Computers in Industry 79 (2016) 14–33

Contents lists available at ScienceDirect

Computers in Industry

journal homepage: www.elsevier.com/locate/compind

Current trends on ICT technologies for enterprise information systems☆

Soumaya El Kadiri[a], Bernard Grabot[b], Klaus-Dieter Thoben[c], Karl Hribernik[d], Christos Emmanouilidis[e], Gregor von Cieminski[f], Dimitris Kiritsis[a,*]

[a] EPFL, STI IGM LICP, Lausanne, Switzerland
[b] ENIT, LGP, Tarbes cedex, France
[c] Faculty Production Engineering, University of Bremen, Bremen, Germany
[d] BIBA – Bremer Institut für Produktion und Logistik GmbH, Bremen, Germany
[e] ATHENA Research and Innovation Centre, Athens, Greece,
[f] ZF Friedrichshafen AG, Friedrichshafen, Germany,

ARTICLE INFO

Article history:
Received 16 June 2015
Accepted 25 June 2015
Available online 20 August 2015

Keywords:
Enterprise information system
Manufacturing
ICT
Data value chain
Context awareness
Usability
Human learning

ABSTRACT

As business conditions change rapidly, the need for integrating business and technical systems calls for novel ICT frameworks and solutions to remain concurrent in highly competitive markets. A number of problems and issues arise in this regard. In this paper, four big challenges of enterprise information systems (EIS) are defined and discussed: (1) data value chain management; (2) context awareness; (3) usability, interaction and visualization; and (4) human learning and continuous education. Major contributions and research orientations of ICT technologies are elaborated based on selected key issues and lessons learned. First, the semantic mediator is proposed as a key enabler for dealing with semantic interoperability. Second, the context-aware infrastructures are proposed as a main solution for making efficient use of EIS to offer a high level of customization of delivered services and data. Third, the product avatar is proposed as a contribution to an evolutionary social, collaborative and product-centric and interaction metaphor with EIS. Fourth, human learning solutions are considered to develop individual competences in order to cope with new technological advances. The paper ends with a discussion on the impact of the proposed solutions on the economic and social landscape and proposes a set of recommendations as a perspective towards next generation of information systems.

1. Introduction

1.1. ICT for manufacturing

Given the context of manufacturing companies, today's consumer demands products of the highest quality accompanied by information and services which together constitute a holistic product experience. There is also a noticeable trend towards the consumer placing more value on the sustainability, pedigree and authenticity of products, making transparency along the stations of individual products' lifecycles a growing concern for industry. Companies are increasing the number of new product introductions in the market leading to decrease the time-to-market and consequently to shorten the life cycle of the product itself. Moreover, sectors of manufacturing which have previously focused solely on the improvement of their products' quality to remain competitive in the marketplace are turning towards emphasizing the after-sales market of their products to remain competitive. Especially the manufacturers of complex and high-value products are investigating new concepts of servitization and through-life engineering services based on the actual usage information of individual products by their customers. Services offered on that basis include traditional activities such as maintenance, upgrades, storage and refurbishing but also include ones provided in the virtual world integrated with social network services [74].

In order to meet these challenges, manufacturers need to take concepts such as item-level and closed-loop Product Lifecycle Management (PLM) [86] into consideration. This relies on the holistic availability of product-related data to all stakeholders throughout the entire lifecycle with the closing of information

☆ This is a contribution of the IFIP WG5.7.

* Corresponding author.
E-mail addresses: soumaya.elkadiri@epfl.ch (S. El Kadiri), bernard.grabot@enit.fr (B. Grabot), tho@biba.uni-bremen.de (K.-D. Thoben), hri@biba.uni-bremen.de (K. Hribernik), chrisem@ceti.gr (C. Emmanouilidis), gregor.cieminski@zf.com (G. von Cieminski), dimitris.kiritsis@epfl.ch (D. Kiritsis).

http://dx.doi.org/10.1016/j.compind.2015.06.008
0166-3615/

loops between the individual phases of the product lifecycle and between different IT layers, from data acquisition, through middleware and knowledge transformation to the business application layer. In order to consistently deliver the product experience demanded by the consumer, relevant information generated throughout the product lifecycle needs to be captured, managed and processed, for which different technological solutions have been proposed [52,68,86]. All of these have in common the augmentation of physical products with "intelligence" to facilitate data generation, processing and networking with other products, users and stakeholders throughout the lifecycle. That intelligence is implemented by different means, such as RFID, PEIDs (Product Embedded Information Devices), embedded systems, smart sensor systems, Single Board Computers (SBC), amongst others.

