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Intelligent Cyber-Enterprise in the Production Context

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Abstract: The paper aims to introduce a new vision for the enterprise of the future, based on the most recent paradigms in manufacturing control and on the newest concepts in technology, as Cyber-Physical Systems, Internet of Things and Internet of Services. The concept of and Intelligent Cyber-Enterprise, based on a dynamic and holistic Knowledge Management System, allowing efficient cooperation and informational exchange between humans and machines is presented.

Keywords: Cyber-Physical Systems, Knowledge Management, cognitive agents, Internet of Things

1. INTRODUCTION

Production, manufacturing or industry as it is referred to by different authors is one of the main drivers of societal (re)evolution.

In time, the concept of manufacturing enterprise has known many changes. The importance of different kinds of enterprise resources was reconsidered and impacted greatly on enterprise development and management.

Generally, the first and second industrial revolutions were considered mainly from the point of view of manufacturing paradigms:

- the first industrial revolution (late 18th century) focused on mechanisation and centralization: tasks previously done laboriously by hand in hundreds of weavers' cottages were brought together in a single cotton mill, and so, the factory concept was born
- the second industrial revolution (early 20th century) was marked by the assembly line implemented by Ford and the concept of mass production.
- the third industrial revolution (early 21st century) is the consequence of globalization end environment awareness and it will be represented by the flexible, intelligent, adaptive enterprise.

Inherently, manufacturing paradigms changed in time. Its own results acted as drivers. (Dumitrache and Caramihai, 2010). Mass production gave place to customization and to flexible manufacturing. Flexible manufacturing requested new approaches in control, organization and management. And the most important of all, it requested a new approach towards human resources, who became, gradually, the most important production asset.

One of the effects of industry evolution was the development and the increased accessibility of education. Insidiously, the request for qualified labour force increased, and education became more and more affordable as well as desirable. Educated people improved the efficiency of production systems, creating new needs and demanding new organizations; they made industry pro-active and started a trend of social-awareness.

In the last couple of years were many attempts to define the relation between society as a whole and the industrial trends, especially with respect to the immediate challenges and short-future needs of the former: increased ageing population in developed countries, new and special needs in health-care and assistive technologies, environmental pressures and the scarceness of resources, globalization a.s.o.

From these attempts, as well as from the tremendous technological development, a new industrial revolution is approaching: digital manufacturing.

Some specialists are foreseeing that 3D printers and the use of new materials and regenerable energy[1] will completely change the manufacturing concept, as customers will be able to design and print their own products, replacing concepts as supply chain management or enterprise resource planning by something completely different, probably based on SOA principles. But this is an extreme scenario; it is more probable that manufacturing of complex products with strong reliability and security requirements will be still made by dedicated enterprises, with certified competencies and responsibilities.

New IT technologies and concepts are already re-shaping the use of information in and between enterprises, the creation and management of knowledge and especially the interactions: between machines, between humans and between humans and machines.

The new revolution in manufacturing could be a knowledge management-driven one. Already, from manufacturing cells to agent-oriented control architectures, from entities to embedded systems and towards Cyber-Physical Systems (CPS) there is a definite evolution towards what can be defined as the Cyber-Enterprise (Dumitrache and Caramihai, 2013) whose emergent behavior, adaptivity and pro-activity

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[1] http://www.economist.com/node/21553017

to market and socio-environmental challenges could qualify it as intelligent.

By merging the virtual and the physical world of manufacturing through CPS and considering all aspects connected with real life, we have to create the enterprise of future as an Intelligent Cyber-Enterprise with main facilities as: adaptivity, self-organization, cognition and sustainability.

In this new type of enterprise we are finding the agility, adaptability, autonomy and flexibility in production systems to face succesfully high dynamics and uncertain environments.

Integration of cognitive objects into a hierarchical architecture of enterprise management and control, coordinating shop-floor production, creates a knowledge-based environment which allows self-configuring, self-healing, self-optimizing and self-protecting capabilities.

