Knowledge Management in Intelligent Manufacturing Enterprise

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Abstract: - The paper is presenting new trends in manufacturing paradigm, supported by knowledge management concepts and architectures. Evolution of manufacturing and of knowledge management was a dual process, each of them supporting and triggering the other's qualitative shifts. In the context of future e-economy and knowledge society, new challenges are appearing. A knowledge management architecture is presented, supporting intelligent enterprise, by using concepts from complex system theory and control engineering approaches.

Key-Words: - manufacturing paradigm, intelligent enterprise, knowledge management, complex systems

1 Introduction

It is a widely recognized assertion that information means power and that wisdom should be the ultimate goal of humans.
But the real need of a formal approach was triggered by the technological qualitative bound and its implications, as it is presented in Figure 1.
After the Second World War, tremendous changes arrived both in the industry and society. The computer era was at its beginning and, together with its implication in industry, human resources management took also a new shift.
The first shift of manufacturing paradigm was brought by automation: Numerical Control Machines, Industrial Robots, and, later on, whole Automated Manufacturing Systems, have operated the change from mass production to customization and, more than affecting the customer position in the product life-cycle, required new views of human resources management.
Process specification became an important activity, concerning not only production processes, but also training ones. Storing and retrieving processes information and data developed into self-contained disciplines, which resulted in document management and databases engineering. First difficulties in the transfer of data between different purpose software applications (as CAD and CAM) underlined the differences between data and information.
Anyway, in years '70 the paradigm of "Flexible Manufacturing System" was defined, in strong

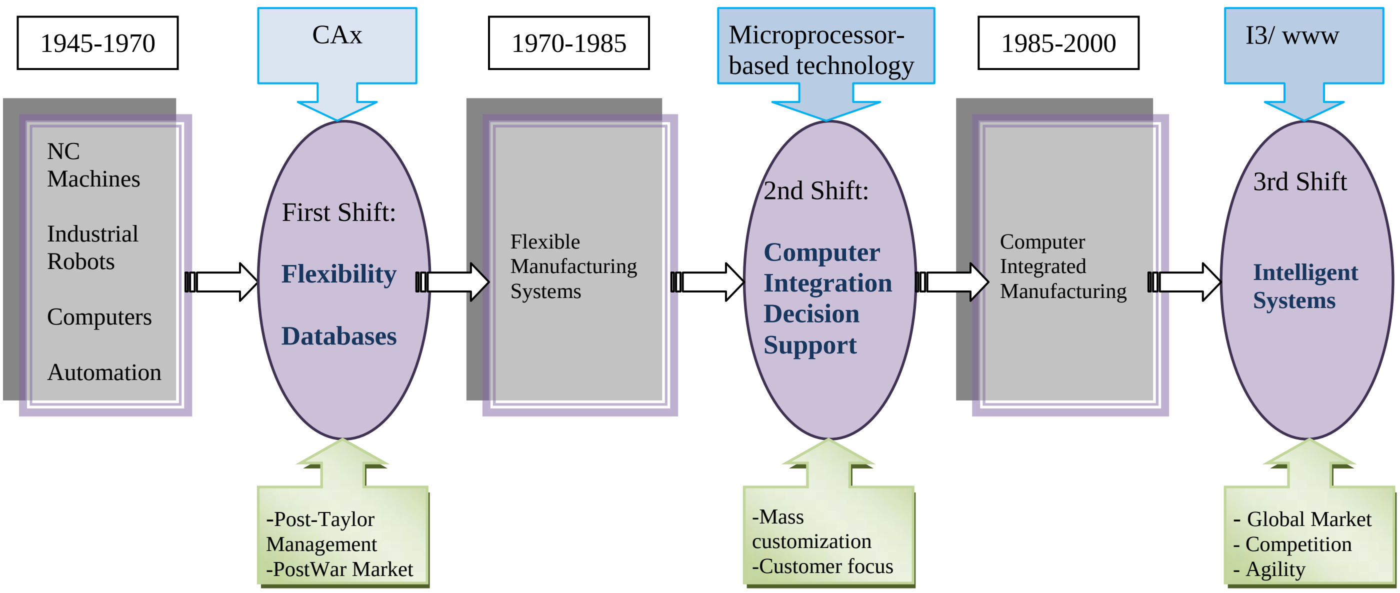


Figure 1

connection with that of “information technology”, implying mainly computer-aided document management and database management. [1]

