

Towards a Comparative Analysis of Interoperability Assessment Approaches for Collaborative Enterprise Systems

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Abstract. Challenges such as globalization and novel technologies are changes-drivers that require transformation within enterprises and their environments. To handle that, enterprises are progressively collaborating with others and becoming part of a Networked Enterprises (NE). In this collaborative and transdisciplinary context, one of the difficulties faced by companies willing to work together, are the interoperability problems between their systems. In order to avoid these problems and consequently, take corrective actions on time, enterprises need to predict and solve potential problems before they occur. To deal with that, evaluations can be performed to assess interoperability and therefore identify strengths and weaknesses of the considered enterprise systems. Despite, numerous interoperability assessment methods existing in the literature, many of them address only one interoperability aspect. In addition, they can also use different approaches and metrics to perform the interoperability evaluation. Thus, it can be difficult when enterprises have to deal with multiple interoperability aspects within a NE. Hence, the objective of this paper is to propose an analysis of the main relevant evaluation methods regarding interoperability. The proposed analysis is essential and will serve as a first step towards proposing a new approach for assessing enterprise systems interoperability within a NE..

Keywords. Networked Enterprise, Transdisciplinary, Collaborative Enterprise System Interoperability, Interoperability Assessment

Introduction

Nowadays, the dynamics of the socio-economic environment leads enterprises to face a variety of challenges such as globalization, new technologies, financial crisis, new markets, etc. These challenges are change-drivers that require transformation within enterprises and their environments [1]. To deal with that, enterprises are progressively shifting their boundaries and collaborating with other companies and participating in a so-called Networked Enterprise (NE) [2]. The companies that compose a NE can have different sizes (e.g. small, medium and large enterprises), they can be geographically distributed (e.g. collaborations between regional, national and international enterprises), and also can be field-specific enterprises (e.g. a NE composed by only marketing agencies) or transdisciplinary enterprises [3] (e.g. collaboration among

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different disciplines such as marketing, production engineering, financial, healthcare, etc.). Considering this collaborative and transdisciplinary context, i.e. NE context, and based on [3], [4], [5], [6], [7], we argue that one of the difficulties enterprises may face, regarding effective collaboration, is the development of interoperability among their collaborative enterprise systems (CESs). The term CESs, in this paper, represents the enterprise systems that collaborate with systems from other enterprises within the NE. In light of this, the Networked Enterprise meta-MODEL (NEMO) [2] has been proposed to address the importance of the interoperability within a NE, describing it as a crucial requirement that needs to be verified when starting a new collaboration [8], [9]. As soon as this requirement is not achieved, interoperability becomes a problem that must be solved [10]. Interoperability problems are mainly related to incompatibilities that obstruct the sharing and exchanging of any kind of information, but mainly contextual information, between CESs [11]. To deal with this kind of problem, specific evaluations can be performed to have a clear view about strengths and weaknesses of the considered NE in terms of interoperability, at an early stage [2]. Numerous methods and approaches have been proposed in the literature regarding interoperability assessment [12], [13], [14], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24]. Some surveys can be found in [7], [25] and [26]. Among these methods and approaches, three kinds of interoperability measurements can be identified [16], [27]: the measurement performed (1) before the interoperation starts and when partners are unknown; (2) before the interoperation starts and when partners are known; and (3) during the interoperation between two known partners. This latter measurement is out of scope of this paper, because it is performed only during interoperation, meaning that it is too late to identify interoperability problems at this stage. To our best knowledge, despite the variety of these evaluation methods, none addresses both (1) and (2) types of measurements at the same time, considering all interoperability aspect [11]. Therefore, identifying interoperability aspects to be assessed, and the related key features is mandatory to support the NE interoperability development, including the detection and prediction of problems at early stage. Thus, the following questions are raised: “How can we assess the interoperability of CESs within a collaborative and transdisciplinary context, when dealing with different interoperability aspects?” and “Which method(s) is (are) to be chosen in this context?”

