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Architecture and operational mechanisms of networked manufacturing integrated platform

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Networked manufacturing is an advanced manufacturing pattern, born out of Internet technology and catering to an increasingly strong trend toward economic globalisation. In this paper the definition and basic features of networked manufacturing are presented, based on a review of state-of-the-art technology and an analysis of the requirements for enterprise collaboration. This paper will also give the architecture and the main functions of the networked manufacturing system, along with the related technologies. As a supportive platform for the implementation and operation of networked manufacturing systems, the Networked Manufacturing Integration Platform (NMIP) is discussed in detail. Since the NMIP must be able to support the collaboration between enterprises as well as to preserve the autonomy of each enterprise, the NMIP based on a multi-agent system control framework is put forward. This paper not only gives the system architecture and the main functions of the NMIP, but also discusses the mechanisms for the integration of applications under the NMIP environment from three aspects including integration technologies, topological structure, and realization strategies. Finally, the application of networked manufacturing in China is briefly presented.

Keywords: Networked manufacturing; Integrated platform; Multi-agent system; System architecture

1. Introduction

Over the last ten years, the advancement of the Internet has ushered in a new era for methods of manufacture. As an advanced manufacturing pattern, networked manufacturing is born out of industrial requirements as well as information technologies, which was also the case for several other former advanced manufacturing patterns (Fan *et al*. 2003). In terms of industrial requirements, enterprises have already begun to use networked manufacturing patterns to improve their business management and enhance their competitiveness in the market. In terms of information technologies, rapid progress and widespread application of information technologies, especially the Internet technology, have accelerated the research and application of the networked manufacturing pattern.

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Montreuil (2000) states that networked manufacturing aims at helping manufacturing businesses not only to survive but also thrive in the dynamic and open business context of the twenty-first century.

Yang (2000) points out that because of rigid organisation structure and centralised resources, traditional manufacturing patterns are inapplicable to the new requirements of a networked economy. Therefore, it has become urgent to develop a market-driven networked manufacturing pattern which is crucial for manufacturing enterprises to break away from their current predicament and to pursue new market profits. Networked manufacturing involves new forms of manufacturing organisation, such as network organisations, extended organisations and virtual organisations. Thus, collaboration and partnership become the important concepts in organisation management. More information can be found in Wright *et al*. (1997) and Cloutier *et al*. (2001).

Networked manufacturing covers the whole product lifecycle. Liu (2002) defines networked manufacturing as a set of manufacturing activities (including market control, product design, material management, manufacturing process, product-sales and after-sales service), manufacturing technologies, and manufacturing systems. Yan (2000) considers that networked manufacturing enables the circulation and integration of information and knowledge from product design to manufacturing, and enables resource sharing between geographically distributed enterprises, thus endowing enterprises with the ability to respond to the market quickly.

Since the early 1980s, a number of research projects sponsored by governments, research institutions and enterprises all around the world have been carried out. In the early 1990s, the American government put forward a plan named 'Advanced Manufacturing Technology' which included the development of the Factory American Net (FAN) designed to integrate the manufacturing enterprises in America. To date, there are many other American projects including the Next Generation Manufacturing (NGM), the National Industrial Information Infrastructure Protocols (NIIIP), and the CSCCM project which aims at computer-supported collaborative management. In addition, Korea, Japan and Canada also have their own networked manufacturing plans. In China, the National High Technology R&D Programme (863 Programme) has also supported a number of research projects on networked manufacturing. In addition, there have been some important international projects such as the Russian–American Virtual Enterprise Network (RA-VEN) funded by America and Russia, and the development of an InteRActive EnGineering Portal for Open Networks (DRAGON) project funded by China and the European Union.

Most of the research projects mentioned above focused only on specific details of networked manufacturing. A systematic theory of the concept, methodology, models and tools is still lacking, thus creating a gap in the research on networked manufacturing. One of the primary purposes of this study is to fill this gap.

Another aim of this study is to develop an effective platform for networked manufacturing systems. Existing platform technologies cannot provide sufficient support for the increasingly large scale of networked manufacturing systems.

