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A review on E-business Interoperability Frameworks

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ABSTRACT

Interoperability frameworks present a set of assumptions, concepts, values, and practices that constitute a method of dealing with interoperability issues in the electronic business (e-business) context. Achieving interoperability in the e-business generates numerous benefits. Thus, interoperability frameworks are the main component of e-business activities. This paper describes the existing interoperability frameworks for e-business, and performs a comparative analysis among their findings to determine the similarities and differences in their philosophy and implementation. This analysis yields a set of recommendations for any party that is open to the idea of creating or improving an E-business Interoperability Framework.

1. Introduction

The term "e-business" generally refers to the application of information and communication technologies (ICT) to improve business activities, including providing or enhancing services and managing business operations (Amor, 2000; Beynon-Davies, 2004; Gerstner, 2002). In the e-business context, applications and software systems should be interoperable (Berre et al., 2007a; Parazoglou, 2006). Interoperability enables ICT systems to facilitate information exchange and promote service compatibility between systems (Jardim-Goncalves et al., 2013; Mattiello-Francisco et al., 2012; Truex et al., 1999; Zwegers, 2003). Therefore, interoperability in the e-business context has become a critical issue (Novakouski and Lewis, 2012; Watch, 2005).

Interoperability in the e-business context has multiple definitions (Kosanke, 2006; Levine et al., 2003; Morris et al., 2004a), such as interoperability is defined as "Interoperability means the ability of information and communication technology (ICT) systems and of the business processes they support to exchange data and to enable the sharing of information and knowledge" (European-Commission, 2010; Ralyté et al., 2008; Sourouni et al., 2007).

The following four definitions of interoperability have been given by IEEE: (1) "The ability of two or more systems or elements to exchange information and to use the information that have been exchanged" (Breitfelder and Messina, 2000; Geraci et al., 1991). (2) "The capability for units of equipment to work efficiently together to provide useful functions" (Radatz et al., 1990). (3) "The capability – promoted but not guaranteed – achieved through joint conformance with a given set of standards, that enables heterogeneous equipments, generally built by various vendors, to work together in a network environment" (Breitfelder and Messina, 2000; Radatz et al., 1990). (4) "The ability of two or more systems or components to exchange and use the exchanged information in a heterogeneous network" (Breitfelder and Messina, 2000; Radatz et al., 1990).

The ATHENA project adopts the IEEE definition of interoperability as "The ability of two or more systems or components to exchange information and to use the information that has been exchanged" (ATHENA, 2005a; Geraci et al., 1991; Hilliard, 2000; Ruggaber, 2005).

In the e-business context, "Interoperability means the ability of information and communication technology (ICT) systems and of the business processes they support to exchange data and to enable the sharing of information and knowledge" (Benguria and Santos, 2008; European-Commission, 2004; Hueppi, 2008).

Achieving e-business interoperability generates numerous benefits (Carney and Oberndorf, 2004; Choi and Whinston, 2000; European-Communities, 2008; Poppel, 1987), such as improved efficiency, transparency, accountability, and access, as well as cost effective service coordination (Curts and Campbell, 1999; Novakouski and Lewis, 2012; Schade, 2005). Lack of interoperability could cost the industry a huge amount of money (ATHENA, 2007; Ruggaber, 2005). In its investigation, the Yankee Group in the United States revealed that solving interoperability

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problems accounted for 40% of ICT project costs in majority of leading manufacturing industries (Kerravala, 2002).

Attaining interoperability requires resolution at several distinct levels. According to Carney and Oberndorf (2004), Chen (2006), de Normalisation and für Normung (2011), Heiler (1995), Kasunic and Anderson (2004), Levine et al. (2003), Morris et al. (2004b), Munk (2002), there are four levels of interoperability. The interoperability levels are technical, syntactic, semantic, and organizational interoperability.

(1) *Technical interoperability* is achieved among communications–electronics systems or items of communications–electronics equipment when services or information could be exchanged directly and satisfactorily between them and their users (Novakouski and Lewis, 2012). In referring to specific cases, the interoperability degree must be defined (Kinder, 2003; Kosanke, 2006). Technical Interoperability is typically associated with hardware/software components, systems, and platforms that enable machine-to-machine communication. This type of interoperability often focuses on communication protocols and the infrastructure required for those protocols to function (Rezaei et al., 2013; Van der Veer and Wiles, 2008).
(2) *Syntactic interoperability* is defined as the ability to exchange data. Syntactic interoperability is generally associated with data formats. The messages transferred by communication protocols should possess a well-defined syntax and encoding, even if only in the form of bit-tables (Rezaei et al., 2014a; Van der Veer and Wiles, 2008).
(3) *Semantic interoperability* is defined as the ability to operate on that data according to agreed-upon semantics (Lewis and Wrage, 2006). Semantic interoperability is normally related to the definition of content, and deals with the human rather than machine interpretation of this content. Thus, interoperability at this level denotes that a common understanding exists between people regarding the definition of the content (information) being exchanged (Guijarro, 2009; Hall and Koukoulas, 2008; Van der Veer and Wiles, 2008).
(4) *Organizational interoperability* pertains to the capability of organizations to effectively communicate and transfer meaningful data (information) despite the use of a variety of information systems over significantly different types of infrastructure, possibly across various geographic regions and cultures. Organizational interoperability relies on the successful interoperability of the technical, syntactic, and semantic aspects (Gionis et al., 2007a; Rezaei et al., 2014b; Van der Veer and Wiles, 2008).

Therefore, as a multidimensional concept, interoperability can be viewed from numerous perspectives and approached from various directions (Rezaei and Shams, 2008b). A framework is necessary to reconcile all these perspectives, approaches, and directions, which are frequently different. Moreover, a framework is a practical tool for comparing concepts, principles, methods, standards, and models in a particular realm. Interoperability framework is specifically a mechanism for enabling interoperability between entities that mutually pursue an objective (Javanbakht et al., 2008; Kajan, 2011; Kuziemsky and Weber-Jahnke, 2009; Rezaei and Shams, 2008a). Therefore, interoperability must be recognized and conveyed via a framework (Chen, 2009; Legner and Wende, 2006).

The European Interoperability Framework defines an interoperability framework as follows: “An interoperability framework can be defined as a set of standards and guidelines that describes the way in which organizations have agreed, or should agree, to interact with each other. An interoperability framework is, therefore, not a static document and may have to be adapted over time as technologies, standards and administrative requirements change” (European-Commission, 2004).

The ATHENA project defines an interoperability framework as follows: “An interoperability framework provides a set of assumptions, concepts, values and practices that constitutes a way of viewing and addressing interoperability issues” (Lillehagen and Solheim, 2004).

The E-business Interoperability Framework constitutes the cornerstone for resolving interoperability issues in the e-business context. These frameworks further provide the required methodological support to an increasing number of projects related to the interoperability of enterprise applications and software systems to enhance the management of their complexity and risk, and ensure that they bring the promised added value (Lillehagen and Solheim, 2004; Zutshi, 2010).

In this direction, this paper presents the existing E-business Interoperability Framework (Interoperability Development for Enterprise Application and Software Framework, ATHENA Interoperability Framework, Enterprise Interoperability Framework, and GridWise Interoperability Context-Setting Framework), and provides an overview of their main concepts and recommendations. Additionally, this paper performs a comparative analysis of the existing E-business Interoperability Framework to determine the similarities and differences in their philosophy and implementation. This analysis yields a set of recommendations for any party that is open to the idea of creating or improving an E-business Interoperability Framework.

The structure of the paper is as follows: in Section 2 the interoperability issues are outlined. An introduction to the available E-business Interoperability Framework is presented in Section 3. Section 4 compares the interoperability frameworks under study on the basis of the interoperability issues proposed in Section 2. A discussion on the findings is conducted in Section 5 leading to conclusions in Section 6.

2. Interoperability issues

This section describes a set of interoperability issues (enterprise interoperability scientific areas) observed in the results of the FP7 ENSEMBLE project (Koussouris et al., 2011). The interoperability issues are categorized into four different granularity levels. The interoperability issues that belong to a higher granularity level are regarded as super-sets of interoperability issues that belong in a lower level (Koussouris et al., 2011). According to the four granularity levels, Fig. 1 illustrates an overview of the identified interoperability issues. Each interoperability issue is further detailed in the following sections. It is required to note that the proposed interoperability issues (scientific areas) aim to promote more focused and concrete research attempts towards the goal of establishing interoperable enterprise systems, as they belong to a smaller abstraction level of that of the four fundamental interoperability layers adapted by European Interoperability Framework (European-Commission, 2004, 2010; Koussouris et al., 2011).

