The Intelligent Manufacturing Paradigm in Knowledge Society

Ioan Dumitrache and Simona Iuliana Caramihai
POLITEHNICA University of Bucharest
Romania

1. Introduction

The today society has to face great challenges due, ironically, to its own development capacity and speed, that resulted in phenomena like globalization and competition, in a more and more rapidly changing environment.

The development of Information & Communication Technologies (ICT), which was intent to solve usual problems, became actually a driver for the increased complexity of socio-economical advance.

In this context, especially in manufacturing, the role of human resources was, for the last century, ambiguous, with balances between the trends that relied mostly on technology and those that trusted human superiority.

Actually, it is the role of knowledge management, as a relatively new discipline, to find a way by which humans and technology could optimally collaborate, towards the benefits and satisfaction of whole society.

This work intends to propose some functioning principles for knowledge management architectures, where human and software agents could coexist and share knowledge, in order to solve new problems.

The authors have taken into account researches in the fields of manufacturing system, as well as from the area of knowledge management, control systems, organizational research and complexity analysis, in order to develop a model for the imbricate development of manufacturing and knowledge.

The first part presents the evolution of manufacturing paradigm, underlining the parallel development of ICT and knowledge management.

The second one focuses on the paradigm of Intelligent Manufacturing and presents some of the developed control approaches based on complexity theory and multi-agent systems.

The following part presents some developments in the field of the knowledge management and the last ones introduce the authors view on the subject.

Finally, some future trends towards a knowledge society where humans and software agents will symbiotically work through their mutual progress and satisfaction are suggested.

2. Historical evolution of manufacturing and knowledge management concepts

From very long time ago people knew that information means power and that good decisions critically depend on the quality and quantity of analysed data, as well as on a good reasoning capacity.

Wisdom and intelligence were always considered to be necessary qualities for success, even if not always sufficient, and procedures to acquire them were studied since the beginning of human civilisation. ("*By three methods we may learn wisdom: First, by reflection, which is noblest; second, by imitation, which is easiest; and third, by experience, which is the bitterest*"- Confucius)

There were identified subtle differences, between information and knowledge ("*Information is not knowledge*" - Albert Einstein) for instance, or between erudition and wisdom. Links between learning and reasoning capacity ("*Learning without thought is labour lost; thought without learning is perilous*"- Confucius), the genesis of new ideas and the triggering events for great inventions, the good balance between expertise and innovation – were and still are goals of study for educators, philosophers, scientists and even managers.

But the real need of a formal approach and understanding was triggered by the technological qualitative bound and its implications.

After the Second World War, tremendous changes arrived both in the industry and society (Figure 1). The computer era was at its beginning and, together with its implication in industry, human resources management took also a new shift.
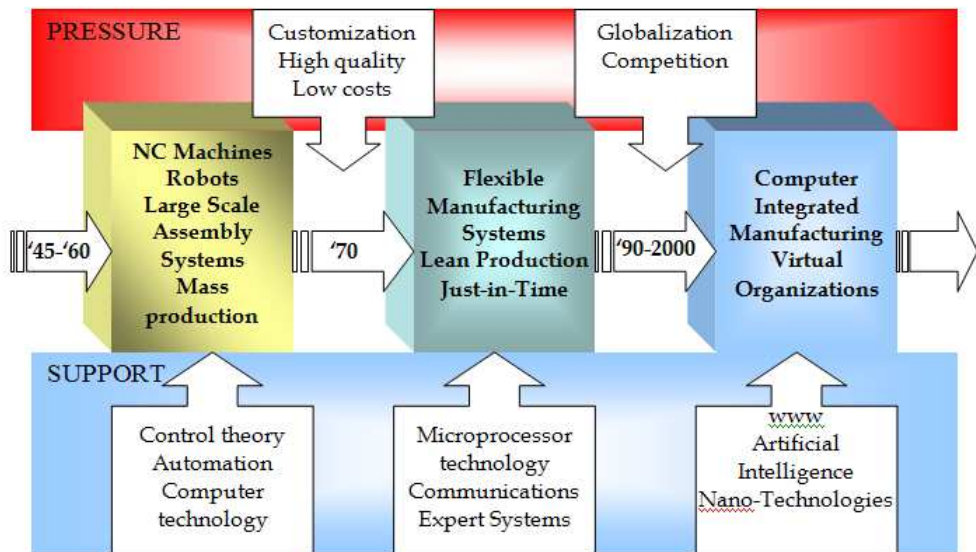

Fig. 1. Evolution of manufacturing paradigms

Indeed, the era of control and automation can be dated from the middle of the XX century, as some of the most important connected events in science and engineering occurred between years '45 and '60 (Mehrabi et al., 2000): first electronic computer in 1946, invention of transistor in 1946-47, integrated circuits and the first electronic digital computer, as well

as first applications of automatic control in industry in 1949-50; development of numerical control (NC) and NC languages, invention of machining center and first industrial robot between 1950-60. Especially after 1956, an important role in leading the research in the field of control was played by the International Federation of Automation and Control.

New management challenges were also brought by the increased market demands for products, that resulted into a rapid development of new enterprises and, subsequently, into an increased competition for customers and profit. Large scale assembly systems and mass production shop floors expanded and improved until it became obvious that a new manufacturing approach was necessary.

With customers realizing to be real drivers of the industrial development, the quality of products and the high productivity, though extremely important goals for manufacturing enterprises, were no more sufficient: in order to attract new customers and to keep the old ones, diversity of products as well as the capacity to bring new desirable products on the market became key factors in an enterprise success.

This evolution resulted not only in supplementary attention for technologies and automation, but also into new managerial concepts with regard to human resources and to knowledge assets, and also into an increased complexity of the manufacturing enterprise as a system, demanding new concepts and theories for control and performance evaluation.

The first shift of manufacturing paradigm (fig.1) was brought by new control concepts: 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 (Seppala et al., 1992; Adler, 1995). As manufacturing is an activity where the importance of the quality of man and machines is overwhelmed only by the importance of their interaction, it is interesting to note that automation imposed two contrasting views on human resources: the first one consider humans as the source of errors and relies on machines and extensive automation, and the second regards people as a source of fast error recovery.

