NETWORKING CONCEPTION FOR E-MANUFACTURING SYSTEMS

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Abstract. Current extended enterprise resource planning and supply chain management systems do not provide adequate facilities for addressing the problems of unpredictable changes taking place in a global market. The lack of cohesive self-organized coordination mechanisms at the local and global levels does not provide efficient and cost-effective responses on time. This paper addresses the conceptual question of multiplatform integration for designing worldwide network of supply chain and enterprise resource planning systems. The main idea is based on merging two separate approaches, i.e. integrated agent-based network models of e-manufacturing systems and virtual field-based information networks of intelligent agents.

Keywords: multiagent systems, e-manufacturing, global enterprise resource planning, supply chain management, virtual computational field.

1. Introduction

A major problem facing business organizations is how to provide efficient and cost-effective responses to complex and unpredictable changes that take place in a global market, i.e. how to become even more dynamic and adaptive in the ever changing mass customized markets.

Current limitations stem from the fact that the first generation of enterprise resource planning (ERP) products has been designed to integrate the various operations of an individual firm. In modern supply chain management (SCM), however, the unit of analysis has become a network of organizations, rendering these ERP products inadequate in the new economy (Akkermans, Bogerd, Yücesan, 2003).

Extended ERP (EERP) reflected the fact that most leading non-manufacturing industries turned to ERP systems for ‘backbone’ financial transaction processing capabilities (Gartner Research Group, 2000). The next ERP iteration was called the enterprise application suite (EAS), as it was tailored for service industries too.

Responding to the growing demand, vendors had to extend ERP from an enterprise-wide domain to the inter-firm collaborating (IFC) approach, which later grew into the ERP II platform. In sum, ERP II is an evolution from ERP that clearly extends business processes, opens application architectures, provides vertical-specific and horizontal functionality as well, and is capable of supporting global enterprise-processing requirements [6].

In the global economy, that means the emergence of collaborative networks of enterprises, “win-win” strategies, efficient mass customization, and sharing of resources, information and supply chains. These technologies would spare global resources and use them in the more effective way.

More specifically, this paper addresses the above mentioned issues by designing concepts of multi-agent systems (MAS), capable of facilitating integration and communication among ERP and SCM systems. It has long been proven that these domains can be modeled using multi-agent approaches involving interactions amongst manufacturing organizations, their customers, suppliers, etc. with different (possibly conflicting) individual goals and propriety information (Zhang et al. 2006; Monteiro, Anciaux 2007). However, not much research has been undertaken to unite everything under one cohesive multi-agent umbrella.

Of course, there is a lot of research done for SCM and ERP integration, using many of different platforms and methods, as this is an area that has, indeed, received a lot of attention amongst researchers in the past two decades. Specifically, regarding the MAS platform, recent team work lead by Zhang (Zhang et al. 2006) is implementing an agent-based approach for e-manufacturing and supply chain integration. Monteiro and others (Monteiro, Anciaux 2007) explore MAS approach for multi-site coordination. A somewhat similar, yet more SCM oriented research is done by, for instance, Turoski (Turoski 2002) and Ghiassi and Spera (Ghiassi, Spera 2003). They developed agent-based techniques for coordinating activities of e-commerce and internet-based supply chain system for mass customization markets.

Li and Fong (Li, Fong 2003) and Choy and Lee (Choy, Lee 2002) proposed agent-based archi-
Concluding this section, let’s briefly discuss the content of the paper. The research subject of this paper consists of two frameworks, which are discussed next. The first framework is dealing with business application and another with conceptual modeling. The first and second sections describe the first framework, i.e. MAS based simulation platform for EERP and SCM integration in the network (information) economy. In fact, we are investigating how both EERP and SCM can be integrated in a cohesive whole. Meanwhile, the third and fourth sections describe the second framework, i.e. field-based information network of intelligent agents. Finally, the fifth section ends with discussion and conclusions.

