31

AGENT-BASED ARCHITECTURE FOR VIRTUAL ENTERPRISES TO SUPPORT AGILITY

Heli Helaakoski
VTT Technical Research Centre of Finland
P.O.Box 3, FIN-92101 Raahe, FINLAND
heli.helaakoski@vtt.fi
Päivi Iskanius
University of Oulu, Faculty of Technology
Department of Industrial Engineering and Management
P.O. Box 4610, 90014 Oulu, FINLAND
paivi.iskanius@oulu.fi
Irina Peltomaa
VTT Technical Research Centre of Finland
P.O.Box 3, FIN-92101 Raahe, FINLAND
irina.peltomaa@vtt.fi

Global competition forces enterprises to concentrate on their core competencies while transforming themselves to participate in emerging inter-enterprise formations following the virtual enterprise (VE) paradigm. VE is a form that offers high flexibility, agility and resilience for enterprises to survive and prosper in the globalized economy. This paper introduces the real world VE that uses agent-based software to support agility. This research is conducted as a case study in the business network, which consist of several small and medium-sized enterprises (SME) and one focal company operating in the steel manufacturing industry in Northern Finland. The new VE, called SteelNet is aiming towards global markets with the support of effective information sharing.

1 INTRODUCTION

The world economy is undergoing a fundamental structural change driven by both globalization and the revolution of information and communication technology (ICT). Cooperation across traditional organizational boundaries is increasing, as outsourcing and electronic business is enabled by the Internet and other modern information-producing and communication-enabling ICT technologies. The Internet enables the use of other supporting technologies, which not only transmit information but also share information based on the intended meaning, the semantics of the data (Davies et al., 2003). One of these technologies is *agent software technology,* which has been considered as an important approach for developing industrial distributed systems (e.g. Jennings et al., 1995; Jennings and Wooldridge, 1998; Shen et al., 2003). Agent technology is seen one of the most promising technologies to enable flexible and dynamic coordination in the business network and support decision-making in every-day logistics activities and operational duties.

When inter-organizational cooperation moves beyond the buying and selling of goods and well-defined services, there is thus a need for flexible infrastructures that support inter-organizational communication, coordination and management. The challenge for the future is to create agile enterprises using modern technologies,

organizational forms and people to develop a new virtual form of manufacturing that transcends existing mindsets that are becoming increasingly dominated by the latter manufacturing dogma. *Virtual enterprise* (VE) has become an important business solution during the last decade. VE emphasizes the nature of networking and cooperation and offers high flexibility, agility and resilience. Several well known companies such as Benetton, Dell, Nike and Cisco have organized themselves based on this paradigm (e.g. Cao and Dowlatshahi, 2005; Tatsiopoulos et al., 2002). There is evidence that companies on the basis of network perform very well within their own industries. Network companies are at the moment more common in the fields affected by rapid technological change and growth. Networking is a way to acquire sensitivity and ability to adapt oneself to fast changes. This, however, do not constrain the VEs into high-tech industries. They are applicable to all industries, which are dynamic in nature.

Networking requires information integration, coordination and resource sharing and organizational relationship linkages. The organizational relationship linkages include communication channels between the supply chain members, performance measurement and sharing of common visions and objectives. In rapidly changing business environment, companies should not only be able to form linkages with a wide range of other organizations, but they should be able to form those linkages even more quickly, and be able to dissolve them rapidly and form new linkages as market conditions dictate (Daniel et al., 2005). These linkages are called inter-organizational systems (IOS) that automate the flow of information across organizational boundaries and link a company to its customers, distributors, or supplier.

This paper introduces the real-life VE that considers the use of agent-based solution for forming linkages between companies. The research work is conducted as a case study in the business network, which consist of several small and medium-sized enterprises (SME) and one focal company operating in the steel manufacturing industry in Northern Finland. This paper introduces the requirements for ICT in VE and discusses the suitability of agent technology to meet these requirements. The paper describes the SteelNet agent-based solution which was developed in this research to form lingages and to support mutual activities in case VE. This agent-based solution is called SteelNet system. The research work has been done in close collaboration with case VE and real end users, therefore we have been able to combine the theoretical knowledge and practise. A substantial amount of qualitative material from different sources (single and group interviews, observations, documents, and questionnaires) have been collected and qualitatively analyzed as an entity by the research group, and sometimes also by the company staff.