By self-configuring capabilities, a production system adapts itself to unpredictable conditions by automatically changing its configuration, adding or removing new resources or creating new tasks.

By self-optimizing capabilities, a production system tunes itself pro-actively to improve its performances, by goal-directed control as a response to environmental changes.

These capabilities are developped by using cognitive agents with attributes as perception, analyse, learning, planning.

This paper aims to present a framework for the design of an Intelligent Cyber-Enterprise as an emerging model for today's challenges faced by manufacturing industry, based on the most recent developments in the field (smart and cognitive factories, use of SOA and Internet of Things, smart sensors networks a.s.o.) and on a CPS approach with respect to Knowledge Management (KM).

Next section will present a short overwiev of the intelligent manufacturing concept development, underlining some basic approaches in Smart Factories and Cognitive Enterprise paradigms, in a view based on the CPS concept.

Section III will present the concept, derived from these approaches, of the intelligent Cyber-Enterprise, based on a knowledge-driven, agent-based, CPS-oriented view.

2. NEW APPROACHES IN INTELLIGENT MANUFACTURING

2.1 Evolution of manufacturing concept

There are many ways in which evolution of manufacturing concepts can be presented, especially because it is not linear; there is a very strong interconnection between basic shop-floor manufacturing methodology, production organization, control architectures, technologies, and mostly, information management.

Until recently manufacturing paradigms were focused on one aspect at a time:

- At *shop-floor level*, manufacturing evolved from disparate machines, to production lines and then towards Flexible Manufacturing Systems, viewed as a set of Flexible Manufacturing Cells interlinked by a common transport system and respectively by a common information flow; the physical location of the cells is important rather from the organizational and technological point of view; not from the conceptual one.
- At *organizational levels*, though, every stage in shop-floor manufacturing was considered from the point of view of resource optimization, reducing costs, integrating the information flow, ensuring the constant and measurable quality of products in any condition – developing concepts as Total Quality Management, Computer-Integrated Manufacturing, Concurrent Engineering, Extended Enterprise, Virtual Manufacturing, Lean-manufacturing, Workflow Management, Business Process Modelling a.s.o. Applying different combinations of these approaches in different conditions resulted in different types of enterprises, whose success depended rather on the adequacy of means to their specific operating conditions, than to the intrinsic value of every paradigm.
- *Control architectures* used the available technologies in order to solve in optimal conditions – cost and reliability being the main factors – manufacturing challenges. They have basically evolved from centralized, hierarchical architectures towards agent-oriented structures with different degrees of hierarchy embedded, as a compromise between flexibility & robustness and efficiency & predictability. Resource planning and scheduling, supply chain management and real-time monitoring evolved in parallel, as support for control.
- *Information flow management* has known the most spectacular evolution in the last years: since the microprocessor development and between the continuous increase of computer availability in industrial purposes and the increased software interoperability and standardisation, information management has influenced both enterprise organization and control approaches. Manufacturing enterprises have gradually increased the importance allotted to information and knowledge until they understood that these represent one of their most important asset. Knowledge Management (KM) evolved as a discipline from which it is expected today to solve many of the challenges enterprises are facing, but especially to fully use all their capabilities and to pro-actively act on the market.
- *Technologies* had usually answered to demands expressed by industry; some of them, as microprocessor, Internet or RFID allowed real paradigm shifts at control, information flow management and organizational levels.

The problem is that all these aspects are inter-related when generating an emergent behaviour of the enterprise and any change made in one of them will affect not only the global performances of the enterprise, but also the functioning of others – and not always for the best.

This is the reason for which in the last decade there were developed several holistic strategic approaches related to the enterprise as a whole. Some of the most interesting, which will be shortly referred to in the following sub-sections are the Cognitive Factory and the Smart Factory

2.2. The Cognitive Factory

The Cognitive Factory is a relatively recent research trend, where artificial cognitive capabilities were used for the control of production systems. In (Bannat et al.2011) are presented in detail the problems that this approach has to solve, as well as some of the work lines.

