Introduction to Cloud Manufacturing

Li Bohu[1,2], Zhang Lin[1], Chai Xudong[2]
(1. Engineering Research Center of Complex Product Advanced Manufacturing Systems, Ministry of Education, Beihang University, Beijing 100191, P. R. China;
2. Beijing Simulation Center, Beijing 100854, P. R. China)

Abstract: Cloud manufacturing is a new, networked and intelligent manufacturing model that is service-oriented, knowledge based, high performance, and energy efficient. In this model, state-of-the-art technologies such as informatized manufacturing, cloud computing, Internet of Things, semantic Web, and high-performance computing are integrated in order to provide secure, reliable, and high quality on-demand services at low prices for those involved in the whole manufacturing lifecycle. As an important part of cloud manufacturing, cloud simulation technology based on the COSIM-CSP platform has primarily been applied in the design of a multidisciplinary virtual prototype of a flight vehicle. This lays the foundation for further research into cloud manufacturing.

Key Words: informatized manufacturing; cloud manufacturing; cloud computing; networked manufacturing

1 Trends of Manufacturing Informatization

The manufacturing industry is an important pillar of China's national economy and security. As detailed in the tenth five-year plan, the Chinese government views manufacturing informatization as a strategic measure for realizing new-era industrialization. Manufacturing Informatization draws together information technology; modeling and simulation; modern management technology; design, production, and experiment technology; system engineering technology; and product-related technology, which is used to integrate and optimize the three factors (people and organization, management, and technology), and the four flows (information flow, material flow, value flow, and knowledge flow) to improve product quality, service, and energy efficiency. Production costs and development time are also reduced.

The goal of manufacturing Informatization is to enhance competitiveness of enterprises in order to accelerate their development[1-2]. The idea of manufacturing in this article encompasses the whole product manufacturing lifecycle—from market analysis to design and production, testing, training, usage, and maintenance; and finally, dismantlement.

Generally, the manufacturing Informatization system is developing toward being integrated, digital, intelligent, agile, networked, green and service-oriented. Service, resource environment and knowledge-based innovation[3] are key factors for enhancing core competitiveness in the manufacturing industry. By 2009, China had become the world's second largest industrial manufacturing country, second only to the U.S. However, it has not yet turned into a high-end manufacturing power. "Made-in-China" is generally considered to be at the low end of the international value chain, because of weak innovation and limited resources. China's manufacturing industry therefore needs to break through these barriers as soon as possible, and transition into a service-oriented[4], green[5] and "created-in-China" manufacturing mindset.

Based on the requirements of manufacturing industry and the rapid development of information technologies, the concept of cloud manufacturing[3] was proposed for promoting the development of manufacturing Informatization. Research into cloud manufacturing technology will accelerate the development of an intelligently networked, service-oriented manufacturing industry in China.

2 Technological Basis of Cloud Manufacturing

Cloud computing is a new service-oriented computing technology that has emerged in recent years[6-7]. In cloud computing, mass, highly virtualized computing resources are organized using a cloud computing platform, and a large-scale resource pool is formed to provide unified services. Individuals and enterprises can access computing resources on-demand through heterogeneous, self-governing Internet services. Professional IT and networking companies—third-party service operators—build computing repositories and service centers in which "clouds" of virtualized resources are stored and offered as services.

This work was funded by the National Basic Research Program of China ("973" Program) under Grant No. 2007CB310900, and the National High Technology Research and Development Program of China ("863" Program) under Grant No. 2007AA04Z153.

When cloud computing resources are replaced with cloud manufacturing resources, cloud computing operation models may offer new ways of achieving networked and informatized manufacturing systems with high efficiency, service-oriented and low energy consumption.

