Multiple Agents-Enabled Systems Coalition for Integrated Manufacturing Processes and Supply Chain Management For Steel Industry

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Abstract: Most business negotiation in supply chain and information exchange in manufacturing processes are heavily human-involved. The processes of negotiation and information exchange are usually time consuming and unreliable. Software agents have been increasingly explored to improve the information flow and the decision-making process. 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. Further evolvement of the frameworks to other industries is expected.

1. Introduction

Networked manufacturing enterprises are now moving towards open information exchange for integrating their activities with those of their suppliers, customers, and partners within supply chain networks. Due to the rapid evolvement of Internet technology, software agents can be used to improve the information flow and the decision-making process within a company and among collaborative companies in a supply chain. E-business started with using the Electronic Data Interchange (EDI) [1] standard to tender invitations, render quotes, and transfer procurement orders. Since Web-based technology and standards are prevalent, Rosettanet [2] and ebXML [3] have been adopted by an increasing number of companies as the current standards. Recently, agent technology has been considered as an important approach for developing industrial distributed systems. Software agents can 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 enterprises' activities such as design, planning, scheduling, manufacturing execution, and product distribution, with those of their suppliers, customers, and partners into an open, distributed intelligent environment via networks [4], [5], [6].

In this paper, we present how agents and agent systems can assist in transmitting information within and between companies. A community of agents can make decisions and carry out tasks within a manufacturing network company or across companies in a manufacturing supply chain. We have proposed 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 aim of the SteelNet project is to research the use of agents in industrial business networks by developing an agent-based prototype. 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 U.S. Government. Within the NIST research activities, agent communication is performed in a prototype multi-agent platform to demonstrate sharing of manufacturing knowledge and process data throughout the product lifecycle. 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 framework, 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 [7]. Furthermore this paper introduces the business and manufacturing cases where the first prototype of business and manufacturing agents has been implemented collaboratively by the PIF and SteelNet projects.

This paper is organized as follows: Section 2 describes a multiple agents-enabled business and manufacturing systems coalition framework. Section 3 presents an ontological engineering environment that supports agent communication. Section 4 provides an overview of our prototype implementations. Section 5 concludes the current work and outlines future plans. Acknowledgements and a disclaimer follow this last Section. All the references are in the last section of the paper.

2. A Multiple Agents-enabled Framework for Business and Manufacturing Networks

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 the relationship management among business entities, as shown in Figure 1. These events are relevant to 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 marketplaces, a network for workflow/supply-chain management, and a network for supplier relationship management [8]. Recently, many researchers, [9], [10], [11], and [12] have studied the use of software agents that are autonomous and intelligent for easing this complex surrounding of business networks in electronic commerce.

Figure 1 also shows that a company's business network is connected to the company's own 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 computerized models of products or processes, visualize data, and do scientific computation for making decisions.