Nevertheless, as repetitive tasks were more and more assigned to machines, though increasing the speed and the reliability of the production, human resource became more creative at the design level and more skilled in order to operate at the shop floor level, as a result of training and instruction, and thus becoming a valuable asset for the enterprise. Moreover, with the increasing importance of computer-aided techniques, high qualified personnel needed complementary training in computer use.

The need of a change was underlined also by the oil crisis (1973) which continued with a major depression in USA machine tool industry and the recession of automotive industry. At that moment, the Japanese manufacturing enterprises, which have emphasized the importance of human resource and of discipline of production, based on an accurate definition of design and manufacturing processes, proved their superiority on the international market by achieving high-quality products at low costs.

In years '70 the paradigm of "Flexible Manufacturing System" was defined, as a machining system configuration with fixed hardware and programmable software, capable to handle changes in work orders, production schedules, machining programs and tooling, so as to cost-effective manufacture several types of parts, with shortened changeover time, on the same system, at required (and variable) volume and given quality. The capability of storing and retrieving information and data proved to be one of the key factors for the efficiency of

those new (and expensive) systems. As a consequence, the development of new disciplines as computer-aided document management and database management was highly stimulated. First difficulties arisen in the transfer of information between software applications, as CAD and CAM, that had different approaches to integrate the same data.

On the other hand, another of the key factors of enterprise success became the capacity to shorten the duration of product life cycle, especially in the design and manufacturing phases. One of the approaches used for accomplishing this goal was found to be the detailed enterprise process decomposition and specification allowing re-use, analysis and optimisation and anticipating the concurrent engineering paradigm.

This new paradigm can be considered as a pioneer for the evolutionary approaches in intelligent information systems with direct applications in manufacturing.

From the manufacturing point of view, terms and procedures should be more precisely defined, in order to allow the different kinds of flexibilities, as they were defined by (Browne, 1984) and (Sethi and Sethi, 1990)

- **Machine flexibility** - The different operation types that a machine can perform.
- **Material handling flexibility** - The ability to move the products within a manufacturing facility.
- **Operation flexibility** - The ability to produce a product in different ways
- **Process flexibility** - The set of parts that the system can produce.
- **Product flexibility** - The ability to add new products in the system.
- **Routing flexibility** - The different routes (through machines and workshops) that can be used to produce a product in the system.
- **Volume flexibility** - The ease to profitably increase or decrease the output of an existing system.
- **Expansion flexibility** - The ability to build out the capacity of a system.
- **Program flexibility** - The ability to run a system automatically.
- **Production flexibility** - The number of products a system currently can produce.
- **Market flexibility** - The ability of the system to adapt to market demands.

From the informational point of view, two main trends can be identified: One, which takes into account storing and retrieving data and information, as well as more complex structures as NC programmes, part design documents, software libraries a.s.o. Its aim is to allow cost reduction by reusability of problem solutions and to shorten product life cycle by using computer aided activities and automatically exchanging product details between different software applications. In time, this trend resulted in developing disciplines as document management, database design and management etc. that can be considered a precursor of first generation knowledge management.

Some drawbacks already appeared: even if the number of information technologies (IT) providers were still reduced comparatively with today, difficulties arise when data and information had to be shared by different applications or transferred on other platforms. Investing in IT was proved not to be sufficient for increasing manufacturing efficiency over a certain limit, exactly because of these information portability problems. Having the right information at the right place and at the right time seemed to be less obvious, despite (or even because of) increasingly extensive databases.

Even today there are no generally acknowledged definitions for data and information, but the extensive development of computer aided manufacturing was one of the first occasions to discriminate between content directly observable or verifiable, that can be used as it is –

data – and analyzed and interpreted content, that can be differently understood by different users – information – even if they work in the same context.

The accumulation of those drawbacks, combined with the increasing tendency of customization (resulting, for enterprises, in the need of extended flexibility) started a sort of 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. In other words, the diversification and complexity of manufacturing production resulted in the complexity of manufacturing enterprises as production systems.

The other trend was re-considering the importance of human resources. Not only new kinds of specialists entered the labour market – software specialists whose contribution to product cost reduction and quality increase was indirect and which were rather expensive, but high level specialists from different other areas needed training in computer use for being more efficient. However, even with those added costs, it became obvious that expert human resource was an extremely valuable asset for the enterprise, especially in the manufacturing area, where innovation capacities, as well as the possibility to rapidly solve new problems with existent means were crucial. One problem was that such experts were rare and expensive. Their expertise was augmented by their experience into a company, by what is now called organisational knowledge and this raised a second and more important problem: when an expert changed the company, one brought in the new working place some of the knowledge from the old one.

This is the reason for this second trend developed in expert systems theory and knowledge engineering, cores of second generation knowledge management.

The concepts of expert systems were developed at Stanford University since 1965, when the team of Professor Feigenbaum, Buchanan, Lederberg et .all realised Dendral. Dendral was a chemical expert system, basically using "if-then" rules, but also capable to use rules of thumb employed by human experts. It was followed by MYCIN, in 1970, developed by Edward H. Shortliffe, a physician and computer scientist at Stanford Medical School, in order to provide decision support in diagnosing a certain class of brain infections, where timing was critical.

Two problems have to be solved in order to build expert systems: creating the program structure capable to operate with knowledge in a given field and then building the knowledge base to operate with. This last phase, called "knowledge acquisition" raised many problems, as for many specialists were difficult to explain their decisions in a language understandable by software designers. It was the task of the knowledge engineer to extract expert knowledge and to codify it appropriately. Moreover, it was proven that something exists beyond data and information – knowledge – and that is the most valuable part that a human specialist can provide.

Expert systems started to be used despite the difficulties that arise in their realization and despite the fact that an "expert on a diskette" (Hayes-Roth et al, 1983) was not always a match for a human top-expert: but they were extremely fast, not so costly and could not leave the company and give to competitors its inner knowledge. Moreover, learning expert

systems could improve their performances by completing their knowledge bases and appropriately designed user-interface allowed them to be used for training human experts.

Even if expert systems and their pairs, decision support systems are now considered more to be results of artificial intelligence, techniques used in extracting and codifying knowledge are important parts in knowledge management policies.