This solution is typically conceived (Rungger et al., 2008) for manufacturing enterprises dealing with low-volume and high-diversity production, where efficiency is drastically limited by the capacity of adaptation of the production system.

The solution is to introduce the so-called *cognition* into technical systems: cognitive technical systems are understood as entities showing abilities of perceiving momentary situations, classifying and interpreting them and executing appropriate actions and strategies in order to accomplish varying production tasks.

In the context of production, it signifies that there should be conceived means to convert data in information and then in knowledge, in order to construct models reflecting the actual state of production. Based on them, it is foreseen to generate on-line appropriate production plans and control programs.

In (Brecher et al., 2012) is given an example of the work developed within the Cluster of Excellence “Integrative Production Technology for High-Wage Countries” for a robotized production unit.

The idea of this approach is to integrate – or rather emulate – human reasoning capabilities at machine/ plant level and to perform modelling, planning and control into a highly integrative way, adapted to the real context.

We believe that this goal may be achieved also by an integrating CPS modelling approach, where real humans are part of CPS, giving high efficiency to communication, context interpretation and knowledge integration, with implicit learning capabilities.

2.3. The Smart Factory

The smart factory is designed according to sustainable and service-oriented business practices, by converging technical and business processes into CPS models.

Using a flexible network of CPS-based production systems, the high level of automation of all processes creates the smart factory.

Flexible production systems which are able to respond in all real-time conditions allow the in-house production processes to be optimized and integrated into a global network of adaptive and self-organizing production units.

In figure 1 is presented a CPS-oriented view of the Smart Factory.

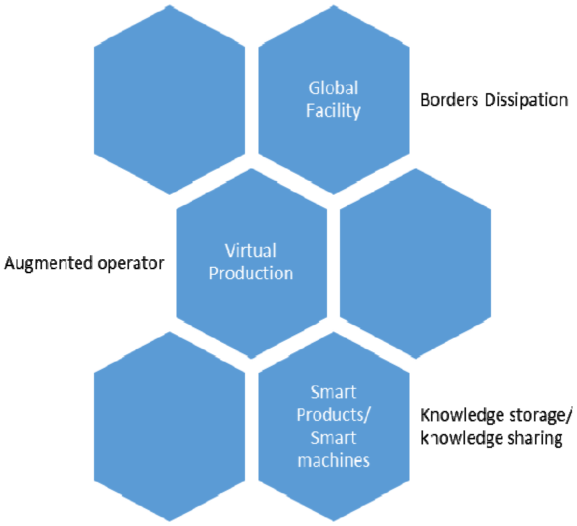

Fig. 1 Smart Factory in a CPS-oriented view

A smart factory should be typically working into a global environment, with different physical locations, each one with its particular competencies and functionalities, costs and availability.

The optimal use of such a *Global Facility* requests a so called *Border Dissipation* approach: the planning of production and production capacities extensions should take into account a situation-based global planning for local production and development.

It would request for each sub-system of the enterprise both the capacity of independent action under planning defined specifications and the capacity of communication allowing the transfer of meta-data, information and knowledge between components in order to offer reliable context-oriented behaviour.

3. KNOWLEDGE-DRIVEN INTELLIGENT MANUFACTURING ENTERPRISE

The most important common points in Cognitive and Smart Manufacturing approaches are:

- Enterprise is a network of autonomous entities which differ in nature (human and artificial), physical structure, functionalities and local purposes; but which should generate, by their inter-connection, an intelligent emergent behaviour with a common goal;
- Enterprise is a complex, highly dynamic system, facing an unpredictable environment, to which it should adapt by re-active and pro-active behaviour;
- The link between enterprise entities is information flow; any modern enterprise should have an integrative information system;
- Knowledge is one of the most important asset of an enterprise;

- Humans may be considered as intelligent agents that are acting in close interconnection with other resources, giving them superior goals and capabilities.

From those considerations it is this paper view that the concept of the Intelligent Manufacturing Enterprise of the future should be based on three pillars:

I. A CPS – oriented enterprise model: a CPS is a structure which possess a set of internal characteristics, which determine its functionality, autonomy, purpose, etc. and the communication capability.