The remainder of this paper is organised as follows. Section 2 gives the definition and basic features of networked manufacturing. Section 3 expounds the architecture of networked manufacturing systems, followed by the technologies categorised in section 4. Section 5 introduces the Networked Manufacturing Integrated

Platform (NMIP) as a supportive platform for the construction and operation of networked manufacturing systems. An NMIP architecture based on a multi-agent system co-ordination control framework is presented and the mechanisms for the integration of applications are given. Finally, the application of networked manufacturing in China is briefly presented in section 6.

2. Definition and features of networked manufacturing

As illuminated in section 1, many experts, scholars and engineers have obtained abundant results in networked manufacturing research, which constitute a solid foundation for deeper research into its theories, methods, tools and systems (Fan 2003).

2.1 *Definition of networked manufacturing*

Networked manufacturing consists of basic theories, universal methods, various networked manufacturing systems customised for enterprises and related technologies. The definition of networked manufacturing and some explanations are given below.

Networked manufacturing is an advanced manufacturing pattern that suits the global trends towards a knowledge-based economy and global manufacturing. Its primary goal is to speed up an enterprise's response to the market and to improve the competitiveness of the enterprise. By applying networking technologies, manufacturing technologies and other related technologies, a networked manufacturing system that meets the specific requirements of an enterprise can be constructed. This system can help an enterprise to carry out business activities in the whole product lifecycle while minimizing the limitations caused by the distribution of geographical location. Meanwhile, the collaboration between enterprises and sharing of all kinds of social resources can be realized through networked manufacturing systems, thus providing the market with needed products and services with higher speed, better quality and lower cost.

Here we define 'networking technologies' to include Internet, Intranet and Extranet technologies; 'collaboration between enterprises' to include product design collaboration, manufacturing collaboration, supply chain collaboration and business collaboration; 'social resources' to consist of manufacturing resources, intelligent resources and environment resources.

2.2 *Features of networked manufacturing*

A summary of the basic features of networked manufacturing includes:

- Networked manufacturing is a network-based manufacturing pattern. It provides theory and methodology for enterprise operation and business management in the global environment of the Internet, Intranet and Extranet.
- It covers all the business activities in an enterprise, and provides support for the whole product lifecycle.
- It improves competitiveness of an enterprise by speeding up its response to the market. At the same time, the manufacturing system can reconfigure and reorganise its functions and operational modes to adapt to changes in demands.

- It overcomes the problems caused by distance between the enterprises located far away from each other and enables the collaboration between those enterprises. It helps to control and manage remote resources and processes easily through network. It also provides face-to-face communication with their customers, partners and suppliers.
- It emphasises resource sharing within the whole society. Enterprises should collaborate with each other and make good use of all the social resources in their production activities. Through collaboration and resource-sharing between enterprises, product innovation and manufacturing capabilities are boosted, which leads to low-cost and high-speed product design and manufacturing.
- It can take the form of various configurations and employ a variety of systems with different functions depending on specific enterprise situations and different requirements.

2.3 *The transformations triggered by networked manufacturing*

Since networked manufacturing is a completely new manufacturing pattern that is consistent with the rules of a networked economy, its operational modes and management conceptions of the enterprise differ from the traditional ones. Therefore, in addition to the technological problems in the implementation of networked manufacturing systems, more important issues are how to establish the enterprise culture, management style and operational mode in the network economy environment. The transformations in enterprise management conceptions and operational mode triggered by networked manufacturing are summarised in table 1.

2.3.1 Business range. Networked manufacturing breaks the barriers of business range and management style caused by regional distribution. An enterprise can develop its business globally and find its partners in any part of the world. It can also implement a more adaptive management style with the help of networked manufacturing systems.

2.3.2 Operational time. Since the networked manufacturing pattern is not restricted by geographical distance, the concept of operational time which was previously limited to a time zone has changed greatly. An enterprise can set up

Table 1. Transformations in enterprise management conceptions and operational mode triggered by networked manufacturing.

