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Complex Adaptive Systems Focused Intelligent Manufacturing

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Abstract

The American Institute of Industrial Engineering formulated in 1955 the following paradigm for Manufacturing Systems: conceptual and detailed design, as well as socio-technologic-economic systems including heterogeneous resources (human, financial, technologies, capital, and energy resources). During the last five decades many paradigm shifts have been identified. The paper is focused on the current achievements sustaining the time of convergence for different recent paradigm shifts. The authors do believe that Intelligent Autonomous Manufacturing Systems should be an appropriate purpose within global digital era.

Key words: *Interoperability, intelligent manufacturing, complex adaptive systems*.

Introduction

The short list of paradigm shifts in Advanced Manufacturing Systems research agenda could include: Computer Integrated Manufacturing and Engineering Systems (C.I.M.E. - 1976), Flexible Manufacturing Systems (FMS – '80), Lean Manufacturing ('90), Agile Manufacturing, Fractal and / or Holonic Manufacturing Systems ('90), Intelligent Manufacturing Systems (2000).

But, once again, the paradigms for the Next Generation of Internet – oriented Enterprises have been shifted also [14]. During the - post - Taylor era the rigid framework for hierarchical authority/ responsibility pyramid, many new concepts have been proposed (Virtual Enterprise, Concurrent Enterprise, Extended Enterprise, Collaborative Enterprise, Networked Enterprise) [15, 16].

The vision and roadmap for the Next Generation of sustainable Internet – networked Enterprise, have a list of challenging qualitative features like: social/ legal/ framework/ entrepreneurial/ interoperability/ customer satisfaction/ total quality management a.s.o.

If somebody uses the triplet PSO (Product/ Services/ Organization) the Collaborative Distributed Dynamic Enterprise (CD2E) which is based on Smart Concurrent Engineering design methodology, Intelligent Manufacturing and last, but not least Peer – to – Peer Distributed Knowledge Based Systems (P2P - DKbS) should offer an attractive goal for thousands of research laboratories, universities and R&D departments from large trans-national companies worldwide. The new digital and global economy requires the effort reactive Collaborative Networks to be sustainable on e-markets. [12].

The “intersection” between Virtual/ Extended Enterprise and Virtual/ Open University is going to consolidate the Learning Organization solid concept.

The General System Theory and Application [von Berthallanfy 1930-1976] has been recently rediscovered by both economists and engineers. The MIT/ System Engineering Dept research team highlights that the focus must be put on second and third category of complex adaptive systems, called System of Systems [A. Sage, 1999]. The taxonomy developed in terms of degree of complexity & modelling uncertainties. The second step after Technical Systems (e.g. Flexible manufacturing Systems) is Socio – economic – organizational – Systems and the third is represented by Context Systems (Society, Cognitive, a.s.o.).

On the other hand, the well-known Artificial Intelligence techniques and their applications in Advanced Manufacturing Systems (AMS) have proved mature enough. Machine Learning (ML), Data mining (DM), Knowledge Acquisition and Management, Multi – Agent Systems – “Agent Cities” are some of them.

The new list of scientific disciplines (web Science, Networked Science, Information Systems, etc.) having already captured a critical mass of results as well as “best-practice” implementation such as the “speed” for Technology Transfer and thinking Innovatively is continuously increasing [Enterprise Networking].

The present paper is an attempt to present the debate – oriented survey on the state – of the art and research outlook within the challenging domain of advanced manufacturing systems. The IT labs–based Research Institute of Automatic Control and Computer Science Faculty [www.acs.pub.ro] of POLITEHNICA University of Bucharest have the honour of developing a strategic partnership both for Romanian universities and for colleagues worldwide.

Digital World Theory-based Modeling Framework

The Digital World Theory (DWT) has emerged as “a new approach in modeling interacting systems, from fundamental interactions including QUANTUM GRAVITY, to complex systems like communication networks, i.e. DWT models natural and artificial reality alike” [8].