Terms and procedures should be more precisely defined, in order to allow the different kinds of flexibilities (design, technologic, machine, process), and, consequently, more and more data and information were stored, in order to be easily retrieved and transmitted; specialization and training of human resources started to increase in importance, rising in “human resource management” as a new management approach.

Some drawbacks already appeared: difficulties arise when data and information should be shared by different applications or transferred on other platforms. Increasingly extensive databases, software applications and computers proved less efficient than estimated.

The accumulation of those drawbacks, combined with the increasing tendency of customization (resulting, for enterprises, in the need of extended flexibility) started a spiral: more flexibility required more automation and more computer-aided activities (design, planning, manufacturing etc.), more computers, NC equipments and software application thus requiring more data & information sharing and transfer, meaning more interfacing between applications and eventually hardware, and consequently more specialized people – all those things implying elevated capital and time. On the other hand, due to the socio-economical continuous progress, more and more producers entered the market, competing for customers by highly customized products, lower process and shorter delivery times.

As very suggestively presented in the beginning of the first edition [2], the feeling existed that some qualitative change should be made, in order to break this spiral. And, effectively, consortiums of hardware and software suppliers, important manufacturers interested in flexibility, research institutes and universities, managed new shift in manufacturing paradigms - resulting in the concept and support of Computer Integrated Manufacturing – Open System Architecture (CIM-OSA) [3].

An important aspect of the ESPRIT CIM-OSA project is its direct involvement in standardization activities. Its two main results are the Modeling Framework, and the Integrating Infra-Structure. The Modeling Framework supports all phases of the CIM system life-cycle from requirements definition, through design specification, implementation description and execution of the daily enterprise operation. The Integrating Infrastructure provides specific information technology services for the execution of the Particular Implementation Model, but what is more important, it provides for vendor independence and portability.

As for knowledge management paradigm, the integrationist paradigm in manufacturing was equal with the ability to provide the right information, in the right place, at the right time and thus resulted in defining the knowledge bases of the enterprise.

Knowledge is, for data and information, what is integrated enterprise for flexible manufacturing. This concept, together with standardization supported by the Integrated Infrastructure, has marked a shift in knowledge management –as a discipline that started to be recognized. Knowledge engineering and data mining, supporting first generation of knowledge management, brought their support in developing new types of manufacturing systems.

At the end of ‘2000, the process of knowledge management mainly implies the identification and analysis of knowledge, the purpose being the development of new knowledge that will be used to realize organizational goals. Because knowledge is usually gathered from a geographical and informational distributed system, knowledge management architecture should fulfill the following:

- detection and identification of knowledge
- storage and modeling of knowledge
- inference of conclusions
- retrieval and visualization of knowledge
- decision making

This view is representing what was called “first generation knowledge management” and can already be retrieved at the core of modern manufacturing paradigms, supporting concepts as concurrent/ collaborative engineering, virtual factory, and extended enterprises.

However, things will not stop here: challenges and pressure from the “outside” of manufacturing systems became stronger requiring for enterprise new approaches, as collaboration and networking, on short or long time horizon.[4]

2 Intelligent Enterprise

Actually, the most important driver of the evolution of both manufacturing and knowledge management paradigms seems to be the necessity of enterprise collaboration, with approaches at ontological level for knowledge sharing.