2 AGILITY SUPPORTING VIRTUAL ENTERPISES

ICT and globalization change the face of manufacturing. Today's globalized manufacturing is exhibiting the following characteristics: networking, meaning that the coordination of these functions makes intensive use of electronic networks and of virtual and geographical clusters of expertise, mass customization, in that methods of production must allow for detailed customization of products to meet the needs of individual markets and customers, and digitization, in the sense that many of these processes are controlled by advanced computer systems, which limit the need for human intervention (Tatsiopoulos et al., 2002). The emerging business

paradigm agility is the competitive advantage in the global manufacturing environment. Agility is the ability of an enterprise to rapidly respond to changes in an uncertain and changing business environment, whatever its source - customers, competitors, new technologies, suppliers, government regulation, etc is (Goldman et al., 1995). It is believed that the agility can be realized by dynamically reconfigurable virtual enterprise. *Virtual enterprise* (VE) is commonly defined as a temporary, cooperative alliance of independent companies, who come together to exploit a particular market opportunity (Browne and Zhang, 1999). The idea of VE is meant to establish a dynamic organization by the synergetic combination of dissimilar companies with different core competencies, thereby forming a "best of everything" consortium to perform a given business project to achieve maximum degree of customer satisfaction (Lau et al., 2000). VE companies assemble themselves based on cost-effectiveness and product uniqueness without regard to organization size, geographic location, computing environments, technologies deployed, or processes implemented. They share cost, skills, and core competences which collectively enable them to access global markets with world class solutions that could not be provided by any one of them individually (Browne and Zhang, 1999).

The life cycle of a VE has four stages: creation, operation, evolution and dissolution. When an enterprise has a market opportunity, the enterprise searches potential partners and negotiates with them through the information infrastructure. After contracts are signed, a VE is created for the manufacturing of a product. Then the VE manages the process of the manufacturing of the product. When the product is completed and a new market opportunity is created, the VE can be reconfigured so as to meet the resource requirement. When the mission of the VE is fulfilled the VE is finally dissolved. In other words, VE is characterized by frequent reconfiguration. (Wu and Su, 2005) Ideally, VE companies share capabilities, capacities, costs and risks to fulfill specific customer demands. As an example, project-oriented business typically acts as a VE concept. VE is created in order to manage an individual project, and after the customer order or project is delivered to the customer, also VE is dispersed.

VE form has several advantages, especially for SMEs. Companies in the VE type of business network can be smaller than normally. Because of this, there are less levels of bureaucracy which allows VE to react more quickly. Also, the VE companies can be more specialized to a particular task (i.e. manufacturing, distribution, R&D) and may actually perform better. They concentrate on their core competencies and by networking complement their non-core activities. This specialization may result in improved efficiency and effectiveness. Resources, including money, technology, labor, managerial skills, etc. are utilized more efficiently. SMEs that want to take advantage of a global market opportunity can ally themselves with a company that has expertise or market share in a given region or country. (Strader et al., 1998)

The success of the VE depends on intensive information sharing, which is enabled by sophisticated information technology to make business information transparent, seamless and easily accessible at any time and at any place. It is vitally important for the companies in a VE to share data and information and to communicate with each other effectively. Therefore, it is crucial to have an information infrastructure so that the data can be managed efficiently and inter-operation can be realized. The design and implementation of suitable information

management system for VE is complex activity. The software system has to support the distributed design and operation of many activities that are depending on each others and may have time restrictions. Software has to provide access to legacy software or through simple web interfaces. The information sharing and management in VE is a demanding domain that requires the adoption of emerging software solutions.