Therefore, to model and design reality, a QUANTUM computing language (Quantum software) became the next step in the evolution of Digital World Theory.

Special relativity and Quantum theory are implemented with one stroke as a **Quantum Information Flow in a Dynamic Network** [7, 8].

For the mathematician, system engineer, economist, one could mention: “why fields should be replaced by bi-fields (Hopf objects) as part of the categorization of both mathematics and physics, how the commutative determinant can be generalized as the Feynman path Integral!”

The present version of the DWT sketches the “object-oriented” Q++ language and provides implementation considerations. Q++ is similar in purpose and presentation to any other computer programming language (automation/formal languages/ logic correspondence), except the gates process quantum digits. The mathematics tools/technology needed to take into account quantum fluctuations, i.e. a dynamic hardware as opposed to a fixed hardware configuration is encapsulated into the QDR approach.

The main contributions are the following:

(i) a new methodology: a broad goal and theoretical technology used (unified math/physics/computer science approach) in order to design the theory to last a few decades (not just another resonance/ theoretical physics cycle) ;

(ii) new methods and techniques based on intelligent machines, GRID computing (e.g. lattice QCD for computability with ease for the "Human Interface");

(iii) a "top-down" design approach (necessary for the stratified complexity of the future's theoretical constructs), in order to make it "upgradeable" and to allow each scientist to design his/her own layer, within his/her own level of expertise, and with care for the interface between layers.

The overall philosophy can be summarized as: (Modeling) Reality (IS) Quantum Computing. This reflects the dual interpretation of mathematical models. To be more specifically Quantum Interaction = Quantum Communication.

By focusing on the subject to discuss in this paper, a buzz concept "Digital Business Eco Systems" (DBES) represents for our Virtual Research Team [16] a high potentiality key-concepts of Next Generation of non-monolithic complex adaptive, evolutionary networked enterprises.

We propose as a basis for the middle tier of Interoperability between the two tiers of DBES and the Intelligent Manufacturing Systems (IMS), the DWT systemic approach.

As a beginning point for our research, a Terra-model for DBES within "Blue Ocean" of the global, digital economy has been developed, [16] emphasizing on a DWT basis as interface for interoperability. The DBES Terra-model is presented in figure 1.

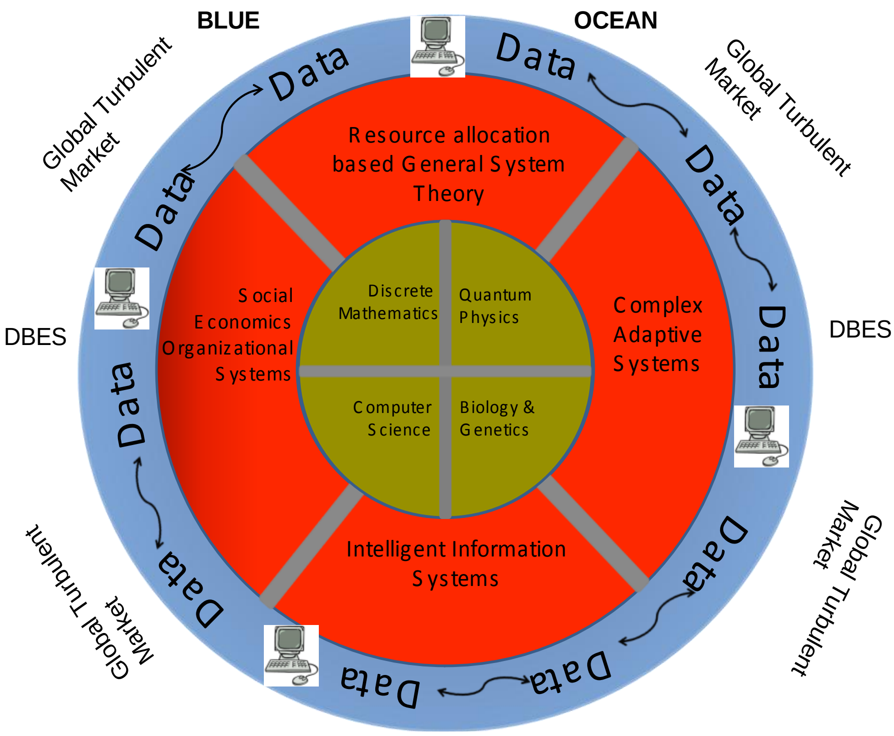

Fig. 1a. Terra Metamodel of DBES development.