In the framework of incoming effectiveness and quality of service in a global e-economy, networked, collaborative manufacturing paradigm includes:

design, programming, operation and diagnosis of automation behaviour in distributed environments, system integration models, configuration and parameterization for communication connected devices, heterogeneous networks for automation-based quality of services, life-cycle aspects for distributed automation systems and remote maintenance.

Collaborative Networked Organizations (CNO) represent a new dynamic world, based on cooperation, competitiveness, world-excellence and agility (Figure 2).. They are complex production structures – scaling from machine tools, robots, conveyors, etc., to knowledge networks, including humans – and should normally be designed as communities of autonomous but cooperative/ collaborative entities.

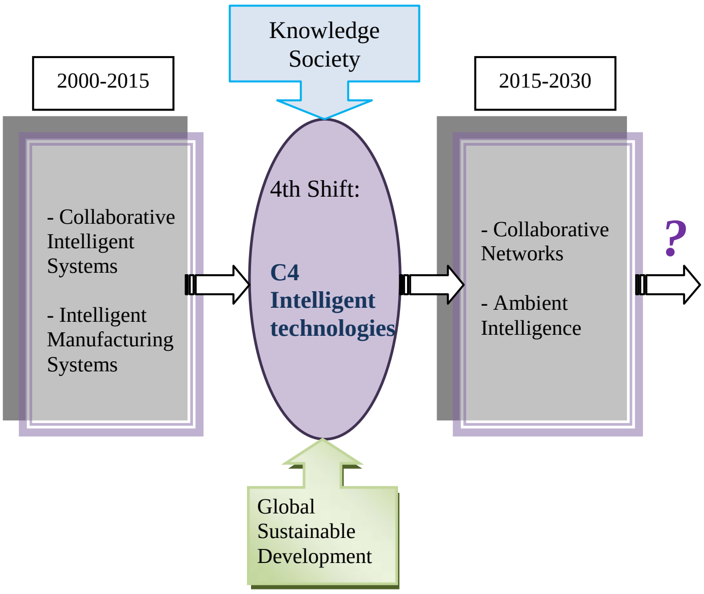


Figure 2

The problem is, one cannot design such a structure, provided they are highly dynamical and result from changing market necessities that can bring former “business foes” to become associates on vice-versa. In order for an enterprise to be a sound candidate for a CNO, it has to solve at least the following aspects of its functioning:

- Increased autonomous behaviour and self-X ability (self-recovery, self-configuration, self-organization, self-protection etc.),
- Increased abstraction level, from signals to data, to information, to knowledge, to decision or even wisdom;
- Integrated solutions for manufacturing execution systems, logistics execution systems a.s.o.
- Coherent representation of interrelations between data-information-knowledge

This is the reason for the great focus on problems like enterprise interoperability and especially a new kind of knowledge management, allowing to structures virtually different to coherently exchange true knowledge. Intelligent Manufacturing Systems (IMS) is a paradigm that reflects the concern for those problems

However, the nature and the basic characteristics of "intelligence" are still subject for endless debates and there is no widely recognized ontology of the field. Usually, it is associated with some abilities, as problem solving, communication and learning capabilities.

In fact, adaptation and self-organization are probably the most important phenomena linked to intelligence and they can be viewed as common factors in different approaches of intelligence definitions. The adjustment of behavioral patterns, eventually resulting in functional dynamic reconfiguration, is one of the clearest acts of adaptation. This correction is the result of applying different methodologies, concepts, approaches, logical schemes, etc. that finally represent the ability of reasoning and logical deduction.

At the level of abstract systems, a system that adapts well can minimize perturbations in its interaction with the environment and behaves successfully. Intuitively, this adaptation can be performed by a system that reacts to external stimuli by appropriately enacting different predefined processes. If the system has not a sufficient capacity of discerning between external events or it has no appropriate process to trigger for a given stimulus, it is unable to adapt anymore. This is the reason for the learning capacity is one of the most important factors for adaptation and thus for intelligence.