3 INFORMATION TECHNOLOGY FOR VIRTUAL ENTERPRISE

Due to the rapid development of ICT, the numbers of new IOSs are promising to improve the intensive information sharing. These are Enterprise Resource Planning systems (ERP), web services, electronic hubs and enterprise portals. These systems and technologies may improve the adoption of IOS, but most of these solutions are still insufficient for SMEs. Building such systems require lot of investments, time and knowledge, which SMEs scarcely have in changing business environment. ERPs require additional layers or middleware and WS provides only interface to other information systems, to create such solutions both approaches demand investments and skilled personnel. Electronic marketplaces and enterprise portals are focused for large enterprises due to the high initial costs. For SMEs those systems with external linkages are beneficial, when relationships are constant and the volumes are high in terms of material and costs. The external linkages to other enterprises are beneficial but they also may encumber the personnel of SMEs which are collaborating with several other enterprises via several systems. Hence, SMEs are trying to look for light-weight solutions which provide necessary information management and sharing properties. The design and development of invisible, easy to use and affordable ICT infrastructures is a key prerequisite for the effective large-scale implantation of the collaborative networks paradigm (Camarinha-Matos, 2003).

ICT should support the main business activities of VE by providing 1) network partner management, 2) network management, 3) VE configuration and 4) collaborative time, cost and quality control (Jagdev et al., 2001). Network partner management requires maintaining the capability/capacity information and performance history information. Network management is for storing the project experience data for future evaluation and to maintain collaboration preferences among partners. VE configuration gathers the customer requirements and controls the procurement process of the VE. Collaborative time, cost and quality control mechanism handles the project management concerning scheduling, budget and quality.

In this research, the information management is approached by using an agent-based approach. In a number of research studies, agent technology has been recognized as a promising approach to provide linkages between enterprises (Jennings et al., 2000; Norman et al., 2003; Papazoglou, 2001; Shen and Norrie, 1999) and to overcome the problems of traditional software. The benefits of the agent technology comparing to traditional software are (Jennings et al., 2000):

- flexibility; agents' actions can be based upon the agent's current situation, rather than being prescribed in advance
- agility; new services can be added and configured with minimal effect on other agents;

- adaptability; since an agent's choices can be guided by feedback received from previous invocations of particular paths through the business process.

The main advantages of this approach over more traditional counterparts such as management information systems, workflow management, and enterprise integration are that it offers greater flexibility, agility and adaptability. Agent technology provides a better means of building applications in certain domains where other solutions may be too expensive or time-consuming. It is suitable for problems where data, control, expertise or resources are distributed and need to interact with one another in order to solve the problem. Agents are also the most appropriate metaphor for representing a given software functionality when the system is naturally regarded as a community of cooperating autonomous components. Agents can also be used for making legacy components interact with each other, or possibly with new software components, by building an agent wrapper (Genesereth and Ketchpel, 1994).

4 AGENT-BASED SYSTEM FOR THE CASE VIRTUAL NETWORK

The case network structure is stable, but not static: network actors are active, and within the existing network structure, current relationships change, new relationships are formed and some relationships are terminated. In SteelNet system the main emphasis was set to achieve collaborative time, cost, and quality control, which in the same time partly covers network management (stores information about executed projects). Due to the time and resource limits, the network partner management and VE configuration was not implemented complete. There is also a question about maturity of VE, while companies do not want to share sensitive business information like capacity information.

The case network set requirements for the SteelNet system; they required support for following activities:

- sending and receiving request for quotation/quotation/order within VE
- making work order for all VE companies in same time (via Internet)
- the follow-up of project status in real-time
- support for document management concerning projects/deliveries
- resource management of the VE, e.g. services, personnel and machinery
- report on operation in VE, such as amount and time of use, used services, management of changes
- flexible change of quotation to order

The SteelNet system is a multi-agent system in which dedicated agents carry out their tasks in collaboration. SteelNet multi-agent architecture is used at the inter-company level, where each company is represented by a group of agents (Helaakoski et al., 2006; Feng et al., 2007). The agents in one company are responsible for coordinating its actions in the business network by co-operating with each other and communicating with agents in other companies. The agents use FIPA ACL as a communication language, and inter-company communication takes place over the Internet and is protected by SLL encryption (Secure Socket Layer).

