Heli Helaakoski

Adopting agent technology in information sharing and networking

Adopting agent technology in information sharing and networking

Heli Helaakoski

Academic dissertation to be presented, with the assent of the Faculty of Technology of the University of Oulu, for public defence in Auditorium TS101, Linnanmaa, on April 4th, 2008, at 12 noon.

Abstract

The thesis is concerned with the adoption of agent technology in information
sharing and networking. Companies are networking with changing partners, and
information sharing among enterprises with heterogeneous system environments
is increasing all the time. Since the types and sizes of the networked companies
vary, flexible and effective information sharing systems are needed. Networking
systems have to conform to the requirements of different information technology
structures and different information representation formats. Small and medium-
sized enterprises in particular need flexible and effective networking solutions.

The thesis reviews the use of agent-based applications in industrial
environments, and especially in the area of supply chain management. Agents
are autonomous, problem-solving computational entities capable of effective
operation in dynamic and open environments, and they are therefore able to
provide a suitable solution for complex process management among networked
companies. The thesis proposes the agent-based system called SteelNet as a
networking system for a business network. The area of application of the
SteelNet system is supply chain management in a real-world business network.
The design and implementation of an agent-based system for a case business
network is described.

The aim of the research was to consider the adoption of agents for supply chain
management in collaborative enterprises as compared with other approaches.
The system described here was designed, implemented and tested in a real-life
case, a business network in northern Finland. The SteelNet agent-based solution
consisted of collaborative task-specific agents representing companies and
various activities in the business network. The basis of agent communication and

collaboration is domain ontology, which describes the concepts of the area of application. The SteelNet system is built up on a JADE agent platform.

The result of this research is a SteelNet agent-based system which provides information sharing and networking properties in a business network. The domain of the research is supply chain management and the SteelNet prototype applications are focused on this field. The prototype applications concern procurement process and manufacturing process follow-up in a business network. The agent-based design of the SteelNet also enables it use in other areas of application, requiring only the definition of new task-specific agents and a new domain ontology.

The SteelNet system enables flexible and effective information sharing among different types of companies, such flexibility being required especially by small and medium-sized enterprises. The system provides different integration levels for companies – integration into the company's own systems or use via web pages. This is required on account of the dynamic nature of a business network. The graphical appearance of the system is clear and easy to use.

Preface

My interest in agent technology started in 2000 when I was doing my master's thesis in the Genie project (Genie of the Net-An Environment for Ubiquitous Servants) at VTT (VTT Technical Research Centre of Finland). During the years I have continued the work with agents and ontologies although the domain area has changed.

Original publications

I   Helaakoski, H., Iskanius, P. & Peltomaa, I. (2005) Current trends in steel product industry – Drivers towards e-business. The e-2005 eChallenges conference. Ljubljana, 19–21 October 2005. In: Cunningham, P. & Cunningham, M. (Eds.) Innovation and the Knowledge Economy: Issues, Applications, Case Studies. Part 2, Vol. 2. Information and Communication Technologies and the Knowledge Economy Series, European Commission: Information Society and Media. Amsterdam: IOS Press. Pp. 1661–1668.

II   Helaakoski, H., Iskanius, P., Peltomaa, I., Kipinä, J. & Ojala, K. (2006) Agent technology for supporting real-time supply chain management. International Journal of Agile Systems and Management, Vol. 1, No. 4, pp. 360–375.

III Iskanius, P., Helaakoski, H., Kipinä, J., Ojala, K. & Peltomaa, I. (2005) Development steps towards e-business. In: ICAM 2005. Proceedings of the International Conference on Agility. Helsinki, 27–28 July 2005. Espoo: Helsinki University of Technology. Pp. 171–178.

IV Iskanius, P., Helaakoski, H., Alaruikka, A.-M. & Kipinä, J. (2004) Transparent information flow in business networks by using agents. In: Proceedings of the 2004 IEEE International Engineering Management Conference, Vol. 3. Singapore, 18–21 October 2004. Singapore: Stallion Press. Pp. 1342–1346.

V   Helaakoski, H., Iskanius, P., Peltomaa, I. & Kipinä, J. (2006) Agile business model in the steel product industry sector. In: Chai, K. H., Hang, C. C. & Xie, M. (Eds.) Proceedings of the 2006 IEEE International Conference on Management of Innovation and Technology, Vol. 2. Singapore, 21–23 June 2006. Pp. 1010–1014.

VI Helaakoski, H., Feng, S. C., Jurrens, K. K., Ojala, K. & Kipinä, J. (2004) Collaborative software agents in steel product industry. In: Proceedings of the IASTED International Conference on Artificial Intelligence and Applications. Innsbruck, 16–18 February 2004. Calgary: Acta Press. Pp. 147–152.

VII   Helaakoski, H., Kipinä, J. & Haapasalo, H. (2004) An agent architecture for steel product business networks. In: Proceedings of the Sixth International Conference on Enterprise Information Systems, Vol. 4. Porto, 14–17 April 2004. Setúbal: INSTICC. Pp. 467–470.

VIII   Feng, S. C., Helaakoski, H., Haapasalo, H. & Kipinä, J. (2007) Software agents-enabled systems coalition for integrated manufacturing processes and supply chain management. International Journal of Manufacturing Technology and Management, Vol. 11, No. 2, pp. 157–173.

IX   Alahuhta, P., Löthman, H., Helaakoski, H., Koskela, A. & Röning, J. (2006) Experiences in developing mobile applications using the Apricot Agent Platform. Special issue of Springer's Personal and Ubiquitous Computing Journal, Vol. 11, No. 1, pp. 1–10.

Contents

List of abbreviations

ACL   Agent Communication Language

AI   Artificial Intelligence

API   Application Programming Interface

B2B   Business-to-business

BDI   Belief-Desire-Intention

BN   Business Network

BPM   Business Process Management

EDI   Electronic Data Interchange

EJB   Enterprise Java Beans

ERP   Enterprise Resource Planning

FIPA   Foundation for Intelligent Physical Agents

FIPA ACL Foundation for Intelligent Physical Agents,
Agent Communication Language

FIPA SL   Foundation for Intelligent Physical Agents, Semantic Language

GUI   Graphical User Interface

HTTP   Hypertext Transfer Protocol

ICT   Information and Communication Technology

IIOP   Internet Inter-ORB Protocol

IOS   Inter-organisational System

JADE   Java Agent DEvelopment framework

JVM	Java Virtual Machine
KIF	Knowledge Interchange Format
KQML	Knowledge Query and Manipulation Language
KSE	Knowledge Sharing Effort
LAN	Local Area Network
LGPL	Lesser General Public Licence version
MAS	Multi-Agent System
NIST	National Institute of Standards and Technology
ORM	Object-Relational Mapping
PIF	Process Integration Framework
RFQ	Request For Quotation
SCM	Supply Chain Management
SSL	Secure Socket Layer
SME	Small and Medium-sized Enterprises
SMTP	Simple Mail Transfer Protocol
TCP/IP	Transmission Control Protocol/Internet Protocol
TLS	Transport Security Layer
WBS	Work Breakdown Structure
WS	Web Services
XML	eXtensible Markup Language

1. Introduction

Enterprises today are living in a changing business environment characterized by global competition, rapid development of technology, increased cost pressure and more aggressive demands from customers. It has become critical in terms of their survival for them to combine forces to compete jointly in the market. Both large organizations and SMEs are forming business networks, which means voluntary-based economic and social co-operation between independent companies. Networking is a term that is familiar to most of us and has many meanings and applications. In this thesis *a business network is a group of companies using their combined talents and resources to co-operate for joint functions*. Some other net-structure concepts can also be found in the literature, e.g. "virtual supply chain" (Hewitt 2000), "value net" (Bovet & Martha 2000), and "virtual enterprise" (Browne & Zhang 1999). Information and communication technology (ICT), especially the Internet, has greatly accelerated the diffusion of inter-organisational networks and has intensified collaboration between organisations. Regardless of company size and type of business, virtually all organisations' ICT systems are nowadays interconnected (Li et al. 2006).

The success of a business network depends on intensive information and knowledge sharing, which should be implemented by means of sophisticated information technology in order to make the business information transparent, seamless and easily accessible at any time and in any place (Maamar et al. 2001). Information systems in a value chain can make businesses more efficient and reduce operating costs when they work together collaboratively by eliminating labour-intensive work and enhancing responsiveness. All the time business mergers, acquisitions and consolidations continue and demand more agility and more flexibility at greater speed, information sharing will grow in importance. The real challenge for enterprises today is to build an infrastructure that enables information, in all formats, to be utilized freely at the right time and in the right place (Pollock & Hodgson 2004).

The research domain of this thesis is supply chain management (SCM) in a business network in the heavy steel manufacturing industry, which consists of companies that differ in size and type. A supply chain is a business process, which according to one definition (Smith & Fingar 2003), is "the complete and

dynamically coordinated set of collaborative and transactional activities that deliver value to customers". According to Cooper et al. (1997) and Lambert et al. (1998), "Supply chain management is the integration of key business processes from end user through original suppliers that provides products, services, and information that add value for customers and other stakeholders". The essential core of SCM is by definition supply chain integration, which today is increasingly being managed through information and communication technology (ICT). Supply chain integration is defined in Christopher (1998) and Lambert et al. (1998) as process integration upstream and downstream in the supply chain. According to Lee (2000), supply chain integration has three aspects: 1) information integration, 2) coordination and resource sharing, and 3) organizational relationship linkages. Information integration refers to information about important supply chain parameters shared among the supply chain members. This includes any type of data (e.g. demand data, inventory data, capacity plans, production and schedules, promotion plans or shipment schedules) that could influence the actions and performance of the members of the supply chain. Coordination and resource sharing refer to the realignment of decisions and responsibility in the supply chain. Organizational relationship linkages include communication channels between the supply chain members, performance measurement and the sharing of common visions and objectives.

For companies operating in increasingly demanding environments, this means that they should form linkages with a wider number and variety of organisations and for a wider range of activities, such as trading, outsourcing and collaboration. Since market forces are becoming more severe, increasingly turbulent and volatile, companies should not only be able to form linkages with a wide range of other organizations, but they should also be able to form those linkages more quickly and be able to dissolve them rapidly and form new linkages as market conditions dictate (Daniel & White 2005). These linkages are inter-organizational systems (IOS) that automate the flow of information across organizational boundaries and link companies to their customers, distributors or suppliers.

Traditionally inter-organizational systems have been tightly coupled, and therefore have required considerable relationship-specific investments. The first inter-organizational systems were developed for transmitting electronic messages about 25 years ago, Electronic Data Interchange (EDI) (Iskandar et al.

2001) having been the most effective form of electronic messaging to date. EDI has enabled the exchange of messages by containing standard business objects such as invoices, purchase orders or electronic funds, but it is both limited and inherently inflexible in its ability to activate a value chain. It is able to transmit basic information about business transactions, but it is unable to adapt to rapidly changing market conditions (Yang & Papazoglou 2000). Furthermore, EDI has often been proprietary in nature, expensive to develop and time-consuming to deploy, resulting in a reluctance on the part of organizations to change existing relationships or develop new ones. Due to the rapid development of ICT, the number of new IOSs is promising to improve the linkages between trading partners, which now include Enterprise Resource Planning (ERP) systems, web services, electronic hubs and enterprise portals.

ERPs are configurable software packages that provide an integrated suite of systems and information resources that coordinate operational and management processes across internal business activities such as procurement, accounting, finance and human resources. They are proprietary, expensive and require a great effort to integrate with other information systems, as they are designed for internal use. Web services (WS) (Newcomer 2002) provide open standards for interfaces, and communication between these components ensures that these web services can be integrated with each other and with existing applications, regardless of the programming language used to create them or the platform on which they run. Many WS solutions to date have been implemented within single enterprises in order to provide internal integration between existing applications, and work on integration between enterprises is now under way. Internet-based electronic marketplaces are defined as "web-based systems which enable automated transactions, trading or collaboration between multiple business partners" (White & Daniel 2004). Today's electronic marketplaces aid the procurement process for both buyers and suppliers and offer additional services which include information exchange, such as order placement, design support and supply chain planning (Dai & Kaufmann 2002). The largest enterprises and their direct partners traditionally form linkages of this kind only between parts of a network, which result in the network working at a sub-optimal level (Zeng 2001). According to Malone et al. (1987), increasing product specificity and the complexity of product descriptions are detracting from the use of electronic markets. An enterprise portal, defined as "a flexible information technology platform that allows dispersed sources of information to

be linked together, whilst providing users with the opportunity to customise what they need from the information source" (Chan & Chung 2002), provides information system linkages between enterprises. Enterprise portals can allow increased coordination and collaboration between individuals and working groups, but such coordination and control activities can easily become a burden, especially for SMEs.

These systems and technologies may improve the adoption of IOS, but most solutions of this kind are still insufficient for SMEs. Building such systems requires substantial investments in time and knowledge, which SMEs can scarcely afford in a changing business environment. ERP systems require additional layers of middleware, and WS provides only an interface to other information systems, while both approaches demand investments and skilled personnel in order to create such solutions. Electronic marketplaces and enterprise portals are focused on large enterprises, due to the high initial costs, and systems with external linkages are beneficial for SMEs, only when the relationships are constant and the volumes are high in terms of material and costs. External linkages with other enterprises are beneficial, but they may also encumber the personnel of an SME that is collaborating with several other enterprises via different systems. Hence SMEs try to look for lightweight solutions which provide the necessary information management and sharing properties.

Agent technology has been recognised in a number of research papers as a promising approach to providing linkages between enterprises (Jennings et al. 2000a, Norman et al. 2003, Gijsen et al. 2002, Papazoglou 2001, Shen & Norrie 1999) and overcoming the above-mentioned problems. Agents and agent-based systems still lack universally accepted definitions, but most researchers agree that agents should be autonomous, social, reactive and pro-active. According to Jennings et al. (2000a), its benefits relative to traditional software are the following:

- flexibility: agents' actions can be based on their current situation rather than being prescribed in advance

- agility: new services can be added and configured with minimal effect on other agents

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

Agents are identical to active objects in most important respects. For example, they encapsulate both state and behaviour, and communicate by passing messages. But beyond that, an agent is a rational decision-making system that is capable of reactive and pro-active behaviour and of interleaving these types of behaviour as the situation demands. Furthermore, object-oriented research has not addressed issues such as cooperation, competition, negotiation and computational economies, which form the foundation for multi-agent systems development (Wooldridge 1997).

Ontologies form an essential part of agent technology, providing a mutual understanding of the domain for agents, so that they are able to communicate and co-operate. An ontology can be regarded as a terminology that describes the domain that agents share.

1.1 Objective and scope of the research

Since the environment of business networks is dynamic and complex, the finding of a suitable information technology solution for information and knowledge sharing is a severe problem. Small and medium-sized enterprises (SMEs) in particular suffer from a lack of efficient, flexible and reasonably priced software solutions for integrating their activities with those of their suppliers, customers and partners. Enterprises are not willing to take on one more software solution in addition to old ones which may become obsolete in the near future as the composition of the network changes. So far, the markets have not been able to provide flexible and cost-effective solutions for business networks.

This thesis will consider the use of agent technology in company networking, especially to enable information sharing among networking companies. The focus will be on the adoption of agent technology in business networks, i.e. the design, development and implementation of agent-based systems. The objectives of this thesis have been the following: to study the requirements for supply chain information management in business networks, to research the suitability of agent technology for networking and to develop a flexible and efficient software solution for a case business network. The work has been conducted in two projects: SteelNet (Software agent solutions for the steel product industry's

logistic processes) and SteelNet2 (Supply Chain Management in Value Networks by means of Multi-agent Systems) during the years 2002–2006. The parallel agile business process development focused on the same network has been described in Iskanius (2006).

Since information sharing among enterprises with heterogeneous system environments is increasing all the time, the requirements for a flexible and effective information sharing system are obvious. The traditional knowledge engineering approaches, with large scale knowledge bases, are inappropriate because of the distributed nature of a business network. Agents, on the other hand, are autonomous problem-solving computational entities capable of effective operation in dynamic and open environments, and they are therefore able to provide suitable solutions for complex process management among networked companies. An agent-based system is thus proposed for managing logistic process information in a business network. This thesis describes the design and implementation of an agent-based system for a real-life case, a business network in northern Finland. The architecture of the SteelNet system consists of collaborative task-specific agents representing companies and serving as a basis for the agent collaboration domain ontology, since the SteelNet system is built up on a JADE agent platform[1].

The result of this research is the SteelNet agent-based system, which provides information sharing and networking properties for a business network. The domain of the research is supply chain management and the SteelNet prototype applications are focused on this field. The design of the SteelNet also enables other domains to be addressed by defining new task-specific agents and a new domain ontology.

To summarize, the assertion is that agent technology provides a feasible solution for information and knowledge sharing in company networking and that the designs and implementations presented in this thesis can be used to achieve more efficient information sharing among collaborative companies. Agent technology can be used for information sharing among heterogeneous applications and systems and for supporting networking in an industrial environment regardless of the domain. The prototype implementations confirm

---

[1] Available at http://jade.tilab.com/.

the flexibility and reconfigurability of agent-based solutions, while they also strongly support a plug-and-operate approach. Although the thesis considers a specific application area, networking in the heavy steel industry, the designs and implementation can be generalized and applied to other domains by defining a domain-specific ontology in each case and reconfiguring the tasks of the agents.

The main contributions of the thesis are the following:

− a survey of the suitability of agent-based solutions for the domain of supply chain management, focusing especially on information sharing and networking properties

− an analysis of the requirements for supply chain management in business networks

− the design of the information sharing system for a heterogeneous enterprise environment consisting of several companies with different information technology infrastructures

− the design and prototype implementation of an agent-based system for information sharing.

The main contribution of the thesis is presented in detail as a collection of original publications enclosed as appendices I–IX.

1.2 Outline of the thesis

The introductory part of the thesis is organized as follows:

Chapter 2 introduces the basic concepts and components of software agent technology, in order to place the main contributions of the thesis in context. Since a comprehensive software agent solution consists of agents that communicate by means of a mutual agent communication language and by sharing a mutual understanding based on an agreed ontology, the chapter gives a short overview of these concepts.

The types of agent-based solutions are presented in Chapter 3, which especially reviews the use of agent-based technology in both academic research and commercial products in industrial environments.

Chapter 4 describes the requirements and challenges associated with information sharing and networking, and also the industrial environment where the agent-based solution was to be adopted and the manner in which ICT technologies are adopted in the case network.

Chapter 5 describes the agent-based solution developed here, providing an account of the requirements of the case business network, the case processes implemented, the system infrastructure and the prototype implementation.

Chapter 6 discusses main results and contributions of the thesis, and considers directions for further development and open problems for future research. The thesis is concluded in Chapter 7.

1.3 Summary of the original publications

This section summarizes the content of the publications and clarifies the contribution of the author. The co-authors have agreed on the descriptions. The publications are based on work carried out by the author between 2002 and early 2006. None of the publications have previously been used as a part of a doctoral thesis.

Publications I–V focus on the role of information and ICT in business networks, and especially in the case business network. They propose the agent-based system for developing the SCM and supporting agility in the case network. The requirements for an information management system and for the development of ICT use in the case business network are defined.

Publications VI–IX propose the SteelNet agent-based architecture for IOS in the case business network. They define the business network and the conceptual approach of using agent technology in this particular network. They also discuss co-operation between agent-based systems within and between companies. Publication IX proposes a mobile approach to using agents in a service supply chain.

Publication I proposes digital business design as a future business model to support agility in supply chains, presenting the process of developing a business network as consisting of an e-business roadmap and a supporting software solution for inter-organizational coordination in the business network. Since the whole development process requires changes in ways of acting, the adoption of e-business by companies is also discussed.

The author has designed the development and implementation process for the SteelNet system to meet the challenges set by a changing business environment. Dr. Päivi Iskanius contributed the business expertise required for this publication (Chapter 3), and Ms. Irina Peltomaa, B.Sc., contributed to the SteelNet implementation process and assisted in writing the publication.

Publication II reviews the role of information technology in supply chain management and the use of agents in logistic systems. It discusses the use of agents in industrial business networks for transmitting information related to the supply chain between companies and their Enterprise Resource Planning (ERP) systems. It also describes the iteration process involved in the development of the SteelNet system.

The author defined the development process for the SteelNet system and assessed the suitability of agents for supporting supply chain management in such a system. Dr. Päivi Iskanius contributed the supply chain management expertise. Ms. Irina Peltomaa, B.Sc., Mr. Janne Kipinä, B.Sc., and Mrs. Kaija Ojala, M.Sc., contributed to the development process.

Publication III presents the process of developing an industrial business network that aims to be competitive in global markets by increasing its agility. The process consists of developing an e-business roadmap and a supporting software solution for the business network.

The author described the software development process in the business network and introduced the technical study. Otherwise the publication was written by Dr. Päivi Iskanius. Mr. Janne Kipinä, B.Sc., Mrs. Kaija Ojala, M.Sc. and Ms. Irina Peltomaa, B.Sc., made comments and revised the publication.

Publication IV was written in the early phase of the research and describes the methodology and the importance of information and ICT in supply chain management. It proposes the conceptual framework of a multi-agent system for business networking.

The author designed the conceptual framework for using agents in supply chain management, and Dr. Päivi Iskanius and Ms. Anna-Maija Alaruikka, M.Sc., provided expertise regarding supply chain management. Mr. Janne Kipinä, B.Sc., assisted in designing the conceptual framework.

Publication V introduces an agile business model supported by an agent-based system. It discusses the role of ICT in creating agility and the use of agents to support an agile business model. SteelNet is introduced as a case study supporting the promotion of agility in a real-world business network. This publication introduces the second application case, the procurement process.

The author studied the role of agents in an agile business model and the benefits of the agent-based SteelNet system in meeting the agility requirements in the case study. Dr. Päivi Iskanius provided the business approach and wrote about the agile business model. Ms. Irina Peltomaa, B.Sc., and Mr. Janne Kipinä, B.Sc., assisted in describing the case study.

Publication VI focuses on the SteelNet design phase before any implementation, describing the use of agents and proposing an agent-based architecture. The author bore the main responsibility for this publication, which marked the initiation of research collaboration between VTT and NIST (National Institute of Standards and Technology, USA).

This was the first publication produced by the author herself, having been written jointly at NIST and the University of Oulu. The author described the SteelNet system in co-operation with Mr. Janne Kipinä, B.Sc., and Mrs. Kaija Ojala, M.Sc., while Dr. Shaw C. Feng and Dr. Kevin K. Jurrens described the agent-based process integration framework.

Publication VII introduces the first definitions of the SteelNet system and gives an overview of related agent solutions. It defines the case business and specifies its requirements. It also proposes agents to carry out activities in the business

network and sets out the first version of the agent-based architecture. The prototype application to manufacturing process follow-up is presented.

The author investigated the related agent solutions and designed the use of agents for carrying out the tasks in the business network according to the business functionalities. The architecture of the system was defined in co-operation with Mr. Janne Kipinä, B.Sc. Prof. Harri Haapasalo provided the business approach and revised the manuscript.

Publication VIII describes the change in the business environment and provides a review of agent-based solutions in manufacturing and supply chain management. The paper introduces an agent-enabled framework for business and manufacturing networking and presents the components of multi-agent systems, agent communication and the ontology of such networks. It also describes a framework in which two systems, PIF (Process Integration Framework) from NIST and SteelNet from VTT, could be integrated in order to share manufacturing information among companies. Information is defined in this paper as comprising logistic information and information related to the manufacturing process itself (tool selection, removal rates, etc.). Two prototype implementations are described.

The author designed the framework with related components together with Dr. Shaw C. Feng from NIST. Mr. Janne Kipinä, B.Sc., carried out the implementation process and provided the description of the SteelNet implementation. Prof. Harri Haapasalo complemented the business view and provided valuable comments.

Publication IX describes the basic architecture of the Apricot agent platform developed for providing context-aware and personalized mobile services and the development of four demonstrations built upon it. Since there had previously been no agent platforms supporting mobile service development, the experiences gained from this work were extremely valuable and provided guidance for developing agent-based services in other domains.

The author contributed to the development of the Apricot platform in co-operation with Mr. Petteri Alahuhta, M.Sc., and Mr. Henri Löthman, M.Sc., and also contributed in co-operation with Mr. Petteri Alahuhta to setting the

requirements for mobile service development and designing two of the demonstrations: a mobile instant messenger and a mobile car sales application. The Apricot platform description was provided by Mr. Henri Löthman and the context-aware messaging and service viewer demonstrations by Mr. Arto Koskela, M.Sc. Prof. Juha Röning provided comments and revised the manuscript.

2. Software agent technology

Agents can be viewed as autonomous, problem-solving computational entities capable of effective operation in dynamic and open environments. Agents are often deployed in environments in which they interact and possibly cooperate with other agents that may have conflicting aims. Agent-based technologies, which have emerged from a convergence of distributed object systems and distributed artificial intelligence (Wooldridge & Jennings 1995), are already providing benefits in manufacturing, SCM and B2B exchanges.

2.1 Software agents

Although there has been a lot of discussion about the definition of agents and agent-based systems and so far there is still a lack of universally accepted definitions, most agent researchers agree with the definitions formulated by Wooldridge and Jennings (1995). Perhaps the most general use of the term agent is to denote a hardware or (more commonly) software-based computer system that possesses the following properties:

– autonomy: agents operate without the direct intervention of humans or others and have some kind of control over their actions and internal state (Castelfranchi 1995)

– social ability: agents interact with other agents (and possibly humans) via some kind of agent-communication language (Genesereth & Ketchpel 1994)

– reactivity: agents perceive their environment (which may be the physical world, a user, via a graphical user interface, a collection of other agents, the Internet, or perhaps all of these combined), and respond in a timely fashion to changes that occur in that environment

– pro-activeness: agents do not simply act in response to their environment, but are able to exhibit goal-directed behaviour by taking the initiative.

Some agents may have additional characteristics, and some attributes may be more important than others for certain types of application. Other researchers emphasize various other attributes as follows:

– Mobility is the ability of an agent to move around an electronic network (White 1994).

- Veracity is the assumption that an agent will not knowingly communicate false information (Galliers 1988b).

- Benevolence is the assumption that agents do not have conflicting goals, and that every agent will therefore always try to do what is asked of it (Rosenschein & Genesereth 1985).

- Rationality is (crudely speaking) the assumption that an agent will act in order to achieve its goals and will not act in such a way as to prevent its goals being achieved – at least insofar as its beliefs permit (Galliers 1988a).

The basic feature of an agent is that it interacts with its environment. The agent senses its environment, uses what it senses to choose an action, and then performs the action through its effectors. The input can be messages that are received, and the action can be the sending of messages. A representation of simple agent-environment interaction is given in Figure 1 (Vidal et al. 2001).
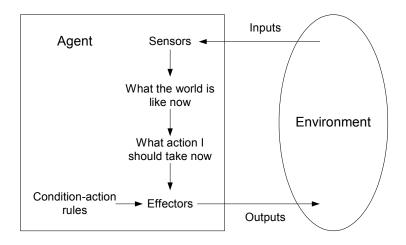
Figure 1. Simple agent-environment interaction (Vidal et al. 2001).

An agent-based system is defined in this thesis as a system that is both designed and implemented in terms of agents. It may contain only one agent, which carries out some defined tasks, while a multi-agent system (MAS) consists of several interacting agents and therefore is more complex and capable of solving more versatile problems.

2.2 Typology of agents

Agents can be classified by several dimensions (Nwana & Ndumu 1998): by their mobility, by their ability to be deliberative or reactive, or by the attributes they should exhibit, e.g. autonomy, learning and cooperation. Gilbert et al. (1995) described intelligent agents in terms of agency, intelligence, and mobility. Agency is the degree of autonomy and authority vested in the agent; it can be measured by the nature of the interaction between the agent and other entities in the system. Intelligence is the degree of reasoning and learned behaviour: the agent's ability to accept the user's statement of goals and carry out the task delegated to it. Mobility is the degree to which agents themselves travel through the network.

There are no definitive distinctions for classifying existing software agents. Nwana (1996) proposes seven types of agents to clarify the understanding of agent typology. The classification is summarized in Figure 2, where heterogeneous agent systems refer to applications that combine agents from two or more of these categories.
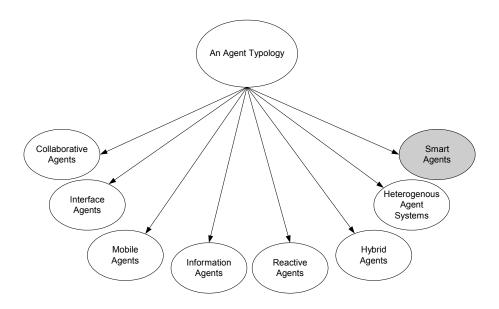
Figure 2. A classification of software agents (Nwana 1996).

Franklin and Graesser (1996) have offered a taxonomy, which is presented in Figure 3. This taxonomy covers most examples found in the literature. Below this initial classification, they suggest that agents can be categorized by control structure, environment, the language in which they are written, and application.
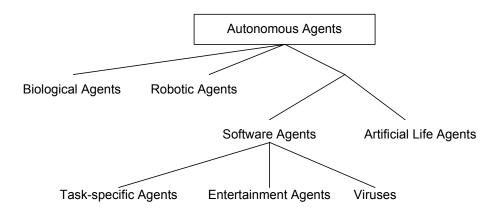
Figure 3. Agent taxonomy by Franklin and Graesser (1996).

In an e-business environment, Papazoglou (2001) has proposed a typology of agents based on their functionality and competencies. Business agent typology has four subcategories: application agents, personal agents, general business activity agents and system-level agents. A categorization of business agents is presented in Figure 4 (Papazoglou 2001).

There is no unambiguous way to classify agents when there are no definitive distinctions between agents. Gilbert et al. (1995) described agents by their terms of intelligent abilities, whereas classification by Nwana (1996), Franklin and Graesser (1996) and Papazoglou (2001) refer to the competencies of agents. The taxonomy presented by Franklin and Graesser (1996) is a high-level classification which can be completed by Nwana's classification. Papazoglou's typology is focused on the business domain for clarifying the understanding of business agent typology. This thesis approaches agent taxonomy according to Franklin and Graesser (1996) by focusing on software agents and in that category especially on task-specific agents. To complement this classification, the agents represented in this thesis are a heterogeneous agent system (Nwana 1996) because they combine agents from the collaborative agent as well as the information agent categories.
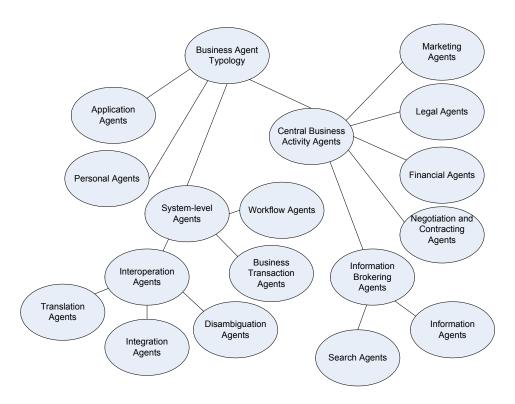
Figure 4. A business agent typology (Papazoglou 2001).

2.3 Agent communication

The functionality of an agent-based system depends on inter-agent communication. Software agents need to be able to communicate with users, with customers, with system resources and with each other in order to cooperate, collaborate and negotiate. Therefore agents require three fundamental components: a common communication language, a common understanding of the exchanged knowledge and the ability to exchange what is included in the communication language and shared knowledge (Finin et al. 1997).

For communication, agents use an Agent Communication Language (ACL), which defines the types of messages exchanged and their meanings. It also has to define the syntax and semantics of the language. The most widely used ACLs (Labrou et al. 1999, Labrou 2001) are KQML (Knowledge Query and Manipulation Language) (Finin et al. 1997) and FIPA ACL (the Foundation for Intelligent

Physical Agents Agent Communication Language) (Foundation for Intelligent Physical Agents 2002a), although other ACLs also exist. KQML was developed in the early 1990s as part of the US government's ARPA Knowledge Sharing Effort (KSE) (Fikes et al. 1991) and is a language and protocol for exchanging information and knowledge which has been used extensively. The Foundation for Intelligent Physical Agents (FIPA) is a non-profit organization aimed at producing standards for the interoperation of heterogeneous software agents[2].

The sharing of a common understanding of the exchanged knowledge is realised by using a shared content language and ontology. The most common content languages, which define the content of the message, are KIF (Finin et al. 1997, Foundation for Intelligent Physical Agents 2003) and FIPA SL (Foundation for Intelligent Physical Agents 2002b). In agent-based applications a common ontology refers to an explicit specification of the ontological commitments of a set of programs. An ontology should be an objective (i.e. interpretable outside of the program) description of the concepts and relationships that the agents use to interact with other agents, programs, knowledge bases and human users. An agent will commit itself to an ontology if its observable actions are consistent with the definitions in that ontology. Apart from the ACL and the ontology, agents have to have the ability to exchange messages and to transport messages over the network, usually using a lower-level protocol such as SMTP, TCP/IP, IIOP or HTTP.

Agents do not engage in single-message exchanges but have conversations according to a pre-arranged coordination protocol. These conversations are task-oriented, shared sequences of messages such as negotiations or auctions. Agents send messages to each other to achieve certain purposes: to inform, to warn, to elicit help, to share knowledge or to promise something. These are called speech acts, and are usually defined in terms a BDI model, comprising beliefs (what the agent knows), desires (what the agent wants) and intentions (what the agent is doing).

According to (Finin et al. 1997), the primary importance of software agents lies in their ability to communicate with other applications and share knowledge. The components of such an agent are summarized in Figure 5.

---

[2] Available at http://www.fipa.org/index.html.
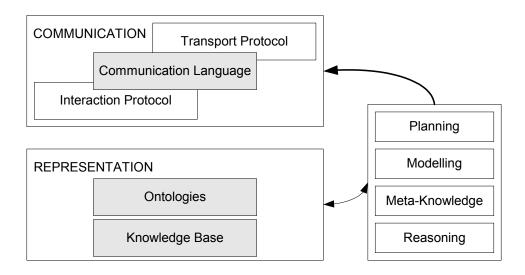
Figure 5. Interoperating software agents identify three classes of component: representation components, communication components and components that are not directly related to shared understanding (Finin et al. 1997).

2.4 Ontologies

Ontologies have many definitions, since the history of the notion of ontology can be traced as far back as ancient Greece. The most widely agreed definition in the Artificial Intelligence (AI) community is represented by that of Tom Gruber (Gruber 1993): *An ontology is an explicit specification of a conceptualisation.* A few years later Borst (Borst 1997) modified Gruber's definition as follows: *Ontologies are defined as a formal specification of a shared conceptualisation.* These two definitions are merged and explained in Studer et al. (1998) as follows: "*An ontology is a formal, explicit specification of a shared conceptualisation.* A *'conceptualisation'* refers to an abstract model of some phenomenon in the world by having identified the relevant concepts of that phenomenon. '*Explicit'* means that the type of concepts used, and the constraints on their use are explicitly defined. '*Formal'* refers to the fact that the ontology should be machine readable, which excludes natural language. '*Shared'* reflects the notion that an ontology captures consensual knowledge, that is, it is not private to some individual, but accepted by a group." Other definitions of ontologies are presented in Gómez-Pérez et al. (2004).

Ontologies are used in Artificial Intelligence (AI) to facilitate sharing and reuse of knowledge. The use of ontologies in knowledge engineering, natural language processing and knowledge representation began in the 1990s and has since extended into intelligent information integration, co-operative information systems, information retrieval, electronic commerce and knowledge management. In practise, ontology provides a shared and common understanding of a domain that can be communicated between people and heterogeneous and widely spread application systems (Fensel 2001).

FIPA (Foundation for Intelligent Physical Agents 2001) defines an agent ontology as "a common vocabulary of agreed upon definitions and relationships between those definitions, to describe a particular subject domain". In the FIPA communication model the communicating agents share the ontology of communication defining speech acts and protocols which is presented in Figure 6. In order to have communication, agents must also share an ontology of their domain of application and have to agree on the terminology that they use to describe this domain. In an open environment, agents are designed around various ontologies, either implicit or explicit, although explicit ontologies, together with a standard mechanism for accessing them and referring to them, are necessary in order to allow communication.
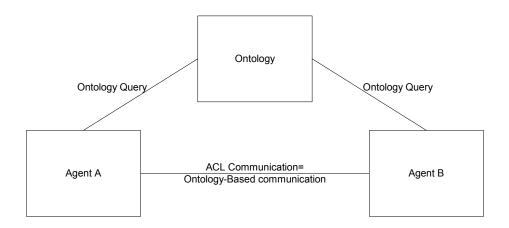
Figure 6. The model of ontology-based communication (Foundation for Intelligent Physical Agents 2001).

In general, an ontology is a formal description of a domain of discourse, consisting of a list of concepts and relationships between these concepts, where the concepts are classes of objects in the domain and the relationships are hierarchies of these classes.

Ontologies may include more information than relationships, such as

– properties

– value restrictions

– disjointedness statements

– specifications of logical relationships between objects.

A part of the SteelNet ontology which defines the area of application of the manufacturing process is presented in Figure 7. The ontology contains general concepts, manufacturing-specific concepts and accessory concepts, and these concepts in turn have attributes that define them, and also relations with other concepts.
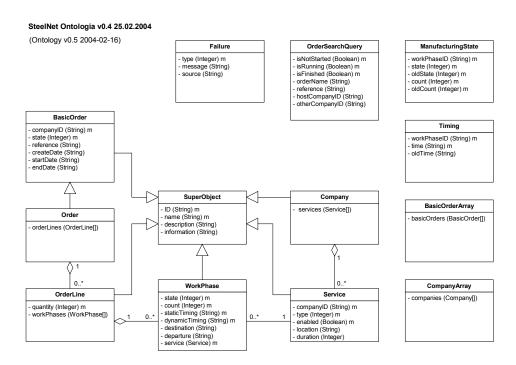
Figure 7. Part of the SteelNet ontology.

2.5 Agent toolkits

Agent-based systems require a significant infrastructure, since they have to provide several layers of functionality, such as message transportation and a dynamic mechanism. Adopters therefore usually use agent toolkits to deploy the agent infrastructure or agent applications. These toolkits provide the basic building blocks to support an agent-based system. According to Wooldridge and Jennings (1999), the designing of an agent architecture by yourself often leads to two mistakes: firstly, developing a new, reliable architecture with sufficient power requires significant research and development resources, which the majority do not have, and secondly, the design process should be carried out in tandem with a major research effort in order to result in an architecture that is sufficiently novel to generate interest and revenue. Even so, there is no generally accepted architecture, although overall patterns are beginning to emerge.

A generic toolkit framework (Luck et al. 2004) is presented in Figure 8 which consists of an environment for running agents, high-level services, low-level services, software for building agents and software for managing the agent system. The agents are usually developed separately, and the toolkit provides a framework for this.
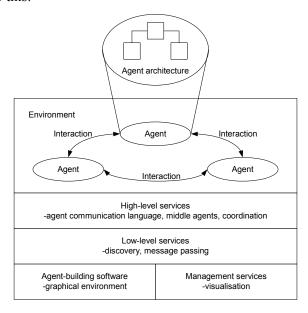
Figure 8. A generic agent toolkit framework (Luck et al. 2004).

A brief description is given here of three agent tools which were considered for use in this research: JACK, JADE and Zeus, the final decision in the SteelNet project having been in favour of JADE. Further information about multi-agent tools is given in Mangina (2002), which describes some tools and products which are available for working in the field.

JACK Intelligent Agents, developed by Agent Oriented Software Pty. Ltd. and the University of Melbourne, is an environment for building, running and integrating commercial-grade multi-agent systems using a component-based approach. It has its own JACK Agent Language that extends Java with agent-oriented concepts such as agents, capabilities, events, plans, agent knowledge bases, and resource and concurrency management. When developing an agent solution with JACK, users need only to select the required components from the JACK component library, which contains the following components: run time environment, compiler, BDI agent model, simple team model, development environment, agent debugger and the JACOB object modelling framework (JACOB Object Modeller). The editors allow developers to define agents, capabilities, plans, events and agent databases, in addition to which the JACOB modeller provides facilities for integrating with other processes or existing applications, including support for inter-process data transport based on object-oriented data modelling. JACOB provides libraries to support this inter-process connectivity in Java and C++. JACK is a commercial product but is free for evaluation purposes (JACK Intelligent Agent Agent Manual 2005).

JADE (Java Agent DEvelopment Framework), a software framework from the Telecom Italia Lab., provides for the implementation of multi-agent systems through a middleware that complies with the FIPA specifications and through a set of tools that supports the debugging and deployment phases. The agent platform can be distributed across machines (which do not even need to share the same OS) and the configuration can be controlled via a remote Graphical User Interface (GUI). The configuration can even be changed during run time by moving agents from one machine to another one as and when required. JADE is implemented completely in the Java language and the minimal system requirement is version 1.2 of JAVA (the run time environment or JDK). Some years ago JADE was integrated with the results of the LEAP project, which developed a lightweight agent platform for small devices such as PDAs and phones. JADE is free software and is distributed by TILab, the copyright holder,

in open source software under the terms of the LGPL (Lesser General Public Licence Version 2) (Bellifemine et al. 2003).

The ZEUS toolkit[3] from the BT Exact Technologies' Intelligent Systems group is a synthesis of established agent technologies with some novel solutions. It is free for academic use and provides a library of software components and tools that facilitate the rapid designing, development and deployment of collaborative agent applications. The aim of the ZEUS project was to create a relatively general purpose and customisable, collaborative agent building toolkit that could be used by software engineers with only basic competence in agent technology to create functional multi-agent systems. The toolkit delineates between domain-level problem-solving (the acquisition, representation and use of domain-specific knowledge in problem-solving) and agent-level functionality (application-independent multi-agent issues such as communication, co-ordination, task execution and monitoring, and exception handling) so that developers can concentrate on implementing the domain-specific problem-solving abilities of their agents. The ZEUS toolkit is based on the 'visual programming' paradigm and supports an open design in order to ensure that it is easily extensible. It consists of a set of components written in the Java programming language that can be categorized into three functional groups (or libraries): an agent component library, an agent building tool and a suite of utility agents comprising name server, facilitator and visualizer agents. The components of the Agent Component Library together enable the construction of an application-independent generic ZEUS agent that can be customized for specific applications by imbuing it with problem-specific resources, competences, information, organizational relationships and co-ordination protocols.

There are significant differences between the approaches represented by agent tools, so that there is no means of measuring the suitability of one approach versus another. Since the tools are developing all the time, it is up to developers to make their own choice based on a variety of factors. Each approach has its benefits in low-level services, but the current trend is towards more lightweight approaches. There are clear management benefits in having agents operating within dedicated platforms, since they can easily provide monitoring and management tools. In high-level services the communication is usually based on

---

[3] Available at http://labs.bt.com/projects/agents/zeus/.

FIPA ACL, as although JACK has its own language, it also supports the FIPA ACL. Ontology support varies, and only ZEUS has its own ontology editor.

2.6 Characteristics of agent solutions

Agent technology will probably never be adopted as widely as object-oriented programming, since it has a narrower area of applications. Any new technology has to possess one of two things (Jennings & Wooldridge 1998):

− the ability to solve problems that have hitherto been beyond the scope of automation – either because no existing technology could be used to solve them, or because it was considered too expensive (difficult, time-consuming, risky) to develop solutions using existing technology

− the ability to address problems that can already be solved and to solve them in a significantly better way (cheaper, easier, more effective or faster).

Software agent technology is suitable for solving new types of problems in reactive systems. A capability for solving new problems is required in open systems, where the structure of the system is capable of dynamic change. One example of an open system is the Internet, where the software system must be able to operate autonomously and without guidance. Complex software systems require modularity and abstraction, which can be provided by agents. A multi-agent system can solve a complex overall problem by partitioning it into sub-problems handled by interacting agents. Furthermore, intelligent agents may provide a means for human-computer interaction in ubiquitous computing systems.

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 & Ketchpel 1994).

To summarize, the benefits of agent-based solutions are 1) feasibility, 2) robustness and flexibility, 3) reconfigurability and 4) redeployability (Mařik & McFarlane 2005). Feasibility means that in some cases agents are the only feasible automated solution for distributed decision-making. Agent-based systems are robust since there is no central element and no central decision-making, so that the loss of one subsystem does not cause a fatal failure in any other subsystem. Agent systems can be reconfigured by changing, adding or removing hardware or software modules, as they support a plug-and-operate approach. The same agent-based system can be redeployed in different subsystems of the manufacturing facility and company, using the same communication standards and negotiation scenarios. There are also several barriers that need to be confronted before widespread adoption. These are the costs, the guarantee of operational performance, scalability, engineering education, design methodologies, standards and the performance of the agent system (Mařik & McFarlane 2005). The agent research community has published case studies on the successful agent technology deployment in order to provide guidance to potential adopters (Munroe et al. 2006).

2.7 Summary

This chapter has presented the definition of an agent that is most agreed upon. According to this definition, an agent is autonomous, has social skills, is reactive and is able to act pro-active. An agent may also possess additional attributes such as mobility, veracity, benevolence and rationality. The basic feature of an agent is that it is able to interact with its environment and work upon that interaction. Usually, agents work in collaboration with other agents in multi-agent systems. The typology of agents classifies agents mainly based on agent abilities or agent competencies and functionalities.

Agent communication and ontologies form a basis for agent collaboration by providing means for communication and mutual understanding. Agents use agent communication languages and at the moment the most common languages are FIPA ACL and KQML. Above communication languages, content languages

are needed to define the content of the message and coordination protocols to enable agent conversations. Ontologies provide shared understanding for agents by defining a common vocabulary of a particular subject domain.

Agent toolkits are used to implement agent-based systems and this chapter has given an overview of three agent tools: JACK, JADE and Zeus. The development work of this thesis has been built using JADE agent framework because it is FIPA compliant and it is compatible with the Protégé ontology environment. Furthermore, it is open software that also provides an open forum for developers and the user community.

Agent-based systems are suitable for solving complex problems. The benefits of the agent-based solutions are feasibility, robustness and flexibility, reconfigurability and redeployability. The case environment of this thesis consists of several companies that have a complex problem of supply chain management in a heterogeneous environment. The benefits of the agent-based system are evident for such an environment which requires flexibility and the ability to react to changes in the technical structure.