The objective of this paper is to propose a comparative analysis of the main relevant evaluation methods regarding interoperability. This needs, first of all to identify evaluation criteria to be taken into account, considering the related works and the context of our research. The proposed analysis is essential and will serve as a first step towards proposing a new approach for assessing CESs interoperability within a NE.

The rest of the scientific paper is organised as follow – Section 1 presents the relevant related works on interoperability within a NE. Section 2 shows the analysis of interoperability evaluation methods. Also in this section the findings are discussed and some perspectives highlighted. The conclusion and future work are brought forward in Section 3.

enterprises that wish to exchange information and may have different internal structures and processes [28]. Compliance to legislation [28], [29] is also considered in this context. Consequently, Organizational barriers are concerned with the incompatibilities of organisation structure, management techniques and legal issues implemented in two or more enterprises [11]. It is worth noting that interoperability is a not-bidirectional property [21]. Given two entities A and B and measuring their interoperability level $I(x,y)$ it is structurally coherent to find $I(A,B) \neq I(B,A)$. This structural property doesn't impact the evaluated methods because of its internal feature but it explains the behavioural aspects of the approached property concepts.

1.2. Related works on Interoperability assessment

To support enterprise members of a NE to better interoperate, the interoperability between their CESs requires being assessed and continuously improved [16]. According to [16] interoperability assessment methods can be classified based on four properties; (a) the type of interoperability assessment, which are Levelling (defining a basic set of interoperability maturity levels that CESs can achieve) or Non-levelling (not using the maturity model approach). (b) The used measure, which are Qualitative (Subjective methods defined by the general criteria of the CESs evaluation) or Quantitative (Methods that define numeric values to characterise the interoperations between CESs). (c) The used approach, which are Black Box (Methods considering mainly the analysis of the CESs inputs and outputs without worrying about their properties and interactions) or White Box (Methods where the concept for which input-output mappings, the transformation structure as well as the state of the CESs are known). (d) The application context, which can be a priori or a posteriori. The a priori context uses the potentiality measurement which relates to the potential of a CES to be interoperable with a possible future partner whose identity is not known at the moment of evaluation. The a posteriori application context uses two measures: (i) the compatibility measurement is done concerning the identified barriers to interoperability. This measure can only be performed when the two CESs of the interoperation are known. (ii) The performance measurement is to be done during the test or operation phase of two interoperating CESs. As asserted in the introduction, this latter type of measurement is not considered in this paper. Although, it is worth noting that this kind of measurement is relevant when the enterprises want to validate their potential measures i.e. to verify if the potential measures are aligned and coherent with the real ones. The next section introduces the existing methods and approaches that deal with the interoperability assessment.

1.3. Overview on Interoperability Assessment Methods

A variety of assessment methods can be found in the literature. Many of them are defining a maturity model which consists in a framework that describes, for a specific area of interest, a number of levels of sophistication at which activities in this area can be carried out [30]. The main existing interoperability maturity models are the Levels of Information System Interoperability (LISI) maturity model [12], the Organisational Interoperability Maturity Model (OIMM) [13], the Levels of Conceptual Interoperability Model (LCIM) [14], the Enterprise Interoperability Maturity Model (EIMM) [15] and the Maturity Model for Enterprise Interoperability (MMEI) [16].

Besides these maturity models, we have identified other methods such as: the GRAI Grid [17], the European Telecommunication Standards Institute (ETSI) method [18], the layered interoperability score (i-Score) [19], the Enterprise Interoperability Degree Measurement (EIDM) compatibility matrix [20], the Yahia et al. [21] approach based on semantic blocks [22] and some ICT standard validation methods [23], [24].

In the next section we aim at analysing the evaluation methods, taking into account all the properties and interoperability aspects identified on the previous sections.