In accordance with the scope of this paper and in alignment with Koussouris et al. (2011) (Fig. 1), the comparative analysis of the existing E-business Interoperability Framework will be performed, and additionally extended over:

- The first granularity level of interoperability issues consists of data interoperability, process interoperability, rules interoperability, objects interoperability, software systems interoperability, as well as cultural interoperability.
- The second granularity level of interoperability issues focuses on

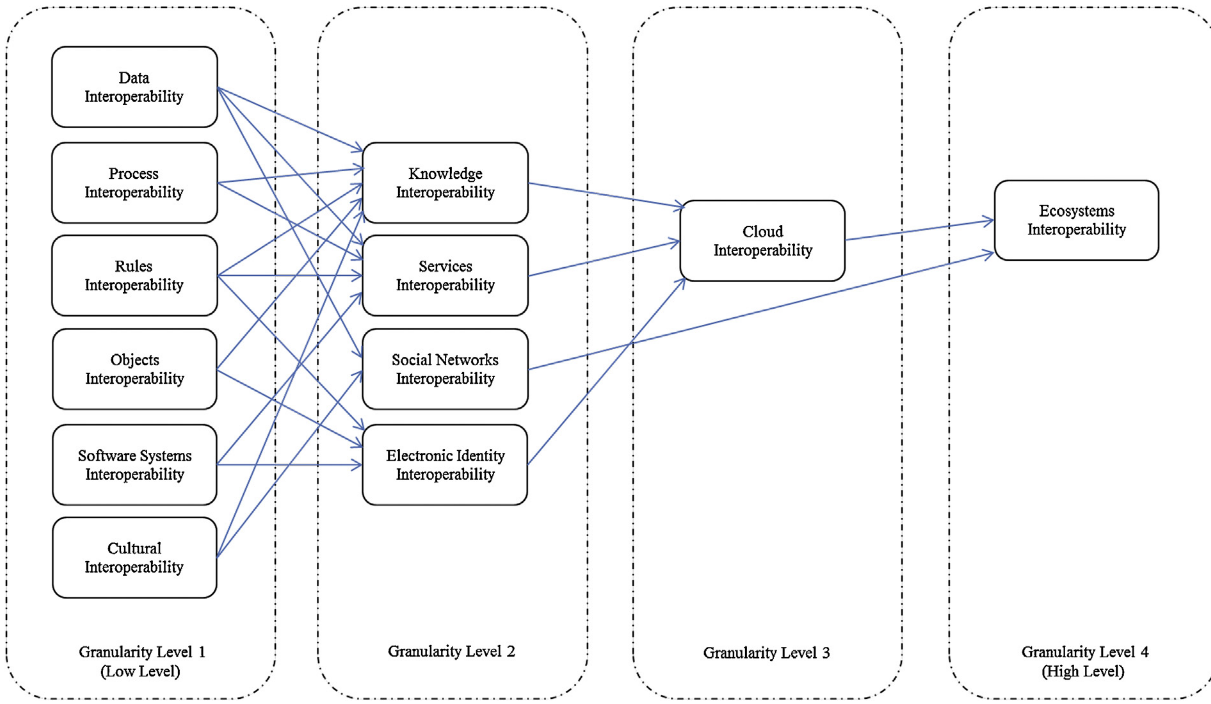

Fig. 1. Interoperability issues.

- ◦ Knowledge interoperability, which consists of elements coming out of data interoperability, process interoperability, rules interoperability and cultural interoperability.
- ◦ Services interoperability, which incorporates facts from process interoperability, data interoperability, rules interoperability and software systems interoperability.
- ◦ Social networks interoperability, consisting of elements coming out of cultural interoperability and data interoperability, and
- ◦ Electronic identify interoperability, which is strongly related with objects interoperability, software systems interoperability and rules interoperability.
- The third granularity level of interoperability issues includes cloud interoperability, which takes elements from services interoperability, knowledge interoperability, and electronic identity interoperability, and tries to infuse them with cloud characteristics.
- Lastly, the fourth granularity level of interoperability issues involves ecosystems interoperability, which deals with virtual and digital enterprises and is related to cloud interoperability and social networks interoperability.

In this paper, the methodological approach to the analysis of the E-business Interoperability Framework is thus based on the following steps:

1. The contents of the E-business Interoperability Framework are extracted and analyzed (Section 3). The scope of the analysis presents an overview of the complete set of guidelines and specifications.
2. A comparison of the E-business Interoperability Framework is detailed based on the following interoperability issues: data, process, rules, objects, software systems, cultural, knowledge, services, social networks, electronic identify interoperability, cloud interoperability, and ecosystems (Section 4).
3. A comparison and contrast of the various frameworks and a discussion of the lessons learned to follow the presentation of comparison matrixes in Section 5.

3. E-business Interoperability Framework

This section reviews existing E-business Interoperability Framework. These frameworks were identified through a search of relevant articles published on the Web of Science database. Using keywords such as "interoperability" and "framework," Google Scholar was utilized as a tool to complement the search.

3.1. Interoperability Development for Enterprise Application and Software Framework

The Interoperability Development for Enterprise Application and Software (IDEAS) Framework (Fig. 2) was developed by the IDEAS project based on the ECMA/NIST Toaster Model, ISO 19101, and on ISO 19119 and was augmented through the quality attributes (Bourrières, 2006; Zwegers, 2003). The IDEAS Framework is aimed at reflecting the view wherein Interoperability is achieved on multiple levels: inter-enterprise coordination, physical integration, syntactical application integration, semantic application integration and business process integration.

The IDEAS Framework points out that interoperability between two cooperating enterprises must be achieved on different levels (application, data, communication, business, and knowledge) (Chen et al., 2008a).

All related issues in the management and organization of an enterprise are addressed in the business layer. The business layer of the IDEAS Framework details how the enterprise is organized, the way it operates in producing value, and the way the internal relationships with the personnel and the external relationships with the suppliers, customers, and partners are managed. In the business layer, interoperability is the organizational and operational ability of the enterprises to cooperate with one another (Chen et al., 2008a).

The business layer of the IDEAS Framework contains the decisional model, the business model, and the business processes. The decisional model identifies the decisions to make and the ways such decisions are made for an enterprise. This model also defines

	Framework 1st Level	Framework 2nd Level	ONTOLOGY	QUALITY ATTRIBUTES			QUALITY ATTRIBUTES		
			Semantics	Security	Scalability	Evolution	Performance	Availability	Portability
ENTERPR. MODEL	Business	Decisional Model							
		Business Model							
		Business Processes							
	Knowledge	Organisation Roles							
		Skills Competencies							
		Knowledge Assets							
ARCHITECT PLATFORM	Application	Solution Management							
		Workplace Interaction							
		Application Logic							
		Process Logic							
	Data	Product Data							
		Process Data							
		Knowledge Data							
		Commerce Data							
	Communicat ion								

Fig. 2. IDEAS Framework (Zwegers, 2003).

the degree of responsibility for each operating unit, position, and role. The business model describes the commercial relationships between enterprises and the manner by which they offer services and products to the market. The business processes are sets of activities that are geared towards delivering value to the customers (Chen et al., 2008a).

The knowledge layer of the IDEAS Framework involves representing, structuring, and acquiring personal or collective enterprise knowledge. This layer relates to the internal aspects of knowledge. In products, for example, the knowledge layer, aside from considering the external aspects, describes the operation and control activities of the administration, including their personnel management strategies (Chen et al., 2008a).

Interoperability at the knowledge layer of the IDEAS Framework relates to skills compatibility as well as to the assets of the enterprise, namely, its knowledge and competencies that are unique from those of other enterprises. In the knowledge layer, the methods and tools supporting the diffusion, organization, collection, and elicitation of business knowledge in an enterprise are addressed. Several models are included in this layer. For example, the organizational model roles could be defined by the internal organization, the chain value, the enterprise network, or the value constellation. The organization capability and the organization of employees performing tasks under certain conditions are defined in the skills competency model. The knowledge assets of enterprises are the capital formalized in terms of references, rules, norms, and procedures (Bourrières, 2006; Chen et al., 2008a; Zwegers, 2003).

The application, data, and communication layers of the IDEAS Framework allow enterprises to operate, make decisions, and exchange information. The business process model and the knowledge layer orchestrate the overall execution of the enterprise application. In turn, the enterprise application is identified in the business process model and represented and stored in the knowledge layer. Interoperability at the aforementioned layers is defined as the ability of enterprises to cooperate with other external organizations and involves the utilization of such layers in providing interoperation between enterprise resources (Bourrières, 2006; Chen et al., 2008a; Zwegers, 2003).

Furthermore, the application, data, and communication layers of the IDEAS Framework consist of diverse areas such as application logic, data logic, process logic, workplace interaction, and solution management. Application logic refers to the computation carried out by the enterprise system to attain a business result. Data logic is defined as the product and requirement of the enterprise system during its lifecycle and involves content management and repository services. Process logic is the series of steps taken by an application. Workplace interaction can be described as human interaction with the system via input, output, and navigation. Finally, solution management comprises the procedures and tools required by the administrators of the enterprise system, including monitoring and simulation tools as well as role and policy management (Bourrières, 2006; Chen et al., 2008a; Zwegers, 2003).