	Traditional manufacturing	Networked manufacturing
Business range	Limited by regional distribution	Develop business globally
Operational time	Fixed in a time zone	24 hours, seven days a week
Organisational structure	Function oriented	Process- or project-oriented
Resource	Resources inside the enterprise	Resources of the whole society
Relationship between enterprises	Competitive only	Unification of competition and collaboration

a number of development groups in different locations of the world, and transfer the design tasks between these groups. Following their time-zone sequence, the groups make around-the-clock developments possible and significantly shorten the traditional product lifecycle.

2.3.3 Organisational structure. Applying the pattern of networked manufacturing, an enterprise should construct a process- or project-oriented organisational structure so that the human resources are arranged dynamically according to the requirements of the task.

2.3.4 Resource. The enterprise should extend its resource range from resources inside the enterprise to the resources of the whole society. By making good use of all the social resources, including manufacturing resources, knowledge resources and financial resources, the product innovation capability and manufacturing capability can be improved for a single enterprise as well as the whole colony of enterprises.

2.3.5 Relationship between enterprises. In the era of networked manufacturing, it is out-of-date to consider enterprises only as competitors. A conception of competition and collaboration should be emphasised. For example, in the supply chain, the relationship between every two conjoined enterprises changes from a contractual relationship to a partnering relationship, which means the partners should share their knowledge and information, and partake in the shared profit and risk.

3. The architecture of networked manufacturing systems

A networked manufacturing system is a manufacturing-oriented virtual network based on the Internet and other related technologies. Networked manufacturing provides manufacturing enterprises with manufacturing services in a way that is similar to how the Internet provides information services. Furthermore, networked manufacturing supports the collaboration between services and therefore it enables the collaboration between enterprises.

Figure 1 illustrates the operational mode of networked manufacturing. Based on the basic network connection provided by the Internet, Intranet and Extranet and supported by an information integrated infrastructure, networked manufacturing achieves integration in two dimensions. Along the horizontal dimension, it provides a seamless connection between resources and users from various enterprises. In the vertical dimension, it integrates all kinds of manufacturing systems in an enterprise such as PDM and ERP, along with the sharing of all forms of libraries including product resource libraries, manufacturing resource libraries and knowledge libraries.

The architecture of networked manufacturing is a layered structure, as shown in figure 2. The functions of each layer from inner to outer are as follows:

3.1 *Core level*

The core level provides the networked manufacturing system with basic elements such as manufacturing network protocols and the basic technological architecture, which includes all related structure standards, specifications and guidelines.

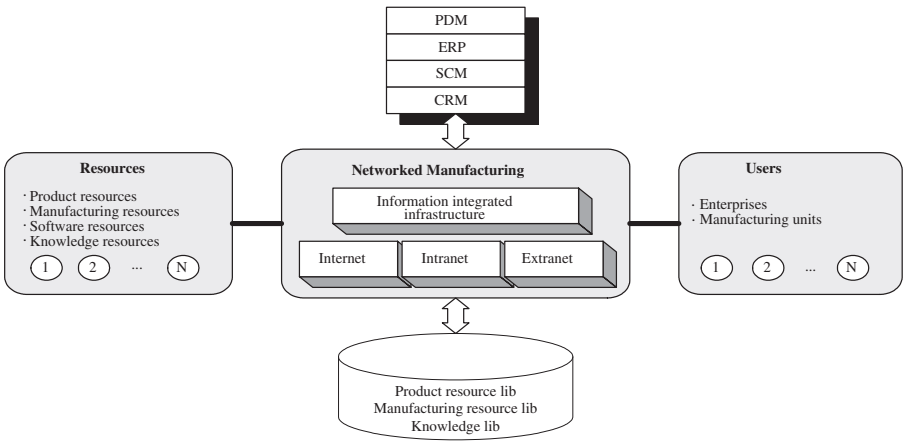

Figure 1. The operational mode of networked manufacturing.

