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Challenges and current developments for Sensing, Smart and Sustainable Enterprise Systems

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ABSTRACT

As technology advances and thus Information and Communication Technologies (ICT) evolve, a new enterprise model must be devised to face future digital enterprise needs. This paper discusses issues and emerging trends that must be addressed if a true sensing and smart enterprise is to be achieved to meet sustainability requirements. Methods are required to capture enterprise reality and to provide a seamless interoperable digital enterprise model. The paper summarises several challenges to be addressed by future research in enterprise modelling. Challenges are discussed from the Enterprise, Information, Computational, Engineering and Technological points of view, according to the ODP-RM (Open Distributed Processing—Reference Model). To some extent, progress on some challenges has already been made and solutions are expected to materialise in the near future. Other challenges have only recently been identified and potential solutions cannot yet be predicted. The paper offers a discussion of these challenges for the future enterprise along with the required enterprise model; it also introduces the concept of the Sensing, Smart and Sustainable (S^3) Enterprise System. The position paper expresses opinions derived from the existing general research priorities and directions identified by the International Federation for Automatic Control–Technical Committee on Enterprise Integration and Networking (IFAC–TC 5.3).

1. Introduction

Increased global competition is pushing companies to become more sustainable in the economic, environmental and social senses. To really become sustainable, enterprises must build true *smart* systems (including human and technological systems) to react rapidly and flexibly to the changing environment. Mobile devices, social networks or real-time systems produce a great deal of data and information. *Smart* decisions are required that take a large amount of information into account. *Sensing* systems are required to be able to handle, organise and analyse all data/information sources in order to feed the smart systems part. Next generation information systems need to support the S^3-Enterprise (i.e. Sensing, Smart and Sustainable Enterprise).

Traditional firms are lacking the models, competencies, processes and technologies to meet today's challenges driven by a hyper connected world, a flat world [27]. Existing enterprises will not survive in the future if they do not improve their digital competencies. Digital competencies include not only being able to work with software services and applications, but make use of digital representations (including enterprise models) to support and improve business value. Successful companies must transform themselves into sustainable and digital enterprises. This transformation into a digital enterprise requires positive disruptions in the business models, value chains, processes and operating models, key performance indicators as well as the strategic use of Information and Communication Technologies (ICT).

There is a need to leverage the use of accelerating technologies that are converging, such as networks, mobility, big data analytics, cloud computing, security, social computing, cyber physical

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systems and sensors. These increasingly growing technologies will radically impact business processes and business strategies. In the next few years everything will be digitised: digital society, digital customers, digital design, digital manufacturing, digital logistics, digital healthcare, digital energy and digital services (including government). A digital enterprise requires sensing its environment and then acting upon the perceived information in order to make faster, better and smarter decisions to become competitive and sustainable. We call this vision the S^3-Enterprise (Sensing, Smart and Sustainable Enterprise).

The concept of the *sensorconomy*, depicts enterprises as connected to different kinds of smart sensors and mobile devices in their networks to have real-time data, providing applications with information and knowledge from diverse contexts (for example, social networks, factory information, consumer behaviour, mobilisation of resources and supply chains) to make right decisions for industry operations. The sensing enterprise combines the concepts of sensors with mobile technology and distributed intelligence to perform analysis and decision-making, both in the real and digital worlds. This concept is a cornerstone for new scenarios of the future Internet of Things based enterprise.

The use of intelligent services and agents in the cloud is increasingly becoming a critical factor for next generation ICT systems. The future enterprise system must have access to interconnected data that is dynamically scalable. Extremely adaptable computing and sensing environments as well as smart ecosystems are the basis for a new generation of sustainable (including green) enterprises. In a globally connected economy, individual people or firms cannot achieve environmental, social/ethical or economic sustainability of any object (physical or virtual) without achieving ubiquitous ability of the objects and their creators and users to exchange and understand shared information/knowledge. This will require collaboration and cooperation to perform intra-inter-processes, i.e. interoperation [22].

The vision proposed herein presents the future S^3-Enterprise (Sensing, Smart and Sustainable) concept based on the following principles for the next generation of systems in a digital economy [64]:

1. Collaboration from inside the organisation and outside of social networks (customer centric).
2. Transparency for open information access and cloud based processing to enable community response.
3. Sharing to embrace open innovations and collaboration processes.
4. Empowerment gained by a collective intelligence of humans and artificial agents.

These principles are in severe contrast with the current industrial-age model which is highly centralised and based on closed innovation, ad-hoc enterprise systems and knowledge ownership. However, as the industry environment is becoming more open and digital where the dominant communication model is social, community-based and collective in nature, enterprises need to be optimised in terms of business and technology to focus outside. They need to become more [28]:

1. Focused-customer centric (Towards Collaboration).
2. Adapted to increasing transaction volumes, regulation and the needs of integrating global markets resulting in the true interoperation of systems (Towards Transparency).
3. Operationally efficient using the best competence available (Towards Sharing), and
4. Agile at using knowledge from many sources to identify and manage risk (Towards Empowerment).

In this paper, we will discuss ICT architectures, models, modelling techniques, applications and systems required to satisfy the following concepts to face all the challenges of new conceptualisations, improving enterprise architectures and languages, and improving methods for model management and education. Each of these concepts is further described in the following sections with the goals of:

1. Contribute with new conceptualisations
   a. Creation of new paradigms and concepts to tackle the challenges and issues of the new digital enterprise.
   b. Addressing the challenges of designing, creating and operating; Sensing, Smart and Sustainable Enterprises (S^3-Enterprises).
   c. Re-thinking the concepts of complex adaptive enterprise systems to be the foundations of future S^3-Enterprises.
   d. Proposing new concepts to manage the complexity of sustainable, intelligent, resilient and agile enterprise systems.
2. Recommend improvements to enterprise architectures and languages
   a. Creation of reference models for the sensing and sustainable enterprise based on open and collaborative networked organisations.
   b. Use of a universal standard, user-oriented, interface in the form of a unified enterprise modelling language (for example, UEML [67]) based on pre-defined characteristics to be available on all commercial modelling tools.
   c. Use of enterprise modelling and simulation tools commercially available taking into account function, information, resource, organisation and financial aspects of an enterprise as well as including human aspects, exception handling and process coordination. Simulation tools need to be configurable, distributed and agent-based simulation tools.
   d. Use of integration platforms and integrating infrastructures (available as commercial building blocks) for plug-and-play solutions.
3. Propose methods for model management and education
   e. Design of model-driven architectures that include model-based components available as commercially available building blocks to provide for the design, implementation and reengineering of large-scale systems to support integration of a single enterprise as well as collaborative networked organisations.
   f. The development of tools and systems where enterprise models can be accurately verified and validated and even accredited for use in enterprise process execution.

The discussion of the vision for enterprise models for the future S^3-Enterprise (Sensing, Smart and Sustainable) is structured along the five viewpoints as defined by the ISO/IEC 10746 ODP-RM – Open Distributed Processing – Reference Model [35]. These five viewpoints are used for organisational purpose to guide the discussion:

(a) The enterprise viewpoint: A viewpoint of the enterprise as a system and its environment that focuses on the purpose, scope, strategies and policies.
(b) The information viewpoint: A viewpoint of the enterprise and its environment that focuses on the semantics of the information and information processing performed.
(c) The computational viewpoint: A viewpoint of the enterprise and its environment that enables distribution through functional decomposition of the system into objects, which interact at interfaces.
(d) The engineering viewpoint: A viewpoint of the enterprise and its environment that focuses on the mechanisms and functions