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The Architecture of a Product Collaborative Design Platform Based on Cloud Manufacturing

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Abstract: Product design is crucial for improving product quality and lowering manufacturing costs. Cloud manufacturing is emerging as a new manufacturing model and an integrated technology and has become an important development direction for advanced manufacturing. To adapt to the transformation of traditional manufacturing to service-oriented and innovative manufacturing, this study investigates the current status of collaborative design and summarizes problems regarding the sharing and on-demand use of massive resources in traditional manufacturing. Furthermore an architecture of a product collaborative design platform based on cloud manufacturing is proposed and the meaning of each layer is explained in detail. Three key technologies for building the platform are discussed: cloud manufacturing technology, product family and product platform technology, and product collaborative design technology. Finally, using a cloud-manufacturing-based product collaborative design platform system established by a company as an example, the system architecture and functions of the platform are analyzed, and the differences in task assignment and completion time between cloud manufacturing and traditional manufacturing are compared. The effectiveness and superiority of the cloud manufacturing-based system are verified, and the application and research directions of the system are prospected.

Keywords: cloud manufacturing; collaborative design; product platform; resource encapsulation; platform architecture

1 Introduction

Product design is an important aspect that affects product quality and manufacturing costs. Collaborative design can fully utilize existing design resources and maximize value. It is an optimization strategy for reducing product design costs. Although the traditional distributed network system environment can complete collaborative design tasks, it is limited by the static nature of software and hardware systems [1]. The problem of "information islands" in design resources results in the unbalanced use of resources, rendering it impossible to achieve the sharing and on-demand use of massive resources as well as fully satisfy the requirements of users for system dynamics. Therefore, it is important to investigate methods to allow designers to fully access and utilize abundant design resources, improve product design level, and reduce product design costs during product collaborative design.

The method to effectively improve the efficiency of product collaborative design and achieve a breakthrough in the traditional design mode has always been highlighted in academia and industry, both domestically and abroad. Golightly et al. [2] discussed collaboration technologies in cloud manufacturing environments. The Massachusetts Institute of Technology in the United States launched a Distributed Integrated Computer-Assisted Environment research project and established a cloud-based product design system that is convenient for collaborative tasks [3].

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Stanford University in the United States conducted the Scalable Framework and Methodology of Concurrent Engineering project, where team members shared design knowledge and design concepts through cloud technology [4]. The Boeing Company of the United States uses Internet-based collaborative design to manage manufacturing companies in more than 40 countries and regions worldwide to jointly manufacture the Boeing 787 passenger aircraft, achieving a shorter development cycle by 30% and a cost reduction of 50% [5]. The results of Katzmaier et al. [6] indicate that Internet-based design patterns surpassed traditional design patterns in terms of versatility, diversity, and synergy. Furthermore, domestic research teams have conducted investigations regarding cloud design and simulation technology as well as built a cloud simulation platform that can be used for the collaborative design of aircraft virtual prototypes [7]. In summary, Internet-based product collaborative design is supported by a good technical foundation and affords significant technical advantages, such as improvements in design efficiency, design versatility, and synergy. However, for high-precision equipment information, advanced expert experience, and design knowledge resources, manufacturing models with better computing capabilities are urgently required to achieve product design collaboration and resource sharing such that heterogeneous resources can be effectively organized, managed, and configured, and resource utilization can be improved [8].

The cloud manufacturing model not only affords the advantages of cloud computing, but also the advantages of advanced manufacturing models such as flexible manufacturing and networked manufacturing [9]. The cloud manufacturing model can efficiently share and coordinate massive manufacturing resources as well as offers good system openness and user participation; these aspects are important for the development of advanced manufacturing models [10]. Table 1 shows a comparison between the cloud manufacturing model and other advanced manufacturing models. The product platform for cloud manufacturing can transcend the company's departmental boundaries and resource constraints and realize resource sharing. To transform the traditional manufacturing industry to service-oriented and innovative manufacturing industries, a cloud-based product collaborative design platform architecture was built. Furthermore, the advanced manufacturing technology of the platform architecture was investigated. Finally, a cloud manufacturing product collaborative design system developed by a company was used as an example, where the architecture and functions of the platform system was analyzed, and its effectiveness and superiority were verified.

Table 1. Comparison between cloud manufacturing model and other advanced manufacturing models.