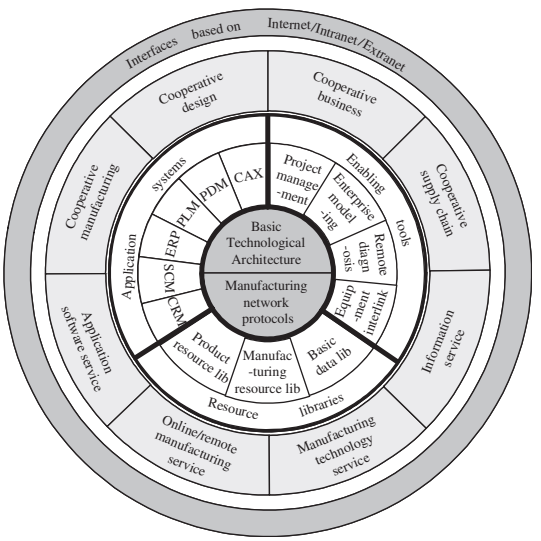

Figure 2. The architecture of networked manufacturing. The levels from inner to outer: Core level; Software and enabling tools level; Applications service level; User level.

3.2 *Software and enabling tools level*

This level includes all kinds of application systems, enabling tools and resource libraries. It supports the building and operation of networked manufacturing systems. The application systems include CAX, PDM, PLM, ERP, SCM, and CRM. The enabling tools include project management, enterprise modelling, remote fault diagnosis and equipment interlink tools. The resource libraries include product resource libraries, manufacturing resource libraries and basic data libraries.

3.3 *Application service level*

This level is composed of the application services which cover most functions during the operation of networked manufacturing, such as co-operative design, co-operative

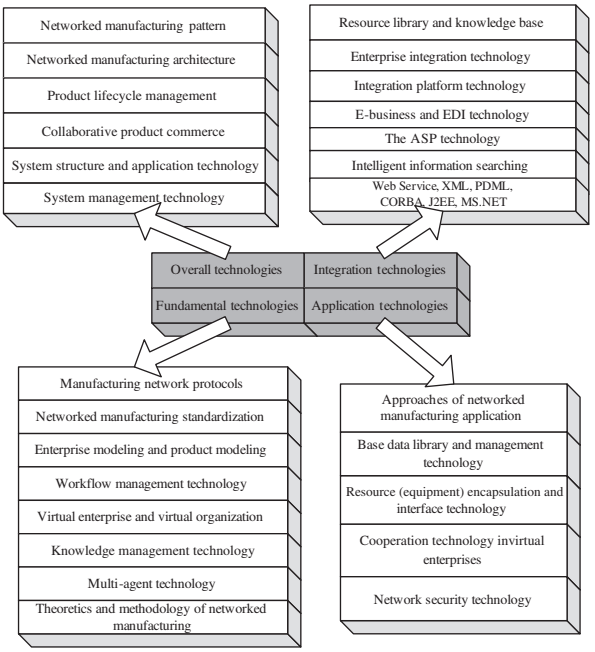

Figure 3. Technologies of networked manufacturing.

manufacturing, co-operative business, co-operative supply chain, information service and manufacturing technology service.

3.4 *User level*

At the user level, the networked manufacturing system provides users with various interfaces based on physical networks such as the Internet, Intranet and Extranet, so that users are able to carry out all kinds of applications with the support of the networked manufacturing system.

As a whole, the core level, software and enabling tools level and application service level are assembled into a NMIP, which will be expounded in section 5.

4. Technologies of networked manufacturing

Many technologies are involved in the development and implementation of networked manufacturing systems. These technologies can be categorised as overall technologies, fundamental technologies, integration technologies and application technologies. Figure 3 illustrates each of these four types of technologies.

4.1 *Overall technologies*

Overall technologies aim at studying the structure, management and application of networked manufacturing systems from a systematic point of view. Overall technologies include networked manufacturing pattern, its architecture, its system

structure and application technology, its operation and system management, as well as some important technologies such as the Collaborative Product Commerce (CPC) and the Product Lifecycle Management. The CPC will be introduced in the following paragraphs as an example of one of these technologies.