3. Agent-based applications

Although agent-based solutions are used in many different domains, the applications can be divided into two main groups: distributed systems and personal software assistants. In distributed systems agents work as processing nodes in systems that usually consist of several agents (multi-agent systems), while personal software assistant agents are proactive assistants for the users working in a particular application. There are several other ways of classifying agent applications, and in this thesis it will be done by application domain. A classification according to domain type was made, since this view fits best with the objectives of the work. This chapter reviews the various agent application types, with the main emphasis on commercial and industrial research applications.

3.1 Fields of agent applications

Agents are used in various ways in commercial applications. Firstly, they are used as personal assistants in information management. Agents manage information by filtering and gathering it from the Internet (Lieberman et al. 2001) or by handling emails to reduce the user's workload (Maes 1994). Personal agents manage electronic information, engaging in tasks proactively on behalf of the user in order to find, filter, assess and present information to the user in the most appropriate manner (Crabtree et al. 1998). In the Internet, agents are used to add value and personalization to the underlying information infrastructure by indexing and searching the web (Etzioni 1996, Caglayan & Harrison 1997). Secondly, they collect and manage distributed information from various electronic data sources. In electronic commerce, agents have been proposed for selling and buying goods, comparing prices or doing personalized shopping (Chavez & Maes 1996, Zacharia et al. 1999, Sandholm 2000, Menczer et al. 2002), while in entertainment applications they are used in games and virtual environments to provide intelligence and personalization (Wavish 1996, Fatima et al. 2005, Fogel 2003, Kenyon 2006, Maes 1995, Moore & Greengrass 2000, Wassink et al. 2006, Grand et al. 1997). In the medical field they can support health care, organize medical staff and engage in patient monitoring (Huang et al. 1995, Larsson & Hayes-Roth 1998, Nealon & Moreno 2002, Nealon & Moreno 2004).

3.2 Agent applications in industry

Many researchers see agent technologies as being in the chasm of development, taken seriously only by early adopters but not yet accepted by the majority of potential users, who tend to be more pragmatic about new technologies (Luck et al. 2005). The agent research community has provided powerful theories, algorithms and techniques with an immense potential for deployment in various industrial applications, but the commercial companies and industrial adopters have not had the courage to invest in the adoption of these novel theoretical advancements for solving industrial problems.

There are several smaller companies and a few big industrial organizations at the moment that integrate multi-agent system concepts into their industrial operations. The main bottlenecks hindering the rapid, massive adoption of agent-based solutions have been recognized as being (Pechousek & Marik 2006):

- limited awareness of the potentials of agent technology in industry – agents are used in few specialized disciplines, while they remain unused in others to which they would be well suited

- limited publicity for successful industrial projects involving agents

- misunderstandings about the capabilities of the technology, inflated expectations on the part of the early industrial adopters and subsequent frustration.

Agent-based applications have been reported in the following industrial areas to date: manufacturing, process control, telecommunication systems, air traffic control, traffic and transportation management, information filtering and gathering, electronic commerce, business process management, human capital management, skills management, (mobile) workforce management and defence (Luck et al. 2003). The use of agent technology does not reveal the maturity of the applications, however, as some of those reported are still at the prototype phase. This section introduces the most promising agent applications from several research groups and some commercial products.

3.2.1 Industrial research agent applications

There have been a number of research projects related to information systems in business networks, and various architectures and platforms have been proposed to support distributed operating over company boundaries.

The Palo Alto Collaborative Testbed (PACT) (Cukosky et al. 1993) was one of the first demonstrations of both collaborative research efforts and agent-based technology. The PACT experiments showed how pre-existing engineering software systems can be combined to constitute a distributed system of integrated design information and services. The PACT architecture encapsulates each component system with an information agent, which serves to bridge the idiosyncrasies of access to that system's knowledge and abilities. The information agents use KQML as their communication language, with KIF as the exclusive representation language. MADEFAST (Cukosky et al. 1996), an early example of collaborative work by defence contractors using the Internet, used the web for collaborative design, particularly for sharing and exchanging design documents, including CAD models, notes, test results, calculations and other information related to the design.

The MetaMorph project at the University of Calgary developed a mediator-centric federation architecture for intelligent manufacturing (Maturana & Norrie 1996). In MetaMorph I, agents were used to represent manufacturing devices and products or parts to be fabricated, while mediators were used to coordinate the interactions among them. The following research project, MetaMorph II, was aimed at integrating the manufacturing enterprise's activities with those of its suppliers, customers and partners to form an open, distributed intelligent environment. For this purpose a hybrid agent-based architecture combining the mediator and autonomous agent approaches was proposed (Shen & Norrie 1998).

DEDEMAS, GNOSIS-VF and PRODNET II are all Esprit projects funded by the European Union. The DEDEMAS (Decentralized Decision Making and Scheduling) approach provided a Mediator-based mechanism for decentralized decision-making and scheduling covering both the multi-site operations of a company and its chain of external suppliers (Tönshoff et al. 2000). The purpose of the Mediator is to extend and integrate the functionality and data of existing

legacy systems. The GNOSIS-VF (Virtual Factory) (Kalliokoski et al. 2000) was concerned with the development of a Virtual Factory Platform, i.e. information technology support for a Virtual Factory. The main objectives were to design the distributed operational web-based client-server architecture for a Virtual Factory and develop tools for its platform. The PRODNET II (Production Planning and Management in an Extended Enterprise) (Camarinha-Matos 1997) project developed a reference architecture and open platform to support industrial virtual enterprises, with special focus on the needs of small and medium-sized enterprises. The PRODNET infrastructure includes two main modules for each enterprise in the network: an Internal Module representing the autonomous unit of a particular company and a Cooperation Layer containing functionalities for the interconnection between the company and the whole network.

The Process Integration Framework (PIF) project at National Institute of Standards and Technology (NIST) has developed a multi-agent system to integrate machining process optimization software with a Numerical Control (NC) programming system in order to maximize the material removal rate in machining processes (Feng et al. 2004). Within the NIST research activities, agent communication is performed in a prototype multi-agent platform to demonstrate the sharing of manufacturing knowledge and process data throughout the life-cycle of the product. NIST's work provides support for a variety of transactions among business entities and engineering activities within a company. NIST's multiple agents-enabled business and manufacturing systems coalition framework includes business and manufacturing networks, an ontological engineering environment, a multi-agent architecture, agent interactions, an agent message format and business rules (Feng 2005).

Agents are used in the Intelligent Manufacturing Systems program to implement a manufacturing system to integrate manufacturing engineering software systems for intelligent manufacturing (Deen 2003, Marik et al. 2003). Agents are also used to control production activities (Fan & Wong 2003) and to represent machines collaborating or competing with each other for jobs on a factory floor (Parunak 1993, Lu & Yih 2001, Usher 2003, Shaw 1988).

The ADEPT (Advanced Decision Environment for Process Tasks) project conducted by British Telecom Labs was concerned with the flexible management of business processes (through automated negotiation) within a

static organizational structure. The ADEPT system consists of multiple software agents that concurrently negotiate an agreement on how resources should be assigned to support the business process. The agents are responsible for business process provisioning, enactment and compensation. The ADEPT system was deployed in two real world applications: one with BT and one with ICI Engineering (Jennings et al. 2000a, Jennings et al. 2000b).

The CONOISE-G[4] project carried out by several British agent research groups (University of Cardiff, University of Aberdeen, BT Exact Technologies and University of Southampton) has developed a service-oriented architecture for robust and resilient virtual organizations on the Grid. The aim is to provide mechanisms to ensure effective operation of virtual organizations in the face of disruptive and potentially malicious entities in dynamic, open and competitive environments. The solution consists of a service-oriented architecture with integrated mechanisms for decision-making, trust and reputation management, policing and QoS monitoring. An evaluation of the solution is now under way with respect to the various individual components and their interactions (Preece et al. 2005).

Business-to-business transactions in the supply chain management area consist of several typically repeated chains of events, such as the requisition of resources, a request for quotes from candidate business entities, the selection of vendors, an enactment and delivery order and relationship management among business entities. These events are relevant to the functions of several business networks, including a strategic sourcing network, an electronic procurement network, a virtual enterprise network, a product design network, manufacturing, inventory and delivery management, a network of electronic marketplaces, a network for workflow/supply-chain management and a network for supplier relationship management (Blake & Gini 2002). The use of autonomous, intelligent software agents has been studied in Gijsen et al. (2002), Karageorgos et al. (2002) and Collins et al. (2002) with the aim of easing this complex of business networks in electronic commerce, and a multi-agent architecture has been developed to help decision-making in supply chain re-engineering, i.e. to help managers to understand the costs, benefits and risks associated with various alternatives (Swaminathan et al. 1996). An agent-oriented system has also been

---

[4] Available at http://www.conoise.org.

developed to allow agents that manage supply chain activities to interact with each other within a role-based organizational model in order to perform negotiation, coordination and acquisition functions in supply chains (Fox et al. 2000).

Agent technologies are best suited for domains that involve interaction between entities from more than one organization, although many agent applications have been implemented as closed systems inside a single company or organization. When using environments with multiple companies, the implementation of a successful agent-based application requires agreement and coordination from all the companies.

The agents in MASCOT (Multi-Agent Supply Chain COordination Tool), an agent-based decision support environment for dynamic supply chain management developed by the Robotics Institute, help users from multiple organizations to collaborate over the development and revision of supply chain solutions. These agents are customizable, mixed-initiative decision support tools that act as coordination and collaboration wrappers for the management modules associated with a given supply chain entity. An initial version of the MASCOT architecture was developed and validated in coordination between a machine shop and a tool shop, and the architecture has been further validated recently through experimentation with more complex supply chain configurations (Sadeh et al. 2003).

ExPlanTech[5] is a multi-agent architecture that enables the creation of a flexible and reconfigurable component-based system that allows distributed computation and flexible data management. It is built on top of the JADE agent platform and has agents of several types: planning, resource, cockpit, extra-enterprise (EE) and enterprise-to-enterprise (E2E) (Pechoucek et al. 2005). Most of the implementations of ExPlanTech are in manufacturing production planning and simulation, and it can also be connected to ExtraPlanT, which addresses the concept of extra-enterprise production planning not only within an enterprise but also with other enterprises (e.g. suppliers, co-operators involved in the supply chain or virtual organization environments) (Hodik et al. 2005). One case of the use of ExtraPlanT has been reported.

---

[5] http://www.unisoft.gr/explantech/project.asp?subid=exp_1b.

3.2.2 Commercial agent applications for industry

Some start-up companies offer specific agent products for industry as the cornerstones of their business. This chapter briefly overviews the companies that provide agent-based solutions. Tryllian[6] in the Netherlands has developed its own Agent Development Kit, which it uses as a basis for its services in information management. Agent Technology Pty. Ltd.[7] uses smart and intelligent software agents in business integration and adaptive supply chain solutions.

Agent Oriented Software Ltd. (AOS) has developed the JACK multi-agent platform[8], which enables fast and easy development of applications and integration of disparate applications. In their case project, Human Variability in Computer Generated Forces project (HV-CGF), AOS, together with the UK Ministry of Defence (MoD), used agent technology for modelling human variability in military environments and developed an agent-based simulation environment. The project was built on the JACK Intelligent AgentsTM toolkit (Howden et al. 2001).

Magenta[9] provides software solutions and applications based on multi-agent technology. Their agent-based solutions support real-time, real-world scheduling, planning and resource allocation, personalised internet applications and applications for complex businesses. In their pilot case, the developers used the agent paradigm as a design tool for developing an Ocean i-Scheduler, an intelligent scheduler for the cargo fleets of Tankers International, one of the world's major Very Large Crude Carrier (VLCC) oil tanker pools. The Ocean i-Scheduler assists the human schedulers at Tankers International in planning and re-planning which cargoes are to be assigned to which vessels in their fleet (Himoff et al. 2005).

CapGemini[10] focuses on the use of agents to optimise adaptive transportation, supply, and production networks. CapGemini has made agent pilots in real-time

---

[6] Available at http://www.tryllian.com.
[7] Available at http://www.agent-technology.com.au/index.html.
[8] Available at http://www.agent-software.com.
[9] Available at http://www.magenta-technology.com/.
[10] Available at http://www.us.capgemini.com/services/serv_overview.asp?ServID=29.

dispatching and optimising the transport execution for logistic providers. They have also used agents to simplify and automate the complex forecasting process and to synchronise the supply and demand in the supply chain process for retailers.

Cougaar Softaware Inc.[11] provides an intelligent agent-based middleware system called ActiveEdge for building complex, distributed, intelligent applications for the commercial and military sectors. Cougaar technology has been tested in various secure, time-critical operational environments while it was being developed in the Defense Advanced Research Project Agency's (DARPA) Cognitive Agent Architecture (Cougaar) project.

Eurobios[12] use agent-based modelling in their simulation tool. The simulation model developed by Eurobios combines agent technology with discrete event simulation, so that the agents represent interacting entities with behaviour rules and decision capabilities attached, while the processes are simulated using events that occur concurrently or consecutively (Darley & Sanders 2004). Eurobios has made agent implementations for risk modelling and simulation in the manufacturing industry, for operational risk management as well as for inventory management.

Lost Wax[13] has developed the Lost Wax Agent Framework, which provides an environment for the design, development and deployment of multi-agent systems. They focus on deploying agents in supply chains and in logistics, manufacturing, telecommunications and financial services.

Quarto Software GmbH[14] develops software solutions based on the Fred delegation platform, mainly in the area of business process automation. Quarto software calls agents Freds, smart objects which are based on ontologies, are dynamic, reusable and can represent their content in various forms.

---

[11] Available at http://www.cougaarsoftware.com/.
[12] Available at http://www.eurobios.com.
[13] Available at http://www.lostwax.com/.
[14] Available at http://www.quarto.at/.

Whitestein Technologies[15] has an agent-based Living System product that offers various, agent-based, autonomic business solutions for the logistics, transportation, manufacturing, and telecommunications industries. In one of their agent pilot projects, their agent-based Living Systems Adaptive Transportation Networks (LS/ATN) provides automatic optimisation for large-scale transport companies, taking into account the many constraints on their vehicles, fleets, cargo and drivers. The optimisation is achieved by a community of agents representing geographical regions and uses an auction-like protocol to decide the most appropriate transport solutions (Dorer & Calisti 2005).

Furthermore, there are some user organisations which have recognised the benefits of agent technology, the best known being DaimlerChrysler, which has used agent technology for scheduling car production on the factory floor and deployed an agent system in one of its production lines in Stuttgart (Bussmann & Schild 2000).

3.3 Summary

Agent-based applications can be classified in several ways into two main groups: distributed systems and personal assistants. This thesis classifies agent applications based on their domain which best fits to the objectives of the work. Agents have been deployed in various domains. They are personal assistants in information management, managing, filtering, assessing and presenting information to the users in the most appropriate manner. Agents collect and manage information in ecommerce, provide intelligence and personalisation for games and virtual environments and assist in several ways in the medical field. However, the main emphasis of this review is on industrial applications in order to give an overview of the agent research and commercial applications in the industry domain.

The use of agents in industry has been researched for several years, yet the adoption of agents at their full potential is in its early stages. Reasons for slow adoption are limited awareness of agents' capabilities and a lack of knowledge about successful industrial agent solutions. There has been a lot of research into

---

[15] Available at http://www.whitestein.com.

the use of agent-based solutions in manufacturing and supply chain management, but most of it has focused on information management within the organisation. Since the concept of networking, or a virtual enterprise (VE), has become more imperative, research into the use of agents across organizations has increased.

During this research, agent-based systems for supply chain management in business networks were starting. In the manufacturing industry, the agents had been used to integrate and coordinate design and manufacturing information or to manage business processes within one organisation. This review also shows that the use of agents throughout a supply chain that includes several companies is becoming more common as well as more researched. While integrated supply chain management is a complex and distributed process, agent technology is well suited for it. Yet there are no agent-based implementations for business networking where the roles and tasks of the companies can change depending on delivery. Furthermore, the existing agent-based systems are suited for companies that have a good level of information technology infrastructure. There is still a lack of research of agent-based systems for such environments that consist of several companies with different levels of information technology infrastructure and when the collaboration of the companies is full of changes.

The review of commercial agent applications was made in order to provide the state of the art about the commercialisation of agent-based systems and implementations. During this research, most of the agent tools and platforms were under development, as well as the development of FIPA specifications. The review shows that agent-based systems are becoming more popular in industry, especially in the domain area of the supply chain, yet there is no ready solution for the problems this thesis is focusing on.

4. Agent-based information sharing and networking

A business network is a temporary consortium of independent member companies and individuals who come together to exploit a particular market opportunity. The companies assemble themselves based on cost-effectiveness and product uniqueness without regard to organization size, geographical location, computing environments, technologies deployed or processes implemented. They share costs, 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. The success of the business network depends on *intensive information sharing*, which is enabled by sophisticated information technology designed to make the business information transparent, seamless and easily accessible at any time and in any place (Browne & Zhang 1999).

The design and implementation of a suitable information management system is a complex activity. The software system has to support the distributed design and operation of many activities that are dependent on each other and may have time restrictions, and it has to provide access to legacy software or simple web interfaces. Information sharing and management in a business network is a demanding domain that requires the adoption of emerging software solutions.

It was decided in this research to design and implement such an information management system using an agent-based approach. The SteelNet project viewed information sharing as a collection of autonomous agents that negotiate with one another and come to mutually acceptable agreements that coordinate their interdependent sub-activities. 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.

This chapter reviews the general requirements for business process systems, and in more detail the requirements for a supply chain management system. A description of a business network is also given, together with the special requirements set by this business network. Although the implementation of the

agent-based system was focused on this case network, the applicability of the system was considered during the design and implementation process. Since agent technology is fairly new and still rarely adopted, the last chapter describes the typical model of e-business implementation in order to compare the agent-based model with it.

4.1 Requirements for information sharing in a business network

Information systems for SCM must incorporate six principles in order to provide adequate support for enterprise planning and operations, which must be taken into account when designing or evaluating information systems as SCM applications (Bowersox & Closs 1996). There are four principles for the information itself and two for the information systems. Firstly, the information must be readily and consistently *available to all* who need it. Information regarding SCM activities, such as order and inventory status, is traditionally often paper-based, which does not support the need to respond to customers and improve management decisions. Information availability can reduce operating and planning uncertainty. Secondly, the information must be *accurate.* Accuracy means that there must be consistency between physical counts or status and information system reports. Increased information accuracy reduces uncertainty and lowers inventory requirements. Thirdly, the information must be *timely*, i.e. the delay between an activity occurring and it becoming visible in the information system should be minimized. Any delay will reduce planning effectiveness and increase the inventory requirements. Fourthly, the information should be *appropriately formatted*. The right information must be in the right structure and sequence. The first of the two principal expectations regarding the information systems is that they must be *exception-based* in order to highlight problems and opportunities. If the system can identify exceptional situations which are not a part of the normal process, planners will be able to focus their attention on these. Furthermore, the information systems should be *flexible* in order to be able to meet both system users' and customers' needs. Systems should be able to provide data tailored to specific customer requirements.

The role of software in supply chain integration is to allow the human and manual activities to be assigned appropriately. In other words, it must provide

access to the software tools required to complete the tasks and to ensure that the dependences between the tasks are satisfied. According to Jennings et al. (2000a), the key characteristics of a business process application are the following:

− The processes are dynamic and unpredictable, a priori specification of all the activities is hard.

− The processes involve a mixture of human activities and automated tasks, with the exact ratio varying between applications.

− Multiple organizations may be involved in the process and attempts to maximize its own profit within the overall activity.

− Processes may be physically distributed within one site, across a country, or even between continents.

− The tasks, information and resources involved in the business process are subject to decentralized ownership within organizations.

− Different groups within organizations are relatively autonomous, maintaining their own control over resources and their own information systems.

− There is a high degree of natural concurrence, in that many interrelated tasks may be running at any given point in the business process.

− There is a requirement to monitor and manage the overall business process.

In general, business process applications are distributed within or among organisations, and they must support dynamic processes. Software must also support business by providing overall control to the business process that might have shared ownership among multiple organisations. All these factors require flexible and distributed business applications.

4.2 Description of the case business network

The research reported in this thesis was conducted in two research projects: SteelNet (Software agent solutions for the steel product industry's logistic processes) and SteelNet2 (Supply Chain Management in Value Networks by means of Multi-agent Systems) during years 2002–2006. The aims of these

projects were to remove the restrictions imposed by traditional communication tools by developing a mutual software solution and to support the development of the business network towards agility. In the SteelNet case the business network (BN) consisted of several SMEs and one focal company operating in the steel product industry in Northern Finland. A business network was defined here as a stable set of business activities by which several enterprises have agreed to contribute their expertise towards the completion and supply of a product that caters for a relatively stable market. Communications among the supply chain partners were designed to minimize inventory and lead times across the whole chain, to monitor quality and to enact improvement programmes.

The SteelNet BN consisted of several independent companies engaged in engineering and the manufacture of heavy steel components for civil engineering, steel works, power plants, the pulp and paper industry and the oil and gas industry, including offshore projects. The typical work phases were machining, bending, welding, flame cutting and coating, while the largest company in the BN was responsible for manufacturing the steel. The companies were familiar with each other, as they had been collaborating for several years. This had helped each of them to develop its own fields of expertise and there was only a limited amount of overlapping. The variety and capability of the machine tools and welding machines, and also the sizes of the workshops tended to steer each company in a typical direction and therefore reduced overlapping.

Since competition in the steel industry had become more severe, the companies were looking for means of strengthening their competitive position and the agility of their BN. Despite the long collaboration, there was a lack of mutually agreed working methods and means of information sharing. The BN needed support for supply chain integration in terms of shared deliveries, and it was this that led them to take part in the present research.

Networking in manufacturing is focused on small series, one-of-a-kind complex products and turnkey systems (Jagdev & Thoben 2001), and the SteelNet BN was no exception to this, in that it was manufacturing project-based special products, parts and components for the shipbuilding and offshore industries, for instance. One-of-a-Kind Production is defined in (Tu 1997) as a particular production method by which a product (i.e. 'One') ordered by an individual customer within a specific product domain (i.e. 'a-Kind') can be developed and

produced. A main contractor sets up a project to meet an inquiry or order from a customer. This main contractor is defined as *a company that receives a customer inquiry or an order and plans the main combination and configuration of the project consortium and manages through the customer order-fulfilment* (Gijsen et al. 2002). The customer in the case of a one-of-a-kind product is defined as a legal entity *that sets up an inquiry or an order to a company that can offer the needed products or services* (Gijsen et al. 2002). Typical projects in the SteelNet BN tended to involve other enterprises that engineered or produced sub-components for the final product, so that a typical process might includes the manufacture of a specified steel, flame cutting to specified dimensions, bending, the welding of components together and the necessary assembly fittings, with all of these phases possibly taking place in different companies.

According to (Gijsen et al. 2002), the main business activities of a VE should be supported by ICT as follows:

− Network partner management, to maintain capability/capacity information and performance history information.

− Network management, to store project experience data for future evaluation and to maintain collaboration preferences among partners.

− A VE configuration, to gather customer requirements, to create a work breakdown structure and a mapping of the network partners to it, to search for missing vendors, to send requests for proposals to all the vendors involved, to merge the proposals received into a combined proposal to be sent to the customer, and to prepare contracts to be signed by the customer and participating vendors.

− Collaborative time, cost and quality control: mechanisms to ensure that the project is completed in time and within the approved budget, and that it satisfies the quality requirements.

The main emphasis in this work was placed on collaborative time, cost and quality control, which at the same time covered network partner management (capability information) and network management (stores information on the projects executed). VE configuration was implemented despite gathering the customer information and searching for missing vendors outside the network. In network partner management, the capacity information was left outside the

implementation. There was also the question of the maturity of the BN, since the companies were in the early stages of networking and were not ready to share sensitive business information such as that on production capacity and information about customers. As BN will become more mature, these issues must be implemented in order to support the competitiveness and effectiveness of the whole BN.

In the SteelNet case an update of the system was provided by the research partners, but in a real business environment the service provider could be a Third Trusted Party. Another possibility is that the service would run at the site of the main contractor, but this naturally depends on the nature of the BN.

4.3 The case network for the agent-based solution

Information sharing in the SteelNet system is based on an agent architecture in which the agents transmit logistic information between the collaborative companies seamlessly and transparently. This information is used for supply chain co-ordination across enterprises by means of task-specific combinations of agents tailored to the particular business network process that needs to be supported and the various tasks that need to be fulfilled.

To achieve the full benefits of an agile business model the information sharing has to take place in real time and be reliable and seamless. Accuracy of information and system adaptability are emphasized when sudden and unexpected changes take place in the supply chain, and such changes are inevitable, arising as a consequence of machinery breakage or a customer's altered delivery requirements. Digitalization guarantees the availability of information to all the participants in the supply chain, reduces manual work and allows faster lead times.

A business network consists of independent companies collaborating with each other, each having several fairly autonomous departments with employees doing their own jobs. This can be viewed as a three-layer entity: company, department and employee. Each of these layers can be modelled as an agent, since they are all autonomous and co-operative entities. One agent representing one company

does not provide a good solution, because it would cause complex design inside the agent, which should be capable of handling all company-level activities. On the other hand, one agent per employee would create very complex agent communities that would be rather inefficient. The best solution for the case network was to divide the agent responsibilities at the level of departments or activities, such as sales, management and manufacturing.

This division of agent responsibilities led to a multi-agent system in which each company had several agents with different objectives communicating with their counterparts in the collaborating companies and with other agents in their own company. This approach is described in Figure 9.
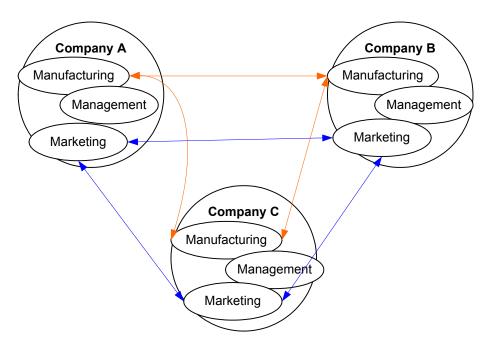
Figure 9. Task-specific agent interaction.

As the agents are concerned about their autonomy and self-interests, they are able to retain valuable information that a company does not wish to share, e.g. on the state of demand for its products. On the other hand, they are able to negotiate with other companies to provide some of that information on demand, thus helping to improve decision-making in the collaborating companies.

4.4 Adoption of emerging technologies in the case network

The adoption and use of information technologies varied within the SteelNet BN. Some companies had a comprehensive ERP with interfaces to suppliers and customers, while others had only obligatory financial management systems and some proprietary applications. The companies used a variety of solutions for information sharing within the network: discussions, phone calls, emails, faxes and proprietary applications. Some companies used EDI or XML-based systems for electronic transactions outside the network. There was a strong desire to benefit more from information technology in the sharing of information and management of the network, as the current solutions were regarded as inadequate.

According to Muffatto and Payaro (2004), use of the Internet for supply chain integration can be described via an evolutionary model that involves two variables: *network integration* and *technological integration*. Network integration consists of sharing the resources and collaboration in a common environment by means of information networks, while technological integration is a company's ability to maintain ICT systems that control many of its functions and interact with each other using either similar communication protocols or enabling interfaces. The model, described in Figure 10 proposes five levels for the implementation of e-business within an existing company.

Levels of e-business implementation:

1. Traditional communication tools manage the information flow between various players in the same supply chain and company.

2. Internal integration: the company integrates its functions into a management information system.

3. Web-based communication tools: the Internet is used to communicate with suppliers and other players involved in the supply chain. The players can access and use various services via the Web, but the integration between information systems must be carried out manually.

4. The XML web-based platform involves more integration between a company's internal management system and the Web environment. The

interface between the two environments must be developed and only medium to large-sized companies which have significant contract power with regard to their suppliers and customers can carry out this level.

5. Integrated enterprise: the information system being developed would have to bring together different companies working in the same field into a kind of consortium. By using Web interfaces, a platform is created in which many suppliers and customers can collaborate to make some processes more efficient.
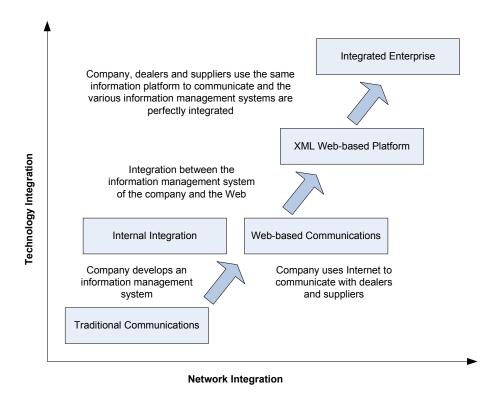
Figure 10. Evolutionary model for e-business implementation (Muffatto & Payaro 2004).

The companies in the case business network are at the levels 1 to 3 in their overall operations, but some companies were at level 4 in their one-to-one collaboration. The slow adoption of e-business in SMEs is understandable, as even levels 1 and 2 require high implementation costs, particular skills and stable, trusting relationships within the network. It is also very unlikely that all networking

companies would commit themselves to the same software, so that they should be prepared for the extra costs and extra time entailed in building interfaces between different IT systems. Despite the costs and use of resources, the companies will still have to find a solution for managing information and sharing it with users from other organizations, and for keeping the information up-to-date and reliable. These problems are highlighted in business networks, as the structure of the network varies depending on goods or services produced, so that enterprises are not willing to commit themselves to heavy investments in software solutions that may be useless for the next order. Instead they try to look for lightweight solutions which provide the necessary information management and sharing properties. Level 3 is an appropriate solution for small enterprises, since there are no significant investments required with regard to technology and skills.

4.5 Summary

Business networking is increasing all the time regardless of the size and type of the companies. The effectiveness of the network depends on its ability to share information in a reliable manner. This requires a suitable information management system that supports distributed design and operation of many activities in a heterogeneous business environment. Agent-based systems are well suited to such complex environment because they offer flexibility, agility and adaptability.

The environment of business networks and, especially, the focus on supply chain information integration set special requirements for information itself and supporting information systems. Supply chain information has to be available to all partners, as well as accurate and timely and appropriately formatted. An information system in a business network must be exception-based to highlight sudden changes and it must be flexible, suitable both for users and customers. Therefore, an information system must support business by providing overall control to the business process that has shared ownership among multiple companies.

The case business network of this thesis consists of several SMEs and one focal company operating in the steel product industry. The companies in the BN had been collaborating for several years but they were looking for means of

strengthening their competitive position and the agility of their collaboration. They wanted to develop mutually agreed working methods and means of information sharing. In a business network, this means support for network partner management, networks management, network configuration and control of collaborative time, cost and quality.

This thesis proposes an agent-based information system for the case business network in which agents transmit supply chain information between the collaborative companies. In the proposed solution, task-specific combinations of agents are tailored to the particular business network process that needs to be supported and the various tasks that need to be fulfilled.

The companies in the case business network were in various levels of information technology adoption. This chapter presents five levels for the implementation of e-business within companies. E-business implementation levels start from the use traditional communication tools and end up in a fully integrated enterprise that is collaborating with suppliers and customers via web interfaces. While the companies in the business networks will always be on different levels of e-business adoption, the information system in the BN must support the collaboration of the companies on different levels.

5. The SteelNet agent-based solution

This section describes the design and implementation of the SteelNet agent-based solution for the manufacturing business network and supply chain integration. As described earlier, the success of supply chains nowadays depends on ensuring that the right amount of the **right kind of information** is in the right place at the right time and for the agreed price. The SteelNet research had two aspects, how to identify the right kind of information and how to share this information within the business network. The SteelNet system provides real-time logistic information for each company in the network and uses this information for supply chain co-ordination between the enterprises by means of task-specific combinations of agents tailored to the particular business network process that needs to be supported and the various tasks that need to be fulfilled.

This chapter gives a brief description of the functional and technical requirements set for the SteelNet system, describes two cases of its use and introduces the technical architecture and services.

5.1 SteelNet BN requirements for the networking system

When the requirements of the BN companies were identified at the beginning of SteelNet project, most of them were similar to those discussed above in connection with ICT support for a VE. The companies placed most emphasis on the flexibility of the ICT system, i.e. support for the following activities:

- a company joining the BN
- a company leaving the BN
- the BN having different projects/orders
- the BN collaborating with other networks
- equal rights, responsibilities and opportunities to host inquiries and projects for each company
- interoperability with legacy systems representing different levels of integration, e.g. for strategic, frequent and occasional partners
- secure information sharing.

The obvious requirement was the real-time exchange of supply chain information, which may be concerned with product availability, the inventory level, shipment status, production requirements, demand forecasts or production schedules.

In the specification phase the end users of the system were also interviewed, in this case the managing directors, production managers, workshop foremen and project managers, depending on the company. They required support for the following activities:

– sending requests for quotations/quotations/orders to all/some of the companies in the BN

– receiving requests for quotations/quotations/orders from other companies in the BN

– making work orders for all the BN companies at the same time (via the Internet)

– monitoring the status of the project in real time

– document management concerning projects/orders

– resource management in the BN, e.g. services, personnel and machinery

– reports on operations in the BN, such as amounts of materials and time of use, services used, management of changes

– flexible changes to quotations or orders.

When defining the SteelNet system it was assumed that not all the supply chain partners would necessarily be willing to agree on the adoption and specifications of the technical system to be used in the business network. As the implementation of a cross-organizational ICT system was likely to be considered costly, time-consuming and risky, the adoption and use of the present system had to be easy and profitable, without high investments. The second main concern was to avoid the duplication of manual work when feeding information into SteelNet and the company's own ERP system.

5.2 Case processes in the SteelNet system

The SteelNet system was tested with two case processes, both involving the sharing of logistic information within the BN. Since the composition of agents depends on the functionality required in the application, the need for case processes was evident. The processes were the procurement process and monitoring of the manufacturing process in the business network. The content of the information was thus restricted to these two cases and the combination of agents tailored to them.

The projects in the Steelnet BN are quite complex with regard to manufacturing methods, quality issues, locations and timing, and each consists of a project management process and a project execution process, both are dispersed among the BN companies. A project is therefore not a linear procedure but a combination of concurrent sub-processes producing material and information flows that have to be managed by the host of the project. Sudden changes are common, and the designs, plans, timetables, materials or manufacturing methods may change during the project.

5.2.1 The case procurement process

One characteristic of a business network is that it combines the expertise of more than one enterprise in a delivery or project, which implies that there will always be some overlap in expertise and thereby competition between the enterprises. The host for each order will use competitive bidding among the networked enterprises in order to achieve a competitive price and good terms of delivery. A procurement process in the SteelNet BN is presented in Figure 11.

The customer sends an inquiry to one of the companies in the BN (buyer in BN), which gathers all the information needed and converts it into a request for a quotation (RFQ). This divides the proposed project into hierarchical units of tasks and sub-tasks, and the buyer looks for preferred partners (suppliers in the BN) with the required expertise for each of these tasks and sends RFQs to them. The buyer will usually send several similar RFQs to different suppliers in order to be able to choose the most advantageous quotation. Each RFQ will consist of tasks, processes, timing and pricing. The suppliers reply with their quotations and the buyer will choose the most suitable combination of suppliers to fulfil his quotation to the customer.
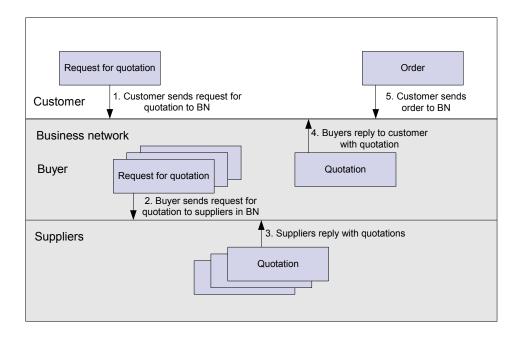
Figure 11. The quotation process in the case business network.

The procurement process demands efficient information sharing, as the BN handles thousands of RFQs a year, which all require manual work and a high level of knowledge. For the BN, real-time information and electronic exchanges of messages may reduce the amount of time and money spent on overlapping work. The documents in the procurement process are created according to an agreed format, which makes comparison between the quotations received more efficient and easier. As there is a minimum knowledge requirement, the RFQ will contain at least the most crucial information. As all the information exchanged is stored electronically, nothing is left to depend on a person's memory. Notifications about any needs for changes are seamless, and accurate, reliable information is available at any time.

5.2.2 Monitoring of the case manufacturing process

In a business network a number of enterprises at different locations will contribute to the manufacturing process in a project, as different phases require different knowledge and skills. A distribution takes place not only between the

phases of a project, but also within the phases, as many parties at different locations will typically be involved in the design or manufacturing phases. After receiving an order from a customer, the host of the project will convert that order into a work breakdown structure (WBS), which will include a manufacturing plan with detailed tasks, materials, manufacturing phases, inspections, transportations and timing. The host will insert the WBS into the SteelNet system, where all the partners in the projects can access it. When the partners need more information about the tasks assigned to them, additional communication between the host, the customer and the respective partner is needed. After final agreement, the work can start and the partners can update the status of the work according to its completion.

The SteelNet system ensures that all the partners involved are aware of the phase and location of the components, and in the case of sudden or unexpected changes they can re-plan their operations and resources according to this information. Unexpected changes can be delays in material supplies, manufacturing defects or machine breakdowns, for example, and in each case real-time information sharing can greatly reduce the additional expenses. The SteelNet system enables agent-mediated information sharing through each company's own ERP system or via a web browser. A typical supply chain in the SteelNet BN is presented in Figure 12 (Iskanius 2006). In Figure the blue symbols represent the information transmission and light blue square symbols the actual working phases.

Typically, one company hosts the whole delivery working together with varying subcontractors. The hosting company may have several departments in one delivery (e.g. sales, production). For example, the sales department gets an order from a customer, and it then plans WBS and orders material and defined work phases from subcontractors. Typically in this case network work phases are bending, welding, machining, flame cutting, assembling and painting. Since companies are geographically distributed, transportation is also one work phase. The host of the delivery controls the whole delivery process in case of sudden changes (delays, material or work faults, etc.). When all the work phases are done, the delivery or part of the delivery is inspected by the host and delivered to the customer.
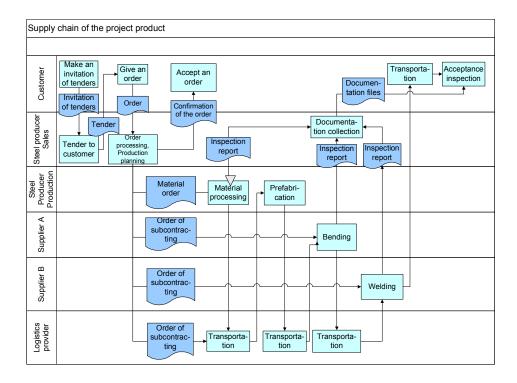
Figure 12. A typical supply chain for a heavy steel component in the SteelNet business network.

5.3 The SteelNet agent-based system infrastructure

The SteelNet system environment consists of several companies participating in the business network. In order to provide and maintain networking services, the system also requires a service provider which takes overall care of the services, their authentication, database maintenance and further development. The environment of the SteelNet network in which the system supported by a service provider shares logistic information among the networked companies is presented in Figure 13.
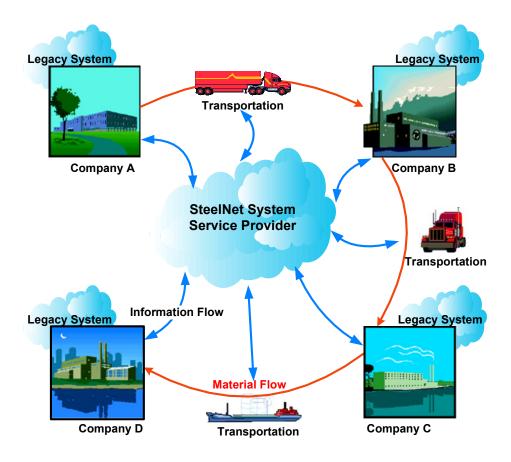
Figure 13. The environment of the SteelNet system, in which collaborating companies share logistic information about mutual projects or orders.

In the SteelNet system, the service provider hosts the main agent container and each company has their own SteelNet agent container that is connected to the main agent container. The main agent container coordinates agent collaboration and provides database services. In the research phase, the main agent container was situated in the research laboratory's premises while after the research it is maintained by a software house or operator that provides networking services to the companies. The company agent container may have a connection to other information systems in the company by the means of agents. Figure 14 presents the physical environment of the SteelNet system. Each company has their own local area network (LAN) protected with a firewall. SteelNet agent container and workstations work in LAN in each company. Agents from different companies

and the service provider exchange messages and collaborate via the Internet by using HTTP-protocol.
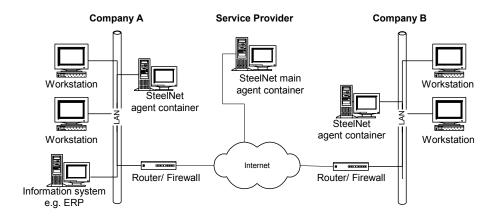
Figure 14. The physical environment of the SteelNet system.

The system uses both distributed and centralized data storage models, the distributed model for exchanging bilateral business data, e.g. various documents, between two companies, where each has its own database in which to store information, and the centralized model for exchanging information between numerous companies, e.g. shared notifications of the manufacturing process status in a supply chain, in order to provide transparent information access throughout whole supply chains. The centralized model is also used for company-level authentication services, supplied by the service provider.

5.3.1 The SteelNet agent-based architecture

The SteelNet system is a multi-agent system in which dedicated agents carry out their tasks in collaboration. The multi-agent architecture is used at the inter-company level, where each company is represented by a group of agents. The agents in one company are responsible for coordinating their 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 SSL 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.

An architecture in which there is one company and a service provider is presented in Figure 15. The company system possesses extension modules to connect it to the company's existing ERP system, the primary aim being to enable full ERP integration to be used in business-to-business communication. Since the level of ICT adoption in SMEs varies greatly, the system also has to provide web application-based user interfaces that can be used instead of ERP integration. Some of the modules provide persistent data storage solutions by means of database implementations. The user interfaces (web-based and service provider's administration application) also use the agents and modules through their service interfaces.
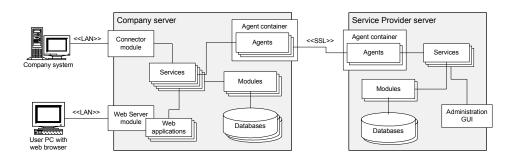
Figure 15. Architecture of the SteelNet system.

The company agent server contain several services, the agent container, agents, web applications and a company connector module for integrating legacy systems. Some of the services also contain an information source for storing company-specific information. All the services can be accessed via the system's service registry which other modules and services can use. The modular

structure of the SteelNet system enables flexibility, but only by adding new agents can the functionality of the system be increased. The architecture of a company agent server is presented in Figure 16 (Kipinä et al. 2005).
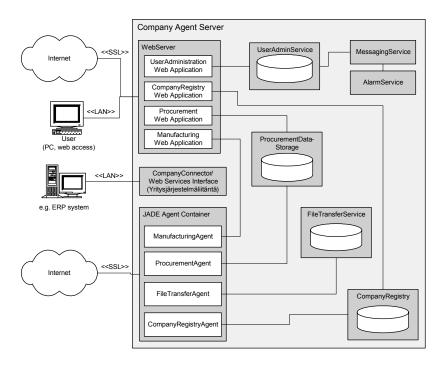
Figure 16. Architecture of a SteelNet company agent server.

5.3.2 SteelNet services

In addition to the framework's core functionality and agent functions, the SteelNet system provides various basic services which implement various services to be used in developing specific applications for the system. These basic services are a company registry, a web application server, file transfer, user administration, system-to-user messaging and alarm services and the service provider's administration application. The modules of the basic services with services, agents, web applications and classes are presented in Figure 17.
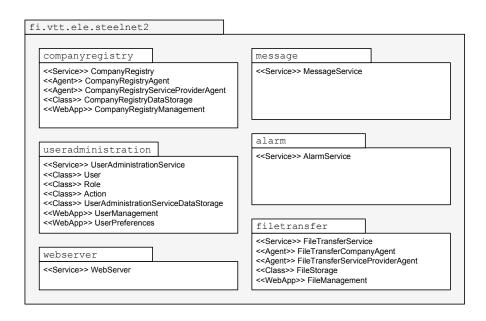
Figure 17. Basic services in the SteelNet system.

The company registry contains information about companies registered in the SteelNet system, including facts about them, contact persons and information about the work and material services they provide for other companies in the network. The implementation of the company registry consists of a service provider agent and database and several company agents, one for each company. The information is available as a database on the service provider side, but also as a cache on the company side. The service provider agent updates the information in the cache in the case of data modification. The company registry information is available to the user through a web application, and the company can manage its own information through this same application.

The user administration service provides user authentication, authorization and preference storage services. User authentication uses hashed passwords, but can be extended to cover more advanced methods, as the service also accepts user-specific binary data for storage. The user authorization service provides access control based on a user-role-action model in which the users have roles and the roles contain other roles and actions. Each action describes a task to be authorized, e.g. "add new user" for the administrator role. Preference storage is dynamic, so that any other service can use it to store user-specific preferences,

e.g. the messaging service uses it to store users' messaging preferences. User information is managed through two web applications: one for users to manage their own information and the other for system administrators to create new users, delete old ones and manage user information. The user administration service is company-specific, so that the information is accessible only by the company in question.

The web application server is responsible for launching the web applications specified for each company. All web applications are launched in the same JVM (Java Virtual Machine) with the rest of the system, so that all of the services can be used by web applications. The web application server module integrates an Apache Tomcat servlet container in the system. The server provides a single-sign-on feature for all web applications and relies on the user administration service for user authentication and authorization.

The file transfer service enables files to be attached to ontology concepts, e.g. documents in the procurement process. File attachments are identified by their digital fingerprints to prevent errors in transfer or versioning. The file transfer service consists of a service provider agent and company agents, and the files are stored in distributed databases which reside in the various companies. Agents negotiate a file transfer for authentication and authorization purposes, and if the transfer is agreed, they exchange transfer-specific security credentials. Files are transferred through a TLS (Transport Layer Security) protected connection over the Internet.

