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Editorial

Computer in Industry Special Issue on ‘‘Interoperability and Future Internet for Next-Generation Enterprises’’ Editorial and state of the art

1. Introduction

Today's global markets drive enterprises towards closer collaboration with customers, suppliers and partners. Interoperability problems constitute fundamental barriers to such collaboration [7]. A characteristic of modern economic life is the requirement on continuous and rapid change and innovation [49]. The success of an enterprise more and more depends on its ability to seamlessly interoperate with other agile enterprises, and to be able to adapt to actual or imminent changes. Flexible and adaptive interoperability of enterprises, with aligned business processes and information technology [3,33], thus emerges as a key business feature. This new enterprise reality calls for advanced technological support, preferably in harmony with technology developments of the Internet, which is our dominant universal communication and information infrastructure.

The role of the current Internet for enterprise collaboration and interoperability is essential but has primarily been focused on the technical domain. Many challenges, both technical and non-technical, have emerged during the evolution of the Internet. These challenges are addressed in order to shape what since recently is referred to as the Future Internet [48]. Although there is no agreement on its precise technology, structure and application, there is a clear consideration of the user perspective in the Future Internet [5,40,46]. From the enterprise-as-a-user perspective, this means that the Future Internet should be able to empower enterprises to innovate by creating new business value in collaboration as well as in competition with other enterprises, based on relevant knowledge about each other and the market. It should do so in a sustainable and socially responsible fashion, making efficient use of physical resources with a minimal environmental footprint. Therefore, we envision an Internet that comprises a universal business support system in which enterprises enjoy interoperability services that can be invoked on the fly according to their business needs. Such interoperability services may require physical sensing capabilities [23] as well as extensively exploiting knowledge assets [45].

This special issue aims at contributing to a consolidation of the theoretical and empirical knowledge on enterprise interoperability, and at promoting novel ideas and early experience regarding the use and realization of the Future Internet vision to advance Enterprise Interoperability. The International IFIP Working Conference on Enterprise Interoperability (IWEI) is a conference series that became one of the main gatherings for the academic and industrial communities interested in enterprise interoperability. This special issue's call for papers arose from the 3rd International IFIP Working Conference on Enterprise Interoperability (IWEI, 2011), but the call was open to participants of IWEI 2011 as well as to the entire research community interested in this area.

2. Major developments

Enterprise systems, or enterprises for short, are business organizations of some complexity that engage in planned activities to realize specific goals. For example, a commercial enterprise sells goods or services to customers with the goal of making profit and increase wealth for its owners. The use of Information and Communication Technology (ICT) in enterprises, which started in the 1960s and 1970s, gave rise to the concept of enterprise interoperability. Increasingly more elaborate information systems enabled enterprises to improve their performance and secure their competitiveness. These information systems hosted enterprise applications to automate support for the management of core assets and to partially automate business activities of an enterprise. Enterprise interoperability problems emerged due to the inability of different applications to share data and to be incorporated in an overall business process. Two main historic developments can be distinguished [51]:

- Enterprise Application Integration (EAI): Different enterprise applications within a single enterprise generally operate on shared data. In order to avoid data duplication and enable the passing of data from one to another application, various middleware solutions have been proposed. The most advanced solutions are those that not only provide technical interoperability between applications, but also are process-aware and integrate automated with human tasks according to the enterprise's business process. More recent developments introduce service interfaces to hide the heterogeneity of enterprise applications. Alternatively, enterprise applications may be encapsulated in a service with a business value that can be used in a service-oriented architecture according to various business scenarios with (see below).
- Business-to-Business Integration (B2BI): Any enterprise interoperates with other enterprises (e.g., suppliers, partners, transporters, customer organizations). Since all these enterprises employ software applications controlled by partially automated business processes, it would be advantageous to connect the automated business processes directly. As with enterprise application integration, interoperability is problematic due to

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the heterogeneity of enterprise applications, which are now situated in different enterprises and have to exchange data via a communication infrastructure such as the Internet. Moreover, the local processes of the enterprises have to be connected without exposing too much of the internal business logic while fulfilling the requirements of the collaboration. Early developments supporting the connection of computer systems in different enterprises include Electronic Data Interchange (EDI). EDI standards define documents and procedures for document exchange in various industry sectors. Developments in the area of distributed computing led to Service Oriented Architectures (SOA). With this approach, the public view of an enterprise process is exposed as a service, comprising the operations that the enterprise is willing to offer to the outside world. Services have no embedded dependencies to other services. Instead, they have to be composed using a composition logic that defines the coordinated use of services, in order to achieve the objectives of specific enterprise collaboration. Web services are the current realization of SOA. Web services technology is based on standards for defining messages and for exchanging messages on top of Internet protocols. As opposed to EDI, they do not consider industry specific messages and message exchanges, but provide the infrastructure for business collaboration in terms of technology services.