According to the Aberdeen Group (1999), CPC is a new category of software and services that use Internet technologies to tie products, marketing, field services, and customers into a tighter global knowledge net. In fact, CPC is not only a piece of software, but also a solution. It also includes a combination of historical systems, and other information repositories.

The CPC technology includes four important features. Firstly, CPC is based on the collaboration between the participants in the value chain. Secondly, CPC pursues not only the local improvement of product design, manufacturing, sale, stock and management, but also the optimization of the value chain from the viewpoint of the whole product lifecycle. Thirdly, CPC helps to represent and exchange the information of various resources within an enterprise or an extended enterprise, and the information here should be organised based on the product design data. Finally, CPC makes product innovations more easily.

There are currently many CPC systems available on the market, such as WindChill (PTC), Accelis (SDRC), and In-key (Unigraphics Solutions).

4.2 *Fundamental technologies*

Fundamental technologies are the common technologies that are used not only in networked manufacturing systems, but also in many other information systems. Fundamental technologies include the theory and methodology of networked manufacturing, manufacturing network protocols, networked manufacturing standardisation, enterprise modelling and product modelling, workflow management, virtual enterprise and virtual organisation, knowledge management, and multi-agent technology.

Among these fundamental technologies, manufacturing network protocols and networked manufacturing standards are the most important. Many protocols and standards are relevant to networked manufacturing such as the National Industrial Information Infrastructure Protocols (NIIIPs) which were developed by the NIIIP Consortium, the protocols and standards developed by the American Production and Inventory Control Society (APICS), the STandard for Exchange of Product Data (STEP), the IEC 61131-3 Industrial Control Programming Standards and the PROFIBUS Industrial Data Highway Standard.

But there are still many standards in networked manufacturing which need to be developed. For example, standards for information exchange in networked manufacturing systems are still lacking, as well as standards for an integration interface allowing applications to be integrated into networked manufacturing systems.

4.3 *Integration technologies*

Integration technologies are system integration and enabling technologies used in design, development, and application implementation of networked manufacturing systems. They include the development of design/manufacturing resource libraries and knowledge bases, enterprise application integration technology, integration

platform technology, the application service provider (ASP) technology, e-business and the electronic data interchange (EDI) technology, intelligent information searching technology and other supportive technologies such as web services. Among these technologies, integration platform technology is the most important in developing networked manufacturing systems, and will be discussed in detail in section 5. The next paragraph will introduce the ASP technology, which represents another important technology in networked manufacturing.

The ASPs emerged in the late 1990s, often as an extension to the functions of Internet service providers (ISPs) in the early years. The objectives of the ASPs are to realize the resource sharing of intra- and inter- enterprises, to improve the innovation capability of manufacturing enterprises, to exploit the group advantage of manufacturing industries, and to promote the establishment of product value chains. The ASP Industry Consortium (2001) defines an ASP as a company that manages and delivers application capabilities to multiple entities from a data centre across a wide area network. A typical ASP hosts software and/or data in a centralised data centre and delivers applications to many users over a network. Usually an ASP also rents its own hardware to customers and provides technical support and maintenance. Small- and medium-sized enterprises are the typical users of ASPs. These enterprises usually have neither enough funds nor qualified staff to set up and maintain the software environment they need. ASPs can bring them a number of benefits, such as lower cost, shorter installation time, lower risk, and the access to the latest technologies (Currie 2000).

4.4 *Technologies of application*

Technologies of application support the application implementation of networked manufacturing systems. Technologies of application include the approaches of networked manufacturing application implementation, basic data library building and management technology, resource (equipment) encapsulation and interface technology, co-operation technology in virtual enterprise and network security technology.