The messaging service provides system-to-user messaging facilities. This currently takes place via e-mail, but it is possible to connect other communication methods to the SteelNet system. The alarm service uses the messaging service to inform users about events in the system, e.g. the receipt of a new request for a quotation or a delayed schedule in a manufacturing process. By default, users receive messages and alarms according to their roles, but they can change their preferences via a web application to receive only notifications and alarms that they are interested in.

The SteelNet system is managed from the service provider's premises. The system administration tool is automatically launched in the service provider's server when starting up the SteelNet system, but has no remote log-in

possibility, which improves system security. The administration tool allows the addition of new companies to the SteelNet system, the removal of companies and the modification of company information.

5.3.3 SteelNet agents

The SteelNet system contains several collaborating agents, some of them are for general purposes like CompanyRegistryCoordinatorAgent, CompanyRegistryAgent, FileTransferCompanyAgent and FileTransferCoordinatorAgent. Application-specific agents are developed for application procurement and manufacturing process control.

Each agent container has a company registry that stores and updates information about other companies and their services in the BN. The company registry agent contains two agents: CompanyRegistryCoordinatorAgent and CompanyRegistryAgent. *CompanyRegistryCoordinatorAgent* coordinates the company registry and communicates with CompanyRegistryAgents by updating changes in companies' services. *CompanyRegistryAgent* is in the company agent container, where it updates and maintains the services provided by other companies in the network. CompanyRegistryAgent also updates a company's own service variety to other company agents.

FileTransferService enables the transmission of attachment files in the network. The manufacturing process contains work instructions, plans and material bills that have to be delivered together with working order. FileTransferService transmits the attachment files based on ontology concepts both from local data stores and from other companies' data stores. *FileTransferCompanyAgent* and *FileTransferCoordinatorAgent* negotiate and transmit attachments between companies.

ManufacturingAgent is an application-specific agent that monitors the manufacturing process. It coordinates the actions related to the manufacturing process in company agent container. ManufacturingAgent collaborates with *ManufacturingCoordinatorAgent* located in the main agent container in order to get information about the manufacturing process in other companies. The other

modules in the manufacturing process application are database connector and company connector.

ProcurementAgent is another application-specific agent for procurement process control purposes. It is located in the company agent container and, unlike other agents, it collaborates directly with other ProcurementAgents in other companies. Procurement agents transmit information about procurement process (Quotation, Order, etc.) that have confidential information about costs, timing and capacity. Therefore, the collaboration is a direct negotiation between two company agents.

5.3.4 Agent communication in SteelNet

The agents in the SteelNet system communicate via FIPA ACL, which supports the use of ontologies for defining the content of the messages. SteelNet uses the FIPA Request Interaction Protocol (Foundation for Intelligent Physical Agents 2002c) as a basis for agent communication.

In the manufacturing process, the monitoring application Manufacturing-CompanyAgent, ManufacturingCoordinatorAgent, the company web application and the manufacturing database connector use FIPA request protocol for communication. The communication is presented in Figure 18.
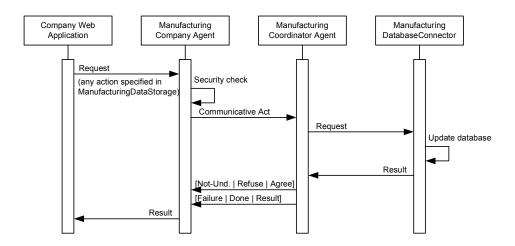
Figure 18. Agent interaction in manufacturing process monitoring.

ManufacturingCompanyAgent starts the interaction protocol by asking for the communicative act from ManufacturingCoordinatorAgent. The communicative acts are defined in the ontology, and in the manufacturing process they are: EstablishOrder, GetOrder ChangeDynamicTimings, ChangeManufacturing-States, ChangeOrderState SearchOrders, ChangeOrderInformation, AddOrder-Line, AddWorkPhase, RemoveOrderLine, RemoveWorkPhase, ChangeOrder-Line, ChangeWorkPhase, ChangeWorkPhaseService, InformNewOrder, Inform-OrderInformationChange, InformManufacturing-StatesChange, InformOrder-StateChange and InformDynamicTimingsChange. The receiver can refuse, agree or inform that it does not understand the request. If the coordinator agent accepts the message, it is transmitted to the database connector. Upon a successful request accomplishment, the sender will be informed that the request is done, about the result of the request, or about failure of the request.

As an example of agent messaging in procurement process, the communication between two task-specific company agents in the procurement process is presented in Figure 19. The initiator of the communication is the Procurement Company Agent sends a Request for Quotation (RFQ) message to the other company, where the corresponding agent receives it. The time between the message exchanges can vary depending on user actions. The messages drawn with a solid line in the diagram represent the ideal flow of messages when a quotation leads to an order. Optional messages are represented by dashed lines as follows:

− The initiator makes changes to the document that has been sent, and a replace message is sent to update the document already received.

− The initiator wants to withdraw the document that has been sent, and a cancel message is sent.

− The receiver does not want to respond to the document, and a reject message is sent.

In the case of a cancel or reject message, the communication may continue if the initiator sends a new version of the document. Otherwise it will end. In the case of a quotation document there is a specific message which the receiver of the quotation can send to indicate that the quotation has been accepted. The acceptance is not binding, but an order will most likely follow.
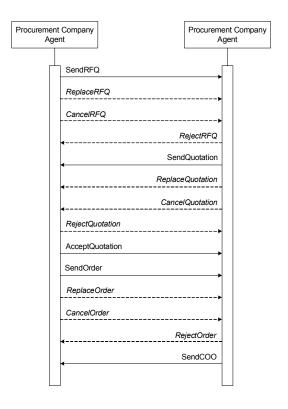
Figure 19. Communication between two task-specific company agents in the procurement process.

5.3.5 Ontology of the SteelNet system

The ontology of SteelNet defines the contents of the agent communication, i.e. the concepts of the business domain and the relations between them. The use of domain-specific ontologies provides a consistent format for the information. In the system as implemented the ontology is used not only in agent communication, but also in the processing of information, communication between parts of the system and the storing of information in a database.

The SteelNet ontology contains two types of concept: physical and abstract (agent actions). Concepts are used for information handling and communication, while agent actions are used for agent communication. The overall SteelNet ontology consists of the common SteelNet ontology and ontologies for the company registry service, the procurement process application (including business documents) and the manufacturing monitoring application. The

company registry ontology includes concepts for presenting companies, contact persons, addresses and detailed information. The concepts of the common SteelNet ontology, their attributes and relationships are presented in Figure 20.
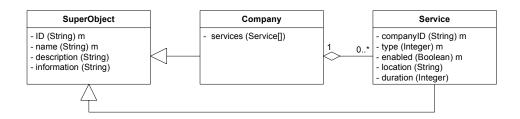
Figure 20. The common ontology of the SteelNet system.

The manufacturing ontology includes concepts for defining manufacturing process templates in the procurement phase and concepts for the actual manufacturing phase, while the procurement ontology includes concepts for the quotation and purchasing processes, various types of business document (request for quotation, quotation, order, confirmation of order), document items and other document-related concepts, e.g. delivery and payment terms. This ontology is used to transfer documents electronically between companies and to keep related documents in one place, forming electronic folders, and in general to manage the quotation and purchasing processes. The concepts related to the manufacturing process are presented in Figure 21.
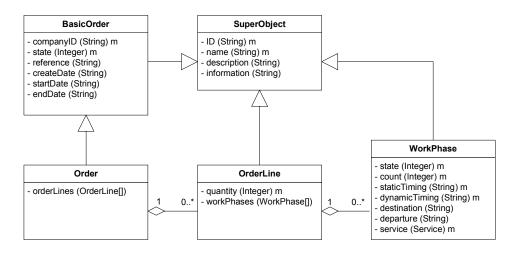
Figure 21. Basic concepts related to the manufacturing process.

The ontology is defined in the Protégé ontology editor (Gennari et al. 2002) and a BeanGenerator Protégé plug-in (Caire & Cabanillas 2002) is used to generate JADE-compliant Java source code files for the ontology. The BeanGenerator has been modified so that it adds metadata annotations to the source files for the EJB (Enterprise JavaBeans) 3.0 Persistence Service. Hibernate, an open source object/relational persistence and query service, is used as the implementation for storing the annotated ontology in a relational database (object-relational mapping, ORM).

5.3.6 The development environment of SteelNet system

The SteelNet system is based on JADE (Java Agent Development Framework), which is a middleware product for the development of distributed multi-agent applications based on a peer-to-peer communication architecture. It enables the distribution of intelligence, initiatives, information, resources and control among mobile terminals and among computers in a fixed network. The environment can evolve dynamically, with agents that appear and disappear in the system according to the needs and the requirements of the application environment. Communication between the agents is completely symmetric, with each peer being able to play both an initiator and a responder role. JADE is fully developed in Java and fully compliant with the FIPA specifications. The internal architecture of the JADE main container with the services provided, life-cycle management, white-page, yellow-page and message transport, is presented in Figure 22 (Bellifemine 2001).

The main reason for choosing JADE as an agent platform was that it is compliant with the FIPA specifications, so that the agents developed can inter-operate with other agents which comply with the same standard. This enables the SteelNet system to collaborate with other FIPA-compliant agents, e.g. other agent-based networks. JADE also provides a homogeneous set of APIs that are independent of the underlying network and the Java version. This is a very important aspect in an unstable business environment which consists of various enterprises with different IT architectures. At the point when research started in 2002, JADE was the most suitable choice for a platform since it was also being actively developed by the European agent community.
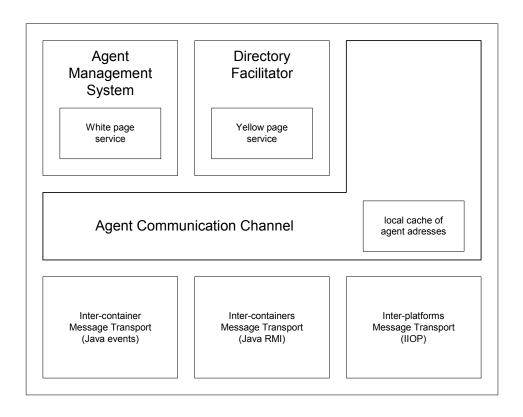
Figure 22. The internal architecture of JADE (Bellifemine 2001).

5.4 SteelNet prototype implementation

In order to validate the approach described above, framework and prototype validation was carried out in SteelNet and SteelNet2 projects during the years 2002–2006. A SteelNet prototype was built in close collaboration with the real manufacturing business network, and this is being tested at the present time. This section reviews the research methodology, implementation process and one test case.

5.4.1 Research methodology

Given that the empirical data were to be collected in a steel manufacturing business network in Northern Finland, research was started by drawing up a list of activities needed in order to analyse the network and its operations and to collect information for the process of developing a software solution. Unstructured interviews were first held to form a realistic understanding of the case companies' core competences, current level of co-operation and facilities for utilizing ICT tools, and then a specific questionnaire for the companies was designed in order to find out what were the critical issues affecting the supply chain. Representatives of the companies were asked to answer open-ended questions covering areas such as information sharing, process integration and collaborative relationships in the network. An ontology containing commonly agreed basic concepts was then formed on the basis of interviews. Thirdly, two sample supply chains were modelled and thematic interviews were held with the operational staff and key persons in the companies in order to identify the possibilities for improving the supply chains. The software solution was designed in parallel to the supply chain modelling.

The first aim in the software development was to accomplish a working software based on the agent technology approach in order to validate the functionality of the system. The working software was developed via several rounds of iteration, starting from non-functional graphical user interfaces (GUI) and ending up with a working agent-based prototype. The second aim was to meet the requirements of the business network that the system should support the daily activities of its end-users by means of agents. The requirement specification and case studies were thus discussed with the BN companies. As an example, the GUIs and the functionality of the system were defined in co-operation with the end-users via several rounds of iteration, which resulted in multiple changes to the software system. One of the aims was to involve the users in the development process, which would ease the adoption of the system in this traditional branch of industry later on.

5.4.2 Test case of monitoring of the manufacturing process

The major aim in the SteelNet system is to share and exchange logistic information between the enterprises contributing to a manufacturing business network. Where information had previously been transmitted in conversations, by phone, mail or email and did not have any specific format, nor was it stored or transmitted electronically, which produced extra manual work for the users, the system offers possibilities to share and exchange reliable real-time information accurately and in a timely manner within the business network if the users are working according to a set of predefined rules. The business network has to commit itself to use of the system for information transmission and also has to define the rules on how and when information must be delivered to the system.

There are different kinds of users in the SteelNet system, of whom some are experienced IT users while others have only basic IT skills. Therefore, the graphical user interfaces (GUI) had to be easy to understand, learn and use. These were implemented with Web technology and simplified to present only the most important information, in order to provide a clear view. A user who needs to transmit extra information can use an additional text field.

The first real-world test case for the SteelNet system was in December 2005 – February 2006. The research laboratory hosted the service and maintained the service provider's agent container and databases. In the test case, companies used the system via the Internet by using web browsers. The project comprised the manufacturing of eleven pile anchors by three companies within the business network. The first company hosted the order, and therefore carried the main responsibility for using the SteelNet system. The host had three subcontractors: two engineering workshops and one transportation company.

The host planned the WBS of the whole project. The WBS consisted of several working phases: raw-material production (steel plates), flame cutting into defined measures, bending and welding of the plates, inspection of the weld joints and some additional work such as painting. Raw material production and flame cutting took place in host company, bending took place in another company and welding, inspections and painting in a third company. There was also the need for transportation between companies and it was planned as one

working phase. The number of produced pile anchors was eleven and therefore the plan consisted of eleven positions, each with seven working phases.

All the companies in the test case used web browsers, and the SteelNet system was not installed on the server of any one company, nor was ERP integration used. The research organisation worked as the service provider in the test case. Access to the system was restricted to company-specific user names and passwords. Users in this test case were the project manager in the host company and production managers or foremen at the engineering workshops. Users in the companies were given one hour of training on how to use the system, which seemed to be enough to make them familiar with it.

The project manager at the host company planned the WBS of the delivery and selected the companies that provided suitable services for this project. The information about companies' service variety (machine types, expert fields, etc.) was updated into the system beforehand. The host inserted the working phases with subcontractors and timing into the SteelNet system via a Web browser. The schedule for delivery was the host's responsibility, and that company programmed the static timing into the system.

Figure 23 presents the information of the test case in the SteelNet system. First, it defines the order information: order name, host company and order number, and state of the delivery (plan/running/closed). Secondly, it presents positions with working phases. Each working phase contains timing defined by the host. As the companies carry out their tasks, they fulfil the status of the phase by giving the date of the accomplishment. The SteelNet system calculates the difference in timing (waiting/in time/late) and presents it also with different colours (yellow/waiting, green/in time, red/late) in order to highlight problems in project.

The test case proved that the functionality of the software met the requirements set by users. The SteelNet platform was stable during the test case and no malfunctions were detected. Agent collaboration worked without problems and tasks were accomplished. In order to fully test the performance of the system, longer test cases with more users and companies are needed. One problem was faced with firewalls that prohibit agent communication outside the company;

therefore, an agent inside the company has to open the communication channel for conversation.
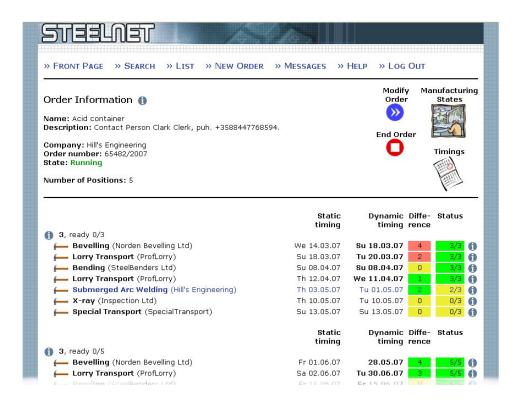
Figure 23. The interface for monitoring the manufacturing process.

The test case was also evaluated by questionnaire after the test use. There were only five respondents because only four companies took part in the test. Most of the users felt that the system was easy to use and learn (mean = 4.69) and the use was pleasant (mean = 3.67). Users relied on the security of the software (mean = 3.56) and were not worried about delivering information via the system. The demand (mean = 3.29) and usability (mean = 3.31) of the system was evaluated as average. The results give some guidance but they must be treated with care because the test time was short with only a few users.

One future test need is to test the system with different kinds of companies, in this test case all the companies used a Web interface. The real benefit of the system will be achieved when the SteelNet system is integrated with companies'

own ERP system. The modules for integration purposes are ready but only internally tested. Therefore, this test case does not reveal the real benefits of the agent-based system, while flexibility, the real benefit of agents, was not tested.

The Steelnet system provided users with the required functionality by delivering the information about projects available to all companies. Test users said that the SteelNet system was easy and convenient to use, and stated in discussions that the system could make their work easier by saving time in information sharing among contributing enterprises and scheduling the work phases. It was also noted that the transparency of the information would help to reduce the lead times of joint deliveries, since it enabled companies to react faster to sudden changes in sub-processes in other companies.

The test case also showed that the use of an ICT system should be agreed on before the project starts. The agreement should cover the rules for using the system, such as inserting information within a certain time limit, information on changes and the implications of not updating the information. Although the people understood the benefits of the system, it was hard to persuade them to change the methods they are familiar with.

6. Discussion

The need for effective information sharing in business networks is a success factor for the competitiveness of BNs. Traditional inter-organisational software solutions are still suited for large enterprises, but there is an urgent need for cost-effective and flexible solutions for SMEs. Existing systems like EDI, Electronic marketplaces and enterprise portals are much too heavy investments for SMEs that may have dozens of partners, suppliers and customers. Although inter-organisational systems have been researched intensively, they are focused on large companies with different needs from those of SMEs. The SteelNet system is focused on SMEs that have varying IT infrastructures and it provides different integration types for such companies. First, the companies may need only a Web interface, but when the partner composition become stable the ERP integration must be possible. The different integration types are important for companies: when the business relationships become stable the ERP integration saves manual work and time.

In this business network, companies have faced a dynamic environment where the information is distributed across changing partners and nothing is stable. The change in business has been enormous and even the roles may change – today's supplier may be tomorrow's subcontractor. The comparison of developed software solutions to existing ones is difficult because, unlike in other networking solutions, the host company in SteelNet can change. In SteelNet, each of the networking partners may host projects while others van be subcontractors. The existing solutions are usually hosted by one large company, with SMEs working as subcontractors. The equality of the system is very beneficial for the companies because even small companies can host their own subcontractors via SteelNet.

The other benefit of SteelNet is that the processes are not defined beforehand and therefore it is suitable for project-oriented companies. In each quotation or manufacturing process, the host first defines the composition of the network according to the services companies are providing to the network. Secondly, the host defines the working plan and allocates tasks for different companies – the process is not defined beforehand. The agent technology supports the flexibility by providing task-specific agents according to users' definitions.

This thesis has shown that using agent technology for information sharing in manufacturing company networking has several advantages. The first is system modularity, meaning it is easier to build and maintain a collection of agents, rather than one complete system, a feature which will facilitate both integration and reconfiguration. This feature suits the dynamic nature of this BN well. This network is project oriented and the used system must be easy to maintain and update according to future needs. Secondly, agents are suited for a distributed environment where information is stored and processed locally. In this type of BN, even the problems are distributed and the data from multiple organisations are needed for problem solving. For SMEs, it is important that agents can automatically transmit information and therefore ease the problem solving in one company without disturbing others. Thirdly, agents have the ability for autonomous decision-making. In a BN where information is distributed but available, agents can solve problems autonomously or in collaboration with users. In BNs the amount of manual work has to be decreased and agents can provide decision support for time-consuming and complex problems. This is very important for small companies with limited resources.

When evaluating the developed SteelNet system, it provides support for managing distributed information in a complex environment. The disadvantage is that, at the moment, it does not provide intelligence by using problem-solving methods. The modular agent-based architecture ensures that the functionality of the system can easily change by building types of agents and defining new concepts into the ontology. The developed agent-based system can also be used in other domains, where there is a need to manage distributed information in a complex environment. The use in other domains requires updating the ontology and task-specific agents.

At the moment, the reasoning in SteelNet is based on rules in the ontology, (relationships between concepts). In future, to fully benefit from the agents' abilities they can take advantage of heterogeneous problem solving technologies. By providing different kinds of task-specific agents, the system can also cater to automatic project planning, resource allocation and decision-making support for the networked companies. Future work in SteelNet will focus on providing intelligent decision making required by different business environments. For example, in the quotation process, agents can use different kinds of negotiation protocols and compose the final quotation autonomously.

In this research, the agents have been used in a real business network and the software solution has been built upon real business needs. Although there is still a lot of development work left, the prototype version is stable and it can be used as it is now. The agent research community has provided powerful theories, algorithms and techniques, but there is still a lack of practical solutions that can be deployed in industry. The work of this thesis proves in practice the benefits of the agent-based system when compared to traditional ones. The agents provide support for the dynamic changes that companies are facing today. This research is a solid sign that the dynamic business environment is also changing attitudes and that industry is looking for new solutions from emerging technologies for their problems.

As the numbers of networks and VEs grows in future, collaboration between networks and other network systems will become a necessity. SteelNet uses the FIPA-compliant JADE platform, which enables collaboration with other FIPA-compliant agents. On the other hand, the modular structure means the system can provide services through a Web interface and therefore collaborate with other networking system while the contents for collaboration are well defined in ontology.

There are still several barriers to the adoption of ICT tools in supply chain management: lack of funds, disparity in trading partners' capabilities, lack of trust, fear of ICT breakdowns, etc. Security and access privileges are the two most important barriers when implementing Internet and extranet technologies in a supply chain. These barriers became familiar in this research. The fear of new technology was raised in several discussions with companies. SMEs do not have enough ICT skills and knowledge to adopt new technology, even though the benefits are obvious. The acquisition and administration of such systems is costly and demanding, and require the allocation of suitable time and resources.

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.

7. Conclusions

Collaboration and business networking is increasing in today's continually changing business environment, and the significance of information sharing and networking is becoming more important than ever. Companies are moving towards an open architecture for integrating their activities with those of their suppliers, customers and partners within supply chain networks. Networking concerns all companies of different types and sizes, and networking solutions should be flexible and effective despite differences in IT infrastructure between the companies. The traditional knowledge engineering approaches with large-scale knowledge bases are inappropriate, because the information is distributed among the networked companies and the owner of the information may vary. Flexibility of the software solution is the key asset in a business network, since the combination of enterprises will vary from one project to another.

This thesis studied information management in a BN in the area of supply chain management. Especially SMEs are looking for cost-effective and flexible solutions for information management in business networks because the existing networking solutions require high investments in terms of both costs and work. In general, business process applications are distributed within or among organisations, and they must support dynamic processes. Software must also support business by providing overall control to the business process that might have shared ownership among multiple organisations. All these factors require flexible and distributed business applications. In the domain area of supply chain management the information has to be available to all partners. It must also be accurate and timely as well as appropriately formatted. The information system in a business network must be exception-based to highlight sudden changes and it must be flexible, suitable both for users and customers.

This thesis has proposed an agent-based solution for information sharing in a business network. Agent technology provides a promising approach to managing distributed information within business networks, since agents offer both flexibility and problem-solving services. When task-specific agents are used to represent companies, these agents can carry out tasks autonomously and release the personnel from routine manual work. In long-term relationships, the agents can be integrated into the company's own ERP system to avoid the duplication

of manual work, while in occasional relationships the agent system can provide Web access.

This thesis has described the agent-based SteelNet system for information sharing in business networking. The SteelNet system is a multi-agent system in which dedicated agents carry out their tasks in collaboration. The multi-agent architecture is used at the inter-company level, where each company is represented by a group of agents. The agents in one company are responsible for coordinating its actions in the business network by cooperating with each other and communicating with agents in other companies. Agents communicate by using FIPA ACL, according to the FIPA request Interaction protocol, while the content of the collaboration is defined in domain specific ontology.

Applications in SteelNet are focused on supply chain management, controlling the quotation process as well as the manufacturing process in the BN. In both applications, the SteelNet system provides distributed information from multiple organisations and makes that information available to all authorized users in an accurate, timely and specified format. SteelNet provides flexible integration for companies: they can use it via a Web browser, an agent container on via an agent container on their own server or fully integrated with their company's own system. Although the prototype of SteelNet is focused on supply chain management, it can be used in other domains of networking by updating the composition of agents and the ontology.

The research has shown the benefits of agents in networking, but there are still many research issues for the future. First, more heterogeneous reasoning methods are needed in order to fully meet the demands of a dynamic business environment. The basic modular architecture denotes this need, while it enables the addition of new agents and keeps modules flexible. Secondly, more assistance for the users is needed in order to provide them with decision-making support. This assistance could come in the form of, for example, suggestions based on experience or forecasts in network. Thirdly, the collaboration with other networks must be ensured. The collaboration with other agent-based systems is enabled because SteelNet is fully FIPA compliant. The collaboration with different kind of networks requires the Web Services interface to be added into system. Once these challenges have been met, agent-based systems will be able to collaborate and communicate.

References

Bellifemine, F. (2001) JADE: what it is and what it is next (Slides). Invited speech at ETAPS 2001, Workshop on Models and Methods of Analysis for Agent Based Systems (MMAABS), Genova, April 2001.

Bellifemine, F., Caire, G., Poggi, A. & Rimassa, G. (2003) "JADE – A White Paper." EXP – in search of innovation. Special issue on JADE, TILAB Journal, September 2003.

Blake, M. & Gini, M. (Guest Editors) (2002) Introduction to the Special Section: Agent-Based Approaches to B2B Electronic Commerce. International Journal of Electronic Commerce, Vol. 7, No. 1.

Borst, W. N. (1997) Construction of Engineering Ontologies for Knowledge Sharing and Reuse. Doctoral thesis. Enschede: Universiteit Twente.

Bowersox, D. J. & Close D. J. (1996) Logistical Management – The Integrated Supply Chain. Singapore: McGraw-Hill International Editions.

Bovet, D. & Martha, J. (2000) Value Nets – Breaking the Supply Chain to Unlook Hidden Profits. New York: John Wiley & Sons.

Browne, J. & Zhang, J. (1999) Extended and virtual enterprises – similarities and differences. International Journal of Agile Management Systems, Vol. 1, No. 1, pp. 30–36.

Bussmann, S. & Schild, K. (2000) Self-organising manufacturing control: An industrial application of agent technology. Proceedings of 4th Int. Conf. on Multi-Agent Systems, Boston, USA. Pp. 87–94.

Caglayan, A. & Harrison, C. (1997) Agent Sourcebook, A Complete Guide to Desktop, Internet, and Intranet Agents. New York: John Wiley & Sons, Inc. 349 p.

Caire, G. & Cabanillas, D. (2002) Jade tutorial application-defined content languages and ontologies. TILab S.p.A. 30 p.

Camarinha-Matos, L. (1997) A Platform to support production planning and management in a virtual enterprise. Proceedings of CAPE'97 – IFIP/SME Int. Conference on Computer Applications in Production and Engineering, Detroit, USA.

Castelfranchi, C. (1995) Guarantees for autonomy in cognitive agent architecture. In: Wooldridge, M. & Jennings, N. R. (Eds.) Intelligent Agents: Theories, Architectures, and Languages. LNAI Volume 890. Heidelberg, Germany: Springer-Verlag. Pp. 56–70.

Chan, M. F. S. & Chung, W. W. C. (2002) A framework to develop an enterprise information portal for contract manufacturing. International Journal of Production Economics, Vol. 75, No. 1–2, pp. 113–126.

Chavez, A. & Maes, P. (1996) Kasbah: An agent marketplace for buying and selling goods. In: Proceedings of 1st Intl Conf. on the Practical App. of Int. Agents and Multi-Agent Tech. (PAAM'96). Practical Application Company.

Christopher, M. (1998) Logistics and Supply Chain Management – Strategies for Reducing Cost and Improving Service. 2nd ed. New York: Prentice-Hall.

Collins, J., Ketter, W. & Gini, M. (2002) A multi-agent negotiation testbed for contracting tasks with temporal and precedence constraints. International Journal of Electronic Commerce, Vol. 7, No. 1, pp. 35–57.

Cooper, M. D., Lambert, D. M. & Pagh, J. D. (1997) Supply chain management: More than a New Name for Logistics. The International Journal on Logistics Management, Vol. 8, No. 1, pp. 1–13.

Crabtree, I. B., Soltysiak, S. J. & Thint, M. (1998) Adaptive Personal Agents. Personal Technologies Journal, Vol. 2, No. 3, pp. 141–151.

Cukosky, M. R., EngelMore, R. S., Fikes, R. E., Genereseth, M. R., Gruber, T. R., Mark, W. S. et al. (1993) PACT: An Experiment in Integrating Concurrent Engineering Systems. IEEE Computer, Vol. 26, No. 1, pp. 28–38.

Cutkosky, M. R., Tenenbaum, J. M. & Glicksman, J. (1996) Madefast: Collaborative Engineering over the Internet. Communication of the ACM, Vol. 39, No. 9, pp. 78–87.

Dai, Q. & Kauffman, R. J. (2002) Business models for internet-based B2B electronic models. International Journal of Electronic Commerce, Vol. 6, No. 4, pp. 41–72.

Daniel, E. M. & White, A. (2005) The future of inter-organisational system linkages: findings of an international Delphi study. European Journal of Information Systems, Vol. 14, No. 2, pp. 188–203(16).

Darley, V. & Sanders, D. (2004) An agent-based model of a corrugated-box factory: the trade-off between finished goods stock and on-time-in-full delivery. In: Coelho, H. & Espinasse, B. (Eds.) Proceedings of the Fifth Workshop on Agent-Based Simulation, 2004.

Deen, S. M. (Ed.) (2003) Agent-Based Manufacturing – Advances in the Holonic Approach. Heidelberg, Germany: Springer-Verlag.

Dorer, K. & Calisti, M. (2005) An adaptive solution to dynamic transport optimization. In: Pechoucek, M., Steiner, D. & Thompson, S. (Eds.) Proceedings of the Fourth International Joint Conference on Autonomous Agents and Multi-Agent Systems: Industry Track. ACM Press. Pp. 45–51.

Etzioni, O. (1996) Moving up the information food chain: deploying softbots on the World Wide web. In: Proceedings of the 13th National Conference on Artificial intelligence (AAAI-96), Portland, OR. Pp. 4–8.

Fan, C. & Wong, T. (2003) Agent-based Architecture for Manufacturing System Control. International Journal of Integrated Manufacturing, Vol. 14, No. 7, pp. 599–609.

Fatima, S., Wooldridge, M. & Jennings, N. R. (2005) A comparative study of game theoretic and evolutionary models for software agents. Artificial Intelligence Review, Vol. 23, No. 2, pp. 187–205.

Feng, S. (2005) Preliminary Design and Manufacturing Planning Integration Using Web-Based Intelligent Agents. Journal of Intelligent Manufacturing, Vol. 16, No. 4–5, pp. 423–437.

Feng, S., Stouffer, K. & Jurrens, K. (2004) Intelligent Agents-Enabled Integrated Manufacturing Planning and Control. In: Proceedings of the 8th International Conference on Computer-Supported Collaborative Work in Design, China, May 26–28, 2004. Pp. 208–214.

Fensel, D. (2001) Ontologies: A Silver Bullet for Knowledge Management and Electronic Commerce. Heidelberg, Germany: Springer-Verlag. 138 p.

Fikes, R., Cutkosky, M., Gruber, T. & van Baalen, J. (1991) Knowledge Sharing Technology Project Overview. Technical Report KSL 91-71. Stanford, CA: Stanford University, Knowledge Systems Laboratory.

Finin, T., Labrou, Y. & Mayfield, J. (1997) KQML as an Agent Communication Language. In: Bradshaw, J. (Ed.) Software Agents. AAAI/MIT Press.

Fogel, D. B. (2003) Evolutionary Entertainment with Intelligent Agents. Computer, Vol. 36, No.6, pp. 106–108.

Foundation for Intelligent Physical Agents. (2001) FIPA Ontology Service Specification. Document number XC00086D. Geneva, Switzerland. 58 p.

Foundation for Intelligent Physical Agents. (2002a) FIPA Communicative Act Library Specification. Document number SC00037J. Geneva, Switzerland. 45 p.

Foundation for Intelligent Physical Agents. (2002b) FIPA SL Content Language Specification. Document number SC00008I. Geneva, Switzerland. 24 p.

Foundation for Intelligent Physical Agents. (2002c) FIPA Request Interaction Protocol Specification. Document number SC00026H. Geneva, Switzerland. 8 p.

Foundation for Intelligent Physical Agents. (2003) FIPA KIF Content Language Specification. Document number XC00010C. Geneva, Switzerland. 27 p.

Fox, M., Barbuceanu, M. & Teigen, R. (2000) Agent-Oriented Supply-Chain Management. International Journal of Flexible Manufacturing Systems, Vol. 12, pp. 165–188.

Franklin, S. & Graesser, A. (1996) Is It an Agent or Just a Program? A Taxonomy for Autonomous Agents. In: Proceedings of the Third International Workshop on Agent Theories, Architectures, and Languages. New York: Springer-Verlag.

Galliers, J. R. (1988a) A strategic framework for multi-agent cooperative dialogue. In: Proceedings of the Eighth European Conference on Artificial Intelligence (ECAI-88). Munich, Federal Republic of Germany. Pp. 415–420.

Galliers, J. R. (1988b) A Theoretical Framework for Computer Models of Cooperative Dialogue, Acknowledging Multi-Agent Conflict. PhD thesis. Open University, UK.

Genesereth, M. R. & Ketchpel, S. P. (1994) Software agents. Communications of the ACM, Vol. 37, No. 7, pp. 48–53.

Gennari, J., Musen, M. A., Fergerson, R. W., Grosso, W. E., Crubezy, M., Eriksson, H., Noy, N. F. & Tu, S. W. (2002) The Evolution of Protégé: An Environment for Knowledge-Based Systems Development.

Gijsen, J., Szirbik, N. & Wagner G. (2002) Agent Technologies for Virtual Enterprises in the One-of-a-Kind-Production Industry. Intl. Journal of Electronic Commerce, Vol. 7, No. 1 (Fall 2002 issue), pp. 9–35.

Gilbert, D., Aparicio, M., Atkinson, B., Brady, S., Ciccarino, J., Grosof, B., O'Connor, P., Osisek, D., Pritko, S., Spagna, R. & Wilson, L. (1995) IBM Intelligent Agent Strategy. IBM Corporation.

Gómez-Pérez, A., Fernández-López, M. & Corcho, O. (2004) Ontological engineering: with examples from the areas of knowledge management, e-commerce and the semantic web. Heidelberg, Germany: Springer-Verlag. 403 p.

Grand, S., Cliff, D. & Malhotra, A. (1997) Creatures: Artificial Life Autonomous Software Agents for Home Entertainment. In: Proceedings of the First International Conference on Autonomous Agents (Agents'97). Pp. 22–29.

Gruber, T. R. (1993) A Translation Approach to Portable Ontology Specifications. Knowledge Acquisition, Vol. 5, No. 2, pp. 199–220.

Hewitt, F. (2000) Demand satisfaction communities: new operational relationships in the information age. The International Journal of Logistics Management, Vol. 11, No. 2, pp. 9–20.

Himoff, J., Skobelev, P. & Wooldridge, M. (2005) MAGENTA technology: Multiagent systems for industrial logistics. In: Pechoucek, M., Steiner, D. & Thompson, S. (Eds.) Proceedings of the Fourth International Joint Conference on Autonomous Agents and Multi-Agent Systems: Industry Track. ACM Press. Pp. 60–66.

Hodik, J., Becvar, P., Pechoucek, M., Vokrinek, J. & Pospisil, J. (2005) ExPlanTech and ExtraPlanT: multi-agent technology for production planning, simulation and extra-enterprise collaboration. International Journal of Computer Systems Science and Engineering, Vol. 20, pp. 357–367. ISSN 0267-6192.

Howden, N., Rönnquist, R., Hodgson, A. & Lucas A. (2001) JACK Intelligent Agents-Summary of an Agent Infrastructure. In: Proceedings of the 5th ACM Int.Conf. on Autonomous Agents.

Huang, J., Jennings, N. R. & Fox, J. (1995) An Agent-based Approach to health Care Management. International Journal of Applied Artificial Intelligence, Vol. 9, No. 4, pp. 401–420.

Iskandar, B., Kurokawa, S. & LeBlanc, L. (2001) Adoption of electronic data interchange: the role of buyer-supplier relationships. IEEE Transactions on Engineering Management, Vol. 48, Issue 4, pp. 505–517.

Iskanius, P. (2006) An agile supply chain for a project-oriented steel product network. Acta Universitatis Ouluensis C 250. Oulu: University of Oulu. 229 p.

JACK Intelligent Agents Agent Manual. (2005) Agent Oriented Software Pty. Ltd. Australia. 220 p.

Jagdev, H. S. & Thoben, K.-D. (2001) Anatomy of enterprise collaborations. International Journal of Production Planning and Control, Vol. 12, No. 5, pp. 437–451.

Jennings, N. R. & Wooldridge, M. C. (Eds.) (1998) Agent Technology. Foundations, Applications and Markets. Heidelberg, Germany: Springer-Verlag.

Jennings, N. R., Faratin, P., Norman, T. J., O'Brien, P. & Odgers, B. (2000a) Autonomous Agents for Business Process Management. Int. Journal of Applied Artificial Intelligence, Vol. 14, No. 2, pp. 145–189.

Jennings, N. R., Faratin, P., Norman, T. J., O'Brien, P., Odgers, B. & Alty, J. L. (2000b) Implementing a Business Process Management System using ADEPT: A Real-World Case Study. Int. Journal of Applied Artificial Intelligence, Vol. 14, No. 5, pp. 421–463.

Kalliokoski, P., Seilonen, I., Ollus, M. & Koskinen, K. (2000) Virtual Enterprise Co-Operation Model for Web-Enabled Production Management for SME-Networks in eBusiness and eWork Conference and Exhibition. Madrid, Spain, 18–20 October 2000.

Karageorgos, A., Thompson, S. & Mehandjiev, N. (2002) Agent-based system design for B2B electronic commerce. International Journal of Electronic Commerce, Special Issue on Agent Technologies for B2B Electronic Commerce, Vol. 7, pp. 59–90.

Kenyon, S. (2006) Behavioral software agents for real-time games. IEEE Potentials, Vol. 25, Issue 4, pp. 19–25.

Kipinä, J., Ojala, K. & Peltomaa, I. (2005) SteelNet2 – tekninen määrittely. Version 2.0 (dated 8.12.2005). Internal report of the SteelNet2 project. 29 p.

Labrou, Y. (2001) Standardizing Agent Communication. In: Marik, V. & Stepankova, O. (Eds.) Multi-Agent Systems & Applications. Advanced Course

on Artifcial Intelligence (ACAI-01) proceedings. Lecture Notes in Computer Science, Vol. 2086, p. 74. Heidelberg, Germany: Springer-Verlag.

Labrou, Y., Finin, T. & Peng, Y. (1999) Agent Communication Languages: The Current Landscape. Intelligent Systems, Vol. 14, No. 2, pp. 45–52.

Lambert, D. M., Cooper, M. C. & Pagh, J. D. (1998) Supply Chain Management: implementation issues and research opportunities. International Journal of Logistics Management, Vol. 9, No. 2, pp. 1–20.

Larsson, J. E. & Hayes-Roth, B. (1998) Guardian: An Intelligent Autonomous Agent for Medical Monitoring and Diagnosis. IEEE Intelligent Systems, Vol. 13, No. 1, pp. 58–64.

Lee, H. (2000) Creating value through supply chain integration. Supply Chain Management Review, Vol. 4, No. 4, pp. 30–36.

Li, M.-S., Cabral, R., Doumeingts, G. & Popplewell, K. (2006) Enterprise Interoperability research roadmap v4.0 31 July 2006. (Read 25.10.2006.) Available at ftp://ftp.cor-dis.europa.eu/pub/ist/docs/directorate_d/ebusiness/ei-roadmap-final_en.pdf.

Lieberman, H., Fry, C. & Weitzman L. (2001) Exploring the Web with Reconnaissance Agents. Communications of the ACM, Vol. 44, No. 9, pp. 69–75.

Lu, T. & Yih, Y. (2001) An Agent-based Production Control Framework for Multiple-line Collaborative Manufacturing. International Journal of Production Research, Vol. 39, No. 10, pp. 2155–2176.

Luck, M., McBurney, P. & Preist, C. (2003) Agent Technology: Enabling Next Generation Computing (A Roadmap for Agent Based Computing). AgentLink.

Luck, M., Ashri, R. & d'Inverno M. (2004) Agent-Based Software Development. Artech House. 208 p.

Luck, M., McBurney, P., Shehory, O. & Willmott, S. (2005) Agent Technology: Computing as Interaction (A Roadmap for Agent Based Computing). AgentLink.

Maamar, Z., Dorion, E. & Daigle, C. (2001) Toward Virtual Marketplaces for E-Commerce. Communications of the ACM, Vol. 44, No. 12, pp. 35–38.

Maes, P. (1994) Agents that reduce work and information overload. Communications of the ACM, Vol. 37, No. 7, pp. 31–40.

Maes, P. (1995) Artificial Life Meets Entertainment: Lifelike Autonomous Agents. Communications of the ACM, Vol. 38, No. 11, pp. 108–114.

Malone, T. W., Yates, J. & Benjamin, R. I. (1987) Electronic markets and electronic hierarchies. Communications of the ACM, Vol. 30, No. 6, pp. 484–497.

Mangina, E. (2002) Review of software products for multi-agent systems. AgentLink. 46 p.

Mařík, V. & McFarlane, D. (2005) Industrial Adoption of Agent-Based Technologies. IEEE Intelligent Systems, Vol. 20, No. 1, pp. 27–35.

Marik, V., McFarlane, D. & Valckenaers, P. (Eds.) (2003) Holonic and Multi-Agent Systems for Manufacturing. Heidelberg, Germany: Springer-Verlag.

Maturana, F. & Norrie, D. (1996) Multi-agent Mediator Architecture for Distributed Manufacturing. Journal of Intelligent Manufacturing, Vol. 7, pp. 257–270.

Menczer, F., Monge, A. & Street, N. (2002) Adaptive Assistants for Customized E-Shopping. IEEE Intelligent Systems, Vol. 17, No. 6, pp. 12–19.

Moore, D. & Greengrass, E. (2000) Design Considerations for Agent Systems that Glean the Internet. IEEE Intelligent Systems, Vol. 15, No. 2, pp. 76–81.

Muffatto, M. & Payaro A. (2004) Integration of web-based procurement and fulfillment: A comparison of case studies. International Journal of Information Management, Vol. 24, pp. 295–311.

Munroe, S., Miller, T., Belecheanu, R. A., Pěchouček, M., McBurney, P. & Luck, M. (2006) Crossing the Agent Technology Chasm: Lessons, Experiences and Challenges in Commercial Applications of Agents. The Knowledge Engineering Review, Vol. 21, pp. 345–392. Based on AAMAS 2006.

Nealon, J. L. & Moreno, A. (2002) The application of agent technology to health care. In: AAMAS02Workshop on the Application of Agent Technology to Health Care, 2002.

Nealon, J. L. & Moreno A. (2004) Applications of Software Agent Technology in the Health Care Domain. Birkhäuser. 215 p.

Newcomer, E. (2002) Understanding web services: XML, WSDL, SOAP, and UDDI. 1st edition (May 13, 2002). Addison-Wesley Professional. 332 p.

Norman, T. J., Preece, A., Chalmers, S., Jennings, N. R., Luck, M., Dang, V. D., Nguyen, T. D., Deora, V., Shao, J., Gray, A. & Fiddian, N. (2003) CONOISE: Agent-based formation of virtual organisations. Proceedings of 23rd SGAI Int. Conf. on Innovative Techniques and Applications of AI, Cambridge, UK. Pp. 353–366.

Nwana, H. S. (1996) Software Agents: an Overview. Knowledge Engineering Review, Vol. 11, No. 3, pp. 1–40.

Nwana, H. S. & Ndumu, D. T. (1998) A brief introduction to Software Agent Technology. In: Jennings, N. R. & Wooldridge, M. C. (Eds.) Agent Technology. Foundations, Applications and Markets. Heidelberg, Germany: Springer-Verlag.

Papazoglou, M. (2001) Agent-oriented technology in support of e-business. Communications of the ACM, Vol. 44, Issue 4, pp. 71–77.

Parunak, V. (1993) MASCOT: A virtual factory for research and development in manufacturing scheduling and control. Technical Memo 93–02. Industrial Technology Institute.

Pechoucek, M. & Marik, V. (2006) Review of Industrial Deployment of Multi-Agent Systems. Submitted for publication to Journal of Autonomous Agents and Multi-Agent Systems.

Pechoucek, M., Vokrinek, J. & Becvar, P. (2005) ExPlanTech: Multiagent Support for Manufacturing Decision Making. IEEE Intelligent Systems, Vol. 20, No. 1, pp. 67–74.

Pollock, J. T. & Hodgson, R. (2004) Adaptive information – Improving Business Through Semantic Interoperability, Grid Computing, and Enterprise Integration. John Wiley & Sons.

Preece, A., Chalmers, S., Oren, N., Norman, T. J., Gray, P. M. D., Shercliff, G., Stockreisser, P. J., Shao, J., Gray, W. A., Fiddian, N. J., Patel, J., Teacy, L., Jennings, N. R., Luck, M. & Thompson, S. (2005) Managing virtual organisations on the grid using agent technology. In: Payne, T. R. (Ed.) AgentLink News, No. 17, pp. 14–17.

Rosenschein, J. S. & Genesereth, M. R. (1985) Deals among rational agents. In: Proceedings of the Ninth International Joint Conference on Artificial Intelligence (IJCAI-85), Los Angeles, CA. Pp. 91–99.

Sadeh, N. M., Hildum, D. W. & Kjenstad, D. (2003) Agent-based e-Supply Chain Decision Support. Journal of Organizational Computing and Electronic Commerce, Vol. 13, No. 3.

Sandholm, T. (2000) Agents in Electronic Commerce: Component Technologies for Automated Negotiation and Coalition Formation. Autonomous Agents and Multi-Agent Systems, Vol. 3, No. 1, pp. 73–96.