3. Definition, scope and motivation

So far we used the terms ‘integration’ and ‘interoperability’ without making a clear distinction between the two. With integration we want to emphasize an overall perspective, which is important for a user of the integrated system who is not interested in or capable of handling particularities of the constituents (software systems, organizational systems, people, and their interactions). Full integration means that component systems are no longer distinguishable in the integrated system [44]. Thus, EAI is about connecting enterprise applications in a seamless business process, allowing them to share data, without being concerned about their technical differences. Similarly, B2BI is about connecting local business processes of two or more enterprises to form a seamless coordination process that fulfils a collaboration purpose, without being concerned about the internals of the local processes. Interoperability emphasizes the reconciliation of local perspectives: the ability to connect two or more systems, by virtue of an agreement that constrains the systems in some defined way. IEEE defines interoperability as “the ability of two or more systems or components to exchange information and to use the information that has been exchanged” [24]. Building on this, we define enterprise interoperability as *the ability of two or more enterprise systems to affect each other's operation in a defined way and through this to contribute to each other's objectives* (including the common collaboration objective).

Enterprise interoperability enables enterprise integration and accomplishes at least ‘loose’ enterprise integration [51]. In other words, enterprise integration requires that enterprise component systems are interoperable, but interoperable component systems do not necessarily form a full integrated system [7].

Enterprise interoperability emerged because of ICT developments. ICT systems require precise and premeditated agreements and mechanisms to make them interoperable, such as being able to exchange data, interpret the data, and use interpreted data as intended (e.g., providing a requested function). ICT is so pervasive and determinant in enterprise operation [30] that enterprise interoperability without consideration of ICT would not make much sense. Nonetheless the scope of enterprise interoperability goes beyond the technical domain [28]. Interoperability must leverage operation within and between enterprises in accordance to their business level objectives. Since enterprises comprise people and processes, many barriers, besides technical ones, may obstruct interoperation, including conflicting business objectives, different organizational structures, different operational procedures, different cultures, lack of trust, confidentiality of processes, constraining security measures etc. Research on interoperability is, therefore, by nature a multidisciplinary and cross-cutting activity [4]. Several individual researchers as well as collaborative research projects and advisory committees have proposed frameworks with various levels of interoperability to master the complexity of handling enterprise interoperability problems and coordinating efforts for standardizing solutions. Successful enterprise interoperability approaches should be comprehensive, covering the range of business and technology concerns, their relationships, and their evolution, in the context of analysis, planning, design and operation.

4. Achievements

In retrospect, we can observe important achievements regarding enterprise interoperability in three areas: initially there was a strong focus on frameworks that aim at structuring the overall problem of enterprise interoperability, then on models that represent knowledge on treating specific enterprise interoperability problems, and more recently on methods that help to create or use models in the design, analysis and operation of networked enterprise systems. These areas are briefly discussed below.

4.1. Frameworks

One of the first attempts to structure the overall problem of enterprise interoperability is the Levels of Information Systems Interoperability (LISI) reference model of the C4ISR Architectures Working Group [6]. This reference model presents five levels of sophistication regarding interoperability of information systems – from completely isolated to enterprise-level interoperability – and treats such levels as stages through which systems should logically progress to improve their interoperability capabilities. In Europe, enterprise interoperability was studied in several projects under the respective Framework Programmes for Research and Technological Development, notably IDEAS (2002–2003), ATHENA (2004–2007), and INTEROP (2003–2007). The FP5 IDEAS project provided a roadmap for interoperability research that served as a basis for the work carried out under the ATHENA FP6 Integrated Project and the INTEROP FP6 Network of Excellence [7]. ATHENA complimented the stratification proposed by IDEAS through incorporating best practices and guidelines, a technical architecture that follows the principles of service-orientation, and the concept of interoperability profile to support interoperability in specific industry sectors [2]. Work in INTEROP started out from the idea that enterprise systems are not interoperable because interoperability has barriers of various kinds and at various levels. INTEROP identified these barriers and proposed principled approaches to remove them [42]. Other project- or committee-based interoperability frameworks include the European Interoperability Framework for eGovernment Services [15], the eHealth Interoperability Framework [39], the eHealth European Interoperability Framework [16], and the Application Integration Framework for Industrial Automation [25]. A framework still appropriate for understanding ICT domain interoperability, though not particularly targeting enterprise interoperability, is the Reference Model for Open Systems Interconnection [26].