As Feigenbaum pointed in (Feigenabum, 1989) it was a concept that complemented traditional use of knowledge, extracted from library resources as books and journals, waiting as "passive objects" to be found, interpreted and then used, by new kind of books that are ready to interact and collaborate with users.

Both trends had to converge finally in order to overcome the expanding spiral of technological drawbacks underlined by the first trend and to adapt management techniques to the ever increasing value of human resources, emphasized by the second one. (Savage, 1990)

And, effectively, consortiums of hardware and software suppliers, important manufacturers interested in flexibility, research institutes and universities, such, for instance AMICE, managed new shift in manufacturing paradigms - shift concretised especially in the concept and support of Computer Integrated Manufacturing (CIM) – Open System Architecture (OSA) (CIM-OSA, 1993)

CIM-OSA defines a model-based enterprise engineering method which categorizes manufacturing operations into Generic and Specific (Partial and Particular) functions. These may then be combined to create a model which can be used for process simulation and analysis. The same model can also be used on line in the manufacturing enterprise for scheduling, dispatching, monitoring and providing process information.

An important aspect of the CIM-OSA project is its direct involvement in standardization activities. The two of its main results are the Modeling Framework, and the Integrating Infrastructure.

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.

Concerning knowledge management, the integrationist paradigm in manufacturing was equivalent 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. Moreover, all drawbacks regarding the transfer of data/ information between different software applications/ platforms in the same enterprise were solved by a proper design of the Integrating Infrastructure and by the existence of standards.

It still remains to be solved the problem of sharing information between different companies and the transfer of knowledge (Chen & Vernadat, 2002).

3. Intelligent Manufacturing Systems: concepts and organization

The last decade has faced an impressive rate of development of manufacturing organizations, mainly due to two driving forces in today's economic:

- *Globalization*, that has brought both a vast pool of resources, untapped skills, knowledge and abilities throughout the world and important clusters of customers in various parts of the world
- *Rapidly changing environment* which converges towards a demand-driven economy

Considering these factors, successful survival in the fast pace, global environment requires that an organization should at least be able to:

- Discover and integrate global resources as well as to identify and respond to consumer demand anywhere in the world.
- Increase its overall dynamics in order to achieve the competitive advantage of the fastest time to market - high dynamics of the upper management in order to rapidly develop effective short term strategies and planning and even higher dynamics for the operational levels
- Dynamically reconfigure to adapt and respond to the changing environment, which implies a flexible network of independent entities linked by information technology to effectively share skills, knowledge and access to others' expertise

The CIM-OSA approach and the paradigms derived from the integrationist theory in manufacturing insisted on very precise and detailed organization of the enterprise as a key factor of success.

However, research exploring the influence of organizational structure on the enterprise performance in dynamic environments, already indicated (Burns and Stalker, 1961; Henderson and Clark, 1990; Uzzi, 1997) that there is a fundamental tension between possessing too much and too little structure.

As a general result, organizations that have too little structure do not possess the capability of generating appropriate behaviours (Weick, 1993), though lacking efficiency, as those using too much structure are deficient in flexibility (Miller and Friesen, 1980; Siggelkow, 2001).

Real-life market development and manufacturing systems performances have confirmed this dilemma for organizations competing in dynamic environments, as their sucess required both efficiency and flexibility.

New manufacturing paradigm arised, from Concurrent Engineering and Virtual Organizations to Intelligent Manufacturing Systems, and networked enterprises, each of them trying to make use of collaborative autonomous structures, simple enough to be versatile, but connected by ellaborated protocols of communications, ready to ensure efficient behavior.

To manage these new kinds of complex systems, a new approach has to be developed, integrating Computer and Communications in order to reinforce the analysis power of Control theory. This can be viewed as the C3 paradigm of control, for collaborative networks. (Dumitrache 2008)

A Virtual Organization (VO) is, according to a widely accepted definition: "a flexible network of independent entities linked by information technology to share skills, knowledge and access to others' expertise in non-traditional ways". A VO can also be characterized as a form of cooperation involving companies, institutions and/or individuals delivering a product or service on the basis of a common business understanding. The units participate in the collaboration and present themselves as a unified organization. (Camarinha-Matos & Afsarmanesh, 2005).

In the framework of increasing 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. (Thoben et al, 2008)

The enterprise itself is regarded as a network integrating advanced technologies, computers, communication systems, control strategies as well as cognitive agents (both humans and/or advanced intelligent systems) able not only to manage processes and products, but also to generate new behaviours for adapting themselves to a dynamic market. The study of the emergent behaviour of those cognitive agents imposes new theories, as the theory of complexity.

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

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.

The above mentioned C3 paradigm of control has shifted, for this new class of systems, to a C4 one, integrating Computers, Communications and Cognition and resulted in the emphasis of the great importance of knowledge in attaining intelligent behaviour. (Dumitrache 2008)

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 is probably one of the first identified phenomenons linked to intelligence and it can be viewed as a sort of common factor in different approaches of intelligence definitions. The adjustment of behavioral patterns 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. On a higher level of adaptation, intelligence requests also the capacity of dynamical self-

organization of communities of agents into common goal-oriented groups, in answer to new problems.