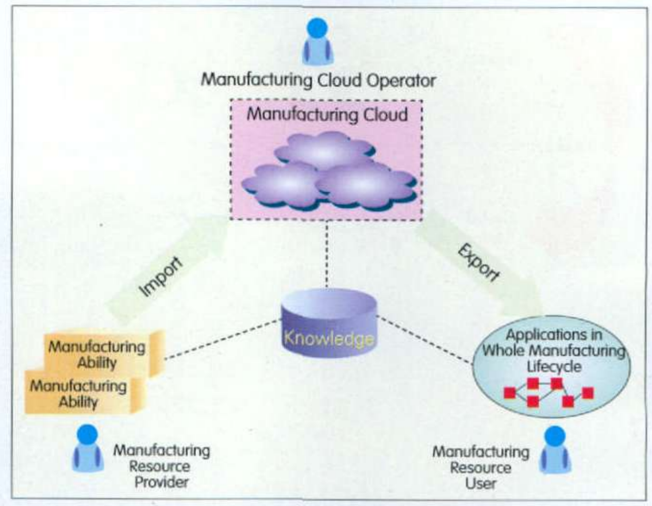
Manufacturing resources include machines, processing centers, and computing equipment used during the whole manufacturing lifecycle. They also include models, data, software, and professional knowledge used during production. Besides cloud computing technology, semantic Web[8], embedded system technology[9], Internet of Things[10], and high-performance computing may be used for virtualization, optimization and scheduling, and collaboration of manufacturing resources. Development of semantic Web technology lays the foundation for knowledge-based intelligent computing, and the rapid development of embedded system technology enables smart access of physical terminal devices. The Internet of Things is quickly growing in line with Radio Frequency Identification (RFID)[11] and sensor technologies and will promote interconnection between things. Development of high-performance computers and high-performance computing technology[12] may provide solutions to complicated manufacturing issues in large-scale collaborative manufacturing.

There is great potential for research and application of cloud manufacturing.

3 Research Progress of Cloud Manufacturing

3.1 Definition of Cloud Manufacturing

Cloud manufacturing is a service-oriented, knowledge-based smart manufacturing system with high efficiency and low energy consumption. In a cloud manufacturing system, state-of-the-art technologies such as informatized manufacturing technology, cloud computing, Internet of Things, semantic Web, high-performance computing, and cloud manufacturing are integrated. By extending and shifting existing manufacturing and service systems[13-14], manufacturing resources and capabilities are virtualized and oriented towards service provision. In cloud manufacturing, pervasive and efficient sharing and coordination of resources and capabilities can be achieved by their unified and centralized intelligent management and operation. Cloud manufacturing provides the whole manufacturing lifecycle with secure, reliable, high quality, and on-demand services at low prices through networked system. The manufacturing lifecycle includes pre-manufacturing (argumentation, design, production and sale), manufacturing (product usage, management and maintenance), and post-manufacturing (dismantling, scrap, and recycling).



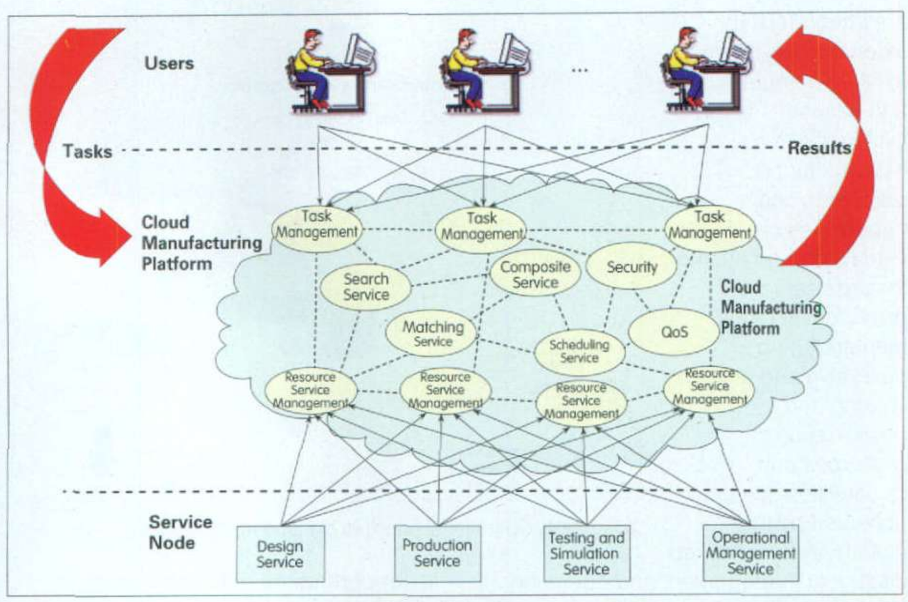
▲Figure 1. Operational principle of cloud manufacturing.

3.2 Operation Model and Key Technologies of Cloud Manufacturing

A cloud manufacturing system consists of manufacturing resources and capabilities, manufacturing cloud, and the whole manufacturing lifecycle applications. It also includes core support (knowledge), two processes (import and export), and three user types—resource providers, cloud operators and resource users. Figure 1 illustrates the operational principle of cloud manufacturing. Manufacturing resources and capabilities are encapsulated as cloud services. This process is called manufacturing resource "import". Depending on different manufacturing requirements, cloud services are combined to form a manufacturing cloud. The cloud provides the whole manufacturing lifecycle applications with diverse services. This process is called "export". Knowledge plays a central role in supporting the entire operating process of cloud manufacturing. It is necessary for intelligent embedding and virtualized encapsulation during import; it assists functions such as intelligent search of cloud services; and it facilitates smart cooperation of cloud services over the whole manufacturing lifecycle. In a cloud manufacturing system, knowledge-based integration across the whole lifecycle is possible.