Increasingly, personal mobile devices (smartphones etc.) are capable of interacting with products and also generating and communicating valuable item-level product data in the context of the individual user's product usage. These devices and the services running on them via apps are thus not only becoming increasingly valuable data sources, but also providers of context information. Most product-relevant data collected via personal mobile devices can and often already is directly connected to a number of Web 2.0 social network services. In Europe, 42% of citizens use online social network services at least once a week [46]. In a recent study of German social network services users and their time spent online, social networks were far ahead with Facebook leading with 56% of internet users being active there [10]. In other countries, like the USA the ratio is even more extreme [140,142,169]. Social network services are not only an accepted part of the daily life of most European citizens, but will also play an increasing role when it comes to future data generation (users) and integration (service providers). Access to the large amounts of product-relevant data continuously generated by users of social network services will only become more important over the coming years. It is crucial to understand the specific terms and conditions of the targeted social network service before starting to implement a solution of both, data capturing and integration.

Besides the emerging, dynamic and item-level data sources relevant to a product's lifecycle, as described in the previous paragraphs, already existing conventional enterprise systems, databases and other data sources will retain their importance in the future. The landscape of relevant IT connected to the lifecycle of an individual product is generally distributed, heterogeneous, and, depending on the nature of the product itself, can be very complex. It generally involves many different enterprise systems distributed across multiple stakeholders, many of which either operate proprietary or legacy systems or can be small enterprises with no notable ICT infrastructure. Furthermore, stakeholders may unpredictably participate to the value chain, making the flexible addition or removal of data sources necessary where the data generated by these providers can be valuable to other stakeholders (e.g. in product design and test processes).

On the other hand, larger corporations will still demand "standardized" software and ICT packages that can efficiently be implemented in multiple sites and countries. The basic functionalities of these EIS need to be the same. Ideally, however, their context awareness is developed to the degree that the same software can be used on different sets of production machinery, for the production of different products and components and be integrated into the practices of different workplace cultures in different countries. These scenarios in combination make the importance of realizing interoperable and scalable EIS even more evident.

From this perspective, several roadmaps and surveys have been produced by various entities between 2004 and 2010, aiming at giving a prospective view on developments over the next 10–20 years. We take a look back at these predictions, to enlist what is already a reality and investigate how what has been realized impacts on or confirms what is still to be done.

1.2. Research roadmaps for the present and for the near future

For exploring the future trends of production systems, we have mainly considered the following roadmaps produced within 2000–2010:

- The main prospective roadmap of the European technology platform Manufuture: «Manufuture, a vision for 2020» [105], released in November 2004, and completed by a «Strategic Research Agenda» in 2006 [106]. These visions are relatively old, but have had a tremendous impact on the following studies.
- "Preparing for our future: developing a common strategy for key enabling technologies in the EU," report of the European Commission [47].
- The roadmap of the IPROMS Network of Excellence [83], gathering more than 30 European partners from Research and Industry.
- The IMS (Intelligent Manufacturing Systems) roadmap "IMS 2020" [80], IMS being a well-known industry-led, international business innovation and research/development program established to develop the next generation of manufacturing and processing technologies.
- The roadmap of the European Commission "Factories of the Future" [48], including a "strategic sub-domain" on ICT-enabled intelligent manufacturing.

In addition we have also considered the survey [159], based on the following (and sometimes less well known) documents:

- For Europe, [55,56,107] (as well as [105], already mentioned).
- For USA, the roadmap "Integrated Manufacturing Technology Roadmapping" [81] and a report on Manufacturing in US by the Dept. of Commerce US Dept. of Commerce, 2004.
- For Japan, a Delphi study on the Technologies of the Future [122], as well as macro-economic studies from [174], PricewaterhouseCoopers [139] and the World Bank [164] on the emerging technologies in 2050.

Two main competitive contexts emerge from the analyzed scenarios and roadmaps:

- A worldwide competition based on the design and management of very efficient *global supply networks*, in a context of increased uncertainty and instability (also linked to the political situation in emerging countries and to climate changes),
- The parallel emergence of *local supply chains* (at the regional, national or continental levels) in order to answer to political, ethical, environmental or supply reliability constraints.

These two opposite tendencies should coexist according to the type of product (raw materials and mass production in the first case; high-tech customized products and products reaching their end of life in the second case).

Facing the increased competition from developing countries, *innovation* is universally considered as a key point for sustainable competitiveness. Even if the conditions for innovation can hardly be formalized, its link with *research*,*knowledge management*, *education* and *free exchanges* is often underlined.

The industrial fabric being mainly composed of SMEs (Small and Medium Enterprises) all around the world, being able to *disseminate new technologies within small companies*, and being