At the level of abstract systems, adaptation can be viewed as following: a system that adapts well can minimize perturbations in its interaction with the environment and behaves successfully. As a simple case study, this adaptation can be done 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 as a response to 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. There is a wide set of applications that involve system adaptation, such as communication systems, banking, energy management, transportation, manufacturing, a.s.o. Besides the necessity to have an adaptive behavior, all those systems have in common, in different degrees, other similarities, like the high dynamics, multiple solutions to a given problem, high heterogeneity.
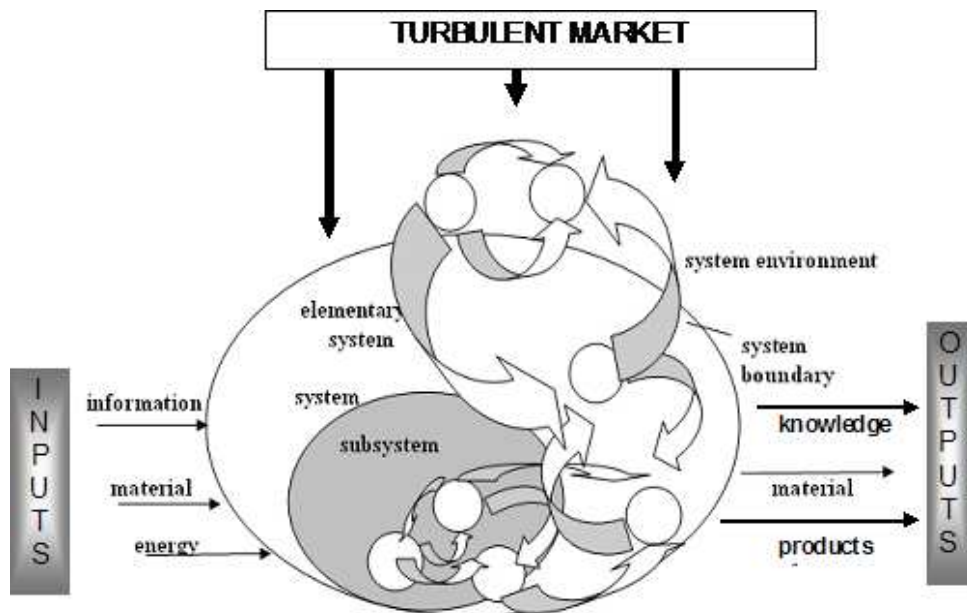

Fig. 2. A systemic view of enterprise

Intelligent Manufacturing Systems (IMS) can be viewed as large pools of human and software agents, with different levels of expertise and different local goals, which have to act together, in variable configurations of temporary communities in order to react to dynamically changing inputs (Figure 2.) and to accomplish dynamically changing objectives.

As systems acting in unpredictable and turbulent environments, 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)

Manufacturing enterprise intelligence should then encompass features as:

Adaptivity – as a primary intelligence level, implying the capacity of acting on rules "if-then-else"

Reasoning – as a higher level that includes preparation of new possible scenarios and strategies "what if..."

Knowledge representation and processing (including focusing, feature identification and organization in connectionist structures)

Considering the problematic and the structure of Intelligent Manufacturing it became obvious that it corresponds to at least some definitions of Complex Adaptive Systems:

Definition 1: A **CAS** is a complex system that includes *reactive* units, i.e., units capable of exhibiting systematically different attributes in reaction to changed environmental conditions.

Definition 2: A **CAS** is a complex system that includes *goal-directed* units, i.e., units that are reactive and that direct at least some of their reactions towards the achievement of built-in (or evolved) goals.

Definition 3: A **CAS** is a complex system that includes *planner* units, i.e., units that are goal-directed and that attempt to exert some degree of control over their environment to facilitate achievement of these goals.

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, dynamic changes in environment.

It is easy to discern that there is a strong similitude between CAS characteristics underlined in the above definitions and the main features of intelligent agents, as they are widely recognized (Wooldridge & Jennings, 1995) :

- *reactivity*: agents should be able to perceive their environment and respond timely and accordingly to external events, in order to satisfy their *design objectives*
- *pro-activeness*: agents should be able to exhibit goal-directed behaviour by *taking the initiative*
- *social ability*: intelligent agents should be capable of interacting with other agents in order to exchange information and knowledge susceptible to support the accomplishment of their objectives

Consequently, it is only natural the fact that control approaches for CAS are mainly based on multi-agent structures (MAS) and theory.

Starting with the well-known Albus model (Albus, 1997) of an intelligent agent, their structure includes, implicitly or explicitly, the following modules:

- World Model (WM) – which includes the information and knowledge detained by the agents and that acts both as a knowledge manager in problem solving and as an integrator of environmental information;
- Behaviour Generation (BG) which ensures the *pro-activity* of the agent by planning different scenarios of activities to be performed by the agent in order to accomplish a given goal and its *reactivity* by scheduling a scenario conforming to external events occurred;
- Value Judgement (VJ) which evaluates scenarios generated by BG module, estimating their effects accordingly with WM knowledge and taking into account the agent designed objectives by cost-objectives functions
- Decision Making (DM) which finally choose the scenario to be executed by the agent

The WM module is the core of an agent and even if its performances can be improved by modifying evaluation procedures in VJ and decision criteria in DM, the real problem solving "power" of an agent resides in the quality and quantity of knowledge it possess.

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.

As a system, the enterprise (or a network of enterprises) will be considered as a complex system, integrating materials, resources, technologies, not only by information technologies infrastructures and management, but 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.

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 that 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 meta-systems, should attain the same performances, but on a greater level of complexity.

Consequently, it is necessary to adapt the system theory to such challenges, in order to deal with system abstractions that are extremely large and complex.

The complexity management paradigm is challenging the traditional management assumptions, by considering that the behavior of the system is not predictable, based on previous information of its evolution, but, on the contrary, it is highly non-linear. As a consequence, the behavior of a complex system is emergent, in the sense that it results from the interaction of many participant's behaviors and cannot be predicted from the knowledge of what each component does. Moreover, an action can lead to several possible outcomes, some of them being disproportionate with the action itself, and it became obvious that the "whole" is very different from the composition of parts.

As a consequence, it results that directing an organizational network towards a given

behavior, expressed in inter-related goals, represents an objective that requests other tools than mathematical modeling, behavior prediction and linear control. Alternative modeling and analysis approaches include hybrid and heuristic techniques, agent-based models, knowledge management and simulation, that seem to represent a more proper way of study.

Digital manufacturing implies intelligent control and integration of micro-electromechanical systems, mechatronics, manufacturing execution systems, multi-agent systems, human-machine systems and e-technologies to digitally control with increased agility the entire manufacturing chain, from design to manufacturing, to maintenance and service, over the whole product and processes life-cycle.