A cloud manufacturing application model is shown in Figure 2. Users send specific requests to the cloud manufacturing platform. This platform is responsible for the management, operation, and maintenance of manufacturing clouds and service tasks such as import and export. It analyzes and divides service requests, and automatically searches the cloud for best-matched services. By a series of processes including scheduling, optimization and combination, a solution is generated and then sent back to the client. A user does not need to communicate directly with every service node, nor find the specific locations and situations of service nodes. Through the cloud manufacturing platform, manufacturing resources and capabilities can be used in the same way as water, gas, electricity, etc.

Cloud manufacturing architecture has five layers: physical layer, virtualized resource layer, service layer, application layer, and user layer, as



▲Figure 2. Application model of cloud manufacturing.

shown in Figure 3[3].

Figure 4[3] illustrates the key cloud manufacturing technologies including:

- System architecture, operation model, standards, and specifications
- Clouding technologies for resources and capabilities
- Comprehensive management technologies for cloud services
- Cloud security and trusted manufacturing technologies
- Management models and technologies of manufacturing cloud services

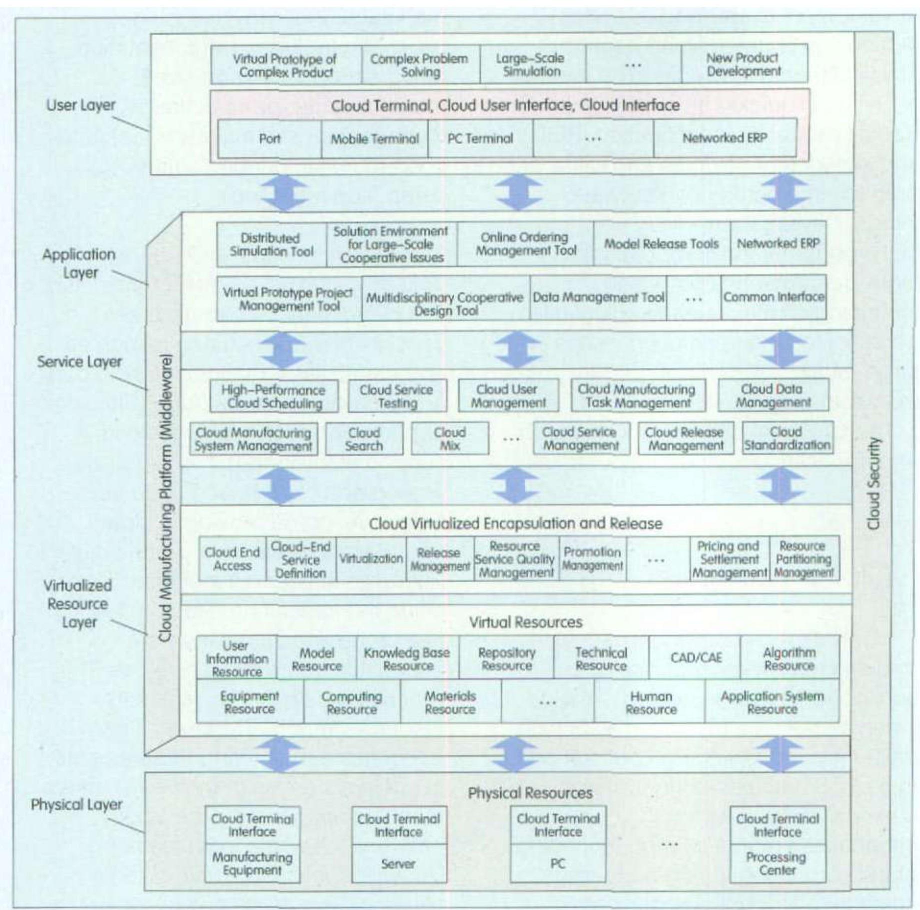
3.3 Primary Research Achievements

To demonstrate the feasibility of the cloud manufacturing concept, our research team developed a typical cloud manufacturing application—cloud simulation technology—based on the COSIM Cloud Simulation Platform (COSIM–CSP)[15]. Cloud simulation technology has primarily been applied in the multidiciplinary design of a virtual flight vehicle prototype. COSIM–CSP uses visual pervasive portal interface technology, project management technology for complex products, simulation resource virtualization, error–tolerance technology, security and trusted mechanism, resource service quality assessment based on semantic knowledge, smart discovery, automatic combination technology, and dynamic scheduling technology. This prototype lays the foundation for further study into cloud manufacturing.

