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By

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Abstract: The proposed paper discusses the current trends on ICT technologies for Enterprise Information Systems. The paper starts by defining four big challenges of the next generation of information systems: (1) Data Value Chain Management; (2) Context Awareness; (3) Interaction and Visualization; and (4) Human Learning. The major contributions towards the next generation of information systems are elaborated based on the work and experience of the authors and their teams. This includes: (1) Ontology based solutions for semantic interoperability; (2) Context aware infrastructures; (3) Product Avatar based interactions; and (4) Human learning. Finally the current state of research is discussed highlighting the impact of these solutions on the economic and social landscape.

1. Introduction

In the manufacturing domain as well as in the service area, the research on ICT for Enterprise Information Systems (IES) is intrinsically linked to the future of production systems. 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. It is therefore interesting to have a look back on these predictions, to list what is already a reality and to investigate how what has been realized impacts or confirms what is still to be done.

1.1. 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 the very fruitful last decade 2000-2010:

- The main prospective roadmap of the European technology platform Manufuture: « Manufuture, a vision for 2020 » (Manufuture 2004), released in November 2004, and completed by a « Strategic research Agenda » in 2006 (Manufuture 2006). 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 (European Commission 2009).
- The roadmap of the IPROMS Network of Excellence (IPROMS 2009), gathering more than 30 European partners from Research and Industry.
- The IMS (Intelligent Manufacturing Systems) roadmap "IMS 2020" (IMS 2010), 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 "Factory of the Future" (European Commission 2010), including a "strategic sub-domain" on ICT-enabled intelligent manufacturing.

In addition we have also considered the survey (Van der Zee and Brandes 2007), based on the following (and sometimes less well known) documents:

- For Europe, (FutMan 2003), (ManVis 2005) (so that (Manufuture 2004), already mentioned).
- For the USA, the roadmap "Integrated Manufacturing Technology Roadmapping" (IMTI, 2000) 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 (NISTEP 2005) so that macro-economic studies from Goldman and Sachs (2003), PricewaterhouseCoopers (PricewaterhouseCoopers 2006) and the World Bank (WorldBank 2007) 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 (see the "Open Innovation" principle).

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 able to integrate them in global but efficient networks is considered as a major challenge.
The necessity to have a holistic approach on the *life cycle* of the products and organizations, taking into account the three dimensions of *sustainable development* (economical, societal, environmental) is also a

common point of most of the studies. The *societal dimensions* of manufacturing (ageing of workers and customers, job insecurity, teleworking...) so that *environmental* considerations (eco-design, economy of resources) may re-orientate classical themes on original topics.
The perception of an increased *customization* of the products and services as a competitive advantage is universally shared. This induces new requirements for information and knowledge management for the development and production of more complex products. The product will be more *active*, during its manufacturing phase but also all along its lifecycle, thanks to *ambient intelligence* and *connected devices*, using technologies such as RFID. This opens new perspectives, under the condition of being able to federate very different communication protocols. In order to make full use of ambient intelligence in a context of product customization and environmental and societal constraints a deep re-design of production systems is required, including:

- more *intelligent machines* thanks to intelligent sensors and actuators, connected under the *multi-agent* or *holonic* paradigm, easier to operate and maintain, easier to reconfigure and in a better interaction with the operators through *augmented interfaces*.
- more *flexible* workshops, that can be re-organized in an opportunistic way,
- organizations able to create at the same time *stable partnerships* on some high tech products, and *ephemeral* but efficient collaborations on short life products, exchanging knowledge (and not only information), using *interoperable* processes and information systems, benefiting intensively from external services accessible in SaaS (Software as a Service) mode, but also from distant human competences available as services.

The resulting increased complexity of the products and organizations of the future, resulting from their required flexibility and resilience, requires new approaches for modeling "*systems of systems*", evaluate their complexity and assess the new risks resulting from their complexity. The principles of the *digital factory*, allowing multi-scale simulation, should allow predicting the performance of both products and production systems.

The coexistence of different actors (individuals and organizations) on the other hand in all the phases of the product and supply chain lifecycles creates a critical need in methods and tools for *collaborative work* and *distributed decision making*. A better interaction between partners within industrial processes should be made possible by the emergence of *communities* (of partners, customers, workers...), for instance using Web 2.0 tools, by a better use of *collective intelligence*.

In relation with these topics, the explosion of use of ICT should allow to better perform classical tasks, especially in a new distributed context, but should also allow to completely re-think the interactions between actors, between the actors and the products and between the actors and the information systems of their organizations.

1.2. Implementation of these roadmaps as seen by large companies and consultancy firms

The recent McKinsey report on IT-enabled business trends for the next decade (Chui et al., 2013) perfectly illustrates how the roadmaps analyzed in the previous section have influenced the perceived future role of ICT in organizations. The report suggests ten trends in which ICT will allow companies to reach a new competitiveness:

1. The "social matrix", meaning that socially enabled applications will become ubiquitous, allowing liking, commenting, and information sharing across a large array of activities, both at the personal and professional levels (see the emergence of communities in the manufacturing roadmaps).

2. The "Internet of All Things", seen as an extension of the previous "Internet of things", taking into account the unexpected proliferation of connected devices. For the authors, before challenging the imagination of engineers through new applications, this context creates a tremendous need for interoperability, at the technical but also semantic level.

3. "Big data, advanced analytics": also noticed in other whitepapers like (Internap, 2014), this trend can be considered as an "ICT oriented" interpretation of the knowledge based factory denoted by manufacturing roadmaps. Indeed, the real challenge of "advanced analytics" in the context of "big data" is

not to process more information, but to create value from information, i.e. to extract and structure re-usable knowledge from data. The link between big data and the learning enterprise is for instance emphasized in the whitepaper (Ziff, 2015) while, in a distributed context underlined by the "manufacturing oriented" roadmaps, the link between big data and interoperability is developed in (McKinsey 2011).

4. "Realizing anything as a service": IT clearly evolves from products (pieces of software that the users should install in their companies) to services, eventually opportunistically accessed. The recent arrival of ERP (Enterprise Resource Planning) products available as services like SAP "Business By Design" is a clear illustration of this trend, but sets again the problems of both semantic and technical interoperability.

5. "Automation of knowledge work": IT is supposed here to allow the automation of knowledge-based activities, like automation technologies have in the past allowed to automate physical activities. In a more modest way, we can bring this trend close to the "learning enterprise", in synergy with point 3.

6. "Integrated digital/physical experiences": as denoted by the manufacturing roadmaps, the "digital factory" should allow unseen possibilities in simulation. The McKinsey report points out that the interaction between the digital world and the human user will require new "natural" interfaces based on visualization (augmented reality for instance) or on gesture/voice interfaces.

7. "Me + free + ease": through this cryptic theme, the McKinsey report refers to the necessity of highly personalized customer service, characterized by extreme ease of use and instantaneous results, requiring to take benefit of point 6.

8. "The evolution of commerce": this more usual trend refers to the B2C generalization, setting again challenges in advanced analytics, interoperability and emergence of communities.

9. "The next three billion digital citizens": this is the number of newcomers (mainly from developing countries) expected in the Internet world in the next decade, setting the problem of the intrusion of the related techniques and resulting behaviors in societies with quite strong and distant traditional cultures.

10. "Transformation of government, health care, and education": Internet and IT are changing the daily life of persons and enterprises quite quickly. For McKinsey, the diffusion of these changes in the areas of responsibilities of the governments is much slower.

1.3. The four "grand challenges"

As seen in the previous sections, research in the field of ICT, which can be easily linked to the requirements of the "factory of the future", involves a number of problems and issues. On the more specific domain of Enterprise Information systems (EIS), we have chosen here to structure them in Four Grand Challenges that need to be tackled and are re-visited in the following. They are summarized in Table 1.

Grand challenges	Related questions
(a) Data Value Chain Management	How to allow data/information analysis, mining, integration, sharing, security through interoperability?
(b) Context Awareness	How to offer scalability and integration capabilities between business processes within EIS?
(c) Usability, Interaction and Visualization	How to deliver new and intuitive ways for interacting with EIS?
(d) Human Learning and Continuous Education	How to support the development of professional competences triggered by new scientific and technological advances?

Table 1: Four grand challenges in next generation enterprise information systems

(a) Data Value Chain Management

The immense amount of data relevant to an organization, from distributed, heterogeneous data sources, will need to be made accessible in an appropriate way (Chui et al., 2013). As seen in previous sections, novel approaches to flexible, virtual and semantic interoperability need to be developed to tackle this problem. Once the data is made accessible, it needs to be processed and analyzed to make use of it in value-adding processes and services. The high volume, velocity, variety and veracity (4 Vs of Big Data) require novel approaches to data analysis and mining. Foremost business customers might not understand the potential benefit of sharing their data with others, or feel the risks associated with sharing data outweigh the potential advantages. A significant challenge is thus to develop incentive systems which make clear the benefits of sharing. As already seen, many products can and do generate data about their usage which can be shared with stakeholders. However, in many cases, owners and users choose not to do so. Business customers are often concerned about exposing operational knowledge which could be used to their disadvantage. Furthermore, open data and social media are increasingly being perceived as valuable sources of product usage information in the design and co-creation of products **(Piller and Tseng 2009)** and the provision of product service systems. These data sources can be used by producers to gather more detailed information about the actual use of a product by individual users, and fed back into different lifecycle phases to inform decisions throughout the lifecycles of the current or future product iterations. A significant challenge is consequently the development of secure infrastructures for sharing data with the different stakeholders (HP, 2014) whilst retaining privacy and data security. This challenge needs to be addressed taking social, technical and legal considerations and solutions into account **(Barnes 2006)**. Secure infrastructures for big and open data sharing will consequently need to involve moving data security controls closer to the data store and data itself, rather than placing them at the edge of the network **(Tankard 2012)** and increasingly mean including technical means to create policy-aware data transactions **(Weitzner 2007)**.

(b) Context Awareness

Interoperability between information sources, as depicted in the previous section, is a first condition for meeting the challenges of data value chain management. A second condition is to give access to the right information that supports a work task, a business decision or a cooperation process, which is often very difficult. In certain situations not all information provided by an information system is important and relevant to the end user. Modern enterprise information systems provide huge amounts of information and in those large volumes very often the user cannot find appropriate and important information at the right time. Moreover, in complex business environments sometimes users are not aware of the current situation which negatively influences the decision making process. It is therefore very important to provide the appropriate information to a user in appropriate situation. Moreover the user also has to understand why the information provided is important which means that he/she has to understand the current situation or to be aware of the context in which it happened in order to understand the real meaning of the information. Therefore it has become crucial for enterprise applications to be aware of the context they are being used in.