Furthermore, a genetic approach has been used as a modelling framework for sustaining the DBES Organizational architecture. As a basis for interoperability at the DBES tier, the basic organizational information has been classified as common or individual and modelled as a DNA structure. The DNA structure is organized in conjunction with other DNA structures to form a Chromosome, which will serve as the "genetic" bases for the development of organizational (SME, company) interoperability.

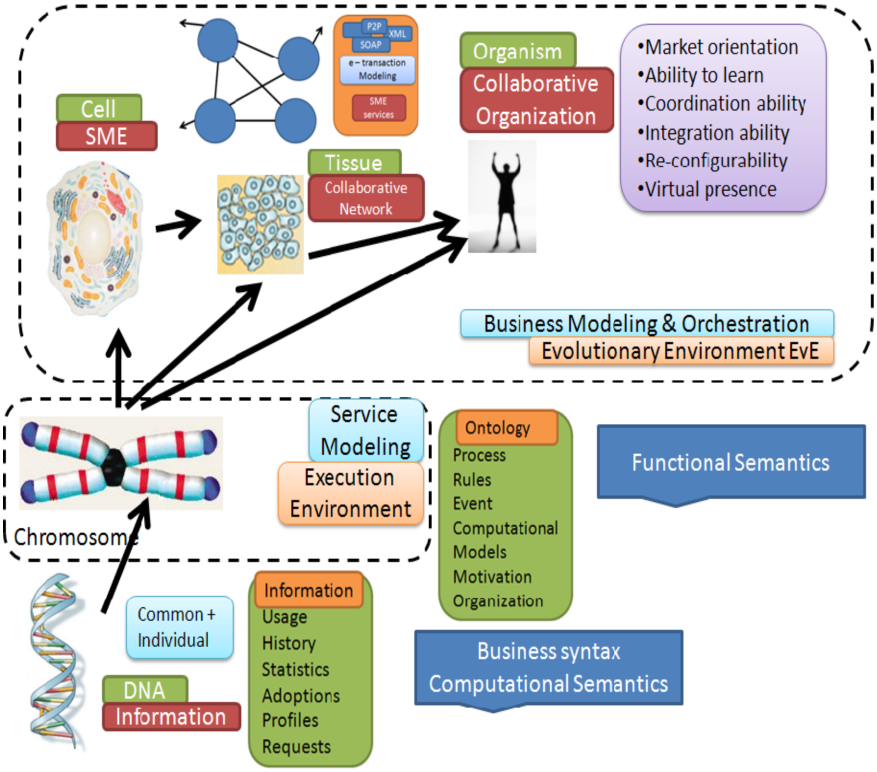

Fig. 1b. Biology inspired DBES framework.

The state of the art in intelligent manufacturing after three decades of intensive research

The well-known paradigm CIM.E (Computer Integrated Manufacturing and Engineering) has been launched by Joe Harrington since 1976. Paradoxically speaking, the two-decades of intensive research for the CIM.E systems the complex information & communication infrastructure system require for a lot of work and money maintenance. In this context, only big actors [e.g. Siemens, IBM, a.s.o.] are able to sustain such CIM oriented-enterprise system [14, 15].