By its inherent autonomy, it allows considering, when strategically planning activities, only from the point of view of functionalities (competencies & knowledge) and behaviour (purpose).

By its communication capabilities, it may change purpose and improve functionalities, thus evolving and adapting to new environments and situations, allowing dynamical reconfiguration for the system it belongs.

CPS-oriented modelling encompass all the advantages of agent-oriented approach and embedded system – implementation, but is adding a supplementary degree of flexibility in communication and sensing and allows an increased level of intelligence by connecting to a knowledge management system.

II. An integrative IT system: The IT infrastructure should include data processing, storage and communication technologies and the entire spectrum of the organization's information systems, including transaction processing systems, management information systems, enterprise resource planning systems, databases (DB) and data warehouses.

One possible way of systematically viewing the IT infrastructure is to consider the capabilities it provides in four important aspects: (Fernandez and Sabherval, 2010).

- *Reach: w*ithin the context of a network, reach reflects the number and geographical locations of the nodes that can be efficiently accessed. Today's development of the concepts of IoT and SOA will allow IT infrastructures to connect every entity represented by a service.
- *Depth*: focuses on the detail and amount of information that can be effectively communicated over a medium; it corresponds to the technological aspects of bandwidth and customization.
- The *richness* of a medium is based on its ability to: (a) provide multiple meanings simultaneously; (b) provide quick feedback; (c) personalize messages; and (d) use natural language. The evolution of IT allowed a significant increase in its ability to support rich communication.
- *Aggregation* refers to the capability of IT infrastructure to store and quickly process information. This enables the aggregation of large volumes of information drawn from multiple sources. Data mining and data warehousing together enable the synthesis of diverse information from multiple sources. ERP, Workflow Management and Business Intelligence Systems are good examples of IT capabilities in information aggregation.

In connection with the CPS-modelling of enterprise resources, structures and processes, the integrative IT-system should be finally capable to link together all drivers and resources related to a certain product to be executed, including the customer and the optimal resources according to user requirements and to the enterprise capabilities and cost issues.

III. A holistic knowledge management system (KMS): if the CPS-oriented modelling represents the back-bone of the enterprise, the knowledge management system should represent its nervous system and mind. It is the support for enterprise intelligent and adaptive behaviour and for its auto-configuration capabilities. The integration is made, through the IT system, at two conceptual levels:

- *At CPS-module level* (Fig.2): As an autonomous system, every CPS module has its own information and knowledge resources. They may have different semantics, depending on their structure, functionalities and origin, encompassing models, goals and functionalities. Some of these are internal and inherent to the CPS physical structure – and they are determining the structure of information they are using for fulfilling them.

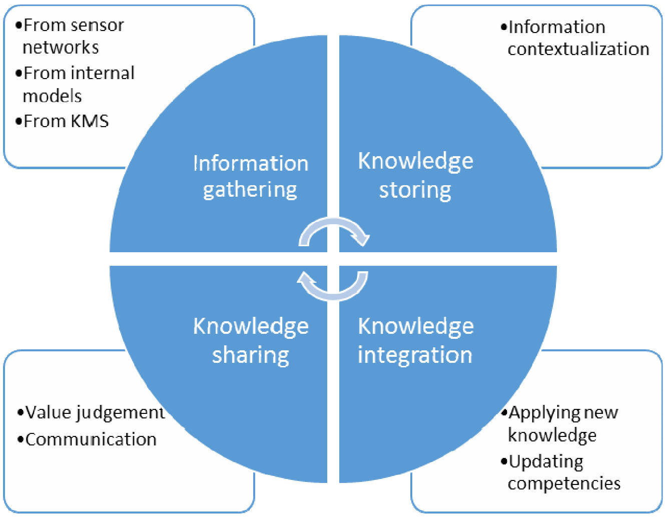

Fig. 2 Knowledge management cycle at CPS-module level

They should not be available for communication with other modules and are usually structurally stable. Knowledge representing them could be considered as explicit and tangible.

