TOWARDS AN INTERNET ENABLED COOPERATIVE MANUFACTURING MANAGEMENT FRAMEWORK

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In this paper, manufacturing management issues are addressed at three levels: inter-enterprise, intra-enterprise and shop floor levels. An Internet enabled framework based on Web services and software agents for cooperative manufacturing management is proposed. A Web based integration environment consisting of an agent based scheduling system, a Web based remote monitoring and control system, and corresponding services is designed and developed for the shop floor management. Prototype implementation is briefly introduced and the ongoing research is prospected.

1. INTRODUCTION

A company that handles all aspects of business activities today focuses only on its core competencies. A Virtual Enterprise (VE) is seen as a temporary alliance of enterprises that come together to share skills and resources in order to better respond to business opportunities, and whose cooperation is supported by computer networks and adequate IT tools and protocols (Camarinha-Matos and Afsarmanesh, 1999). In view of the fact that these distributed organizations are generally managed by dissimilar software systems running on heterogeneous platforms, the recently emerged Web services can provide a higher-level interoperability for connecting business applications across the Web both between enterprises and within each individual enterprise.

In this research, the manufacturing management issues are considered not only at the VE level (inter-enterprise), but also at the enterprise level (intra-enterprise) and the shop floor level. Our previous achievements including *iShopFloor* on the application of software agents to distributed intelligent manufacturing process planning and scheduling and *eShopFloor* on the development of a Web based environment for remote monitoring and control of manufacturing devices (e.g.,

machines, robots) are seamlessly integrated into a cooperative manufacturing management framework proposed in this paper.

The paper is organized as follows: Section 2 provides a brief literature review; Section 3 describes our cooperative manufacturing management framework at inter-enterprise, intra-enterprise and shop floor levels; Section 4 presents briefly a prototype implementation. Section 5 concludes the paper with some perspectives.

2. LITERATURE REVIEW

In this section, we will provide a brief review of Internet and agent applications in manufacturing and virtual enterprise infrastructures.

2.1 Internet and Agents Applications in Manufacturing

Multi-agent has emerged as a promising technology for dealing with cooperation and decision-making in distributed applications. Agent based manufacturing has become a new paradigm for next generation manufacturing systems, together with other manufacturing paradigms such as Holonic Manufacturing Systems, Agile Manufacturing, Reconfigurable Manufacturing, etc. We have conducted an extensive literature survey and published the results previously (Shen and Norrie, 1999; Shen et al., 2001).

During the past decade, the “explosive” evolving of the Internet and the Web has made them the most suitable enabler to implement geographically distributed applications. A number of methods and frameworks have been proposed for building Web based systems for collaborative design and manufacturing. Examples of such systems include *CyberCut* (Smith and Wright, 1996) for Web based rapid machining, *WebCAD* (Kim et al., 1999) for on-line feature-based manufacturability checking, *WEB-DPR* (Xiao et al., 2001) for asynchronous collaboration of complex distributed product realization activities over the Internet, *NEMI* (Dugenske et al., 2000) for a plug and play factory shop floor line control and *iShopFloor* for distributed intelligent manufacturing process planning, scheduling, sensing and control (Shen et al., 2000).

Upon the machine execution level, in order to seek the opportunity in linking CNC machines with the Internet, MDSI uses *OpenCNC* (<http://www.mdsi2.com/>), a Windows-based real time software controller, to automatically collect and publish motion and PLC data on a network. The e-Manufacturing Networks Inc. (Canada) introduced its *ION Universal Interface* and *CORTEX Gateway* (<http://www.e-manufacturing.com/>) to help the old systems go online. Hitachi Seiki and Mazak (Japanese commercial CNC vendors) have also provided solutions since late 1990s for putting machining centers on public networks other than the serial port communication over DNC. We have done a comprehensive survey of similar projects/devices from 21 different vendors (Demirci et al., 2002).

2.2 Virtual Enterprise Infrastructures

Recently significant changes have been made to enterprise strategy and manufacturing paradigms. Virtual enterprise is considered the most advanced and efficient form of networked enterprise organizations. A large number of projects are addressing various aspects of VE infrastructures. Some of the most representative ones are *NIIP* (<http://niip01.npo.org/>), *PRODNET II* (Camarinha-Matos and

Cardoso, 1999), *VIRTEC* (Bremer and Molina, 1999), and *Co-OPERATE* (Azevedo et al., 2002).

NIIP is the largest and the most significant project in VE and industrial supply chain area. Based on OMG, STEP and Workflow, the service based reference architecture applies in particular to the shipbuilding industry. In *PRODNET II*, a consortium is designed and implemented as an open infrastructure. A cooperation layer is attached to each enterprise's internal modules to handle all enterprise cooperation events. The widely used Global Virtual Enterprise framework presented in *VIRTEC* project consists of three components: Virtual Enterprise Broker (VEB), Virtual Industry Cluster (VIC), and Virtual Enterprise (VE). VEB provides general services such as business opportunities recognizing, partners searching, configuring, and performance tracing. The European IST project *Co-OPERATE* aims at developing solutions to enhance the supply chain network of automotive and semiconductor companies. An integrated infrastructure is designed on top of legacy transaction systems with XML being chosen for interoperation between heterogeneous systems. In the virtual enterprise scenario, multi-agent agile scheduling (Rabelo et al., 2001), engineering design platform (Alzaga and Martin, 1999), distributed information management (Tian et al., 2002) and business process management (Camarinha-Matos and Pantoja-Lima, 2000) are also addressed in various projects.