2. Extended Enterprise Resource Planning Platform

As previous studies have shown, current ERP systems lack a modular, open, and internet-like system architecture, or “web-enabled ERP”. Basically, this shortcoming is the reverse side of some of the generic advantages of ERP, where ERP was intended originally to replace a multitude of local legacy systems; a great deal of emphasis was therefore placed on its integrated architecture. In the new network economy, this former strength is rapidly becoming a weakness (Akkermans et al. 2003; Monteiro, Anciaux 2007).

In modern supply chain management (SCM), however, the unit of analysis has become a network of organizations, rendering these ERP products inadequate in the new information economy. Another reason appears to be the advent of the network economy, which is triggering profound changes in all operational levels of enterprises.

The relevant entity for analyzing potential business success is no longer the individual enterprise, but the chain of delivering and supplying organizations; the individual firm is only a single part of this network.

This greatly increases the importance of integration between EERP and SCM for corporate survival. These inferences are confirmed in the number of studies (Akkermans et al. 2003; Gartner Research Group 2000; Peng et al. 1999; Hendricks et al. 2007). Besides, markets are becoming more transparent, customer demands are being met in a more customized manner and, in general, the rate of change in the business world keeps increasing.

The author further implies that telecommunication and internet technologies are most likely to provide the technological means for emergence of the global ERP (GERP). This will make distributed architectures possible, in which standardiza-
tion takes place mainly at the level of information definitions and processes, so that local flexibility in information usage can be maintained at high precision. Needless to say, all these developments are already taking place on a global scale. Hence, IT for SCM in general, and ERP systems in particular, will have to be developed on a worldwide basis (Ghiassi, Spera 2003).

GERP supports mass customization only if customers can configure their products as a combination of a number of predefined options. The emergence of “configurators” (Akkermans, Boggerd, Yücesan 2003; Gartner Research Group 2000) in the ERP ecosystem supports this aspect of mass customization. A configurator in this context is a computer program that translates individual customer demands into feasible product specifications. Using such a configurator, it becomes possible to start an assemble-to-order process. The integration provided by the ERP system would ensure that the unique product ordered by the customer is properly translated into the appropriate production orders (Ciufudean 2008; Revetria 2008).

There is ongoing process of search, as the ERP industry has become an ecosystem of software vendors, middleware vendors, supply chain experts, specialty-software houses, and hardware vendors. This ecosystem is also evolving fairly rapidly in an effort to provide effective supply chain solutions.

According to the recent GRG findings, the challenge for current ERP systems is to move to a more modular, internet-like system architecture (Akkermans et al. 2003), see Fig. 1. This would certainly improve information exchange with all the players in the chain and make the power structures in extended supply chains less dependent on the ERP system of the dominant player in the market segment. Also, it would improve communication with the final customer.

Once EERP is installed (Fig. 1), there exists a process-oriented enterprise transaction backbone that can support—within a single firm—developments in many business areas, including MES, SCM, DIMS, CRM etc. Though, initial architecture of ERP systems were never designed just to support, e.g. SCM, and certainly not across multiple enterprises. Their architectural advantage of being fully integrated for one firm becomes a strategic disadvantage in this new business environment, where modular, open and flexible IT solutions are required. Therefore, EERP, EAS and GERP are under way to fill the gap (Jesus, Pedro 2008).

As literature review indicates, so called GERP, is upcoming trend, which is inevitably approaching to substitute EERP, SCM, CRM etc. The main reasons behind this process are very obvious: 1) economy of global resources, 2) mass customization (convenience for customers), 3) unification of information resources (network information economy), 4) standardization of processes, platforms and business models (convenience for B2B, B2C, G2B etc).

After all, the main driving factors are economical, meaning existence of a clear market need for the new GERP technologies.

In reality, the distribution of the enterprise network cannot be managed only by one and unique data-processing and data base application. The main reason is that the exchange of information and the behaviors, which are specific to operations of the network members, are so complex that they require computing paradigms which need to be decentralized and shared. Consequently, it seems that a MAS architecture (as a middleware) can best meet this need (Monteiro et al. 2007).