The semantic dimension cuts across the application, data, communication, knowledge, and business layers (Chen et al., 2008a). The quality attributes of a system is a supplementary dimension of the framework that is determined by business considerations. These quality attributes, which include the basic statement of the system's behaviours, services, and capabilities, are composed

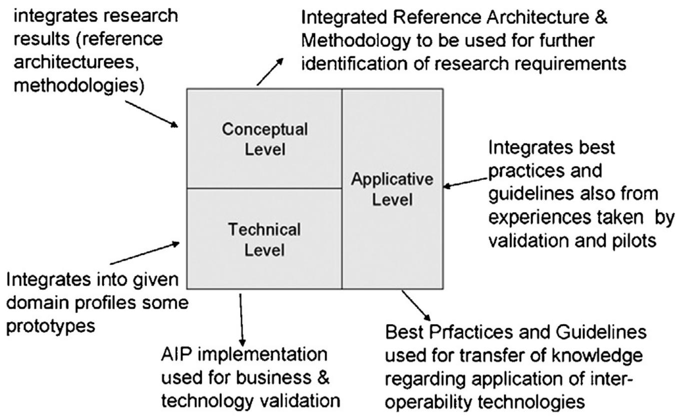

Fig. 3. The AIF (Berre et al., 2007b).

of security (data storage, protection, and transfer), scalability, portability (of application and data), performance, availability, and evolution. The quality attribute achievements have either negative or positive effects on other quality attribute achievements (Chen et al., 2008a). The IDEAS Framework was developed to address enterprise and manufacturing interoperability issues in Europe under the Fifth Framework Programme (FP5) (Chen et al., 2008a).

3.2. *ATHENA Interoperability Framework*

The ATHENA Interoperability Framework (AIF) (Fig. 3) was developed by the ATHENA Integrated Project for software systems and enterprise applications (Berre et al., 2007b). The AIF adopts a holistic view on interoperability with the aim of analyzing and understanding technical requirements and business needs as well as providing a multidisciplinary and model-driven solution approach in solving interoperability problems (Guijarro, 2009).

Synthesizing the research results of the ATHENA project is considered as the main purpose of the AIF. In general, the AIF helps integrators and developers by providing guidelines on how to address the ATHENA solutions with regard to their technical requirements and business needs for interoperability. The structure of the AIF is divided into three parts, namely, conceptual integration, application integration, and technical integration (Berre et al., 2007b; Bourrières, 2006; Ruggaber, 2005).

3.2.1. *Conceptual integration*

The conceptual integration framework of the AIF has evolved from a number of pre-existing frameworks. Concepts, languages, meta-models, and the relationship between models are all aimed towards conceptual integration, in which a modelling foundation is provided for systemizing various aspects of interoperability (Berre et al., 2007c).

Model-driven solution approaches are one of the key aspects of the AIF. The universe of discourse used in collaborating enterprises is the application, data, and communication systems as well as the collaborative enterprise. The solutions for these collaborations, which are focused on modelling the interactions and information exchanges, occur on both technical and business levels (Berre et al., 2007c).

The reference model provided by the AIF states that the modelling solutions arising from three different research areas could be related. A simplistic view of the reference model is illustrated in Fig. 4, which shows the artefacts required by and provided for two collaborating enterprises. In this reference model, interoperations could occur at various levels (information/data, service, process, and enterprise/business). A model-driven interoperability approach is prescribed for each of these levels in which the models

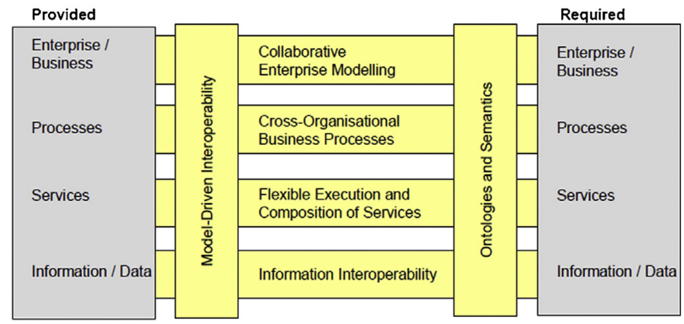

Fig. 4. Simplistic view of the AIF (Berre et al., 2007b).

exchange and formalize the artefacts provided and required. Subsequently, such artefacts must be agreed upon by all parties (Berre et al., 2007c).

The AIF defines a set of meta-models and languages that could be supported by methods and tools to construct the models in question. Starting from the top level, that is, the enterprise/business level, interoperability is considered as the organizational and operational ability of an enterprise to cooperate with other external organizations factually rather than through different working practices, commercial approaches, cultures, and legislations. The Process, Organization, Product (POP) meta-model supports the collaborative enterprise modelling (ATHENA, 2005b).

Making various processes work together is the objective of interoperability at the process level. Process is defined as the sequence of services (functions) depending on specific company needs. Identifying how to connect the internal processes of two companies is necessary in a networked enterprise to create a cross-organizational business process (CBP) meta-model.

Interoperability within the service level involves identifying, composing, and executing various applications that are implemented and designed independently. Services are an abstraction and an encapsulation of the functionality provided by an autonomous entity.

At the information/data level, interoperability is concerned with the processing, exchange, and management of different messages, documents, and/or structures in different entities collaborating with one another.

To overcome the semantic barriers emerging from different interpretations of syntactic descriptions, precise and computer-processable meaning must be associated with each concept using semantics and ontologies. A number of modelling notions are offered by the Object, Process, and Actor modelling language (OPAL) to define the meaning of concepts more precisely. This modelling language also ensures consistency among all levels by relating the concepts at the same and different levels (Berre et al., 2007c).

3.2.2. *Applicative integration*

The applicative integration framework of the AIF focuses on methodologies, standards, and domain models. This framework presents guidelines, principles, and patterns that could be used in solving interoperability issues. Furthermore, it is influenced by the Enterprise Unified Process (EUP), which extends the Unified Software Development Process to cover the entire application, data, and communication lifecycle (Berre et al., 2007c).

3.2.3. *Technical integration*

Application, data, and communication environments as well as technical development are the focus of the technical integration framework of the AIF. The technical integration framework offers application, data, and communication platforms and tools to run and develop software systems as well as enterprise applications.

An integrated architecture supporting collaborative enterprises is described in the technical integration framework of the AIF. This integrated architecture provides a set of tools and infrastructure services to support collaborative product development and design, information interoperability, service execution and composition, as well as cross-organizational business processes (Berre et al., 2007c).

3.3. Enterprise Interoperability Framework

The Enterprise Interoperability Framework was developed within that of the INTEROP Network of Excellence. It aims to identify the basic dimensions of enterprise interoperability, define its research domain, and to determine and establish the domain knowledge (Chen, 2006; Daclin et al., 2006). The adopted Enterprise Interoperability Framework intends to (1) define the domain of enterprise interoperability by elaborating an interoperability framework using a barrier-driven approach and to (2) structure and identify the domain knowledge (solutions) using the framework. The proposed interoperability framework is elaborated based on the concepts developed in several existing models and frameworks, focusing on the concepts that are more relevant in defining the enterprise interoperability research domain (Chen et al., 2008b; Guédria et al., 2009; Jochem, 2010).

3.3.1. Interoperability barriers

Barriers are incompatibilities of various types and of various levels of enterprises. The incompatibilities hinder information sharing and prevent service exchange. Common barriers exist on all enterprises regardless of the sector of activities and size. Developing interoperability means developing solutions and knowledge to remove incompatibilities. Identified barriers are divided into three categories, namely, conceptual, technological, and organizational barriers (Chen, 2006).

Conceptual barriers: Conceptual barriers are concerned with the semantic and syntactic differences in information exchanges. These barriers deal with modelling at a high level of abstraction (for instance, company enterprise models), including that at the programming level (for instance, XML models).

Technological barriers: Technological barriers relate to the incompatibility of information technologies (infrastructure, architecture, and platforms). These barriers are concerned with the standards for the processing, exchange, storage, presentation, and communication of data through computers.

Organizational barriers: Organizational barriers refer to the responsibility, definition, and authority, in addition to the incompatibility, of organizational structures.

3.3.2. Enterprise levels

Interoperations could occur at various levels of an enterprise. Four enterprise levels are based on the ATHENA technical architecture.

Data interoperability: Data interoperability relates to making different query languages and data models work together. It involves finding and sharing heterogeneous information bases wherein different machines with different databases as well as management and operating systems could reside (Chen, 2006).

Service interoperability: Service interoperability refers to identifying, composing, and making various applications that are implemented and designed independently function together. The term "service" is not limited to computer-based applications; it also covers networked enterprises and company functions (Chen, 2006; Francois, 1996).

Process interoperability: Process interoperability intends to make various processes work together. A process refers to the sequence of functions or services depending on company needs. At this level, knowing how to connect the internal processes of two companies is necessary to create a common process in a networked enterprise (Chen et al., 2008b).

barriers / levels	CONCEPTUAL	TECHNOLOGICAL	ORGANISATIONAL
BUSINESS			
PROCESS			
SERVICE			
DATA			

Fig. 5. The two basic dimensions of the Enterprise Interoperability Framework (Chen, 2006).

Business interoperability: Business interoperability involves working harmoniously at the company and organizational levels despite different modes of decision making, work practices, culture, legislations, commercial approaches, and so on. Achieving a harmonious environment could aid in developing businesses between the companies (Chen et al., 2008a).

