribution proposée. Premièrement, une approche basée sur l'ingénierie des exigences a été adaptée pour obtenir des EI pertinentes, établir un lien entre les EI obtenues et les composantes du système concerné et définir les interdépendances entre les EI. Pour conceptualiser formellement les connaissances sur l'ANIN, en englobant l'ensemble des EI, les problèmes et solutions d'interopérabilité ainsi que leurs relations, nous avons proposé l'Ontologie de l'Analyse de l'Interopérabilité (OAI). Une approche d'Ingénierie Système basée sur des Modèles a été appliquée pour définir les concepts de l'ontologie. Un prototype du SAIC utilisant l'OAI comme modèle de connaissance a été développé sur une plate-forme Java. L'outil résultant peut exploiter les connaissances sur l'interopérabilité et les informations provenant de la situation actuelle des systèmes évalués pour identifier les problèmes et améliorations potentiels. La contribution proposée a été évaluée grâce à une étude de cas basée sur une véritable entreprise en réseau.

Mots-clés: Entreprises en Réseau ; Interopérabilité de l'Entreprise; Évaluation de l'Interopérabilité; Systèmes Basés sur la Connaissance; Ontologie; Ingénierie des Exigences; Ingénierie Système Basée sur des Modèles.

Decision support for interoperability readiness in networked enterprises

Abstract. Enterprise systems' interoperability has been identified as a significant issue faced by enterprises, which need to collaborate with other companies and participate within Networked Enterprises. To achieve a higher quality of interoperability and ensure an effective collaboration, a certain number of Interoperability Requirements (IRs) should be satisfied. Thus, interoperability should be verified and continuously improved. A manner for verifying the enterprise systems' interoperability is through the Interoperability Assessment (INAS). However, in general, the notion of "requirement" is implicit and presented as Interoperability Evaluation Criterion (IEC) in the INAS approaches. It also has been identified that the IEC interdependencies are not explicitly defined. Indeed, their interdependencies should be considered as they can support the identification of impacts on the overall system. Further, the majority of the INAS approaches are 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 context, this research proposes a Knowledge-Based Interoperability Assessment System (KBIAS) for supporting decision-making within Networked Enterprises. A Design Science Research (DSR) methodology has been adopted for conducting the work. First, A Requirement Engineering (RE) approach has been adapted to elicit and define relevant IRs, which are father related with system's components. Such IRs are used as IEC during the INAS process. To formally conceptualise the knowledge about the INAS (subsuming the set of IRs, interoperability problems and solutions), we proposed the Ontology of Interoperability Assessment (OIA). A Model-Based System Engineering approach has been applied for defining and organising the concepts of the proposed ontology. A prototype of the KBIAS using the OIA as its knowledge model has been developed in a Java platform. The developed tool can exploit the knowledge about interoperability issues and information from the *as-is* situation of the assessed systems for identifying potential problems and improvements. The contribution proposed in this research has been evaluated through a case study based on a real Networked Enterprise.

Keywords: Networked Enterprises; Enterprise Interoperability; Interoperability Assessment; Knowledge-Based Systems; Ontology; Requirement Engineering; Model-Based System Engineering.