Shaw, M. (1988) Dynamic Scheduling in Cellular Manufacturing Systems: A Framework for Networked Decision Making. Journal of Manufacturing Systems, Vol. 7, No. 2, pp. 83–94.

Shen, W. & Norrie, D. (1998) An Agent-based Approach for Manufacturing Enterprise Integration and Supply Chain Management. Proceedings of the 3rd International Conference on the Practical Applications of Agents and Multi-Agent Systems (PAAM-98), London, England.

Shen, W. & Norrie, D. H. (1999) Agent-based systems for intelligent manufacturing: a state-of-the-art survey. International Journal of Knowledge and Information Systems, Vol. 1, No. 2, pp. 129–156.

Smith, H. & Fingar, P. (2003) Business Process Management: The Third Wave. Meghan-Kiffer Press. 292 p.

Studer, R., Benjamins, R. & Fensel, D. (1998) Knowledge Engineering: Principles and Methods. Data & Knowledge Engineering, Vol. 25, No. 1–2, pp. 161–198.

Swaminathan, J., Smith, S. & Sadeh, N. (1996) A Multi-agent Framework for Supply Chain Dynamics. Proceedings of AI & Manufacturing Research Planning Workshop, Albuquerque, NM.

Tu, Y. (1997) Production planning and control in a virtual One-of-a-Kind Production company. Computers in Industry, Vol. 34, pp. 271–283.

Tönshoff, H.-K., Seilonen, I., Teunis, G. & Leitão, P. (2000) A Mediator-based approach for decentralised production planning, scheduling and monitoring, Proceedings of the International Seminar on Intelligent Computation in Manufacturing Engineering, Capri, Italy, 2000. Pp. 113–118.

Usher, J. (2003) Negotiation-based Routing in Job Shops via Collaborative Agents. Journal of Intelligent Manufacturing, Vol. 14, No. 5, pp. 485–499.

Wassink, I., van Dijk, E. M. A. G., Zwiers, J., Nijholt, A., Brugman, A. & Kuipers, J. (2006) In the Truman Show: Generating Dynamic Scenarios in a Driving Simulator. IEEE Intelligent Systems, Vol. 21, No. 5, pp. 28–32.

Wavish, P. (1996) Situated Action Approach to Implementing Characters in Computer Games. Applied Artificial Intelligence, Vol. 10, No. 1, pp. 53–74.

White, J. E. (1994) Telescript technology: The foundation for the electronic marketplace. White paper, General Magic, Inc., 2465 Latham Street, Mountain View, CA 94040.

White, A. & Daniel, E. M. (2004) The impact of e-marketplaces on dyadic buyer–supplier relationships: evidence from the healthcare sector. Journal of Enterprise Information Management, Vol. 17, No. 6, pp. 441–453.

Vidal, J. M., Buhler, P. A. & Huhns, M. N. (2001) Inside an agent. IEEE Internet Computing, Vol. 5, Issue 1, pp. 82–86.

Wooldridge, M. (1997) Agent-based software engineering. IEEE Proceedings on Software Engineering, Vol. 144, No. 1, pp. 26–37.

Wooldridge, M. J. & Jennings, N. R. (1995) Intelligent agents: Theory and practice. Knowledge Engineering Review, Vol. 10, No. 2, pp. 115–152.

Wooldridge, M. J. & Jennings, N. R. (1999) Software Engineering with Agents: Pitfalls and Pratfalls. IEEE Internet Computing, Vol. 3, No. 3, pp. 20–27.

Yang, J. & Papazoglou, M. (2000) Interoperation support for electronic business. Association for Computing Machinery. Communications of the ACM, Vol. 43, No. 6, pp. 39–49.

Zacharia, G., Moukas, A., Guttman, R. & Maes, P. (1999) An agent system for comparative shopping at the point of sale. European Conference on Multimedia & Ecommerce Bordeaux, France.

Zeng, D. (2001) Managing flexibility for inter-organizational electronic commerce. Electronic Commerce Research, Vol. 1, No. 1–2, pp. 33–51.

Current Trends in Steel Product Industry Drivers towards eBusiness

Heli HELAAKOSKI[1], Päivi ISKANIUS[2] Irina PELTOMAA[3]
[1]*VTT Electronics, Rantakatu 5, FIN-92100 Raahe, Finland*
Tel: +358 20 722 2420, Fax: + 358 8 2101370, Email: heli.helaakoski@vtt.fi
[2]*University of Oulu, Department of Industrial Engineering and Management, P.O Box 4610, FIN-90014 Oulu, Finland*
Tel: + 358 8 553 2939, Fax: + 358 8 553 2904, Email: päivi.iskanius@oulu.fi
[3]*VTT Electronics, Rantakatu 5, FIN-92100 Raahe, Finland*
Tel: +358 20 722 2450, Fax: + 358 8 2101370, Email: irina.peltomaa@vtt.fi

Abstract: This paper studies the importance of agility in today's business environment. We propose a new business model "a virtual enterprise" (VE) and since the success of VE depends of intensive information sharing we propose a supporting software solution for business network. The research work is conducted via a case study in a real life business network, which consists of several small and medium-sized enterprises (SME) and one focal company. The case study describes the design and implementation of agent-based inter-organisational system (IOS), which enables maximum effectiveness, efficiency and productivity of supply chain network.

1. Introduction

Today, we are living in a revolutionary changing business environment defined by global competition, increasing business and technological complexity, faster flow of information and communication, and pervasive globalization. In many industries competitive advantage may depend upon a company's ability to rapidly respond to frequent and unpredictable change whilst producing customized products for customers' specific requirements [1]. The new manufacturing paradigm in today's changing business environment is agility.

Networking seems to be a common trend in today's business and industry practice [2], [3], [4]. Traditionally large corporations have performed all manufacturing in-house, but today they have reassessed their basic make-or-buy decisions in favour of outsourcing. They have focused on their core competencies and started to benefit also other companies' competencies for supporting their own internal core skills. Today each company is somehow integrated into a network of selected suppliers, customers and value-added resellers, and even with competitors. This development offers new opportunities for SMEs as potential co-operation partners. Today SMEs are trying to move towards more collaborative relationships and towards longer-term strategic partnerships, typically in the business network with the focal company.

Effective and efficient business networks needs to manage the coordination of inter-organisational processes (IOP). This requires increasingly information technology (IT) support and at the moment it is not covered sufficiently enough by traditional information and Enterprise Resource Planning (ERP) systems. IT solutions should support the dynamic nature of business networks, easy integration for existing software solutions and ensure the comfortable and affordable business-to-business (B2B) communication. By using new emerging technologies and advantaging the infrastructure of Internet, the inter-organisational coordination of business network is applicable and affordable also for SMEs.

This study proposes the digital business design as a future business model to support agility in supply chains and to provide a competitive advantage in terms of speed and storage capability with simultaneous reductions in cost and size. This paper presents the development process of a business network aiming to be competitive in global markets by increasing its agility. It consists of developing an e-business roadmap and the supporting software solution for inter-organisational coordination in business network. The whole development process of business network requires changes in a way of action, and improvements in using information and communication technology (ICT) more beneficial.

2. Methodology

The empirical data for the study was collected in a business network, which brings together a group of 19 companies – most of them SMEs - in Northern Finland. In practice this study consists of empirical research conducted as a case study in the steel product industry business network between the years 2001-2004. A list of activities was drawn up in order to analyze the network and its operations and to collect information for the development process. *Firstly,* unstructured interviews were held in order to get a realistic understanding of the companies and their activities and to select the business process under study. *Secondly*, based on these discussions, specific questionnaire for companies was designed in order to find out the critical issues of the supply chain. *Thirdly*, two sample product processes (order-delivery processes) were modelled by following through their value chains. Theme interviews with the operational staff and key persons of the companies were held in order to identify the improving possibilities of the supply chains. The purpose of the interviews was to find out the critical issues in information flows and the development possibilities of the information flow. *Finally*, two workshops were arranged in order to start to develop the e-business road map for the business network. The development road map is based on the development frame of [5].

The software development process adopted principles from the agile software development according to [6]. Therefore the technical research is based on iterative prototyping with close discussion and collaboration with the real end users. For example the requirement specification was defined with companies, but in the same it notices the changes in technology and business environment. The IOS is based on mutual knowledge management from different data sources and applications; therefore the knowledge database is based on mutually agreed ontology [7] to ensure the shared understanding about the concepts within the network and to provide a basis for agent communication. The user friendliness and the usability of the software has to be especially noticed and even the first Graphical User Interfaces (GUI) of IOS were tested with the real end users. According to these tests the functionality and the appearance of the IOS were further developed by using several iteration rounds.

3. The New Business Model in Steel Product Industry

3.1 Agility as today's manufacturing paradigm

The way business was conducted even a decade ago is no longer acceptable if a business intends to remain competitive. Earlier, the paradigms where business was managed were economics of *scale, cost* (productivity), *quality* and *time* (delivery speed and reliability), whereas today, as the rate of product change and product introduction increases, *flexibility* and *rapid innovation* are more critical capabilities than ever before [8], [9], [10], [11]. The requirements for economics of scale, based on the traditional assumption of mass production, are coming in direct conflict with the requirements for economics of scope that is maintaining continuous innovation while using people and equipments to cost-effectively

produce smaller amount of a range products [12]. *Agility* addresses new ways of running companies to meet these challenges. Agility is about casting off those old ways of doing things that are no longer appropriate – changing pattern of traditional operation. In a changing competitive environment, there is a need to develop organizations and facilities significantly more flexible and responsive than current existing ones [13]. Agility is largely independent of other best management approaches that a company can practice. Companies ability to make things better, faster, and cheaper today says nothing, or very little, about the ability to change, in a fast and cheap way, to make something else better, faster, and cheaper, or to respond in other respect to unanticipated changes [14].

The need for agility for market competitiveness has traditionally been associated with the supply chains that provide and manufacture innovative products, such as high-technology industry products characterized by shortened life-cycles, high degrees of market volatility, uncertainty in demand and unreliability in supply. Similarly, the traditional industry faces such challenges in terms of requirements for more customized products, solutions to customer problems and shorter order lead-times. Moreover, product life-cycles are shortening, and the need for becoming agile is becoming more prevalent. Some traditional companies are already employing elements of agility because the realities of the competitive environment dictate these changes, but this is usually outside of any strategic vision and is approached in an ad hoc fashion. The lack of a systematic approach to agility doesn't allow companies to develop the necessary proficiency in change, a prerequisite for agility. There are no guidelines telling how much uncertainty can be reduced or how much the complexity should be reduced. The companies have to make a trade-off between vulnerability (increased by uncertainty and complexity) and supply chain agility (flexibility and speed in sourcing, manufacturing and delivery) [15]. This means that instead of aiming at full compliance with the initial definition of agility, companies should concentrate rather on *some selected key aspects* of an agile supply chain.

One way to enhance agility in supply chains is the utilization of right mix of ICT [16], [12]. Many ICT systems have been developed for Supply Chain Management (SCM) from EDI (Electronic Data Exchange) and ERP to newly developed SCM systems and e-business solutions, and recently, software agent technology has shown a great potential for supporting information management in supply networks [17], [18]. By adopting e-business approaches for SCM, companies can realize dramatic returns through efficiency improvements, better asset utilization, faster time to market, reduction in total order fulfilment times, enhanced customer service and responsiveness, penetrating new markets, higher return on assets, and ultimately, higher shareholder value [16]. E-business creates new opportunities to rethink business models, processes, and relationships along the supply chain [19]. Many companies are discovering whole new approaches to conducting business, and even new business opportunities not previously possible [16].

3.2 The new Business Model - Virtual Enterprise

One of the most significant features of modern business environment is that individual companies no longer compete as solely autonomous entities; rather, the competition is between rival supply chains, or more like closely coordinated, cooperative supply networks, also called supply webs [2], [3]. Some other net-structure concepts can also be found in the literature, i.e., "virtual supply chain" [20], "demand satisfaction community" [21], "value net" [22], "value web" [23], "value chain constellation" [5], "virtual enterprise" [24], and "extended enterprise" [25]. All of these concepts present the new form of the digital business design, where the information flows play an integral role within the network. The Internet especially enables the digital business design, which captures customer's real choices in real time and transmits them digitally to other participants of the network. These

Internet enabled chains are frequently referred to also as "e-commerce supply chains" [26]. *E-supply chains* - chains that use e-business models and web technology - can be seen simply as processes necessary to transfer the goods sold over Internet to the customers, but widely e-supply chain is defined as wide-ranging topic related to the supply chain integration [5]. This new structure of the supply highlights the simultaneous communication between different parties and the integration of the supply chain as a whole, not only the communication between the consecutive phases of the process. The common factors of all these concepts are that they are more or less focusing on the customer (producing more value to the customer and thus hooking the customer), dynamic designs that can be continuously developed and adjusted to changes, digital, agile and scalable, network-formed or "amoeba-like", and responding fast to changes [5], [20], [22].

In the following paragraphs, we have taken a closer look to the "virtual enterprise" (VE). [24] defines VE as a temporary consortium of independent member companies and indeed individuals, who come together to exploit a particular market opportunity. 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 [24]. The success of the VE depends on intensive information sharing, and it is enabled by sophisticated information technology, which makes business information transparent, seamless and easily accessible at any time and at any place [24]. Time to market is greatly reduced through quick response manufacturing with integrated and co-ordinated product design and manufacturing from all the participants. Also, VE pursues enterprise partnerships in order to achieve business success in a very competitive environment [24]. According to [27], VE is based on independent partners who create temporary relationships for the purpose of creating new products and services, it is frequently project based, and requires quick-creating and quick-dissolving organization, whose operation especially depends on fast and accurate information transactions.

4. Technology description

According to [28], an evolutionary model of e-business implementation involves two variables: *the network integration* and *the technological integration*. Network integration consists of sharing the resources and collaboration in a common environment by using information networks. Technological integration is a company's ability to have ICT systems, which can be used to control many different company functions, and which interact with each other either using similar communication protocols or adopting interfaces to allow different systems to communicate. The model of [28] proposes five stages for the implementation of e-business within an existing company 1) traditional communication tools, 2) internal integration, 3) Web-based communication tools, 4) XML (extensible Markup Language) Web-based platform, and 5) integrated enterprise. In stage 5 the company, dealers and suppliers use the same information platform to communicate and the various information management systems are perfectly integrated.

This case study presents the software system, which provides a common platform for communication and information transmission of SMEs. It also tackles the problem of system integration between companies by using agent technology. Agent technology has been considered as an important approach for developing industrial distributed systems [17], [18]. According to [29], intelligent business agents are the next level of abstraction in model-based solutions to e-commerce application. By building on the distributed object foundation, agent technology can help bridge the remaining gap between flexible design and usable applications.

4.1   Case study – IOS for industrial network

The SteelNet software solution is focused on knowledge management in the case of a VE, which consist of several SMEs and one focal company. Effective and efficient collaboration of this VE requires technical support for knowledge and information management of IOPs and furthermore changes in their way of actions. Figure 1 presents the SteelNet software agent solution to support supply chain and network coordination by transmitting information about processes and material flows. The SteelNet software agent solution enables information transparency by providing real-time information for network companies about manufacturing states of mutually processed products.
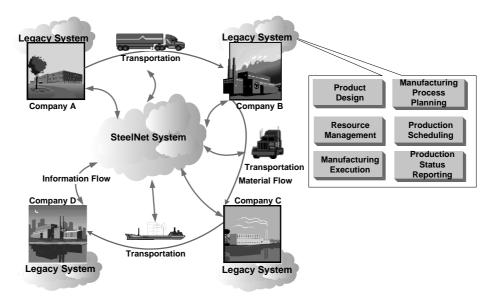
Figure 1 The Coordination of Inter-organisational Prosesses with SteelNet system.

According to [30] an ideal e-commerce application should eliminate the gaps between ordering, distribution and payment, enabling the development of interoperable links to record-keeping and accounting information system. The SteelNet-solution notices these requirements along with logistics information systems (LIS) principles [31]. It is designed to cover the whole procurement process in the network. When the bottlenecks of the procurement process were researched in detail, most of them were found from the manufacturing process and first prototype implementation was focused on controlling this process between companies.

4.2   Implementation process

During the specification process of the manufacturing controlling prototype, SMEs in the business network set the following requirements for IOS:

- IOS must support the different roles of companies; each company can have different roles in the network depending on current delivery. Therefore all companies must have equal rights and responsibilities for using IOS ([32], [33]).
- The integration for companies' own diverging ICT systems must be supported.
- Support Plug-and-play, joining and leaving the IOS have to be effortless.
- Security and access control, controlled information transparency in the IOS.

In the requirement specification the expertise of SME's personnel was exploited, especially when the ontology and the functionality of graphical user interfaces (GUIs) were determined. Ontology definition process was essential in order to provide concept for agent collaboration, while each company understood business concepts differently. The concepts

and the meaning of these concepts were agreed with a shared understanding about the concepts. As a result the manufacturing ontology was the communication basis of agent collaboration. The Protégé ontology environment was used as the ontology tool [34].

In the definition process of GUIs the key aspects were the easiness to use and learning to use it. The GUI's were implemented with web-technology and they were simplified so that only really necessary information was gathered on them. Figure 2 presents the main GUI of the manufacturing control prototype. The user interface shows the central information about order, order lines and manufacturing processes related to order lines for every company in the VE in real-time. The manufacturing states and estimated schedules are described with colour codes, so users can quickly notice whether the manufacturing is on, ahead, or behind an agreed schedule.
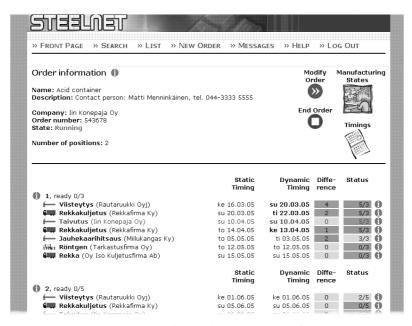
Figure 2 Main GUI of Manufacturing Control prototype.

The most challenging issue during the IOS implementation process was to define the functionality, since each company emphasised different goals and therefore the mutual commitment of the functionality required several meetings. The other challenging issue was to define mutually agreed concepts for VE. These concepts form a basis both for human collaboration and software interoperability. But the most complex challenge was the integration of legacy systems with the prototype, which advantages the use of software agents. These difficulties were coped with through conversation and close co-operation with companies' personnel.

5. Business Benefits

Today's competitive environment requires companies to manage cross-organizational information and at the same time control material flows in order to produce and deliver their products or services better, faster, and cheaper than the competitors. Companies must organize their operations according to the sudden changes in supply chain like customer's changing requirements, changes in resource and capacity. New network-based organizational forms such as VEs make it possible to quickly exploit not only company's own, but also the collective resources of the supply chain. New business designs generate and share mutual information; therefore the information must be visible and transparent through the whole supply chain. Most of the discussion of SCM in business networks is based on the premise that information will be freely shared among partners. This requires a total trust within business network. However, companies are not eager to share information

unless there is a positive proof that sharing information is equally beneficial for all members of the supply chain. The withholding of information by even one member in the chain can lead to loss of trust and dysfunctional behaviour among all members despite the best technology facilitating information flow.

Even though the case network seems to be at the very beginning of adopting the methods of the ICT, the need to improve the level of integration and information sharing is highly recognized in the networking companies. The companies involved in the case network have been enthusiastic to develop their business processes and business models towards e-business. Companies have taken a concrete step by taking part in development process of the SteelNet system. SteelNet system gives an opportunity for real-time and transparent information sharing. It is generated to fit for needs of small and big companies with different levels of ICT systems. Also, SteelNet system has strong characteristics of VE; transparent and seamless business information sharing is being enabled by agent software solution. Network companies together exploit market opportunities and share costs, skills, and core competences. Intensive co-operation between personnel of the companies and researchers has formed the system to answer for the requirements of every day duties.

However, seamless integration with complete information sharing between all supply chain participants is still in the future. Since a number of autonomous companies belong to the supply chain network, it becomes imperative to develop a common mission, goals, and objectives for the group as a whole, while pursuing independent policies at an individual member's level. This scenario offers opportunities for design, modelling, and implementation of supply chain networks for maximum effectiveness, efficiency, and productivity in dynamic environments.

6. Conclusions

The collaboration and sharing of information is growing all the time in business environment. Our paper introduces a case study, a real life VE, where SMEs are working together in order to maintain competitiveness in global markets. The significance of the IOS in this case study is obvious, while current information systems do not cover inter-organisational coordination of processes and the enterprises had constant problems for controlling the mutual processes. SteelNet software solution tries to tackle these problems by providing an affordable and effortless for information management for VE. At the moment, we are about to test SteelNet software in real use and the significance of the software will be really measured.

New business design based on Internet and agent technology integrates physically dispersed manufacturing companies and their customers to ensure that all the members of the business network receive accurate information in a timely manner. This kind of sophisticated ICT system is the basis of an enterprise's information resources, the bridge between partners, a platform for knowledge management and the learning-oriented organisation, as well as a powerful tool for promoting innovations. As ICT systems become really common in action, it has a significant effect to the other business applications, but this is a question for another paper.

References

[1] S. L. Goldman, R. N. Nagel and K. Preiss, Agile competitors and virtual organizations: Strategies for Enriching the Customer. Van Nostrand Reinhold Book, 1995.
[2] D. M. Lambert, M. Cooper and J. D. Pagh, Supply Chain Management: Implementation Issues and Research Opportunities. The International Journal of Logistics Management, Vol. 9, No. 2, 1998, pp. 1-19.
[3] M. Christopher, Logistics and Supply Chain Management - Strategies for Reducing Cost and Improving Service. Prentice Hall, 1998.

[4] M. H. Best, The New Competition. Institutions of Industrial Restructuring. Polity Press, Cambridge, UK, 1990.

[5] C. C. Poirier and M. Bauer, E-supply chain. Berrett-Koehler Publishers, Inc, 2000.

[6] K. Beck, M. Beedle, A. van Bennekum, A. Cockburn, W. Cunningham, M. Fowler, J. Grenning, J. Highsmith, A. Hunt, R. Jeffries, J. Kern, B. Marick, R. Martin, S. Mellor, K. Schwaber, J. Sutherland, and D. Thomas, Manifesto for Agile Software Development, Available at http://www.agilemanifesto.org/, 2005.

[7] D. Fensel, Ontologies: A Silver Bullet for Knowledge Management and Electronic Commerce. Springer-Verlag, 2001, 138 p.

[8] W. J. Kolarik, Creating Quality: Process Design For Results. McGraw-Hill,1999.

[9] Y. Monden, Toyota Production System: An Integrated Approach to Just-In-Time. Industrial Engineering Press, Atlanta, GA, 1998.

[10] J. B. Pine, Mass customisation: the new frontier in business competition. HBS Press, Boston, 1993.

[11] J. P. Womack, D. T. Jones, and D. Roos, Lean Thinking. Simon & Schuster, New York, 1996.

[12] J. Montgomery, and L. O. Levine, The Transition to Agile Manufacturing - Staying Flexible for Competitive Advantage. ASQC Quality Press, Milwaukee, Wisconsin, 1996.

[13] A. Gunasekaran, Design and implementation of agile manufacturing system. International Journal of Production Economics, Vol. 62, 1999, pp. 1-6.

[14] H. T. Goranson, The Agile Virtual Enterprise. Cases, Metrics, Tools, Quorum Books, 1999.

[15] E. Prater, M. Biehl and M. A. Smith, International supply chain agility – Tradeoffs between flexibility and uncertainty. International Journal of Operations & Production Management, Vol. 21, No. 5, 2001, pp. 823-839.

[16] H. Lee and S. Whang, E-business and Supply Chain Integration. Stanford Global Supply Chain Management Forum, SGSCMF-W2-2001, 2001.

[17] N. R. Jennings, J. M. Corera, and I. Laresgoiti, Developing Industrial Multi-Agent Systems. In Proc. of ICMAS'95, San Francisco, The AAAI press/The MIT press, 1995, pp. 423-430.

[18] N. R. Jennings and M. Wooldridge, Applications of Intelligent Agents. In: Agent Technology: Foundations, Applications, and Markets. N. R. Jennings and M. Wooldridge (Eds), Springer, 1998, pp. 3-28.

[19] E. Brynjolfsson and G. L. Urban, Strategies for e-business success. MITSloan Management Review, Jossey-Bass, 2002.

[20] A. Chandrashekar, and P. B. Schary, Toward the virtual supply chain: The convergence of IT and organization. International Journal of Logistics Management, Vol. 10, No. 2, 1999, pp. 27-39.

[21] F. Hewitt, Demand satisfaction communities: new operational relationships in the information age. The International Journal of Logistics Management, Vol. 11, No. 2, 2000, pp. 9-20.

[22] D. Bovet and J. Martha, Value Nets – Breaking the Supply Chain to Unlook Hidden Profits. John Wiley & Sons, New York, 2000.

[23] P. P. Andrews and J. Hahn, Transforming supply chains into value webs. Strategy and Leadership, Vol.26, No.3, 1998, pp. 6-11.

[24] J. Browne and J. Zhang, Extended and virtual enterprises – similarities and differences. International Journal of Agile Management Systems, Vol. 1, No. 1, 1999, pp. 30-36.

[25] J. Browne, B. J. Sackett, and J. C. Wortmann, Future Manufacturing Systems - Towards the Extended Enterprise. Computers in Industry, Vol. 25, 1995, pp. 235-254.

[26] A. Gunasekaran, H. B. Marri, R. E. McGaughey and M. D. Nebhwani, E-Commerce and its Impact on Operations Management. International Journal of Production Economics, Vol. 75, No. 1-2, 2002, p. 185.

[27] J. Zhang, An Architectural Approach to Modelling the Extended Enterprise, PhD Thesis, National University of Ireland, Galway. 1998.

[28] M. Muffatto, and A. Payaro, Integration of web-based procurement and fulfillment: A comparison of case studies, International Journal of Information Management, 24, 2004, pp.295–311.

[29] M. P. Papazoglou, M.P. Agent-oriented technology in support of e-business, Communications of the ACM, Vol. 44, No. 4, 2001.

[30] J. Yang, and M. P. Papazoglou, Interoperation support for electronic business, Communications of the ACM, Vol. 43, No. 6, 2000.

[31] D. J. Bowersox, and D. J. Closs, Logistical Management – The Integrated Supply Chain, Singapore, McGraw-Hill International Editions, 1996.

[32] H. Haapasalo, P. Uutela, and S. Pajari, Developing co-operation in SME Manufacturing Network – Fundamental Concepts from the Steel Product Industry. Proceedings of Conference on Small Business Research, University of Kuopio, Kuopio, Finland, 26 - 28 May, 2002.

[33] P. Iskanius, and H. Haapasalo, Collaboration in steel product industry - developing order delivery process in manufacturing network. Proceedings of International Conference on Industrial Logistics, Vaasa. Finland, 16-19 June, 2003, pp. 270 – 282.

[34] The Protégé Ontology Editor and Knowledge Acquisition System, Available at http://protege.stanford.edu/, 2005.

PUBLICATION II

Agent technology for supporting real-time supply chain management

Agent technology for supporting real-time supply chain management

Heli Helaakoski*

VTT Technical Research Centre of Finland
Rantakatu 5, FIN-92100 Raahe, Finland
E-mail: heli.helaakoski@vtt.fi
*Corresponding author

Päivi Iskanius

Department of Industrial Engineering and Management
University of Oulu
P.O. Box 4610, FI-90014 Oulu, Finland
E-mail: paivi.iskanius@oulu.fi

Irina Peltomaa

VTT Technical Research Centre of Finland
Rantakatu 5, FIN-92100 Raahe, Finland
E-mail: irina.peltomaa@vtt.fi

Janne Kipinä

Department of Electrical and Information Engineering
University of Oulu
Rantakatu 5, FIN-92100 Raahe, Finland
E-mail: janne.kipina@oulu.fi

Kaija Ojala

Ruukki Production
P.O. Box 93, FI-92101 Raahe, Finland
E-mail: kaija.ojala@ruukki.com

Abstract: Information and communication technology is an important enabler of effective Supply Chain Management (SCM). Emerging new technologies have created new possibilities for developing SCM systems and e-business solutions. Recently, the software agent technology has been studied for supporting effective information management in business networks. This paper introduces a business network, where shared information of the network improves lead-time, cost efficiency and faculty for customer service. The research is conducted as a case study in a steel product industry network in Finland and is based on qualitative material and analysed as an entity. The supporting technical research is based on an agent-based prototype for a mutual software system for an industry network.

Biographical notes: Heli Susanna Helaakoski received her Bachelor of Science in Machine Automation from the Oulu Polytechnic and Master of Science in Computer Engineering in 2001 from the University of Oulu. At the moment, she is working on her PhD studies. Since 2000, she has been working as a Research Scientist in VTT Technical Research Centre of Finland. Her research interests are agent technology, ontologies, semantic technologies and mobile applications.

Päivi Iskanius is a Researcher at the Department of Industrial Engineering and Management, University of Oulu. Her research interests are supply chain management and e-business applications in communication and collaboration of the business networks. Further, she examines the importance of innovation for the continuous renewal of a company in today's changing business environment, especially in view of SMEs, and how companies form innovative networks and how they canalise new information, knowledge, technology and other enabling resources for the development and the learning processes of the enterprises. To date she has about 40 research publications in these areas.

Irina Annikki Peltomaa obtained her Bachelor of Science in Computer Engineering from the Polytechnics of Oulu in 1999. Since then she has worked as a Research Engineer in VTT Technical Research Centre of Finland. Her research interests include multi-agent systems, ontologies and application interoperability.

Janne Tapani Kipinä earned his Bachelor of Science in Computer Engineering in 2002 from the Polytechnics of Oulu. At the moment, he works in the University of Oulu. He has over four years of experience in developing agent technology solutions for logistics and supply chain management and in middleware and security solutions for home automation networks.

Kaija Inkeri Ojala obtained her Master of Science in Information Processing Science from the University of Oulu in 1997. Since then she has worked in different software development positions and during the years 2001–2005 as a Researcher in the area of multi-agent systems and ontologies. At the moment she works for Rautaruukki as an IT System Designer.

1   Introduction

Today, we are living in a revolutionary business environment defined by global competition, increasing technological complexity, and an explosion of information and knowledge. Markets are becoming more customer-driven; customers are demanding more variety, better quality, and greater service in terms of reliability and response time. The ability to respond to customers' requirements in ever-shorter timeframes has become crucial. At the same time, new business trends are shortening product life

cycles, broadening product ranges and making possible the ability to process orders in arbitrary lot sizes, while adding variety to them (Goldman *et al*., 1995; Kidd, 1994). Meanwhile, information processing makes it possible to treat masses of customers as individuals, and allow more and more companies to offer individualised products while maintaining high volumes of production (Goldman *et al*., 1995).

One of the most significant paradigm shifts of modern business environment is that individual companies no longer compete as solely autonomous entities; rather, the competition is between closely coordinated and cooperative business networks (Lambert *et al*., 1998; Christopher, 1998; Best, 1990). As a result of this change, companies must be involved in the management of the network of all upstream companies that provide inputs, as well as downstream companies responsible for delivery and after-market service of the product to the end customer (Handfield and Nichols, 1998). As the target of companies is to create better value for their customers, the need for improving the Supply Chain Management (SCM) capability of companies is becoming increasingly recognised (*e.g.*, Christopher, 1998; Schary and Skjøtt-Larsen, 2001; Simchi-Levi *et al*., 2000; Gattorna and Walters, 1996; Hoover *et al*., 2001; Mentzer, 2001). Well-designed supply chain systems can substantially improve efficiency and product quality, and ultimately enhance customer satisfaction and profitability. Getting the right product, at the right price and at the right time to the customer is not only the lynchpin of competitiveness but also the key to survival (Mason-Jones *et al*., 2000). By definition, SCM focuses on joint planning, coordination, and process integration among suppliers, customers and other partners in a supply chain. Its competitive benefits include cost reductions and increased return on assets, as well as increased reliability and responsiveness to the market needs (Chopra and Meindl, 2001).

At the same time that the business environment has changed in a revolutionary way, the technological development and the accessibility of knowledge have created a new possibility to rise to the challenge set by a changed business environment. Especially, the rapid development of the internet and mobile network technologies has offered users, developers and businesses new possibilities to collaborate, access and share information. The internet appears to be a suitable infrastructure for business-to-business communication, which is predicted to become the most important application area of internet technologies in terms of the market volume (Alahuhta *et al*., 2004). While the internet infrastructure enables the use of software agents in B2B solutions, the agent technology has been considered as an important approach for developing industrial distributed systems (Jennings and Wooldridge, 1998; Jennings *et al*., 1995). Agents can be utilised to further automate the supply chain management and reduce the amount of manual work. As a result, both the speed and efficiency of logistic processes will increase.

In this paper, we first introduce the methodology used in this research. Furthermore, we discuss how information technology systems can support the business operations in the network by providing effective information transmission. The aim of studying the use of agents in industrial business networks is to investigate how agents can transmit supply chain-related information among different companies and their Enterprise Resource Planning (ERP) systems. The research is conducted by developing an agent-based prototype that works as a mutual system for networked companies.

2   Methodology and data collection

This study presents some preliminary findings from a specific evolving manufacturing network. The research approach used is descriptive and is based on qualitative material. The empirical data for the study was collected in a steel industry network, which brought together a group of 19 companies in the steel sector in Northern Finland. In practice, this study consists of empirical research conducted as a case study in the steel product industry business network between the years 2001–2004. A list of activities was drawn up in order to analyse the network and its operations.

Firstly, unstructured interviews were held in order to get a realistic understanding of the companies and their activities and to select the business process in which the technical solution should concentrate. The first interviews were carried out in 12 companies, where the core competences, current level of cooperation and facilities for utilising ICT tools were structured. As a result of the interviews, the monitoring of manufacturing supply chain was selected to be the area of the agent-based prototype.

Secondly, based on these discussions, a specific questionnaire for companies was designed in order to find out the critical issues of the effective supply network. In the questionnaire, representatives of six companies answered 34 open-ended questions covering such areas as information sharing, process integration and collaborative relationships in the network. Based on the interviews, an ontology containing commonly agreed basic concepts was formed.

Thirdly, two sample product processes (order-delivery processes) were modelled by following through their value chains. The case processes were chosen for the study because practical processes in the case network were not effective enough and the companies that were involved in these processes recognised the opportunity to integrate the processes by improving open information sharing with a common information system. In the first case, we studied a supply chain of a mass-produced product, and in the second case, a supply chain of a project product. Theme interviews with the operational staff and key persons in the companies were held in order to identify the possibilities for improvement in the supply chains. The purpose of the interviews was to find out the critical issues in information flows.

At the same time that the product processes were being modelled, an iterative design process of a prototype was done. The software solution was designed to be a common information technology solution for a business network. Since the businesses and products within the business network vary, the solution should support changes both in the collaborating companies and in the products.

The basic principle while designing the prototype was to support the business operation of the network in a user-friendly way in order to get accepted by users. Therefore, the functionality and the graphical user interface were developed with the cooperation of the users. In the definition of content-related modules like ontology, the expertise and experience of people who had been working in the steel industry and in the network for several years were used. The aim of the user-friendly approach was to get wide acceptance for the common information system from the start of the design process. The major element of the information system for users is the Graphical User Interface (GUI), therefore even the first non-functional GUIs were tested with the end users of the system. By this approach, the functionality of the system was developed to meet the requirements set by real-life users.

3   Real-time supply chain management

Having an understanding of SCM, it is prerequisite to start by clarifying the term supply chain. The underlying concept of supply chain is simple; a linear sequence of operations organised around the flow of materials from source of supply to their final distribution as finished products to ultimate customers (Hall and Braithwaite, 2001; Schary and Skjøtt-Larsen, 2001). Material flows downstream from the suppliers to the final assembly and information upstream from customer to the suppliers. Information does not reach every participant simultaneously; every participant of the chain receives the information from the previous phase of the process. This reduces the visibility and the flexibility of the process, and the ability to react on customer demand in real-time. In reality, most supply chains are actually networks, because a manufacturer may receive materials from several suppliers, and then supply to several distributors and customers (Christopher, 1998). Christopher (1998) defines the supply chain as:

> "The network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate customer."
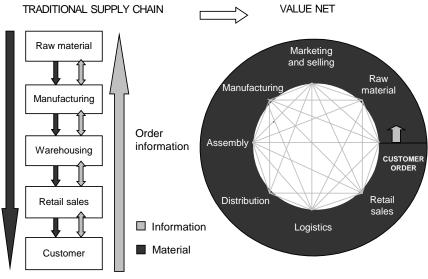
Hence, it would be more accurate to use the terms *supply network* or *supply web* to describe the net structure of most supply chains (*e.g.*, Christopher, 1998; Lehtinen, 2001). Regarding the previous concepts, different, interrelated concepts can be found in the literature: *i.e.*, *virtual supply chain* (Chandrashekar and Schary, 1999) *value net* (Bovet and Martha, 2000), *value web* (Andrews and Hahn, 1998) and *extended enterprise* (Browne *et al.*, 1995). All of the concepts present the new form of the digital business design, where the information flows play an integral role within the network; especially, the internet enables the new business design. The new business design captures the customers' real choices in real time and transmits them digitally to other participants in the network.

In the *new digital business design*, called *value net* later in this study, the customer dominates the supply chain and the chain is organised around the customer order (Figure 1) (Greis and Kasarda, 1997). This new structure of the supply chain highlights the simultaneous communication among different parties and the integration of the supply chain as a whole, not only the communication between the consecutive phases of the process. The value net is a business design that uses digital supply chain concepts to achieve both superior customer satisfaction and company profitability (Bovet and Martha, 2000).

Figure 1	Traditional supply chain versus the value net

Source:	Greis and Kasarda (1997)

## 4	Importance of information in real-time supply chains

The horizontal management of the organisations is possible only, when the information flow among different parties is open and in real-time. Problems occur especially between the d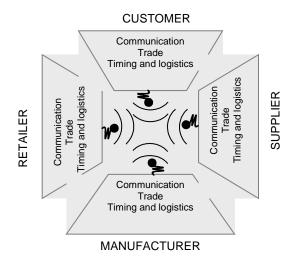ifferent functions and organisations; the interfaces decrease the efficiency of the information flow and the transparency. According to Greis and Kasarda (1997), and Simatupang and Sridharan (2002), these problems can be explained, *e.g.*, by the different information systems, unstable and asymmetric communication, and by information, which is not real-time and updated. Different information systems used in the supply chain can cause problems, not only among the partners but also inside the organisations systems that are incompatible with each other. In a fully integrated network, production and delivery schedules, inventory, order tracking and drawing and design files become open to view and thus transparent to authorised supply chain members.

Greis and Kasarda (1997) and Sakki (2003) talk about communicating around *the round table*, according to the new business design, which emphasises the cross-functional communication in the supply chain (Figure 2).

Traditionally, logistics focused on the efficient flow of goods through the distribution channel, and the information flow was often overlooked, because it was not viewed as being important to customers. In addition to that, the speed of information was limited to the speed of paper. Nowadays, timely and accurate information is more critical to the effective logistics systems for three reasons. First, customers perceive that information, *e.g.*, about order status, is an important element of *customer service*. Any item of information, which is mismanaged, will result in customer dissatisfaction (Singh, 1996). Second, with the goal of reducing total supply chain inventory, it has been realised that information can effectively *reduce inventory and human resource requirements*. Third, information *increases flexibility* (Bowersox and Closs, 1996). Information is the driving

force behind the supply chain, coordinating actions, while freeing them from time and space and potentially involving customers in the supply process (Chandrashekar and Schary, 1999). In this sense, information is the most important factor of the supply chain drivers (*e.g.*, Chopra and Meindl, 2001; Simchi-Levi *et al*., 2000). The *communication throughout the supply chain* and *open, real-time information flow* are crucial factors in order to attain visibility in the supply chain.

Figure 2   Communicating around the round table

Many companies have observed the bullwhip effect that describes the phenomenon of information distortion as it passes from one member to the next across the supply chain. As a result, it is equivalent to not having visibility in a supply chain (Lee, 2002). This deficiency can be in the form of missing information, poor communication, reluctance to share information, and simply wrong data. Inadequate visibility typically occurs at the organisational level (across different organisations, internal or external), geographical level (what happens at different locations), and in time spaces (what has happened in the past). The problem of asymmetric information arises because participating companies generally lack the knowledge required about each other's plans and intentions to adequately harmonise their services and activities. Supply chain members often do not wish to share their private information about demand conditions completely and faithfully with all other members because of the economic value of their information. As a result, the supply chain suffers from sub-optimal decisions and opportunistic behaviour (Simatupang and Sridharan, 2002).

   According to Jahnukainen *et al*. (1995), *the format of the information* flowing in the chain must be well-defined. The data coming from the previous phase of the process must be in such a format that the next phase of the process can use the information without first needing to reshape data. When the communication is standardised, non-value-adding processing of data can be eliminated and the information can be used as efficiently as possible. On the other hand, according to Hannus (1994), the standardised ways to communicate should be replaced by open and free information flows. Supply chain

members share the information in both forward and backward flows that provide adequate visibility across both internal functions and organisations. The data, which is most often shared, include the availability of resources (*e.g.*, capacity, inventory, funds and capability); the status of performance (*e.g.*, time, quality, costs and flexibility); the status of processes (*e.g.*, forecasting, ordering, delivering, replenishing and servicing); and status of contract. The advancements in information technology, such as the internet, enable those data to be gathered and transferred either in real time or on demand (Simatupang and Sridharan, 2002).

5   The role of information technology in supply chain management

As the key of SCM is the integration of processes, both up and downstream in the supply chain, the Information and Communication Technology (ICT) has become an important enabler for this integration process. By optimising and streamlining cross-company processes with ICT, the network can reduce costs, enhance quality, and speed up the operations. Many technologies, which Chopra and Meindl (2001) introduced, share and analyse information in the supply chain. Electronic Data Exchange (EDI) allows companies to place instantaneous, paperless purchase orders with suppliers. *The internet* can be accessed by all and it conveys more information and therefore offers much more visibility than EDI. Enterprise Resource Planning (ERP) systems provide the transactional tracking and global visibility of information from any part of a company and its supply chain that allows intelligent decisions to be made. Supply Chain Management (SCM) provides analytical decisions support in addition to the visibility of information. The difference between ERP and SCM is that ERP only transmits the information about processes while SCM also supports the decision-making of the company by using that information. Enterprise Application Integration (EAI) can be seen as an alternative to ERP, while it also automates the integration process of internal business functions. ERP and EAI focus on integrating business functions into a single system by efficiently utilising information technology, and to share data with third-party vendors and customers (Lee *et al*., 2003).

    Although ICT systems have a huge role in streamlining the logistics processes and in integrating the supply chain, it must be noted that ICT system is only a tool for integration, a thread that links logistics activities into an integrated process. ICT provides a competitive advantage in terms of speed and storage capability with simultaneous reductions in cost and size (Bowersox and Closs, 1996). Logistics information systems must incorporate six principles to adequately support enterprise planning and operations. The following principles must be taken into account when designing or evaluating Logistics Information System (LIS) applications (Bowersox and Closs, 1996). Clearly, one of the reasons is the significance of information:

- Logistics information must be readily and consistently *available to all* that need it. Traditionally, the data regarding logistics activities, such as order and inventory status, are often paper-based, which does not support the need to respond to customers and improve management decisions. Information availability can reduce operating and planning uncertainty.

- Logistics information must be *accurate.* Accuracy means that there is consistency between physical counts or status and LIS reports. Increased information accuracy decreases uncertainty and reduces inventory requirements.

- Logistics information must be *timely*, meaning there should be no delay between when an activity occurs and when the activity is visible in the LIS. The delay reduces planning effectiveness and increases inventory.

- LIS must be *exception-based* in order to highlight problems and opportunities. If the system can identify the exception situations, which are not part of a normal process, planners are then able to focus their attention on situations that require the most attention.

- LIS should be *flexible* to be able to meet both system users' and customers' needs. Systems should be able to provide data tailored to specific customer requirements.

- Information should be appropriately formatted. The right information must be in the right structure and sequence.

6   The use of agents in logistic systems

The concept of the agent lack universally agreed definitions. However, most agent researchers agree on the following definitions (Wooldridge and Jennings, 1995). Perhaps the most general way in which the term agent is used is to denote a hardware or (more usually) software-based computer system that enjoys the following properties:

- *autonomy* – agents operate without the direct intervention of humans or others, and have some kind of control over their actions and internal state

- *social ability* – agents interact with other agents (and possibly humans) via some kind of *agent-communication language* (Genesereth and Ketchpel, 1994)

- *reactivity* – agents perceive their environment (which may be the physical world, a user via a graphical user interface, a collection of other agents, the internet, or perhaps all of these combined), and respond in a timely fashion to changes that occur in it.

Agent technology is one promising software technology for enabling a flexible and dynamic coordination of distributed entities in supply chains. This technology changes the metaphor for human-computer interaction from direct manipulation by the user to indirect management of background agent processes because intelligent agents can autonomously perform a lot of coordination and everyday tasks on behalf of their users (Fischer *et al*., 1996). Agent technology can also be used as an integration system for existing legacy systems. Agents can be used to encapsulate existing software systems to solve legacy problems and integrate manufacturing enterprises' activities such as design, planning, scheduling, simulation execution and product distribution with those of their suppliers, customers and partners into an open, distributed intelligent environment via networks (Fox *et al*., 1993; Barbuceanu and Fox, 1997).

In business networks, agents can carry out several tasks since business-to-business transactions consist of several typically repeated chains of events like the requisition of resources, a request for quotes from candidate business entities, vendor selection,

order fulfilment and delivery, relationship management among businesses, and product life cycle management. These events are relevant to the functions of several business networks, such as a strategic sourcing network; an electronic procurement network; a network for virtual enterprise; a network for product design, manufacturing, inventory, and delivery management; a network of electronic marketplaces; a network for workflow/supply chain management; and a network for supplier relationship management (Blake and Gini, 2002). Many researchers (Karageorgos *et al.*, 2002; Collins *et al.*, 2002) have studied the use of autonomous and intelligent software agents to ease this complex surrounding of business networks in electronic commerce. In Helaakoski *et al.* (2004a), it is shown that agent technology can be used to improve logistics inside companies. Seamless information flow inside the company is one of the basic conditions of a working network.