Item	Flexible manufacturing	Network manufacturing	Cloud manufacturing
System functions	Cooperation	Resource sharing/cooperation	Resource sharing/cooperation
System openness	Many constraints, poor openness	Better openness	Highly open
Resource type	Organization, people, technology	Equipment, people, materials, network, information·	Materials, equipment, software, hardware, logic, people, knowledge
Data amount	Gigabyte level	Terabyte level	Petabyte level
Resource usage	Customization	Dynamic configuration	On-demand dynamic configuration
User participation	Moderate	Moderate	High
Collaboration scope	Several companies	Companies in several industries	Companies in almost every industry
Key technologies	FMT/CAD/AI	Service/ASP/GRID	Service/Cloud computing/ IoT

Note: FMT: flexible manufacturing technology; CAD: computer-aided design; AI: artificial intelligence; ASP: active server pages; GRID: global grid; IoT: Internet of Things

2 Architecture of the cloud manufacturing product collaborative design platform

The traditional product platform architecture can be categorized into a resource layer, a tool layer, and an application layer, where resources and product development task completion are focused independently. In fact, the product development process, which involves significant calculations, is completed through multiparty cooperation. As such, traditional product platforms can no longer satisfy current application requirements. Therefore, based on

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cloud manufacturing technology, this paper proposes a cloud manufacturing product collaborative design platform architecture (Fig. 1). The platform is based on an original architecture that is integrated and expanded to support the business collaboration between distributed enterprises to build a cloud manufacturing product platform. It can effectively share various resources, such as manufacturing, information, technology, and standardized designs related to product development and resource utilization improvement. The cloud manufacturing product collaborative design platform architecture primarily comprises five layers: a resource layer, a cloud technology layer, a cloud service layer, an application layer, and a user layer. The details of each layer are presented in the following subsections.

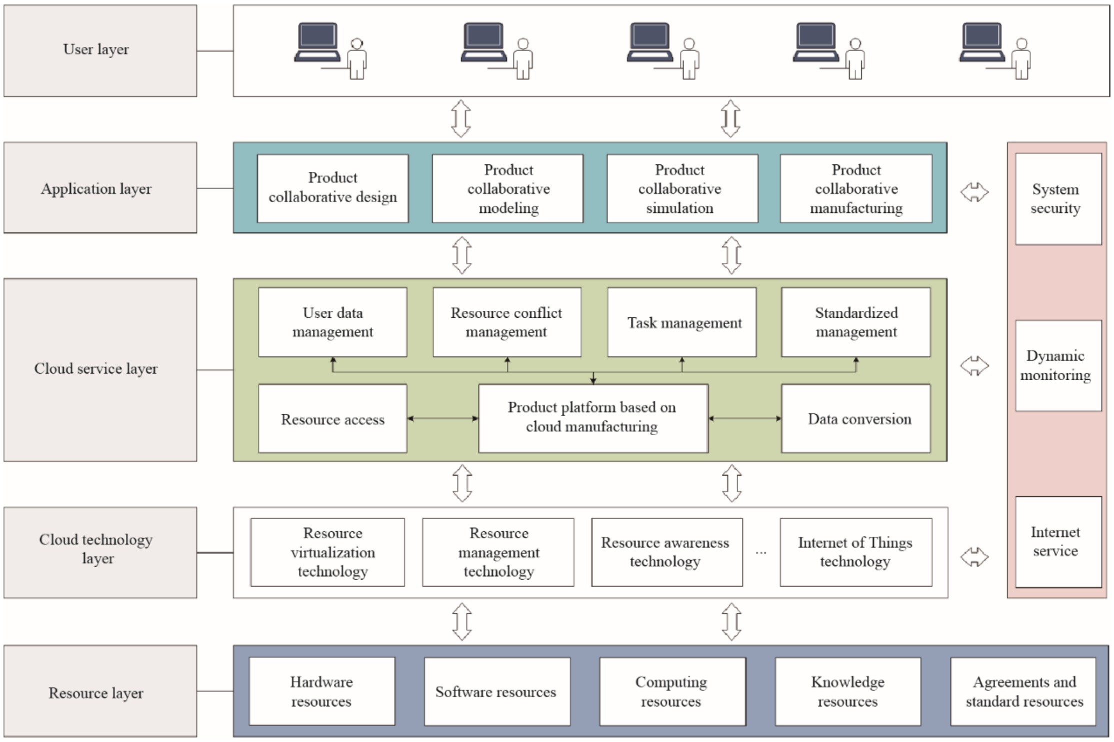

Fig. 1. Architecture of cloud manufacturing product collaborative design platform.