5. Networked manufacturing integrated platform

5.1 *Definition of NMIP*

Based on networks and advanced information technologies, the NMIP is a supportive platform for the implementation and operation of networked manufacturing systems to realize collaboration between enterprises. It provides basic protocols, common services, model management, enabling tools and system management for collaboration between enterprises within a broad distributed environment. It also provides service-based, transparent and consistent information access and application interoperation for information integration, process integration and resource-sharing between enterprises. Thus integration between enterprises including personnel, applications and manufacturing resources can be easily realized to form networked manufacturing systems with specific functions. The collaboration between enterprises mentioned above includes business, product design, manufacturing, and supply chain collaboration.

5.2 *NMIP architecture based on multi-agent system co-ordination control framework*

As the enabling platform for product co-design, manufacturing, business and supply chains, the NMIP must consider the operational features of collaboration between enterprises in a networked environment. It must support the operation of the virtual enterprises, which requires multiple running systems to co-execute together. These running systems include agile supply chain systems, product design systems, e-business systems, resource sharing systems, scheduling systems and decision-making systems. The operation of networked manufacturing systems aided by NMIP is shown in figure 4. It can be concluded that the NMIP must cover the whole product lifecycle and provide full-scale functions for collaboration between enterprises.

Networked manufacturing systems consist of many heterogeneous systems running in a broad distributed environment. These heterogeneous systems, which not only involve various enterprise entities and multiple operational modes, but also contain all functions within the business activities of enterprises, must be able to be reorganised quickly and flexibly according to the different objectives of collaboration. On the other hand, each enterprise in this huge system must keep its autonomy. Therefore, the NMIP should be able to support the collaboration between enterprises and multiple operational modes, as well as to preserve the autonomy of each enterprise. To satisfy these requirements, an NMIP architecture based on a multi-agent system co-ordination control framework is presented.

Multi-agent systems (MAS) represent a new way of analysing, designing, and implementing complex software systems (Jennings *et al.* 1998). A MAS can be defined as a loosely coupled network of problem-solvers that work together to solve problems that are beyond the individual capabilities or knowledge of each problem-solver. These problem solvers—agents—are autonomous and may be heterogeneous in nature.

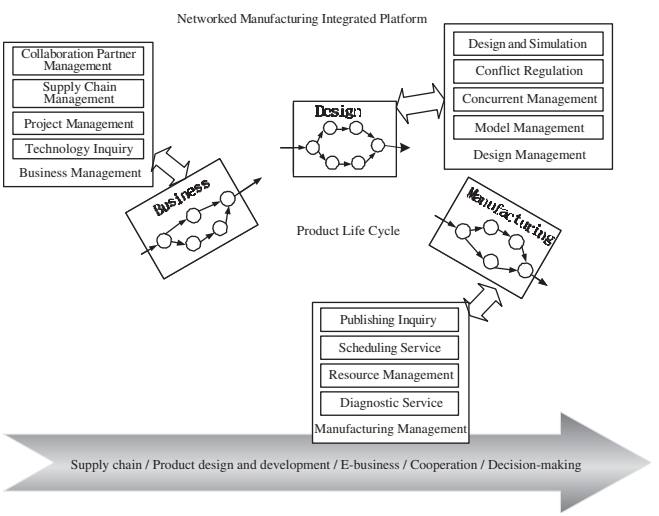

Figure 4. The operation of networked manufacturing aided by the NMIP.

The characteristics of MAS can meet the requirement of networked manufacturing systems. With MAS, all basic services, enabling tools, application software systems and platform management tools can be encapsulated to agents. Thus the co-operation between all functions can be converted to co-operation between agents. In this case, a MAS co-ordination control framework can be used to realize co-operation between these agents by providing consistent methods and strategies. All business functions, resources and information can be registered on the NMIP as agents. The requirements are published as requests of agents. Then the selection of business partners, collaboration and management of business processes can be executed, abiding by the co-ordination strategies between agents defined in the system. The combination of different agents can form some particular application according to different requirements. For example, an information service agent, process service agent, product design agent, collaborative design management agent and co-ordination agent can form a MAS for collaborative product design.

An NMIP architecture based on a MAS scheduling framework and supportive tools is presented in figure 5.