(c) Usability, Interaction and Visualization

Appropriate means of interaction with Next Generation EIS are a further major challenge. On the one hand, the ubiquitous availability and use of computing devices in society mean that expectations towards user interfaces are very different to the past (Chui et al., 2013). On the other hand, the vast amount of data and information to be visualized and manipulated by EIS in the future means that new and intuitive ways of presenting and interacting with that data will be required. Solving user interaction problems requires dealing with context awareness; as depicted in the second big challenge described in the previous section.

(d) Human Learning and Continuous Education

Human learning is the process of identifying and implementing professional competences triggered by new scientific and technological knowledge and implemented in an industrial context to address new professional needs. Engineers and workers will need new life-long learning schemes to assist them in keeping up with the pace of technological change which requires a continuous update of the learning content, learning processes and delivery schemes of manufacturing education. ICT research outcomes of educational institutions are typically presented to the scientific community and are not directly accessible to industry. Uni-directional learning flows, such as learning via training, is surely important but not sufficient to cover the full cycle of enterprise knowledge flows. An upgrade in the learning mechanisms is urgently needed, placing the human at the center of the knowledge flow management process and bridging conventional learning with experiential, social and data-driven learning. Such an upgrade could eventually lead to facilitating transitions between different types of knowledge and enable novel technology/knowledge transfer schemes to have a significant impact on the ICT related innovation performance.

The remainder of this paper is organized as follows. Section 2 provides the various contributions of the authors to the four grand challenges discussed above. Section 3 covers relevant literature review on the subjects related to these challenges and discusses the general state of research. Section 4 discusses the overall contributions highlighting the impact of these solutions on the economic and social landscape. Finally Section 5 concludes these works.

2. Contribution to Next Generation Enterprise Information Systems

This section discusses the various contributions of the authors to deal with the issues and challenges in the next generation of information systems. It is structured into four sub-sections referring to the four grand challenges described in the previous section.

2.1. Ontology based solutions for semantic interoperability

Interoperability is generally defined as the ability for two (or more) systems to exchange information and to use the information that has been exchanged (IEEE 1991). Interoperability concerns data, services process and business, at the organizational, technological and conceptual levels (D. Chen and Daclin 2007). It is therefore not only a matter of standards for data exchange, but also of the common understanding of the exchanged information. In recent years, the use of ontology as a common source of knowledge has raised a lot of interest in research and communities. Ontology is defined in (Gruber 1995) as "a formal, explicit specification of a shared conceptualization". Ontology can be used to describe a domain and to reason about the entities within that domain (Sowa 2000). This means that beside the knowledge gathered in the time of modeling the ontology, additional relations will be automatically built up in time. Modelling and implementing ontology has become an engineering discipline, Ontology Engineering, which refers to the set of activities that concern the ontology development process and the ontology lifecycle, the methods and methodologies for building ontologies, and the tool suites and languages that support them (Gruber 1993). These methodologies offer useful practical guidelines that are referred to by researchers in design and engineering domain such as: DILIGENT (“DILIGENT” 2010), On-To-Knowledge (York Sure, Steffen Staab, and Rudi Studer 2004), NeOn Methodology (Gómez-Pérez 2009), and Methontology (“METHONTOLOGY” 2012). Capturing domain knowledge in cross disciplinary contexts involving several actors with diverse viewpoints and activities requires additional analysis prior to building the ontology. User Story Mapping (USM) is a user-centric method for software functionality requirements applied in lean and agile product design (Jeff Patton 2014). In our work (Milicic et al. 2014) (we have defined a bottom-up approach that consists of gathering USMs from all involved actors and then merge them into one single USM by generalizing them only to such extend that the final model is simple enough. Common concepts and viewpoints are then derived and generalized through a process of merging defined roles, activities and usages as described in Figure 1. The proposed approach, which combined with appropriate tools and methods (such as questionnaires, standards specifications, knowledge based approaches, etc.), results in the specification of a common semantic model for sharing and reusing domain knowledge.

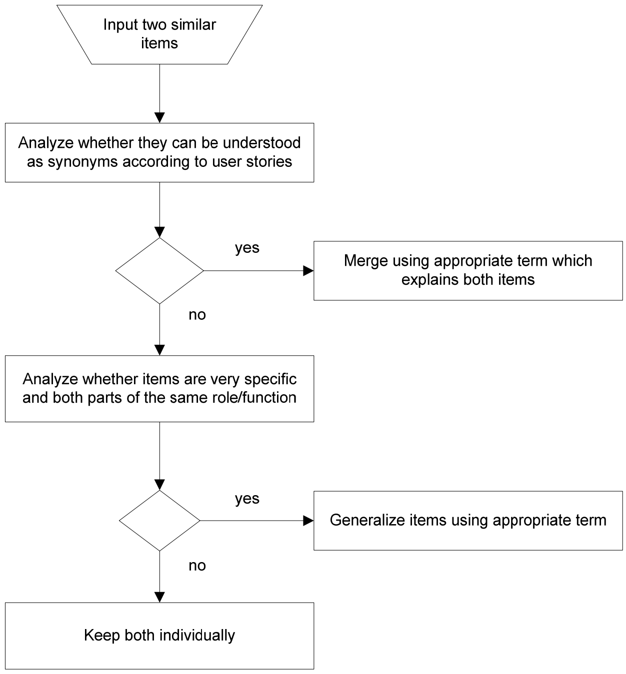

Figure 1: The proposed process for USMs merging *(Milicic et al. 2014)*

As stated earlier, interoperability requires a common understanding of data to support data acquisition, integration and aggregation in a distributed and dynamic stakeholder network. Data is generated in a distributed manner and is stored in heterogeneous and disparate data sources. Additional data streams dynamically generated from the social web and other big data sources are increasingly becoming relevant. Making all of that information available to the relevant stakeholders is a significant challenge. In addition, many of the conventional data sources can be of a proprietary nature due to the small and medium sized enterprises operating in these domains. That means that a data integration approach needs to be flexible and agnostic towards proprietary data sources. Furthermore, stakeholders can change often and unpredictably, making a fast and flexible approach to integrating different data sources necessary.

An appropriate approach to integrating heterogeneous enterprise data from decentralized data sources is semantic mediation. The concept of semantic mediation, on the one hand, eliminates the need for a central data repository or federated schema for all data, and on the other hand, introduces a layer of semantics on top of existing syntactic data structure descriptions to avoid semantic integration conflicts. This allows for the virtual integration of existing data sources on the basis of the *meaning* of the individual data elements. This integration approach has a number of advantages compared to conventional methods. A semantic mediator does not need a federated schema or single data model to operate – new data sources can be integrated or removed quickly and flexibly. Integration targets can be easily accessed by wrapper components, which are semantic transformation and description modules. Transformation rules can be configured by domain experts without coding experience, and semantic descriptions of data sources can be formalized e.g. as ontologies. A semantic mediator enables answering complex and cross-domain queries without any specific knowledge about the data-source itself, through a single interface and common query language. When queried, all ontologies plugged into the mediator by active wrappers are merged and the queries run over the composite ontology.

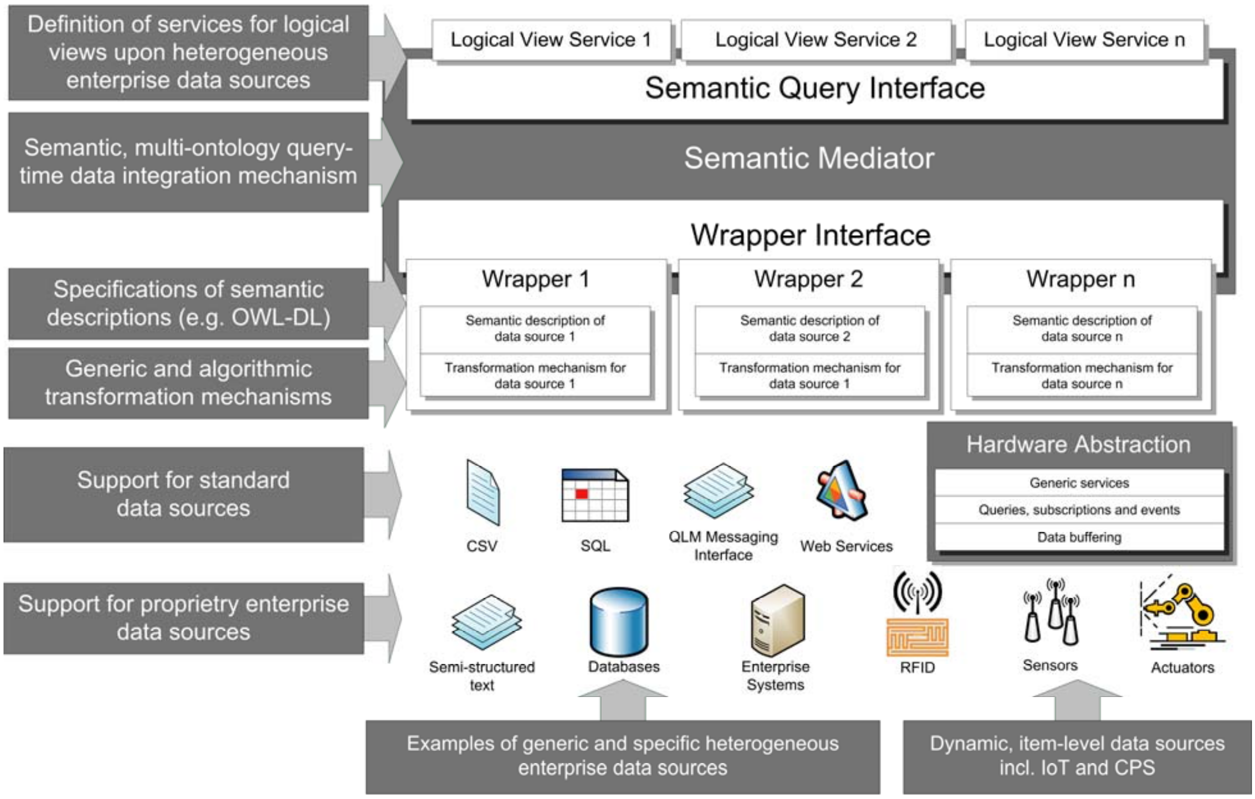

Figure 2: Architecture of a semantic mediator

By applying the principles of semantic mediation, a middleware layer for semantic, virtual interoperability and integration can be created. In the effort to exploit the integrated data as a window onto deeper knowledge exploitation and discovery a number of decision support systems have developed. They can be very diverse in functionality and efficiency; however these systems lack autonomy in the sense that the user has to know what information he or she is looking for. As a consequence, a number of relevant correlations and dependencies between different factors are left unnoticed, simply because they are not assumed. Data mining as a discipline gives a number of tools for resolving this issue. The problem of data mining techniques is that they are still performed mostly manually. Although deterministic steps of the data mining procedures can be supported by existing software tools the others remain an obstacle and they necessarily require human-expert involvement. In this light, we have developed a system for automated data analysis and mining by exploiting the advantages of having a semantic model of data, relaxed time constraints and by allowing sub-optimal accuracy (Milicic et al. 2015). A data mining procedure is followed through in detail. The overall system architecture is depicted in Figure 3 and described hereafter.