3.3.3. Interoperability approaches

According to ISO 14258 (Chen, 2006), the integrated, unified, and federated approaches are the three basic ways to relate entities (systems) to one another to establish interoperations.

Integrated approach: In the integrated approach, a common format exists for all models. This common format must be as detailed as the models. Although not necessarily a standard, this format must be agreed upon by all parties to build systems and elaborate models.

Unified approach: In the unified approach, a common format exists only at the meta-level. Different from the integrated approach, which is considered as an executable entity, the unified approach provides a meaning for semantic equivalence to permit mapping between models.

Federated approach: In the federated approach, no common format exists. Establishing interoperability requires parties to make certain accommodations on the fly. Using this approach implies that no partner imposes their methods, languages, and work models. Partners must therefore share ontologies.

Based on the aforementioned concepts of the proposed Enterprise Interoperability Framework, two basic dimensions are illustrated (Fig. 5): (1) enterprise dimension representing levels of an enterprise (aspects of interoperability) and (2) interoperability dimension representing barriers of interoperability.

Fig. 6 illustrates the interoperability framework with the barriers of conceptual interoperability further detailed into semantic and syntax barriers. The use of the interoperability framework in categorizing and identifying knowledge is also shown in Fig. 6. A piece of knowledge may cover more than one level and may concern more than one barrier. For instance, UEML V1.0 intends to remove the syntactic barrier of the enterprise interoperability model and covers all the four levels, while the Process Specification Language (PSL) contributes to the removal of semantic and syntactic barriers but is limited to the process level (Chen, 2006).

Interoperability approaches, the third dimension added to the other two dimensions of the framework, is shown in Fig. 7. These approaches enable the categorization of solutions and knowledge relating to enterprise interoperability according to the ways of removing various interoperability barriers (Chen, 2006).

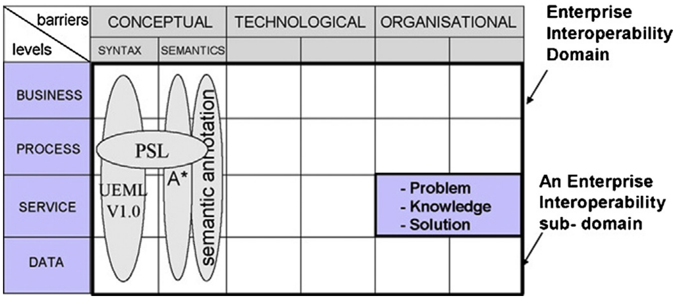

Fig. 6. Use of the framework in defining the domain and in structuring knowledge (Chen, 2006).

For instance, PSL contributes to the removal of conceptual barriers (both semantics and syntax) at the process level through a unified approach.

3.4. GridWise Interoperability Context-Setting Framework

The GridWise Interoperability Context-Setting Framework (Fig. 8) was introduced by the GridWise Architecture Council (GWAC) (Widergren et al., 2007). This framework identifies a set of cross-cutting issues and categorizes interoperability into eight parts that are relevant to the mission of systems integration and interoperation in the electrical end-use, distribution, transmission, and generation industries. In this framework, the major interoperability aspects are grouped into three categories: organizational, informational, and technical.

In the organizational category, the pragmatic aspects of interoperation are emphasized, representing the interactions policy and business drivers. In the informational category, the semantic aspects of interoperation are emphasized. Moreover, this category is focused on the exchanged information and its meaning. In the technical category, the information format or syntax is emphasized. The focus of this category is on the way the information is represented in an exchanged message, including the communication medium.

The interoperability categories are shown in Fig. 8. The GridWise Interoperability Context-Setting Framework pertains to an electricity plus information (E + I) infrastructure. Pragmatic drivers revolve around the management of electricity at the organizational layers. Syntax issues and communications networking involve information technology at the technical layers. At the informational layer, information technology is transferred into knowledge to support the organizational aspects of electricity-related businesses (Widergren et al., 2007).

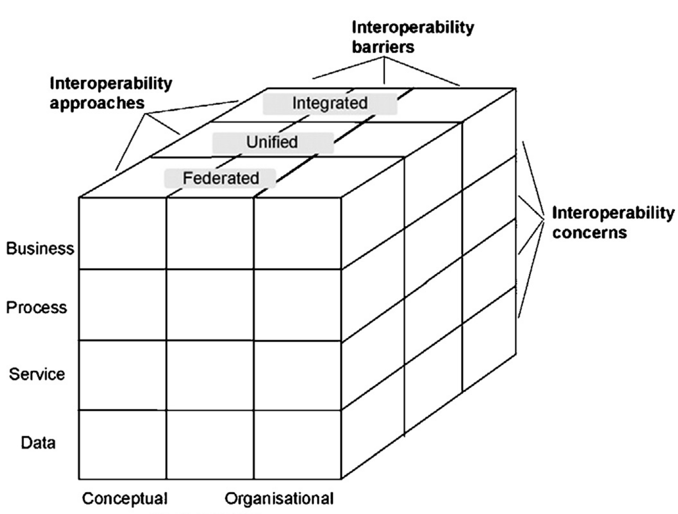

Fig. 7. Three basic dimensions of the Enterprise Interoperability Framework (Chen, 2006).

To achieve interoperation, areas considered as cross-cutting issues must be addressed and agreed upon. Cross-cutting issues are commonly relevant to more than one interoperability category of the GridWise Interoperability Context-Setting Framework. These issues represent the areas that should be investigated to advance interoperability across the web of electric concerns, which involve (i) sharing of content meaning, (ii) identifying resources, (iii) time sequencing and synchronization, (iv) privacy and security, (v) auditing and logging, (vi) state management and transaction, (vii) system preservation, (viii) scalability, reliability, and performance, (ix) configuration and discovery, and (x) system evolution. Fig. 9 shows the cross-cutting issues covering all categories.

4. Comparative analysis of the E-business Interoperability Framework

In this section, the indications alongside each criterion (interoperability issue) in each table denote the corresponding coverage in each particular E-business Interoperability Framework. Examples are presented below.

- √ indicates that the E-business Interoperability Framework has adopted an approach for this criterion, without judging whether this approach provides full or partial coverage for the issue.
- X refers to the lack of a tangible approach to this issue.
- ? characterizes a criterion when the information gathered by the E-business Interoperability Framework specifications is inadequate to evaluate this criterion.

4.1. Data interoperability

Data interoperability describes the ability of data (including documents, multimedia content and digital resources) to be universally accessible, reusable and comprehensible by all transaction parties (in a human-to-machine and machine-to-machine basis), by addressing the lack of common understanding caused by the use of different representations, different purposes, different contexts, and different syntax-dependent approaches (Koussouris et al., 2011; Mykkänen and Tuomainen, 2008). Sub-areas of data interoperability are as follows:

- *Semantic data representation*: semantic data representation refers to the enrichment and representation of data using semantics towards increasing the degree of comprehending the information carried.
- *Data standardization*: data standardization refers to the use of the same set of codes to create generic, yet expandable, data standards to be used by all enterprise systems.
- *Schema matching*: schema matching refers to identifying the existence of semantic relationships between data objects and mapping them to each other.
- *Data mediation*: data mediation refers to the translation and transformation of data between two or more different schemas.

All of the E-business Interoperability Framework focus on semantic data representation sub-area in the data interoperability issue. The data standardization sub-area is merely covered by Interoperability Development for Enterprise Application and Software Framework and GridWise Interoperability Context-Setting Framework. The schema matching sub-area in the data interoperability issue is considered in ATHENA Interoperability Framework

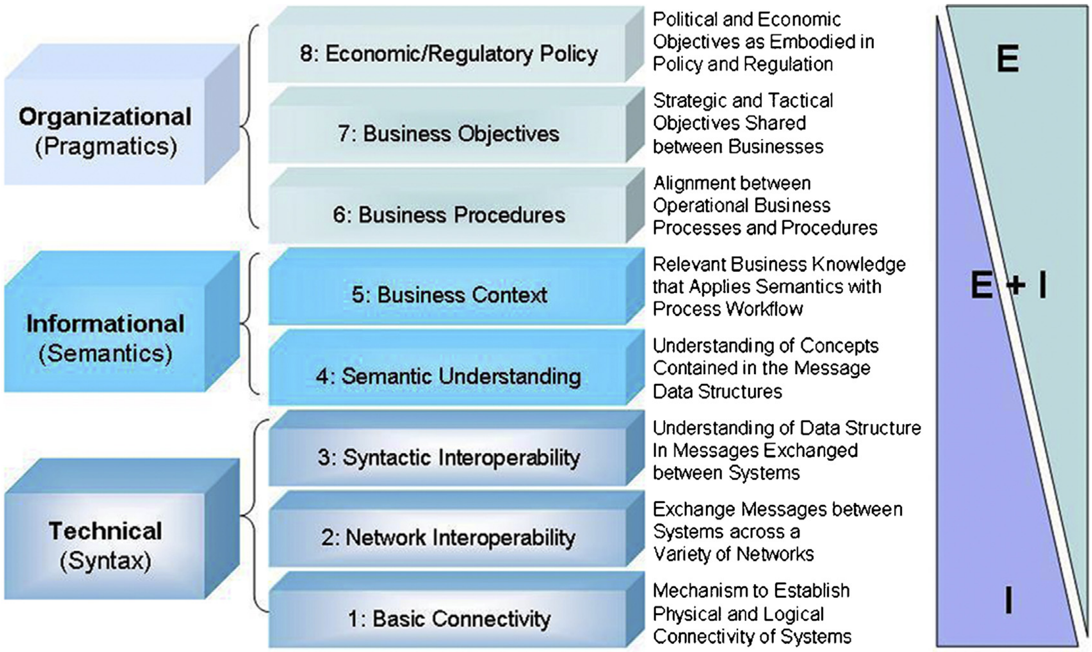

Fig. 8. Interoperability layered categories (Widergren et al., 2007).