As a system, the enterprise (or a network of enterprises) can be viewed as a Complex Adaptive System (CAS), integrating materials, resources, and technologies, especially at knowledge level. The behavior resulted by the appropriate and synergic functioning of all enterprise active components and processes are criteria of enterprise success.

The balance between control and emergence is a real challenge for designing CAS involving non-linear phenomena, incomplete data and knowledge - a combinatorial explosion of states and dynamic changes in environment.

Autonomous manufacturing and logistics systems integrate mathematical models of hybrid systems with intelligent agents into hierarchical multi-purpose architectures, solving all problems of effectiveness and optimal delivering products to customers.

An intelligent enterprise should be characterized by the capacity to be flexible and adaptive in the market environment, but, in addition, it has also to cope with complexity, as it has to process an enormous quantity of information and a comparable amount of processes to trigger. Moreover, the environment itself – the global market, which includes not only customers and providers, but also competing enterprises – is highly perturbed and unpredictable. This context requires from the enterprise the ability to sense unbalances, perturbations and threats, react and adapt quickly, anticipate and predict developments and finally, actively influence the environment. The enterprise as a system has to refine its behavior within timescales much shorter than its employees can do it. Moreover, the enterprise can be included in cooperative networks that, as mega-systems, should attain the same performances, but on a greater level of complexity.

3 Complexity and Knowledge

Intelligent Manufacturing Systems (IMS) have to solve problems as:

- integrated production planning and scheduling (mathematical models and combinations of operation research, estimation of solution appropriateness, parametric scalable modules for production optimisation, integration of intelligent technologies as hybrid intelligent systems)
- real-time production control (recognition situations and related problem solving, decision support, reactive and proactive rescheduling algorithms and production control support systems).
- management of distributed, cooperative systems (multi-agent systems in hierarchical and heterarchical architecture, models for describing production networks, behaviour networks analysis and negotiation mechanisms and communication protocols for efficient behavioural patterns involving inter-related spatial and temporal effects)

and thus require new solutions based on the know-how from control engineering, software engineering and complex systems/ artificial life research.

New design promise scalability, reusability, integrability and robustness, based on the concepts of emergent and self-organizing systems, inspired by living organisms.

CAS modeling IMS should be considered as being rather probabilistic than deterministic in nature and factors such as non-linearity can magnify apparently insignificant differences in initial conditions into huge consequences. It means that the long term predictions for complex systems are not reliable. A reliable prediction procedure should be one based on iteration with small increments.

On the other hand, solving a problem into the framework of a complex system is not, for enterprises or enterprise networks, a task with an infinite time horizon. Sometimes, the solving time is almost as important as the solution.

In short, the complexity theory has attested that:

- complex systems are highly dependent on their initial state
- the future cannot be forecasted based on the past – this means that one can only make one step ahead
- the scaling factor of a non-linear system is highly important for the prediction accuracy

An answer to the double challenge imposed by the intelligent enterprise as a system and by the complexity of problems it has to solve is a representation that uses both functional and managerial autonomous units. There is no more question to control such a system in order to accomplish a given objective, but to structure its composing parts so as to allow to every one to act when the appropriate context appears.

At the beginning of its relatively short history, knowledge management strategies have started from the implicit assumption that all the necessary knowledge exists somewhere and its techniques have to focus on its integration and deployment into practice. As a consequence, at the heart of most of them can be found technological approaches, as data warehousing, groupware, document management, imaging and data mining. Those approaches have improved in a certain measure enterprise performances, but they cannot stand for the future. It was only a stage, that is already called the first generation knowledge management.

The second generation knowledge management involves a new view, which emphasizes both knowledge production and integration. It introduces new terms, concepts and insights, and it definitely implies a new philosophy of enterprise concept. New knowledge can emerge from existent one, if individuals or agents identify new problems.

In [5] was defined a seconde generation knowledge management architecture, based on knowledge modules and able to solve new problems, thus producing knowledge.

The main element of the architecture was the “knowledge module” – concept with both functional and managerial aspects.