Fig. 1 illustrates some of the important elements of enterprise interoperability frameworks that have been agreed upon by most researchers [7,32,42].

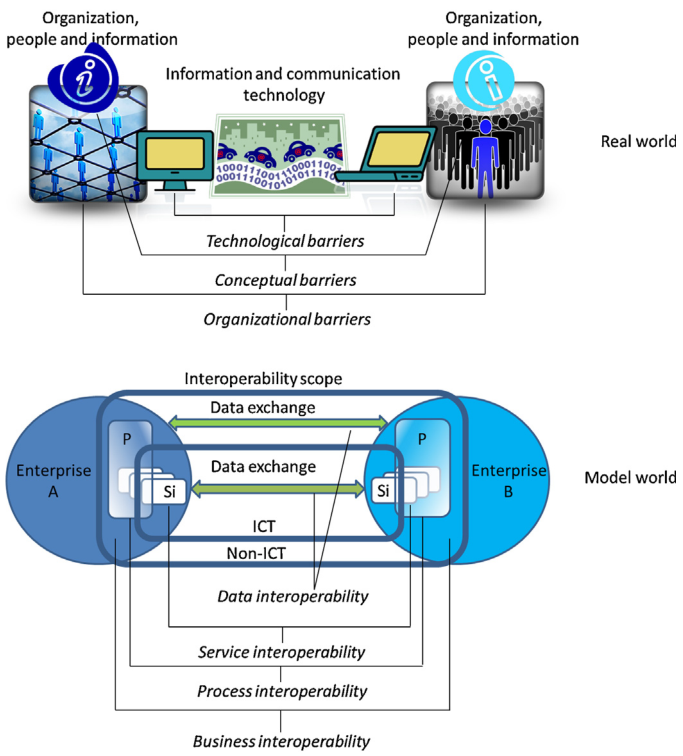

Fig. 1. Illustration of interoperability barriers and concerns.

The figure shows a representation of the real world in which several barriers exist that hamper enterprise interoperability, and a representation of the model world in which enterprise interoperability concerns are identified and related.

The barriers in the real world are identified as follows: (1) organizational barriers: different enterprises have different organizational structures and people assigned with different responsibilities and authorities; (2) conceptual barriers: information which is of common interest to the enterprises is conceptualized and represented in different ways by different enterprises; and (3) technological barriers: incompatible information technologies are employed by different enterprises for processing and exchanging data.

The model world shows that there is an interoperability scope, with an ICT and a non-ICT domain, within which several concerns need to be addressed in order to overcome the mentioned barriers. These concerns are identified as: (1) business interoperability: refers to the harmonized way of working together at the level of organization and people despite cultural, commercial, legislative and other differences; (2) process interoperability: refers to the interoperation of business processes (indicated by ‘P’ in the figure) that define the sequence of activities (or services, indicated by ‘Si’ in the figure) in each of the enterprises. Processes may be (partly) automated or not; (4) service interoperability: refers to the identification, linking and interoperation of services in each of the enterprises. Services may be computer based applications or tasks performed by people; (5) data interoperability: refers to the ability to share information despite the use of different data sources and carriers. This concern may be further divided into levels, namely (5.1) encoding, (5.2) lexical, (5.3) syntactic, (5.4) semantic, and (5.4) semiotic [17]. The concerns can be iterated in an hierarchical structure (not shown in the figure), since businesses can be combined into composite bundles, processes can be presented as services that can be used by higher level processes, and data exchanges can be structured into hierarchical communication layers. The data interoperability concern crosscuts the other interoperability concerns (not shown in the figure), since business, processes and services exchange data using ICT or non-ICT based data channels.