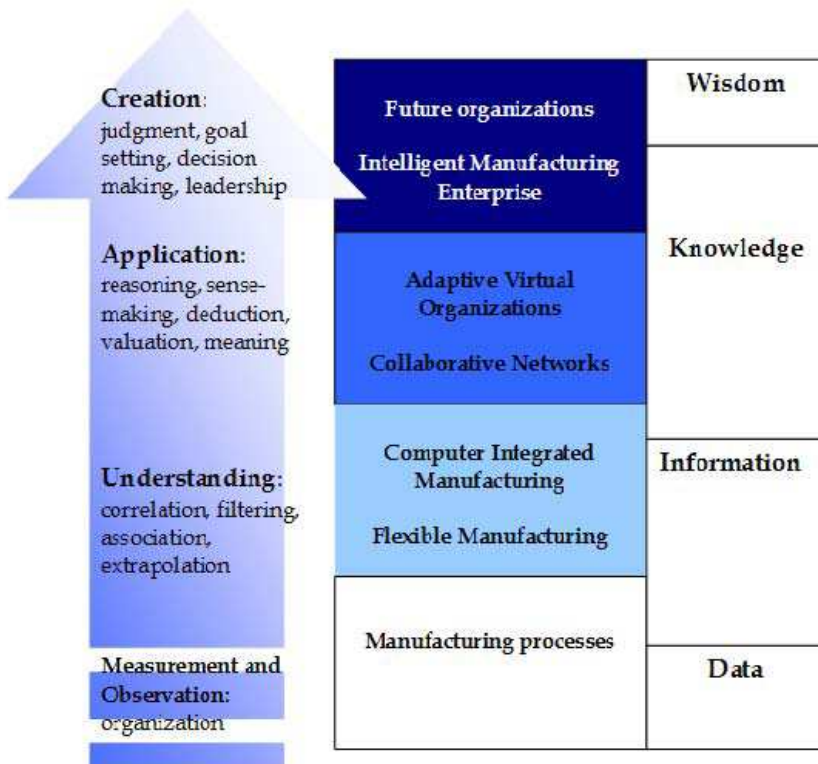## 4. Evolution of Knowledge Management in manufacturing

Fig. 3. Evolution of Knowledge Management

Modern manufacturing (Figure 3) has started in extensively using data, which are the first level of knowledge, in order to ensure a constant quality of products and an optimization of manufacturing processes in terms of time. Sometimes referred as *raw intelligence* or *evidence* (Waltz, 2003), data result from observation and measurement and can be retrieved in primitive messages of low level automation. In order to properly use data for analysis and

optimization, they have to be organized: sorted, classified, indexed a.s.o. and this contextualization transform data in information.

Information needs understanding and information management implies not only filtering and correlation of data, but also association and extrapolation of new obtained information.

As manufacturing paradigms evolved through Flexible Manufacturing Systems and Computer Integrated Systems, procedures of information management were improved until, from models that synthesized static and dynamic relationships between information, a new level of intelligence arise: knowledge.

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

CAS theory holds that living systems (i.e. organizations made up of living, independent agents, such as people) self-organize and continuously fit themselves, individually and collectivelly, to user-changing conditions in their environment.

Knowledge (in the form of theories and „mental models") according to CAS theory, can be represented by „rules"that agents (or people) follow in their ongoing attempts to adapt themselves sucessfully to their environment.

It is expected from the complexity theory to understand how knowledge forms at the level of individual agents and then influences knowledge processing at the level of the collective to produce shared organizational knowledge. The application of complexity theory to a broad range of business and organizational development issues is widening in practice.

There is a profound connection between complexity theory and knowledge management.

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 – including extreme customization, necessity of low production costs and short delivery times as well as necessity of networking enterprises, on short or long time horizon.

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.

There are two main philosophical orientations in knowledge management (Sanchez, 1997):

Personal Knowledge Approach – that assumes knowledge is personal in nature and very difficult to extract from people. It must be transferred by moving people within or between organizations. Learning can only be encouraged by bringing the right people together under the right circumstances.

Organizational Knowledge Approach – implies that knowledge can be articulated and codified to create organizational knowledge assets. Knowledge can be disseminated (using information technology) in the form of documents, drawings, best practice models and so on. Learning processes can be designed to remedy knowledge deficiencies through structured, managed, scientific processes.

The Intelligent Manufacturing paradigm takes into account a synergic combination of these orientations and hopes to lead and attempts to realize a new shift in knowledge management: wisdom. Wisdom means not only using existing knowledge for solving new problems, but mainly the capacity to issue new problems to be solved.

5. Knowledge management and intelligent enterprise

In (Davis et al, 2007) is presented a very interesting study emphasizing the effect of the balance between organizational structure and enterprise efficiency for different kind of enterprises and environments. The conclusions of the study have revealed the following:

There is an inverted U-shaped relationship between structure and performance, that is *asymmetric:* too little structure leads to a catastrophic performance decline while too much structure leads to only a gradual decay

The key dimension of the market dynamism is *unpredictability* that underlines the tension between too much and too little structure. The *range* of optimal structures varies inversely with unpredictability: in unpredictable environments, there is only a very narrow range of optimal structures with catastrophic drops on either side that are likely to be difficult to manage.

Other dimensions of market dynamism (i.e. velocity, complexity, and ambiguity) have their own unique effects on performance

Similar to organization studies, network research presented in the mentioned paper indicates an environmental contingency such that the optimal structure decreases within increasing market dynamism. As in organization studies, the logic is that flexibility becomes more valuable than efficiency as market dynamism increases because of the more pressing need to adjust to environmental change.

The balance of organizational structure is also important for the complexity approach. Complexity theory seeks to understand how system level adaptation to environmental change emerges from the actions of its agents (Anderson, 1999; Carroll and Burton, 2000; Eisenhardt & Bhatia, 2001).

The common conceptualizations of an enterprise as a network of business units, partially connected by commonalities such as the same brand and innovation processes (e.g., Galbraith, 1973; Galunic & Eisenhardt, 2001; Gilbert, 2005), and strategy consisting of unique, yet intertwined decisions such as manufacturing and marketing (e.g., Rivkin, 2000) are also more concrete operationalizations of the abstract concept of a complex adaptive systems.

Intelligent Manufacturing Systems 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 biological ones (living organisms).

Production structures can be considered as Complex Adaptive Systems (CAS), as manufacturing systems presently work in a fast changing environment full of uncertainties.

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.

Complex adaptive systems are to 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.

Bearing this in mind, the approach presented in this paper will allow to start with different evolutions, that will be eventually eliminated when they will prove inappropriate.

In short, the complexity theory has attested that complex systems are highly dependent on their initial state and their future evolution cannot be forecasted based on the past. Moreover, 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 (Dumitrache & Caramihai, 2008), (Dumitrache et al, 2009).