2.1 Resource layer

The resource layer is the physical foundation of the cloud manufacturing product collaborative design platform. The design resources in the platform integrate the computing power, knowledge, software, hardware, related standards, and other resources involved in the product lifecycle. In a cloud manufacturing environment, users can select and use these resources. This layer can effectively solve the problems of design resource overload or idleness and static limitations of software and hardware systems, thereby improving resource utilization.

2.2 Cloud technology layer

In the cloud manufacturing product collaborative design platform, the key to achieving product collaborative design is to solve the problem of design resource sharing in the cloud manufacturing environment. The goal of the cloud technology layer is to efficiently share and manage diverse, heterogeneous, and specific resources; realize the intelligent perception and control of various design resources and capabilities; and monitor, discover, and promptly share virtual resources. The cloud technology layer primarily uses resource virtualization technology, resource management technology, resource awareness technology, and IoT technology to perform a unified standard description and package design resources.

2.3 Cloud service layer

The cloud service layer is intended for designers and provides services through the cloud manufacturing product collaborative design platform. By abstracting the product design process, the key process of product design tasks is refined, the main content of the cloud service layer is obtained, and servicing is performed for managing user data, monitoring resource service quality, assigning design tasks, resolving resource conflicts, and maintaining system security. The cloud service layer is the core layer of the cloud manufacturing product collaborative design platform. The operation and maintenance of the platform, the calculation and allocation of resources, and the management and sharing of data can all be implemented in this layer.

2.4 Application layer

The application layer contains multiple unified function calling interfaces for realizing the basic functions of the cloud manufacturing product collaborative design platform. Based on an actual business scenario and by combining various basic functional interface methods, the application layer can satisfy all the requirements of the design task and realize multiple key functions, including product collaborative design, modeling, simulation, and manufacturing.

2.5 User layer

The user layer is accessed through the network based on the interactive interface, and it directly faces the user's application environment, rendering it convenient for users to access and call various functions of the cloud manufacturing product collaborative design platform. This layer is the intuitive presentation layer of the various functions of the platform in the operating system; it integrates the system environment and system users.

3 Key technologies of cloud manufacturing product collaborative design platform

The cloud manufacturing product collaborative design platform is a complex system. The construction of the platform must be based on cloud manufacturing, product family and product platform technology, and product collaborative design technology, as shown in Fig. 2.

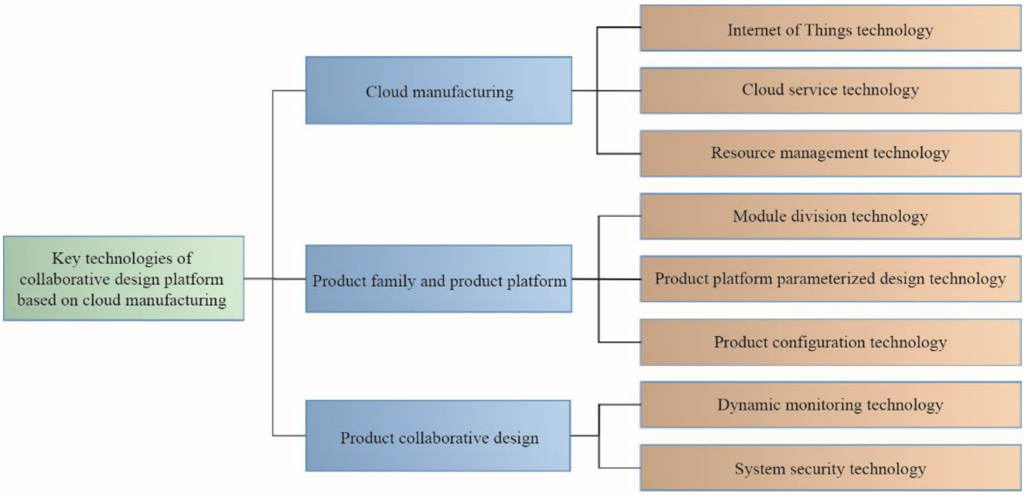

Fig. 2. Key technologies of cloud manufacturing product collaborative design platform.