But the real flexible dimension of a CPS resides in its communication and information gathering capabilities. It allows a CPS-module to define global-oriented goals and new capabilities. It may be connected not only to a sensorial network allowing it to react to the environment, but also to the enterprise KMS, from which it will be informed about global enterprise goals and requests concerning the use of its capabilities.

Moreover, by the KMS may also be transmitted supplementary knowledge, acquired by other CPS-modules, which can allow updating of the internal knowledge. Information and data from the sensorial network is considered by the CPS module as explicit; it is used, after appropriate checking and filtering, for "feeding" its internal models and for fulfilling its goals.

On the other hand, information obtained from KMS is used differently: it may contain either requirements, orders or problems to be solved by the CPS – triggering a cycle which implies information contextualization with respect to CPS competencies and actual state, simulation on internal models, activity planning, decisions based on internal knowledge and communication with other modules – or new pieces of knowledge acquired by some other CPS-modules with similar functionalities.

This alternative requires a similar cycle, but with different consequences: first of all, new pieces of information or knowledge may have different semantics – as the source may have different structure and purposes. Even if it should be represented, by the integrative IT infrastructure, in a comprehensible format, information should be checked by running different internal models and simulation, contextualized in the local semantics and stored as new knowledge – or rejected. Knowledge storing implies also the association of a reliability degree, which may increase or decrease based on subsequent results of knowledge integration. Much of the performance of a KMS relies on an appropriate use of the reliability degree (based on source, on extrapolations, on application results).

Knowledge integration implies application of different knowledge in solving actual problems and updating of internal models and reliability degree. When the reliability degree of knowledge reaches a certain threshold, the result of its application becomes a new competence of the CPS-module. It may be shared with the KMS, closing the cycle.

Finally, information obtained from internal models is a result of simulations which may be used for value judgement allowing decisions and activity planning, and it usually impacts as it is on knowledge storing and knowledge integration steps.

- *At enterprise level* (Fig. 3): a hierarchical, dynamic structure of agents, combining and migrating between levels, according to their competencies and the enterprise goals.

There are several ways in which knowledge may be necessary and used in a manufacturing enterprise, with respect to the time-solving horizon for a given problem, degree of precision and repeatability of results, process models and methodologies that should be used, a.s.o.

Traditionally, there are three control levels considered for a manufacturing enterprise, with respect to the above-mentioned criteria:

- shop floor level – real-time control of material flows, machine programming and monitoring, shop-floor transport systems, repository management
- operational level – workflow management; supply-chain management, production scheduling and planning, order management
- strategic level – goal-setting, product and process design, enterprise development planning

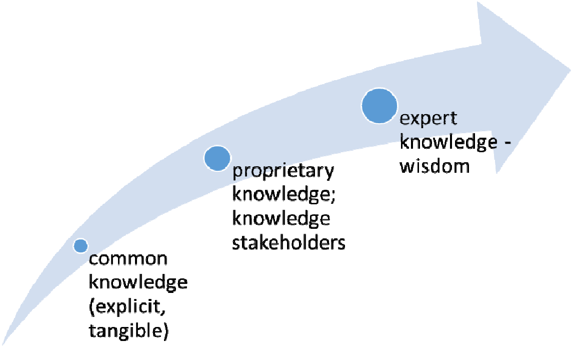

Fig. 3 Knowledge agent dynamics

These levels may be interpreted from the point of view of necessary knowledge:

- at the shop-floor level, the necessary knowledge is generally explicit and public; it consists in process models (as workflows), machine programs, procedures for humans; problems have algorithmic, decidable, reliable solutions, the solving time should be short and results predictable and deterministic. Usually CPS-agents acting at this level are either representing resources or products and their interactions are based on standard communication procedures. Gathering new knowledge is rarely requested at this level, especially because its integration takes time and may imply trial-and-error scenarios, which are not desirable; precision being one of the most important agent success-criteria.
- at the operational level, problems to be solved are more diversified and the systems that should be managed are more dynamic, inter-connected and complex in nature; models and procedures are less precise and they usually should be adapted at an environment that should be firstly identified by inter-agent communication and intelligence exchange. Knowledge used here is partly explicit and may be found in the common KMS, but most of it is what could be called "proprietary knowledge" as it is gathered and integrated for use by specific agents – knowledge stakeholders - that have to deal with specific problems. It may be explicit in the internal knowledge-base of an agent, but it has to gain a certain reliability degree and integration level in order to be made explicit for the KMS. Integration is made by trial-and-error scenarios, which are generally elaborated by every knowledge stakeholder. At this level, the knowledge necessary for solving the same type of problem may be detained by several agents, which could act differently in same circumstances. They have to exchange information in order to converge towards

reliable knowledge and to construct correct models for problem solving.

- At the strategic level, the most important capacity of an agent is pro-activity. The problem-solving environment is the most dynamic and uncertain and the agents should define not only their methods for solving new problems – which they may do by decomposing them in similar operational problems – but also the success criteria by which they have to appreciate the solutions. Here is needed what is called "expert-knowledge" as it is tacit in nature and depends extensively on the internal model of the agent. Choosing correct success criteria impacts greatly on the enterprise survival and progress and such behaviour may be accordingly considered as agent-wisdom.

The system is dynamic in nature not only because agents should always interact and their communication patterns are changing the overall behaviour of the system, but also because at every level there are some problems which have different characteristics. When a resource is breaking down at a shop-floor level, a local re-scheduling problem has to be solved. So some of the agents – usually CPS modules that include human intelligence – have to test trial-and-error scenarios based on the concrete data they have and on eventual appeal to proprietary knowledge. These agents learn and may become knowledge stakeholders, as well as some of operational agents should comply with real-time problem solving time horizon, thus acting at shop-floor level.

New models developed at the operational level may include knowledge useful for the strategic level; and by interaction, an operational knowledge stakeholder may became an expert. There is much research to be done in order to develop reliable methods providing agents the possibility of learning and evolution – a promising approach is working with motivated knowledge agents.

But the most reliable way used today is based on the human-resource integration in CPS modules – as H2M communication is developing, allowing exchanges in explicit and tacit knowledge, and H2H communication remains the best way in exchanging and integrating tacit knowledge.

In this way, the enterprise may be considered to have an organic growth, each part continuously influencing the others, based on a combination of local and global goals. The CPS-modelling approach ensures for sub-systems the possibility to locally comply with a part of environmental dynamics, relying at the same time on the cooperation with other modules for the rest.

The equilibrium maintained through a KMS – allowing the compliance between local and global goals - sustained by an integrative IT system will ensure an optimum development of the enterprise and allow for its adaptive, intelligent behaviour.

6. CONCLUSIONS

The paper is introducing new concepts with respect to the Enterprise of the Future considered as a complex intelligent system. Performances of production systems are reconsidered in the context of IoT and IoS paradigm implementation as ways of improving M2M, H2M, object to object (O2O) communication, based on the cognitive character of the production chain, modelled as a CPS dynamic network, aiming to a sustainable adaptive behaviour.

In the future, the aspect of the sustainable engineering will be explicitly taken into account, by mechanisms encompassed at the level of the cognitive agents and validating the decisions taken at the expert-wisdom level of the enterprise KMS. Sustainable Engineering is based on four pillars: economy, society, technology and environment; the Intelligent Cyber-Enterprise must then consider technical, economical, social and ecological performance, to create a real sustainable Eco-System.

Manufacturing must be sustainable in terms of performance (of products and processes), quality (of products, services and processes) and safety (of people, facilities and infrastructures).

We have to create intelligent products based on embedded devices, allowing innovative operation and new materials allowing easy disassembly/ recovery/ recycling, with lower impact on the environment.

The Intelligent Cyber-Enterprise may solve these aspects, but the transition of actual enterprises towards such structures necessitates special efforts and investments in processes and services re-organization and re-design and especially the formation of a human resource able to integrate the above-mentioned concepts.

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