At a more detailed level, each company's multi-agent system is a modular system framework that provides core functionality in the form of configurable dynamic module loading, a service registry, agent container services and log

services. Further functionality can be added by implementing new modules. The framework treats agents as extension modules, with the exception that they are attached to the agent container. Modules and agents can provide and utilise services by means of the company-level service registry. At the wider inter-company architecture level an agent can be considered to consist of the agent module and all the internal services it uses.

Figure 1 presents three ways of using SteelNet system: 1) Company A has an agent container which integrates ERP system to SteelNet system, 2) Company B has agent container without integration to own systems, or 3) Company C uses SteelNet system via web.

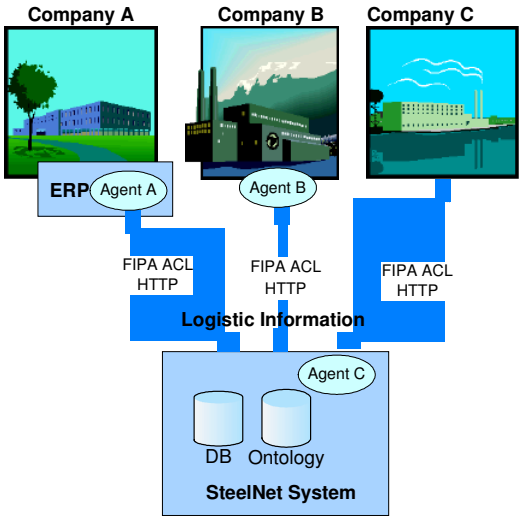

Figure 1 – Agents delivering information in various ways in SteelNet.

The case VE consists of independent companies collaborating with each other, companies that have several autonomous departments and employees. This can be viewed as a three-layer entity, a company, a department and an employee. Each of these layers can be modeled as an agent, since all of them are autonomous and co-operative entities. One agent representing one company would cause complex design inside an agent, as it should be capable of handling all company level activities. On the other hand, one agent per employee would also create very complex and inefficient agent communities. This leads to multi-agent system, where the responsibilities and tasks of the agents are divided by departments or activities, such as sales, management and manufacturing. In SteelNet system each company has several task-specific agents which communicate with their counterparts in the collaborating companies as well as with the agents in their own company.

5 CONCLUSION

This paper gives a real-world example of using agent technology in VE in order to ease the information sharing. Agent technology provides a suitable approach of

managing distributed information within business networks, since they offer both flexibility and problem solving services. Task-specific agents can carry out tasks autonomously and release personnel from routine manual work; furthermore the amount and type of agents can be changed. In long-term relationships, the agents can be integrated into company's own ERP system to avoid manual work duplication, and in occasional relationships, the agent system provides a web access into a system.

In this research, the case VE has taken a concrete step towards supply chain integration while SteelNet system gives opportunity for real-time and transparent information sharing among networked company. The ICT infrastructure varies in companies; therefore SteelNet architecture is designed to be flexible by providing several access manners for companies of different size and types. Intensive co-operation between personnel of the companies and research group has guided functionality and the appearance of the system to meet the requirements of every day duties.

The case VE in this research consisted of several SMEs. Thus the system is implemented to be suitable also for SMEs with minimum joining and maintenance costs. The requirements for joining to the VE are minimized for example advanced ERP system is not required. The SteelNet system can be used via web browser, although the system is possible to be integrated with company's own ERP system. The SteelNet system offers possibility for transparent information sharing, but the obtained benefit depends on the usage of the system. The VE has to define mutually accepted rules for sharing and using of information and follow these rules consistently. The prosperity of VE depends on commitment of companies involved in the VE.

The case business network structure was stable, which enabled the development of a common ICT system. Although the case network was committed to developing a common system, there were unsolved issues before the adoption of SteelNet. One of the most important was the role of the service provider, which can be a Third Trusted Party, or else the service can run at the site of the main contractor. Since all the companies in the SteelNet system are able to host projects, a Third Trusted Party as a service provider would be a natural choice. As the numbers of networks and VEs grow in future, collaboration between networks will become a necessity. This was approached by using the FIPA-compliant JADE platform, which theoretically enables collaboration with other FIPA-compliant agents.