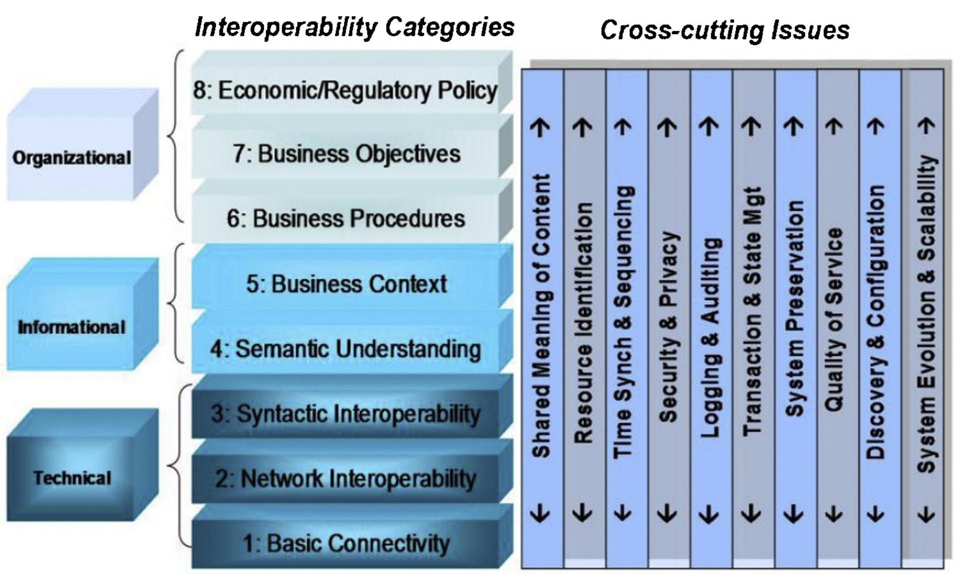

Fig. 9. Interoperability context-setting framework diagram (Widergren et al., 2007).

and GridWise Interoperability Context-Setting Framework. The sub-area of data mediation is only addressed by the ATHENA Interoperability Framework. Table 1 illustrates the mapping of data interoperability sub-areas to the E-business Interoperability Framework.

4.2. Process interoperability

Process interoperability is defined as the ability to align processes of different entities (enterprises), in order for them to exchange data and to conduct business in a seamless way

Table 1
The E-business Interoperability Framework and data interoperability matrix.

E-business Interoperability Framework	Interoperability Development for Enterprise Application and Software Framework	ATHENA Interoperability Framework	Enterprise Interoperability Framework	GridWise Interoperability Context-Setting Framework
Data interoperability				
Semantic data representation	√	√	√	√
Data standardization	√	×	?	√
Schema matching	×	√	×	√
Data mediation	×	√	×	×

(Koussouris et al., 2011). The process interoperability includes the following sub-areas:

- *Process modelling*: process modelling refers to the activities of describing a process or a set of processes through a specific representation method called modelling methodology.
- *Process reengineering*: process reengineering refers to activities employed with the transformation of processes to more generic ones in order to follow the same patterns.
- *Process standardization*: process standardization refers to the definition of universal standard processes that have to be operated by enterprises of any kind.
- *Process alignment*: process alignment refers to the creation of generic process models accompanied with the underlying mapping procedures towards enabling interoperability between processes belonging in different enterprises.
- *Automated process execution*: automated process execution refers to the ability to generate and execute business processes directly from business process models, enabling the automatic generation of processes based on requests from third parties also.

Interoperability Development for Enterprise Application and Software Framework and ATHENA Interoperability Framework focus on process modelling and process standardization sub-areas in the process interoperability issue. In addition, ATHENA Interoperability Framework addresses the automated process execution sub-area. Enterprise Interoperability Framework only focuses on the process modelling. Ultimately, GridWise Interoperability Context-Setting Framework supports the sub-areas of process modelling and process alignment in the process interoperability issue. Table 2 presents the mapping of process interoperability sub-areas to E-business Interoperability Framework.

4.3. Rules interoperability

Rules interoperability is the ability of entities to align and match their business and legal rules for conducting legitimate automated transactions that are also compatible with the internal business operation rules of each other (Gionis et al., 2007b; Koussouris et al., 2011). Sub-areas of rules interoperability are as follows:

- *Rules modelling*: rules modelling refers to documentation and the development of expandable and re-usable models that are able to represent rules (legal or business specific).
- *Business and legal rules homogenization/alignment*: legislation alignment refers to the alignment of the different legislative environments of different territories in order to enable the legitimate conduct of transactions in all involved domains.
- *Rules execution*: rules execution refers to the dynamic processing and handling of rules by systems in order to be able to comply with both legislative and business rules that embrace business processes and transactions.

In rules interoperability issue, sub-area of rules modelling is only addressed by GridWise Interoperability Context-Setting Framework. Business and legal rules homogenization/alignment sub-area is considered in Interoperability Development for Enterprise Application and Software Framework, Enterprise Interoperability Framework, and GridWise Interoperability Context-Setting Framework. The sub-area of rules execution is not supported in any of the E-business Interoperability Framework. Table 3 shows the mapping of rules interoperability sub-areas to E-business Interoperability Framework.

4.4. Objects interoperability

Objects interoperability refers to the networked interconnection and cooperation of everyday objects (Vallecillo et al., 1999). These objects can embrace aspects besides and beyond software components, consistent with the concept of Internet of Things (Gershenfeld et al., 2004). Objects can be really seen as orthogonal concepts, each one having its own specific and distinguishing features. In this context, devices or hardware components interoperability can be seen as a particular case of the object interoperability domain (European-Commission, 2008; Koussouris et al., 2011). The objects interoperability includes the following sub-areas:

- *Radio-frequency identification (RFID) interoperability*: RFID interoperability refers to tags from any vendor to be able to communicate with RFID readers from any vendor, and also to when a given tagged object is able to be identified by RFIED readers of any user in a wide variety of application conditions.
- *Device interoperability*: interoperability between physical devices that involves transferring information through communication channel, using services of different devices, and understanding the meaning of information unambiguously.
- *Smart objects communication*: smart objects communication refers to the communication of smart devices.

Interoperability Development for Enterprise Application and Software Framework, ATHENA Interoperability Framework, and Enterprise Interoperability Framework are not addressing any sub-areas of the objects interoperability issue. The GridWise Interoperability Context-Setting Framework focuses on RFID interoperability and device interoperability sub-areas in the objects interoperability issue. The sub-area of smart objects communication in objects interoperability issue is not even considered by the GridWise Interoperability Context-Setting Framework. The E-business Interoperability Framework and objects interoperability matrix is presented in Table 4.

4.5. Software systems interoperability

Software systems interoperability refers to the ability of an enterprise system or a product to work with other enterprise systems or products without special effort from the stakeholders (Lusk et al., 2006). This can be achieved with a large number of alternative IT architectures stakeholders (Britton and Bye, 2004), and solutions stakeholders (Al-Naeem et al., 2005), including custom, in-house development of APIs, message-oriented middleware and message brokers, service-oriented architecture implementations, or comprehensive stand-alone B2B software gateways (Koussouris et al., 2011). Sub-areas of software systems interoperability are as follows:

- *Web services interoperability*: Service Oriented Architecture (SOA) is a set of design principles used during the phases of systems development and integration in computing. A system based on an SOA will package functionality as a suite of interoperable services that can be used within multiple, separate systems from several business domains. Web services can implement a service-oriented architecture. Web services make functional building-blocks accessible over standard Internet protocols independent of platforms and programming languages. These services can represent either new applications or just wrappers around existing legacy systems to make them network-enabled.
- *Middleware architectures*: middleware is computer software that connects software components or people and their applications. This software consists of a set of services that allows multiple

Table 2
The E-business Interoperability Framework and process interoperability matrix.

E-business Interoperability Framework	Interoperability Development for Enterprise Application and Software Framework	ATHENA Interoperability Framework	Enterprise Interoperability Framework	GridWise Interoperability Context-Setting Framework
Process interoperability				
Process modelling	√	√	√	√
Process reengineering	?	×	×	×
Process standardization	√	√	?	×
Process alignment	×	×	?	√
Automated process execution	×	√	×	?