4.2. Models and standards

Models are operational solutions to interoperability problems, often addressing a specific interoperability concern or level, which prove particularly effective if they come in the form of standards agreed upon by international, industrial and non-profit standards organizations such as IEC, ISO, CEN, ISA, IEEE, OMG, W3C and OAG. The frameworks mentioned earlier (some of which are standards themselves) were often used as source of inspiration and starting point for standardization efforts regarding enterprise interoperability.

Standards related to data interoperability in the ICT domain can conveniently be positioned with reference to the Reference Model for Open Systems Interconnection [26]. Syntactic level data interoperability solutions are routinely provided by the Internet. Web service standards build on the Internet, using XML, SOAP or REST to achieve syntactic level data interoperability, WSDL to achieve service interoperability, and BPEL to achieve process interoperability [43]. Other web service standards are available to support particular features such as transactions and security. In order to support semantic level data interoperability, languages such as OWL were introduced for machine processable knowledge representation, as an important step towards a semantic web of services [37].

These application domain neutral (‘horizontal’) standards were complemented with ‘vertical’ standards for several application domains. For example EDI and ebXML are two standards that support semantic level data interoperability for the exchange of electronic business information between trading partners [19]. Similarly, MANDATE and STEP are two standards that support semantic level data interoperability for the exchange of product model data respectively production and resource data between manufacturing systems [8,38]. Process and service interoperability in the manufacturing domain is supported based on the definition of profiles, resulting in a semi-federated approach to interoperability of manufacturing applications and software units [31].

Several language standards exist for ontology definition, enterprise modelling and process specification [8]. Ontologies are conceptualizations of a worldview and as such important to capture the semantic domain of enterprises. Although different enterprises will inevitably develop and employ different ontologies, using the same language for defining these ontologies will help to achieve mappings between them. OWL is the most prominent ontology language for the web services domain [37]. In the research community, there has been a growing interest in general ontology languages and their foundation. For example, the Unified Foundational Ontology (UFO) has been proposed as a reference ontology that can be used as a foundation for general conceptual modelling languages [22]. Enterprise modelling and engineering are considered as prerequisites to enterprise interoperability [9]. The Unified Enterprise Modelling Language (UEML) aims to be a standard language emerging from existing languages for enterprise modelling, similar to UML in the field of software engineering [13]. BPMN is an accepted graphical language standard for business process modelling, targeting all business stakeholders (not only technical users), but with a mapping to execution languages, in particular BPEL [52]. PSL is an executable language specifically for modelling manufacturing processes [8].

Many more standards exist that bear relevance to enterprise interoperability. For more information, the reader may refer to [8,9,31,38,41].

4.3. Methods

Pre-defined enterprise interoperability models and standards provide solutions to generic interoperability problems. In addition, methods are needed to improve or establish interoperability solutions adapted to the particular needs of the enterprises that want to interoperate. Several such methods have been proposed over the years, for different phases of the enterprise system lifecycle (e.g., design, analysis, operation), for different interoperability domains or levels (e.g., ICT, non-ICT), and for different interoperability aspects or qualities (e.g., maturity, value, sustainability).

The early LISI reference model [6] has an associated maturity model with a practical assessment method for determining the interoperability maturity of an information system or pair of information systems. LISI and many other approaches discuss enterprise interoperability primarily in a technical context. For this reason, researchers advocated for more attentions to non-technical factors, such as strategic, organizational, cultural and economic issues [32]. When considering the non-technical or business context, there is no highest level or maximum enterprise interoperability. Instead, many enterprise-specific circumstances determine what is an optimum level of enterprise interoperability. Legner and Wende [34] propose a method that builds on contingency theory to achieve best-fit business interoperability by taking account of the enterprises' environmental and internal contingencies.

The framework proposed by the ATHENA and INTEROP projects allows for pinpointing interoperability problems at the intersection of identified interoperability barriers, concerns and approaches [42]. Based on this, a stepwise approach for establishing enterprise interoperability can be provided, from the expressions of needs of enterprises to the implementation of interoperability solutions. These steps involve a method to measure interoperability, which considers both maturity and operational performance of the current situation [11]. Using the same framework foundation of ATHENA and INTEROP, a model-driven approach to enterprise interoperability is possible that exploits OMG's Model Driven Architecture (MDA) and associated model-driven technologies [14]. One of the benefits of MDA lies in the separation of business level functions and the choice of technology platforms for supporting such functions. Another architectural framework, the Service Oriented Architecture (SOA), provides an abstraction of technical details of software applications as services, which can be registered, searched and accessed in a distributed environment with an Internet (or other network technology) infrastructure. An approach that combines both MDA and SOA thus offers opportunities to improve interoperability and stimulate reuse of existing interoperability solutions [27].