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.

Reconsidering the intelligent manufacturing enterprise, as mentioned above, as a pool of agents that have to accomplish both explicitly defined goals of themselves and implicitly defined global goals of the enterprise, it can be deduced that they also have to reach a balance between goal-directed and reactive behavior.

More precisely, as stated in (Wooldridge, 2000) we want agents to attempt to achieve their goals systematically, but not blindly executing their scenarios even when the goal is no longer valid. An agent should react to a new situation, in time for the reaction to be of use, but it should not continually react, never focusing enough on a goal to finally achieve it.

This balance can be obtained, as in the case of an manufacturing enterprise, by actually combining the functioning principles of the multi-agent architecture – that shapes the dynamic grouping of agents in global-goal oriented comunities – and the decision making inner mechanisms of agents.

Our approach is considering people as particular enterprise resources: even if the particular knowledge of an individual about "how to accomplish" a goal cannot be extracted, ones skills can be systematically taken into account and used as a primitive action, incorporated in more complex ones.

Actually, knowledge management is recognizing and taking into account two main kind of knowledge co-existing in an organization (Dalkir, 2005): *explicit knowledge*, which is the only

form of knowledge possessed by non-human agents, and which has been codified and structured and *tacit knowledge,* which is the intangible knowledge that only human agents can have.

Organizational knowledge management approach focus especially on procedures to transform tacit knowledge into explicit, but as it is widely recognized the fact that such an objective will not be completely fulfilled, we will present in the following and multi-agent knowledge management architecture that takes into account both kind of agents (human and non-human) and both king of knowledge, focusing only on communication and grouping of agents.

It will be denoted by "knowledge" or by "knowledge module" 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.

It will be also considered that by an activity (as a managerial unit) is denoted the implementation of knowledge (as a functional unit) and, respectively, at a lower level of granularity, by a task, the implementation of a primitive action.

It results from here that:

- the definition of a "knowledge module" is iterative (it can include other knowledge modules);

- it is always important for solving a problem to define primarily a list (part of a common dictionary) of primitive actions – implying, at the organizational level, an important focus on generating, articulating, categorizing and systematically leveraging organizational knowledge assets.

Figure 4 represents a problem solving approach in the following circumstances: a new problem is raised, eventually by the strategic level of a manufacturing enterprise. 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 the one where different stakeholders (individuals, departments), with diverse skills, store and share 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 a knowledge architecture. Some of the implementation requirements include distribution, capacity of

decomposition and aggregation for knowledge modules as well as knowledge hierarchy and classification.
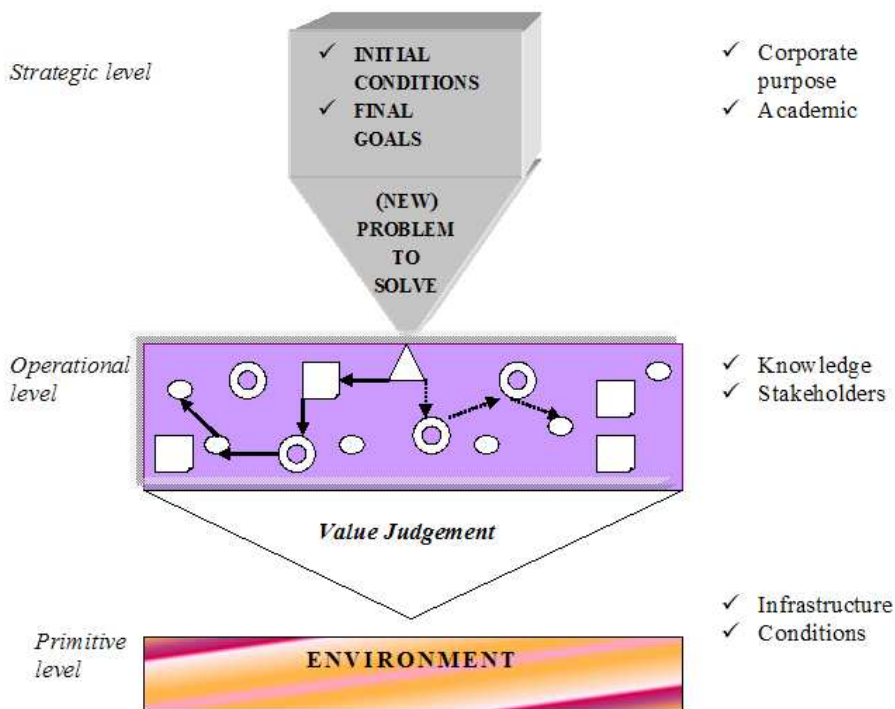

Fig. 4. Problem solving approach

6. Intelligent Systems Architecture for Manufacturing Enterprise – ISAM

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 5.
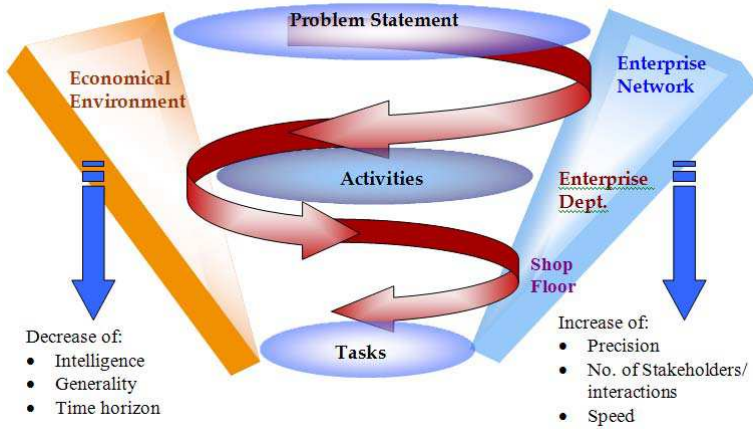
Fig. 5. Knowledge spiral

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.
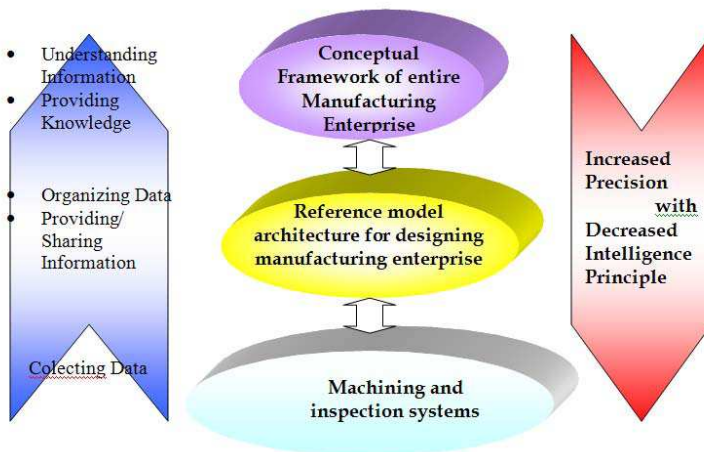

Fig. 6. ISAM architecture

First level of abstraction of ISAM (Figure 6) 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.