But Professor Jimmy Brown has launched since 1986 a new paradigm of the Extended Enterprise. Also, prof. Luis Camarinha-Matos proposed a new paradigm with respect to the Virtual Enterprise / Organization since 1998 [project IST-FP4 PRODNET]. The next step in the chronology of paradigm shift in Intelligent Manufacturing Systems has been recorded since 2008 based on new scientific discipline, so-called Collaborative Networked geographically dispersed Complex Enterprise (consortium-oriented) [www.ecolead.org].

In figure 2 one can see the different approach for developing new organizational modeling framework, including reference models and IT architecture worldwide before 2000.

According to "the breakout of the framework services layers (cross dimension), a key observation in assessing the utility of the framework is the identification of discriminators that enable us to attribute or distinguish the services, or implementations of those services, as belonging to one management layer or another. The enterprises are "living organisms" and thereby have the requirement to evolve their behavior over time to sustain their respective viability within the global environment" [10]. The discriminators serve as a mechanism to group additional detail (in the form of metadata, meta-information, meta-knowledge) needed by the services available at a particular layer.

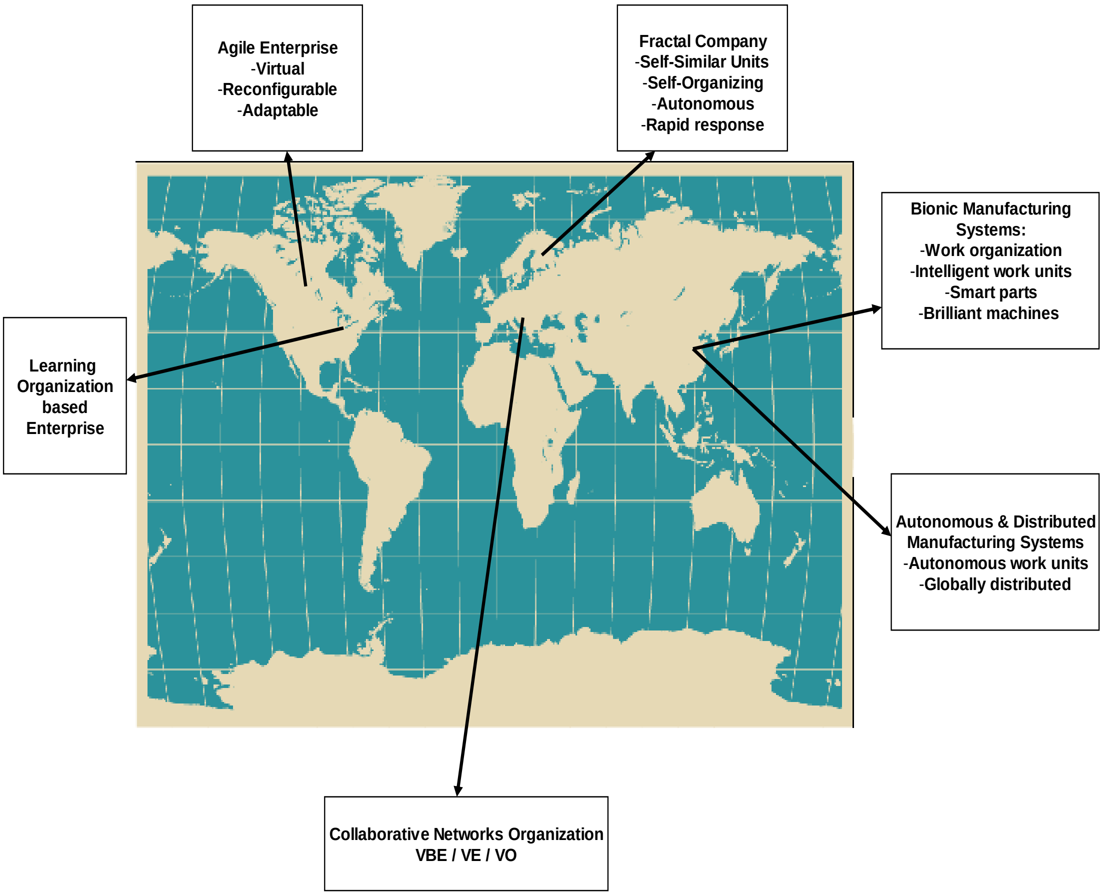

Fig. 2. External Complex Adaptive Systems.