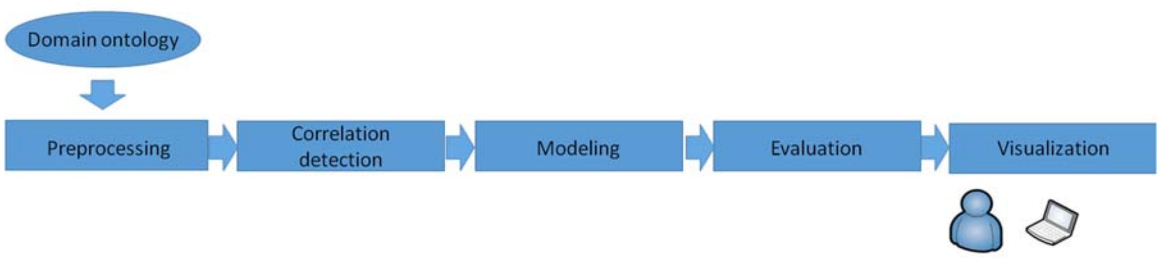

Figure 3: Overall system architecture *(Milicic et al. 2015)*

Data understanding is the process where ontology expert needs to understand the domain from which the data are collected. Data pre-processing is the most challenging to automate. Using the ontology as a base layer of a data mining system is crucial for automation of the pre-processing step. Correlation detection is conducted between only two attributes. Statistical tests are in three possible cases: (i) Continuous to continuous attributes; (ii) Continuous to categorical attributes; (iii) Categorical to categorical attribute. Modeling the data sets considers sequentially, one by one, variables from the data set declared as targets and then an attempt to model the system is made using the remaining data. The best algorithm is selected together with the best model for both classification and regression problems. Evaluation means that algorithm training and the number of models created have to be evaluated using the same criteria and only then can the solution be selected. Finally visualization consists of presenting the results of un-asked questions.

This system is automatic and self-initiated. It can be thought of as a background engine that can be left running and storing results.

2.2. Context-aware infrastructures

Beyond the clear integration and interoperability issues that such a scale of integration brings about, a significant challenge lies with the inherently different nature of the diverse business processes served by individual EIS components, requiring an operability at the business process level (D. Chen and Daclin 2007). A physical product instance is always unique but its digital counterpart has a different digital representation instance when handled by different production subsystems. Similarly, the same process is modeled and handled by different means if considered at the shop floor execution, the operations or the planning level. Modern EIS increasingly incorporate collaborative features, requiring seamless end-to-end data integration across the different manufacturing functions and networks chains. This constitutes a driver towards an emerging paradigm shift in the way information and data exchanges are designed to take place. The product avatar is an example of such paradigm in terms of interaction mechanism with EIS. The following section 2.3 gives more details about this concept. Whereas there are several driving factors for this change, two of them are recognized as the most decisive:

- Increasing ability and capacity for information interactivity of physical entities and actors, being human, equipment or devices, served by multi and web networking and exploiting mobility features.
- Need for exhibiting enhanced responsiveness and dramatic shortening of response time to events, production and work orders, product customization requests, supported by advanced manufacturing technologies, as well as enabling ICT technologies.

The increased interactivity and multi-networked nature of physical entities is fuelled by Internet of Things technologies (IoT) which empower physical product and asset entities to become intelligent (Brintrup et al. 2011; Främling et al. 2013; Kiritsis 2011). The physical IoT entities interactivity is supported by internet-working and web-based programming and is essentially supporting a more proactive engineering approach to be put in place (Demoly, Pels, and Gomes 2013). At the lower level of physical entities, IoT-enabled devices, primarily in the form of smart and wireless sensors, auto-identification and tracking devices and actuators are now highly integrated with the physical products and assets in the form of Cyber-Physical Systems (CPS). They are the prime contributors to the upgrade of conventional assets and products to their intelligent counterparts, that is the Cyber-Physical entities. From an information point of view, all data exchanges are thus confined to the CPS entities, rather than the original products (Conti et al. 2012). This enables their natural integration within the EIS environment, making the asset and product management process largely served by information management approaches. Thus, CPS-enabled IoT infrastructures, supported by web-based computing and multi-networking and mobility features are radically changing the EIS communication-level landscape.

While this transformation has been taking place, the breadth, depth and sheer volume of intra-enterprise and inter-enterprise information exchanges gives rise to new challenges. A key question is how to ensure that the right information, in the right format, is made available to the right actor at the right time. This alignment of information and services to the apparent need or context of a situation is at the heart of context-adaptive or situated computing. A context adaptive-solution should ideally handle the context processing lifecycle, which comprises the acquisition, modeling, processing and dissemination of context (Perera et al. 2014) as described in Figure 3.

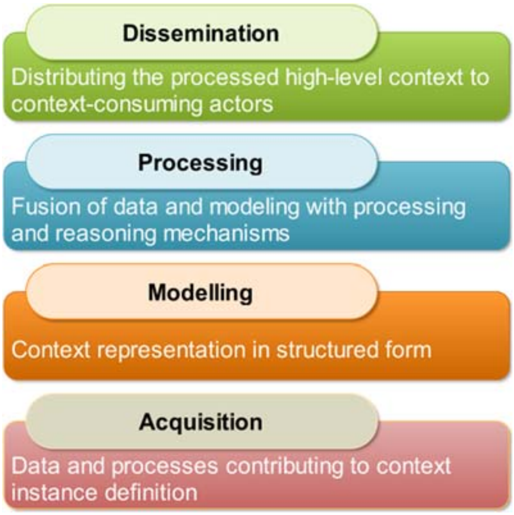

Figure 3: Context Processing Layers (adapted from (Perera et al. 2014))

In order to have context-aware enterprise infrastructures, it is necessary to establish a context acquisition infrastructure. Production and product related data generation at the physical level is generated and communicated by integrating machinery, assets, devices, sensors and in several cases human actors, through wired and wireless networking technologies and appropriate interfaces. All such processes fall into the context data acquisition phase. While an initial level of data processing is performed at this level, the modeling layer is responsible for the alignment of the low-level data with structured modeling taking place at the next layer, the modeling phase. Fusion of data and modeling requires semantic mediation as described in section 2.1 and forms part the context processing phase. Finally in the context dissemination phase, the inferred context is made available to be consumed by actors, essentially driving adaptation of data and services. Context can be broadly classified to fall under different categories, typically considering user, environment, system, service and social context (Emmanouilidis, Koutsiamanis, and Tasidou 2013) (Figure 4).

Such a generic model can be applicable in various application domains and use-cases. The detailed definition of context contributing factors per context categories is application-dependent. Having a generic model provides the distinct advantages of context information exchange as well as reusing of the model. On the other hand it significantly reduces the expressiveness of the model and requires more computing to interpret it. Therefore, this approach proposes the upper model (ontology) which specifies only the common and generic concepts of context and supports context information exchange. However, it is not possible to model different domains only with the upper model, which means that for each case, a domain specific model should be specified.

User Context	
Role	ID, manager, operator, supervisor ..
Work status	assigned task, on task, idle, out ...
Expertise	IT, networking, mechanical eng., ...
Positioning	user location, direction, ...
Identify	ID, preferences impacting on job ...
Sentiment status	standard, urgency, anciety, ...
Other	active tasks, active tags, ...

Business / Servive Context	
Type	assembly, design, maintenance, ...
Task	service task, sequence, ...
Request	issuer of service request, ...
Supply	consummer of service, ...
Conditions	time, priority, ...
Support	service support resources
Other	.....

Social Context	
Group	user belongs in groups(s), ...
Hirerarchy / parent	supervisor, ...
Hierarchy/ child	supervising group members, ...
Hierarchy/ peers	group peers, ...
Interaction	interaction mode, ...
Work status	team assigned tasks, projects, ...
Other	active tags, issues, ...

Environment Context	
Indors	from sensor readings, ...
Outdoors	weather data, ...
Conditions	crowding, congestion, occupancy ...
Location	environment location, ...
Hazard	no, low, medium, high, ...
Category	office, shop floor, warehouse, road...
Other	....

System Context	
Device	device specs / status
Network	network spects / status
Security	security specs / status
Power	power consumption specs / constraints
Type	sytem type (e.g. IT system, production system)
Status	on, off, operating mode
Other	...

Figure 4: Context Categories

This domain specific model should extend the generic upper model and describe the specific domain in more detail. Using the semantic mediator described in section 2.1 we are able to re-use already existing models as domain specific ontology by linking them with the upper ontology. For example, using semantic mediation, data from a semantically described sensor integrated into a product could be mapped onto an upper ontology describing more general product lifecycle concepts. This approach encompasses the interoperability benefits from the upper ontology and expressiveness from the domain specific ontology. The model expressiveness can be refined to serve specific application needs. For example, in asset and maintenance management the generic context model is further instantiated by a domain-specific model (Pistofidis and Emmanouilidis 2013) (Figure 5). The expressiveness of the model can become very detailed for critical information. In Asset Lifecycle Management a key concept is that of Asset Failure Mode. The elaboration of the Context of a Mode comprises information that defines in more detail the circumstances of a failure and thus drive future actions. The failure context can therefore be defined in more detail comprising different types of information (Figure 5): about the asset type and the specific asset of that type; recorded events linked to this specific failure mode, from a single asset or from several assets of the same type; maintenance or operating actions linked to it; and actors or agents (human and non-human), which are relevant to it. The contextualization of knowledge with such domain-specific information, can facilitate the provision of advanced asset management and maintenance services support.