2. Analysis of interoperability assessment methods

The objective of this section is not to provide an exhaustive review of existing assessment methods, but rather it is to present relevant methods that are selected specifically for the purpose of the analysis. The analysis considers some of the already reviewed methods in [7], [25], [26], as well as other and more recent evaluation methods. We intend to identify how these evaluation methods are performing interoperability assessment in CESSs. This will allow us to verify if these methods address both considered types of measurement (i.e. before and after knowing interoperation partner(s)) and their coverage in terms of interoperability aspects. First, we identify the evaluation criteria and the evaluation methods to be analysed. Furthermore, the analysis considering the identified criteria and methods is performed. Based on that, findings and perspectives are discussed at the end of this section.

2.1. Criteria identification

The criteria identified in this section are based on the interoperability assessment domain. The following criteria were chosen because they often appear when describing an interoperability evaluation method. The first considered criterion is the interoperability aspect. This criterion is related to the interoperability level(s) addressed by the evaluation method(s), i.e. conceptual, technical or/and organisational interoperability. The second criterion is based on the method properties described in section 1.2. It regards the type of interoperability assessment (in this paper we will call it as structure property), the used measures, the used approach and the type of interoperability measurements. Considering the structure property, a method can be a Levelling or a Non-levelling method. Taking into account the used measure property, a method can be described as a Qualitative or a Quantitative method. Considering the used approach property, methods can be described as Black Box or White Box methods. For the last property, we will call it “type of interoperability measurement” instead of “application context”. Thus, we will identify which type of measurement the methods adopt rather than classify as a priori or a posteriori. The two considered type are: (1) the measurement before any interoperation starts and the partner(s) is (are) unknown; (2) before any interoperation starts and partner(s) is (are) known.

2.2. Selected evaluation methods

The LISI maturity model [12], OIMM [13] and LCIM [14] are chosen because they cover the technical, organisational and conceptual interoperability aspects respectively. The EIMM [15] is included in this analysis because it brings forward the enterprise domain, focusing mainly on the organisational aspect. MMEI [16] is selected because it

is based on the previous maturity models and covers all aspects of interoperability. Beside these maturity models, we also include the GRAI Grid [17] that identify organisational incompatibilities. Furthermore, the ETSI method [18] and the ICT standards validation methods such as [23], [24] are also included in the analysis because they deal mainly with the technical interoperability evaluation. Finally, the i-Score [19], the EIDM compatibility matrix [20] and the Yahia et al. approach [21] are included in this analysis because they are quantitative methods.

2.3. Analysis considering the Interoperability aspects

The LISI maturity model covers only the technical interoperability between CESs. Considering its limitations, LISI was extended by OIMM and LCIM to cover the organisational and conceptual aspects respectively. LCIM intend to link the technical and conceptual CESs design. EIMM deals with enterprise modelling assessments, which mainly concerns organisational and conceptual interoperability aspects. It focuses on the use of CES models and the maturity of their usage, which requires a correct syntactic and semantic representation [15]. Among the reviewed levelling methods, MMEI is the only covering all interoperability aspects [16], because it is based on the others presented maturity models. Besides these maturity models, we find other methods covering different aspects of interoperability such as the GRAI Grid that focuses on the decisional aspects of the management of CESs, i.e. it deals with organisational interoperability. The ETSI method covers conceptual and technical interoperability as it is designed to check the CESs standards interoperability and conformity. The i-Score addresses the evaluation of organizational processes interoperability. The EIDM compatibility matrix covers all interoperability aspects. However, it does not give a deeper insight on them. The Yahia et al. [21] approach assesses the conceptual interoperability between two CESs. It focuses on the semantic part of it. Finally, the ICT standards validation methods [23], [24] cover the technical interoperability and the syntactic issues from the conceptual interoperability. Table 1 summarises the coverage of the reviewed methods with regard to interoperability aspects.

Table 1. The coverage of the reviewed methods with regards to interoperability aspects. The ‘++’ means “addresses the aspect”, “+” stands for “relevant to the aspect” and ‘-’ is for “do not addresses the aspect”. Inspired from [16].