3. Operational framework

The MAS are regarded as one of the most promising technologies in EERP management. Usually we model such systems with functional agents, which are responsible of several activities such as order acquisition, logistics, transport, or scheduling. The specificity of the agents is to support distributed decision making in the network economy (Zhang et al. 2006; Monteiro et al. 2007; Turoski 2002).
In the GERP, each agent acts like the mediator, e.g., for the local ERP or SCM platforms. The goal of the mediator is to 1) find optimal solutions for the represented entities, 2) to solve conflicts by relaxing constraints, where relaxation is based on a global cost. In general, the main objective of an enterprise network is to minimize the purchase and the production costs as well as to ensure a positive benefit. The global benefit of the effective network of mediators is then a function of the total selling and the total cost, such as:

In a sense, the basic components of the GERP are creating virtual reality, composed by so called virtual enterprise nodes (VEN) or mediators. The clarity of the “virtual game” is determined by the business ethics and norms, but, in principal, it should lead to “win–win” principle on the long run. This principle prevents always benefiting the same company and allows preserving collaborative network.

Even when such relationships exist, the technologies and techniques that would enable such relationships to be explored fully for maximum benefits on all sides need to be developed and thoroughly understood. In this paper, MAS is used in order to coordinate a multi-site network chain with a distributed decision and distributed information network (see Fig. 1). As a result, the potentials of the combination of agent technology and the internet in facilitating all chains integration in the GERP model, forming dynamic partnerships, require our earnest study.

As with most new information technologies, the major problem that faces agent-based enterprise is the skepticism that the manufacturing industry shows towards new technologies (Zhang et al. 2006). In the case of EERP systems, such skeptical attitudes can be attributed to their reputation of being expensive and difficult to implement (Wallace, Kremzar 2001; Gartner Research Group 2000; Zhang et al. 2006), which in turn may be a result of lack of understanding.

Besides, GERP ought to be thought of as a dynamic process of assembling chains of capabilities and not just collaborating organizations. The configuration of the GERP as a network of cooperating business units will evolve continually: with a high frequency business units entering and leaving the network. This is in high contrast to the current ERP implementations, which have monolithic structure.

At the top level the most important is efficient collaboration of managerial and informational processes using corporate business intelligence systems. The level of sophistication provided by these solutions should elaborate on intelligent decision support systems, rule-based expert system functionality etc. Artificial intelligence (AI) techniques are especially welcome with their flexibility, adaptability and self-organizing capabilities.

In the next section, are given some possible conceptual GERP solutions using field-based approach. It aims to give a novel understanding how information exchange between networks could be efficiently represented.

### 4. Field-based MAS simulation concept

This section deals with a novel concept of how to represent communications and operations in the complex MAS network. Instead of the pair-to-pair communication model, the author proposes to adapt a field-based model, where synchronous and asynchronous communication can take place.

As a matter of fact, effective communication stands among the top most important issues in GERP and EERP implementations (Zhang et al. 2006; Ghiaisi, Spera 2003). However, we are not going to delve deep into the technological details, as this is not our main task. Instead, our goal is to understand the relevance and potential benefits of the new approach in general terms.

Contractual based handshaking between two business parties shapes “pair-to-pair” communication in today’s ERP systems. Currently, “pair-to-pair” type of communication between agents is prevalent in all applications (Zrimsek 2003; Monteiro et al. 2007; Li, Fong 2003). However, this is obsolete, as agents’ direct and coupled communication model is badly justified in the real markets. The main reasoning behind this argument is based on the analogy with other extremely complex networks, e.g., telecommunication networks, where “pair-to-pair” connections are not efficient for the multitasking, parallel processing, congested traffic, conflict resolution etc. (Akkermans et al. 2003).

The striking parallel between modern telecommunications network systems and GERP model is obvious – the main information traffic between businesses is flowing through telecommunications networks, which act as a backbone for the modern network-based GERP (Fig. 1). In fact, the internet era has shaped efficient protocols for the complex information traffic in the telecommunication networks, where 1) each agent has capability to send and receive information simultaneously through multiple channels, 2) information flows are selectively managed by the agents’ internal filters etc. Agents themselves have become only nodes (“black boxes”) in the telecommunication networks. Therefore, it is not surprising, that
telecommunication protocols lay sound foundations for the GERP simulation platform.