Staff can become active in this information processing loop by providing their own observations. In the simplest case, following Web2.0-oriented approaches, this can be done via simple tagging mechanisms, such as confirming an event or reinforcing a diagnosis. Essentially, this is equivalent to extending the underlying information model with tagging metadata, enriching field knowledge. This is a simple way of engaging and exploiting the involved personnel expertise, as expressed in daily activities.

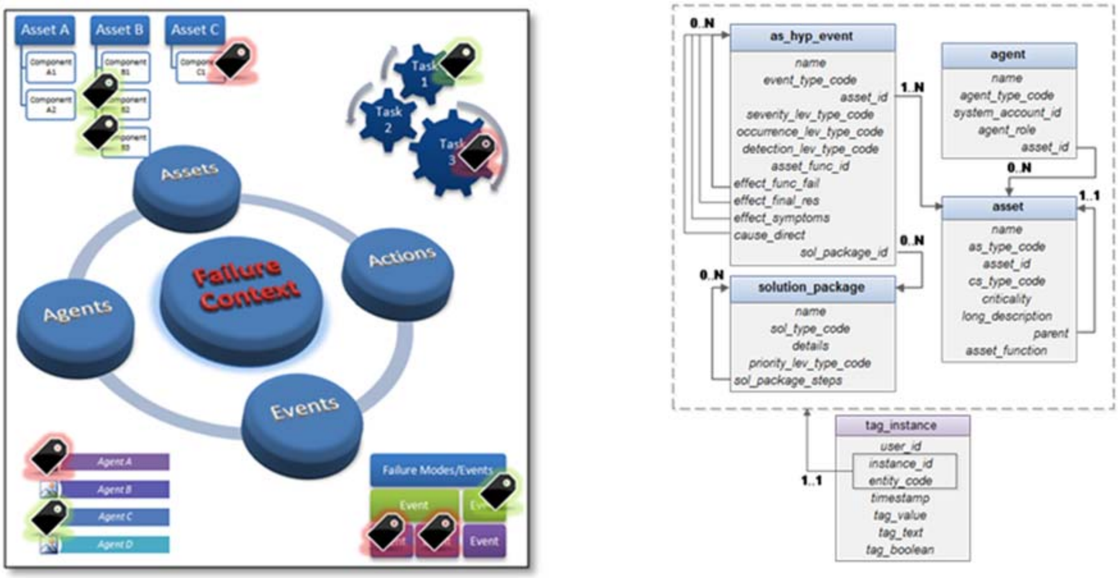

Figure 5: Failure Context in Asset Lifecycle Management (left) Failure Context (right) Metadata Extension ((Pistofidis et al. 2014))

Context modeling prepares the contextually-relevant information to be processed so as to be consumed by different actors. When considering human actors, the provided information and services should be tailored to their profile and role and thus user-specific context needs to be further elaborated.

This level of context modeling prepared the ground for tailoring the information to a specific user but other factors need to be taken into account too. The application also has to be aware of the current state of the business. This implies that the delivered information depends on the overall business situation, essentially an element that falls under the business/service context. While related information already exists in the modern enterprise applications, such as ERP, MES, today the data generation layer of an enterprise is much richer than in the past, hence there is an increasing need for EIS to handle a significantly larger volume of information, which is deemed to be contextually relevant.

One of the most important properties of context is that it its nature is dynamic. The volume of contextually relevant information becomes large and increases both in breadth, as more context parameters are considered, as well as in depth, as more detailed information and history data for specific context parameters accumulate. This is becoming the norm in modern enterprise environments and calls for advanced context processing methods, up to the level of context reasoning, so as to manage the dynamically evolving context and prepare it for dissemination to the relevant actors.

A simplified but typical workflow of context processing is seen in Figure 6. The first step is to capture and collect the information which is considered as contextually relevant and is modeled by means of an ontology. This context could be considered as low order context and it is usually information which is already available in the system or coming from physical sensors (e.g. location, physical measurements, etc). This step allows for further context information interpretation as well as exchange of context information between different applications. Since the low order context could come in large volumes and can change very quickly, sometimes it can be very difficult to interpret it and use it directly. Therefore an intermediate step is added in which the low order context is interpreted as user and business states. Basically in this step the context information is discretized and made more convenient (and less dynamic) for further usage. The low order context is transformed into higher order context which is more suitable for further rule-based interpretation. This transformation, or state assessment, is done using the predefined rules. Also, it is important to note that some user and business states could be directly imported from different external or internal sources (e.g. web agents). Finally, states are used in the last step to define the current situation and according to it, provide the appropriate information to the end user. Situation is considered to be a set of currently active business and/or user states. Again rules are used to interpret the situation and select appropriate information which should satisfy the end.

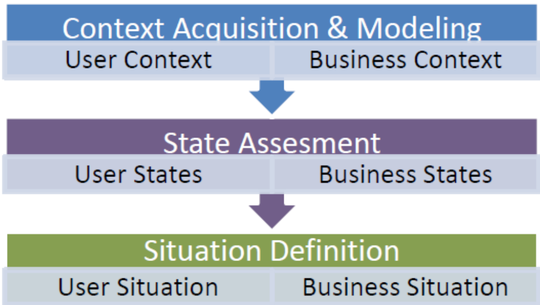

Figure 6: Steps for context interpretation *(Nadoveza and Kiritsis 2014)*

The core of the proposed concept is the upper context ontology which should be able to describe any situation, in which context, certain information provided by the information system is relevant. Due to the nature of enterprise applications and the information which they provide, the upper ontology has been separated in three parts (sub-models). As illustrated in Figure 7**Erreur ! Source du renvoi introuvable.** upper context ontology is divided into three interconnected sub-models: a) User Context, b) Business Context and c) Information Feature model (Nadoveza and Kiritsis 2014).

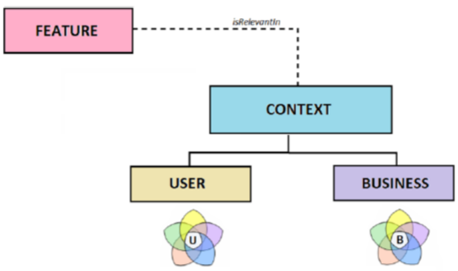

Figure 7: Conceptual Context model

Context can be structured and modeled in different ways, including object-oriented representations (Fernandez-de-Alba, Fuentes-Fernandez, and Pavon 2015), ontologies (Koukias, Nadoveza, and Kiritsis 2013; Tan, Goh, and Lee 2010) and graphical representations (Stack 2012) and its processing can be undertaken by adequate middleware at different levels (Knappmayer et al. 2013; Perera et al. 2014). Context acquisition, modeling, processing and dissemination is now becoming a key element in making efficient use of EIS to offer a high level of customization of delivered services and data (Främling et al. 2013; Knoke et al. 2013).

2.3. The Product Avatar as a contribution to an evolutionary social, collaborative and product-centric and interaction metaphor with EIS

We have underlined the necessity to improve the interaction between the actors of production system, based on extended digital representations of aggregations between physical and informational objects. A product avatar is a good example of this generic principle: it mainly represents information about the product and its current state (Corcelle et al. 2007), (Cassina, Cannata, and Taisch 2009). It puts forward the idea of the digital, information-based representations of individual physical products in virtual environments. These representations are able to interact with other avatars representing other persons or products. A core idea of the Product Avatar concept is the representation of all relevant product data, whether it be stored in enterprise systems or generated by embedded devices, RFID or sensors, in ways suitable to each stakeholder. It can be understood as a digital counterpart which represents the attributes and services of product towards the different stakeholders in its lifecycle. That means, the Product Avatar will appear differently depending on the requirements of the respective stakeholder, and takes into account "multiple identities" of products from the perspective of the different stakeholders. That is, the presentation of a Product Avatar of a machine tool along with the information shown and interaction capabilities given are significantly different for stakeholders such as the manufacturer, customer, or service technician. This corresponds with research on how presentation can improve communication (Garau et al. 2003). The stakeholders interacting with the EIS are heterogeneous and have very different requirements towards the selection, presentation and use of data. They include product designers, manufacturers, sellers, maintenance staff, service providers, recycling operators and, of course, the actual owner of the product in question. Each stakeholder has different preferences and a product avatar is therefore a distributed approach to the interaction with and management of item-level product related information (K. A. Hribernik et al. 2006). Stakeholders such as owners, designers and service personnel may interact with the product avatar e.g. via dedicated desktop applications, web pages, or mobile "apps" tailored to their specific information, service and interaction needs (K. Hribernik, Wuest, and Thoben 2013). As mentioned before, the product avatar can interact with other avatars, be it avatars of product avatars. This can be facilitated, for example, by means of web services, software agents, common messaging interfaces such as IoT O-MI, or a combination of these (Wuest, Hribernik, and Thoben 2012). As product avatars present multiple views upon product data tailored for various stakeholders, ontology-based semantic interoperability as described in Section 2.1 can be leveraged to facilitate this interaction by more easily interfacing the different knowledge domains involved in the product lifecycle.

Research is being conducted by the authors towards the integration of Product Avatars with the social web as an investigation of different modes of interaction of different stakeholders with Next Generation EIS. Social Network Services such as Facebook and Twitter boast user bases which are already familiar with their design, functionality and interaction paradigms. Furthermore, the service is an accepted communication tool, which is used anytime, anywhere via a plethora of different devices both stationary and mobile. The Product Avatar concept is, in essence, inherent to these tools – users of Social Network Services interact with "avatars" of other users as a matter of course. Thus, it seems a small step for product owners who already actively participate in Social Network Services to also interact with their products and the services which augment it through the same channel. Designing a Product Avatar which uses a popular Social Network Service as its interaction channel and conforms to that network's interaction paradigm promises to help users interact intuitively with it and thus enhance user acceptance, immediately leverage the user base for potential new value-added services augmenting the product, and leverage the in-built multimodality and mobility for anytime, anywhere interaction with the Product Avatar. A product avatar may be integrated into an existing social network (for example, as an app on a Facebook page), where it can both make use of existing social media information and push information into the social media service (e.g. pushing status notifications about a product's use as Twitter or

Facebook messages). It may also be implemented as a stand-alone application (e.g. a smartphone app) or as part of an enterprise application suite.