Name	Conceptual		Technical		Organisational	
	Semantic	Syntatic	Standard	Platform	Organisation	Legal
LISI	-	-	++	++	-	-
OIMM	+	-	-	-	++	-
LCIM	++	+	-	-	-	-
EIMM	++	+	-	-	++	+
MMEI	++	++	++	++	++	+
GRAI Grid	-	-	-	-	++	-
ETSI method	-	+	++	++	-	-
I-Score	-	-	-	-	++	-
EIDM – C. Matrix	+	+	+	+	+	-
Yahia et al. approach	++	-	-	-	-	-
ICT Standards validation	-	++	++	++	-	-

2.4. Analysis considering the method structure, measures and approach

Considering the structure-property, all the reviewed maturity models are levelling methods. The other approaches are non-levelling ones. Taking into account the used measure-property, the maturity models are considered qualitative methods. In general, they mainly define a five maturity levels' scale, where the lower level represents an ad-hoc and chaotic interoperation and the higher level represents a fully and effective interoperation. The intermediary levels represent the progression levels which CESs must pass through to achieve the higher level. Moreover, the GRAI Grid, ESTI method and the ICT standards validation methods [23], [24] are also considered qualitative methods. GRAI grid provides, as a result, a graph with all decision centres and information flow within the analysed CESs [17]. The ICT standards validation methods [23], [24] provide binary results, i.e. the standard is valid or not. The ETSI method [18] uses verdicts to classify if the CESs' test results are inconclusive, failed or successful. Furthermore, the identified quantitative methods are: the i-Score, EIDM compatibility matrix and the semantic interoperability approach of Yahia et al. [21]. Indeed, the assessment output of the i-Score is a real number ranging from 0 to 1, where 1 represents the CESs full interoperability. The EIDM approach provides a matrix with 24 interoperability areas where the value "1" is attributed when an incompatibility is found. The degree of compatibility is given by the sum of incompatibilities found, where "0" means higher compatibility and "24" poorest compatibility between the considered CESs. The Yahia et al. approach [21] provides two measures, calculating the potential and effective interoperability. It can also provide a qualitative result, i.e. it organises the numeric values into three categories: "0%" means "systems are not interoperable"; "0 < x < 100%" means "systems are partially interoperable" and 100% stands for "systems are fully interoperable". According to the used approach property, the only methods using the white box perspective are MMEI, the GRAI grid, the Yahia et al. approach [21] and ICT standards validation methods [23], [24]. These methods verify in-depth the different relations within the CESs elements, unlike the others (i.e. LISI, LCIM, OIMM, EIDM Compatibility Matrix and i-Score) that only use the black box approach. Table 2 summarises the analysis of the method properties and presents the value scales and metrics used by each assessment method.

2.5. Analysis considering the interoperability measurement

According to the type of interoperability measurement, we identify the following methods measuring interoperability after enterprises knowing their partner(s) : LISI, OIMM, LCIM, EIMM, ETSI method, i-Score, EIDM compatibility matrix, Yahia et al. [21] approach and finally the ICT standards validation methods [23], [24]. All these methods are capable to assess interoperability when two or more CESs within a NE are known. Moreover, we identify the following methods measuring interoperability before enterprises knowing their partner(s): MMEI and GRAI Grid. Both approaches are designed to assess the enterprises and its CESs capabilities without knowing their future partners. While not their focus, LISI and EIMM can also measure interoperability before interoperation partners are known. Indeed, LISI provides a matrix to calculate the potential technical interoperability of a given ICT system; EIMM states that an enterprise to achieve the maturity level 4 requires dynamic interoperability and adaptation without considering a specific partner. Table 2 also summarises the analysis of the mentioned types of measurements.

Table 2. Analysis of interoperability assessment methods. Where “S” means Structure, “M” means Measure and “A” means Approach. “L” stands for Levelling and “NL” for Non-Levelling. “WB” stands for White Box and “BB” for Black Box. “Qn” stands for Quantitative Method and “Ql” for Qualitative Method. “(1)” stands for “before knowing interoperation partner(s)” and “(2)” stands for “after knowing interoperation partners”. The ‘++’ means “addresses the aspect”, “+” stands for “relevant to the aspect” and ‘-’ is for “do not addresses the aspect”. Inspired on [16].