In the above projects, although many advanced technologies are adopted, such as CORBA, DCOM, STEP, and EDI, the inter-enterprise coordination in these projects is basically the extension from ERP level to supply chain level (either virtual or non-virtual) by packing different functions as agents. The core design methodologies and system infrastructure are still centralized, without full utilization of the latest advances of the Internet and component based technologies. In this paper we will present a loosely coupled and a more secured integration infrastructure for VE cooperation based on Web services (Deitel et al., 2002; <http://www.w3.org/2002/ws/>) and agent technology.

3. COOPERATIVE MANUFACTURING MANAGEMENT FRAMEWORK

The cooperation of manufacturing management can be discussed at three levels: virtual enterprise level (inter-enterprise), enterprise level (intra-enterprise) and shop floor level.

3.1 Virtual Enterprise Level

The virtual enterprise framework can be illustrated in Figure 1. All the agents are connected to the Internet through a middleware, in this context, the Web services. The framework in Figure 1 consists of five kinds of agents at the VE level.

Figure 1: Virtual Enterprise Framework

Broker Agent is the one that performs the mediation tasks among enterprises. The functionalities of the broker agent include:

- **Decomposition of orders.** It decomposes orders and extracts product, quality, volume and due date information. The outputs of the decomposition process are individual products or product bundles. A bundle cannot be separated, which means that all the items inside it should only be accepted or rejected as a whole.
- **Creation of VE.** Broker agent configures the network and triggers the partners searching and selection process for product bundles. The patterns of partnership are stored in order to accelerate future VE formation processes.
- **Coordination during the operation of VE.** Broker monitors and evaluates the performance of the virtual enterprise and makes decisions of re-starting coordination dynamically during the VE operation stage if necessary.

Ontology Agent integrates a repository of ontology. For heterogeneous systems, there are different representations for the same group of terminologies, so it is necessary for these systems to understand each other through the support of semantic services provided by the ontology agent. XML has been seen as the most promising middleware for representing ontologies of various business industries. We can consider embedding the existing ontological systems for applications in manufacturing (Schleoff et al., 1999).

Service Registry is either private or public registry. UDDI specifications define a way to publish and discover information about Web services. It can be seen as a directory service where comprehensive specifications of services rather than just names and addresses can be found and returned. The broker searches the service registry for descriptions of partners' coordination services (see Section 3.2) and launches negotiation process for the allocation of inseparable product bundles.

Portal is a Web server and the only entry to the virtual enterprise. Both the external customers and internal users of participating enterprises enter their orders through the portal. It appears as a B2C Web site with the only difference here that business is provided by multiple enterprises.

Enterprise agents represent enterprises connecting to the VE network (the Internet) through common architectures and interfaces as described in Section 3.2.

3.2 Enterprise Level

Each enterprise can be represented by an enterprise agent and has exactly the same architecture to function autonomously and heterogeneously as agents. Enterprise connects to the public Internet and is protected by a firewall for security and privacy reasons. The enterprise model (Figure 2) is composed of three kinds of components (agents) at the enterprise level: coordination agent, service agents and coordination configuration agent.

Coordination agent is the main part to facilitate the inter- and intra-enterprise coordination. Accordingly, two separate layers, VECL (Virtual Enterprise Coordination Layer) and ECL (Enterprise Coordination Layer) can be distinguished in this agent. VECL competes with other VECLs for product (bundles) published by the VE broker while ECL decomposes the tasks received further to sub-tasks by calling the process planning services, and publishes the sub-tasks to shop floor coordinators for task allocation. During the VE operation phase, ECL, VECL and broker agent are responsible for monitoring at different levels of details by utilizing multiple services or XML databases.

Enterprise's legacy transaction systems should be integrated to protect the investments on such systems. Many functional modules that are accessible from enterprise Intranet or the Internet are packed as different **Service Agents**. These services have access to legacy systems, gather or calculate requested data to XML databases for VE and enterprise coordination. Generally, these services are invoked through ECL, while in some occasions VESL can also invoke individual services directly, depending on the coordination strategies set up by the **Coordination Configuration Agent** (CCA). Web services' availability and coordination rationales can be configured, which gives enterprise greater flexibility to decide its own visibility to the outside world.

In Figure 2, the blocks attached by small dark blocks (marked as "service") represent the service providers. These services can be configured publishing to certain levels of details; therefore the coordination is restricted to certain patterns. The detailed description of three coordination modes can be found in (Hao et al., 2003).

3.3 Shop Floor Level

Our previous research achievements, including *iShopFloor* on the application of software agents to distributed intelligent manufacturing process planning and scheduling, *eShopFloor* on the development of a Web based environment for remote monitoring and control of manufacturing devices and shop floor manufacturing services are integrated into a Web based manufacturing management environment for the ease of cooperation among enterprises.