The agents can support the delivery of supply chain information by providing support for the users' daily activities. The agents are able to transmit logistic information automatically among networked companies; therefore, information sharing is not based on user's memory. Furthermore, agents can propose solutions for user's decision-making and therefore hasten the decision-making process. These features provided by agents are valuable when delivery cycle has to be shortened in the network environment.

7   Technical case study

As a technical case study, a prototype system was built for real-time tracking of manufacturing heavy steel components in a steel industry business network. The prototype system uses agent technology to enable a seamless cross-company information flow in the network concerning manufacturing processes. The prototype is a shared information system among multiple companies, where each company can act as a supplier or be a part of a supply chain.

At first, nine participating companies were interviewed to collect enough information from the application area to provide the working knowledge and to produce a requirement specification. Based on the requirements, a first version of ontology concepts was specified and sample user interfaces were designed. With the sample user interfaces, concepts were presented to selected companies and based on the resulting feedback, some of the terms were changed and the concept model was simplified.

Next, the system architecture was designed based on the specified requirements and the system environment. These consist of equal rights and responsibilities for every company in the business network, security and access control requirements, different network structures including firewalls, company-specific user interfaces, scalability and flexibility, affordable installation and maintenance costs, possibility to integrate to existing systems and a suitable business model. The architecture uses a service provider-based approach, where the service provider is responsible for managing shared databases and company-level access controls and distributing information among companies. The logical view of the SteelNet architecture is shown in Figure 3. Each company has its own agent container that is connected to the service provider's agent container. In all agent containers the basic system functionality is present and by adding agents and other software modules, the functionality can be extended; for example, the manufacturing tracking application is provided by such extension (Helaakoski *et al.*, 2004b).
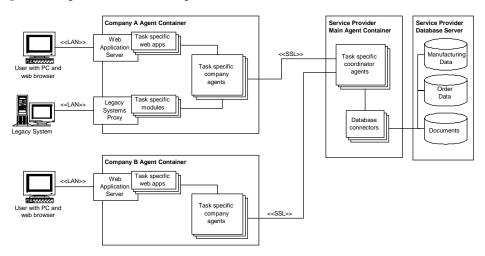
Figure 3   Logical view of SteelNet agent architecture

The agent implementation in the SteelNet system is done using the Java Agent Development Framework (JADE)_agent platform. The JADE was selected for its compliance with the Foundation for Intelligent Physical Agents (FIPA) standards and the use of Java as programming language (Bellifemine *et al.*, 1999). In JADE, the interaction protocol follows FIPA-specified *de facto* standards and the architecture enables agent communication through message exchange based on Agent Communication Language (ACL). FIPA/ACL is used in the system, which supports the use of ontologies for the content definition of the messages. The information exchanged between companies can be, for example, notifications on delivery such as information about production schedules, changes in production requirements or unexpected changes in production (Feng *et al.*, 2006).

The architecture permits a company agent container to be situated in the service provider's premises in case the company itself does not wish to maintain the server. When the system architecture was ready, the system's software modules were specified and the most important ones were implemented to form a first version of the prototype.

The first prototype version was then demonstrated to the end users and they were given a chance to try out the system. The personnel of the companies actively gave feedback on the demonstration. The feedback was analysed, categorised and prioritised and the most important changes were carried out. In the prioritisation of the proposed amendments, we took into account the effect on the functionality of the system, the research challenge, the agreement of the users and the usability. Because of the early involvement of companies in the requirement specification and early user interface tests, only few changes were needed. The feedback mainly concerned the user interface, but in addition, some improvements to the ontology were proposed; for example, more possibilities to add free-form text to describe objects. The key aspects in the definition of GUIs were the ease of use and learning (Helaakoski *et al.*, 2005). After the first iteration round, selected changes were made and additional tools and features were implemented. Then the prototype was demonstrated again to verify the changes and additions. The comments were mostly positive and approving.

In the third iteration round, the prototype system was extended to verify its capability to integrate to companies' existing systems by using add-on modules. Representatives from two companies that have extensive operation management systems were interviewed to gather requirements for the integration module and to gain sufficient knowledge about the technical environment. The existing systems were studied and similarities among them were sought to make the implementation as generic as possible. The integration module was implemented for one of the companies. The module consists of one generic and one company-specific sub-module and a generic GUI tool. The integration module receives information from the company system, translates it to the used ontology format and passes it on to the prototype application. An integration module for the other company can be created by implementing a new company-specific module, which forms less than half of the complete module. Based on the requirements of the companies, the integration module was implemented only as a one-way message passing system.

In the final iteration round, a file transfer extension was added to the system. The extension allows any file (for example, CAD files, documents and pictures) to be attached to almost any ontology concept. The files are transferred securely between companies and access control features are also implemented. This feature had been considered very important from the first interviews with the companies.

At the moment, the prototype system has been in field-tests, which gave important results about the user friendliness, the usability, reliability and demand of the system. Majority of the users felt that the system was easy to learn and use. But the users also expect that all the networked companies would make the commitment to use the system in a defined way. They should deliver the right information in a specified time to the system to ensure the usability and reliability of information. Additional prototype demonstration events are being held continually and the prototype has gained interest also in other industry sectors, so there seems to be a market opening for this kind of business network solutions.

8   Conclusion

Today's competitive environment requires companies to manage cross-organisational information and at the same time control material flows in order to produce and deliver their products (or services) better, faster and cheaper than the competitors can. Companies must be agile and organise their operations according to the sudden changes in the supply chain such as the customers' changing requirements, changes in resource and capacity. New organisational forms, such as extended organisations, make it possible to quickly exploit not only the company's own, but also the collective resources of the supply chain. New organisational models like business networks generate and share mutual information; therefore the information must be visible and transparent through the whole supply chain.

Most of the discussions on SCM in business networks are based on the premise that information will be freely shared among partners. This requires a total trust within the business network. However, companies are not eager to share information unless there is a positive proof that sharing information is equally beneficial to all members of the

supply chain. The withholding of information by even one member in the chain can lead to loss of trust and dysfunctional behaviour among all members despite the best technology facilitating information flow.

The importance of transparent information has also revealed a major factor in our case study in the context of one Finnish steel product industry network. Both of the researched business cases proved that the most critical factors for the transparency of the processes were *the interfaces between different units* and *unnecessary data* processing. These *concrete bottlenecks* occurred especially with the tendering and ordering processes and were caused by all kinds of *changes* that diminished the effectiveness of the processes. One way to avoid these bottlenecks is to specify the information format and the method for sharing information between companies. The case network is adopting the methods of information technology and it has recognised the need to improve the level of integration and information sharing in networks. The companies are enthusiastically developing their collaboration possibilities in ICT and automation technology and in process optimisation and integration.

The technical case study presents how agent technology is adopted in a shared information system of the business network. Since agent technology is a new solution, there are few real-life agent-based applications in the area of logistic information systems. As earlier presented, LIS must incorporate six principles to adequately support enterprise planning and operations. Multi-agent systems fill almost all of these principles. *Accurate and timely* information is *available to all* members of the network, as agents deliver the information through the internet. Agents can communicate with humans, with other information systems, and with other agents. Information is also *exception-based* in order to highlight problems and opportunities while agents are monitoring their environments and reacting to changes. Intelligent agents are capable of reasoning, based on the rules given by the user or knowledge learned from an open environment.

Seamless integration of all supply chain participants with complete information sharing is still in the future but as our prototype shows, we are achieving the goal step by step. In the future, the prototype will be tested with real information content in a business network. Based on these tests we will gather valuable information on how companies can share and manage mutual information and what experiences the companies get by using a mutual software system.

In the future the technical development will even more enable the transparent and strategic utilisation of information; therefore the business network needs to declare a common mission, as well as goals and objectives for the group as a whole. The rapid technological development offers opportunities for design, modelling, and implementation of supply chain networks for maximum effectiveness, efficiency and productivity in dynamic environments. By utilising emerging technologies to support supply chain management, the companies can get remarkable advantages in competitiveness. For example, by using agents to support human routine work and to help in decision-making, the users can use their time more effectively.

Acknowledgements

References

Alahuhta, P., Jurvansuu, M. and Pentikäinen, H. (2004) 'Roadmap for new technologies and services', *Tekes Technology Review*, Vol. 162.

Andrews, P.P. and Hahn, J. (1998) 'Transforming supply chains into value webs', *Strategy and Leadership*, Vol. 26, No. 3, pp.6–11.

Barbuceanu, M. and Fox, M. (1997) 'Integrating communicative action, conversations and decision theory to coordinate agents', *Proceedings of Autonomous Agents' 97*, Marina del Rey, California.

Bellifemine, F., Rimassa, G. and Poggi, A. (1999) 'JADE – A FIPA-compliant agent framework', *Proceedings of the 4th International Conference and Exhibition on the Practical Application of Intelligent Agents and Multi-Agents*, UK.

Best, M.H. (1990) *The New Competition: Institutions of Industrial Restructuring*, Cambridge, UK: Polity Press.

Blake, M.B. and Gini, M. (Eds.) (2002) 'Introduction to the special section: agent-based approaches to B2B electronic commerce', *International Journal of Electronic Commerce*, Fall, Vol. 7, No. 1, p.7.

Bovet, D. and Martha, J. (2000) *Value Nets – Breaking the Supply Chain to Unlook Hidden Profits*, New York: John Wiley & Sons.

Bowersox, D.J. and Closs, D.J. (1996) *Logistical Management – The Integrated Supply Chain*, Singapore: McGraw-Hill International Editions.

Browne, J., Sackett, P.J. and Wortmann, J.C. (1995) 'Future manufacturing systems – towards the extended enterprise', *Computers in Industry*, Vol. 25, pp.235–254.

Chandrashekar, A. and Schary, P.B. (1999) 'Toward the virtual supply chain: the convergence of IT and organization', *The International Journal of Logistics Management*, Vol. 10, No. 2, pp.27, 39.

Chopra, S. and Meindl, P. (2001) *Supply Chain Management – Strategy, Planning and Operation*, Upper Saddle River, New Jersey: Prentice-Hall, Inc.

Christopher, M. (1998) *Logistics and Supply Chain Management: Strategies for Reducing Cost and Improving Service*, Great Britain: Prentice Hall.

Collins, J., Ketter, W. and Gini, M. (2002) 'A multi-agent negotiation testbed for contracting tasks with temporal and precedence constraints', *International Journal of Electronic Commerce*, Vol. 7, No. 1, pp.35–57.

Feng, S.C., Helaakoski, H., Haapasalo, H. and Kipinä, J. (2006) 'Software agents-enabled systems coalition for integrated manufacturing processes and supply chain management', *International Journal of Manufacturing Technology and Management, Special Issue on: Modelling and Optimisation of Supplier-Based Manufacturing and Management*, Inderscience Publishers, (in print).

Fischer, K., Mueller, J.P., Heimig, I. and Scheer, A-W. (1996) 'Intelligent agents in virtual enterprises', *Proceedings of PAAM'96*, London, pp.205–223.

Fox, M.S., Chionglo, J.F. and Barbuceanu, M. (1993) 'The integrated supply chain management system', *Internal Report, Department of Industrial Engineering*, University of Toronto.

Gattorna, J.L. and Walters, D.W. (1996) *Managing the Supply Chain; A Strategic Perspective*, Palgrave Macmillan.

Genesereth, M.R. and Ketchpel, S.P. (1994) 'Software agents', *Communications of the ACM*, Vol. 37, No. 7, pp.48–53.

Goldman, S.L., Nagel, R.N. and Preiss, K. (1995) *Agile Competitors and Virtual Organizations. Strategies for Enriching the Customer*, Van Nostrand, Rinehold, New York.

Greis, N.P. and Kasarda, J.D. (1997) 'Enterprise logistics in the information era', *California Management Review*, Vol. 39, No. 4, pp.55–79.

Hall, D. and Braithwaite, A. (2001) 'The development of thinking in supply chain and logistics management', in A.M. Brewer, K.J. Button and D.A. Hensher (Eds.) *Handbook of Logistics and Supply Chain Management*, Oxford: Pergamon Press, pp.81–98.

Handfield, R.B. and Nichols, E.L. (1998) *Introduction of Supply Chain Management*, Upper Saddle River, New Jersey: Prentice Hall.

Hannus, J. (1994) *Prosessijohtaminen: Ydinprosessien uudistaminen ja yrityksen suorituskyky*, 4th ed., HM & Research Oy, Jyväskylä.

Helaakoski, H., Feng, S.C., Jurrens, K.K., Ojala, K. and Kipinä, J. (2004a) 'Collaborative software agents in steel product industry', *Proceedings of the IASTED International Conference on Artificial Intelligence and Applications*, Innsbruck, Austria, 16–18 February.

Helaakoski, H., Kipinä, J. and Haapasalo, H. (2004b) 'An agent architecture for steel product business networks', *Proceedings of the Sixth International Conference on Enterprise Information Systems*, Porto, Portugal, Vol. 4, pp.467–470.

Helaakoski, H., Iskanius, P. and Peltomaa, I. (2005) 'Current trends in steel product industry – drivers towards e-business', in P. Cunningham and M. Cunningham (Eds.) *Innovation and the Knowledge Economy: Issues, Applications, Case Studies*, Amsterdam: IOS Press, Vol. 2, pp.1661–1668.

Hoover, W.E., Eloranta, E., Holmström, J. and Huttunen, K. (2001) *Managing the Demand-Supply Chain: Value Innovations for Customer Satisfaction*, John Wiley & Sons, Inc.

Jahnukainen, J., Lahti, M. and Luhtala, M. (1995) *Logipro – Towards World Class Make-to-Order Supply Chains*, Report No. 162, Helsinki University of Technology, Otaniemi.

Jennings, N.R. and Wooldridge, M. (1998) 'Applications of intelligent agents', in N.R. Jennings and M. Wooldridge (Eds.) *Agent Technology: Foundations, Applications, and Markets*, Springer, pp.3–28.

Jennings, N.R., Corera, J.M. and Laresgoiti, I. (1995) 'Developing industrial multi-agent systems', *Proceedings of ICMAS'95*, San Francisco: The AAAI Press/The MIT Press, pp.423–430.

Karageorgos, A., Thompson, S. and Mehandjiev, N. (2002) 'Agent-based system design for B2B electronic commerce', *International Journal of Electronic Commerce*, Vol. 7, No. 1, pp.59–90.

Kidd, P.T. (1994) *Agile Manufacturing: Forging New Frontiers*, London: Addison-Wesley.

Lambert, D.M., Cooper, M. and Pagh, J.D. (1998) 'Supply chain management: implementation issues and research opportunities', *International Journal of Logistics Management*, Vol. 9, pp.1–19.

Lee, H. (2002) 'Aligning supply chain strategies with product uncertainties', *California Management Review*, Vol. 44, pp.105–119.

Lee, J., Siau, K. and Hong, S. (2003) 'Enterprise integration with ERP and EAI', *Communications of the ACM*, Vol. 46, No. 2, pp.54–60.

Lehtinen, U. (2001) *Changing Subcontracting. A Study on the Evolution of Supply Chains and Subcontractors*, Department of Industrial Engineering, University of Oulu, Oulu.

Mason-Jones, R., Naylor, B. and Towill, D.R. (2000) 'Lean, agile or leagile? Matching your supply chain to the marketplace', *International Journal of Production Research*, Vol. 38, No. 17, pp.4061–4070.

Mentzer, J.T. (Ed.) (2001) *Supply Chain Management*, London: Sage Publications, Inc.

Sakki, J. (2003) *Tilaus-toimitusketjun hallinta*, Jouni Sakki Oy.

Schary, P.B. and Skjøtt-Larsen, T. (2001) *Managing the Global Supply Chain*, 2nd ed., Copenhagen, Denmark: Copenhagen Business School Press.

Simatupang, T.M. and Sridharan, R. (2002) 'The collaborative supply chain', *The International Journal of Logistics Management*, Vol. 13, No. 1, pp.15–30.

Simchi-Levi, D., Kaminski, P. and Simchi-Levi, E. (2000) *Designing and Managing the Supply Chain*, London: McGraw-Hill.

Singh, J. (1996) 'The importance of information flow within the supply chain', *Logistics Information Management*, Vol. 9, No. 4, pp.28–30.

Wooldridge, M. and Jennings, N.R. (1995) 'Intelligent agents: theory and practice', *The Knowledge Engineering Review*, Vol. 10, No. 2, pp.115–152.

PUBLICATION III

Development steps towards
e-business

In: Proceedings of the International Conference on
Agility. ICAM 2005. Helsinki, 27–28 July 2005.
Espoo: Helsinki University of Technology.
Pp. 171–178.

Development Steps Towards E-business

Päivi Iskanius[1], Heli Helaakoski[2], Janne Kipinä[3], Kaija Ojala[4], Irina Peltomaa[5]

1) Department of Industrial Engineering and Management, University of Oulu, Oulu, Finland, email: paivi.iskanius@oulu.fi
2) VTT Electronics, Raahe, Finland, email. heli.helaakoski@vtt.fi,
3) Department of Electrical and Information Engineering, University of Oulu, Oulu, Finland, janne.kipina@oulu.fi
4), Department of Electrical and Information Engineering, University of Oulu, Oulu, Finland, kaija.ojala@ratol.fi
5) VTT Electronics, Raahe, Finland irina.peltomaa@vtt.fi

Abstract: Real-time information sharing is a first condition of agile supply chain. The companies need to communicate and coordinate with each other via sophisticated electronic system in order to manage integrated supply chains. With the use of information and communication technology (ICT), Internet, and World Wide Web, customers, suppliers, and third-party partners can be linked together to agile address the changing needs of the customers. Companies can do some of their business electronically – actually do e- business. This paper presents the development road map towards e-business and supporting agent-based software solution in industrial business networks in one industrial business network. In this paper, we will discuss how information technology systems can support the business operations towards digital network by providing effective information transmission.

Keywords: Agility, e-business, agent technology, SteelNet system

1. Introduction

One of the most significant paradigm shifts of modern business environment is that individual companies no longer compete as solely autonomous entities, rather, the competition is between closely coordinated, cooperative business networks [1],[2]. Furthermore, today's markets are becoming more international, dynamic, and customer-driven, and customers are demanding more variety, better quality, and greater service in terms of reliability and response time [3], [4]. Companies that are able to take a new approach to business and work closely with partners to design and manage processes that extend across traditional corporate boundaries will succeed in the future.

As the aim of companies is to create better value for their customers, the need of improving effectiveness of supply chain operations is becoming increasingly recognized. Also, the ability to respond to customers' requirements in ever-shorter timeframes has become crucial. Agility – the ability to move quickly to changes in the market demands and to meet customer demands sooner – be they changes in volume, variety or mix - can be seen as an answer for today's enterprise competitive advantage [4],[5]. Agility is not concerned with everything than occurs in the enterprise, but it is concerned with how things are coupled, how they interact,

and how readily that coupling can respond in a beneficial way [6].

The technological development has created new possibilities to rise to the challenge set by changed business environment. New technology enables the accessibility of knowledge according to the anytime-anywhere principle; request for services by users should be always satisfied in an unchanged and transparent way, regardless of the time at which the service is requested and of the place from which is requested [7]. The right mix of information and communication technology (ICT) can enhance agility. According to [8], ICT 1) reduces the product development time to market, 2) reduces the product delivery time to the customer, 3) improves workforce capabilities and flexibility, 4) enhances the flexibility of the product facilities, and 5) improves understanding and control of production processes.

Using Internet technology to communicate to suppliers or customers or sell products and services is becoming a critical success factor for businesses to survive. E-business is redefining market structures and changing the economics of doing business. E-business offers the opportunity to shorten the traditional supply chain dramatically. Also the easy retrieval, transfer, and storage of data to analyze can be a useful supplement for making better decisions.

In a technological point of view the Internet appears to be a suitable infrastructure for business-to-business (B2B)

communication, since it enables the collaborating, accessing and sharing the information for users and businesses. B2B communication is predicted to become most important application area of Internet technologies in terms of the market volume [9]. 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 [10]. The agent technology has been considered as an important approach for developing industrial distributed systems [11], [12]. Agents can be utilized for further automate the supply chain management and reduce the amount of manual work. As a result, both the speed and efficiency of logistic processes will increase.

This paper presents the development process of an industrial business network aiming to be competitive in global markets by increasing its agility. The development process consists of developing an e-business roadmap and the supporting software solution for business network.

This paper is organized as follows; Section 2 describes the research methodology of this study. Section 3 introduces approaches for information management in business network. The development steps towards e-business are introduced in section 4 in a form of case study. Section 5 concludes the paper.

2. Research Design

The empirical data for the study was collected in a steel industry network, which brings together a group of 19 companies in the steel sector in Northern Finland. In practice this study consists of empirical research conducted as a case study in the steel product industry business network between the years 2001-2004. A list of activities was drawn up in order to analyze the network and its operations and to collect information for the development process of the software solution.

Firstly, unstructured interviews were held in order to get a realistic understanding of the companies and their activities and to select the business process in which the technical solution should concentrate. The first interviews were carried out in 12 companies, where the core competences, current level of co-operation and facilities for utilizing ICT tools were structured. As a result of the interviews the monitoring of manufacturing supply chain was selected to be the area of the agent-based prototype.

Secondly, based on these discussions, specific questionnaire for companies was designed in order to find out the critical issues of the effective supply network. In the questionnaire representatives of 6 companies answered 34 open-ended questions covering areas as information sharing, process integration and collaborative relationships in the network. Based on the interviews ontology, containing commonly agreed basic concepts was formed.

Thirdly, two sample product processes (order-delivery processes) were modeled by following through their value chains. The case processes were chosen for the study because

of the fact that practical processes in the case network were not effective enough and the companies that were involved in these processes recognized the opportunity to integrate the processes by improving open information sharing with a common information system. Theme interviews with the operational staff and key persons of the companies were held in order to identify the improving possibilities of the supply chains. The purpose of the interviews was to find out the critical issues in information flows. Parallel to the product process modeling the software development was going on. The software development process was adapted to the principles of the agile software development [13].

Finally, two workshops were arranged in order to start to develop the e-business road map for the business network. Totally 16 key persons from 9 different organizations (both companies and development organizations) gathered together and positioned today's state of art of the network in e-business, and also stated visions of the network in the short and long time period (years 2006 and 2010). The development road map is based on the development frame of [14].

The first aim in the software development was to accomplish working software based on agent technology in order to integrate the conducted prototype with companies' legacy systems. The working software was produced via iteration rounds by implementing prototypes, the first round prototype consisted only the basic functionality. The later prototypes consisted more functionality and sophisticated features which were gradually increased as iteration rounds continued. The second aim was equally important as the first one: to fulfill the requirements set by companies and the real end-users in industrial business network. The objective was to support the business operations in the network by providing a software system to support the daily activities of the end-users. In order to achieve this aim, the application scenario and requirement specification was conducted with a close co-operation of the companies. For example the functionality and graphical user interface (GUI) was designed together with the end-users as a one iteration round.

Close collaboration with users resulted many changes especially for the GUIs. At the first phase non-working GUIs where presented to the users to avoid unnecessary work and too complex interfaces. Not until the suggested features in GUIs were accepted they were implemented. The proposed changes were evaluated and the most important ones got the highest priority and were implemented. By collaboration with the users, the acceptance of the software use will later be easier.

3. Information Management Approaches in Business Networks

The key issue in agile business network is seamless information flow and the management of changes. The most convenient way to realize this is to benefit emerging new technologies. In this section the information management is

studied both from business model approach and technological approach. As a technological approach, the agent technology has been studied as a one of new emerging technologies which offer help for managing information.

3.1 Managing Digital Information Flow

[1] defines the supply chain as "*the network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate customer*". Hence, it would be more accurate to use the terms "supply network" or "supply web" to describe the net-structure of most supply chains [1]. Regarding the previous concepts, different, interrelated concepts can be found in the literature: i.e., "*virtual supply chain", "value net", "value web*", and "*extended enterprise*" [15], [16], [17] and [18]. All of the concepts present the new form of the digital business design, where the information flows play an integral role within the network - especially the Internet enable the new business design. The new business design captures customer's real choices in real-time and transmits them digitally to other participants of the network. The customer dominates the supply chain and the chain is organized around the customer order [19]. This new structure of the supply highlights the simultaneous communication between different parties and the integration of the supply chain as a whole, not only the communication between the consecutive phases of the process. The business design uses digital supply chain concepts to achieve both superior customer satisfaction and company profitability.

Open sharing and real-time information is a key aspect of creating agility in supply chains and the companies need to communicate and coordinate with each other via sophisticated electronic system in order to manage integrated supply chains. In a fully integrated network, production and delivery schedules, inventory, order tracking and drawing and design files become open to view and thus transparent to authorized members of the supply chain. According to [19] and [20], the communication around "*the round table*" is an example of the new business design, which emphasizes the cross-functional communication in the supply chain (Fig. 1).
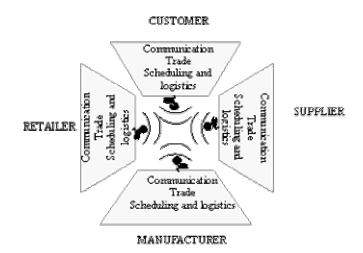

Figure 1. Communication around the round table [20]

Information systems for SCM must incorporate six principles to adequately support enterprise planning and operations. The principles must be taken into account when designing or evaluating information systems as SCM applications [21].

One of the evident reasons is the significance of information. 1) Information must be readily and consistently *available to all* that need it. Traditionally the information regarding SCM activities, such as order and inventory status, are often paper-based, which does not support the need to respond to customers and improve management decisions. Information availability can reduce operating and planning uncertainty. 2) Information must be *accurate.* Accuracy means that there is consistency between physical counts or status and information system reports. Increased information accuracy decreases uncertainty and reduces inventory requirements. 3) Information must be *timely*, meaning that the delay between when an activity occurs and when it is visible in the information system is minimized. The delay reduces planning effectiveness and increases inventory. 4) Information should be *appropriately formatted*. The right information must be in the right structure and sequence. Further, there are two principal expectations to the information systems. 5) Information systems must be *exception-based* in order to highlight problems and opportunities. If the system can identify the exception situations, which are not a part of a normal process, planners are then able to focus their attention on situations that require the most attention. 6) Information systems should be *flexible* to be able to meet both system users and customers' needs. Systems should be able to provide data tailored to specific customer requirements. [21]

3.2 The Possibilities of Agent Technology in Supply Chain Management

In order to build agile supply chain management in business network, the changes in way of action are not enough. Agile SCM requires an efficient use of ICT technology. For example with the use of Internet, customers, suppliers, and third-party partners can collaborate to conform to changing needs of the customers.

Agent technology is one promising software technology for enabling a flexible and dynamic coordination of distributed entities in supply chains. An intelligent agent is a computer that is capable of autonomous action in order to meet its design objects. To be flexible the software system must be [11]:

- *responsive*: agents should perceive their environment (which may be the physical world, a user, a collection of agents, the Internet, etc.) and respond in a timely fashion to changes that occur in it
- *proactive*: agents should not simply act in response to their environment, they should be able to exhibit opportunistic, goal-directed behaviour and take the initiative where appropriate
- *social*: agents should be able to interact, when they deem appropriate, with other artificial agents and humans in order to complete their own problem solving and to help others with their activities.

Agent technology can also be used as an integration system for existing legacy systems. Agents can be used to encapsulate existing software systems to solve legacy problems and integrate manufacturing enterprises' activities such as design, planning, scheduling, simulation execution and product distribution with those of their suppliers, customers and partners into an open, distributed intelligent environment via networks [22], [23].

Agent-based systems have been used in several application areas, such as manufacturing, process control, electronic commerce, and business process management [24]. These examples show that it is possible and even profitable to use agent technology in supply chain management and also in other areas. Agent technology makes it possible to merge distributed computing, mobility and inference in one package.

4. Case study of a Business Network

The case study presents a roadmap of the business network, which aim is to gain competitive advantage by increasing agility. The whole development process of business network requires changes in way of action and improvements in using ICT more beneficial. ICT plays a dominant role in a move towards e-business. In this study the authors are concentrating on examine what the ICT systems can offer to the development of e-business, even we understand that to achieve real agility, there are lot of many other business application

that has to be improved (like design and development, product and service introduction, purchase, procurement and sourcing, marketing, sales, customer service, engineering, planning, scheduling, manufacturing, logistics, customer care and human resources, presented in the table 1). ICT integrates physically dispersed manufacturing companies and their customers to ensure that all the members of the network receive accurate information in a timely manner. ICT is the basis of an enterprise's information resources, the bridge between partners, a platform for knowledge management and the learning-oriented organisation, as well as a powerful tool for promoting innovations. [25] As ICT systems become really common in action, it has a significant effect to the other business applications, but it is question of some other paper.

4.1. A Framework towards e-Business

In this study we have used the framework of [13] in order to develop the road map towards an agile e-business. The work is based on the vision that the case network will have a common functioning ICT system in transferring logistics information between the network companies. In the framework, there are four different e-business levels the network can use as a guide of understanding own position in the framework today, in the near future (2006), and in long-term future (2010) (table 1). The levels are: 1) *internal supply chain optimization*, (level I/II) as a basic level, 2) *network formation* (level III), where the application of advanced supply chain management techniques is used to create the electronic network, 3) *value chain constellation* (level IV), where network members begin sharing resources and utilizing joint assets to enhance the network, and 4*) full network connectivity* (level V), which is achieved as use of the Internet is pervasive and the network is prepared to do business in a digital economy. Level V is not presented in the table 1, because the case network did not position itself so far up.

Table 1. The development steps towards e-business (modified Poirier & Bauer 2000)

Progression Business Application	Level I/II Internal Supply Chain Optimization	Level III Network Formation	Level IV Value Chain Constellation
Information technology	2004 Point solutions	2006 Linked intranets	2010 Internet-based extranet
Design, development, product and service introduction	2004 Internal only	2006 Selected external assistance	2010 Collaborative design, enterprise integration
Purchase, procurement, sourcing	2004	2006	2010 Leverage business unit level

	2004	2006	2010
Marketing, sales, customer service	2004	2006 Internally developed, programs, promotions	2010 Customer-focused, data-based initiatives
Engineering, planning, scheduling, manufacturing	2004 MRP, MRPII, DRP	2006 ERP – Internal connectivity	2010 Collaborative network planning – best asset utilization
Logistics	2004	2006 Pull system through internal/external providers	2010 Best constituent provider – dual channel
Customer care	2004 Customer service reaction	2006 Focused service – call centers	2010 Segmented response system, customer relationship management
Human resources	2004 Internal supply chain training	2006 Provide network resources, training	2010 Interenterprise resource utilization

The starting point of the development is the level I/II, which was set as today's position of the case network. The communication between case network companies today is based basically on mail, e-mail, phone calls or company visits that do not provide much visibility, or agility to the supply chain. Few companies have ERP-systems and the majority have no advanced information management systems at all, and all the ERP-systems work independently as point solutions. The largest company of the case network (called later as the *focal company*) has many ICT systems. It has recently invested to ERP system that will replace most of the old ICT systems in three years. Two of the smaller manufacturing companies (called later as *suppliers*) have operation management systems that are easy to connect to common ICT system.

Today's growing project oriented business is based on interaction and transmission of information, and the focal company, who is generally responsible of the project management, needs to communicate with its suppliers at all levels. Common ICT system can help breaking down barriers between companies in the case network, speed up information flows and turn data into useful collaborative information, in other words, make a supply chain more visible, more agile.

Small suppliers have problems in implementing ICT applications; they don't have enough knowledge and/or financial resources to invest. However, there are some large companies in the case network, which have ICT system implementation experience and knowledge. Furthermore, there are ICT software and hardware companies, which are closely cooperating with the case network companies. In the future ICT and Knowledge Management skills, project management and team working tools will become important issues, when by developing collaboration, the ICT systems change, and also the whole way of doing business change.

Some suppliers in the case network have already started to link electronically with their key customers, and can be positioned in the level III. One supplier has given access to the key customer into its ICT system, and tendering, ordering, and process control is managed electronically. Another supplier has web-based access with its key customer and manages reclamation there. The third example is a direct access between two ICT systems, where both companies can see the status of the production. Furthermore, there are other development processes concerning ICT systems. Some businesses have taken a B2B approach for developing the communication between their ERP-systems. These systems are based on automatic message handling between two systems.

So, the companies in the case network are in the different level in ICT applications and have different potential to adopt ICT, but they have common visions of e-commerce strategies and e-business models and the development work has been started. Also, the success examples from other industries, such as electronic industry and manufacturing industry, encourage the case network in their move towards e-business.

The first step in the development towards e-business, from basic level to the level III, the level of collaboration and cooperation, was positioned to be happened until the year 2006. This level is actually starting level to build the network based on e-business. In this level, the commitments have been done in the high management level and the managers have decided of long-term development operations. Also, in this level, ICT knowledge in all companies is good, and the knowledge and resources are shared between the companies.

The role of the larger companies in developing their supply network is significant. In the case network, the focal company has to take an active role with its suppliers and start common internal ICT development projects. Also, the core competences of the companies have to be identified and strengthen by ICT applications. The case network will determine the used software solutions including the management and filing of mutual information and security issues. Furthermore the mutual information transmission formats needs to be decided together, these include the information transmission format, the used concepts and representation formats. Eventually, each company may have different ERP systems that can communicate with the common ICT system (possibly SteelNet system) in order to handle mutual information. In case a company does not have own ERP system, it can transmit information to other companies by using the SteelNet system or similar via web.

The first elements of the ERP system of the focal company are planned to be in function in the year 2006. This is considered when developing the common ICT system. The objective is that once taped information is transferring in the same format along the whole supply chain.

The second step in the development towards e-business, from the level III to the level IV, was positioned to be happened until the year 2010. The focal company will have its own ERP-system as its main ICT system and there will be a

common logistics system functioning between the network companies. Also the key customers and the logistics provider will be linked into net. Now, all the key suppliers are definitely connected, as well as distributors and customers. Furthermore, the case network will have common business processes and models.

In this level, real-time information for engineering, production and transportation can be transferred along the whole supply chain. Also the customer's demands and orders are moving in the network transparently. The companies in this level understand the e-business methods and try suitable alternatives. Also mobile technology applications will be in function and they are integrated into common ICT system. That kind of example is information exchange between the transportation companies and logistics provider.

As it now seems, the development towards e-business will continue and the progress will lead to the full integrated network, where all the members are linked into common Internet-based extranet. Data will be transferred between the ICT systems creating visibility – best practises will arise and the superior competitive advantage will be possibility to gain.

4.2. SteelNet system – technical study

The requirements in logistic ICT systems have been set in various research studies, e.g. in [26] and [27]. The information has to be available for all the users, appropriately formatted, accurate and reliable; furthermore it has to meet the real-time demands. The system has to be flexible and it has to highlight problems and opportunities. In designing the SteelNet system correspond these requirements was taken to notice. Figure 2 shows one view from the SteelNet system. This application of e-business represents a source of competitive advantage for companies using it.
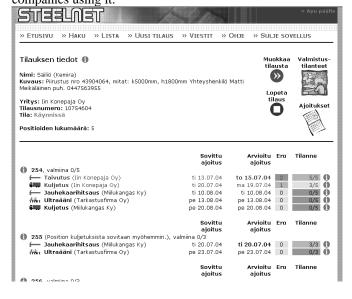

Figure 2. Supply chain management using SteelNet system

In SteelNet system the digitalization of the logistic information was the major aim. This information was previously transmitted vocally, by phone, mail or email, therefore the information did not have any specific format. The SteelNet system makes the logistic information available for all the authorized users. The system offers possibility to mediate information accurately and timely within the business network, but ultimately this depends on the user.

The business network has to commit itself into use of system as a way of delivering information within the network. Furthermore, the business network defines the mutually accepted rules of how the software should be used. For example, it must define the time within the information must be updated into system.

The business network defines the use of mutually agreed vocabulary (ontology) which is used as a basis of the delivered content. This defined ontology is application-specific and must be able to update as activities and deliveries change. The significance of the ontology is to ensure that all users understand the same information in a same way.

The architecture of the SteelNet system is presented in [28] and [29]. In designing the architecture the modularity and the convertibility have been the major aspects. Furthermore, as the SteelNet system is mutual system of the business network, it must be easily connected into companies' own ERP systems. This requirement has been approached in three different ways:

1) The SteelNet system can communicate with company's own ERP system by transmitting the mutual agreed information.
2) SteelNet system can be used via web browser, while the agent container is situated into company's own server.
3) SteelNet system is used via web browser, while the agent container is situated in service provider's premises.

The first concrete step towards e-business has been taken in the network. The SteelNet system responds to the demands for the agile supply chain management. The members of the network have actively taken part for planning and implementing the actual system. The common development and the common goal have enhanced the trust and confidence to each other in the network.

With the help of SteelNet system taking the first step towards e-business has become one step closer. The commissioning of the SteelNet system does not demand high ICT knowledge. The daily operational use of the system is easy and it does not require any special ICT skills.

At the moment (January 2005) the testing phase of the SteelNet system is about to start. The main objective of testing phase is to collect user experience and based on these experiences to improve the functionality and appearance of the SteelNet system. The results of the testing phase also give additional references for the future development of the system.

5. Conclusion

This paper has presented the development process of the case network, which aim is to achieve superior competitive advantage in global markets by increasing its agility. The development process consists of developing e-business roadmap and supporting software solution for business network.

The companies involved in the case network have been enthusiast to develop their business processes and business models towards e-business. Companies have taken a concrete step by taking part in development process of the SteelNet system. As presented in this paper, the authors have implemented a working prototype of SteelNet system for supply chain management. SteelNet system gives opportunity for real-time and transparent information sharing using agent technology. It is generated to fit for needs of small and big companies with different levels of ICT systems. Intensive co-operation between personnel of the companies and researchers has formed the system to answer for the requirements of every day duties.

In the near future the SteelNet system will be tested for real. The purpose of this testing phase is to collect information for future development of the system. During this year the system is going to be extended to the real-time information management in the area of quotation process. The emphasis of the future work will be on importing business model into practice and developing semantics in the business network.

References

1. Christopher, M. 1998. *Logistics and Supply Chain Management - Strategies for Reducing Cost and Improving Service,* Prentice Hall.

2. Lambert, D. M., Cooper M. and J. D. Pagh. 1998. "Supply Chain Management: Implementation Issues and Research Opportunities," *The International Journal of Logistics Management*, 9: 1-19.

3. Mentzer, J. T. 2001. *Supply Chain Management,* London, Sage Publications, Inc.

4. Goldman, S. L., R. N. Nagel and K. Preiss. 1995. *Agile Competitors and virtual organizations: Strategies for Enriching the Customer,* Van Nostrand Reinhold Book.

5. Christopher, M. and D. Towill. 2001."An Integrated model for the design of agile supply chains," *International Journal of Physical Distribution & Logistics Management*, 31(4):235-246

6. Goranson, H. T. 1999. *The Agile Virtual Enterprise. Cases, Metrics, Tools,* Quorum Books.

7. Maamar, Z., E. Dorion, and C. Daigle. 2001. "Toward Virtual Marketplaces for E-Commerce," *Communications of the ACM*, 44(12): 35-38.

8. Montgomery, J. C. and L. O. Levine. 1996. *The Transition to Agile Manufacturing. Staying Flexible for Competitive Advantage,* ASQC Quality Press, Milwaukee, Wisconsin.

9. Alahuhta, P., M. Jurvansuu and H. Pentikäinen. 2004. *Roadmap for New Technologies and Services*, Technology Review 162/2004, Tekes.

10. J. Davies, D. Fensel, F. van Harmelen. 2003. *Towards the Semantic Web, Ontology Driven Knowledge Management*, John Wiley & Sons.

11. Jennings, N. R. and M. Wooldridge. 1998. *Applications of Intelligent Agent, Agent Technology: Foundations, Applications, and Markets*, N. R. Jennings and M. Wooldridge, ed. Heidelberg: Springer-Verlag Inc, pp. 3-28.

12. Jennings N. R., J. M. Corera and I. Laresgoiti. 1995. Developing Industrial Multi-Agent Systems. *In Proc. of ICMAS'95*, The AAAI press/The MIT press, San Francisco, pp. 423-430.

13. Beck, K., M. Beedle, A. van Bennekum, A. Cockburn A., W. Cunningham, M. Fowler, J. Grenning, J. Highsmith, A. Hunt, R. Jeffries, J. Kern, B. Marick, R. Martin, S. Mellor, K. Schwaber, J. Sutherland and D. Thomas. *Manifesto for Agile Software Development,* Available at http://www.agilemanifesto.org/.

14. Poirier, C. C. and M. Bauer. 2000. *E-supply chain,* Berrett-Koehler Publishers, Inc.

15. Chandrashekar, A. and P. B. Schary. 1999. "Toward the virtual supply chain: The convergence of IT and organization," *International Journal of Logistics Management*, 10 (2): 27-39.

16. Bovet, D. and J. Martha. 2000. *Value Nets – Breaking the Supply Chain to Unlook Hidden Profits*, John Wiley & Sons, New York.

17. Andrews, P. P. and J. Hahn. 1998. "Transforming supply chains into value webs," *Strategy and Leadership*, 26 (3): 6-11.

18. Browne, J., P. J. Sackett and J. C. Wortmann. 1995. "Future manufacturing systems-Towards the

Extended Enterprise," *Computers in Industry*, 25: 235-254.

19. Greis, N. P. and J. D. Kasarda. 1997. "Enterprise logistics in the information era," *California Management Review*, 39 (4): 55-79.

20. Sakki, J. 2003. *Tilaus-toimitusketjun hallinta*, Jouni Sakki Oy.

21. Bowersox, D. J. and D. J. Closs. 1996. *Logistical Management – The Integrated Supply Chain,* McGraw-Hill International Editions, Singapore.

22. Fox, M. S., J. F. Chionglo and M. Barbuceanu. 1993. *The Integrated Supply Chain Management System*, Internal Report, Dept. of Industrial Engineering, Univ. of Toronto.

23. Barbuceanu, M. and M. Fox. 1997. "Integrating Communicative Action, Conversations and Decision Theory to Coordinate Agents," *In Proceedings of Autonomous Agents' 97*, Marina del Rey, CA.

24. Luck, M., P. McBurney and C. Preist. 2003. *Agent Technology: Enabling Next Generation Computing, A Roadmap for Agent-Based Computing,* AgentLink Roadmap

25. Jun-Hai, L., A. R. Anderson and R. T. Harrison. 2003. "The evolution of agile manufacturing," *Business Process Management Journal,* 9(2):170-189.

26. Iskanius, P., H. Helaakoski, A-M Alaruikka and J. Kipinä. 2004. "Transparent information flow in business network by using software agents," *In Proceedings of International Engineering Management Conference – IEMC 2004*, Singapore, October 18-21, 2004, pp. 1342-1346.

27. Iskanius, P., A-M Alaruikka A-M and H. Haapasalo. 2004. "Streamlining logistics processes in steel products industry network - From the viewpoint of information flow," In: Aronsson H (Ed) *Proceedings of 16th Annual Conference for Nordic Researchers in Logistics - NOFOMA-2004*, University of Linköping, Linköping, Sweden, June 7-8, 2004, pp. 323–338.

28. Helaakoski H., J. Kipinä and H. Haapasalo. 2004. "An Agent Architecture for Steel Product Business Networks," *In Proceedings of the Sixth International Conference on Enterprise Information Systems,* Volume 4, Porto, Portugal, April 14-17, 2004.

29. Helaakoski H., S.C. Feng, K.K.Jurrens, K. Ojala and J. Kipinä. 2004. "Collaborative Software Agents in Steel Product Industry," *In Proceedings of The IASTED International Conference on Artificial Intelligence and Applications*, Innsbruck, Austria, February 16-18, 2004.

Transparent information flow in business networks by using agents

Transparent Information Flow in Business Networks by using Agents

P. Iskanius[1], H. Helaakoski[2], A.M. Alaruikka[3], J. Kipinä[4]

[1]Department of Industrial Engineering and Management, University of Oulu, Oulu, Finland
[2]VTT Electronics, Raahe, Finland
[3]VTT Building and Transport, Transport and Logistics, Oulu, Finland
[4]Department of Electrical and Information Engineering, University of Oulu, Raahe, Finland

Abstract **- Information technology (IT) is an important enabler of effective supply chain management (SCM). Many information systems have been developed for SCM from EDI and ERP into newly developed SCM systems and e-business solutions. Recently, the use of software agent technology has received a great potential in supporting transparency in information flows of business networks. This paper introduces a business network, where shared information of the network enables an improvement of lead-time, cost efficiency and faculty for customer service in a supply chain. This paper describes the empirical research conducted as a case study in a steel product industry network in Finland and a technical description of an agent-based software solution for a business network. The empirical research is based on qualitative material (interviews, documents and models of order-delivery chains) and it is analysed as an entity. The technical research is based on a prototype of software agent architecture. The prototype is focused on manufacturing of heavy steel component in diverse engineering companies, by following the material and information flow between and within the companies.**

Keywords—**Agent technology, information flow, steel industry**

I. INTRODUCTION

Today the development of business and industry has led us to the situation where it is not individual companies that compete with each other; rather, the competition is between rival supply chains, or more like supply networks [1]. This kind of development has forced companies to improve their supply chain management (SCM) capabilities. Those supply chains that add the most value for customers with the lowest cost in the chain make up the winning supplier network of individual companies. As the key of SCM is the integration of processes, both up- and downstream in the supply chain; the information and communication technology (ICT) has become an important enabler for this integration process. By optimizing and streamlining cross-company processes with ICT, the network can reduce costs, enhance quality, and speed the operations.

Many information systems have been developed for SCM from EDI and ERP into newly developed SCM systems and e-business solutions. Recently, agent technology has been considered as an important approach for developing industrial distributed systems [2], [3].