Name	S	M	Value / Metrics	A	(1)	(2)
LISI	L	Ql	Maturity Level 0 to 4	BB	+	++
OIMM	L	Ql	Maturity Level 0 to 4	BB	-	++
LCIM	L	Ql	Maturity Level 0 to 4	BB	-	++
EIMM	L	Ql	Maturity Level 1 to 5	BB	+	++
MMEI	L	Ql	Maturity Level 0 to 4	WB	++	-
GRAI Grid	NL	Ql	Grid with Decision Centres	WB	++	-
ETSI method	NL	Ql	Interop. and Conformance Verdicts	BB	-	++
I-Score	NL	Qn	a real number ranging from 0 to 1	BB	-	++
EIDM – C. Matrix	NL	Qn	(0,1) for each interoperability area; 0-24 for final result	BB	-	++
Yahia et al.	NL	Qn / Ql	Qn: 0-100% representing the potential and effective interoperability; Ql: Not interoperable, Partially Interoperable, Fully Interoperable	WB	-	++
ICT Standards Validation	NL	Ql	(0-Not valid; 1-Valid)	WB	-	++

The analysis of these methods, allows us to identify their similarities and differences and which assessment type they prioritize. These findings will serve as a basis for the development of an assessment approach for CESs interoperability in the NE context.

2.6. Discussion

In order to achieve objectives targeted by a NE and its members, the CESs interoperability management, including the identification of problems, is a necessity. A simpler manner to avoid interoperability problems and consequently corrective actions, is to predict and solve potential problems before they occur [16]. For that, NE and its members need to plan and be prepared for future interoperations. To this end, enterprises can benefit from the application of an interoperability assessment method. However, as we can observe based on the analysis, MMEI is the only method that sufficiently covers all conceptual, technical and organisational interoperability aspects. Although, it performs only the interoperability measurement before partner are known. We have also found that the majority of the reviewed methods are measuring interoperability after interoperation partners are known, but they deal with a particular aspect of interoperability. Hence, we can assert that there is no method dealing with all interoperability aspects and addressing both types of measurements. Based on that, we propose to elaborate an assessment approach for CESs interoperability. This approach will be developed to be applied in the Networked Enterprise context, regardless the enterprise members’ size, discipline, location, etc. It will deal with types of measurements. It will also cover the main aspects of existing maturity models and non-levelling methods, combining *qualitative and quantitative* metrics to consider both subjective and objective values. We intend to use a *white box* view to consider the different interactions and variables of the CESs to be assessed.

3. Conclusion and Future work

In this paper, we have proposed a comparative analysis of the main relevant evaluation methods regarding the CESs interoperability. Prior to that, an investigation about the relations between interoperability and Networked Enterprise contexts has been done. This allowed the identification of what need to be verified during an interoperability assessment, when considering the different interoperability aspects and its related barriers. Moreover, the identification of the method properties including the different types of measurements has been used to analyse current evaluation methods dealing with multiple interoperability levels. Based on this analysis, we observed that there is no evaluation method addressing sufficiently both considered types of measures as well as not covering all interoperability aspects. As future work, we intend to propose an interoperability assessment approach for CESs covering all interoperability aspects as well as both considered types of measurements. This will be tackled by the extension of MMEI to both considered types of measurement contexts. Quantitative methods will also be used to provide objective results. Furthermore, combining this CES interoperability assessment approach with NEMO, will allow us to build a Framework for Networked Enterprise Interoperability. The NEMO approach has been chosen because deals with all interoperability aspects (c.f. section 1.1) and it covers the two contexts (1) the unknown partners and (2) the known ones. This framework will serve as basis to the development of a decision-support system for preventing and solving Collaborative Enterprise Systems Interoperability problems in a collaborative and transdisciplinary context.

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