A large manufacturing enterprise is organized into management units, which consist of a group of intelligent agents (humans or machines). These agents have a particular combination of knowledge, skills and abilities.

Each agent is expected to make local executive decisions to keep things on schedule by solving problems and compensating for minor unexpected events.

Each unit of management has a model of the world environment in which it must function. This world model is a representation of the state of the environment and of the entities that exist in the environment, including their attributes and relationships and the events, includes also a set of rules that describes how the environment will behave under various conditions.

Each management unit has a set of values or cost functions, that it uses to evaluate that state of the world and by which its performance is evaluated.

Future manufacturing will be characterized by the need to adapt to the demands of agile manufacturing, including rapid response to changing customer requirements, concurrent design and engineering, lower cost of small volume production, outsourcing of supply, distributed manufacturing, just-in-time delivery, real-time planning and scheduling, increased demands for precision and quality, reduced tolerance for error, in-process measurements and feedback control.

These demands generate requirements for adaptability and on-line decision making.

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 (Figure 7) :
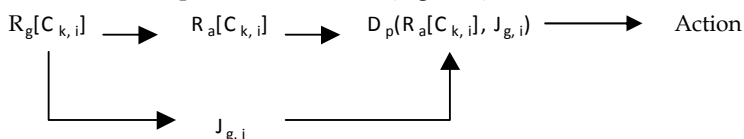
$$R_g[C_{k,i}] \longrightarrow R_a[C_{k,i}] \longrightarrow D_p(R_a[C_{k,i}], J_{g,i}) \longrightarrow \text{Action}$$

$$J_{g,i}$$

Fig. 7. Grouping-Focusing and Searching loop

where

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

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

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

$J_{g,i}$ – represents a 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.

7. Future trends

„Recent developments in manufacturing and logistics systems have been transformed by the influence of information and communication, e-Work and e-Service collaboration and wireless mobility, enabling better services and quality to consumers and to communities, while bringing new challenges and priorities" (Nof et.al, 2008) – such was the beginning of the milestone report presented by the IFAC Coordinating Committee on Manufacturing & Logistics Systems at the last IFAC Congress. And indeed, last years have seen a tremendous technological development, best reflected in manufacturing, which necessitates new approaches of management in order to cope with.

Knowledge management in particular, owing to its evolution that parallels that of manufacturing paradigms, is expected to issue new methods allowing humans to both benefit from - and increase the value of – technological advances.

It can be foreseen a hybrid knowledge structure, where the interaction between human and non-human knowledge stakeholders will became transparent and will allow creation and use of meta-knowledge.

Until then, some of the following developments could be expected, combining knowledge management advances with technological ones:

- Integration of human and technical resources to enhance workforce performance and satisfaction
- „Instantaneous" transformation of information gathered from a vast array of diverse sources into useful knowledge, for effective decision making
- Directing of manufacturing efforts towards the realization of ecological products, though contributing to sustainable development
- Development of innovative manufacturing processes and products with a focus on decreasing dimensional scale
- Collaborative networks, including human and software agents as an hierarchical and heterarchical architecture
- Development of a new theory of complex systems, taking into account the emergent and hybrid representation of manufacturing systems

Finally, the agility for manufacturing, and the wisdom, for knowledge management, will represent challenges for the new generation of embedded intelligent manufacturing.

Knowledge management is essential in the globalization framework, where success is effectively based on the cooperation capacity and on creative intelligence.

8. References

Adler, P.S. (1995). Interdepartmental interdependence and coordination: The case of the design/manufacturing interface. *Organization Science*, 6(2): 147-167.

Albus, J.S. (1997) The NIST Real-time Control System (RCS): An approach to Intelligent Systems Research. *Journal of Experimental and Theoretical Artificial Intelligence* 9 pp. 157-174

Albus, J.S. & Meystel, A.M. (2001) *Intelligent Systems: Architecture, Design, Control*, Wiley-Interscience, ISBN-10**:** 0471193747 ISBN-13**:** 978-0471193746

Anderson, P. (1999). Complexity Theory and Organization Science. *Organization Science*, 10: 216-232.

Browne, J.; Dubois, D.; Rathmill, K.; Sethi, S.P.& Stecke, K. E. (1984). Classification of Flexible Manufacturing Systems. *The FMS Magazine*, April 1984, p. 114-117.

Burns, T. & Stalker, G. M. (1961). *The management of innovation*. Tavistock, London

Camarinha-Matos L & Afsarmanesh, H. (2005). Collaborative Networks: a new scientific discipline, *Journal of Intelligent Manofacturing* , No.16 , Springer Science, pp 439-452

Carroll, T.N. & Burton R.M. (2000). Organizations and Complexity. *Organization Theory*. 6: 319-337.