Since enterprises continuously evolve in supply chains and other business networks, it is necessary to maintain and sustain the interoperability of enterprise systems in these environments. One approach to sustainable interoperability is based on harvesting the new technology paradigms of the Future Internet, specifically those related to enterprise network configuration, architectures and data models, and enterprise interoperability science fundamentals [28]. Concepts of system theory may be applied to manage the evolution of interoperability and to reach sustainable enterprise interoperability [12].

One non-technical factor of enterprise interoperability that increasingly attracts attention is that of business value of enterprise collaboration [35]. The use of interoperability standards can provide substantial economic benefits [38], which can be estimated with quantitative methods based on data collection from industry surveys and case studies [18]. However, assessing the potential value of (new) business models which depend on enterprise interoperability is much more difficult. An important basis for exploring the value of e-commerce ideas has been put forward in [20]. More recent methods extend this by considering the uncertainty regarding business characteristics [29] and incorporating utility functions to balance between various value attributes that enterprises may have [50].

Ontologies are often used to capture and share knowledge within enterprises, and therefore provide a basis for sharing meaning in enterprise networks. However, such ontologies usually have evolved independently over time in different industry sectors and companies. This raises an issue for enterprise interoperability whenever disparate ontologies are involved. To deal with this issue, a common ontology with a convenient scope for the interoperation can be agreed upon, or mappings can be defined to overcome the semantic differences between the ontologies in use during the interoperation. As an example of the first approach, Lu et al. [36] discuss a product-centric ontology framework demonstrated in a supply chain make-to-order process. An example of the second approach can be found in [10], where the authors identify the nature of semantic mismatches and the essential elements for an ontology mapping method. Service ontologies play a special role in enterprise interoperability. This is the case since 'service' is an important concept in the business domain (service sector) as well as the ICT domain (SOA), however with different meanings. Service ontologies have been developed to clarify this distinction, and to facilitate service and semantic level data interoperability [47].

Business interoperability is one of the less explored areas of enterprise interoperability, as mentioned earlier, certainly if one considers it in combination with semiotic level data interoperability. Methods to address these concerns, sometimes referred to as pragmatic interoperability, dealing with enterprise circumstances and meaning in context, are scarce and preliminary [1,21].

5. Challenges

Considering the achievements already made in enterprise interoperability, we identify three areas with important next challenges.

5.1. Alignment between technical and non-technical interoperability

With technical interoperability we mean any type of interoperability that is mediated by a computer system. For example, by utilizing web services standards it is possible for independently developed software application components to interoperate, even across organizational boundaries, and to coordinate the use of such applications in a workflow. Non-technical interoperability refers to interoperability of people or of organizations run by people. Non-technical interoperability is driven by stakeholder goals, constrained by external and internal factors (such as legislation, organizational structure, and operational procedures), and affected by culture, mood and situation. In order to be effective, technical interoperability has to be well-aligned with non-technical interoperability. In the end, performance indicators at the non-technical level determine whether interoperability is effective and efficient. However, since many activities at the non-technical level are often supported by activities at the technical level, both levels are equally important and solutions at different levels should work with and not against each other (a quality sometimes referred to as vertical interoperability).

5.2. Assessing risks of inadequate enterprise interoperability and added value of improved enterprise interoperability in real-world settings

Insufficient interoperability may lead to missing opportunities to achieve goals that can only or easier be achieved with the help from others. Insufficient interoperability thus translates to lack of effectiveness and efficiency. It has important financial consequences, and impacts the competitiveness and sustainability of a business. However, evaluating enterprise interoperability and assessing its value in a given setting is still a largely unexplored field. A quantitative assessment of enterprise interoperability for a current situation and several possible future situations would allow for founded decision-making concerning changes to an organization. Initial work in this area has been done based on maturity modelling and enterprise architecture analysis. Most advanced are attempts to capture the uncertainty of a considered situation, and to derive the consequences of such uncertainty for the relevant performance indicators. For example, chances of an unreachable business partner, unavailability of an application server, or loss of information can then be incorporated in more realistic analyses.

