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Towards a sustainable interoperability in networked enterprise information systems: Trends of knowledge and model-driven technology

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ABSTRACT

In a turbulent world, global competition and the uncertainty of markets have led organizations and technology to evolve exponentially, surpassing the most imaginary scenarios predicted at the beginning of the digital manufacturing era, in the 1980s. Business paradigms have changed from a standalone vision into complex and collaborative ecosystems where enterprises break down organizational barriers to improve synergies with others and become more competitive. In this context, paired with networking and enterprise integration, enterprise information systems (EIS) interoperability gained utmost importance, ensuring an increasing productivity and efficiency thanks to a promise of more automated information exchange in networked enterprises scenarios. However, EIS are also becoming more dynamic. Interfaces that are valid today are outdated tomorrow, thus static interoperability enablers and communication software services are no longer the solution for the future. This paper is focused on the challenge of sustaining networked EIS interoperability, and takes up input from solid research initiatives in the areas of knowledge management and model driven development, to propose and discuss several research strategies and technological trends towards next EIS generation.

1. Introduction

Traditional ways of doing business do not provide the expected leverage any more. Companies do not survive and prosper solely through their own individual efforts and isolated knowledge; and speeding up the rate of industrial transformation to high added value products, processes and services has been the key message of policy makers and industrial roadmapping initiatives for the last decade [1]. Enterprises have to become agile, sensitive to changes in market forces, and capable of responding with incremental modifications in business and services provided (adaptation) as well as anticipating radical changes by responding with new and breakthrough business models (innovation) [2]. This involves a mix of both cooperative and competitive elements, and the use of networking concepts such as the virtual enterprise or the enterprise ecosystem, is becoming more common [3,4].

Envisaging to marshal more resources than they currently possess, enterprises can use extended and virtual enterprise concepts to enable collaborations both inside and outside their boundaries [5,6]. These collaborative organizational forms allow them to pursue goals such as co-designing, co-manufacturing, co-marketing, etc. [7]. In fact, companies should focus on their core competencies while improving relationships with customers, streamlining supply chains, and creating valued networks between buyers, vendors and suppliers to gather all the skills in the network instead of in the single enterprise. Also, with the *Future Internet*

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initiative and the novel technology associated to it, it is highly likely that new opportunities for creativity and innovation rise, and new forms of participation that span the world are enabled [8]. However, even though this demonstrates an enormous potential for economic improvement, enterprise information systems (EIS) designed for collaboration are still far from an industry-wide adoption, and issues as trust and interoperability are impairing a wider impact.

Hence, ensuring the original work on interoperability [9–13], followed by the advent of XML technology and motivated by the reasons presented before, enterprise and EIS interoperability is nowadays a strong focus of research [14–16]. Defined as the capacity that two or more enterprises, and their systems, have of cooperating over a period of time towards a common objective, Enterprise Interoperability (EI) is being addressed across several areas, such as, data, processes, objects, software, culture, knowledge, services, social networks, cloud, and even ecosystems interoperability [16,17]. EI complements the disciplines of enterprise architecture, and systems engineering, providing the tools necessary to incorporate new and legacy systems to both inter and intra-enterprise needs, while facilitating cooperation in large value added networks [18]. System methodologies for EI allow organizations to keep its technical and operational environment, while improving its methods of work and the effectiveness of the installed technology.

Nevertheless, traditional EI solutions are often inflexible and difficult to adapt to meet the requirements of dynamic and evolutive networks that characterise the novel networked environments. By and large interoperability is a broad and complex subject, and the development of generic solutions capable of mediating different types of EIS is difficult. Thus most development is either relying on international accepted standards for data exchange, e.g. STEP, EDI/EDIFACT, ebXML, UBL [19–22], or is implemented on a peer-to-peer basis. However, as EIS evolve and become more complex, the need for interoperable operation, automated data interchange and coordinated behaviour of large-scale infrastructures becomes highly critical [14]. Architectures, modelling frameworks and tools, as well as methodological approaches have been continuously evolving to cope with emerging collaborative organizations in industry and society, but in spite of research efforts up-to date, the proper scientific foundations for EI remain scarce [16], and fast and efficient re-adaptation of solutions is still a need.