Consider, though, that there is another way to represent communication in the complex hierarchical GERP network. The author argues that field-based approach works very well for the multi-agent GERP simulation. The information in a form of fields is emitted and absorbed by the environment and the agents themselves.

In fact, for efficient functioning, agents have to possess a sensor type of receptive mechanism to be attuned to the specific information emitted from the sources they are interested in. In fact, there is no other way to deal with the large amount of different information flowing currently in the information networks. In some sense, agents are using filters to be senseless for some information and very sensitive to other information.

According to the above discussion, the novelty of this work is to simulate a multi-agent environment immersed in the fields of heterogeneous information. The frequency domain, indeed, is the only suitable media for the representation of the infinite information flow. Specific small pieces of information can be represented as a single band in the frequency spectrum whereas more sophisticated information can be represented as a set of bands (unique composition of frequencies).

Most importantly, the spectrum can track energy associated with the possessed information (spectrum bands are prioritized according to the frequency scale). Consequently, relatively simple rules may help to organize agents’ internal states, oriented to optimize the total internal energy. Whereas, the simulation’s objective could determine the form of functional relation between the type of information and it’s energy representation on the frequency scale (there is a direct relation between frequency and energy).

Using Fourier transformation, we can translate agents’ time dependent behavioral patterns (which is nothing else but information) to the frequency domain. In this case, each agent’s characteristic behavior set is represented by his unique spectrum pattern.

Following this line of reasoning, we could imagine each agent as a set of internal frequencies, which resonate if triggered by the external fields with the coherent frequencies. The resonating frequencies are then transferred to other frequencies following agent’s internal “production rules”, see Fig. 2. These rules are nothing else but frequency transformation laws, which govern agent’s dynamic behaviour (O’Leary, 2000). In order to understand the underlying “production rules” context we have to uncover the whole layer of principles and ideas coming from a multitude of other interdisciplinary studies.

Being inspired from the natural systems, we are starting to understand that in order to construct self-organizing and adaptive systems in the social domain, it may be more appropriate focusing on the engineering of the proper interaction mechanisms for the components of the system, rather than on the engineering of their overall system behavior (Wallace, Kremzar 2001).

According to Tesfatsion (Tesfatsion, Judd, 2006), economies are complex dynamic systems, where large numbers of micro agents engage repeatedly in local interactions, giving rise to global regularities which in turn feed back into the determination of local interactions. The result is an intricate system of interdependent feedback loops connecting micro behaviors, interaction patterns, and global regularities. As elaborated by numerous commentators, the modeler must now come to grips with challenging issues such as asymmetric information, strategic interaction, expectation formation on the basis of limited information, mutual learning, social norms, transaction costs, externalities, market power, predation, collusion etc.

This is a highly heterogeneous information network with many links and complex interrelations. Uncoupled and indirect interactions among agents require the capability of affecting and perceiving the context. The context is modeled here as virtual data fields, where each spatial or logical node stores the pervasive field values. The model promotes mediated interactions by exploiting some sort of distributed information that can be used as a means to enforce indirect and uncoupled interactions among agents and that can also be expressive enough to represent contextual information in a form locally accessible and immediately usable by agents.
One of the closest examples in this area is amorphous computing (Koh et al. 2007). Another interesting proposal in that direction is the Multi-layered Multi Agent Situated System (MMASS), defining a formal and computational framework relying on a layered environmental abstraction (De Paoli, Vizzari 2003). MMASS were related to the simulation of artificial societies and social phenomena, for which the physical layers of the environment were also virtual spatial abstractions. In the last decade, a number of other field-based approaches were introduced like Gradient Routing (GRAd), Directed Diffusion, “Co-Fields” at TOTA Programming Model, CONRO, etc (Maei, Zambonelli 2006).