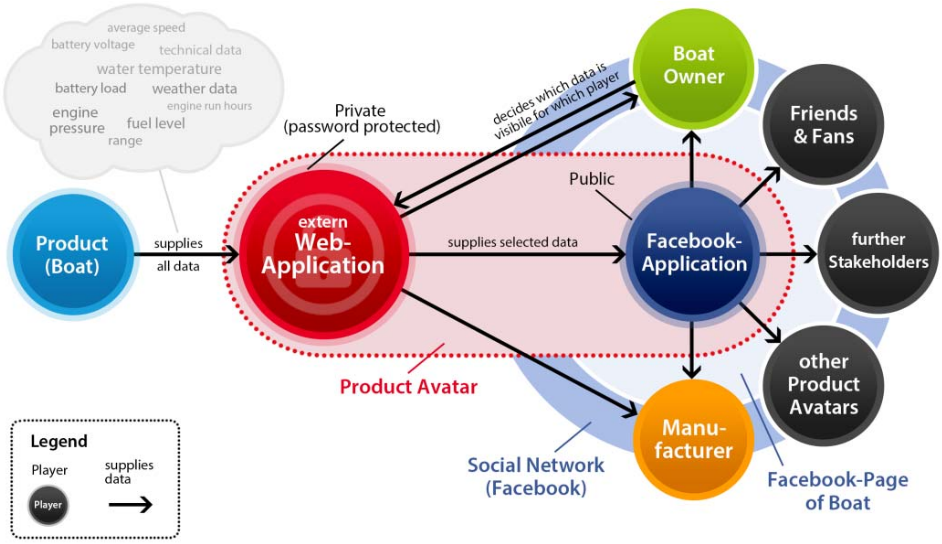

Figure 8: Concept of the Product Avatar for a Leisure Boat (K. Hribernik, Wuest, and Thoben 2013)

2.4. Human learning solutions for continuous education

As seen in the introduction, switching from the information-based enterprise to the knowledge-based enterprise is a major challenge for today's companies. Learning has long been associated in the past with personnel education and training. However enterprise knowledge management is much more than that. It can be defined as the process of creating value from an organizations' intangible assets; it combines notions from several different domains, such as organizational behavior, human resource management, artificial intelligence and information technology (Liebowitz 2001). Uni-directional learning flows, such as learning via training, is surely important but not sufficient to cover the full cycle of enterprise knowledge flows. Knowledge itself is substantiated only in tandem with the human actors that carry it. Considering the extended information and knowledge-oriented environment that enterprise staff operate in, traditional learning approaches fail to take advantage from opportunities to substantiate, validate and even refine enterprise knowledge on the basis of daily evidence and experience. An upgrade in the learning mechanisms is urgently needed, placing the human at the center of the knowledge flow management process and bridging conventional learning with experiential, social and data-driven learning. Such an upgrade could eventually lead to facilitating transitions between different types of knowledge, being tacit or explicit.

Nevertheless, it can be difficult for experts to describe from scratch a non-contextualized generic knowledge (Kolb 2000). Therefore, techniques allowing to reuse knowledge contained in past experiences have recently been the object of an increasing attention. Enterprise Information systems have a major role to play in that context, since they include huge data warehouses used to collect data for many years. Within this context, it is difficult for industry to comprehend and to adapt to the technological advances in a direct way. Indeed, it is often easier for operational actors to validate the expertise extracted from past experiences than to directly structure knowledge. Such human-contributed and validated knowledge is essentially placed as a layer of metadata upon the actual enterprise data. Minimal human-contributed knowledge can now be contributed in ways already popular in social computing, such as tagging. For example, operators and maintenance staff may tag recorded events to validate an observation or diagnosis, a process that contributes a layer of metadata on top of the actual data, in a way similar to tagging mechanisms in social networks (Pistofidis et al., 2014).

European enterprises consider the lack of qualified personnel and the lack of information on technology as being the major knowledge-related factors hampering innovation today. Thus, the implementation of Knowledge Engineering, Data Mining and Big Data techniques, and the blending of multiple knowledge flows to include the human at the center of the knowledge management loop, combined with modern concepts of training, novel Industrial Learning and technology/knowledge transfer schemes can have a significant impact on the ICT-driven innovation performance of European manufacturing.

Industrial learning and training involves constraints and requirements not present in formal higher education courses, as it is often directed towards learners who have already entered their working life. This introduces different time, space and cost constraints for the learning process. Furthermore, the starting point and expected outcomes of the learning process can vary significantly, as typically observed in multi-disciplinary fields, such as in modern enterprise and manufacturing activities. Therefore, such training processes rarely fit within formal education but can critically benefit from the exploitation of opportunities offered by informal learning processes.

Enterprise learning is increasingly benefitting from technological solutions supporting informal, everyday and on-the-job training (OJT) in order to develop both individual staff competences as well to upgrade the overall human resources competence affordances level of the organization. OJT is highly effective as it contextualizes in practice the learning experience, facilitating the cognitive process of learning by aligning the learners’ mindset with the context of the training task under consideration. Nonetheless, the involved costs in OJT can be significantly high. Augmented reality supported training has been employed as a more-cost efficient alternative, although it is typically more applicable to specialized training, such as maintenance training, (Besbes et al. 2012; Haritos and Macchiarella 2005; Jee et al. 2011; Nakajima and Itho 2003; Platonov et al. 2006; Savioja et al. 2007; Schwald and Laval 2003; Toro et al. 2007; Yamabe and Nakajima 2012) and involves relatively high costs if it were to be made more broadly applicable.

Earlier technology-enhanced learning (TEL) support has been delivered primarily in the form of e-learning and web-based learning (Rolstadas 2013). More recently, the TEL tools portfolio is rapidly expanding to make more efficient joint use of learning concepts, methodologies and technological enablers to achieve more direct, effective and lasting learning impact. Employing virtual learning environments (VLE), trainees are empowered to follow their own training pace, learning topics and assessment tests that fit their needs (Emmanouilidis 2009; Papathanasiou et al. 2013). Training can become ubiquitous through mobile learning (Hung and Zhang 2011; Mierlus-Mazilu 2010; Papathanasiou et al. 2014). The spread of use of social networking tools has also brought attention to the contribution of social and groupware learning (Casagranda et al. 2011; Westerhout et al. 2011).

Considering the outcome of learning processes in manufacturing industry with respect to trainees job performance does not only depend on the cognitive process of learning but also on non-cognitive aspects, such as motivation, culture, attitude, gender and anxiety, industrial training efficiency can benefit from approaches that seek to improve the overall learning and performance framework (Conolly, Cubbins, and Murphy 2010). Significant contributors in the last few years towards such an end have been approaches such as game-based learning (Dominguez et al. 2013), including serious games (Duin et al. 2012; Hauge, Pourabdollahian, and Riedel 2013; Kerga et al. 2013; Messadia et al. 2013; Oliveira et al. 2013; Pernelle et al. 2013), as well as personalized and context-adaptive learning (Papathanasiou et al. 2012), including mobile learning (Papathanasiou et al. 2014). The concept of context is well-applicable to learning personalization, and can be enriched by aspects of social and collaboration-based learning, offered through VLEs (Limpens and Gillet 2012). The combination of context-awareness within the IoT framework in ambient environments enables the delivery of context-adaptive learning (Garcia et al. 2011; Papathanasiou et al. 2014; Papathanasiou et al. 2012). Learning personalization has explored different paths but in general it involves some type of mechanism for tracking the learning process evolution. In some cases it further involves interaction with other actors participating in the learning process, such as tutors or other peer learners. A learner profile can be built, taking into account initial competences, learning requirements, as well as learning activity processes and outcomes. The profiling can be performed on the basis of a competency-based learner model ontology (Siadaty et al. 2011), updated through agents monitoring the learners interaction and learning path, using a typical Learning Management System, such as Moodle (Bremgartner and de Magalhaes Netto 2012).

The introduction of personalization and collaboration concepts, such as peer learning support in industrial learning does not only expand the toolset available to delivering training, but evidence has shown that contributes also to the adoption prospects of the introduced TEL solutions in the workplace (Cheng et al. 2011). Besides contributing to learning support, TEL tools also assist in streamlining and standardizing the assessment process, through self-assessment mechanism or blended e-assessment (Llamas-Nistal et al. 2013; Papathanasiou et al. 2013). Overall, a significant trend in enterprise learning for industrial and manufacturing competences development is a synergy between individual learning, including personalized learning, organizational learning, typically in the form of sharing internal and external to the enterprise knowledge, with collaborative learning, served by social and collaboration tools and platforms. This is the essence of Computer Supported Collaborative Learning (CSCL) a term that evolved from the established Computer Supported Collaborative Working (CSCW) environments (Goggins, Jahnke, and Wulf 2013). The combination of individual learning, organizational learning and collaborative learning, facilitated by establishing adequate learning flows is emerging as a significant enabler leading to more effective enterprise learning (Lanz, Majuri, and Tuokko 2013).