Table 3
The E-business Interoperability Framework and rules interoperability matrix.

E-business Interoperability Framework	Interoperability Development for Enterprise Application and Software Framework	ATHENA Interoperability Framework	Enterprise Interoperability Framework	GridWise Interoperability Context-Setting Framework
Rules interoperability				
Rules modelling	?	?	×	√
Business and legal rules homogenization/alignment	√	×	√	√
Rules execution	×	×	×	?

processes running on one or more machines to interact. This technology evolved to provide for interoperability in support of the move to coherent distributed architectures.
- *Interoperability conformance & testing*: software interoperability testing is the activity of proving that end-to-end functionality between (at least) two communicating systems as required by those systems' base standards.
- *Interoperable software models & building blocks*: an interoperable software model usually defines a technical infrastructure. Additionally, the mediator defines the mechanisms (connectors) to be used for the interaction and communication between components.

In software systems interoperability issue, web services interoperability sub-area is considered in Interoperability Development for Enterprise Application and Software Framework, ATHENA Interoperability Framework, and GridWise Interoperability Context-Setting Framework. The middleware architectures sub-area is not supported by any of the E-business Interoperability Framework. The sub-area of interoperability conformance and testing is only addressed by ATHENA Interoperability Framework, and the sub-area of interoperable software models and building blocks is only considered by Interoperability Development for Enterprise Application and Software Framework. Table 5 illustrates the mapping of software systems interoperability sub-areas to E-business Interoperability Framework.

4.6. Cultural interoperability

Cultural interoperability is the degree to which knowledge and information is anchored to a unified model of meaning across cultures. Enterprise systems that take into consideration cultural interoperability aspects can be used by transnational groups in different languages and cultures with the same domain of interest in a cost-effective and efficient manner (Koussouris et al., 2011). The cultural interoperability includes the following sub-areas:

- *Language interoperability*: language interoperability refers to the automatic and seamless translation of physical languages.
- *Alignment in traditions, religions and ethics*: alignment in traditions, religions and ethics refers to finding ways of respecting each individual's cultural needs while at the same time promoting collaboration and cooperation.

In cultural interoperability issue, language interoperability sub-area is considered by ATHENA Interoperability Framework and GridWise Interoperability Context-Setting Framework. The sub-area of Alignment in traditions, religions and ethics is not supported by any of the E-business Interoperability Framework. Table 6 presents the mapping of cultural interoperability sub-areas to E-business Interoperability Framework.

4.7. Knowledge interoperability

Knowledge interoperability is the ability of two or more different entities to share their intellectual assets, take immediate advantage of the mutual knowledge and utilize it, and to further extend them through cooperation (Koussouris et al., 2011). Sub-areas of knowledge interoperability are as follows:

- *Knowledge sharing & knowledge repositories*: knowledge sharing and knowledge repositories refers to the employment of methods and tools for recording and storing knowledge in a way that is retrievable and meaningful to every party that is allowed to access it.

Table 4
The E-business Interoperability Framework and objects interoperability matrix.

E-business Interoperability Framework	Interoperability Development for Enterprise Application and Software Framework	ATHENA Interoperability Framework	Enterprise Interoperability Framework	GridWise Interoperability Context-Setting Framework
Objects interoperability				
RFID interoperability	×	×	×	√
Device interoperability	?	?	×	√
Smart objects communication	×	×	×	×

Table 5
The E-business Interoperability Framework and software systems interoperability matrix.

E-business Interoperability Framework	Interoperability Development for Enterprise Application and Software Framework	ATHENA Interoperability Framework	Enterprise Interoperability Framework	GridWise Interoperability Context-Setting Framework
Software systems interoperability				
Web services interoperability	√	√	×	√
Middleware architectures	?	?	×	×
Interoperability conformance & testing	×	√	×	?
Interoperable software models & building blocks	√	×	×	?

- *Business units knowledge alignment*: business units alignment refers to the integration, sharing and collaboration of multiple business units in terms of knowledge in order to deliver a product or a service.
- *Ontology matching*: ontology matching refers to the determination of relationships and correspondences between various knowledge concepts that are incorporated in ontologies.
- *Business knowledge reasoning analysis & representation*: it refers to the tools for business knowledge reasoning analysis and representation.

ATHENA Interoperability Framework and Enterprise Interoperability Framework focus on knowledge sharing and knowledge repositories, business units knowledge alignment, and ontology matching sub-areas in knowledge interoperability issue. Interoperability Development for Enterprise Application and Software Framework addresses business units knowledge alignment and ontology matching sub-areas. The GridWise Interoperability Context-Setting Framework only focuses ontology matching in knowledge interoperability issue. Table 7 shows the mapping of knowledge interoperability sub-areas to E-business Interoperability Framework.

4.8. Services interoperability

Services interoperability can be defined as the ability of an enterprise to dynamically register, aggregate and consume composite services of an external source, such as a business partner or an internet-based service provider, in seamless manner (Koussouris et al., 2011; Papazoglou, 2008). The services interoperability includes the following sub-areas:

- *Automatic service discovery and description*: automatic service discovery, description, composition, negotiation refers to tools, methodologies and infrastructures enabling the automatic discovery of services offered by enterprises and the dynamic composition of them in order to conduct business in an automated manner with no extra modification in the enterprise systems.
- *Service co-design*: service co-design in an enterprise involves the individuals from all levels of an organization in the innovation process—empowering them as co-designers of service concepts so they can develop a more cohesive experience at the point of use.
- *Service level agreements alignment*: a service-level agreement (SLA) is a contract between a network service provider and a customer that specifies, usually in measurable terms, what services the network service provider will furnish.
- *Enterprise mashups*: an enterprise mashup, also referred to as a business mashup, is an application that combines data from multiple internal and public sources and publishes the results to enterprise portals, application development tools, or as a service in an SOA cloud. Enterprise mashups must also interoperate with enterprise application technologies for security, governance, monitoring, and availability.
- *Service orchestration*: service orchestration refers to the composition of processes from existing services. An orchestration defines external interactions as well as internal actions. External interactions include invoking other services and receiving incoming messages; internal actions include data transformations and calculations.
- *Service choreography*: a choreography describes service interactions from the perspective of an external observer, seeing only what is happening in the services' interfaces. It does not describe what is happening inside a participating service.

In service interoperability issue, all of the E-business Interoperability Framework focus on automatic service discovery and description and service co-design sub-areas. Service level agreements alignment, enterprise mashups, and service choreography sub-areas are not supported by any of the E-business Interoperability Framework. The sub-area of service orchestration in service interoperability issue is only considered by ATHENA Interoperability Framework. The E-business Interoperability Framework and service interoperability matrix is presented in Table 8.

4.9. Social networks interoperability

Social networks interoperability refers to the ability of enterprises to seamlessly interconnect and utilize social networks for collaboration purposes, by aligning their internal structure to the fundamental aspects of the social networks (Abel et al., 2009; Koussouris et al., 2011). Sub-area of social networks interoperability is as follows:

Table 6
The E-business Interoperability Framework and cultural interoperability matrix.

E-business Interoperability Framework	Interoperability Development for Enterprise Application and Software Framework	ATHENA Interoperability Framework	Enterprise Interoperability Framework	GridWise Interoperability Context-Setting Framework
Cultural interoperability				
Language interoperability	×	√	?	√
Alignment in traditions, religions and ethics	×	×	×	?

Table 7
The E-business Interoperability Framework and knowledge interoperability matrix.

E-business Interoperability Framework	Interoperability Development for Enterprise Application and Software Framework	ATHENA Interoperability Framework	Enterprise Interoperability Framework	GridWise Interoperability Context-Setting Framework
Knowledge interoperability				
Knowledge sharing & knowledge repositories	×	√	√	×
Business units knowledge alignment	√	√	√	?
Ontology matching	√	√	√	√
Business knowledge reasoning analysis & representation	?	×	?	×

- *Social network characteristics infusion*: social network integration refers to the integration of specific social media aspects and characteristics in the organizational structure of an enterprise in order to be able to utilize seamlessly such infrastructures and their functions.

None of the E-business Interoperability Frameworks focus on social network characteristics infusion sub-area in social networks interoperability issue. Table 9 illustrates the mapping of social networks interoperability sub-area to E-business Interoperability Framework.

4.10. Electronic identity interoperability

Electronic identity interoperability refers the ability of different electronic identity systems within or across the boundaries of an enterprise to collaborate in order to automatically authenticate and authorize entities and to pass on security roles and permissions to the corresponding electronic identity holders, regardless the system that they originate from (Koussouris et al., 2011; Palfrey and Gasser, 2007). The electronic identity interoperability includes the following sub-areas:

- *Digital signatures interoperability*: digital signatures interoperability is the mutual recognition of electronic signatures among countries, that involves overcoming of the current legal (legislation, management authorities) as well as technical heterogeneities in terms of attributes, validation, format and algorithms (IDABC, 2009).
- *Federated identity management systems interoperability*: a federated identity management system supports the technologies, standards and use-cases which serve to enable the portability of identity information across otherwise autonomous security domains.
- *Enterprise context mobility*: it refers to the mobility of an enterprise to collaborate.