II. METHODOLOGY

This study presents some preliminary findings from a specific evolving manufacturing network. The research approach used is descriptive and is based on qualitative material. The empirical data for the study was collected in a steel industry network, which brings together a group of 19 companies in the steel sector in Northern Finland. In practice this study consists of empirical research conducted as a case study in the steel product industry business network between the years 2001-2004. A list of activities was drawn up in order to analyze the network and its operations. *Firstly,* unstructured interviews were held in order to get a realistic understanding of the companies and their activities. The first interviews were carried out in 12 companies, where the core competences, current level of co-operation and facilities for utilizing ICT tools were structured. *Secondly*, based on these discussions, specific questionnaire for companies was designed in order to find out the critical issues of the effective supply network. In the questionnaire representatives of 6 companies answered 34 open-ended questions covering areas as information sharing, process integration and collaborative relationships in the network. *Thirdly*, two sample product processes (order-delivery processes) were modeled by following through their value chains. The case processes were chosen for the study because of the fact that practical processes in the case network were not effective enough and the companies that were involved in these processes recognized the opportunity to integrate the processes by improving open information sharing with a common information system. In the first case, we studied a supply chain of a mass-produced product and the second case was a supply chain of a project product. Theme interviews with the operational staff and key persons of the companies were held in order to identify the improving possibilities of the supply chains. The purpose of the interviews was to find out the critical issues in information flows.

Representatives of 10 companies were interviewed and a technical questionnaire was carried out to gather requirements for an agent-based prototype system to improve information flow in business networks. More interviews were held during the early development process to refine the requirements and at later stages of the development the prototype was demonstrated to the companies to further evolve the agent system.

1

III. New Business Desing for Supply Chain

Traditional supply chain is often structured as a chain consisting of consecutive actions following each other (Fig. 1). Material flows downstream from the suppliers to the final assembly and information upstream from the customer to the suppliers. Information does not reach every participant simultaneously; every participant of the chain receives the information from the previous phase of the process. This reduces the visibility and the flexibility of the process, and the ability to react on the customer demand in real-time. In the *new digital business design,* the customer dominates the supply chain, which is organized around the customer order (Fig. 1) [4]. A supply chain should not be thought automatically as a chain, where all the actions follow each other but rather as a net, where different operations parties have a real-time connection with each other. This new structure of the supply chain highlights the simultaneous communication between different parties and the integration of the supply chain as a whole, not only the communication between the consecutive phases of the process.

A supply chain is a dynamic process and involves a constant flow of information, material, and funds across multiple functional areas, both within and between chain members. In reality, most supply chains are actually networks, because a manufacturer may receive material from several suppliers, and then supply several distributors and customers. Hence, it would be more accurate to use the terms "*supply network*" or "*supply web*" to describe the net-structure of most supply chains [1]. Regarding the previous concepts, different, interrelated concepts can be found in the literature: e.g., "*virtual supply chain*" [5], "*value net*" [6], "*value web*" [7], and "*extended enterprise*" [8].

All of the concepts present the new form of the digital business design, where the information flow plays an integral role within the network - especially the Internet and e-commerce enable the new business design.

The new business design captures customer's real choices in real time and transmits them digitally to other participants of the network. The five characteristics illustrated in table 1, distinguish a new business design and give it the edge over a traditional business design, which relies on supply chain thinking.
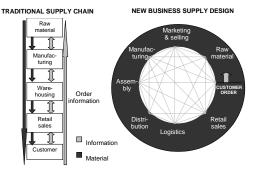

Fig. 1. From traditional supply chain towards new business design [4].

Table 1

Towards New Business Design [6]

Traditional supply chain	New business design
One size fits all	Customer-aligned
Arm's length and sequential	Collaborative and systemic
Rigid, inflexible	Agile, scalable
Slow, static	Fast-flow
Analog	Digital

Together these five characteristics constitute a competitive differentiated business design. When establishing new business design companies need to learn new ways of relating to customers and suppliers, to redesign internal processes, and to digitize them as well. The work of some functions may have to be eliminated or outsourced [6].

IV. The Importance of Information Flow

Traditionally logistics focused on an efficient flow of goods through the distribution channel, and the information flow was often overlooked, because it was not viewed as being important to customers. In addition to that, the speed of information was limited to the speed of paper. Nowadays, timely and accurate information is critical for the effective logistics systems for three reasons. First, customers perceive that for example information about order status is an important element of *customer service*. Any item of information, which is mismanaged, will result in customer dissatisfaction [10]. Second, with the goal of reducing total supply chain inventory, it has been realized that information can effectively *reduce inventory and human resource requirements*. Third, information *increases flexibility* [11]. Information is the driving force behind a supply chain while freeing coordinating actions from time and space and potentially involving customers in the supply process [5]. In this sense, information is the most important factor of the supply chain drivers (e.g. [12], [13]) The *communication through out the supply chain* and *open, real-time information flow* are crucial factors in order to attain visibility into the supply chain.

Many companies have observed the bullwhip effect that describes the phenomenon of information distortion as it passes from one member to the next across the supply chain. As a result, it is equivalent to not having visibility in a supply chain [14]. This deficiency can be in the form of missing information, poor communication, reluctance to share information, and simply wrong data. Inadequate visibility typically occurs at the organizational level (across different organizations, internal or external), geographical level (what happens at different locations), and in time spaces (what has happened in the past). The problem of asymmetric information arises because of participating companies generally lack the knowledge required about each other's plans and intentions to adequately harmonize their services and activities. Supply chain members often do not wish to share their private informa-

tion about demand conditions completely and faithfully with all other members due to the economic value of their information. As a result, the supply chain suffers from suboptimal decisions and opportunistic behaviour [9].

According to [15], *the format of information* flowing in the chain must be well defined. The information coming from the previous phase of the process must be in such a format that the next phase of the process can use the information without needing first to reshape it. When the communication is standardized, non-value-adding processing of information can be eliminated and it can be used as efficiently as possible. On the other hand, according to [16], standardized ways to communicate should be replaced by open, free information flows. Supply chain members share information in both forward and backward flows that provide adequate visibility across both internal functions and organizations. The most often shared information includes the availability of resources (e.g. capacity, inventory, funds, and capability); the status of performance (e.g. time, quality, costs, and flexibility); the status of processes (e.g. forecasting, ordering, delivering, replenishing, and servicing); and the status of a contract. The advancements of information technologies such as the Internet, enables information to be gathered and transferred either in real time or on demand [9].

V. THE ROLE OF INFORMATION TECHNOLOGY

Information technology (IT) is an important enabler of an effective supply chain management [13]. IT provides a competitive advantage in terms of speed and storage capability with simultaneous reductions in cost and size [11]. Although IT systems have a huge role in streamlining the logistics processes and in integrating the supply chain, it must be noted that IT system is only a helping tool towards the integration, a thread that links logistics activities into an integrated process.
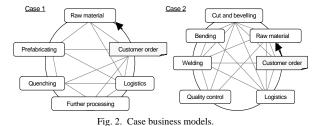
Logistics information systems must incorporate six principles to adequately support enterprise planning and operations. The principles must be taken into account when designing or evaluating Logistics Information System (LIS) applications [11]. One of the evident reasons is the significance of information. 1) Logistics information must be readily and consistently *available to all* that need it. Traditionally the data regarding logistics activities, such as order and inventory status, are often paper-based, which does not support the need to respond to customers and improve management decisions. Information availability can reduce operating and planning uncertainty. 2) Logistics information must be *accurate.* Accuracy means that there is consistency between physical counts or status and LIS reports. Increased information accuracy decreases uncertainty and reduces inventory requirements. 3) Logistics information must be *timely*, meaning that the delay between when an activity occurs and when it is visible in the LIS is minimized. The delay reduces planning effectiveness and increases inventory. 4) LIS must be *exception-based* in order to highlight problems and opportunities. If the system can identify the exception situations,

which are not a part of a normal process, planners are then able to focus their attention on situations that require the most attention. 5) LIS should be *flexible* to be able to meet both system users and customers' needs. Systems should be able to provide data tailored to specific customer requirements. 6) Information should be appropriately formatted. The right information must be in the right structure and sequence.

According to [17], with a right technology choice, a company can communicate with its suppliers at all levels, help break down barriers between companies, speed up information flows, and turn data into useful collaborative information. In other words, the company can make a supply chain visible. There are many technologies, which [12] introduce, share and analyze information in a supply chain. *Electronic Data Exchange (EDI)* allows companies to place instantaneous, paperless purchase orders with suppliers. *The Internet* can be accessed by all and it conveys more information and therefore offers much more visibility than EDI. *Enterprise Resource Planning (ERP)* systems provide the transactional tracking and global visibility of information from any part of a company and its supply chain that allows intelligent decisions to be made. *Supply chain management (SCM)* provides analytical decisions support in addition to the visibility of information. ERP systems show to a company what is going on and SCM systems help a company to decide what it should do.

In today's Internet environment a*gent technology* is one promising software technology for converting traditional supply chains to supply networks. The technology enables a flexible and dynamic coordination of distributed entities and transparent information flow between collaborative companies.

VI. CASE PROCESSES

The case supply chains studied are roughly presented in Fig. 2 by following the new digital business design according to [4]. As seen in Fig. 2, quite a lot of information contacts seem to appear between the different actions (or units) in the case supply chains. The primary issue of the management of these supply chains may be what data should be transferred, which data are significant for SCM, which data can safely be ignored, and how the data should be analyzed and used.

Fig. 2. Case business models.

VII. AGENT TECHNOLOGY IN BUSINESS NETWORKING

Although agents can be understood in many ways, it is quite commonly accepted that agents can be described as software systems that are autonomous, co-operative (social behaviour), reactive and pro-active [18]. Agent technology is a set of specifications and tools to facilitate the creation of agent systems. The technology includes for example specifications for an Agent Communication Language (ACL) and interaction protocols to enable agents to communicate with each other. A multiagent system is a collection of individual agents that communicate and co-operate as individual, self-interested entities, meaning that each agent is primarily concerned about fulfilling their own goals [19]. This study presents how these methodological and technological characteristics of agents can be utilized in enhancing the information flow in a business network.

A business network consists of independent companies collaborating with each other, and companies have several rather autonomous departments with employees doing their jobs. This can be viewed as a three-layer entity, a company, a department and an employee. Each of these layers can be modelled as an agent, since all of them are autonomous and co-operative entities. One agent representing one company does not seem to be attractive option because it would cause complex design inside the agent, as it should be capable of handling all company level activities. On the other hand, one agent per employee would create very complex agent communities that would be rather inefficient. For the case network the best solution is to divide agent responsibilities by departments or activities, such as sales, management and manufacturing.

The aforementioned division of agent responsibilities leads to a multiagent system, where each company has several agents with different objectives and which communicate with their counterparts in the collaborating companies as well as with the agents in their own company (Fig 3).
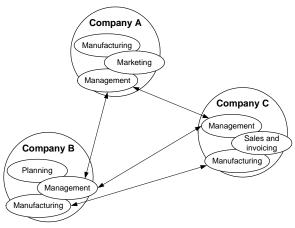

Fig. 3. Agent interaction in a business network.

As the agents are concerned about their autonomy and self-interests, they are able to restrain valuable information that a company does not wish to share, for example about demand conditions. On the other hand they are able to negotiate with other companies to give some of that information on demand, thus helping to improve decision making in the collaborating companies.

For open and standardized communication in the network, agents use de-facto standards specified by The Foundation for Intelligent Physical Agents (FIPA). For the message transportation between agents there are specifications for a message transport service, transport protocols and envelope and ACL representations. The communication is covered with specifications for communicative acts, content languages and interaction protocols. Furthermore there are specifications to support the use of ontologies inside of agents and in agent messages.

Ontologies are an important aspect of the agent technology. Ontologies can be used to describe domain specific knowledge so that agents are able to understand each other. They contain for example knowledge about business objects and their hierarchies and descriptions of actions related to the objects. By using domain specific ontologies in communication agents provide consistent format for information.

Security is an important factor in business networking and this is where the agent technology has a major drawback. There are no widely accepted methods for security among agents and currently all security features specific to the selected agent platform. However, there is an ongoing work by the FIPA to standardize agent security.

VIII. CASE APPLICATION

A prototype agent application has been developed for following the material and information flow between and within companies that manufacture heavy steel components as a supply network. In addition to real-time tracking of manufacturing-related information the application includes the following basic services: a web application server to provide user interfaces, a user administration service, an alarm service and an information management service [20].

In the application agents are modelled based on the major functionalities of the companies (for example manufacturing, management and transportation) and they are able to communicate and collaborate with the agents in the other companies via the Internet. Extension modules are being developed for the prototype application to enable seamless information exchange with the companies' legacy systems.

During the requirement specification process with the participating companies domain specific ontology concepts were identified and specified. Typical actions inside and between the companies were also identified and specified in the ontology as actions that the agents can perform. The ontology was further evolved and expanded throughout the development process.

IX. DISCUSSION

This study reflects the importance of transparency of an information flow in a context of one Finnish steel product industry network. Both of the business cases proved that the most critical factors for the transparency of the processes are *the interfaces between different units, unnecessary data processing, concrete bottlenecks,* which occurred especially with the tendering and the order processes, and all kind of *changes* that deteriorate the effectiveness of the processes. The information flow is not seamless because the logistics information systems used are incompatible, and some of the companies do not have any LIS.

However, even the case network seems to be in the very beginning in adopting the methods of the information technology, the need to improve the level of integration and information sharing is highly recognized in the networking companies. The companies are enthusiastically developing their collaboration possibilities, in ICT and automation technology and process optimization and integration. In order to be able to respond to more comprehensive global customer requirements the network needs to enhance the information sharing and transparency. The development requires investments in information systems that give a rise to co-ordinated and synchronized planning.

Agent technology is a new information technology solution and there has been little application of that technology in the logistics area so far. Better information control by the means of agents strengthens the competitiveness of the case network. As [11] presented, LIS must incorporate six principles to adequately support enterprise planning and operations. Multiagent systems seem to fill almost all of these principles. Information is *available to all* members of the network *accurate and timely,* as agents deliver the information through the Internet. Agents can communicate with humans, with other information systems, and with other agents. Information is also *exception-based* in order to highlight problems and opportunities. Agents are monitoring their environments and reacting to changes. Intelligent agents are capable of reasoning based on the rules given by the user or knowledge learned from an open environment. Agent systems are also flexible, since agents can be organized according to different control and connection structures.

However, the agent technology is still in the early stage of application, especially in the logistics area. Also, according to [21], seamless integration with complete information sharing between all supply chain participants is still in the future. Since a number of autonomous business entities belong to the supply chain network, it becomes imperative to develop a common mission, goals, and objectives for the group as a whole, while pursuing independent policies at an individual member's level. This scenario offers opportunities for design, modelling, and implementation of supply chain networks for maximum effectiveness, efficiency, and productivity in dynamic environments.

REFERENCES

[1] M. Christopher, *Logistics and Supply Chain Management. Strategies for Reducing Cost and Improving* Service, 2nd Ed. Prentice Hall, Great Britain, 1998.

[2] N. R. Jennings, J. M. Corera, and I. Laresgoiti, "Developing Industrial Multi-Agent Systems," in *Proc. of ICMAS'95*, San Francisco, The AAAI press/The MIT press, pp. 423-430.

[3] N. R. Jennings, and M. Wooldridge, "Applications of Intelligent Agents. Agent Technology: Foundations, Applications, and Markets." N. R. Jennings, and M. Wooldridge, Ed. Springer, 1998, pp. 3-28.

[4] N. P. Greis, and J. D. Kasarda, "Enterprise logistics in the information era," *California Management Review*, vol. 39, no. 4, pp. 55-79, 1997.

[5] A. Chandrashekar P. B. and Schary, "Toward the virtual supply chain: The convergence of IT and organization", *International Journal of Logistics Management*, vol. 10, no. 2, pp. 27.39, 1999.

[6] D. Bovet, and J. Martha, *Value Nets – Breaking the Supply Chain to Unlock Hidden Profits.* John Wiley & Sons, New York, 2000.

[7] P. P. Andrews, and J. Hahn, "Transforming supply chains into value webs," *Strategy and Leadership,* vol. 26, no. 3, pp. 6-11, 1998.

[8] J. Browne, P. J. Sackett, and J. C. Wortmann, "Future manufacturing systems- Towards the Extended Enterprise," *Computers in Industry,* vol. 25, pp. 235-254, 1995.

[9] T. M. Simatupang, R. and Sridharan, "The Collaborative Supply Chain," *The Journal of Logistics Management*, vol. 13, no. 1, pp. 15-30, 2002.

[10] J. Singh, "The importance of information flow within the supply chain," *Logistics Information Management*, vol. 9, no. 4, pp. 28-30, 1996.

[11] D. J. Bowersox, and D. J. Closs, *Logistical Management – The Integrated Supply Chain.* Singapore, McGraw-Hill International Editions, 1996.

[12] S. Chobra, and P. Meindl, *Supply Chain Management – Strategy, Planning and Operation.* Upper Saddle River, Prentice-Hall, Inc., New Jersey, 2001.

[13] D. Simchi-Levi, P. Kaminski, and E. Simchi-Levi, *Designing and Managing the Supply Chain.* McGraw-Hill, London, 1999

[14] H. Lee, "Aligning Supply Chain Strategies with Product Uncertainties," *California Management Review,* vol. 44, pp. 105-119, 2002

[15] J. Jahnukainen, M. Lahti, and M. Luhtala, *Logipro – Towards World Class Make-to-Order Supply Chains,* Report no: 162, University of Technology, Otaniemi, Helsinki, 1995.

[16] J. Hannus, *Prosessijohtaminen. Ydinprosessien uudistaminen ja yrityksen suorituskyky.* 4. p., HM & Research Oy. Jyväskylä, 1994.

[17] J. T. Mentzer, *Supply Chain Management.* Sage Publications, Inc., London, 2001.

[18] M. Wooldridge, and N. R. Jennings, "Intelligent Agents: Theory and Practice," *The Knowledge Engineering Review*, pp. 115-152, Oct. 1994.

[19] M. Wooldridge, *An Introduction to Multiagent Systems.* John Wiley & Sons Ltd, England, 2002.

[20] H. Helaakoski, J. Kipinä and H. Haapasalo, "An Agent Architecture for Steel Product Business Networks," in *Proc. of the Sixth International Conference on Enterprise Information Systems, Volume 4*, Porto, Portugal, pp 1-1.

[21] J. Varghese, A Portfolio Approach to SCM. Available: http://www.darwinmag.com/read/020103/scmplans.html.

Agile Business Model in the Steel Product Industry Sector

H. Helaakoski[1], P. Iskanius[2], I. Peltomaa[1], J. Kipinä[3]

[1]VTT Technical Research Centre of Finland, P.O.Box 3, FI-92101 Raahe, Finland
[2]Department of Industrial Engineering and Management, University of Oulu, P.O.Box 4610, FI-90014 Oulu, Finland
[3]Raahe Unit, University of Oulu, Rantakatu 7 A, FI-92100 Raahe, Finland

Abstract-Today's success manufacturing paradigm is agility that emphasizes customer orientation, networking and the benefits of e-business. The new agile business model has set also new requirements for supporting ICT infrastructure. As the enterprises are forming dynamic networks and the products are changing in variety and volume, the supporting ICT infrastructure has to be flexible in order to work in heterogeneous application environment. This paper proposes an agent-based solution to support agile business model in manufacturing business network. The paper describes a SteelNet case study in which a business network has used agent-based solution to support the new business model. The case study also introduces the implementation and testing processes of SteelNet system.

I. INTRODUCTION

Today's success manufacturing paradigm is agility that emphasizes customer orientation, networking and the benefits of e-business. Developing agility means not about small-scale continuous improvements, but radical changes, an entirely different way of doing business. Especially the digital business models, which captures customer's real choices in real time and transmits them digitally to other members of the supply chain, allow enterprises to react rapidly and continuously, innovative ceaselessly and take on new strategic imperatives faster and more comfortably than with the old business models. Companies that implement digital business models are often the best in their industries.

As the aim of companies is to create better value for their customers, the need of improving effectiveness of supply chain operations is becoming increasingly recognized. Also, the ability to respond to customers' requirements in ever-shorter timeframes has become crucial. Agility – the ability to move quickly to changes in the market demands and to meet customer demands sooner – be they changes in volume, variety or mix - can be seen as an answer for today's enterprise competitive advantage [1],[2]. Agility is not concerned with everything that occurs in the enterprise, but it is concerned with how things are coupled, how they interact, and how readily that coupling can respond in a beneficial way [3].

The requirement for agility has increased networking which is a common trend in today's business and industry practice [4], [5], [6]. Traditionally large corporations have performed all manufacturing in-house, but today they have reassessed their basic make-or-buy decisions in favour of

outsourcing. They have focused on their core competencies and started to benefit also other companies' competencies for supporting their own internal core skills. Today each company is somehow integrated into a network of selected suppliers, customers and value-added resellers, and even with competitors.

Agile business model emphasizes the benefits of e-business while the right mix of information and communication technology (ICT) can remarkable enhances agility. According to [7], ICT 1) reduces the product development time to market, 2) reduces the product delivery time to the customer, 3) improves workforce capabilities and flexibility, 4) enhances the flexibility of the product facilities, and 5) improves understanding and control of production processes. For example the coordination of inter-organisational processes (IOP) in business networks requires increasingly ICT support. At the moment, this is not covered sufficiently enough by traditional information and Enterprise Resource Planning (ERP) systems. ICT solutions should support more the dynamic nature of business networks, easy integration for existing software solutions and ensure the comfortable and affordable business-to-business (B2B) communication. By using new emerging technologies and advantaging the infrastructure of Internet, the inter-organisational coordination of business network is applicable and affordable also for small and medium-size enterprises (SMEs). Agent technology has been recognised as a promising approach for manufacturing enterprise integration and supply chain management (SCM) [8]. It provides flexibility and problem solving services, which are requirements in enterprise collaboration [9]. According to its definition, an agent is a computer system situated in a certain kind of environment, and it is capable of autonomous action in order to meet its designed objective [10]. Agents are often deployed in environments, in which they interact, and maybe cooperate, with other agents including both people and software. These environments are known as multi-agent systems.

This paper proposes an agile business model for steel product industry sector. The paper describes possibilities of agent technology to support the agile business model while business network is aiming towards e-business. Furthermore, this paper introduces a case study, called "SteelNet", of implemented agent-based system, which support agile business model in steel industry sector in Northern Finland.

II. Agile Business Model

The way business was conducted even a decade ago is no longer acceptable if a business intends to remain competitive. Earlier, the paradigms where business was managed were economics of *scale, cost* (productivity), *quality* and *time* (delivery speed and reliability), whereas today, as the rate of product change and product introduction increases, *flexibility* and *rapid innovation* are more critical capabilities than ever before [11], [12]. The requirements for economics of scale, based on the traditional assumption of mass production, are coming direct conflict with the requirements for economics of scope that is maintaining continuous innovation while using people and equipments to cost-effectively produce smaller amount of a range products [7]. *Agility* addresses new ways of running companies to meet these challenges. Agility is about casting off those old ways of doing things that are no longer appropriate – changing pattern of traditional operation. In a changing competitive environment, there is a need to develop organizations and facilities significantly more flexible and responsive than current existing ones [13]. Agility is largely independent of other best management approaches that a company can practice. Companies ability to make things better, faster, and cheaper today says nothing, or very little, about the ability to change, in a fast and cheap way, to make something else better, faster, and cheaper, or to respond in other respect to unanticipated changes [3].

The need for agility for market competitiveness has traditionally been associated with the supply chains that provide and manufacture innovative products, such as high-technology industry products characterized by shortened life-cycles, high degrees of market volatility, uncertainty in demand and unreliability in supply. Similarly, the traditional industry faces such challenges in terms of requirements for more customized products, solutions to customer problems and shorter order lead-times. Moreover, product life-cycles are shortening, and the need for becoming agile is becoming more prevalent. Some traditional companies are already employing elements of agility because the realities of the competitive environment dictate these changes, but this is usually outside of any strategic vision and is approached in an ad hoc fashion. The lack of a systematic approach to agility doesn't allow companies to develop the necessary proficiency in change, a prerequisite for agility. There are no guidelines telling how much uncertainty can be reduced or how much the complexity should be reduced. The companies have to make a trade-off between vulnerability (increased by uncertainty and complexity) and supply chain agility (flexibility and speed in sourcing, manufacturing and delivery) [14]. This means that instead of aiming at full compliance with the initial definition of agility, companies should concentrate rather on *some selected key aspects* of an agile supply chain.

Reference [15] argues that the adopted *e-business models* to supply chain integration include more than just efficiency progress. According to [16], new business models based on networks are the key to competitiveness and wealth creation.

While companies begin to realize the promise if e-business-enabled supply chain integration, they often discover entirely new ways of pursuing business objectives, developing strategies and business models that were neither apparent nor possible prior to the Internet. The new digital business models achieve both superior customer satisfaction and company profitability [17].

Different, interrelated concepts that emphasize the network-nature and the supply chain digitalization can be found in the literature, i.e. *"value net"* [17], *"value web"* [18], *"virtual enterprise"* [19], and *"agile enterprise"* [20]. While each of these concepts differs with respect of particular details, they all represent the new form of the digital supply chain, where information flows play an integral role within the network. Especially the Internet-enabled supply chain captures customer's real choices in real time and transmits them digitally to other participants of the network. Internet-enabled chains are frequently referred also to as *"e-commerce supply chains"* [21], or *"e-supply chains"* - chains that use e-business models, Internet and web technology [22].

The new structure of the supply chain emphasizes simultaneous communication between different parties and the supply chain integration as a whole, as well as communication between the consecutive phases of the process. In the transaction web, different transactions, such as ordering and paying, can be undertaken in one place and at one time. It is no longer just about the supply – it's about creating value for customers, the company, and its suppliers. Nor it is a sequential, rigid chain. Instead it is a dynamic, high-performance network of customer - supplier partnerships and information flows. [17], [20]

III. Agent Technology to Support Agile Business Model

Agile business model sets high demands for the supporting ICT architecture in business network. ICT infrastructure must allow the enterprise to cope with the uncertainty of future needs by also offering a base for future applications. It must facilitate the information sharing across the enterprise and among the networking enterprises. ICT infrastructure flexibility refers to the degree to which its resources are shareable and reusable [23] over time, and the speed and cost with which it can be aligned to new business processes. According to [9] flexibility is the possibility to support new use cases by changing existent components or adding of new components, but without changing the architecture. For example, in SteelNet network the enterprises are joining and leaving the network, since the network has a dynamic structure that depends on the deliveries that needs to be carried out. Thus, the ICT infrastructure must facilitate information sharing and coordination of IOP without depending on the number of enterprises or the presence of one particular enterprise.

According to [24] agent technologies suit domains that have one of the following properties:
- requires solving highly complex problems or controlling highly complex systems

- has distributed, not centrally available information required for solving problems or controlling systems
- has a dynamically changing environment and problem specification
- must integrate a high number of heterogeneous software (and possibly hardware) systems.

Therefore agent-based solutions are suitable to support agile business model, which requires flexibility and the use of distributed information in problem solving in dynamically changing environment.

Several agent technology application areas typically relate to manufacturing. For example in production, agents are used to highly complex planning problem solving and controlling dynamic, unpredictable, and unstable processes. In business networks and supply chain management, agent technologies can be used to support forming business alliances, planning long-term and short-term cooperation deals, and managing supply chains [24]. Agent technology has been recognised as promising approach to be used in manufacturing enterprises and networks [8], [25], [26]. The agent technology is particularly applicable for the sharing and exchange of information and knowledge among collaborative manufacturing enterprises [27].

IV.   CASE STUDY

According to [28], traditional communication tools have limitations such as the implementation costs, the difficulty in interacting with other information systems, the need for a company's partners to adopt the same technology, the need for particular skills, the lack of flexibility which makes it difficult to bring in new partners and creates high switching costs for those who wish to leave. The information transmission is slow, probability of errors is high and the achievement of agility is impossible.

This case study presents agent-based software system which aim is to remove the restrictions of traditional communication tools and to support the development of business network towards agility. The described case study, called SteelNet, is conducted in Northern Finland during years 2002-2005. In SteelNet case the business network consists of several SMEs and one focal company operating in the steel product industry sector. Business network defined as a stable set of business activities by which several enterprises have agreed to contribute their expertise towards the completion and supply of a product that caters to a relatively stable market. Communications among the supply chain partners have been designed to minimise inventory and lead time across the whole chain, to monitor quality and to enact improvement programmes [29]. In SteelNet system the information sharing is based on agent architecture, where agents transmit logistic information between collaborative companies seamlessly and transparently. This information is used for supply chain co-ordination across enterprises; the co-ordination is achieved by means of task specific combination of agents. The combination is tailored to the particular business network process that needs to be supported and the various tasks that need to be fulfilled.

To fully achieve benefits of agile business model the information sharing has to be real-time, reliable and seamless. Information accuracy and system adaptability is emphasised when sudden and unexpected changes take place in supply chain. These changes are inevitable; they can for example be a consequence of machinery breakage or customer's changing requirements about the delivery. The digitalised information guarantees the availability of information for all participants of the supply chain and reduces the manual work, which decreases the risk of human errors.

Since the nature of business network dynamic, enterprises are not willing to commit high investment costs for supporting ICT system. In SteelNet this was achieved by using a service provider approach, where enterprise can make a service agreement with the service provider and use the system simply via web applications. This enables the dynamic nature for business network; enterprises can join or leave business network according to changes in consortium. Another requirement for ICT system is the possibility to connect enterprises' existing Enterprise Resource Planning systems to developed ICT system. In SteelNet case this was approached to provide installation of SteelNet system and its web applications to their enterprises' own server, which enables a possibility to extend the system with their own modules, for example any required ERP connection modules. The aim is that companies with existing systems can continue to use those exactly as before whereas other companies would use the SteelNet web applications as a simple ERP system.

The majority of companies in the case business network did not have suitable system to be integrated in the SteelNet. This led to a requirement that he graphical user interfaces (GUIs) of the web applications must be easy to learn and use. End users of the SteelNet system also valuated clearness and simplicity of the GUIs, where essential information is easy to find. The SteelNet system requires some minimum amount of clearly defined data to be fed in, but extra information is possible to add through free-form fields.

Effective distribution and use of knowledge and interoperability in managing an entire business operational flow are substantial requirements of successful business network. [30], [27] The SteelNet system is designed to manage IOP within the business network, especially focusing on information sharing and exchange. The most severe problems in information delivery ere examined and identified in some previous collaborative deliveries. The most important areas to get involved in were communication during procurement process and the manufacturing process follow-up in different enterprises.

At the first development phase of the SteelNet system a real-time manufacturing follow-up prototype was implemented and at the second phase the emphasis was on developing a prototype for information and document management and sharing in procurement process. The manufacturing follow-up prototype has been introduced in [31].

The key purpose of the procurement process prototype is to provide document and information exchange and to increase agility in procurement processes. Previously the prac-

tices were very inconsistent and varying and the process was time-consuming. Requests for quotation could be received via telephone or email and the quotation was send by fax or email. The contents of documents and the detail of information varied greatly. With help of the SteelNet system procurement process is unified and the flow of the process accelerates which improves competitiveness of the network compared to the other networks. The network has better capability to respond changes and to service the customer with higher quality. Additionally more precise and consistent information is available during the procurement process.

The SteelNet system is implemented using multi-agent architecture, which enables transparent inter-company information exchange and seamless information sharing between companies. The system consists of one service provider and several participating companies, each having an agent container for task specific agents and modules. Task specific agents are responsible for coordinating actions in a certain business area, for example connecting the SteelNet system to the company's ERP system or managing a procurement process. Communication between agents is carried over Internet protected with Secure Sockets Layer (SLL) encryption. In the procurement process prototype the communication is done mainly directly between companies. Modules and agents provide and utilize services, which are registered in company level service registry.
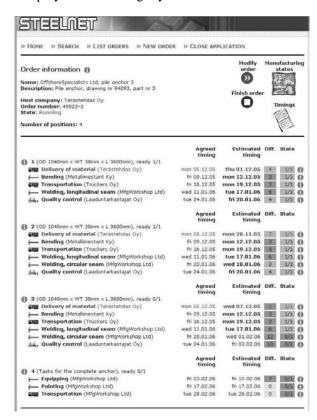
Base services and modules of SteelNet system include company registry, web application server, file transfer service, user administration service and alarm service. Company registry contains information about companies registered in the SteelNet system and what manufacturing, transportation, designing and inspection services and materials they provide to the business network. User administration service provides company specific user authentication, authorization and preference storage services. Web application server provides the web based user interfaces to end-users. Alarm service informs users about events in the system, for example when a new request for quotation is received. Users can change their alarm message preferences along their interests. File transfer service provides a possibility to attach any type of files to other objects (documents, company descriptions, and manufacturing processes) in the system and transfers the files securely between companies by using access control and encrypted connections.

The SteelNet system has lately been tested for real-time manufacturing process follow-up in the real life. The delivery included several pile anchors containing different work phases in three different companies. The companies involved in the delivery used the SteelNet system through web-based GUIs without connection to companies ERP systems. The users where given a short one hour education about the using of the system and due to the clarity and simplicity of the GUIs the amount of the education was found adequate. The evaluation of the test results is under work, but the first feedbacks from the users were positive. The users experienced that the SteelNet system eases the work and save the working time by automatically delivering manufacturing information among networking enterprises. The information transparency enables the lead-time reduction, since the system reveals the bottlenecks of the manufacturing process. Fig. 1 presents an interface to SteelNet system via web browser. The content of information is from the conducted test case.

V. CONCLUSION

Successful and profitable business nowadays demands agile collaboration between individual companies. Therefore the ability to manage and to share cross-organizational information is in a key role in achieving advantage over competitors. Business network introduced as a new business model fulfilling the agility requirement set by demanding customers and increased competition. The agile business model by itself is not enough in order to achieve flexibility; it also requires supporting ICT solution. The emerging development of ICT and specially the infrastructure of the Internet have enabled new possibilities to share and exchange information. The versatility and flexibility of agent-based ICT solutions provides a way to manage markets and customers' changing demands and thereby strengthen the competitiveness of the business network.

This paper introduces the SteelNet system, an agent-based ICT solution for agile IOP management in business network. The information in SteelNet system is available to all members of the business network accurately and timely, which

Fig. 1. SteelNet user interface.

gives networked enterprises a possibility to interact sudden changes in a beneficial way. The transparency of schedule information makes it possible to quickly respond to the changes along the supply chain and reduce the lead time of deliveries. With the help of the SteelNet system the amount of information management in network can be minimized which reduces the risk of human errors and the total costs in supply chain.

According to experiences collected during the collaboration with companies and the development process of the SteelNet system, it has clearly come out that there is a lot of work to be done; not only in the developing the technical solution but also in the clarifying the working model of the business networks and fortifying the trust between companies. The SteelNet system is further developed according to the results gathered from the test case. The positive results motivate the continuation of the development and testing processes.

REFERENCES

[1] S.L. Goldman, R.N. Nagel and K. Preiss, *Agile competitors and virtual organizations: Strategies for enriching the customer.* Van Nostrand Reinhold Book, 1995.

[2] M. Christopher and D. Towill, "An integrated model for design of agile supply chains," *IJPDLM*, vol. 31, no. 4, pp. 235-246, 2001.

[3] H.T. Goranson, *The agile virtual enterprise: Cases, metrics, tools.* Quorum Books, 1999.

[4] D.M. Lambert, M. Cooper and J.D. Pagh, "Supply chain management: Implementation issues and research opportunities," *IJLM*, vol. 9, no. 2, pp. 1-19, 1998.

[5] M. Christopher, *Logistics and supply chain management – Strategies for reducing cost and improving service.* Prentice Hall, 1998.

[6] M.H. Best, *The new competition: Institutions of industrial restructuring.* Polity Pess, 1990.

[7] J.C. Montgomery and L.O. Levine, *The transition to agile manufacturing: Staying flexible for competitive advantage.* ASQC Quality Press, 1996.

[8] W. Shen and D.H. Norrie, "Agent-based systems for intelligent manufacturing: A state-of-the-art survey," *Int J KAIS*, vol. 1, no. 2, pp. 129-156, 1999.

[9] A.T.M. Aerts, N.B. Szirbik and J.B.M. Goossenaerts, "A flexible, agent-based ICT architecture for virtual enterprises," in *Computers in Industry*, vol. 49, no. 3, pp. 311-327, 2002.

[10] N.R. Jennings and M. Wooldridge, "Applications of intelligent agents," in *Agent Technology: Foundations, Applications, and Markets*, N.R. Jennings and M. Wooldridge Eds. Berlin: Springer, 1998, pp.3-28.

[11] W.J. Kolarik, *Creating Quality: Process Design For Results.* McGraw-Hill, 1999.

[12] Y. Monden, *Toyota Production System: An Integrated Approach to Just-In-Time.* Industrial Engineering Press, 1998.

[13] A. Gunasekaran, "Design and implementation of agile manufacturing system," *Int J Prod Econ*, vol. 62, no. 1-2, pp. 1-6, 1999.

[14] E. Prater, M. Biehl and M.A. Smith, "International supply chain agility – Tradeoffs between flexibility and uncertainty," *IJOPM*, vol. 21, no, 5, pp. 823-839, 2001.

[15] H. Lee and S. Whang, "E-business and supply chain integration," *Stanford Global Supply Chain Management Forum*, SGSCMF-W2-2001, Stanford University, 2001.

[16] R. Kalakota and M. Robinson, *E-business: Roadmap for Success.* Addison-Wesley, 1999.

[17] D. Bowet and J. Martha, *Value Nets – Breaking the Supply Chain to Unlook Hidden Profits.* New York:John Wiley&Sons, 2000.

[18] P.P. Andrews and J. Hahn, "Transforming supply chains into value webs," *Strategy and Leadership*, vol. 26, no. 3, pp. 6-11, 1998.

[19] J. Browne and J. Zhang, "Extended and virtual enterprises - similarities and differences," *IJASM*, vol. 1, no. 1, pp. 30-36, 1999.

[20] N.P. Greis and J.D. Kasandra, "Enterprise logistics in the information era," *CMR*, vol. 39, no. 4, pp. 55-78, 1997.

[21] A. Gunasekaran, H.B. Marri, R.E. McGaughey and M.D. Nebhwani, "E-commerce and its impact on operations management," *Int J Prod Econ*, vol. 75, no. 1-2, pp. 185-197, 2002.

[22] C.C. Poirier and M.J. Bauer, *E-Supply Chain.* San Francisco:Berret-Koehler Publishers Inc, 2000.

[23] J.E. Sims, "Framework for adaptive interoperability of manufacturing enterprises FAIME," in *SPIE Proceedings*, vol. 2913, B.L. Maia Goldstein Eds. Bellingham Wash.:SPIE, 1996, pp. 289–303.

[24] M. Pechoucek, J. Vokrinek and P. Becvar, "ExPlanTech: Multi-agent support for manufacturing decision making," *IEEE Intelligent Systems*, vol. 20, no. 1, pp. 67-74, 2005.

[25] S.A. Petersen and M. Gruninger, "An agent-based model to support the formation of virtual enterprises," *in Proc. of MAMA'2000*, Woolongong, 2000.

[26] N.B. Szirbik and H.S. Jagdev, "The future IT systems for virtual enterprises: Product-oriented agent providers?," in *Proc. of ETFA'01*, IEEE Press, 2001, pp. 261-171.

[27] W. Shen and D.H. Norrie, "An agent-based approach for information and knowledge sharing in manufacturing enterprise networks," *IJNVO*, vol. 2, no. 2, pp. 173-190, 2004.

[28] M. Muffatto and A. Payaro, "Integration of web-based procurement and fulfillment: A comparison of case studies," *IJIM*, vol. 24, no. 4, pp. 295-311, 2004.

[29] H.S. Jagdev and K.-D. Thoben, "Anatomy of enterprise collaborations," *IJPPC*, vol. 12, no. 5, pp. 437-451, 2001.

[30] J. Yang and M.P. Papazoglou, "Interoperation support for electronic business," *CACM*, vol. 43, no. 6, pp. 39-47, 2000.

[31] P. Iskanius, H. Helaakoski, J. Kipinä, K. Ojala and I. Peltomaa, "Development steps towards e-business," in *Proceedings of the International Conference on Agility ICAM2005*, Helsinki, 2005, pp. 171-178.

Collaborative software agents in steel product industry

COLLABORATIVE SOFTWARE AGENTS IN STEEL PRODUCT INDUSTRY

Heli Helaakoski[1], Shaw C. Feng, Kevin K. Jurrens[2], Kaija Ojala[3], and Janne Kipinä[4]

[1]VTT Electronics, Rantakatu 5, FIN-92100 Raahe, Finland
[2]Manufacturing Engineering Laboratory, NIST, Gaithersburg, Maryland 20899, U.S.A.
[3]University of Oulu, Rantakatu 5, FIN-92100 Raahe, Finland
[4]Oulu Polytechnic, Raahe Institute of Computer Engineering and Business, Rantakatu 5, FIN-92100 Raahe, Finland

Abstract

In recent years there has been increasing work where software agents have been used in manufacturing enterprises. Improving the information flow within the company and between the collaborative companies is very important to increase the competitive position and profitability. Networked manufacturing enterprises are now moving towards open information exchange for integrating their activities with those of their suppliers, customers, and partners within wide supply chain networks. In manufacturing processes, agents can support the integration of predictive models, process planning, and shop floor machining activities. Software agents can also be used to integrate manufacturing applications with the business applications. This paper presents how agents can be exploited for manufacturing enterprise integration and supply chain management to meet such requirements in steel and its related industries.

Key Words

Distributed manufacturing systems, supply chain management, intelligent agents, multi-agent systems, agent-mediated workflow and supply chain management.

1. Introduction

The first business-to-business (B2B) systems were developed by the idea of transmitting electronic messages representing such documents as invitation tenders and purchase orders about 25 years ago. These message transfer systems were based on the B2B protocol standards such as Electronic Data Interchange (EDI) [1]. However, these systems have become legacies and are very inflexible and expensive to use especially for small and medium size companies. Current Internet technologies are expected to ease these restrictions by being more efficient and economical. Through the use of Internet technologies, the traditional B2B systems have extended to business networks where several companies are collaborating via electronic messages.

Business-networked systems typically consist of several repeated chains of events like the requisition of resources, a request for quotes from candidate business entities, vendor selection, order enactment and delivery, relationship management among businesses, and product

life cycle management. These systems can be used to support the functions of several business networks, such as a strategic sourcing network, an electronic procurement network, a network for virtual enterprise, a network for product design, manufacturing, inventory, and delivery management, a network of electronic marketplaces, a network for workflow/supply-chain management, and a network for supplier relationship management [2]. These networks are based on the Internet. Recently, many researchers have studied the use of software agents that are autonomous and intelligent for easing this complex environment of business networks in electronic commerce.

While business networks have the focus on information transmission between companies, the information flow within the companies is equally important. Improving each company's own supply chain management is a key mechanism for increasing competitive position and profitability. Agent-based technology provides a way to design and implement systems that integrate legacy systems into business networks. Additionally, software agents have been increasingly used in the product and process development in industry over the past years due to the rapid evolvement of the Internet technology. Agents with access to product design and process planning knowledge bases can aide engineers to reduce product development costs. Agents are also used in the integration of design, process planning, machine control, and shop-floor job execution in the mechanical part manufacturing industry.

In this paper, we present how a community of agents can make decisions and carry out tasks within a manufacturing company or across companies in a manufacturing supply chain. We have proposed a company network architecture that is connected to enterprises' legacy systems by using agents. The business network of agents is being developed by the SteelNet project at VTT (Technical Research Centre of Finland). The aim of SteelNet project is to research the use of agents in industrial business networks by developing an agent-based prototype. Better information control by the means of agents strengthens the competitiveness of the SteelNet company network.

A product design and manufacturing network of agents is being developed by the Process Integration Framework project of the Manufacturing Engineering Laboratory at the National Institute of Standards and Technology (NIST), a federal agency within the U.S. Government. Within the NIST research activity, agent communication is performed in a prototype multi-agent platform to demonstrate sharing of manufacturing knowledge and process data throughout the product lifecycle. Due to the use of common development and agent communication methodologies, a collaboration has been formed to take advantage of potential overlapping objectives. The goal of the collaboration is to further develop the demonstration capabilities so that agents from both the business and engineering networks are able to exchange messages and share knowledge with each other. Our system provides the support for a variety of transactions among the business entities and among engineering activities within a company.

This paper is organized as follows: Section 2 describes the business case and the basic functionalities of an agent-oriented system for managing business networks. Section 3 describes a framework for integrating predictive process models, process planning systems, design systems, and machine tool control. Section 4 describes related work. Section 5 concludes the current work and outlines our future plans. Section 6 has acknowledgements. Section 7 contains a disclaimer. All the references are in the last section of the paper.

2. An Agent-oriented Business-Networked System for the Steel Industry

The SteelNet business network consists of several collaborating companies in the steel products industry. Within the business network, companies work together as a distributed supply chain, while each of these companies has its own field of expertise like bending, flame cutting, and welding. Besides this business network each company has its own customers and partners, therefore each company must have equal rights and responsibilities in the SteelNet system. In other words, each company independently requests for quotes or makes orders unlike traditional subcontractor systems.

In the SteelNet system, agents represent major functionalities of a company. Figure 1 shows the usual operations in manufacturing companies, which are substituted by agents in the SteelNet system. The agents are able to communicate and collaborate both within the company and with agents from other companies via Internet. This enables the seamless information flow though all operations in the company and also through the entire business network.
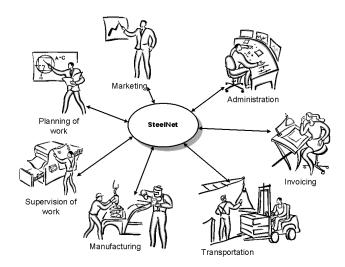

Figure 1 The SteelNet business network.

Figure 2 shows a physical view of the SteelNet architecture. On the left side is a simplified view of a company network consisting of many workstations and one agent container server in local area network. The company LAN (Local Area Network) is connected to the Internet through firewall. In practice all companies have different network structures, since the companies vary from small engineering workshops to big corporations with hundreds of personal computers, servers and other systems networked together across far-reaching geographical locations. However, the basic principle is that the agent container server is accessible from workstations and that there is a firewall protecting the company network. On the right side is the service provider with the main agent container server connected to the Internet and database server connected through local connection. In practice there is a firewall protecting the servers in the service provider side also, but it has been omitted in the picture since it does not limit the traffic required by the SteelNet application.
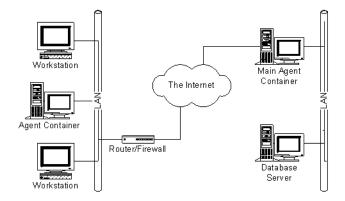

Figure 2 Physical view of SteelNet architecture.