The manufacturing Enterprise Interoperability, Integration and Networking (EI2N) multidisciplinary domain provides a rich strategic research agenda for thousand of labs world wide [2]. The „old" paradigm, so called „Enterprise Modeling Management and Control" (EMMC) has already captured since '80 the critical means of knowledge, methodologies, methods, techniques, as well as best practices. Beyond the Framework 5.6 successful completed projects, like the ADACOR, the CE.NOE many challenging scientific contributions have been published during last two years [12].

Despite the poly-semantic concept of SYSTEM [e.g. "a set of connected things that work together for a particular purpose", "a method of organizing or doing things to complete a mission, which is going to be decomposed in terms of objectives and activities", the following definition could be used:

A manufacturing enterprise system is n-tuple involving

$$E: f[M_p, M_o, M_a, M_r, M_k, M_A, G] \,, \qquad (1)$$

where:

- M_p: a set of various technical and economical (manufacturing, design, business, management);
- Mo: a set of "computational objects";
- M_a: a set of both artificial and human agents;
- M_k: a set of both tacit and social knowledge;

- M_A: a set of activities (integrated by flow-work management);
- G: a business goal that is based on a decomposition roll (objective/ activities/ tasks) to be completed.

During the last decade a huge joint research effort has been done to classify the set of concepts enhancing the new organizational patterns of the next generation of manufacturing enterprising [e.g. Extended Enterprise, Virtual Enterprise, Collative Enterprise, Collaborative Networked Enterprising] [1].

A potential definition which should be improved by dealing with the sound issues, could offer a merging systemic (complex adaptive system) formulation:

A virtual enterprise is an open geographically dispersed metasystem which has a formal support within a 3-Dimenssions "Universe of discourse" U (Discrete Event Dynamic Systems/ Information Systems/ Knowledge based Systems), generating a set of "fabrications" F in terms of M_{view} set of various multi-view (perspective) representations, such as the b common business goal is achievable optimally or suboptimal:

$$VE : \{U (\bullet), F(\bullet), M_{view}(\bullet), G\} . \tag{2}$$

i) M_v; a set of specific models (functional model, organizational model, information model, data/metadata model, economic model, a.s.o.)

ii) F: a set of "fabricators" (autonomous system) supporting a specific role within a planned scenario, such as a nominal state trajectory of the System of Systems (Sos should be explicitly governed)

But every manufacturing enterprise (focused on the SMEs) is sustainable, if and only if the business portfolio (b) provides profit. Due to the last two decades of intensive research in the domain of Business Informatics (BI), a trivial statement could be "business are more dependent upon the Information and Communication Technology (ICT) - based Information Systems coherency & consistency". These sustainable manufacturing enterprises should offer, than ever before, a variety of products and a-services in a highly competitive environment of global turbulent market.

The Virtual Enterprise Architecture proposes a 3 tiers structure divided in multiple layers as shown in figure 3.

The middle tier is designed to ensure the interoperability between the lower manufacturing system tier viewed as a network of interconnected layers and entities (Intelligent Manufacturing System) and the upper Business tier (Digital Business EcoSystem) modeled as an ecosystem of actors. Using such an architecture one can design new models and tools to ensure the interoperability between manufacturing entities in the same organization, between manufacturing entities located in different organizations, between manufacturing layers and business layers of the same organization and between manufacturing layers and business layers located in different organizations.

The degree of complexity rises exponentially, as well as the modeling uncertainties degree of this large scale of meta-systems.