A "knowledge module" is a sequence (partly ordered) of primitive actions and/ or activities that are necessary to fulfill a given objective. Every

action/ activity can have assigned – if necessary – resources, costs, duration, parameters a.s.o.
An activity (managerial unit) denotes the implementation of a knowledge module (functional unit) and, respectively, at a lower level of granularity, a task is the implementation of a primitive action.
The problem solving approach is: a problem is raised by the strategic level. At this level, problem specification is made taking into account very general knowledge, as enterprise purpose, technologies and theories that are available a.s.o. Problem specification is made in terms of initial conditions and final results.
The operational level is that one where different stakeholders (individuals, departments), with diverse skills, store knowledge.
The problem solving is performed by a technique of puzzle "trial and error": activities that start with the specified initial conditions are considered to be potential parts of the solution. Their results are simulated and analyzed and will be the initial conditions for the step two of the iterative process of solution generation. The procedure will continue until the desired final conditions will be attained or until no advance could be made. A solution will be a sequence of activities where the first one has the initial conditions of the problem and the last one has the desired outcomes.
It is clear that in an appropriate context, a problem could have several solutions. On the other hand, the state space of possible solutions could explode, imposing the necessity of a control mechanism that will eliminate trajectories which are obviously false. This mechanism is represented by a value judgment block. Criteria for eliminating unpromising partial solutions could reside in implementation conditions (unavailable infrastructure, for instance), or in more complex and flexible domain-dependent structures, that can improve by learning.
Obviously, a very important problem is the implementation of such architecture. Some of the implementation requirements include distribution, capacity of decomposition and aggregation for knowledge modules as well as knowledge hierarchy and classification.
The main attributes of intelligent architectures for manufacturing, as perception, reasoning, communication and planning (or behaviour generation) are organized on different layers and need a large, distributed knowledge base. On the other hand, they necessary include several levels of abstraction. Usually, strategic goals are relatively unclear, with respect to the practical aspects concerned by the shop-floor on-line activities, and they need stepwise decomposition and reformulation in order to be achieved. Moreover, it is not sure enough from the beginning if the system can fulfil strategic specification.
Although those considerations, knowledge can emerge from knowledge and the generic process is the same, even if formal specifications are different. The process of knowledge management is following a spiral, as presented in Figure 3.