Figure 3 shows the logical architecture for SteelNet, again left hand side presenting one company in the business network and right side presenting a service provider. On the company side there are two general-purpose software modules, the HTTP server/servlet container and the

legacy systems proxy. By utilizing Java servlet technology and the servlet container any agent or other software module running in the agent container server can provide web-based user interfaces to users in the company local area network (LAN). For each task, for example manufacturing or sales, there is a separate agent and an accompanying interface to transfer data to the agent. Furthermore, the agent may register its user interface servlet to the servlet container. The agent can also provide a module to the legacy systems proxy to interact with legacy systems in the company network. The idea behind the accompanying common interface is that the agent is neutral to whether the data is fed by a user through web interface or by the legacy system proxy after extracting it from a legacy system.
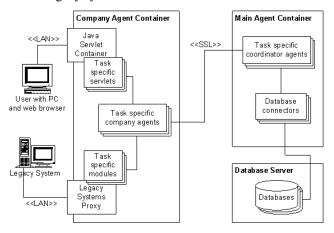

Figure 3 The logical view of SteelNet architecture.

The service provider side contains coordinator agents for each task. Each coordinator agent acts as a bridge between task agents in different companies and also provide a data storage for the agents. The use of coordinator agents makes the system somewhat centralized, but it has some very considerable advantages. Firstly, the data is readily available, and in obscure situations it is easier to inspect if the data has been changed and by whom. Secondly, direct communication between agents in companies is likely to be interfered by a company firewall. In the main agent container, the same common interfaces are used in the company side to provide transparency to where the data is actually stored. The coordinator agents just obtain the data through the interface to some specific module, which then creates the actual database queries to the database server. Communication between the main agent container and agent containers located in companies is secured by using the Secure Sockets Layer (SSL) connection.

In the future, the architecture will be enhanced in order to make it more affordable and decentralized. In large business networks, the main agent container may not be able to handle all of the processing loads caused by the vast amount incoming and outgoing data. Perhaps some hybrid solution would work in this kind of environment,

so that instead of the single main container, there would be several, so-called, super-peers.

3. An Agent-based Process Integration Framework for Steel Part Manufacturing

A framework for integrating predictive process models, process planning systems, design systems, and machine tool control that enables the flexible integration of heterogeneous manufacturing applications has been developed by staff of the NIST Predictive Process Engineering (PPE) program. With an emphasis on information requirements on the integration of software and hardware systems for predictive process engineering, the framework includes the component architecture, interaction sequence model, message and communication format, agent platform, process knowledge, and supporting tools. The purpose is to describe agent behaviors, communication methods, and agent system structure.

3.1 Component architecture

The component architecture describes the software components used in the agent-based integrated design, planning, and control system. Figure 4 shows the agents that are executed in the agent platform. The agents include a design agent, a group of process planning agents, the capability repository agent, and the manufacturing control agent. Humans interact with the agents through the graphical user interfaces (GUI). The design agent communicates with a CAD system to send and retrieve information about part design. A CAD system defines the shape and attribute information of a design of part components or an assembly.
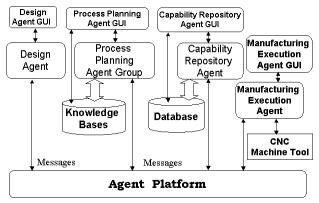

Figure 4 A multi-agent system architecture.

Figure 5 shows agents in the process planning agent group. The process planning agent communicates with a Computer-Aided Process Planning (CAPP) system and a CAM system to generate numerical control (NC) programs. CAPP software provides functions for selecting processes and resources and for generating process sequences. The NC software is used to create tool paths

and NC programs for running computer numerically controlled machine tools. The agent sends and retrieves information about machining process planning to and from both CAPP and CAM systems. It also interacts with the Tool Material Selection Agent to select an appropriate cutting tool material based on the material properties of the product. The tool material selection agent selects the cutting tool material based on workpiece material, tool life requirements, and desired cutting speed. Tool material selection rules are stored in a knowledge base. The material removal rate evaluation agent uses a mathematical model to calculate the maximum material removal rate based on the dynamics of the specific machine tool, the configuration of the cutting tool/tool holder/machine spindle, and factors in the machining process. The agent calculate an optimal set of cutting parameters, including cutting speed, feed rate, and depth of cut, based on the specific conditions.
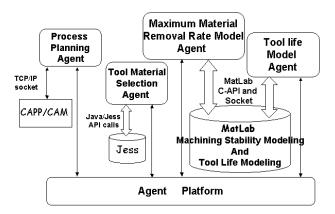

Figure 5 The process planning agent group.

Figure 6 shows that the capability repository agent performs on the agent platform and uses a database for storing and retrieving the capability information about each agent that provides services. Based on the FIPA specifications [3], the agent platform manages the agent activities.
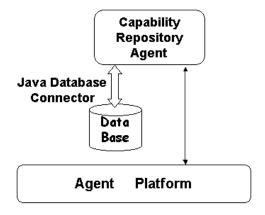

Figure 6 Capability repository agent.

3.2 Interaction model

The interaction model specifies the timing and sequence of function calls – the interactions among agents. Figure 7 shows interactions among agents for one of the scenarios used in the integration framework. All the agents, except the Process Planning and Capability Repository agents, must first register their capability in the database. From within the CAM system, the manufacturing engineer launches the Process Planning agent to determine and provide the optimal cutting parameters. Based on knowledge from the Capability Repository, the Process Planning agent obtains the tool material information by sending a request to the Tool Material Selection agent. With this information, the Process Planning agent then determines an optimal set of process parameters based on analysis from both the machining stability perspective (i.e., highest material removal rate while maintaining a stable cut) and the cutting tool life perspective (i.e., recommended material removal rate to achieve specified cutting tool wear rate and tool life). With the result, the NC program can therefore be completed within the CAM system.
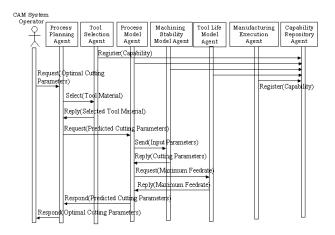

Figure 7 Agent interaction diagram

3.3 Message format

Agents communicate with each other by exchanging messages. A message has two sections: message header and message content (also known as message body).

The header contains the information regarding the sender, receiver(s), subject, date, time, and priority. There is also a slot that contains the agent identification (AID). Using the AID, the information about an agent, such as its name, can be retrieved from a repository or agent directory.

The message content contains information regarding the intent. There are two types of content: illocutionary and perlocutionary. The illocutionary message is used to inform other agents, such as registering an agent's capability. The perlocutionary message is used to request actions of other agents, such as a request for machining process optimization or a call for proposal. Message

content has the following attributes: an action verb, an object, preconditions, and constraints. The action verb is used to indicate the type of action to be taken by the receiver, such as request, propose, and query. An object is the result or expectation. Examples of classes of objects can be found in [4]. Classes related to the milling process have been applied. Preconditions are the properties that the sender may supply. Constraints are limitations with which expected results should be constrained. They are specified to provide information to the receivers to produce valid results. Agents must have intelligence to process messages. A body of knowledge supports the intelligence of an agent.

3.4 Knowledge base

The source of agent intelligence is in the knowledge base. This knowledge base contains rules that govern the agent behaviors. An agent's knowledge includes how to inquire about the capability of other agents and how to perform special tasks. For example, special tasks may include functions such as tool material selection, machining stability analysis, or tool life evaluation. Basic rules for tool material evaluation can be commonly found in literature on process planning for metal cutting [5]. More specific and customized rules can be entered into the knowledge base. The rules are structured using propositional logic. The rules for both machining stability analysis and tool life evaluation are in mathematical form. The machining stability analysis is based on machining measurements and a machining chatter analysis and the tool life evaluation is based on the Taylor tool wear principle, both methods documented in the literature [6]. These two mathematical models are implemented using available mathematical software tools.

3.5 Manufacturing resource database

The manufacturing resource database contains information about the equipment and tools used in the machining process, such as data and attributes for the machine tools, cutting tools, and fixtures. The structure of the database is relational, and the database is accessible by external programs via the Java database connector. In the database, a machine tool is defined by a set of attributes, such as the maximum power, the maximum cutting force in each axis, the maximum workspace dimensions, tool magazine information, the number of cutting axes, the maximum spindle speed, and available cutting tools. A cutting tool is defined by another set of attributes, such as tool identification, tool length, tool size, number of cutting edges, cutting angles on each edge, tool material, and tool overhang as mounted in its holder. Other resource information, such as for fixtures, workpiece materials, and operator skills can also be stored in the database. An object model on machining resource information can be found in [5].

4. Related work

Recently a number of research projects have been related to information systems of business networks. Different architectures and platforms have been proposed to support distributed operating over company boundaries.

The NIIIP (The National Industrial Information Infrastructure Protocols) consortium was a team of organisations that entered into a co-operative development agreement with the U.S. Government. The main aim of this consortium was to develop inter-operation protocols for manufactures and their suppliers. The NIII protocols made it easier for engineering organizations to share technical product data over the Internet. They did this by building on the ISO 10303 (STEP) standard for product data exchange. STEP provided common definitions for product data that can be read and written by many CAD/CAM/CAE and PDM systems [7, 8].

The MetaMorph project at the University of Calgary developed the mediator-centric federation architecture for intelligent manufacturing [9]. In MetaMorph I, agents were used to represent manufacturing devices and products or parts to be fabricated, while mediators were used to coordinate the interactions among them. The following research project, MetaMorph II aimed to integrate the manufacturing enterprise's activities with those of its suppliers, customers and partners into an open, distributed intelligent environment. For this purpose a hybrid agent-based architecture, combining the mediator and the autonomous agent approaches, was proposed [10].

DEDEMAS, GNOSIS-VF and PRODNET II are all Esprit projects founded by the European Union. The DEDEMAS (Decentralised Decision Making and Scheduling) approach provided a Mediator-based mechanism for decentralised decision making and scheduling covering both multi-site operations of one company and its chain of external suppliers [11]. The purpose of the Mediator is to extend and integrate the functionality and data of existing legacy systems. The GNOSIS-VF (The Virtual Factory) [12] concerned about development of the Virtual Factory Platform, i.e. information technology support for the Virtual Factory. The main objectives were the design of the distributed operational web-based client-server architecture for the Virtual Factory and development of tools for the Virtual Factory Platform. PRODNET II (Production Planning and Management in an Extended Enterprise) [13] project developed a reference architecture and an open platform to support industrial virtual enterprises with special focus on the needs of small and medium sized enterprises. The PRODNET infrastructure includes two main modules for each enterprise in the network: Internal Module representing the autonomous unit of a particular company and Cooperation Layer containing the functionalities for the inter-connection between the company and the whole net.

5. Conclusions and Future Work

The work of SteelNet is continuing by implementing the first prototype with a web-based graphical user interface. The prototype will be completed by the end of the year 2003. As a first test case we will follow a distributed supply chain of manufacturing a heavy metal component in three different companies. Furthermore, the first prototype serves as a test case for evaluating technical solutions and especially for the secure agent messaging through SSL in a real-business situation. After the first prototype is completed, the work will go on by embedding the agents into companies' own legacy systems.

A prototype agent-based integration framework to enable the use of machining process knowledge with higher-level manufacturing applications has been developed. Within this framework, data can be transmitted from a client agent to the appropriate service-providing agent(s). The intelligent agents can be used to optimize process performance through standard agent communication protocols and implemented mathematical process models with specified goals and constraints. The process planning agent optimized the NC programs with regard to tool life and material removal rate using services provided by two additional agents. This multiagent system has demonstrated an approach for system interoperability. The agents communicate with each other using the FIPA standard message format and a common vocabulary. Further enhancements are expected to provide additional capabilities and to address additional scenarios. When the system is further expanded, the agents will also compete with each other for providing the best possible services.

Collaborative efforts between VTT and NIST will continue to advance the respective research objectives. It is expected that the collaborations and further development will lead to increased capability in the respective prototype and demonstration systems.

6. Acknowledgements

7. Disclaimer

No approval or endorsement of any commercial products by the National Institute of Standards and Technology (NIST) is intended or implied. Certain commercial software and hardware systems are identified in this paper in order to facilitate understanding. Such identification does not imply that these systems are necessarily the best available for the purpose.

References

[1] B. Iskandar, S. Kurokawa and L. LeBlanc, Adoption of electronic data interchange: the role of buyer-supplier relationships, *IEEE Transactions on Engineering Management*, Volume 48, Issue 4, 2001, 505-517.

[2] M. Blake and M. Gini (Guest Editors), Introduction to the Special Section: Agent-Based Approaches to B2B Electronic Commerce, *International Journal of Electronic Commerce*, Volume 7, Number 1, 2002, 7.

[3] The Foundation for Intelligent Physical Agents (FIPA), http://www.fipa.org

[4] S. Feng and E. Song, A Manufacturing Process Information Model for Design and Process Planning Integration, *Journal of Manufacturing Systems*, Volume 22, Number 1, 2003, 1-16.

[5] D. Nelson and G. Schneider, *Applied Manufacturing Process Planning* (Prentice Hall, Inc., 2001).

[6] G. Boothroyd and W. Knight, *Fundamentals of Machining and Machine Tools*, 2nd edition (New York: Marcel Dekker, Inc., 1988).

[7] The National Industrial Information Infrastructure Protocols, http://www.niiip.org

[8] The National Industrial Information Infrastructure Protocols (NIIIP) Consortium, http://www.steptools.com/projects/niiip

[9] F. Maturana and D. Norrie, Multi-agent Mediator Architecture for Distributed Manufacturing, *Journal of Intelligent Manufacturing 7*, 1996, 257-270.

[10] W. Shen and D. Norrie, An Agent-based Approach for Manufacturing Enterprise Integration and Supply Chain Management, *Proceedings of the 3rd International Conference on the Practical Applications of Agents and Multi-Agent Systems (PAAM-98)*, London, England, 1998.

[11] H-K. Tönshoff, I Seilonen, G. Teunis and P. Leitão, A Mediator-based approach for decentralised production planning, scheduling and monitoring, *Proceedings of the International Seminar on Intelligent Computation in Manufacturing Engineering*, Capri, Italy, 2000, 113-18.

[12] P. Kalliokoski, I Seilonen, M. Ollus and K. Koskinen, Virtual Enterprise Co-Operation Model for Web-Enabled Production Management for SME-Networks in *eBusiness and eWork Conference and Exhibition*. Madrid, Spain. 18-20 October 2000.

[13] L. Camarinha-Matos, A Platform to support production planning and management in a virtual enterprise, *Proceedings of CAPE'97 – IFIP/SME Int. Conference on Computer Applications in Production and Engineering*, Detroit, USA, 1997.

An agent architecture for steel product business networks

AN AGENT ARCHITECTURE FOR STEEL PRODUCT BUSINESS NETWORKS

Heli Helaakoski

VTT Electronics, Rantakatu 5 A, FIN-92101 Raahe, Finland
Email: heli.helaakoski@vtt.fi

Janne Kipinä

Oulu Polytechnic, Raahe Institute of Technology and Business, Rantakatu 5 A, FIN-92101 Raahe, Finland
Email: ext-janne.kipina@vtt.fi

Harri Haapasalo

Department of Industrial Engineering, University of Oulu, P.O. Box 4610, FIN-90014 University of Oulu, Finland
Email: harri.haapasalo@oulu.fi

Abstract: Networked manufacturing enterprises are now moving towards more open information exchange for integrating their activities with those of their suppliers, customers and partners within wide supply chain networks. Therefore there has been increasing need for software systems to support business networks. This paper introduces SteelNet agent architecture, which facilitates a real collaboration of companies by enabling a seamless information and material flow in a business network. Different operations of order-delivery process in the network have been modelled as agents that are able to collaborate with each other. The SteeNet agent architecture is a basis for a prototype that handles the operations of manufacturing steel products in a supply chain.

1 INTRODUCTION

The development of business and industry has led to a situation where companies cannot compete alone anymore and this has created a need for the companies to network with each other. These business networks are rather complex coalitions of business relationships where different counterparts of individual relationships and networks actively communicate with each other (Gummesson, 2000).

Traditional Electronic Data Interchange (EDI) and legacy systems no longer respond to today's needs, because they are very inflexible and expensive to use and maintain, especially for small and medium-size companies. Current Internet technologies are expected to ease these restrictions by being more efficient and economical. With the development of Internet technologies, the traditional B2B systems have extended to business networks where several companies are collaborating via electronic messages.

Recently, agent technology has been considered an important approach for developing industrial distributed systems (Jennings et al., 1995, Jennings and Woolridge, 1998). Agents can be used to encapsulate existing software systems to solve legacy problems and integrate the activities of manufacturing enterprises, such as design, planning, scheduling, simulation execution and product distribution, with those of their suppliers, customers and partners into an open, distributed intelligent environment via networks (Fox et al., 1993, Barbuceanu and Fox, 1997).

The SteelNet project presents an agent architecture for networked medium and small size manufacturing companies. The SteelNet architecture takes into account the fact that the networked companies use different types of information technology and various data security solutions,

which must be able to collaborate with the SteelNet system. The purpose of this paper is to present how a community of agents can make decisions and carry out tasks within a manufacturing network. By digitising the information flow between the collaborative companies they have a possibility to increase their competitive position and profitability.

This paper is organised as follows: section 2 describes the business case of the SteelNet project. Section 3 describes a technical architecture for network manufacturing enterprises. Section 4 describes a prototype application for distributed manufacturing. Section 5 concludes and outlines our future plans and work.

2 STEELNET BUSINESS CASE

Business-to-business transactions consist of several typically repeated chains of events like the requisition of resources, a request for quotes from candidate business entities, vendor selection, order enactment and delivery, relationship management among businesses, and product life cycle management. These events are relevant to the functions of several business networks, such as a strategic sourcing network, an electronic procurement network, a network for virtual enterprise, a network for product design, manufacturing, inventory, and delivery management, a network of electronic marketplaces, a network for workflow/supply-chain management, and a network for supplier relationship management (Blake and Gini, 2002). Autonomous and intelligent software agents are capable of easing this complex environment of business networks in electronic commerce.

The SteelNet business network consists of several collaborating companies in the steel product industry. Within the business network, companies work together as a supply chain, while each of the companies has their own field of expertise like bending, flame cutting and welding. Besides this

business network each company has its own customers and partners, therefore each company must have equal rights in the SteelNet system (Haapasalo et al., 2002, Iskanius and Haapasalo, 2003).

In the SteelNet system, agents represent major functionalities of a company. Figure 1 shows the usual operations in manufacturing companies, which are substituted by agents in the SteelNet system. They are able to communicate and collaborate within the company and likewise with other companies' agents via the Internet. This enables a seamless information flow though all the operations in a company and also through the whole business network. Practical operations in a business network have been analysed through some business cases, in order to reflect the reality. Delivery processes for products in project deliveries (modules of oil drilling rigs) and in volume production (hardened plate products) have been modelled in the SteelNet project.

3 TECHNICAL ARCHITECTURE FOR NETWORKING MANUFACTURING ENTERPRISES

The SteelNet environment consists of several manufacturing companies that have different network structures. However some generalisations can be made, in particular that companies have a private LAN (Local Area Network) which is connected to the Internet through a firewall. Legacy systems and workstations are located in the LAN. The selected architecture must enable workstations and legacy systems to interact with the SteelNet system as well as enable the companies to share information with each other without any modifications to the company firewall (Helaakoski et al., 2003).

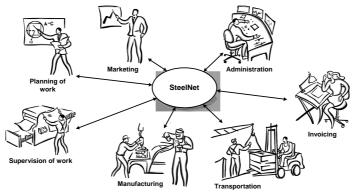Figure 2 shows the SteelNet architecture. The

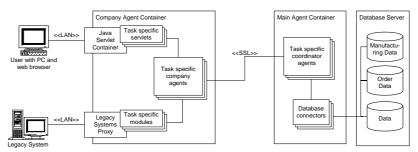Figure 1: Usual operations in a manufacturing company.

Figure 2: The SteelNet architecture.

architecture consists of one service provider and one or more companies. Each company has their own agent container server and a set of task specific agents. Each of these agents handles one of the roles presented earlier in Figure 1. The service provider has corresponding co-ordinator agents, that act as mediators between agents of the same role in different companies. Furthermore, the co-ordinator agents provide a data storage for the company agents. The communication between agents is secured by using a Secure Sockets Layer (SSL) connection.

The SteelNet architecture defines a set of basic services that are available for all agent containers in the system. The services include a web application server to provide user interfaces, a user administration service, a file distribution service and an alarm service and an information service for companies' to register their manufacturing and transportation services to the network.

The use of co-ordinator agents makes the system centralised, but it has some very considerable advantages. All data is easily available and in obscure situations it is easier to inspect if the data has been changed and by whom. Furthermore, security issues can be addressed more easily in a centralised environment that in a decentralised one.

One drawback in this centralised approach is scalability. When the number of companies and active agents grows significantly, co-ordinator agents won't be able to handle the vast amounts of incoming and outgoing data in reasonable time. Thus, in the future the architecture should be enhanced in order to make it more affordable and decentralised.

The architecture enables the physical location of the company agent container to be in the service provider's premises. This arrangement will be especially useful for small companies that do not have such legacy systems that need to be connected to the SteelNet system, or if they don't have enough resources to maintain an agent container server.

In the SteelNet project, business models are being developed to enable the use of information systems in an open manner between independent companies. After a suitable business model is found the technical solution must be further refined to facilitate the use of the business model.

4 PROTOTYPE APPLICATION FOR DISTRIBUTED MANUFACTURING IN THE STEEL PRODUCT INDUSTRY

The SteelNet architecture forms a base, on top of which the functionality of an electronic distributed supply chain is built by implementing agents for different roles. In the SteelNet project a prototype application is being developed to demonstrate the use of the architecture in a real-world supply chain. The first phase of the prototype implementation has been completed and it includes the basic services described earlier, except the file distribution service, and an application for a real-time tracking of heavy steel product manufacturing in a business network.

The manufacturing tracking functionality has been implemented by developing company and co-ordinator agents to share manufacturing-related data with each other using well-defined ontology. The co-ordinator agent provides facilities to store the data securely. The co-ordinator agent notifies the company agents about events that they might be interested in, for example a new manufacturing order in which the company is involved in or a change of a schedule. This enables the company agents to raise alarms when there seems to be delays in the manufacturing process, so that the companies can re-arrange their internal schedules, thus helping to reduce any undesired bull-whip effect, especially for companies that are at the end of the process chain.

In the first phase, the company agents provide a web application that is used to update information in the system. The user interfaces are delivered by using standard Java Servlet and JSP technology-

based web applications that can be used with any modern web browser.

The second phase of the prototype implementation will be completed during the spring of 2004. The main focus is to integrate company agents with legacy systems. The integration work will start with two companies participating in the SteelNet project. The described prototype addresses the issues related to information flow and transparency in a distributed manufacturing process. By using electronic distribution of information with the help of agents, the information flow can be improved significantly, which can be considered essential for optimising throughput times of manufacturing processes.

For the implementation, JADE (Java Agent Development Framework) has been selected as the used agent platform. JADE's main features are compliance to FIPA standards for software agents and the use of the platform-independent Java programming language (Bellifemine et al., 1999).

5 CONCLUSIONS

This paper describes the information technology problems in networking companies to form a supply chain. An agent technology-based technical architecture is presented to address the problems. A prototype application using the architecture in the context of distributed manufacturing in steel product industry is described.

The presented architecture intends to distinguish itself from similar ones by being designed and implemented for real-world use by companies of various sizes and in different industries. At the current state the architecture has limitations in scalability, which need to be addressed in the future.

The described prototype implements an application for efficient distribution of information in distributed manufacturing, but later the system can be easily extended to cover other areas of a supply chain network. The companies participating in the SteelNet project have tested the prototype in laboratory conditions and the results are promising. The prototype will be field-tested during the spring of 2004, thus creating more valuable information for future development of the architecture and prototype.

The agent technology has proven to be an applicable and affordable solution for electronic business networks. However, the technology needs to be developed further to provide a significant benefit when compared to traditional methods.

ACKNOWLEDGEMENTS

REFERENCES

Barbuceanu, M. and Fox, M., 1997. Integrating Communicative Action, Conversations and Decision Theory to Coordinate Agents. *In Proceedings of Autonomous Agents'97*, Marina del Rey, CA.

Bellifemine, F., Rimassa, G. and Poggi, A., 1999. JADE - A FIPA-Compliant Agent Framework. *In Proceedings of the 4th International Conference and Exhibition on the Practical Application of Intelligent Agents and Multi-Agents*, UK, 1999.

Blake, M.B. and Gini, M., 2002. Guest Editors, Introduction to the Special Section: Agent-Based Approaches to B2B Electronic Commerce, *International Journal of Electronic Commerce*, Volume 7, Number 1, Fall 2002, pp. 7.

Fox, M.S., Chionglo, J.F., and Barbuceanu, M., 1993. *The Integrated Supply Chain Management System. Internal Report,* Dept. of Industrial Engineering, Univ. of Toronto.

Gummesson, E., 2000. *Suhdemarkkinointi 4P:stä 30R:ään.* 2nd ed. Yrityksen Tietokirjat & Evert Gummesson, Jyväskylä. 453 p.

Haapasalo, H., Uutela, P., and Pajari, S., 2002. Developing co-operation in SME manufacturing network – fundamental concepts from the steel product industry. *In Proceedings of Conference on Small Business Research,* University of Kuopio, Kuopio, Finland.

Helaakoski H., Feng S.C., Jurrens K.K., Ojala K., and Kipinä J., 2004. Collaborative Software Agents in Steel Product Industry, *The IASTED International Conference on Artificial Intelligence and Applications*, Innsbruck, Austria, accepted.

Iskanius, P. and Haapasalo, H., 2003. Developing order-delivery process in manufacturing network case of steel product industry. *In Proceedings of 20th International Manufacturing Conference - IMC-20*, Cork, Ireland.

Jennings, N.R. and Wooldridge, M.J., 1998. Applications of Intelligent Agents. *Agent Technology: Foundations, Applications, and Markets*. Jennings, N.R. and Wooldridge, M.J (Eds.), Springer, pp. 3-28.

Jennings, N.R., Corera, J.M. and Laresgoiti, I., 1995. Developing Industrial Multi-Agent Systems. *In Proceedings of ICMAS'95*, San Francisco, The AAAI press/The MIT press, pp. 423-430.

VII/4

PUBLICATION VIII

Software agents-enabled systems coalition for integrated manufacturing processes and supply chain management

Software agents-enabled systems coalition for integrated manufacturing processes and supply chain management

Shaw C. Feng*

Manufacturing Engineering Laboratory, 100 Bureau Drive,
Stop 8260, Gaithersburg, Maryland 20899, USA
E-mail: feng@nist.gov
*Corresponding author

Heli Helaakoski

VTT Electronics, PO Box 3, Rantakatu 5, FIN-92100 Raahe, Finland
E-mail: heli.helaakoski@vtt.fi

Harri Haapasalo

Department of Industrial Engineering, University of Oulu,
PO Box 4610, FIN-90014 Oulu, Finland
E-mail: harri.haapasalo@oulu.fi

Janne Kipinä

Department of Electrical Engineering, University of Oulu,
Rantakatu 5, FIN-92100 Raahe, Finland
E-mail: janne.kipina@oulu.fi

Abstract: Most business negotiations in supply chain and information exchange in manufacturing processes are heavily human-involved using proprietary data formats. The processes of negotiation and information exchange are usually time consuming and unreliable even in routine tasks. Software agents have been increasingly explored to improve the information flow and the decision-making process within networked manufacturing enterprises. In order to use agents in manufacturing applications, a software agent-enabled process integration framework for manufacturing and supply chain management has been developed and is described in this paper. The framework includes agent architectures, interaction protocols, message exchanges, an ontological engineering environment, business rules and knowledge bases and databases. The initial implementation of the framework has been tested by a prototype multi-agent system in a steel product business network and a manufacturing network.

Keywords: agent architecture; autonomous agents; manufacturing planning; multi-agent system; supply chain management; systems integration.

Biographical notes: Shaw C. Feng works in the Manufacturing Systems Integration Division of the Manufacturing Engineering Laboratory at the National Institute of Standards and Technology. He received his PhD degree in mechanical engineering from the University of Wisconsin-Madison in 1987. He has six years' experience in developing CAD, CAM and automated inspection software for computer integrated design and manufacturing. Dr Feng has published numerous reports and papers in the areas of design and process planning integration, manufacturing execution, concurrent engineering, process planning, solid/surface modeling, automated manufacturing systems, geometric tolerancing, inspection planning, and inspection data analysis.

Heli Susanna Helaakoski received a Bachelor degree of science in machine automation from the Oulu Polytechnic and Master of Science in computer engineering in 2001 from University of Oulu. At the moment she is working on her PhD studies. Since 2000 she has been a research scientist at the Technical Research Centre of Finland. Her research interests are agent technology, ontologies and mobile applications.

Harri Jouni Olavi Haapasalo received his Master's degree in 1995, Licentiate degree in technology in 1997, Master's degree in Economics and Business Administration in 1998 and his Doctor's degree in technology Industrial Engineering and Management in 2000. All of these degrees are from the University of Oulu. He has about three years' industrial experience in the construction industry. Since 1995 he has worked at the University of Oulu, firstly as a researcher and assistant. He has been professor in Industrial Engineering and Management since 1998.

Janne Tapani Kipinä received his Bachelor of Science in computer engineering in 2002 from the Polytechnics of Oulu. At present he is working in the University of Oulu. He has over four years experience in developing agent technology solutions for logistics and supply chain management and in middleware and security solutions for home automation networks.

1   Introduction

The development of business and industry has led us to the situation where a single company cannot compete alone any more. Pursuing effectiveness in operations has become an increasingly important trend since the 1980s. The origins lie in industrial and international development (Hoover et al., 2001; Simchi-Levi et al., 2000). Markets are becoming more international, dynamic and customer-driven; furthermore, customers are demanding more variety, better quality and greater service in terms of reliability and response time (Mentzer, 2001). Companies that are able to take a new approach to business and work closely with partners to design and manage processes that extend across traditional corporate boundaries will become more competitive; therefore, the information management will be a critical enabler for the development of business networks – not only to automate the information utilisation in an evolving way but also reengineer the business processes.

Because of these changes, we need to have different means in information-processing, which makes it possible to treat masses of customers as individuals and allows more and more companies to offer individualised products while maintaining high volumes of production (Goldma et al., 1995). Scale, cost, quality, and time are the paradigms where business is managed (see Table 1) (Kolarik, 1999; Suri, 1998; Womack and Jones, 1996). According to Harrington (2000), the 21st century is bringing rapid innovation, driven by the continuing advanced technology boom and expanding global markets. The accelerating rate of change will continue to be driven by the exponential growth and global availability of information, technologies and technology-based infrastructure. A key factor to supply chain management (SCM) is the integration of processes in the supply chain – both upstream and downstream. The information and communication technology (ICT) has become an enabler for process integration. Operations in a supply chain are based on interaction and transmission of information; therefore, information and communication have had a significant role in business evolution.

Table 1   Criticality of information and communication – paradigms for success

	Before 1980	*1980s*	*1990s*	*Today/tomorrow*
To be winner at the market	Product quality	Customer satisfaction	Time to market	– Balance expectations for all interest groups
				– Continuous improvement in internal efficiency
To stay in the market	Costs	Product quality	Customer satisfaction	Time to market (ability to create added value for customers
Precondition for entering the market	Right product	Costs Right product	Product quality Costs Right product	Customer satisfaction Product quality Costs Right product

Source: (Iskanius and Haapasalo, 2003).

While the business environment has changed in a revolutionary way, the technological development and the accessibility of knowledge have created new possibilities for enterprises towards open information exchange. Now companies can integrate their activities with their suppliers, customers and partners by means of information technology. Specifically, the rapid development of the internet and mobile network technologies has offered users, developers and businesses new possibilities to collaborate, access and share information. The internet appears to be a suitable infrastructure for business-to-business communication, which is predicted to become the most important application area of internet technologies in terms of the market volume (Alahuhta et al., 2004). Internet infrastructure enables the use of software agents in Business-to-Business (B2B) solutions, and the agent technology has been considered an important approach for developing industrial distributed systems (Jennings et al., 1995; Jennings and Wooldridge).

Agents can be utilised for further automating supply chain management and reducing the amount of manual work. They can also assist in the automation of negotiation and engineering data exchange to increase the competitive position and profitability of a company in a business network. In manufacturing processes, agents support the integration of predictive models, process planning and shop floor machining activities. Agents can also be used to encapsulate existing software systems to solve legacy problems and integrate manufacturing enterprise activities such as planning, scheduling, manufacturing operation and product distribution with those of their suppliers, customers and partners into an open, distributed intelligent environment via networks (Barbuceanu and Fox, 1997; Fox, et al., 1993; Shen et al., 2001).

In this paper, we present how agents and agent systems can assist in transmitting information within and between companies. We describe how a community of agents can make decisions and carry out tasks within a manufacturing network company or across companies in a manufacturing supply chain. Our work is based on a business network architecture that is connected to enterprises' legacy systems by using agents. The business network of agents is being developed by the SteelNet project at VTT – Technical Research Centre of Finland and the University of Oulu. The SteelNet project is funded by Tekes – the National Technology Agency of Finland, VTT and the companies associated with this project in order to study the use of agents in industrial business networks by developing an agent-based prototype. This agent-based prototype is focused for a business network consisting of one steel producer, engineering workshops and engineering offices (Helaakoski et al., 2004a). The prototype transmits the follow-up information in manufacturing of heavy steel components in this business network. A product design and manufacturing network of agents is being developed by the Process Integration Framework (PIF) project of the Manufacturing Engineering Laboratory at the National Institute of Standards and Technology (NIST), a federal agency within the US Government. Within the NIST research activities, agent communication is performed in a prototype multi-agent platform to demonstrate the sharing of manufacturing knowledge and process data throughout the product life cycle. NIST's work provides support for a variety of transactions among the business entities and among engineering activities within a company. NIST's multiple agents-enabled business and manufacturing systems coalition framework includes business and manufacturing networks, an ontological engineering environment, a multi-agent architecture, agent interactions, agent message format and business rules. The first two components are discussed in this paper. The last four components have been described in Helaakoski et al. (2004b). Furthermore this paper introduces the business and manufacturing cases where the first prototype of business and manufacturing agents has been studied collaboratively by the PIF and SteelNet projects.

This paper is organised as follows: Section 2 reviews the current state of research in applying software agents to manufacturing and supply chain management. Section 3 describes an agent-based business and manufacturing systems coalition framework. Section 4 provides a structure of components in a multi-agent system. Section 5 presents agent communication networks. Section 6 proposes an ontological engineering environment that supports agent communication. Section 7 has an overview of our prototype implementations. Section 8 concludes the current work and outlines future plans. Acknowledgements and a disclaimer follow Section 8.

2   A review of software agents in manufacturing and supply chain management

This section provides a brief review of the related literature in applying software agents to help companies manage manufacturing and supply chain activities. In the manufacturing area, agents are used to directly interact with existing (legacy) computer-aided design and manufacturing systems to enable these systems to be integrated with other systems in a manufacturing enterprise, such as scheduling systems, process planning systems, process optimisation systems, design analysis systems, manufacturing execution systems and manufacturing resource planning and acquisition systems. The CIIMPLEX project has developed an agent-based enterprise system to integrate design, process planning and scheduling systems to allow timely information flow between various departments in a manufacturing company (Peng et al., 1998). The PIF project at the NIST project has developed a multi-agent system to integrate machining process optimisation software with a Numerical Control (NC) programming system to maximise the material removal rate in machining processes (Feng et al., 2004). The PACT project has developed a concurrent design environment using software agents to reduce design lead time and provide better communication among collaborators (Cutkosky et al., 1996). In the Intelligent Manufacturing Systems programme, agents are used to implement a holonic manufacturing system to integrate manufacturing engineering software systems for intelligent manufacturing (Deen, 2003; Marik et al., 2003). In addition, agents are also used in controlling production activities (Fan and Wong, 2003) and in representing machines to collaborate or compete with each other for jobs on a factory floor (Lu and Yih, 2001; Parunak, 1993; Shaw, 1988; Usher, 2003).

In the supply chain management area, business-to-business transactions consist of several typically repeated chains of events, such as the requisition of resources, a request for quotes from candidate business entities, the selection of vendors, an order of enactment and delivery and relationship management between business entities. These events are relevant to the functions of several business networks, including a strategic sourcing network, an electronic procurement network, a virtual enterprise network, a network of product design, manufacturing, inventory, and delivery management, a network of electronic market places, a network for workflow/supply-chain management and a network for supplier relationship management (Blake and Gini, 2002). The use of autonomous and intelligent software agents has been studied (Collins et al., 2002; Gijsen et al., 2002; Haapasalo et al., 2002; Karageorgos et al., 2002) for easing this complex surrounding of business networks in electronic commerce. A multi-agent architecture has been developed to help decision making in supply chain reengineering, such as helping managers to understand the costs, benefits and risks associated with various alternatives (Swaminathan et al., 1996). An agent-orientated system has also been developed to allow agents who manage supply chain activities to interact with each other within a role-based organisational model to perform functions of negotiation, coordination and acquisition in supply chains (Fox et al.).

From our review, there is a lack of a multi-agent framework for integrated manufacturing and supply chain management. This is needed by companies, both suppliers and clients, for greater efficiency in production management, response to market changes and price negotiation.

3   A multiple agents-enabled framework for business and manufacturing networking

In Figure 1 the companies are collaborating via mutually accessible information systems. The business network is connected to the company's enterprise resource planning system including the manufacturing network. The major internal activities in manufacturing companies are product engineering, manufacturing planning and production management. The agents interact with engineering systems in design, planning, scheduling and production management systems. Some of the agents retrieve data from databases and/or engineering rules from knowledge bases. These agents assist human engineers to build computerised models of products or processes, visualise data and do scientific computations for making decisions.

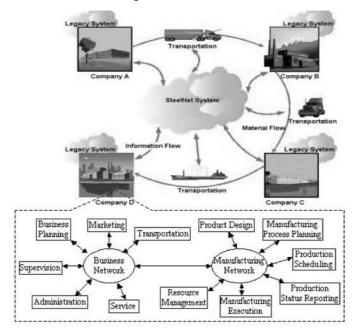**Figure 1**   Business and manufacturing networks

Figure 2 shows a logical view of a multi-agent system architecture. A company network consists of many servers and personal computers (PCs). Servers include firewall servers, web servers and agent container servers. A graphical user interface (GUI) to agents is displayed on web browsers in personal computers (PCs). A multi-agent system can also be integrated into companies' legacy systems and they are therefore transparent for the users. Agents are in several agent containers on servers, connected by a local area network (LAN). The company LAN is connected to the internet through a firewall within a firewall server. In practice, all companies have different network structures, since the companies vary from small engineering workshops to large corporations with hundreds of personal computers, servers and other systems networked together across far-reaching geographical locations. However, the basic principle is that the agent user interfaces are accessible from a PC and there is a firewall protecting the company network.
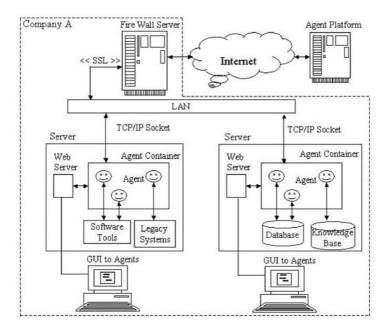
Figure 2   Logical view of networked agents

4   Components of a multi-agent system

The main agent container in the agent platform provides a facility for agents of all the companies in the business network to communicate with each other. In addition, the agent may register its capability and identification in the agent platform. The main agent container is located in a central server that is assessable via the internet. The major functions of the agent platform include managing an agent joining in, logging out and message exchange. Communication of the agents is secured by using the secure socket layer (SSL) connection. The agents in this architecture are decentralised. Agents execute on an agent platform, which manages the messages between agents. The capability repository agent performs on the agent platform and uses a database for storing and retrieving the capability information about each agent that provides services. The agent platform manages the agent activities. The platform functions and components are largely based on the Foundation of Intelligent Physical Agents (FIPA) specifications (FIPA, 2003). The major functions include agent container management, message transport service and agent directory facility. The messages sent by agents are dispatched and directed by the platform.

The component architecture describes the software components used in the agent-based integrated design, planning, and control system. Figure 3 shows the agents that are executed in the agent platform. The agents include a design agent, a group of process planning agents, a capability repository agent and a manufacturing execution agent. Humans interact with the agents through the graphical user interfaces (GUI). The design agent communicates with a computer-aided design (CAD) system to send and retrieve information about part design. A CAD system defines the shape and attribute information of a design of part components or an assembly.

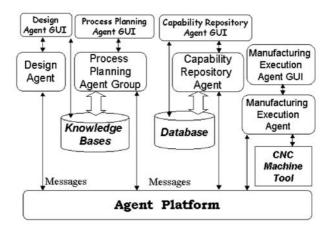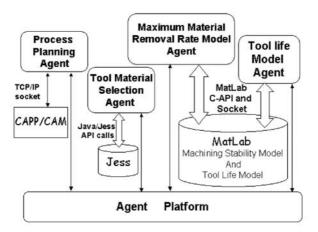**Figure 3**   Multi-agent system architecture

Figure 4 shows agents in the process planning agent group. The process planning agent communicates with a computer-aided process planning (CAPP) system and a computer-aided manufacturing (CAM) system to generate numerical control (NC) programmes. CAPP software provides functions for selecting processes and resources and for generating process sequences. The NC software is used to create tool paths and NC programmes for running computer numerically controlled machine tools. The agent sends and retrieves information about machining process planning to and from both CAPP and CAM systems. It also interacts with the tool material selection agent to select an appropriate cutting tool material based on the product attributes. The tool material selection agent selects the cutting tool material based on workpiece material, tool life requirements and desired cutting speed. Tool material selection rules are stored in a knowledge base. The maximum material removal rate evaluation agent uses a mathematical model to calculate the maximum material removal rate based on the dynamics of the specific machine tool, the configuration of the cutting tool/tool holder/ machine spindle and factors in the machining process. The agent calculates an optimal set of cutting parameters, including cutting speed, feed rate and depth of cut, based on the specific conditions. The tool life model agent has a mathematical model of the life of insert tools. This agent estimates the life of a selected tool, based on a lot size and coefficients derived from previously conducted tool-life experiments.

5   Agent communication in networks

Agents communicate with each other by exchanging messages. A message has two sections: message header and message content (also known as message body). The header contains the information regarding the sender, receiver(s), subject, date and time that the message is sent by the sender, date and time that the message is received by the receiver and the priority. In the sender or receiver information, there is a slot that contains the agent identification (AID). Using the AID, the information about an agent, such as its name, can be retrieved from a repository or agent directory.

Figure 4   Process planning agent group

The message content contains information regarding the intent. There are two types of content: illocutionary and perlocutionary. The illocutionary message is used to inform other agents, such as registering an agent's capability. The perlocutionary message is used to request actions of other agents, such as a request for machining process optimisation or a call for a proposal. Message content has the following attributes: an action verb, an object, preconditions and constraints. The action verb is used to indicate the type of action to be taken by the receiver, such as request, propose and query. An object is the result or expectation. Examples of classes of objects can be found in Feng and Song (2003). Classes related to the milling process have been applied. Preconditions are the properties that the sender may supply. Constraints are limitations with which expected results should be constrained. They are specified to provide information to the receivers to produce valid results. Agents must have intelligence to process messages. A body of knowledge supports the intelligence of an agent.

An example of agent communication in a manufacturing network is shown in Figure 5. This interaction model specifies the timing and sequence of function calls – the interactions among agents. It shows interactions among agents for the scenario used in the integration framework. All the agents, except the process planning and capability repository agents, must first register their capability in the database. From the CAM system, the manufacturing engineer launches the process planning agent to determine and provide the optimal cutting parameters. Based on knowledge from the capability repository, the process planning agent obtains the tool material information by sending a request to the tool material selection agent. With this information, the process planning agent then determines an optimal set of process parameters based on analysis from both the machining stability perspective (i.e. highest material removal rate while maintaining a stable cut) and the cutting tool life perspective (i.e. recommended material removal rate to achieve specified cutting tool wear rate and tool life). With the result, the NC programme can, therefore, be completed within the CAM system.

Figure 6 shows the interaction diagram in a business network where agents are exchanging information between companies. The sent information can be notifications on delivery such as information about schedules, changes or a cancellation.

Figure 5   Agent interaction diagram
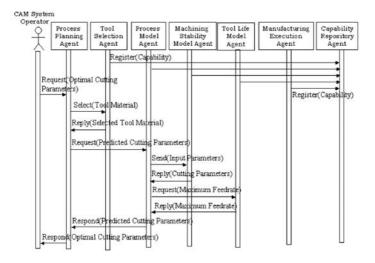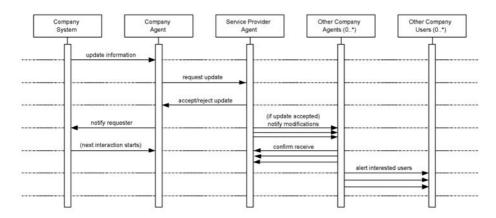

Figure 6   The interaction model in business network

The source of agent intelligence is the knowledge base. This knowledge base contains rules that govern agent behaviour. An agent's knowledge includes how to enquire about the capability of other agents and how to perform special tasks. For example, special tasks may include functions, such as tool material selection, machining stability analysis or tool life evaluation. Basic rules for tool material evaluation can be commonly found in literature on process planning for metal cutting (Nelson and Schneider, 2001). More specific and customised rules can be entered into the knowledge base. The rules are structured using propositional logic. The rules for both machining stability analysis and tool life evaluation are in mathematical form. The machining stability analysis is based on machining measurements and a machining chatter analysis and the tool life evaluation is based on the Taylor tool wear principle, and both methods are documented in the literature (Boothroyd and Knight, 1988). These two mathematical models are implemented using the mathematical software tools available.