The Interoperability Development for Enterprise Application and Software Framework and Enterprise Interoperability Framework are not addressing any of the electronic identity interoperability issue sub-areas. The GridWise Interoperability Context-Setting Framework focuses on the sub-areas of federated identity management systems interoperability and enterprise context mobility. The ATHENA Interoperability Framework is only concentrating on enterprise context mobility in electronic identity interoperability issue. Table 10 presents the mapping of electronic identity interoperability sub-areas to E-business Interoperability Framework.

4.11. Cloud interoperability

Cloud interoperability defines the ability of cloud services to be able to work together with both different cloud services and providers, and other applications or platforms that are not cloud dependant (Koussouris et al., 2011). The scope of interoperability refers both to the links amongst different clouds and the connection between a cloud and an organization's local systems (Dillon et al., 2010) in order to realize the seamless fluid data across clouds and between cloud and local applications (Janssen et al., 2013; Koussouris et al., 2011). Sub-areas of cloud interoperability are as follows:

- *Unified cloud interfaces (SaaS Io)*: unified cloud interfaces refer to the design of standard interfaces for direct communication and interoperation between clouds from different providers.
- *Cloud federation*: cloud federation refers to the ability to utilize heterogeneous cloud resources as a unified and universal computing environment without experiencing the issues that can be caused by this differentiation.
- *IaaS interoperability*: IaaS interoperability refers to the ability of resources on one IaaS provider to communicate with resources on another IaaS provider.
- *PaaS interoperability*: PaaS interoperability refers to the ability of resources on one PaaS provider to communicate with resources on another PaaS provider.

Table 8
The E-business Interoperability Framework and service interoperability matrix.

E-business Interoperability Framework	Interoperability Development for Enterprise Application and Software Framework	ATHENA Interoperability Framework	Enterprise Interoperability Framework	GridWise Interoperability Context-Setting Framework
Services interoperability				
Automatic service discovery and description	√	√	√	√
Service co-design	√	√	√	√
Service level agreements alignment	×	×	×	×
Enterprise mashups	×	×	×	×
Service orchestration	×	√	?	×
Service choreography	×	?	?	×

Table 9
The E-business Interoperability Framework and social networks interoperability matrix.

E-business Interoperability Framework	Interoperability Development for Enterprise Application and Software Framework	ATHENA Interoperability Framework	Enterprise Interoperability Framework	GridWise Interoperability Context-Setting Framework
Social networks interoperability				
Social network characteristics infusion	?	×	×	×

Table 10
The E-business Interoperability Framework and electronic identity interoperability matrix.

E-business Interoperability Framework	Interoperability Development for Enterprise Application and Software Framework	ATHENA Interoperability Framework	Enterprise Interoperability Framework	GridWise Interoperability Context-Setting Framework
Electronic identity interoperability				
Digital signatures interoperability	×	×	×	?
Federated identity management systems interoperability	×	?	×	√
Enterprise context mobility	×	√	?	√

Table 11
The E-business Interoperability Framework and cloud interoperability matrix.

E-business Interoperability Framework	Interoperability Development for Enterprise Application and Software Framework	ATHENA Interoperability Framework	Enterprise Interoperability Framework	GridWise Interoperability Context-Setting Framework
Cloud interoperability				
Unified cloud interfaces (SaaS Io)	×	×	×	×
Cloud federation	×	×	×	×
IaaS interoperability	×	×	×	×
PaaS interoperability	×	×	×	×

The unified cloud interfaces (SaaS Io), cloud federation, IaaS interoperability, and PaaS interoperability sub-areas in cloud interoperability issue are not supported by any of the E-business Interoperability Framework. Table 11 shows the mapping of cloud interoperability sub-areas to E-business Interoperability Framework.

4.12. Ecosystems interoperability

Ecosystems interoperability can be defined as the ability of instant and seamless collaboration between different ecosystems and independent entities, entities within the ecosystems and as the ability of different independent entities to formulate virtual structures for specific purposes (Koussouris et al., 2011). The ecosystems interoperability includes the following sub-areas:

- *Business ecosystems interoperation*: business ecosystems interoperation refers to the ability of Business Ecosystems to cooperate in order to dynamically converge and operate towards a common goal.
- *Interoperability within Virtual Enterprises*: virtual enterprise integration refers to the ability of two or more virtual enterprises to be able to communicate and collaborate in all business levels in a seamless and automated way.
- *Business Strategy Alignment*: Business Strategy Alignment refers to the ability of business to achieve their strategic goals.

None of the E-business Interoperability Framework focus on sub-areas of ecosystems interoperability issue (Business Ecosystems Interoperation, Interoperability within Virtual Enterprises, and Business Strategy Alignment). The E-business Interoperability Framework and ecosystems interoperability matrix is presented in Table 12.

5. Discussion

An interoperability framework defines the standards, policies, and information specifications, which enables predictable interconnection and exchange between separate systems and allows systems to work together. It provides the shared vision and rules for executing coordinated changes to support complex, emerging interactions between organizations. The publication of interoperability guides and resulting engagement with all levels of interoperability is critical to success. The state-of-the-art analysis on the E-business Interoperability Framework reveals that the existing E-business Interoperability Framework have carried out considerable efforts to support the interoperability issues in the first, and the second granularity levels, however the interoperability issues in the third granularity level (cloud interoperability) and the fourth granularity level (ecosystems interoperability) are not supported in the existing E-business Interoperability Framework. Furthermore, the analysis of the E-business Interoperability Framework indicates that efforts to build an E-business Interoperability Framework have usually been devoted to production of guidelines and standards addressing the following four levels of interoperability: technical, syntactic, semantic, and organizational.

More in details, quality attributes are a supplementary dimension of the IDEAS Framework. Business considerations determine the qualities that must be accommodated in a system. The considered attributes are (1) security, (2) scalability, (3) portability, (4) performance, (5) availability, and (6) evolution. Emphasis must be placed on the fact that the achievement of any quality attribute will have an either positive or negative effect on the achievement of other quality attributes [32]. To achieve interoperation, the GridWise Interoperability Context-Setting Framework defines cross-cutting issues. The scope of the E-business Interoperability Framework mainly extends over business-to-business (B2B)

Table 12
The E-business Interoperability Framework and ecosystems interoperability matrix.

E-business Interoperability Framework	Interoperability Development for Enterprise Application and Software Framework	ATHENA Interoperability Framework	Enterprise Interoperability Framework	GridWise Interoperability Context-Setting Framework
Ecosystems interoperability				
Business ecosystems interoperation	×	×	×	×
Interoperability within virtual enterprises	×	×	×	×
Business strategy alignment	×	×	×	×

and cross-business transactions. Most E-business Interoperability Framework are also accompanied by the relevant specifications that elaborate, for example, on business, service, and data interoperability issues.

As a result, the interoperability frameworks vary significantly in the way they address interoperability issues. Specifically, the GridWise Interoperability Context-Setting Framework and the IDEAS Framework [19], which address interoperability from an abstract perspective, detect interoperability issues in the organizational, conceptual, and technical layers. The AIF is defined as the main layers of the interoperability of entities, wherein interoperability issues emerge. Different frameworks for interoperability aimed at establishing a consensus on some aspects co-exist and vary from framework to framework.

The IDEAS Framework investigates interoperability from different organizational aspects and levels. It also considers a strategic transition in different interoperability aspects and supports the implementation of this transition plan. The IDEAS Framework focuses on three related research fields, namely, enterprise modelling, architecture and platform, and ontology, rather than on the fields of interoperability. The AIF involves interoperability knowledge, which this framework considers as an enterprise asset. This framework has different interoperability approaches and is composed of the interoperability methodology and the interoperability reference architecture. Moreover, the AIF contains two success criteria: (1) generic and extensible solution approach to interoperability, wherein the AIF is ought to be usable and applicable in numerous user scenarios containing diverse interoperability requirements; and (2) instantiation of the framework with research results from ATHENA, wherein the AIF is capable of successfully integrating the results of three research areas (enterprise modelling, architectures and platforms, and ontology) and presents a holistic view to solve interoperability issues at the application, data and communication, and enterprise levels. As the AIF is based on the IDEAS model, it faces the same problems of the IDEAS Framework, which is focused on other research fields rather than on interoperability. The Enterprise Interoperability Framework models knowledge and offers a picture of the research situation in the interoperability field. The main components of the Enterprise Interoperability Framework are knowledge, measurement, and engineering of interoperability. The Enterprise Interoperability Framework only focuses on interoperability research fields and is not applicable. The structured components of this framework only offer an overall view of issues related to interoperability. The GridWise Interoperability Context-Setting Framework strives to communicate and organize ideas about distributed system integration that can be used by decision makers, architects, designers, and solution providers within the electric system community. This is not a general framework; it is only applicable in electric systems.