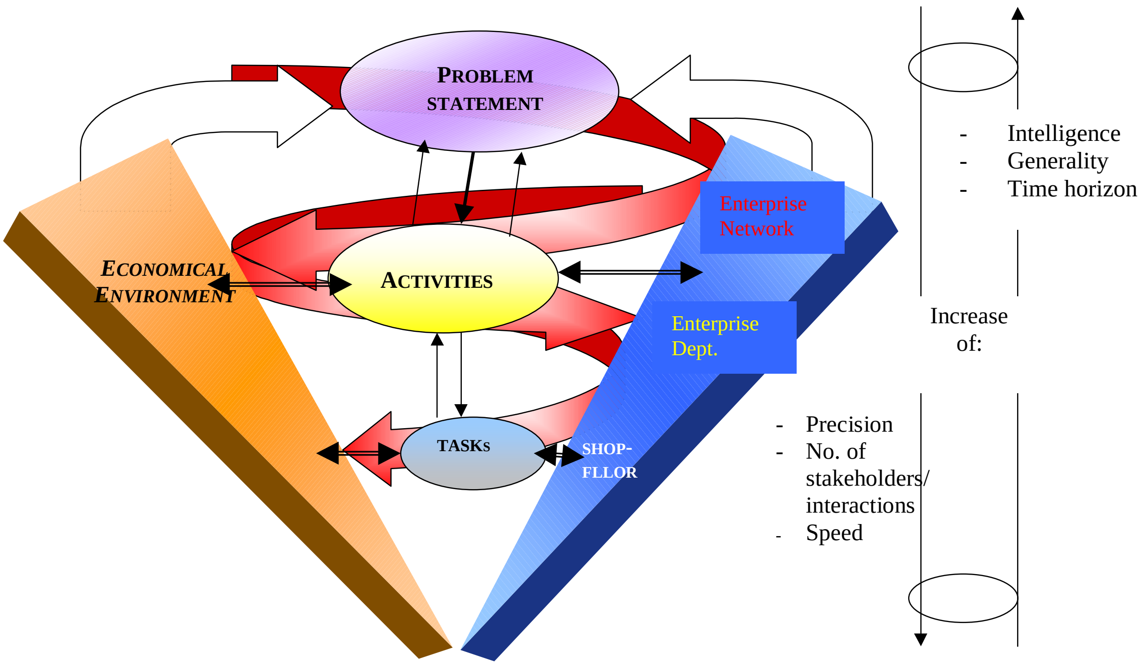


Figure 3

4 Intelligent Systems Architecture for Manufacturing– ISAM

The ISAM model allows a large representation of activities from detailed dynamics analysis of a single actuator in a simple machine to the combined activity of thousands of machines and human beings in hundreds of plants.

First level of abstraction of ISAM provides a conceptual framework for viewing the entire manufacturing enterprise as an intelligent system consisting of machines, processes, tools, facilities, computers, software and human beings operating over time and on materials to create products.

At a second level of abstraction, ISAM provides a reference model architecture to support the development of performance measures and the design of manufacturing and software.

At a third level of abstraction, ISAM intend to provide engineering guidelines to implement specific instances of manufacturing systems such as machining and inspection systems.

To interpret all types of activities, ISAM adapts a hierarchical layering with different range and resolution in time and space at each level. In this vision could be defined functional entities at each level within the enterprise such that each entity is represented by its particular responsibilities and priorities at a level of spatial and temporal resolution that is understandable and manageable to itself.

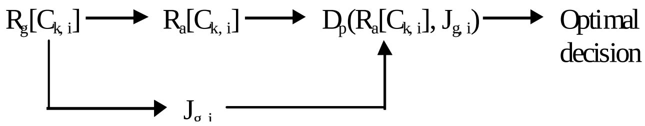
The functional entities, like as agents, receive goals and priorities from above and observe situations in the environment below. Each functional entity, at each level has to provide decisions, to formulate plans and actions that affect peers and subordinates at levels below.

Each functional entity needs access to a model of the world (large knowledge and database) that enables intelligent decision making, planning, analysis and reporting activity into a real world with large uncertainties and unwanted signals.

The ISAM conceptual framework attempts to apply intelligent control concepts to the domain of manufacturing so as to enable the full range of agile manufacturing concepts.

The ISAM could be structured as a hierarchical and heterarchical system with different level of intelligence and precision. For each level, the granularity of knowledge imposes the operators Grouping (G), Focusing Attention (F) and Combinatorial Search (S) to get an optimal decision.

For a representation of knowledge into categories like $C_{k,i}$ for each level of the hierarchy we have to define a chain of operators G, F and S:



where

$R_g[C_{k,i}]$ – is a knowledge representation of grouping

$R_a[C_{k,i}]$ – is a representation of attention

$D_p(R_a[C_{k,i}], J_{g,i})$ - decision-making process

$J_{g,i}$ – cost function associated for each level i

Knowledge is represented on each level with a different granularity and by using GFS (Grouping, Focusing Attention, Combinatorial Search) operators which organize a decision process. At each level of the architecture is implemented a dual concept-feed-forward and feedback control and the GFS operators are implemented on different levels.

4 Conclusion

Knowledge Management is a paradigm that evolved in parallel with- and driven by the evolution of manufacturing systems. As the future imposes the concept of Intelligent Manufacturing Enterprise, knowledge management has also to evolve in order to support this new paradigm. The paper presents the common history of the two paradigms and proposes a new knowledge management architecture based on complexity theory ideas and control engineering approach.

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