In fact, almost all proposed systems are either employed for various technological or robotics applications and very few of them like MMASS, Agent-Based Computational Demography (ABCD) or Agent-Based Computational Economics (ACE Trading World application: simulation of economic phenomena as complex dynamic systems using large numbers of economic agents involved in distributed local interactions (Tesfatsion, Judd 2006) are suitable for programmable simulations of GERP.

For the effective implementation of spectra as a universal energy-information warehouse, we first have to transform all tangible objects-resources to their energy equivalents and then to interrelate different types of energy as intangible information stored in the form of corresponding sets of spectral bands. The deep meaning of it is based on the principle of reductionism and universality as we are looking for the most universal means to reduce multiplicity of forms into the singularity of content.

5. Conclusions

This paper sheds new light on the conceptually novel platform for transformation of EERP systems to the GERP (Global Enterprise Resource Planning), which would operate in the local and global level as well. In the global economy, that means emergence of collaborative networks of enterprises, “win-win” strategies, efficient mass customization, and sharing of resources, information and supply chains. These technologies would spare global resources and use them in more effective ways.

The new approach is no longer enterprise-oriented, but rather information flow and processes-oriented. In conceptual terms, this paper is presenting a pioneering approach that would enable simulation of dynamic interaction of e-manufacturing network of organizations and supply chains, which together compose a kernel of the complex modern information economy.

The main novelty is based on merging two separate approaches 1) integrated agent-based network models of e-manufacturing systems and supply chains (GERP and SCM simulation platforms), and 2) a field-based information network of intelligent agents.

The author further implies that telecommunications and internet technologies are most likely to provide the technological means for emergence of the global ERP (GERP). This will make distributed architectures possible, in which standardization takes place mainly at the level of information definitions and processes, so that local flexibility in information usage can be maintained at high precision. Needless to say, all these developments are already establishing themselves on a global scale. Hence, telecommunications and internet solutions for integrated SCM, ERP and CRM systems will have to be developed on a worldwide basis.

In reality, the distribution of the enterprise network cannot be managed by only one unique data-processing and data base application. The main reason is that the exchange of information and the behaviors, which are specific to operations of the network members, are so complex that they require computing paradigms which need to be decentralized and shared. Consequently, it seems that a MAS (Multi-Agent System) architecture (as a middleware) can best meet this need. Artificial intelligence (AI) techniques are especially welcome with their flexibility, adaptability and self-organizing capabilities.

GERP ought to be thought of as a dynamic process of assembling chains of capabilities and not just collaborating organizations. The configuration of the GERP as a network of cooperating business units will evolve continually with a high frequency of business units entering and leaving the network. This is in high contrast to the current ERP implementations, which have a monolithic structure.

As the study shows, the study of coordinated models goes beyond computer science, in that also evolutionary computation, behavioral sciences, social sciences, business management, artificial intelligence, and logistics somewhat strictly deal with how social agents can properly coordinate with each other and emerge as globally coherent behaviors from local interactions.

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here as virtual data fields, where each spatial or logical node stores the pervasive field values. The model promotes mediated interactions by exploiting a type of distributed information that can be used as a means to enforce indirect and uncoupled interactions among agents and that can also be expressive enough to represent contextual information in a form locally accessible and immediately usable by agents.

In the second part of this paper, the author introduces a novel concept: how to represent communications and operations in the complex MAS network. Instead of the “pair-to-pair” communication model, the author proposes to adapt a field-based model, where synchronous and asynchronous communication can take place.

In sum, the novelty of the proposed approach is based on the principle of reductionism and universality.

The author assumes that, following this line, we could imagine each agent as a set of internal frequencies, which resonate if triggered by the external fields with the coherent frequencies. The resonating frequencies are then transferred to other frequencies following agent’s internal “production rules”. These rules are nothing else but energy transformation laws, which govern agent’s dynamic behavior.

The author is at pains to emphasize that these findings represent an initial first “take” on the simulation of such complex social systems like proposed GERP. This work, though, gives some clear outlines and their explanatory sources. Moreover, the author has spent a considerable amount of this paper examining the methodological novelty of proposed approaches. Subsequent papers will focus more on the empirical aspects of the current research, which already show the feasibility and validity of the presented ideas.

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