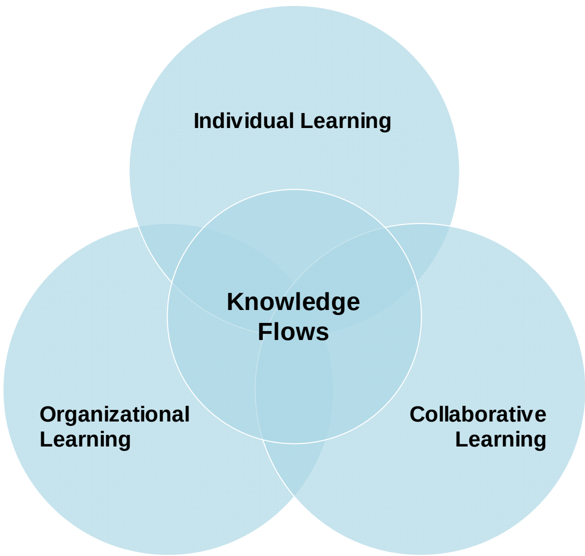

Figure 9: Learning flows in enterprise learning (adapted from *(Goggins, Jahnke, and Wulf 2013)*)

Establishing efficient learning flows is therefore a prime target for Future Enterprise Information Systems. Considering the breadth and the depth of the involved knowledge, the enterprise human resources and their required competences to meet performance targets, as well as current enterprise learning practices, a clear need of tailoring the offered learning to the exact needs each time, in a way similar to how context-adaptive computing aims to tailor offered services according to the perceived situation each time. This is achieved by upgrading the enterprise learning processes to the level of becoming become context-adaptive. In this view, the required competences in an enterprise are not static but are evolving over time and therefore the development of contextually enriched competence models are needed (Cerinsek, Petersen, and Heikura 2013). This dynamic view of competence development for the factories of the future has driven the competence building model approach, wherein motivational aspects coupled with skills and knowledge are necessary for mastery in job performance (competence), a viewpoint that reflects upon the need to establish multi-directional knowledge flows within an enterprise (Kiritsis et al. 2013).

The previous sections have developed the suggested Four Grand Challenges. In the next section, some (non-exhaustive) research solutions are investigated addressing these various points are analysed.

3. Current Status of Research

3.1. Ontology based approaches

The term Ontology has gained currency in Computer Science in the eighties through the recognition of the overlap between work done in philosophical ontology and the activity of building the logical theories of artificial intelligence systems. John McCarthy holds in 1980 that builders of logic-based intelligent systems must first list everything that exists, building an ontology of our world (McCarthy 1980).

The notion of ontology has been widespread in the field of information systems and data integration. It was recognized that the provision of a common reference ontology as a conceptual view on top of pre-existing information sources might provide significant advantages, and the term 'ontology' came to be used by information scientists (Smith 2003). More recently, ontology has gained importance and popularity with the advent of the Semantic Web. Semantic Web is a vision proposed by the inventor of the World Wide Web, Tim Berners Lee, in order to extend the capabilities of internet by attaching semantic information to internet contents. In this context, in order to obtain an automated access to the information contained in the Web, information items are described by means of metadata provided by ontology.

The literature proposes a number of ontology-based solutions supporting semantic interoperability between information systems. This includes wrappers to adapt local sources through schema matching using ontology as a reference schema; and mediators to perform integration of data from the adapted local sources (ERP, CRM, PDM, etc.) through query decomposition and optimization (Patil, Dutta, and Sriram 2005); (Chang and Terpenny 2009; Chang, Sahin, and Terpenny 2008); (Dartigues et al. 2007; Dartigues 2003) ; (Abdul-Ghafour 2009) ; (Grosse, Milton–Benoit, and Wileden 2005) ; (Panetto, Dassisti, and Tursi 2012) (Y.-J. Chen, Chen, and Chu 2009); (Sang Bong Yoo 2002); (Lee et al. 2010); (Cho, Han, and Kim 2006). Other solutions use ontology to enable data exchange. They bring a high added-value since they enable exchanging data along with related semantics compared to an XML-based data exchange approach (machine-interpretable versus machine-readable) (Rico et al. 2014); (Dartigues et al. 2007; Dartigues 2003); (Sang Bong Yoo 2002). The main advantage of these solutions is that they take advantage from reasoning capabilities enabled through description logics embedded in the ontology.

It can be highlighted that ontologies act as a key enabler for simultaneously overcoming several issues. Entreprise Information Systems are as such, not only technical issues in terms of interoperability or data integration are dealt with, but also business and engineering problems in terms of knowledge representation, knowledge capture or reuse. However, some of the proposed ontologies could be criticized for their ad hoc nature, being designed mainly to meet the requirements of a particular application or problem and can be subjected to changes when requirements or viewpoints change. They could be also criticized for the lack of expressiveness that describes the "reality" of the domain, leading thus to be considered as light-weight ontologies or from the point of some ontologists to be questioned about their eligibility with respect to ontological commitments.

It might be interesting to dwell upon the core concept of ontologies. According to (Smith, 2003) ontologies (in information science) deal with alternative possible worlds and not with reality itself; worlds which are defined with respect to the requirements of a specific context. This means entities represented in the ontology are only recognized by the context in question and they possess only properties which the context can recognize. Consequently, the goal of ontology for information scientists is no more the "truth" relative to a reality in philosophical contexts. But rather the goal is the "truth" relative to a conceptualization in order to achieve a certain degree of relevance with respect to the requirements of a context. Our position is very much in line with Smith (2003) who holds that information systems ontologists have abandoned the Ontologist's credo in the traditional philosophical sense and have adopted instead a view of ontology simply as a 'conceptual model' (El Kadiri and Kiritsis 2015).
Constructing one single shared ontology as in the philosophical sense would require a neutral and common framework to be established and supported by standardization organizations. Some initiatives have been already carried out namely such as OntoSTEP under NIST (National Institute of Standards and Technology) activities; Internet of Things Open standards under the Open Group activities. Collaboration with philosophers is also to not be neglected. The Ontek project is a successful example of such collaboration (Smith 2003). Such standardized ontologies should act as a point of reference for system designers to extract context specifications. Another approach to the construction of one single shared ontology is the definition of an upper ontology, which will be dedicated to the specification of highly general and domain-independent categories. The upper ontology would then be designed to serve as common neutral backbone, which would be supplemented by the work of ontologists working in more specialized domains using modularization principles.
If no efforts are made, we will simply be witnessing a translation of the problem being faced by traditional databases and that ontology came to address, that is: several ontologies using identical concepts or terms but with different meaning; or the same meaning expressed via different terms (El Kadiri and Kiritsis 2015). With this in mind, the prospect would arise of leveraging and combining all efforts already made by research communities, standards bodies and industrial companies in order to commonly define backbone ontologies.
It is important to note that related research works are conducted in parallel with ongoing advances in semantic technologies (Kiritsis D. 2013). With the perspective of a single and neutral backbone ontology in mind, the holistic approach of data integration can be enabled through the adoption of the Linked Data principles (El Kadiri, Milicic, and Kiritsis 2013). In this light, linking all relevant information, independent of its format, location, originator, and time can be enabled resulting in an integrated eco-system that involves multi-domain aspects, made possible through semantic interoperability.

3.2. Context-awareness: Current status and challenges

Over the past years, reliance on enterprise applications for providing and storing in-formation has grown rapidly. These applications will become much more complex in the future and are going to be used on any number of devices, from mobile smart phones to industrial computer networks. Thus, to increase their efficiency and electiveness, applications will need to be made aware of the context they are being used in, in order to automatically adapt to it (Nadoveza and Kiritsis 2014).

As a matter of fact, in certain situations not all information provided by an information system is important and relevant to the end user. Modern enterprise information systems provide huge amounts of information and in those large volumes very often the user cannot find appropriate and important information at the right time. Moreover, sometimes in complex business environments users are not aware of the current situation which negatively influences the decision making process. So it is very important to provide the appropriate information to a user in appropriate situation. But just providing the information does not solve the problem. The user has also to understand why the provided information is important which means that he/she has to understand current situation or to be aware of the context in which it happened in order to understand the real meaning of the information. Therefore it has become crucial for enterprise applications to be aware of the context they are being used in.

Nowadays enterprise applications collect and store various kinds of data and in-formation. This data describes users as well as various aspects of business. That means that if properly interpreted, that data could be used to describe the overall user and business context. However this is no easy task as context data is subject to constant change and it could be highly heterogeneous.

Semantic descriptions such as ontologies allow the derivation of a holistic representation of user interactions as well as context related information in a single, application-independent framework (Kiritsis D. 2013). By analyzing status information retrieved directly from user interactions, a system for context-driven access will be able to generate input parameters to identify the context-information: For instance a user is logged in as “structural designer” and clicks on a specific part such as a “structural node”. By assigning both input parameters to an ontology model for the context, further findings can be derived automatically.

Thus, efficient and effective means of modeling the information are needed. One of the biggest problems in the existing solutions is the variety of the used context models as well as the ways to find and access the context sources. Every system and framework uses its own format to describe context and its own communications mechanisms to access it. We believe that standardized formats for this domain are important for the enhancement of context-aware systems to shift the focus from the communication between context sources and users to the development of valuable context services.

A context model must meet the following requirements defined in (Krummenacher and Strang 2007).

- Applicability. A context model should be able to be used for many different applications entered around a single task. This requirement thus demands that context models be flexible in the way they can complete a given task, due to the fact that context data is heterogeneous.
- Information analysis. Context information, as already stated, can be of many different types, and is thus extracted from a multitude of sources. The model must be able to compare the information resulting from different measurements. Furthermore the model must be able to determine the source of information and how it has previously been processed. This requirement is known as traceability. Finally, acquired data from multiple sources may be incomplete or contradict it-self, resulting in the need for methods for resolving such issues.
- History. Any context model must provide a means of storing and accessing past information. Indeed past information can be useful to make predictions that may be valuable for present decisions.
- Inference. The information acquired from devices such as sensors is only raw data, also known as low-order context. A context model is required to able to apply reasoning on low-order context data in order to obtain high-order context on which to base its decisions.

Considerable research is being made into developing ontologies specifically designed for context descriptions, generally by extending existing basic ontology languages such as OWL (McGuinness and Harmelen 2004). Such ontologies include CONON (Wang et al. 2004), CoDAMoS (Preuveneers et al. 2004) and SOUPA (H. Chen et al. 2004). They define new classes related to applications that interact with humans. However most of the current available context models are applied in the pervasive and ubiquitous computing and are meant to capture only the low level physical context. Context models for complex enterprise applications which are able to describe the context in which an enterprise application has to provide its services are not being addressed in the research community so far. Also, considering that a significant amount of information that can be considered as context is already available in the system, we believe that utilizing the virtual and logical context could improve the usability of the enterprise application without investing a lot of resources in the new information infrastructure.