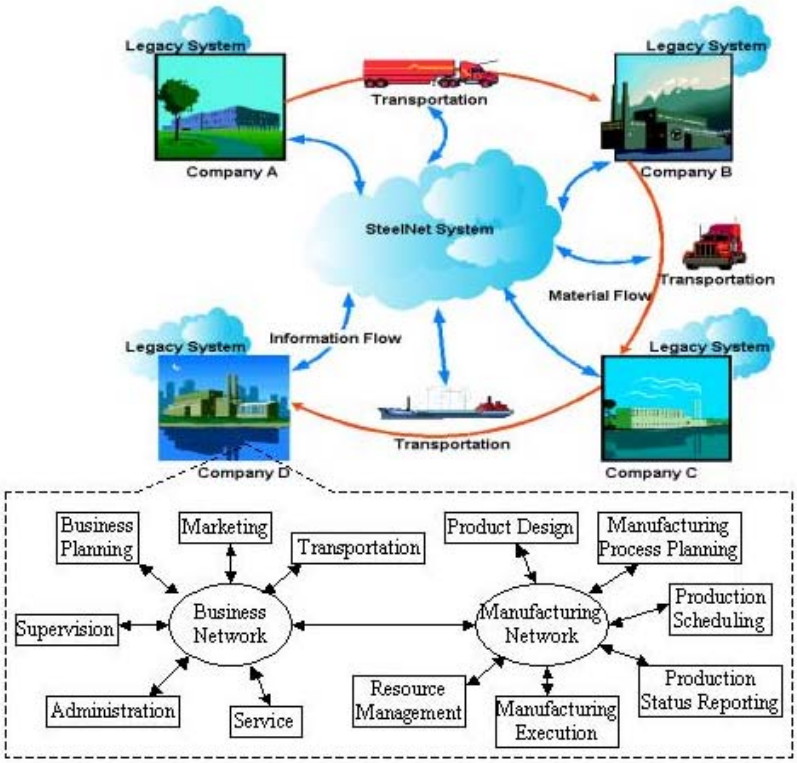

Figure 1 Business and Manufacturing Networks

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). 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. There is a firewall protecting the company network. The agent platform in the main agent container, connected to the Internet, provides a facility for agents of all the companies in the business network to communicate with each other. Furthermore, the agent may register its capability and identification in the agent platform. The agent platform 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 between the agent platform, which may contain the main agent container, and agent containers located in companies, is secured by using the Secure Socket Layer (SSL) connection. The agents in this architecture are decentralized. In a large business network, software tools, databases, and knowledge bases are usually distributed.

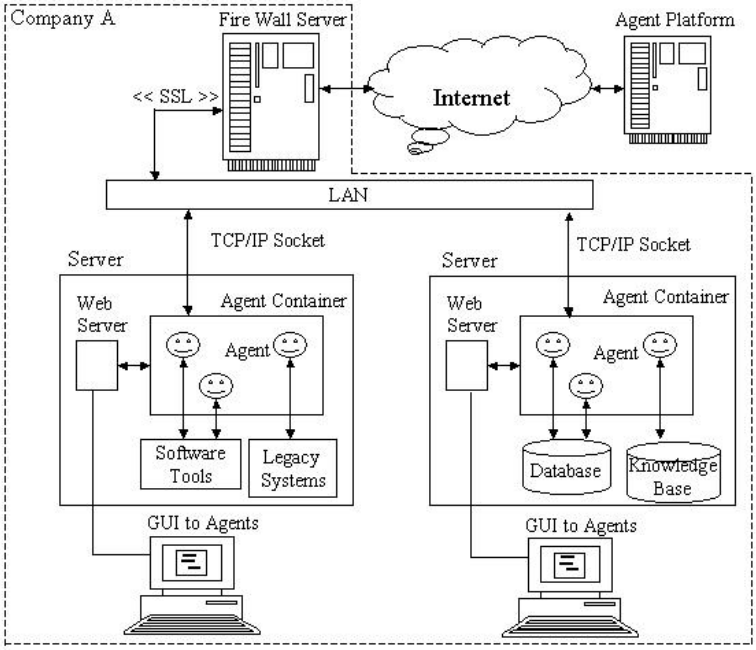

Figure 2 Logical View of Networked Agents

3. 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 relations among them. The JADE [13] compatible ontology was designed and implemented using the Protégé ontology editor [13]. In the PIF project the Web Ontology Language (OWL) [15] and Process Specification Language (PSL) [16] 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 [17].

4. Prototype 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) program 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 optimization, 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 3. A machining process simulation was performed, as shown in Figure 4. Details of the implementation are described in [18].