The triplet PSO (Product/ Services/ Organization) the Collaborative Distributed (worldwide) Dynamic Enterprise (CD2E) which is based on Smart Concurrent Engineering design methodology, Intelligent Manufacturing and last, but not least Peer – to – Peer Distributed Knowledge Based Systems (P2P - DKbS) should offer an attractive goal for a thousands of research laboratories, universities and R&D departments from large trans national companies worldwide. The new digital and global economy requires the effort reactive Collaborative Networks to be sustainable on e-markets [12].

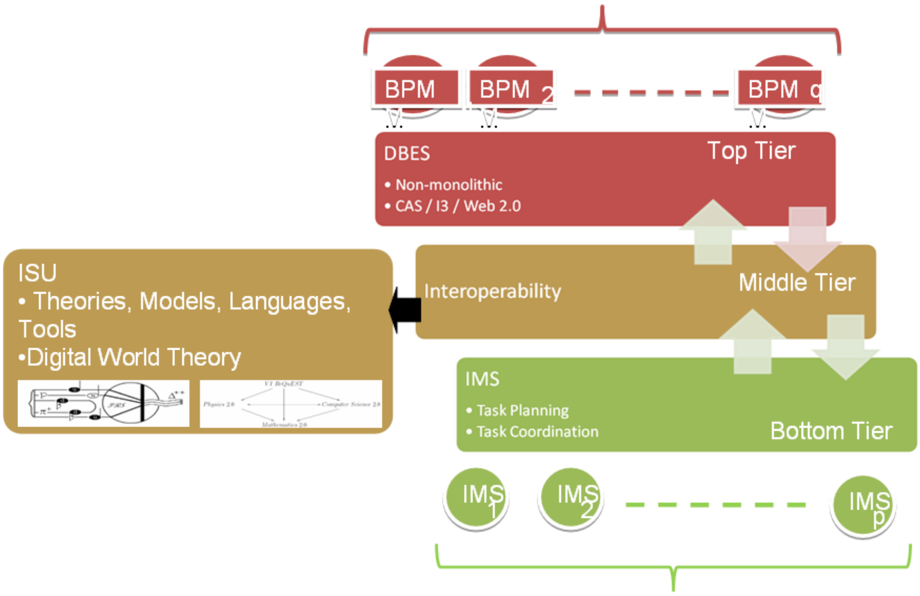

Fig. 3. Virtual Enterprise Architecture

An academic pilot to incubate the next generation of digital business ecosystem

The paper aims at promoting a new design approach for workflow management and control system based on DES formal representation, as well as using hybrid methods and techniques captured from Petri Net technology [6] and Queing Systems. In this purpose, a new systemic approach for designing the WFMS is presented.

In figure 4 the conceptual design is concerned with providing the reference architecture for three layered supervisor. As controlled activity oriented business cases the configurator module generates the set of cases as value added chains of economical processes.

The second layer involves with the original functional block meaning the workflow controller. The workflow controller architecture was presented upon a queuing engine described by Eshuis and Wieringa [6].

The two interfacing modules have been designed for the following sub-functions:

- collecting data from the business environment;
- object oriented embedding data in order to provide efficient data management;
- implementing the automatic executing interface to transform activities in actions.

The third layer implements the decision making functions for three time horizon management:

- For the first level, the strategic management will operate with What If models in order to support scenario analysis;
- For the second level the appropriate algorithms for resources optimum allocation are implemented;
- For the third level the operational management is concerned with supervisory control implementation, which is responsible with the optimal control policy delivery in terms of constraints (time and costs) as well as emergency situations.

The supervisory module is feeding with metadata provided by an interface module.