3.3. Human in the Loop – New and Emerging Interaction Metaphors, Usability and Ergonomics

The impact of the social web on Human Computer Interaction

The advent of social media and the Web 2.0 has drastically changed the way how and by whom information is generated and interacted with, as well as fundamentally modifying how people communicate to and relate with each other. Completely new, simple and intuitive interaction metaphors are being developed for people to create and share information in a hitherto unprecedented world-wide, immediate, social collaborative space. The interfaces and software ecosystems of modern mobile devices reflect the speed and simplicity of collaboration on the social web in the fast, iterative and evolutionary development of apps for every conceivable – and some inconceivable – function. “There is an app for that” has become a figure of speech. These fast development and hype cycles mean that these interaction metaphors are constantly evolving at a hitherto unprecedented pace. These development impact Enterprise Information Systems in a number of ways. With regards to Enterprise Information Systems, for the first time, most workers are used to more technologically and ergonomically advanced systems from their leisure time than they are at work. They are also used to creating content in rich, intensely collaborative networked environments which may conflict with the work paradigms presented at work. This leads to a dissonance between the workers´ expectations with regards to EIS ergonomics.

Interaction with Cyber-physical Systems

Future manufacturing and logistics systems need to be developed to satisfy the requirements emerging from the market as described in the introductory paragraph. These systems will need to be highly flexible, adaptive and robust to be able to sustainably produce new products with shorter lifecycles, high amount of variants and higher reaction times (Richter 2007). To achieve the required degree of flexibility, tomorrow’s manufacturing and logistics systems are envisaged to be modular, intelligent and capable of interacting with similar networked components (Franke et al. 2014). The development of this kind of future production systems is supported by the research initiative “Industrie 4.0”, which is a part of the high-tech strategy of the German government. The cornerstone of the so-called “fourth industrial revolution” is the use of cyber-physical systems (CPS) in manufacturing and logistics (Veigt, Marius, Lappe, Dennis, and Hribernik, Karl A 2013). According to (Gorldt et al. 2013) CPS use sensors to capture data about the physical world and actuators to influence it. They can store and process the captured data in order to proactively or reactively interact with both the physical and digital worlds. Distributed CPS communicate with each other via digital networks, making their data and services available worldwide. Humans can interact with CPS using multimodal human-computer interfaces. CPS facilitate new services, functions and characteristics which go beyond the current capabilities of embedded systems. CPS can be differentiated from similar systems such as embedded systems or PEIDs (Product Embedded Information Devices) in that they are integral, sociable, local, irreversible, adaptive, autonomous and highly automated (Lee and Lee 2006; Rajkumar 2007). They capture the distributed application and environmental situations and can interactively influence them in cooperation with their users or operators. CPS are context-sensitive, distributed, cooperative sociotechnical systems of systems (Acatech 2011; Geisberger and Broy 2012). Whilst conventional views of CPS emphasized the integration of physical and computational elements (Chituc and Restivo 2009), recent research is investigating how best humans can participate in CPS. In (Zamfirescu et al. 2013) an anthropocentric CPS (ACPS) was defined, as a reference model for factory automation that integrates the physical component (PC), the computational/cyber component (CC) and the human component (HC) to cope with this complexity. The key characteristic of an ACPS reference model is its unified integrality which cannot be further decomposed into smaller engineering artefacts without losing its functionality.

Human in the Loop

An example of delivery of context-relevant learning support is the provision of contextually relevant maintenance training, wherein context is determined by a number of factors falling under five typical categories, namely User, Environment, System, Service and Social/Collaboration context (Papathanasiou et al. 2014) (Figure 10). An example of a simple workflow that starts with context identification, followed by context-dependent service delivery is shown in the sequence diagram of the same Figure. Upon NFC-supported context identification (part 1 of the sequence diagram), the delivery of learning and support content is determined by the context specifics (part 2 of the sequence diagram).

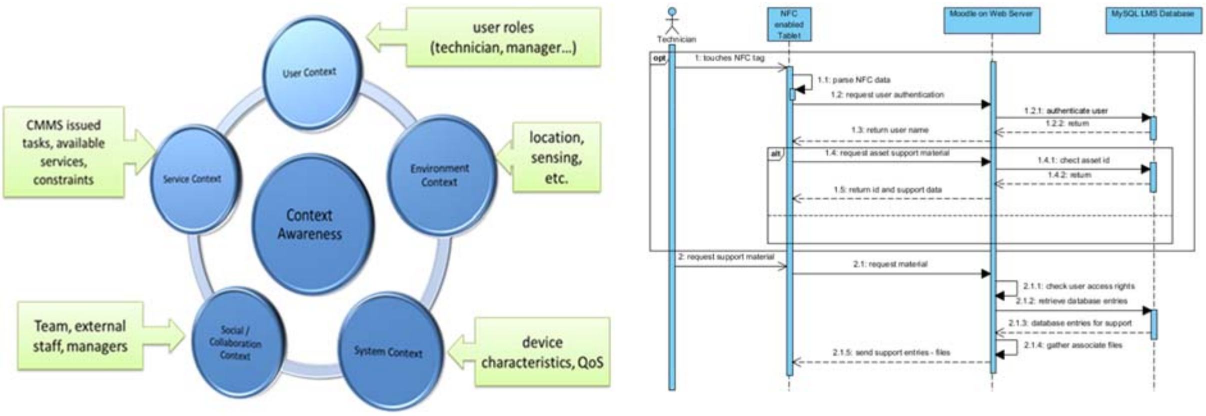

Figure 10: Example Context in Learning: left: context categories ; right context-dependent service delivery sequence diagram (Papathanasiou et al., 2014)

Enterprise learning experience can be delivered through Learning Factory concepts, wherein prototype manufacturing testbeds and simulations can be coupled with web-based learning and serious gaming to offer a real-like contextualised learning experience through an ambient laboratory environment (Plorin and Muller 2014). Taking into account the dynamic and evolving landscape of enterprise learning, the rapidly changing business environment and the adoption of new technologies, makes it necessary to foster closer academic-industrial collaborations to deliver high quality and effective enterprise learning (Boer et al. 2013). The learning factory concept is highly relevant as a convergence point for such synergies (Chryssolouris, Mavrikios, and Mourtzis 2013; Mavrikios et al. 2013) and the incorporation of manufacturing-relevant ICT skills is crucially important, considering the pervasive presence of ICT tools in virtually all manufacturing tasks (Bufardi and Kiritsis 2013).

3.4. Web 2.0 tools as a way to collaborative " learning ecosystem"

We have seen that Data Mining in a Big Data context may be a way to extract and structure information that can then be a source for defining a learning enterprise. A radically different solution has recently emerged, taking the opportunity given by Web 2.0 tools, and especially social and collaborative tools, to exploit the collective intelligence and interactions of the actors. The "Web 2.0" is mainly considered as a paradigm in which the traditional difference between providers and consumers of information is bridged thanks to a set of tools making bilateral communication and information/knowledge sharing easier (Kaplan et al., 2010). According to Anderson (2007), these tools may be gathered in seven main categories:

1. Social networks. These tools allow creating communities of users having common interests, in order to exchange information. Among many others, Facebook and LinkedIn are known examples of these tools.

2. Aggregation services. These tools allow displaying information coming from different web services on another web site, through content syndication. Syndication is made possible by the use of protocols like RSS - Rich Site Summary (RSS 0.91) and its variants (Anderson, 2007).

3. Data mashups. In the Web 2.0 context, mashups are compound objects built using information or images coming from different web sources. RSS feeds are possible solutions for gathering the basic pieces of information allowing to build a mashup.

4. Tracking and filtering content. These services keep track of, filter, analyze and allow to search for data or multimedia content in web pages. They can at the same time gather data (e.g. using RSS) and format it for an efficient display (Amann, 2012).

5. Collaborating. This category gathers tools allowing to collect and formalize knowledge in a collaborative way (using wikis) but also to improve the productivity of the collaborative work.

6. Replicate office-style software in the browser. These web tools allow the user to build his own customized desktop on the base of data/information/services found on the Web.

7. Source ideas or work from the crowd. The objective is to look for ideas or solutions using an outsourcing process that can be found in external sources made available on blogs or micro-blogs.

Some experiments aiming at implementing 2.0 tools in companies are described in articles or research documents, but much more in blogs. A survey of recent experiments is for instance provided in (Grabot et al., 2014) in which present applications are classified according to the following objectives:

The web 2.0 as a means to improve the relationships with partners. These experiments aim at creating more dynamic links with external partners of the company (mainly suppliers and customers). They are most of the time based on social networks (especially Facebook pages) or blogs.

The web 2.0 for creating an employee's network within the company. The web 2.0 is here the logical evolution of the enterprise Intranet. Typical applications allow the employees to create groups of common interest using social networks, then exchange information. Examples can be found in (Rosen, 2009) (Passant, 2008).

The web 2.0 for producing knowledge. The goal is here more ambitious than in previous case, since it is to produce knowledge in a collaborative way, and not only to exchange information. Content management tools are here privileged, including wikis and forums.

The web 2.0 for opening the company on its environment. This point does not deal with external partners like in previous sections, but denotes the access of an "external wisdom" from companies with which the enterprise has no formal link, like in the "Benchmarks" of the 2000's. Examples can be found in (Cheng, 2011) and (Williams, 2009).

The web 2.0 as a tool for collaborative work. This category deals with extensions of groupware tools making benefit of an easier communication thanks to Web 2.0 tools. Examples can be found in (Neil, 2009) and (Neumann, 2009).

The web 2.0 as a social experiment in the company. A quite atypical experiment is cited in (Dennison, 2007): British Telecom noticed that 4000 of its employees had subscribed to a Facebook group called

"BT", allowing them to exchange on their work in the company. In order to control any possible leak of confidential information, the company decided to offer the same opportunity to its employees using an internal system. A comprehensive set of services was opened, including wikis, blogs and social networks, and was massively adopted.

Nevertheless, it is interesting to notice that in all the surveyed cases, the 2.0 tools were deployed in parallel of the enterprise information system, but were not formally linked to it. Some studies on the "ERP 2.0" have nevertheless been published, presented in section

0.The case of ERP information systems

ERP (Enterprise Resource Planning) systems are now the backbone of the information system of any large organisation. They have brought many crucial improvements in the companies, principally with their unique database avoiding data duplication, their "process" orientation, the integration of all the functions of the organisation and the "best practices" they are carrying. Nevertheless, they have been and are still often criticized, with reasons including:

- their complexity, making it difficult for the users to have a global view on the processes in which they are involved,
- the temptation of centralized control that they bring into the organization,
- their "administrative" orientation, since they require the users to provide large amounts of data related to their daily work,
- the fact that their "best practices" are often more or less imposed to the users,
- the standardisation of the communication between employees that they may bring.