1.1. The grand challenge: Sustainable interoperability

The previously explained gap has been preventing the generalization and full reuse of the methods and tools that have been developed so far, and is threatening EI as a long-term domain for research. Indeed, reaching an interoperable state has been target of research teams for some time with many results already available. In the future, the real grand challenge resides in enabling this reuse to streamline EIS evolution and adaptation while **sustaining the interoperability of networked systems**, or in short, **sustainable interoperability (SI)**, the interoperability that convenes the needs of the present without compromising the ability of future changes, meeting new system requirements, and performing adequate adaptation and suitable management of the transitory elements.

In the scope of this research, "sustainability" concerns the quality and efficiency of EIS interoperability, which delineates the capacity to endure and improve cooperation within a networked environment. In a business-to-business perspective, SI categorises enterprise information systems and networks that are considering interoperability along the adaptive organisation's lifecycle, enabling enterprises to evolve at their own pace without harnessing

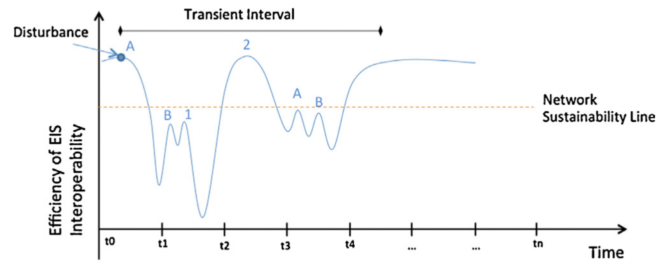

Fig. 1. Grand challenge: a scenario for sustainable interoperability of networked EIS.

the overall performance of the networks they are inserted in, nor causing downtime and service outages. This grand challenge crosses multiple industrial domains. Indeed, in a 2010 study by Gartner, information systems configuration management is identified as a key process for any IT endeavour [23]. The study foresees that in a near future, a large percentage of mission critical service outages would be caused by change/configuration/release, integration and hand-off issues.

As new technologies are adopted, new dynamics will be introduced opening doors to external service providers, increasing the relevance of interoperability. This complexity requires more rigour in the configuration management process. Not understanding the impact of a single change to a system or software on the broader service or application may have a negative effect (e.g. outage transient) in the network. As illustrated in the scenario of Fig. 1, even with the EI research available, a network disturbance can cause relatively large transient intervals where the measured interoperability can fall bellow a certain threshold, the network sustainability line, below which the network ceases to be viable (see the study in [24] for interoperability costs). Financial services, telecommunications, manufacturing and energy lead the list of industries with a high rate of revenue loss during IT downtime [25]. In the scenario, actions marked as A, B, 1, or 2, represent the EIS adaptation/evolution that causes network disturbance. The grand challenge proposed in this paper targets the development of research that helps to (semi) automatically detect, reduce and avoid transient periods, keeping the network sustainable.

2. Concerns on EIS engineering and interoperability: A technology outlook

Several international research initiatives have shown a considerable progress in EI over the last years [16]. Developments on enterprise architectures for modelling and engineering, model-driven development, or the endorsement of several standards for EI are just some examples that will be further detailed along this section. Such advancements provide the baseline technology for roadmapping future research targeting the SI grand challenge, and have also unveiled new challenges and trends concerning a sustainable interoperability among networked EIS. With the introduction of the Human and social activity in the interoperability investigations, dynamicity, uncertainty and complexity increase exponentially [26,27]. Indeed, following Holland's perspective, adaptation also builds complexity [28]. It needs to be managed at the risk of loosing efficiency.

A common way for changes to occur is by including or excluding particular EIS function, adding or eliminating service connections among enterprises, or even changes in data representation or structuring. However, such change at the EIS level embodies an immediate evolution and presents a disturbance to the enterprise network, more specifically to its direct business partners. They will most likely need to adapt in face of that evolution, thereby changing the environment for the original agent. Considering the