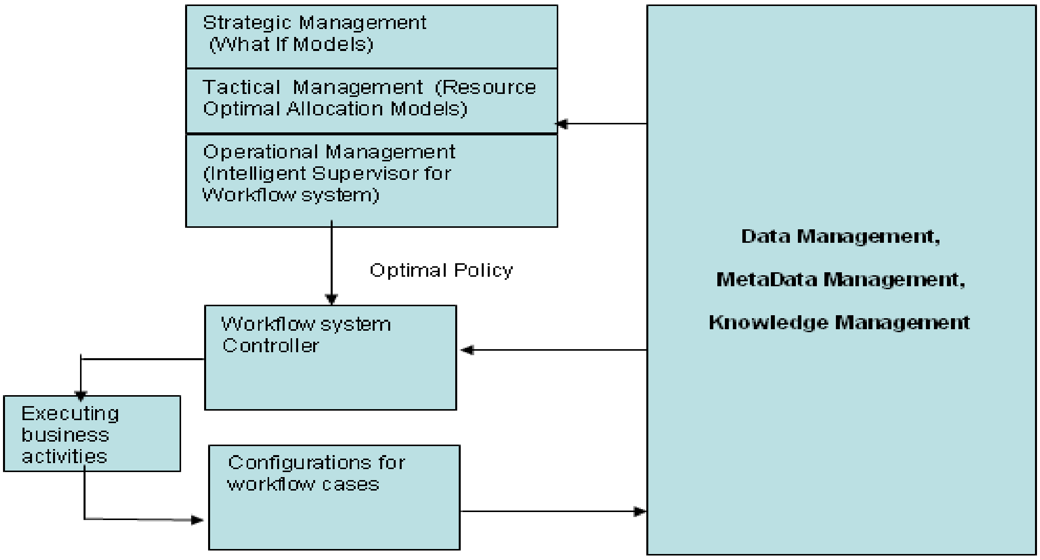

Fig.4. Conceptual design of the WFMS control.

The distribution of knowledge on workflow management is organized on the basis of distributed information decision support system. The key problem is concerned with developing the user interface to search the decisions in the knowledge base. A multi-agent management system develops flexible individualized, interactive, adaptive environment of decision making support involving intelligent agents. The intelligent agent is represented as the user interface conducting dialog to define the attributes of business cases and to determine the level of the decision making support. Fixing attributes of critical situations and decisions accepted by the managers, the intellectual agent realizes constructive feedback between decision support information systems and users. The agent is programmed for dialogue with the user in the problem oriented natural language. To develop the way of decision support for the intelligent agents it is possible to use the built –in functions of agents programming.

Conclusions and further work

The initial objectives of this paper are related with the DBES interoperability analysis methodology, but this Complex Adaptive System of Systems needs a great deal of research effort: DBES analysis (global & local performance evaluation); DBES formal tools to prove the stability of such evolutionary, self-organizing, complex systems; DBES synthesis methods and techniques; DBES-ICT-tools development and their integration e-Collaborative platform; Data-mining tools for open-source orient software platform; Compatibility, Interoperability and Integrability new methodologies; Ontology development for this DBES discipline having strong TRANSDISCIPLINARY domain features; Guide of best practices-oriented DBES pilots; Developing the scientific bridge between Ecological Economics [Common, et all] and DBES cross domains; Traceability, Availability concepts [Herve Panetto,] [12].

From the Intelligent Manufacturing Systems point of view, there is a great challenge to identify, model and implement the interoperability of Complex Adaptive System of Systems as part of the Digital Business Eco-System.

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Fabricaţie inteligentă orientată pe sisteme adaptive complexe

Rezumat

Institutul American de Inginerie Industrială a formulat în 1955 următoarea paradigmă pentru Sistemele de Fabricaţie: proiectarea conceptuală şi detaliată, în aceeaşi măsură ca şi sistemele socio-tehnologice, include resurse eterogene (umane, financiare, tehnologice, capital şi resurse energetice). În perioada ultimelor cinci decade au fost identificate multe transformări de paradigme. Lucrarea este axată pe prezentarea realizărilor actuale referitoare la timpul de convergenţă pentru diferite transformări recente de paradigme. Autorii susţin ideea conform căreia Sistemele Inteligente de Fabricaţie Autonomă trebuie să reprezinte un obiectiv important al erei globale digitale.

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