5.3. Dynamically adapting enterprise interoperability to cater for or exploit changes in real-world settings

Even more ambitious than assessing enterprise interoperability in different static situations, is runtime analysis of enterprise interoperability, possibly followed by an improvement-targeted adaptation of the current enterprise interoperability solution. However, there is a clear ground and motivation to explore the possibilities of direction. First of all, technological developments have greatly advanced the ability to monitor 'things' and to communicate such information in real-time to interested parties. Secondly, interest in enterprise architecture is growing and wider uptake will push efforts of organizations to automatically update such a model with the real changes to one's business. And finally, progress in the area of foundational ontology and semantic technologies increase the possibility of sharing information at the technical level that is relevant to enterprise interoperability as a whole. Hence, there is information generated by monitoring and captured in real-time architecture models that is relevant to enterprise interoperability and therefore should be shared between current and potential partners, and used for decision-making to optimize enterprise interoperability at runtime. This, of course, requires a fusion of different areas of research, and the adoption of a common research agenda.

6. Special issue articles

This special issue contains six research articles, which address important enterprise interoperability issues. We ordered the articles from more business-oriented to more technical-oriented, but all articles pay to some extent attention to the alignment of different – business and information technology – levels.

The first article, "Towards a business model reference for interoperability services" by Otto, Ebner, Baghi, and Bittmann, addresses the lack of business models for enterprise interoperability. The authors study the business value of enterprise interoperability by looking at interoperability information (i.e., information about how two or more systems can be enabled to exchange data) as an economic good. The proposed model is applied in two cases studies, one in the automotive industry and one in the ICT industry, demonstrating efficiency gains for the users and feasibility in real-life scenarios.

The next article, "Structural elements of coordination mechanisms in collaborative planning process and their assessment through maturity models" by Cuenca, Boza, and Alemany, considers the maturity assessment of a specific kind of business-level enterprise interoperability, namely collaborative planning processes. Structural elements for the coordination mechanisms in this field are identified as important for assessing maturity. The maturity model distinguishes five levels for each of the elements. A case study in the ceramic industry provided insights in the deployment and utility in a real supply chain.

Gong and Janssen study the business-IT alignment problem of enterprise interoperability in their article "An Interoperable Architecture for Implementing Strategy and Policy in Operational Processes". They explore how to adapt operational processes to changing business strategies and other requirements, and propose an architecture based on three types of knowledge repositories (domain ontology, business rules, and service descriptions). This architecture was tested in various scenarios where policies are directly implemented in operational business processes. The tests show that the architecture contributes to the agility of policy implementation, while business processes comply with strategy and policy and costs can be reduced.

The fourth article by Coutinho, Cretan, and Jardim-Goncalves, titled "Sustainable Interoperability on Space Mission Feasibility Studies," is inspired by the difficulty of reaching and maintaining the interoperability of enterprises with service-dispersed strategies such as in the aerospace industry. They propose a framework for achieving sustainable interoperability covering both business-people aspects and technology aspects. The core of the framework is a negotiation mechanism for developing an interoperable stable system and to agree on a new stable state every time changes in the environment occur. The framework is applied in a real business case of the European Space Agency – Concurrent Design Facility.

Zinnikus, Cao, and Fischer present a service platform and modelling framework in their article "Agent-supported collaboration and interoperability for networked enterprises: modelling interactions and service compositions." With their approach, a collaborative process is used as a starting point to derive interoperable agent solutions at each of the partners involved in the collaboration. Emphasis is put on a model-driven development of interoperable services and automated agent-code generation for these services. The approach is demonstrated with a supply-chain scenario from the COIN project.

In the last article, titled "Model-driven approach to enterprise interoperability at the technical service level," Khadka, Sapkota, Ferreira Pires, Van Sinderen, and Jansen study model transformations for service-based enterprise collaboration. Similar to the previous article, they start with a collaborative process (service choreography) to capture the interoperability requirements from the business level. They then explore the different design and technology options to refine the collaborative process into interoperable services and coordination activities assigned to individual partners. The approach was demonstrated with simple cases in the e-business domain using a prototype implementation.

We hope that these articles will provide useful insights to both researchers and practitioners, and will lead to inspiration for further research advancing the state of the art of enterprise interoperability.

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