Chen, D. & Vernadat, F. (2002). Enterprise Interoperability: A Standardisation View, *Proceedings of the ICEIMT'02 Conference: Enterprise Inter- and Intraorganizational Integration, Building International Consensus* , Ed. K. Kosanke et.al, ISBN 1-4020-7277-5

CIMOSA: Open System Architecture for CIM (1993) Research Reports Esprit / Project 688/5288. AMICE Ed. Springer;, ISBN-10: 3540562567 ISBN-13: 978-3540562566

Davis,J. P.; Eisenhardt K & Bingham B.C. (2007) Complexity Theory, Market Dynamism and the Strategy of Simple Rules, Proceedings of DRUID Summer Conference 2007 on Appropriability, Proximity Routines and Innovation, Copenhagen, CBS, Denmark, June 18 - 20, 2007

Dalkir, K. (2005). Knowledge Management in Theory and Practice. Elsevier, ISBN-13: 978-0-7506-7864-3, ISBN-10: 0-7506-7864-X

Dumitrache, I. (2008) From Model-Based Strategies to Intelligent Control Systems. *WSEAS Transactions on Systems and Control*, No.6, Vol.3, pp.569-575, ISSN 1991-8763

Dumitrache, I. & Caramihai, S.I. (2008) Towards a new generation of intelligent manufacturing systems *Proceedings of the 4th International IEEE Conference on Intelligent Systems*, 2008, vol.I, pp.4-33 – 4-38, IEEE Catalog Number CFP08802-PRT, ISBN 978-1-4244-1740-7

Dumitrache, I.; Caramihai, S.I. & Stanescu A.M. (2009) Knowledge Management in Intelligent Manufacturing Enterprise. *Proceedings of the 8th WSEAS International Conference on Artificial Intelligence, Knowledge Engineering and Data Bases*, pp.453-459, ISBN: 978-960-474-051-2, Cambridge, February 21-23, WSEAS Press

Eisenhardt, K. M. & Mahesh M. B. (2001) Organizational Complexity and Computation. *Companion to Organizations*. A. C. Baum (ed.), Oxford, UK: Blackwell Publishers.

Feigenbaum, E. (1989) **–** Toward the library of the future. *Long Range Planning*, 22(1):122

Galbraith, J. (1973) *Designing Complex Organizations*. Reading, MA: Addison-Wesley.

Galunic, D. C. & Eisenhardt, K.M. (2001) Architectural Innovation and Modular Corporate Forms. *Academy of Management Journal*, 44: 1229-1250.

Gilbert, C. (2005) Unbundling the Structure of Inertia: Resource vs Routine Rigidity. *Academy of Management Journal*, 48: , 741-763.

Hayes-Roth, F.; Waterman, D. & Lenat, D. (1983) *Building expert systems*. Reading, MA, Addison-Wesley.

Henderson, R. M. & Kim B. C. (1990) Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms. *Administrative Science Quarterly*, 35: 9-30

Mehrabi M.G.; Ulsoy A.G. & Koren Y. (2000). Reconfigurable manufacturing systems: key to future manufacturing. *Journal of Intelligent manufacturing*, Vol. 11, 2000, pp. 403-419

Miller, D. & Friesen, P. H. (1980) Momentum and Revolution in Organizational Adaptation. *Academy of Management Journal*, 23: 591-614.

Nof, S.Y.; Filip, F.; Molina A.; Monostori, L. & Pereira, C.E. (2008) Advances in e-Manufacturing, e-Logistics and e-Service Systems – Milestone Report , *Proceedings of the 17th IFAC World Congress*, Seoul, 2008, pp.117-125

Rivkin, J. W. (2000) Imitation of Complex Strategies. *Management Science*, 46: 824-844.

Savage, C. M. (1990) *5th generation management*, Ed. Butterworth-Heinemann, ISBN 0-7506-9701-6

Seppala, P.; Tuominen, E. & Koskinen, P. (1992). Impact of flexible production philosophy and advanced manufacturing technology on organizations and jobs. *The Engineering and Manufacturing*, Prentice Hall, Englewood Cliffs, NJ

Sethi, A. K & Sethi, S. P. (1990). Flexibility in Manufacturing: A Survey. *The International Journal of Flexible Manufacturing Systems*, Vol. 2, 1990, pp. 289-328.

Siggelkow, N. (2001) Change in the Presence of Fit: the Rise, the Fall, and the Renascence of Liz Claiborne. *Academy of Management Journal*, 44: 838-857.

Thoben, K-D Pawar K. & Goncalves R. (Eds.) *Procs. Of the 14th International Conference on Concurrent Enterprising*, June 2008, ISBN 978 0 85358 244 1

Uzzi, B. (1997) Social Structure and Competition in Interfirm Networks: The Paradox of Embeddedness. *Administrative Science Quarterly*, 42: 36-67.

Waltz, E. (2003). *Knowledge Management in the Intelligence Enterprise*. Artech House, ISBN 1-58053-494-5

Weick, K. E. & Karlene H. Roberts (1993) Collective Minds in Organizations: Heedful Interrelating on Flight Decks. *Administrative Science Quarterly*, 38: 357-381.

Wooldridge, M. & Jennings N.R. (1995) Intelligent Agents: Theory and Practice. *The Knowledge Engineering Review*, 10(2):115-152

Wooldridge M. (2000). Intelligent Agents. Multiagent Systems: A Modern Approach to Distributed Artificial Intelligence The MIT Press ISBN-10: 0262731312 ISBN-13: 978-0262731317
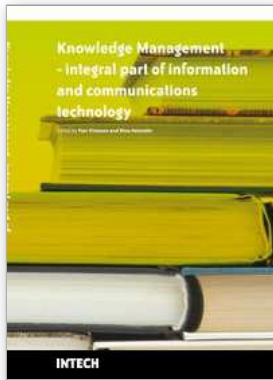
Knowledge Management

Edited by Pasi Virtanen and Nina Helander

This book is a compilation of writings handpicked in esteemed scientific conferences that present the variety of ways to approach this multifaceted phenomenon. In this book, knowledge management is seen as an integral part of information and communications technology (ICT). The topic is first approached from the more general perspective, starting with discussing knowledge management's role as a medium towards increasing productivity in organizations. In the starting chapters of the book, the duality between technology and humans is also taken into account. In the following chapters, one may see the essence and multifaceted nature of knowledge management through branch-specific observations and studies. Towards the end of the book the ontological side of knowledge management is illuminated. The book ends with two special applications of knowledge management.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Ioan Dumitrache and Simona Iuliana Caramihai (2010). The Intelligent Manufacturing Paradigm in Knowledge Society, Knowledge Management, Pasi Virtanen and Nina Helander (Ed.), ISBN: 978-953-7619-94-7, InTech, Available from: http://www.intechopen.com/books/knowledge-management/the-intelligent-manufacturing-paradigm-in-knowledge-society

INTECH
open science | open minds