Figure 2: Enterprise Model

3.3.1 Intelligent Shop Floor – *iShopFloor*

The *iShopFloor* is shown as the part inside the dashed oval in Figure 3. The proposed system is mainly composed of three types of components: resource agents, product agents, and service agents. A detail description of *iShopFloor* can be found in (Shen et al., 2000).

All the Machine Agents (MAs) within a shop floor register to a Directory Facilitator (DF), which provides registration service for MAs, look-up service for Shop Floor Coordinator (SFC) and match learning service after task commitments. SFC behaves as the dynamic scheduling coordinator of the shop floor that allocates time and operations to MAs under its supervision as well as the coordination interfaces to legacy systems and other services. The machining process and status information are facilitated and carried out by the Product/part agent (PA, static or mobile) for manufacturing operation monitoring and lower level intelligent machine control.

There is an interface between shop floor level and the enterprise level manufacturing management cooperation, which is the coordination process running between shop floor coordinators and enterprise coordination layer.

Figure 3: Shop Floor Manufacturing Management Environment

3.3.2 Shop Floor on the Internet – eShopFloor

The *eShopFloor* is a Web based collaborative environment for real-time monitoring and control of manufacturing devices in the shop floor. Instead of using camera images, a manufacturing device can be represented by a scene graph-based Java 3D model in an applet. Once downloaded from an application server, the Java 3D model is rendered by local CPU, which not only provides users greater flexibility for visualization but also largely reduces the network traffic (Wang et al., 2002).

In Figure 3, we can see secure partitions of factory network, Intranet and the public Internet. The mid-tier application server connects to the Intranet, factory network and the public Internet (across a firewall) and handles major functionalities and security concerns. All the client transactions have to pass the single entry point, *Session Manager*, for user authentication and session control. The physical machines are connected to the dedicated factory network that is accessible only through *Signal Collector* (a servlet for sensor data collection) and *Commander* (a servlet for passing

control commands). With *Registration* (a list of sensor data subscribers) and *Signal Publisher* (a servlet for sensor data distribution), the system adopts the publish-subscribe pattern to avoid redundant accessing of the same sensor datasets and to reduce network traffics.

3.3.3 Integrated Shop Floor Management Environment

An environment aiming at integrating existing *iShopFloor* and *eShopFloor* systems is developed. As shown in Figure 3, this Web application has been integrated in the *eShopFloor* interface so as to provide the user a unique Web access. Scheduling data is gathered by SFC and stored in Scheduling & Machining Status database. The requests from a Web interface (Gantt chart Java applet) are transmitted to the corresponding Gantt chart servlet, which in turn calls a server-side component (Java Bean) to access the database (Web approach) or to talk with SFC for data retrieval process (agent approach).

Several services of shop floor manufacturing management are constructed as separate components in the scheduling application server for the support of VE and enterprise cooperation.

4. PROTOTYPE IMPLEMENTATION

A proof-of-concept prototype of *iShopFloor* (Shen et al., 2000) is implemented in an agent framework using Java and following FIPA specifications (<http://www.fipa.org/>). Communications among agents are implemented using Java socket communication. All intelligent machine agents use the same software modules with machine-related data (i.e. IP address and port numbers) instantiating before 'plugging' into the network. Product/part agents are represented through Java objects and are serialized into XML form.

An *eShopFloor* prototype (Wang et al., 2002) is developed using the Web and Java technologies to demonstrate the monitoring and control of physical devices in the shop floor. Particularly, the client-side user interface is developed and encapsulated into applets and all the business logics are realized by separate servlets running on an application server. HTTP streaming is adopted for applet-servlet communication.

An integrated software environment has been developed to combine the *iShopFloor* and *eShopFloor* prototypes (Stecca et al., 2003). A Web based GUI is triggered from the *eShopFloor* interface and can display the real time schedules of the entire shop floor as well as an individual machine. Current prototype has functions for zooming, highlighting a machine, checking an individual task, etc.

Shop floor management services are designed and developed as separate components on the application server for future extension from shop floor management to enterprise level cooperation. The whole architecture of virtual enterprise and the enterprise level applications are under development.

5. CONCLUSIONS

A new cooperative framework is proposed to cover all the manufacturing management issues on virtual enterprise (inter-enterprise), enterprise (intra-enterprise) and shop floor levels. Multi-agent and Web services are the main technologies adopted in this framework. For the manufacturing scheduling, monitoring and control of shop floors, this paper presents our recent research on *iShopFloor* and *eShopFloor*. Internet, Java/Java3D, XML, and agents are the key technologies adopted in the prototype implementation. After all these functions can be conducted through the Web, they can easily be wrapped up as services to respond to external requests for shop floor manufacturing processes.

The results presented in this paper are part of our ongoing R&D work. Future work on this research includes: Web services UDDI, SOAP, WSDL implementations; cooperation and business process management of virtual enterprise; distributed information management architecture; and security and privacy mechanisms.

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