The components of an NMIP include four levels: network and data services, common services, business services, and user services. The main functions of each level are illustrated as follows:

5.2.1 Network and data services. This level is the foundation of the NMIP, which is composed of a basic information infrastructure, protocols, a MAS scheduling framework and supportive tools, and some model libraries. The basic information infrastructure includes network, databases, OS and digital controlling systems.

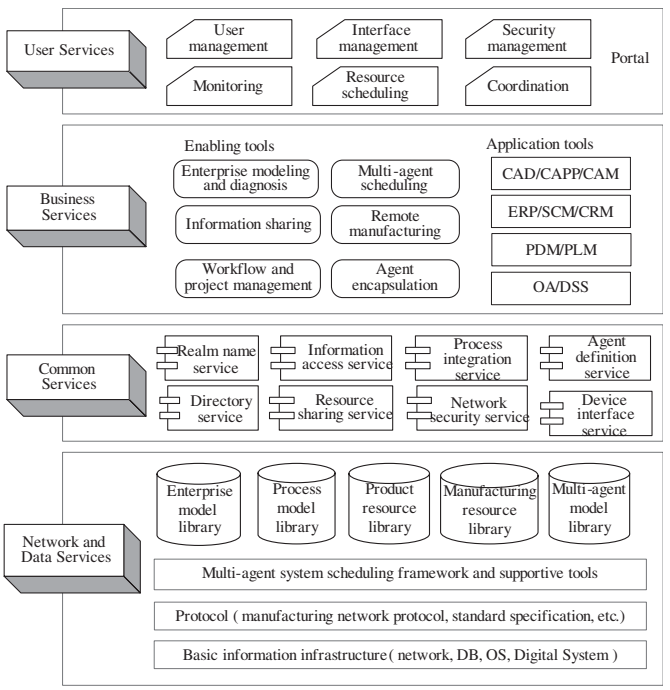

Figure 5. NMIP architecture based on a multi-agent system coordination control framework.

The digital controlling systems refer to the computer systems employed by digital manufacturing devices, which can provide the connection between manufacturing devices and other information systems. Protocols consist of general protocols and specifications for networked manufacturing systems, such as CORBA, XML, Web Service, WFMC, and STEP. The NMIP also contains a set of libraries including the enterprise model library, process model library, product resource library, manufacturing resource library, and multi-agent model library. These model libraries can provide models, knowledge, and standards for networked manufacturing systems. During implementation, the model libraries of an NMIP can be improved and renewed continually.

5.2.2 Common services. This level provides fundamental common services for networked manufacturing systems. It consists of several major components including realm name service, directory service, information access service, resource sharing service, process integration service, network security service, agent definition service, and device interface service.

5.2.3 Business services. This level contains necessary enabling tools and application tools for business applications. Enabling tools are the requisite tools to support the construction and execution of networked manufacturing systems, such as enterprise modelling and diagnosing, information sharing, workflow and project management, multi-agent scheduling, remote manufacturing, and agent encapsulation. Application tools refer to the application systems for product design and business management, such as CAD/CAPP/CAM, ERP/SCM/CRM, PDM/PLM, and OA/DSS.

5.2.4 User services. This level is the portal of an NMIP, which provides uniform and secure user interfaces to enable geographically distributed users to access all kinds of services provided by an enterprise's information system. The portal utilises role-based information agents to record the styles and data of all users. The portal is supported by some integrated platform tools, which provide a construction and implementation environment for the integrated platform. These tools can be sorted into several types: user management, interface management, security management, monitoring, resource scheduling, and co-ordination.

5.3 *Mechanisms for the integration of applications*

The mechanisms for the integration of applications under the NMIP environment can be discussed from three aspects: integration technologies, topological structure, and realization strategies.

From the aspect of integration technologies, the extent of coupling differs according to the different requirements of integration. It is better to employ a tight coupling method to integrate several function entities to form a more powerful function. The loose coupling method is more suitable to realize the integration between different enterprises. The intermediate one can be used to integrate different business systems in one enterprise.