6 REFERENCES

1. Browne J, Zhang J. Extended and virtual enterprises – similarities and differences. International Journal of Agile Management Systems 1999; 1(1): 30-6.
2. Camarinha-Matos LM. Infrastructures for virtual organizations - where we are. In Proceedings of IEEE Conference Emerging Technologies and Factory Automation - ETFA '03, 16-19 Sept. 2003, 2: 405-14.
3. Cao Q, Dowlatshahi S. The impact of alignment between virtual enterprise and information technology on business performance in an agile manufacturing environment. Journal of Operations Management 2005; 23: 531-50.
4. Daniel EM, White A. The future of inter-organisational system linkages: findings of an international Delphi study. European Journal of Information Systems 2005; 14(2): 188-203.
5. Davies J, Fensel D, van Harmelen F. Towards the Semantic Web, Ontology Driven Knowledge Management. John Wiley & Sons, 2003.

6. Feng SC, Helaakoski H, Haapasalo H, Kipinä, J. Software agents-enabled systems coalition for integrated manufacturing processes and supply chain management. International Journal of Manufacturing Technology and Management 2007; 11(2): 157–73.
7. Genesereth MR, Ketchpel SP. Software agents. Communications of the ACM 1994; 37(7): 48–53.
8. Goldman SL, Nagel RN, Preiss K. Agile Competitors and Virtual Organizations: Strategies for Enriching the Customer. Van Nostrand Reinhold, 1995.
9. Jagdev HS, Thoben K-D. Anatomy of enterprise collaborations. International Journal of Production Planning and Control 2001; 12(5): 437–51.
10. Jennings NR, Corera JM, Laresgoiti I. Developing Industrial Multi-Agent Systems. In Proceedings of ICMAS'95, San Francisco, 1995, The AAAIpress/The MIT press, 423-30.
11. Jennings NR, Wooldridge M. Applications of Intelligent Agents. In Agent Technology: Foundations, Applications, and Markets, NR Jennings and M Wooldridge, eds. 1998, Springer, 1998, 3-28.
12. Jennings NR, Faratin P, Norman TJ, O'Brien P, Odgers B. Autonomous Agents for Business Process Management. International Journal of Applied Artificial Intelligence 2000; 14(2): 145-89.
13. Helaakoski H, Iskanius P, Peltomaa I, Kipinä J, Ojala K. Agent technology for supporting real-time supply chain management. International Journal of Agile Systems and Management 2006; 1(4): 360–75.
14. Lau HCW, Chin KS, Pun KF, Ning A. Decision supporting functionality in a virtual enterprise network. Expert Systems with Applications 2000; 19(4): 261-70.
15. Norman TJ, Preece A, Chalmers S, Jennings NR, Luck M, Dang VD, Nguyen TD, Deora V, Shao J, Gray A, Fiddian N. CONOISE: Agent-based formation of virtual organizations. In Proceedings of 23rd SGAI International Conference on Innovative Techniques and Applications of AI, Cambridge, UK, 2003, 353-66.
16. Papazoglou M. Agent-oriented technology in support of e-business. Communications of the ACM 2001; 44(4): 71–7.
17. Shen W, Norrie DH. Agent-based systems for intelligent manufacturing: a state-of-the-art survey. International Journal of Knowledge and Information Systems 1999; 1(2): 129–56.
18. Shen W, Kremer R, Ulieru M, Norrie D. A collaborative agent-based infrastructure for Internet-enabled collaborative enterprises. International Journal of Production Research 2003; 41(8): 1621-38.
19. Strader TJ, Lin F-R, Shaw MJ. Information infrastructure for electronic virtual organization management. Decision Support Systems 1998; 23: 75-94.
20. Tatsiopoulus IP, Ponis ST, Hadzilias EA, Panayiotou NA. Realization of the virtual enterprise paradigm in the clothing industry through e-business technology. Production and Operations Management 2002; 11(4): 516-31.
21. Wu N, Su P. Selection of partners in virtual enterprise paradigm. Robotics and Computer-Integrated Manufacturing 2005; 21(2):119-31.