With regard to the strengths of the existing E-business Interoperability Framework, all of the existing E-business Interoperability Framework cover the data interoperability and process interoperability in the first granularity level of interoperability issues, and knowledge interoperability and services interoperability in the second granularity level of interoperability issues, as seen in Table 13. Most of the existing E-business Interoperability Framework include the rules interoperability, objects interoperability, software systems interoperability, and cultural interoperability in the first granularity level of interoperability issues, and electronic identity interoperability in the second granularity level of interoperability issues (see Table 13). As illustrated in Table 13, as for the weaknesses of the existing E-business Interoperability Framework, none of the existing interoperability frameworks contain the social networks interoperability in the second granularity level of interoperability issues, cloud interoperability in the third granularity level of interoperability issues, and ecosystems interoperability in the fourth granularity level of interoperability issues.

Moreover, in each of the existing E-business Interoperability Framework, different sets of interoperability attributes have been defined, and most of the interoperability frameworks cover the relevant attributes of the technical and organizational interoperability, and a few of them support the relevant attributes of syntactic and semantic interoperability.

In this direction, the insight gained from the study of the aforementioned E-business Interoperability Framework is reviewed in this paper for others that intend to create an E-business Interoperability Framework. These realizations are summarized as follows:

In terms of interoperability levels, an E-business Interoperability Framework cannot be realized by addressing only the technical interoperability level. A bottom-up approach beginning with technical interoperability is necessary to enable interoperability across business. The beginning point is situated on top with organizational interoperability. In this context, syntactic and semantic interoperability issues deserve greater priority and effort than the technical interoperability level. An E-business Interoperability Framework defines and addresses all the attributes relevant to different levels of technical, syntactic, semantic, and organizational interoperability. From the perspective of interoperability issues, E-business Interoperability Framework cannot be realized by addressing only data, process, knowledge, and service interoperability issues. Interoperability issues should be further supported by gaining a more concrete understanding of rules, objects, software systems, cultural, social networks, electronic identity, cloud, and ecosystems interoperability issues. In the E-business Interoperability Framework, mechanisms and metrics for determining the increasing maturity of interoperability must be predicted.

Regarding the completeness of the frameworks examined, the ATHENA Interoperability Framework and the GridWise Interoperability Context-Setting Framework appear to have a more complete set of specifications (sub-areas) on e-business interoperability issues. The ATHENA Interoperability Framework includes a clear methodology to achieve interoperability in the e-business context. It has been used as the basis for the definition of E-business Interoperability Framework and for providing guidance to business managers and interoperability officers. The GridWise Interoperability Context-Setting Framework has gained critical achievements regarding interoperability aspects, such as technical, informational, and organizational. In order to be able to implement

Table 13
The E-business Interoperability Framework and interoperability issues matrix.

E-business Interoperability Framework	Interoperability Development for Enterprise Application and Software Framework	ATHENA Interoperability Framework	Enterprise Interoperability Framework	GridWise Interoperability Context-Setting Framework
Interoperability issue				
Data interoperability	√	√	√	√
Process interoperability	√	√	√	√
Rules interoperability	√	×	√	√
Objects interoperability	√	×	×	√
Software systems interoperability	√	√	×	√
Cultural interoperability	×	√	×	√
Knowledge interoperability	√	√	√	√
Services interoperability	√	√	√	√
Social networks interoperability	×	×	×	×
Electronic identity interoperability	×	√	×	√
Cloud interoperability	×	×	×	×
Ecosystems interoperability	×	×	×	×

and test in real-life settings, an E-business Interoperability Framework must be specified to a higher degree of detail. An E-business Interoperability Framework must consider the needs and views of the full range of stakeholders. This requires the representation of various segments and a consensus-making process for decisions about update plans, actual revisions, and complementary material. The GWAC was sponsoring an interoperability forum in the fall of 2007. The objective of this meeting was to engage the electric system community to develop a plan and organization for maintaining the framework and related material over time. The GridWise Interoperability Context-Setting Framework provides a set of example scenarios that highlight the use of the framework, particularly the categories of interoperability. Three scenarios are provided: one on a residential demand response interface between a residence and the electricity provider, another on a commercial building demand response interface, and one on a congestion management scenario.

The Interoperability Development for Enterprise Application and Software (IDEAS) Framework seems to lag behind the advancements on interoperability. The Enterprise Interoperability Framework (EIF) defines the research domain of enterprise interoperability with enterprise levels (business, process, service, and data), and help to identify and structure the knowledge of the domain with interoperability barriers (technological, conceptual, and organizational barriers). The Enterprise Interoperability Framework (EIF) is well received in enterprise interoperability with interoperability approaches (federated, unified, and integrated) and is often cited as one of the foundational documents when enterprise interoperability is discussed.

6. Conclusions

This paper presents an overview of the development of E-business Interoperability Framework. An E-business Interoperability Framework contains standards and concepts that should be followed to ensure success with interoperability issues. It provides assumptions, values, and practices to practitioners in terms of enabling seamless interaction within their enterprises as well as with other enterprises. Several attempts have been made to develop interoperability frameworks to improve e-business interoperability.

Based on the findings of this research and the directions provided by relevant literature, future perspectives that could be done to promote the E-business Interoperability Framework adoption should cover the following two areas:

(1) Scientific research focuses on the missing elements, such as social networks interoperability, cloud interoperability, and ecosystems interoperability. Thus, an E-business Interoperability Framework should address all interoperability issues. Moreover, metrics and properties could be identified to improve the development of interoperability between systems. Major challenges lie ahead in the scientific area of software systems interoperability in view of new technological and computer science's advances that indicate the need of a ubiquitous approach that guarantees a high degree of maintainability against the rapid software technology evolution.

An E-business Interoperability Framework should be simple and easy to understand for the convenience of the developers. The E-business Interoperability Framework must consider the existing standards for implementing interoperability to enhance the structure of interoperability. Structuring E-business Interoperability Framework is necessary in ensuring consistency and avoiding redundancy. For future research and development, the E-business Interoperability Framework must be defined based on the standard concepts and definitions of interoperability and interoperability issues. The existing technology of interoperability should also be considered. Furthermore, given that today, more emphasis is placed on semantic interoperability for creating a general understanding between systems, the interoperability framework must focus on the semantic interoperability.

(2) Practical research concerns on all the sub-areas relevant to each interoperability issue. Therefore, an E-business Interoperability Framework should address all the sub-areas of interoperability issues. It also focuses on interoperability issues for which scientific research has proposed a solution that has not yet been applied effectively in the E-business Interoperability Framework. Examples are researches that support process reengineering, rules execution, service choreography, social network characteristics infusion, and cloud federation.

In order to tackle the interoperability issues, much progress has been made in terms of developing conceptual and algorithmic frameworks and deploying semi-automatic tools for schema matching and data mapping, promoting semantic reconciliation and mediation techniques, and creating adapters and wrappers. The methods and proofs-of-concept proposed are accompanied by experiments that prove their offerings and the weaknesses, yet such laboratory-oriented approaches need to expand and improve in order to cover real-life situations in enterprise environments (Koussouris et al., 2011). The knowledge interoperability issues, not only involves semantics area that constructs common dictionaries for supporting and easing out the operations of knowledge sharing and spreading amongst various entities, but also includes other facets, ranging from business units alignment to context aware systems. To tackle the knowledge interoperability issues, standards, methodologies, tools, and not to mention large-scale experiments and case studies on those aspects need to be investigated. In addition to, knowledge sharing which are not only concentrated in documents, and tangible assets exchange, but also relies heavily on individuals, operating on their own or as part of business units (Koussouris et al., 2011).

An E-business Interoperability Framework clearly indicates that system and software solutions cannot be designed and developed in isolation if the goal is to achieve interoperability. E-business Interoperability Framework must imply on the systems and software design, and affect the software engineering principles and methods. They can be classified as patterns, helpful in the development of new enterprise applications and interoperable systems including (Charalabidis and Chen, 2004):

- Architecture-related patterns (such as system granularity, system coupling/decoupling modes, system connectivity standards).
- Modelling-related patterns (such as model transformations and patterns and model abstraction layers).
- Ontology-related patterns (such as ontological schemas and data dictionaries).
- Software engineering patterns leading to increased interoperability (such as object coupling and encapsulation rules).

From the interoperability perspective, encapsulation has a particular importance when it comes to software systems, services, social systems, cloud and ecosystems. Encapsulation allows the "layering" of new components on top of existing components, using only information about the functionality and interfaces provided by the existing components. It must refer to the design of classes and objects to restrict access to the data and behaviour by defining a limited set of messages that an object can receive (Armstrong, 2006; Lutowski, 2005; Zweben et al., 1995).

The principles and methodologies for designing and developing system and software in the form of interoperable services that expose well-defined business functionalities formulate a solid basis must be extended and applied for interoperability purposes. The loose coupling of business logic (services) and technology is an example of interoperability that have to be applied in various scientific areas as well. Web services are a promising way to implement SOA enabling the loose coupling of functionality at service interfaces. E-business Interoperability Framework indicate software and system components should be loosely coupled with the software and system components that interact with them.

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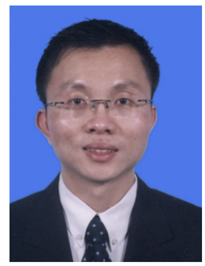

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