Currently, there are three types of topological structures that can be used to integrate applications, i.e. End-to-end, Star and BUS structures. In the End-to-end structure, applications are connected directly and they communicate with each other

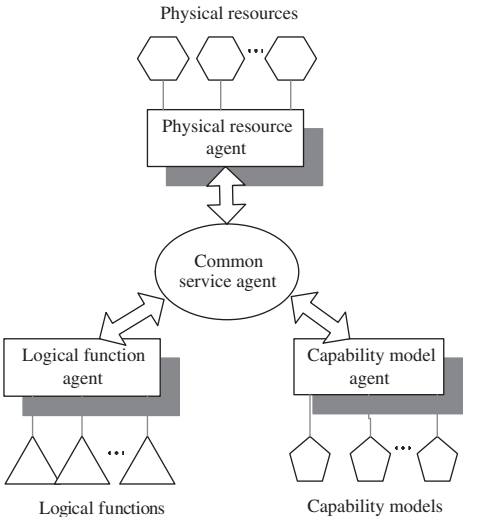

Figure 6. Agents in the NMIP and their relationships.

through agents and adapters. In the Star structure, all applications are connected to a central server. In the BUS structure, each application is linked to a bus logically so they can communicate through the bus. The particular type of topological structure which will be used in integration depends on the environment and application type. In the NMIP, the most common structure used to support the whole system integration is the combination of the Star and BUS structure.

One of the major challenges of the NMIP is to coordinate the operations and interactions between the diverse resources such as applications, services, information, and digital devices. The main integration method used in networked manufacturing systems is agent encapsulation. The agents can be classified into four types depending on the function they address. The common service agents deal with the co-operation relationships between multi-agents. The physical resource agents are designed for encapsulating the physical entities (e.g. software tools, devices, and persons). The logical function agents are used to describe the logical constraint rules of functions (e.g. plan and schedule). The capability model agents can publish and discover partners based on a capability model through the encapsulation and description of enterprise core capability. Figure 6 illustrates these agents and their relationships.

6. Application in China

The National High Technology R&D Programme of China (863 Programme) realized the importance and opportunity brought by the new production trend of networked manufacturing as early as 1998. At present, the 863 programme has supported many projects to study and implement networked manufacturing. All these projects have played a very important role in the research and application of networked manufacturing technologies. In recent years, a great many achievements have been made and many applications have been implemented. This paper will just give one example.

The regional networked manufacturing system in the Pearl River Delta in Guangdong province was chosen as an example based on the requirements of the industrial enterprises in the Pearl River Delta. To provide a supportive platform for collaboration on business, techniques and production for small- and medium-sized enterprises in this area based on the Internet, the Chinese Manufacturing Collaboration Net (CMCN) was developed and implemented. With the CMCN, large numbers of small- and medium-sized enterprises can make use of the Internet sufficiently to share manufacturing resources and dynamic collaboration of business with the lowest costs. As a result, the total manufacturing capacity in the Pearl River Delta has been enhanced greatly. There are currently about 20 000 enterprise members registered in this system, among which more than 3000 enterprises have already been certificated. The CMCN has won a good reputation in the manufacturing field and caught broad attention from all over the world.

7. Conclusion

Networked manufacturing is an advanced manufacturing pattern for enterprises to run their businesses by using networks, especially the Internet. It is also a new manufacturing pattern that has emerged with the growth of today's knowledge-based economy and network-oriented economy. Networked manufacturing systems enable the sharing and selection of a variety of resources including information and technologies for design, manufacturing and management, and provide a collaborative environment that offers various manufacturing services (including all activities in enterprise operations). At the same time, since the related theory, methodology and application of networked manufacturing systems are far from maturity, it is still an open field where many new technologies and problems need to be studied. In the future, research topics in networked manufacturing, such as information exchange standards in networked manufacturing systems, co-operative design and manufacturing methods and tools, integration of networked manufacturing systems, networked manufacturing platforms, and the market pattern of networked manufacturing, need great attention.

Acknowledgements

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