As a result, a huge body of literature exists on the reasons of a poor level of "adoption" of these tools by their users. Since most of these problems deal with implication, communication, collaboration and knowledge sharing, including Web 2.0 tools in ERP systems has recently been an object of interest from an increasing number of researchers and practitioners. The term "Web 2.0" refers to a new way in which software developers and end-users started to utilize the Internet: that is, as a platform whereby content and applications are no longer created and published by individuals, but instead are continuously modified by all users in a participatory and collaborative fashion. These issues are of course of critical interest for companies, which permanently seek for new ways to involve more deeply their employees, but also their customers and suppliers, into their business processes. Especially, it may be tempting to consider that these new applications could address some of the problems linked to the use of an ERP, often considered as creating social tensions within the companies.

Implementing an ERP system, then maintaining it, requires a very efficient and competent IT department, which may be a difficulty for small enterprises. As a consequence, the idea of installing the ERP in a dedicated company that would provide a secure access to its customers has emerged many years ago: the company Atos Origin is for instance a specialist in this domain (Atos Origin, 2004). This idea has been extended with the concept of "Software as a Service" (SaaS) (Turner et al., 2003). In that case, the software has been natively designed for a remote access as a service, and is maintained by its editor or an access provider. The consequences of this paradigm are for instance analyzed in (Wortmann, et al., 2011). Some known ERPs are now available as services, like Business By Design, the SAP ERP system dedicated to medium size companies.

More generally, SaaS solutions belong to the "cloud computing" paradigm, grouping three main classes: Software as a Service, Infrastructure as a Service and Platform as a Service. In (Grubisic et al., 2014) and (Faasen et al., 2013), the authors analyze the possible acceptation of companies for the Cloud Computing paradigm applied to ERPs. (Lewandoswski et al., 2013) focus more specifically on its possible use in SMEs, while critical success factors for such solution are suggested in (Emam, 2013). Indeed, the advantages of this solution are important: the customer can focus on the usage of the ERP system - which is still a great problem - but on the other hand, he has to be sure of the constant availability of the system and of the security of its data. To answer such questions, the quality of service provided by three types of ERPs available on Internet is analyzed in (Park et al., 2013).

More innovative applications are possible using the Cloud concept: for instance, a comprehensive ERP system could be built on the base of various services available on the cloud (Gelogo et al., 2014; Zhang et al., 2013). Nevertheless, such solutions still belong to the research field.

4. General Discussion

Given the context of manufacturing companies, today's consumer demands products which are of the highest quality and 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 (Hribernik et al. 2012).

In order to meet these challenges, manufacturers need to take concepts such as item-level and closed-loop Product Lifecycle Management (PLM) (Jun, Kiritsis, and Xirouchakis 2007) into consideration, which rely on the holistic availability of product-related data to all stakeholders throughout the entire lifecycle with the closing of information 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 (Fleischmann et al. 1997; Hans, Hribernik, and Thoben 2010; Jun, Kiritsis, and Xirouchakis 2007). All of these have in common the augmentation of physical products with "intelligence" to facilitate data generation, processing and networking 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 the Europe, 42% of the citizens use online social network services at least once a week (Eurobarometer 2012). 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 (BITKOM 2014). In other countries, like the USA the ratio is even more extreme (Rohrbeck, Steinhoff, and Perder 2010; Wuest, Hribernik, and Thoben 2012; Yoo and Huang 2011). Social network services are not only an accepted part of the daily life of most European citizens, but also will play an increasing role when it comes to future data generation (users) and integration (service providers). The 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, of course 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 and 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 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).

In addition developments such as ontology-based semantic interoperability and product avatars will foster an increased pervasiveness of knowledge between stakeholders of the product lifecycle. This means that previously separate domains will more easily be able to combine their knowledge to improve processes, product quality, efficiency, and other characteristics. For example, departments and companies involved in product testing and maintenance processes rarely exchange their knowledge. However, they increasingly becoming aware that an exchange of knowledge can significantly improve processes in both domains. The introduction of product avatars or similar technology will also empower consumers/customers to influence product design choices in a more direct way. Product designers will be able to quickly and precisely react to consumer feedback, choices and product use patterns. As a consequence, consumers will no longer be passive but become proactive stakeholders in the product lifecycle. Better knowledge about product use can also inform end-of-life processes, leading to more efficient and sustainable energy and resource use scenarios.

From the point of view of industrial enterprises, one of the main groups of future users of next generation EIS, additional challenges are inherent to the application of the new ICT systems. One has to bear in mind that, large global corporations that have the financial means to operate state-of-the-art EIS – be it the ERP systems cited in section 3.5, extensive product-data management systems or PLM systems – in terms of sheer numbers do not represent the majority of industrial companies overall. SMEs with few selected dedicated EIS are far more representative.

For the latter, the new SaaS and Web 2.0 paradigms offer the opportunity to enjoy the benefits of ICT in improving their business processes much more readily. Instead of having to acquire – and implement – large, monolithic software structures, in the future it is feasible for SMEs to simply purchase "enterprise apps" that solve a particular problem at hand. Thus tomorrow's SMEs may resemble the personal users of mobile devices of today: They will operate a number of EIS developed by different software/technology providers. They will expect that these EIS function on the same devices for human-machine interaction. Furthermore, as the collection of "apps" grows, the requirement for these separate EIS to interoperate will increase.

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.

5. Conclusion

Enterprise Information Systems have grown in complexity, comprising systems for managing different aspects of business processes and functions, systems responsible for integrating data, knowledge, decisions, processes and actors across the broader manufacturing ecosystem, including collaborating enterprises and supply chains. It is noteworthy that research in the field of EIS involves a number of already known problems and issues in data, information and knowledge management (data integration, information exchange, interoperability, information search, knowledge discovery, etc.) but also issues in terms of human-machine interactions and learning. Through this paper, the authors have sought to point out a set four big challenges they are addressing in their research together with the current state of the state of the art. These challenges deal with the following questions:

(i) How to allow data/information analysis, mining, integration, sharing through interoperability?
(ii) How to offer scalability and integration capabilities between business processes within EIS?
(iii) How to deliver new and intuitive ways for interacting with EIS?
(iv) How to support the development of professional competences triggered by new scientific and technological advances?

It comes as no surprise that several enabling technologies (semantic technologies, product avatar, Web 2.0, serious games, etc.) have been adopted by the research community as promising approaches to foster and support the next generation of EIS. Four major contributions and research orientations elaborated by the authors and their teams have been discussed in the paper. First, the semantic mediator is proposed as a key enabler for dealing with interoperability issues next generation of EIS. The semantic mediator makes use of ontologies to federate all relevant data independent of its format, location, originator, and time. Ontologies and underlying semantic technologies play a fundamental role in making an increased value from data that is brought together with its meaning and that is scalable to the level of the web. Second, the context-aware infrastructures comes to enable the alignment of information and services to the apparent context of a situation. This infrastructure leans on advanced mechanisms such as context-adaptive or situated computing and acts as a key element in making efficient use of EIS to offer a high level of customization of delivered services and data. Third, the product avatar is a contribution to an evolutionary social, collaborative and product-centric and interaction metaphor with EIS. It puts forward the idea of the digital, information-based representations of individual physical products able to interact with the EIS. Fourth, the human learning solutions aim to develop individual competences in order to cope with new technological advances.

Taking advantage from future technology innovations and advances, research orientations towards next generation of EIS require delivering: (i) Advanced algorithms for processing large and continuously increasing amount of data; (ii) Solutions for leveraging the collaborative intelligence produced through social media to collect relevant information in actual contexts; (iii) New human-machine interaction mechanisms and EIS users behavior awareness capturing; (iii) Tools and solutions to boost intelligence of human resources in interacting with next generation of EIS.

The potential for achieving positive social and economic impact by introducing disruptive ICT technologies into next generation enterprise information systems is huge, as indicated by a recent relevant McKinsey report (Bughin, Chui, and Manyika 2013). A contribution to achieving such impact is expected to be made by all four specific challenges that this paper has opted to highlight. Specifically, technologies related to the big data life cycle and associated data value chains, are now recognized as having past the stage when they were considered as a frontier technology and have become acknowledge as a set of capabilities that must be pervasively incorporated across enterprise functions and operators. Their linkage to the social aspects of computing is recognized as the new "powerful social matrix", constituting the bond that brings together and leverages upon the collective value adding contributions of employees, customers, manufacturers and suppliers. Making interaction between production and other secondary assets, devices and people operating across the production and value chains, through enhanced EIS interfaces achieves a much more powerful integration of information and knowledge flows than ever before, greatly facilitated by internet of things technologies and context-aware infrastructures. The upgrade in the staff capacity to play a more active role in future enterprise activities, achieved by the incorporation of learning supporting technologies, leads to a better integration and valorisation of the great potential of individual human and collective knowledge. When considered altogether, the McKinsey report foresees that the collective economic impact of such transformative information technologies could lie between $10 trillion to $20 trillion annually in 2025 (Bughin, Chui, and Manyika 2013). The McKinsey report and other related studies are taken into account in a recent US Chamber of Commerce study, which identifies huge impact potential on several fronts:

(a) generating new goods and services, wherein information is either the product itself or it contributes significantly to the quality of another product
(b) optimizing production processes and supply chains
(c) improving marketing via personalization, including the integration of customer feedback into product design
(d) enhancing organizational management, making it highly data and evidence-driven
(e) and driving faster research and development, thus accelerating the innovation process (USCOE 2014).

In Europe also, following an initiative by the Bureau of European Policy Advisers (BEPA), Rand Europe has carried a study that highlighted the role of new technologies in achieving clearly identified social impacts on several areas that have been studies in parallel, namely (a) the rise of global 'middle class' (b) the empowerment of individuals (c) the changing demography of a globalized world and associated impact on different societies (d) the role of mobility; and (f) old and new labor considerations for work (Horvath et al. 2015).

With data that has meaning, with interlinked knowledge, with context-aware and human-centric infrastructures, the overall solutions and approaches discussed in this paper contribute to the transition towards the next generation of EIS, an integrated eco-system that is becoming more instrumented, more interconnected and more intelligent, with great potential for achieving a lasting societal impact

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