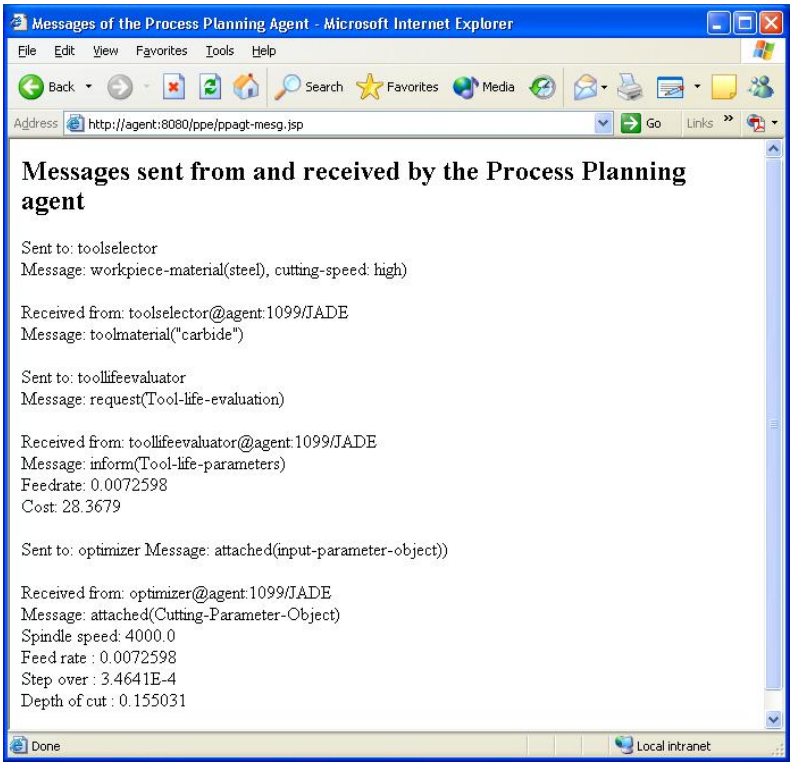

Figure 3 Messages of an agent

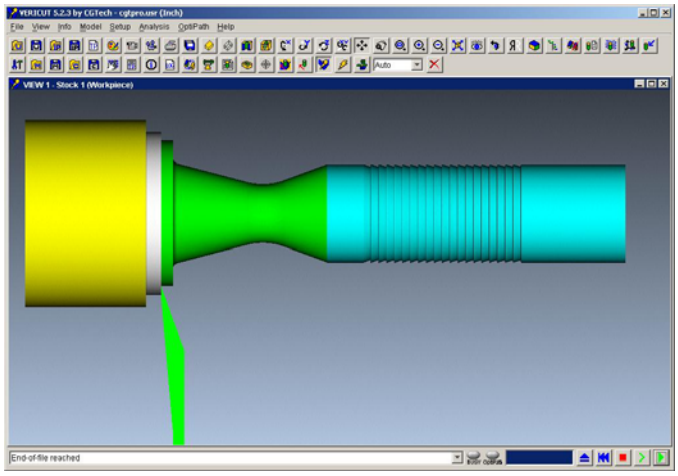

Figure 4 Machining Process Verification

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 a 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 designing, manufacturing, transportation 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 a 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 necessary actions. For example, when there are delays in the manufacturing process, a company agent alarms the company's supervisor to re-arrange their internal work schedules, thus helping to reduce any undesired bull-whip effect and to maximize the utilization of their machinery.

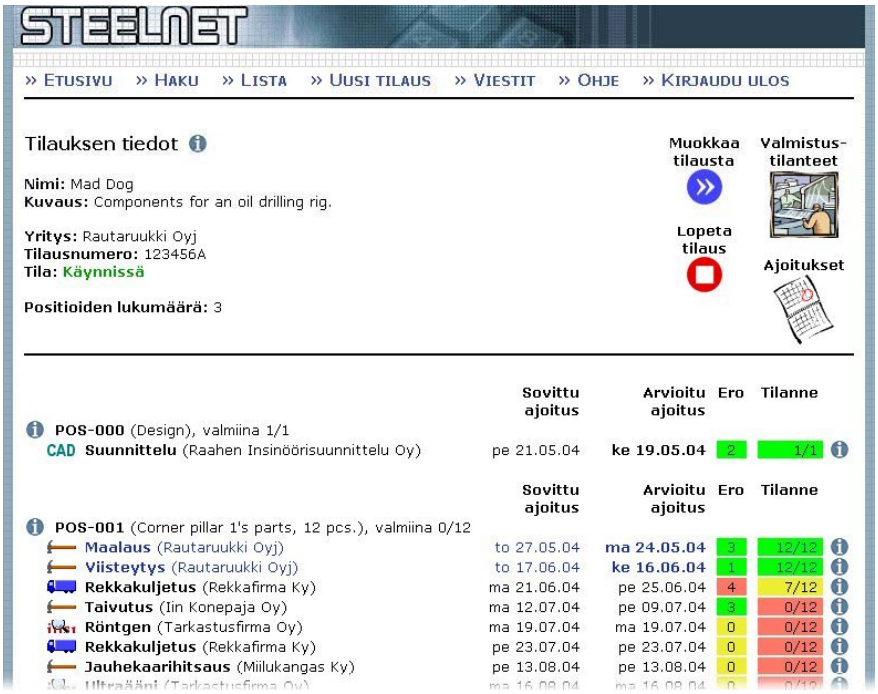

Figure 6 GUI of the SteelNet manufacturing agent showing an overview of a manufacturing process

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 6 presents the basic order view user interface of a manufacturing company agent. 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 color codes so users can quickly notice whether the manufacturing is on, ahead, or behind an agreed schedule.

The SteelNet prototype has been implemented by using the JADE (Java Agent Development Framework) agent platform. JADE was selected due to its use of the platform-independent Java programming language and compliance to FIPA standards for software agents [13].

5. Conclusions and Future Work

In this paper we have introduced a software agent-enabled process integration framework, which exploits software agents in business network and distributed automation for manufacturing enterprises. By means of two prototypes, 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 is 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. 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 agents system can also provide alarms, which inform users automatically about unexpected changes in 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. 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 VTT (Technical Research Centre of Finland) and NIST. 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.

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