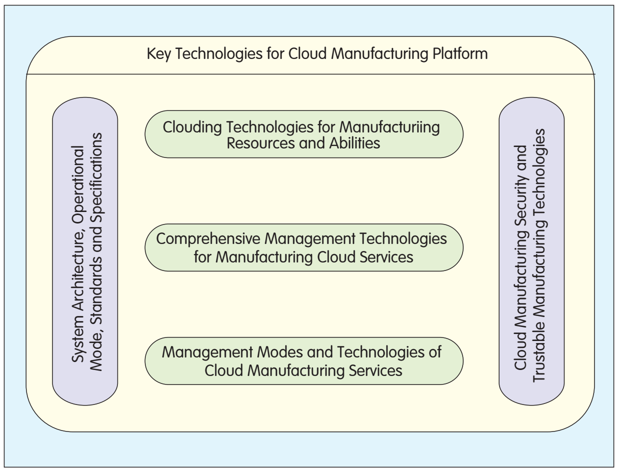
4 Prospects for Cloud Manufacturing

Cloud manufacturing is a new model to manufacturing Informatization and has huge development potential. Research into cloud manufacturing relies on the joint efforts of industry, academia and government. The application of cloud manufacturing will be a gradual, long–term process rather than an overnight project. For the success of cloud manufacturing, enterprises should have good foundation on internal integration of information and processes. Therefore, there is a relative high entrance standard to implement cloud manufacturing for the majority of manufacturing enterprises.

The future development of cloud manufacturing will face many challenges in key technologies.



▲Figure 3. Cloud manufacturing system architecture.



▲Figure 4. Key cloud manufacturing technologies.

Besides the integration technologies of cloud computing, Internet of things, semantic web high performance computing, and embedded systems, several important technical issues must be solved such as knowledge based resource clouding, cloud management engines, collaboration between cloud manufacturing applications, and visualization and user interface in cloud environments.

5 Conclusions

After information and processes have been integrated and inter-enterprise integration has been achieved, manufacturing Informatization technologies focus on core value factors such as service, environment, and knowledge. A new smart manufacturing model—cloud manufacturing was proposed. Further research into cloud manufacturing will accelerate the development of an intelligent, networked, service-oriented, informatized manufacturing industry. This article discussed the technical basis, concept, operation model, architecture, and key technologies of cloud manufacturing. It presented the primary research achievement, and looked into the future of its development.

Acknowledgment: Thanks to Dr. Ren Lei and Dr. Tao Fei from Beihang University, and Dr. Hou Baocun from Beijing Simulation Center for their contributions to this work.

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Biographies

Li Bohu

Li Bohu is an academician at the Chinese Academy of Engineering (CAE), and a doctoral advisor and honorary dean of the School of Automation Science and Electrical Engineering at Beihang University. He is also the former president of the Chinese Association for System Simulation, director of the Systems Engineering Society of China, and director of the China Computer Federation. He has researched complex system modeling and simulation, and integrated manufacturing systems of complex products for many years. He has previously been awarded one first and three second prizes in the National Science and Technology Progress Awards of China, and has won 14 ministry–level science and technology progress prizes. He has also published 260 academic papers.

Zhang Lin

Zhang Lin is a professor and doctoral advisor at Beihang University. He is the vice president of the Chinese Association for System Simulation, director of Chinese Association for Artificial Intelligence. His research interests include networked manufacturing, complex system modeling, simulation and control, and software engineering. He was awarded the advanced individual at the fifteenth anniversary of the National High Technology Research and Development Program of China ("863" Program). He has participated in over 20 national science research projects in China. He has published 60 peer reviewed journal papers.

Chai Xudong

Chai Xudong is director of the Chinese Association for System Simulation. His research interests include complex system modeling and simulation, design of virtual products, and integrated manufacturing systems. He has previously been awarded first and second prizes in the National Defense Science and Technology Progress Awards of China, second prize in the Science and Technology Progress Award of Ministry of Electronics of China, and second prize in the Science and Technology Progress Award of Ministry of Education of China. He has published 90 academic papers.