The manufacturing resource database contains information about the equipment and tools used in the machining process, such as data and attributes for the machine tools, cutting tools and fixtures. The structure of the database is relational, and the database can be accessed by external programmes via the Java database connector. In the database, a machine tool is defined by a set of attributes, such as the maximum power, the maximum cutting force in each axis, the maximum workspace dimensions, tool magazine information, the number of cutting axes, the maximum spindle speed and available cutting tools. A cutting tool is defined by another set of attributes, such as tool identification, tool length, tool size, number of cutting edges, cutting angles on each edge, tool material and tool overhang as mounted in its holder. Other resource information, such as for fixtures, workpiece materials and operator skills, can also be stored in the database. An object model on machining resource information can be found in (Jurrens et al., 1998).

6 Ontological engineering environment

An ontological engineering environment is a set of methods and tools for humans to specify the meaning of concepts in a domain, the relationships between concepts and the rules for extending and exploiting the domain-specific ontology. Our ontologies are restricted to supply chain management and manufacturing. Currently, the environment consists of ontology specification languages, language-processing tools and an ontology edition tool.

The ontology for the SteelNet prototype describes basic concepts in the domain area and relationships among them. The Java Agent Development Framework (JADE) (Bellifemine et al., 1999) compatible ontology was designed and implemented using the Protégé ontology editor (Protégé). In the PIF project the web ontology language (OWL) and Process Specification Language (PSL) are used. OWL is used for specifying objects, such as tools, products, and machines. PSL is used for specifying business and manufacturing processes. Classes, properties, and constraints in OWL are used by agents to form their knowledge bases and a part of their messages. The authoring tool used is Protégé. The processing tool used is Jena, an application programming interface to OWL documents.
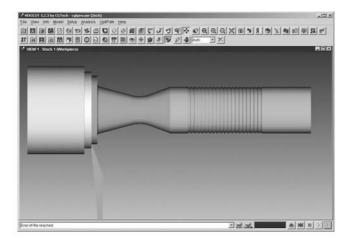
7 Implementations

In the manufacturing network, the multi-agent system has been tested with an example of a turned metal part. A process plan, selected tools, machining parameters and a Numerical Control (NC) programme were generated through the coordination of agents. The example part has outside features, such as grooves, neck and cylindrical profile, and inside features, such as holes, rounded edge and funnel, to be machined. Agents for process planning, tool selection, process parameter optimisation and machine tool control are initiated through web access that provides a GUI for a user as an access to the multi-agent system. After starting a multi-agent system, the user can start agents. Human operators can monitor the message exchange of agents. An example is shown in Figure 7. A machining process simulation was performed, as shown in Figure 8. Details of the implementation are described in Feng et al. (2004).

Figure 7   Messages of an agent

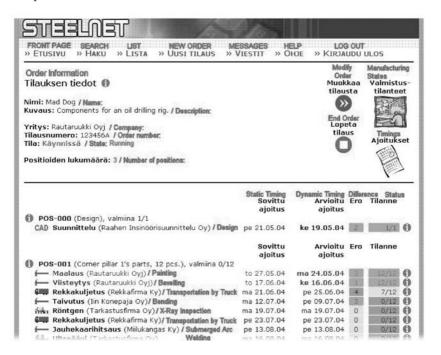**Figure 8**   Machining process verification

In the SteelNet project, a prototype application is being built for electronic supply chains by implementing agents for different roles in a business network. The first phase of the prototype implementation has been completed and includes a set of basic services and an application for real-time tracking of heavy steel product manufacturing in a business

network. The basic services are a web application server providing user interfaces, a user administration service, an alarm service and an information service for companies to register their design, manufacturing, transport and inspection services to the business network's service repository.

The manufacturing follow-up application contains company and service-provider agents to share manufacturing-related data with each other using a well-defined ontology. The service provider agent provides secure data storage facilities for the company agents. Furthermore, the service provider agent notifies the company agents about events that they might be interested in, for example, a new manufacturing order in which the company is involved, or a change of schedule. The company agents inspect these events. If any abnormality occurs, they send alarms to the responsible users in the companies so that they can take the necessary action. For example, when there are delays in the manufacturing process, a company agent alerts the company's supervisor to re-arrange their internal work schedules, thus helping to reduce any undesired bull-whip effect and to maximise the utilisation of their machinery.

In this first phase of prototype implementation, the company agents provide a web application that is used to update information in the system. The user interfaces are delivered by using standard Java Servlet and Java Server Page (JSP) technology-based web applications. Figure 9 presents an agent GUI to order products in a manufacturing company. The user interface shows information about an order, and its order lines and manufacturing processes related to them. The manufacturing states and estimated schedules are described with colour codes, so users can quickly notice whether the manufacturing is on, ahead, or behind an agreed schedule.

Figure 9   GUI of the SteelNet manufacturing agent showing an overview of a manufacturing process

The SteelNet prototype has been implemented by using the JADE agent platform. JADE was selected due to its use of the platform-independent Java programming language and compliance to FIPA standards for software agents (Bellifemine et al., 1999).

8   Conclusions and future work

In this paper, we have introduced a software agent-enabled process integration framework, which exploits software agents in business networks and distributed automation for manufacturing enterprises. By means of a prototype implementation, it is shown that agent technology can be used for information transmission and handling inside a company and between companies in a business network. It is also shown that it is possible to integrate these two multi-agent systems with the developed framework. Based on our implementations, it has been shown that the agent technology improves the accuracy, reliability and speed of information flow, and thereby reduces internal costs in companies by cutting delivery cycles and enabling seamless information flow within a company and a business network. The greater potential of efficiency improvements lies in the fact that time has become a more and more critical factor in business. When automation makes the information transmission faster and also accurate, it actually is an enabler for possibilities that are not attainable otherwise. Agents assist the users of traditional industrial systems by executing the routine tasks of humans. This increases the speed and accuracy of information by eliminating human errors. The agent system can also provide alarms, which inform users automatically about unexpected changes in the supply chain.

The companies participating in the SteelNet project have tested the prototype application and its web interfaces. The on-going work focuses on designing and implementing a framework to integrate it with companies' own legacy systems. The integration work of companies' legacy systems by the means of agents is a challenging task where agents provide a way to exchange and transmit information between companies. Although agents simplify the integration by collecting and delivering the information from companies' legacy systems into a business network, there are questions about the content of the information. The mutual ontology for information needs to be defined in business network, and in integration this defined ontology is mapped into companies' legacy systems. The other challenging issue is how to ensure security in business network. The technical security is solved by using SSL connections but still the legal contract needs to be made.

The basic idea of agent technology and application developed here has been the readiness to connect new companies or participants to utilise the application or to withdraw from the system. The technology does not set any high barriers, because the system is rather easy to use and does not require large financial investment. In proportion the applicability to other supply chains requires some configuration and justification, because the basic set of steel product supply chain changes the structure compared to other chains, however the idea of criticality of information sharing is the same in every chain.

In the near future the prototype will go through a field test, which will provide more valuable information for the development of the agent framework. Furthermore, enhancements are expected to provide additional capabilities and to address additional scenarios, based on collaborative efforts between NIST and VTT. For the NIST activity,

initial specifications on agent messaging and agent interaction protocols for design and manufacturing will be developed and tested, building from the current implementations.

The basic idea of agent technology and application developed here has been the ease by which new companies or participants join to utilise the application or withdraw from the system. The technology does not set any high barriers, because the system is rather easy to use and does not require large financial investment. In proportion, the applicability to other supply chains requires some configuration and justification, because the basic set of steel product supply chain changes the structure compared to other chains, however the idea of criticality of information sharing is the same in every chain.

Acknowledgements

Disclaimer: No approval or endorsement of any commercial products by the National Institute of Standards and Technology (NIST) is intended or implied. Certain commercial software and hardware systems are identified in this paper in order to facilitate understanding. Such identification does not imply that these systems are necessarily the best available for the purpose.

References

Alahuhta, P., Jurvansuu, M. and Pentikäinen, H. (2004) 'Roadmap for new technologies and services', *Tekes Technology Review*, No. 162.

Barbuceanu, M. and Fox, M. (1997) 'Integrating communicative action, conversations and decision theory to coordinate agents', *Proceedings of Autonomous Agents*, Marina del Rey, Canada.

Bellifemine, F., Rimassa, G. and Poggi, A. (1999) 'JADE – A FIPA-compliant agent framework', *Proceedings of the 4th International Conference and Exhibition on the Practical Application of Intelligent Agents and Multi-Agents*, UK.

Blake, M. and Gini, M. (2002) (Guest Eds.) (2002) 'Introduction to the special section: agent-based approaches to B2B electronic commerce', *International Journal of Electronic Commerce*, Vol. 7, No. 1.

Boothroyd, G. and Knight, W. (1988) *Fundamentals of Machining and Machine Tools*, 2nd edition, Marcel Dekker, Inc.

Collins, J., Ketter, W. and Gini, M. (2002) 'A multi-agent negotiation testbed for contracting tasks with temporal and precedence constraints', *International Journal of Electronic Commerce*, Vol. 7, No. 1, pp.35–57.

Cutkosky, M.R., Tenenbaum, J.M. and Glicksman, J. (1996) 'Madefast: collaborative engineering over the internet', *Communication of the ACM*, Vol. 39, No. 9, pp.78–87.

Deen, S.M. (Ed.) (2003) *Agent-Based Manufacturing – Advances in the Holonic Approach* Heidelberg, Germany: Springer-Verlag.

Fan, C. and Wong, T. (2003) 'Agent-based architecture for manufacturing system control', *International Journal of Integrated Manufacturing*, Vol. 14, No. 7, pp.599–609.

Feng, S. and Song, E. (2003) 'A manufacturing process information model for design and process planning integration', *Journal of Manufacturing Systems*, Vol. 22, No. 1, pp.1–16.

Feng, S., Stouffer, K. and Jurrens, K. (2004) 'Intelligent agents-enabled inegrated manufacturing planning and control', in *Proceedings of the 8th International Conference on Computer Supported Collaborative Work in Design*, China, May 26–28, pp.208–214.

Foundation for Intelligent Physical Agents (FIPA), (2003) 'Abstract Architecture Specification,' http://www.fipa.org, December 2003.

Fox, M., Barbuceanu, M. and Teigen, R. 'Agent-oriented supply-chain management', *International Journal of Flexible Manufacturing Systems*, Vol. 12, pp.165–188.

Fox, M., Chionglo, J. and Barbuceanu, M. 'The integrated supply chain management system', an Internal Report, Department of Industrial Engineering, University of Toronto.

Gijsen, J., Szirbik, N. and Wagner, G. (2002) 'Agent technologies for virtual enterprises in the one-of-a-kind-production industry', *International Journal of Electronic Commerce*, Vol. 7, No. 1, pp.9–35, M.E. Sharpe Inc. Publications.

Goldman, S., Nagel, R. and Preiss, K. (1995) *Agile Competitors and Virtual Organizations – Strategies for Enriching the Customer*, Van Nostrand Reinhold Book.

Haapasalo, H., Uutela, P. and Pajari, S. (2002) 'Developing co-operation in SME manufacturing network – fundamental concepts from the steel product industry', *Proceedings of Conference on Small Business Research*, University of Kuopio, Kuopio, Finland.

Harrington, H. (2000) *Project Change Management*, McGraw Hill.

Helaakoski, H., Feng, S., Jurrens, K., Ojala, K. and Kipina, J. (2004) 'Collaborative software agents in steel product industry', *Proceedings of the IASTED International Conference – Artificial Intelligence and Applications*, February 16–18, Innsbruck, Austria, pp.147–152.

Helaakoski, H., Kipinä, J. and Haapasalo, H. (2004) 'An agent architecture for steel product business networks', in *Proceedings of the Sixth International Conference on Enterprise Information Systems*, Vol. 4, Porto, Portugal, April 14–17.

Hoover, W., Eloranta, E., Holmström, J. and Huttunen, K. (2001) *Managing the Demand-Supply Chain*, John Wiley and Sons.

Iskanius, P. and Haapasalo, H. (2003) 'Collaboration in steel product industry – developing order delivery process in manufacturing network', *Proceedings of International Conference on Industrial Logistics*, 16-19-6, Vaasa, Finland, pp.270–282.

Jena, http://jena.sourceforge.net

Jennings, N. and Wooldridge, M. (Eds.), 'Applications of intelligent agents', in *Agent Technology: Foundations, Applications, and Markets*, Springer, pp.3–28.

Jennings, N., Corera, J. and Laresgoiti, I. 'Developing industrial multi-agent systems', *Proceedings of ICMAS'95*, San Francisco, CA: The AAAI Press/The MIT Press, pp.423–430.

Jurrens, K., Algeo, M. and Fowler, J. (1998) 'Beyond product design data: data standards for manufacturing resource', *Rapid Response Manufacturing: Contemporary Methodologies, Tools and Technologies*, J. Dong (Ed.), London: Chapman and Hall, Ch 6, pp.84–120.

Karageorgos, A., Thompson, S. and Mehandjiev, N. (2002) 'Agent-based system design for B2B electronic commerce', *International Journal of Electronic Commerce, Special Issue on Agent Technologies for B2B Electronic Commerce*, Vol. 7, pp.59–90, Autumn.

Kolarik, W. (1999) *Creating Quality: Process Design For Results*, McGraw-Hill.

Lu, T. and Yih, Y. (2001) 'An agent-based production control framework for multiple-line collaborative manufacturing', *International Journal of Production Research*, Vol. 39, No. 10, pp.2155–2176.

Marik, V., McFarlane, D. and Valckenaers, P. (Eds.) (2003) *Holonic and Multi-Agent Systems for Manufacturing*, Heidelberg, Germany: Springer-Verlag.

Mentzer, J. (2001) 'Managing supply chain', *Supply Chain Management Review*, pp.83–84.

Nelson, D. and Schneider, G. (2001) *Applied Manufacturing Process Planning*, Prentice-Hall, Inc.

Parunak, V. (1993) 'MASCOT: a virtual factory for research and development in manufacturing scheduling and control', Technical Memo 93-02, Industrial Technology Institute.

Peng, Y., Finin, T., Labrou, Y., Chu, B., Long, J., Tolone, W.J. and Boughannam, A. (1998) 'A multi-agent system for enterprise integration', in *Proceedings of PAAM'98*, London, UK, pp.155–169.

Process Specification Language (PSL), http://www.nist.gov/psl

Protégé, http://protege.stanford.edu

Shaw, M. (1988) 'Dynamic scheduling in cellular manufacturing systems: a framework for networked decision making', *Journal of Manufacturing Systems*, Vol. 7, No. 2, pp.83–94.

Shen, W., Nore, D. and Barthes, J. (2001) *Multi-agent Systems for Concurrent Design and Manufacturing*, Taylor and Francis Publishing Co.

Simchi-Levi, D., Kaminsky, P. and Simchi-Levi, E. (2000) *Designing and Managing the Supply Chain: Concepts, Strategies, and Case Studies*, McGraw-Hill.

Suri, R. (1998) *Quick Response Manufacturing: Company Wide Approach to Reducing Leadtimes*, Productivity Press Inc.

Swaminathan, J., Smith, S. and Sadeh, N. (1996) 'A multi-agent framework for supply chain dynamics', *Proceedings of AI & Manufacturing Research Planning Workshop*, Albuquerque, NM.

Usher, J. (2003) 'Negotiation-based routing in job shops via collaborative agents', *Journal of Intelligent Manufacturing*, Vol. 14, No. 5, pp.485–499.

Web Ontology Language (OWL), http://www.w3.org/2001/sw/WebOnt

Womack, J. and Jones, D. (1996) *Lean Thinking*, Simon & Schuster.

Experiences in developing mobile applications using the Apricot Agent Platform

Experiences in Developing Mobile Applications using the Apricot Agent Platform

PETTERI ALAHUHTA[1], HENRI LÖTHMAN[1], HELI HELAAKOSKI[1,] ARTO KOSKELA[2], JUHA RÖNING[2]

[1]*VTT Electronics, Kaitoväylä 1, 90571 Oulu, Finland*

`{Petteri.Alahuhta, Henri.Lothman, Heli.Helaakoski}@vtt.fi`

[2] *University of Oulu, Linnanmaa, PL 4500, 90014 Oulun yliopisto, Finland*

`{Arto.Koskela, Juha.Roning}@ee.oulu.fi`

Abstract. The trend of increasing mobile services has set a new challenge for service providers: how to develop more advanced and user friendly, context-aware and personalized mobile services for the users. Apricot Agent Platform is an agent-based software platform designed for developing context-aware and personalized mobile services. Apricot Agent Platform supports the development of user-friendly mobile services by providing tools for combining various mobile and Internet-based services. Apricot agent architecture consists of an agent platform, agents and agent containers. For the developers of mobile services, it provides built-in functionality and communication mechanism. Furthermore, this paper describes four demonstrators that are built up on the Apricot Agent Platform to evaluate the usability and efficiency of the platform in processes of building mobile services. The results of the evaluation indicate relatively promising results and the further target for development is revealed.

Keywords Mobile Application, Mobile service, Agent platform, context-awareness, Personalisation

Introduction

Mobile applications and services have been considered an important era of the information and communications technology [1]. The development of mobile network technologies as well as mobile terminals has offered users, developers and businesses new opportunities to access information, communicate or be entertained. Person-to-person communication has been the main service for the end users of mobile terminals. In addition to traditional voice communication and voice mail, the Short Message Service (SMS) has been dominating the mobile service area, at least in Finland [2]. Manufacturers of mobile devices as well as network operators have been promoting mobile data services such as Multimedia Messaging, Mobile Browsing and Mobile Email. However, the growth in mobile data services hasn't been as fast as operators in the market expected. Since the technology is mature enough to produce mobile services, there must be other reasons that prevent large-scale use of the services. From the regular user's viewpoint, three factors can be identified that make the use of mobile services complicated:

- Mobile data services are hard to find
- Mobile data services are not easy to use
- Mobile data services do not provide added value [3].

Users know how to use PC and network-based services for viewing, searching, extracting and maintaining information, they are able to store and process digital content and share it with other people and communities. In the mobile context the situation is quite the contrary.

An average user of mobile phones has just learned how to benefit from mobile phone calls and short messages. Neither the technology nor the culture for using mobile data services have developed enough that mobile applications and services could be considered a real choice for using digital information services.

In current SMS-based mobile service markets, the customer first needs to know about the existence of the service; and secondly he needs to remember the phone number of the service and a defined format of SMS message for achieving a certain service. For example, in order to acquire a weather forecast, you type the SMS message "WEATHER OULU" and send it to the number 12345, and you get weather information as a return message. In order to be beneficial to the user, the user should be able to get more advanced and versatile mobile services in a simpler way. We believe that this can be realized by integrating several mobile or internet services to create one combined service that meets the needs of users better than many simple services alone. The mobile service would be even more prospective and user-friendly if it would automatically deliver the integrated, personified services. However, if the idea is to support the users in their tasks when on the move, easier ways to find services should be available. Possible solutions might be the use of context information or personal preferences to automate the use of search engines [4].

Several researchers have proposed the use of intelligent agents for developing software applications [5], [6]. Agent systems are also considered suitable for systems that integrate existing software systems and therefore assist the users of those systems [7], [8]. The first version

of Apricot Agent Platform [9] focused mainly on the agent-based component of the intelligent environment, which manages services on behalf of the user. Since the use of mobile devices has increased, the demand on agents accompanying users in such devices is inevitable. Mobility has set new requirements for agent systems, either the agents or agent platforms must run on small devices like mobile phones and PDAs. Or the mobile terminal must be devised with an application that provides a user interface to the personal agent running on the server side. One of the first lightweight agent platforms is JADE-LEAP[10], a FIPA-compliant agent platform that runs on small devices. The CRUMPET [11]-project has made an extension to the FIPA-OS agent platform called MicroFIPA-OS [12]. MicroFIPA-OS has been proposed as a framework for nomadic agent-based applications [13]. The Apricot research rises to the challenge set by the availability and usability of mobile services for the user. Since there is an obvious need to assist users of mobile services, the service developers must be able to easily produce user-friendly mobile services. Apricot research approaches the development of user-friendly services step by step. As a first step, we have developed an Apricot Agent Platform for mobile service developers, through which the mobile services can be produced to provide added value for regular users of mobile handsets. The second step will be integrating several existing services in a way that is most convenient for the user.

The aim of Apricot research can be summarized as follows:

1) Support for developing mobile services in order to help users.

2) Integration support to combine mobile and web-based services to respond to the user preferences in the most convenient way.

In our approach to research, we have made several iteration rounds of developing, starting from the basic features of the agent platform, such as functionality of the agents and mobility.

This paper introduces the basic architecture of the Apricot platform and gives a short description of the implemented demonstrators that has been used for evaluating the usability and efficiency of the Apricot Agent Platform for service development.

The rest of the paper is organized as follows. The next section defines the mobile environment and mobile services discussed in this paper. The Apricot platform is presented in the next section. The following section describes the implemented demonstrators. Discussion about the findings of this research will be given after the description of demonstrators and the paper will conclude with a glance at the future work.

Mobile environment and services

The main advantage in mobile services compared to stationary information processing is the mobility itself. Mobile technology enables people to access digital information located in the Internet or be entertained outside the reach of stationary Internet access. The mainstream focus of mobile service researchers is called the anytime-anywhere principle: requests for services by mobile users should be always satisfied in an unchanged and transparent way, regardless of the

time at which the service is requested and the place from which it is requested [14].

In this paper *mobile service* refers to the use of a mobile terminal, such as mobile phones or personal digital assistants (PDA), and mobile telecommunication network for delivering an electronic service for the customer. The service can be a delivery of information (such as news, timetables, tickets, etc,) or entertainment content (like video clips, ring-tones, images). The service can also be an operation of an actuator controlled using a mobile terminal (remote control, activating lighting, controlling heating, etc). The mobile service is typically part of a larger system. In addition to the mobile end of the service, there are other components in the service as well. Server implementations, networking and databases are typically needed in order to produce a feasible mobile service. The mobile service is often a complementary service to other electronic services. For example, there may be a downscaled mobile version of an Internet site.

Mobile application refers to program code executed in a mobile terminal. A mobile application may use networking capabilities which makes it a part of the mobile service. It may also be a stand-alone application. For example, a data collection application may in many cases be a stand-alone application. Single-player games, calculators and alarm clocks in mobile terminals can also be considered mobile applications.

In addition to the benefits of mobile technology, there are also great challenges in mobile communication and computing. The environment of a person on the move is highly dynamic. Restricted computing

power and bandwidth, limited memory as well as constricted input/output capabilities in the mobile devices make it challenging for the mobile service providers to produce services that really benefit the user in her tasks and in information needs when one is on the move. Context awareness and personalization have been studied [15] extensively in order to develop technology to help the users consume electronic services while on the move. Personalization and context awareness are also close to the focus of the Apricot project.

The Apricot Platform

The Apricot platform is a distributed software platform, which provides different tools for service development, maintenance and monitoring purposes. The design of the Apricot platform is a combination of several different approaches, which are familiar from the Internet and from the computer systems and their designs. The main technologies utilized in the design of the Apricot platform are: Web Services [16], Enterprise Java Beans (EJB)[17], FIPA Agent Architecture [18], Semantic Web [19], and FIPA Agent Communication Language (ACL) [20].

1.1. The Apricot Architecture

The architecture of the Apricot platform follows the FIPA agent architecture. It specifies the main components and system agents, which are the mandatory parts of an agent platform. The architecture also specifies the structure of the messages and the communication

protocol between the agents which are implemented into the platform accordingly. The content language used in the agent messages is a XML version of the RDF (Resource Description Framework) languages N-Triplets [21]. This conversion is the result of a requirements posed by the mobile terminals MIDP (Mobile Information Device Profile) 2.0 Java implementation and the PC's Java environment. Both of these environments lack the build to support RDF parsing, which is not the case with XML. N-Triples is a line-based, plain text format for representing the RDF abstract syntax. It is a small subset of Notation3 [22]. When N-Triplets are combined with the task model of the Apricot agent, it creates a simple and effective framework to create and use the services that are deployed into the Apricot platform. The referred agent task model is inherent to the Apricot agent model. It is a programming paradigm that is derived from a model of how the Apricot agent processes information. It also defines how the services that they provide are constructed. The Apricot architecture is presented in Fig 1.

The Apricot architecture is very similar to Internet architecture and to the basic client-server-model. Agent services act as servers, which provide the routing services, information repositories and network applications. The agent containers act as peers of the network, also providing different kinds of information services. The agent model provides the building blocks for realizing information services. The Apricot terminal is a window to this network and its services, such as a web browser, serve as a window to the World Wide Web.

1.2. The Agent Service

The Agent service is a server side component of the Apricot platform. It provides services to the network as follows:

- Directory services: Yellow Pages, and White Pages.
- Application deployment services: Application/Service upload and removal.
- Message routing services: A routing table for connected agent services and agent containers.
- System Database Services: access to vocabulary, task, profile and midlet resources.
- Authentication services: Access control for system resources and user identification.

The Directory Services implementation follows the FIPA Abstract Architecture specification [17] by providing the core services defined for the agent platform. However, in the Apricot platform these services have been extended with additional features. These features enable the platform to perform basic presence services [23] so that the developer can create different kinds of services that use the presence framework. Another noteworthy feature of these directory services is the Apricot platforms core feature, which provides support for dynamic adaptation of new services. A high-level overview of the structure of the Apricot agent service is presented in Fig 2.

1.3. Apricot Agent Container

The Apricot agent container is a lightweight version of the Apricot agent service. It is an application container that provides the application and service deployment/removal functions. It is designed to be an application repository for support application/service distribution which gives the system scalability - the service network can be extended dynamically, robustness- the services can be duplicated and distributed around the network and processing power - a service can be a composite service where parts of it are distributed around the network. The Apricot agent container is presented in Fig 3.

Both the agent service and the agent container contain three layers, which are the same in both implementations (The HTTP/Socket front end, Application Pool and Transport Layer). These three components form functionality similar to a simplified EJB framework where there is a container component, which contains the Java beans, and the application part, which is implemented with Java beans. In the Apricot platform, these two main components of the EJB paradigm correspond to the agent container as the environment and Apricot agent as the Java bean. The major difference in these implementations can be found in the functional implementation of the developed application.

1.4. The Apricot Agent

According to the Java bean model, Apricot agent can be described as an entity bean, which describes the functionality most accurately.

However, it is still not a comprehensive definition for an Apricot agent. The main difference comes from the design of the Apricot agent, which encloses the session bean functionality and also partially enfolds the functionalities of the message-driven object. This is due to the process-like nature of the task instances. These tasks are run concurrently and they form the applications by themselves or they are sub-units of another application. The design of the apricot agent model, illustrated in Fig 4, has been influenced by the UNIX architecture, and the functional model in particular.

The development of the Apricot agent model was guided by the goal to hide some of the peculiarities of the agent technology and to develop tools that ease the application development for developers who are not familiar with agent technology. The outcome of this was the Apricot agent model, which uses the EJB model and leans on the task and process model of the UNIX architecture. The EJB model is used because of its design, which encapsulates and defines the entities and their capabilities from each other to form an easily manageable object model. The EJB model is extended in the Apricot agent model by introducing a task paradigm for the service and application construction. These tasks are the building blocks of the different application. They conceal some of the agent-related concerns from the developer, such as the language, ontology, protocol and content language processing. This approach is similar to what is described by Berger et al. [24]. They named these components generic service

components. The comparison between the characteristics of Apricot agents and Java beans is presented in Table 1.

1.5. The Apricot Service Model

The Apricot platform is an environment for developing and deploying heterogeneous services into the IP network. These services are consumed by the end user via his personal agent, which acts as an interface to the service network composed of heterogeneous service agents.

The Web Services model is used and extended in the service discovery and the consumption of the discovered services. The personal agents adapt themselves to the service, which is described using the RDF format [25]. These descriptions are published in and queried from the Yellow Pages service. These service descriptions contain information about the service itself, service provider, service location, language, protocol, ontology, the location and names of the Java classes that implement the functionality, and also the names of the Midlet UI classes and their locations.

According to the service descriptions, the personal agent loads the Java classes and starts using the service accordingly. These service descriptions made in RDF format remotely follow the Semantic Web [26] approach where the research focus is on describing the web resources and pages to enable the use of the web content by computers. The service usage is presented in Fig 5. The figure describes the sequence of events in an example scenario where Mike's personal

agent has already adapted itself to a news service and is now providing the service for him.

The EJB framework was used here to illustrate the similarities between the designs of these two systems and to give a solid cornerstone for comparison of the Apricot platform. The motivation to create an Apricot system came from the mobile world where the mobile users needed to be served with services that have some degree of personalization and context awareness. The common Personal Agent (PA) model was the most suitable for this scenario. However, this scenario posed a handful of design issues that had to be solved accordingly.

1. The system should be able to facilitate a large number of PA's.
2. This should be done in a manner in which the maintenance would not become an issue.
3. The PA's should be able to adapt new services dynamically.
4. How the services should be designed so that they could be dynamically adaptable.
5. How the terminal represents the new services adopted by PA's and how they are consumed by the end user.

The first two issues of the PA paradigm will not pose a problem for the EJB implementation, but the last three are somewhat out of the scope of the EJB intended application area.

Implementation of Mobile Applications using Apricot Agent Platform

This section briefly describes the demonstrators built on the Apricot platform. The original assumption was that using Apricot Agent Platform would make the development of multi-user applications and services easier and faster that without the help of such tools.

The demonstrators have been realized to validate features in the platform that support person-to-person communication, community communication, content management and multi-agent coordinated tasks. Moreover, these demonstrators aim to prove that development of mobile services using the Apricot platform is relatively easy and fast and, furthermore, take advantage of the capabilities of the agents. These demonstrators were built in a short time by exploiting the features provided by Apricot Agent Platform.

The descriptions of demonstrators introduce the main features and advantages of each application. The four demonstrators are *Mobile Instant Messenger*, *Mobile Car Salesman*, *Location- and user preference-based messaging application* and *Service Viewer*.

1.6. Mobile Instant Messenger

The Apricot Mobile Instant Messenger (IM) is a demonstrator built on Apricot Agent Platform. The main purpose of building the demonstrator was to test the basic features of the platform. These features include content sharing, networking, management of personal agents and communication between personal agents.

The main features of Mobile Instant Messenger are:

- Private instant messaging between different registered users.
- Public chatting between registered users of the chat channels.
- Management of different chat channels.
- Sharing of textual content within a community.

The functionality of the demonstrator can be realized using existing technology like Short Message Service (SMS), which might have been an even more robust means of realizing previously-mentioned functionality. There are also other instant messaging services available for mobile terminals e.g. in [27]. However, the purpose of realizing the instant messaging service using Apricot Agent Platform was to assess the viability of the platform. The communication concept of the mobile instant messenger demonstrator has been illustrated in Fig 6.

Mobile instant messenger clients were implemented in a Symbian environment on a Nokia 6600 mobile phone. In figure 6, the messenger clients can be considered to be the users called Lisa, Mike, Pekka and Joe. The terminal client was implemented using Java Mobile MIDP version 2.0. Networking was done over GPRS connections.
Mobile Instant Messenger was implemented in a couple of weeks by a programmer who was not involved in the development of the platform. During the course of developing the demonstrator, the Apricot platform proved to be a useful tool for realizing this kind of mobile service. Despite the claim of usefulness of the platform, it must be stated that an alternative implementation was not realized. Therefore, we can only assume that when using an Apricot platform the implementation was

effective, since the platform takes care of basic mobile service routines such as networking and message routing.

1.7. Mobile Car Salesman Application

The Mobile Car Salesman application was built up to prove the reusability and flexibility of services and applications previously implemented on top of an Apricot platform. The Apricot Instant Messenger application existed at the time the design and implementation of the Car Salesman-demonstrator was started. The other point of interest was the next generation mobile services, in which there will be a high level of interactivity in B2C markets. In particular, mobile marketing is a growing area of business and the demand for user-friendly, flexible mobile service development tools will grow.

Dealer end features of the Mobile Car Salesman application are:

- A duplex communication channel between the dealer and customers for customer approved conversation initiation.
- A view of users' requirements for the car
- A way for the dealer to update the cars-for-sale information.
- A channel for sending advertisements.

Customer end features:

- Browsing through the list of cars for sale.
- Update the watcher's information concerning requirements for cars.
- Modifying the alert routines and channels.

- Browsing and responding to received advertisements.

All communication in this application was built on the existing instant messenger (IM) software. This application uses the IM software for carrying the messages concurrently while the other user uses the IM for its original purpose. The development time used on the Car Salesman application was reduced due to the high reusability of the existing IM software.

This experiment does not give an accurate result regarding how flexible the platform actually is or what the actual reduction of development time is. However, it states the benefits of developing new applications on top of others. It also proves that the platform design supports the expandability of the applications as planned. This feature also raises questions on what will happen if the underlying application is updated. This kind of situation is handled by the Apricot platform if the Apricot agent design guides have been followed during the implementation of application.

The Apricot platform has a built-in feature, which automatically updates those clients that are trying to use the recently updated service. This update operation is done dynamically and does not require any manual work by the system administrator. The update sequence is in fact almost the same procedure as the service adaptation done by the Apricot Agent when they adapt a service for the first time.

1.8. Location- and user preference-based messaging application

An application for context-aware messaging was built to test and demonstrate the possibility of combining the Apricot platform and a reactive, event-driven control system in order to achieve a reliable and fast compound system. The basic idea was to design robust control architecture for context-based applications such as context-sensitive message delivery. For instance, context-sensitive message delivery can be used for location-dependent communication between family members or workmates.

In order to enhance the reliability and robustness of the system depicted, a two-level architecture has been developed. The system is distributed into intelligent and reactive domains. In the intelligent domain, the Apricot platform is used for high-level reasoning. In the reactive domain, independent state machines are used for message delivery.

The reactive level components of the system are independent state machines capable of using contextual information during their execution. Reconfigurable state machines are constructed on–the-fly from RDF-based State Machine Markup Language descriptions [28]. The reactive system is used for delivering messages based on the contextual information, such as location information from a Position and Navigation System (PANS). Messages are received via an IMAP4-compliant email server and presented with the terminal device most suitable for the user's current context. Communication between the components is arranged through a simple CORBA-based interface called Property Service, also introduced in [28].

Apricot platform agents are used for controlling and configuring the reactive system. The intelligent agent acquires contextual information to make high-level control decisions. Based on the decisions, the agent configures the reactive components by supplying new SMML-descriptions for the state machines. In the actual implementation depicted in Fig 7, decision-making is made by the user via the agent's configuration interface.

The intelligent and reactive domains can be physically separated into a logical system, where reactive components are executed in-house and intelligence is provided by an external party. Loose cohesion between the intelligent and reactive domains enables continuous system functionality even during network disruptions. The idea of using an agent system to control self-reliant applications is thus applicable.

1.9. Service Viewer

A Service Viewer application evaluates the support of Apricot platform in the adaptation of mobile services in the user's mobile terminals. In this application, the user's personal agent (PA) dynamically adapts the terminal user interface according to the variable services. The Service Viewer has mechanisms to deliver the services built in the Apricot network (E.g. Instant Messenger, Mobile Car Salesman, etc.) to the users of these services. Service descriptions define the appearance of services in terminal. The Viewer also provides the user with an execution frame for the GUIs and the delivered information.

The Apricot terminal deals with this problem by regenerating the terminal application-midlet every time the user wants to start using a new service provided by the Apricot network. This regeneration is supervised and carried out by the users PA, which knows the current composition of the user's terminal. It also receives the information about services the user would like to use. According to this information, it prepares and delivers a new Service-midlet into the user's mobile phone.

This approach to implementation of the terminal-application gives the service developer the opportunity to freely and independently design the service GUI's and their functionalities. This is not the case, for example, if the developer is using a terminal platform that uses some UI description language, such as the user interface markup language (UIML) or extensible user interface language (XUL). Despite the benefits in the Apricot terminal application, there are also drawbacks. The main drawback is that the use of the service viewer requires a lot of bandwidth, because the terminal software easily grows to more than 1mb in size. Most likely it will continue to grow even larger. Another problem we encountered was the unstable implementation of the Java Over the Air (OTA) specification by some mobile terminal manufacturers. A lot of features specified in the OTA specification were missing from the mobile phone implementations. Due to this problem, there are no guarantees that the software developed for one Java MIDP 2.0 enabled mobile phone will work in another. Furthermore, there are even fewer guarantees of compatibility between software and the program code in the actual mobile phone. This

problem will probably diminish over time as the implementations of the OTA specification get better.

Conclusions

The vision behind this research was the requirement to assist the use of mobile services by integrating several services in a way that is convenient and transparent for the user. Our research approached the solution step by step, first by developing technology enablers for mobile service providers and secondly by making demonstrators, the aim of which is to solve the usability and availability problems of mobile services. As our work continues, we will be able to produce user-friendly mobile services with the help of Apricot platform.
This paper has shown how agent-based systems can be used for developing software systems, particularly for producing user-friendly mobile services. We also show how Apricot Agent Platform facilitates the implementation work of mobile services by providing an agent platform and agent frames with basic functionality. We have built several demonstrators for evaluation purposes of Apricot platform, we have used less hours for building up the demonstrators than ever before for producing mobile services.
We have been able to show that Apricot system provides an easy way to produce mobile services, since the agents have basic features already built-in, such as functionality and communication mechanism. In other words, agents can be considered partially reusable software components.

As the tendency for mobility grows all the time, we have also introduced a lightweight version of the Apricot platform. Apricot Agents are able to provide an interface on mobile phones with Java Virtual Machine support. In the demonstrators, so called Smart Phones-type mobile phones were used as they provide relatively good processing power as well as memory capacity. We believe that it would also be possible to implement Apricot systems in mobile environments with more limited resources; however, this kind of test was not carried out during the experiments described in this paper.

These results of Apricot research can be extended in a number of directions. We have two major targets for development: to further develop Apricot platform to fully rise to the challenge set by the mobile environment and to develop Apricot-supported applications for real business cases to benefit users. Technically, the development of the platform has to improve usability, stability and performance in order to test it in real-life business cases.

Acknowledgment

References

1.   Senn, J.A., The Emergence of M-Commerce, Computer , vol. 33 (12) , pp. 148-150, 2000.

2.   Snellman, K., Mobiilipalvelumarkkinat Suomessa 2003 (In Finnish), Liikenne-ja viestintäministeriön julkaisuja 24/2004.

3.   Anckar, B.; D'Incau, D.; Value-added services in mobile commerce: an analytical framework and empirical findings from a national consumer survey, System Sciences, 2002. HICSS. Proceedings of the 35th Annual Hawaii International Conference on , 7-10 Jan. 2002

4.   Antoniou, G., Van Harmelen, F. A Semantic Web Primer, MIT Press, ISBN 0-262-01210-3, April 2004b

5.   Jennings, N.R. and Wooldridge, M.J. 1998. Applications of Intelligent Agents. Agent Technology: Foundations, Applications, and Markets. Jennings, N.R. and Wooldridge, M.J (Eds.), Springer, pp. 3-28.

6.   Aylett R., Brazier, F., Jennings, N., Luck, M., Preist, C., and Nwana, H., Agent Systems and Applications, The Knowledge Engineering Review, 13(3), 303-308, 1998.

7.   Helaakoski, H., Feng, S.C., Jurrens, K.K., Ojala, K., and Kipinä, K., Collaborative Software Agents in Steel Product Industry, The IASTED International Conference on Artificial Intelligence and Applications, Innsbruck, Austria, February 16-18, 200

8.   Stroulia, E., and Hatch, M.P., An Intelligent Agent Architecture for Flexible Service Integration on the Web, IEEE Transactions on Systems, Man and Cybernetics-Part C. Applications and Reviews, vol.33,no.4,November 2003.

9.   Riekki, J., Huhtinen, J.; Ala-Siuru, P.; Alahuhta, P.; Kaartinen, J.; Röning, J., Genie of the net, an agent platform for managing services on behalf of the user , Computer Communications.Vol.26(2003) Nr:11,pp.1188 - 1198

10.   M. Berger, M.,et al., "Porting Distributed Agent-Middleware to Small Mobile Devices," Proc. First Int'l Joint Conf. Autonomous Agents and Multi-Agent Systems (AAMAS '02), Workshop 16 (Ubiquitous Agents on Embedded, Wearable, and Mobile Devices), 2002.

11.   Poslad, S., et al., "CRUMPET: Creation of User-Friendly Mobile Services Personalised for Tourism," Proc. Second Int'l Conf. 3G Mobile Comm. Technologies (3G 2001), 2001.

12.   Tarkoma, S., and Laukkanen, M., "Supporting Software Agents on Small Devices," Proc. First Int'l Joint Conf. Autonomous Agents and Multi-Agent Systems (AAMAS-02), 2002.

13.   Laukkanen, M., Helin, H., and Laamanen, H., "Supporting Nomadic Agent-Based Applications in the FIPA Agent Architecture," Proc. First Int'l Joint Conf. Autonomous Agents and Multi-Agent Systems (AAMAS '02), 2002.

14.   Maamar, Z., Dorion, E., Daigle, C., Toward Virtual Marketplaces for E-Commerce, Communications of the ACM, 44(12):35:38, Dec. 2001.

15.   Mäntyjärvi, J., Sensor-based context recognition for mobile applications. Espoo, VTT Electronics, 2003. 118 p. + app. 60 p. VTT Publications; 511, ISBN 951-38-6253-4; 951-38-6254-2, http://www.vtt.fi/inf/pdf/publications/2003/P511.pdf

16.   Web services http://www.w3.org/2002/ws/

17.   Enterprise JavaBeansTM Specification,, http://java.sun.com/products/ejb/ Version 2.1

18.   FIPA Abstract Architecture Specification, http://www.fipa.org

19.   W3C Semantic Web Activity: www.w3.org/2001/sw/

20.   FIPA ACL Message Structure Specification http://www.fipa.org

21.   N-Triples W3C RDF Core WG Internal Working Draft. http://www.w3.org/2001/sw/RDFCore/ntriples/

22.   Notation 3 by Berners-Lee http://www.w3.org/DesignIssues/Notation3

23.   Nokia, Mobile Internet Technical Architecture, "Solutions and tools", IT Press

24.   Berger M., Bouzid M., Buckland M., Lee H., Lhuillier N., Olpp D., Picault J., and Shepherdson J., "An Approach to Agent-Based Service Composition and its Application to Mobile Business Processes" IEEE Transactions on Mobile Computing Vol. 2, No. 3, July-September 2003

25.   Resource Description Framework (RDF): Concepts and Abstract Syntax, http://www.w3.org/RDF/

26.   Berners-Lee T., Hendler J. and Lassila O. (2001) The Semantic Web. Scientific American, May.

27.http://my-symbian.com

28.   Mäenpää T., Tikanmäki A., Riekki J., Röning J. (2004) A Distributed Architecture for Executing Complex Tasks with Multiple Robots. The 2004 IEEE International Conference on Robotics and Automation (ICRA), New Orleans, USA, April 26 - May 1, 2004.
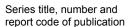
Table 1. Comparison of the Features of an Apricot Agent and EJB Objects

The Apricot Agent	Corresponding EJB-Object
1) Concurrent multiple service/skill task execution environment.	-

2) Static developer defined or dynamic service/skill composition.	-
3) Can act as a client and/or a server.	-
4) Provides an object view of data in the database.	*Entity Object*
5) Allows shared access from multiple users.	*Entity Object*
6) Identified by a unique key.	*Entity Object*
7) Can be long-lived	*Entity Object*
8) Is asynchronously invoked.	*Message-Driven Object*

Figure legends:

Fig. 1. The Apricot Architecture

Fig. 2. The Apricot Agent Service

Fig. 3. Apricot Agent Container

Fig. 4. Apricot Agent Model

Fig. 5. Apricot Service Usage Model

Fig. 6. Components of Mobile Instant Messenger Demonstrators

Fig. 7. Control Architecture Implementation

Author(s)
Helaakoski, Heli

Title
Adopting agent technology in information sharing and networking

Abstract

The thesis describes the adoption of agent technology for information sharing and networking. Companies are engaged in networking with changing partners and information sharing among enterprises with heterogeneous system environments is increasing all the time. Since the types and sizes of the networked companies vary, flexible, effective information sharing systems are needed. Networking systems have to conform to the requirements of different information technology structures and information representation formats. Small and medium-sized enterprises in particular need flexible, effective networking solutions.

The thesis reviews the use of agent-based applications in industrial environments, and especially in supply chain management. Agents are autonomous, problem-solving computational entities capable of effective operation in dynamic and open environments, and therefore they are able to provide a suitable means of complex process management among networked companies. The thesis describes the agent-based system called SteelNet, for networking in supply chain management, and its design and implementation in a case business network.

VTT PUBLICATIONS

657   Szilvay, Géza R. Self-assembly of hydrophobin proteins from the fungus *Trichoderma reesei.* 2007. 64 p. + app. 43 p.

658   Palviainen, Marko. Technique for dynamic composition of content and context-sensitive mobile applications. Adaptive mobile browsers as a case study. 2007. 233 p.

659   Qu, Yang. System-level design and configuration management for run-time reconfigurable devices. 2007. 133 p.

660   Sihvonen, Markus. Adaptive personal service environment. 2007. 114 p. + app. 77 p.

661   Rautio, Jari. Development of rapid gene expression analysis and its application to bioprocess monitoring. 2007. 123 p. + app. 83 p.

662   Karjalainen, Sami. The characteristics of usable room temperature control. 2007. 133 p. + app. 71 p.

663   Välkkynen, Pasi. Physical Selection in Ubiquitous Computing. 2007. 97 p. + app. 96 p.

664   Paaso, Janne. Moisture depth profiling in paper using near-infrared spectroscopy. 2007. 193 p. + app. 6 p.

666   Prunnila, Mika. Single and many-band effects in electron transport and energy relaxation in semiconductors. 2007. 68 p. + app. 49 p.

669   Aarnisalo, Kaarina. Equipment hygiene and risk assessment measures as tools in the prevention of *Listeria monocytogenes* -contamination in food processes. 2007. 101 p. + app. 65 p.

670   Kolari, Kai. Fabrication of silicon and glass devices for microfluidic bioanalytical applications. 2007. 100 p. + app. 72 p.

671   Helaakoski, Heli. Adopting agent technology in information sharing and networking. 2007. 102 p. + app. 97 p.