3.1 Key technologies of cloud manufacturing

3.1.1 IoT technology

The application of IoT technology in cloud manufacturing comprises three levels: (1) the use of sensor devices and technologies for perceiving various manufacturing equipment, Internet connections, automatic control, etc.; (2) the promotion of intelligentization of logistics and energy in the manufacturing system as well as intelligent operations in support services, such as intelligent interactions and collaboration between services; and (3) the communication support of cloud manufacturing users [11].

3.1.2. Cloud service technology

Cloud service technology uses IoT, virtualization, and other technologies to encapsulate knowledge-based distributed design resources and manufacturing capabilities, resulting in highly virtual resources (such as software, hardware, computing capabilities, expert knowledge, and related standards involved in the product lifecycle). It provides users with applications for the full lifecycle of manufacturing in the form of cloud services. Users can access these applications to share and call related design resources and capabilities. The formation process of cloud services is the process of servicing cloud manufacturing resources and capabilities [1]. Fig. 3 shows the relationship

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among users, resources, and cloud services in the cloud manufacturing system.

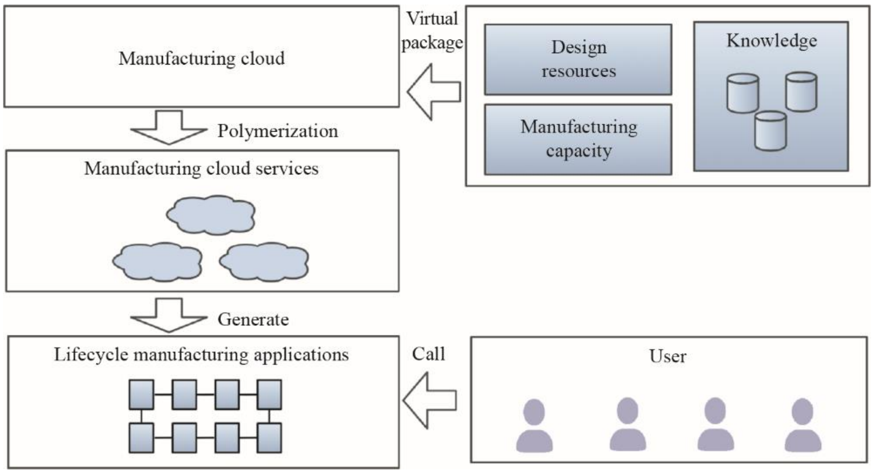

Fig. 3. Relationship among resources, cloud services, and manufacturing clouds in cloud manufacturing system.

3.1.3. Resource management technology

Resource management is key yet challenging for the cloud manufacturing product collaborative design platform to describe, encapsulate, search, and push heterogeneous and remote design resources. Resource management technology primarily focuses on four aspects: unified classification and description of resources, resource virtualization, resource discovery, and resource binding strategy.

(1) Unified classification and description of resources. Based on the characteristics of the distribution, heterogeneity, autonomy, large quantity, and multiple types of design resources in the cloud service environment, relevant technologies are used to uniformly classify and describe various resources to facilitate the integration, sharing, and management of resources. For example, extensible markup language, web services ontology language, and unified modeling language are used to establish corresponding extensible description templates. When establishing a resource description, the requirements of resource discovery, integration, and matching must be considered, and resources must be described as completely as possible.

(2) Resource virtualization. To address the multi-location and heterogeneity of resources, resources deployed in the cloud manufacturing system must be virtualized to facilitate unified access on the network. Resource virtualization primarily comprises two stages: virtual description and service encapsulation. Virtual description aims to establish a resource description specification that comprehensively expresses manufacturing resource information in a unified virtual resource data model, whereas service encapsulation extracts the functional characteristics of design resources from a virtual resource data model and encapsulates them as cloud services for interoperability with cloud platforms in a unified interface [12].

3.2 Key technologies of product family and product platform

3.2.1 Module division technology

The application of module division technology in the cloud manufacturing product platform primarily includes the following: (1) Based on function and structure, the product is classified into unit modules through algorithms, product modules are constructed, and different products are formed through the selection and combination of modules to satisfy market requirements [13]. (2) The complex task is promptly decomposed into multiple schedulable subtasks; subsequently, the mapping relationship of the completed tasks is created in the cloud manufacturing environment. Finally, the user of each subtask is coordinated to complete the task.

3.2.2 Product platform parametric design technology

Parametric design technology is a typical product platform technology. First, the parameterized design data received from the user interface are processed, and the driving parameters of the structural model are generated based on the parameter transfer relationship. Second, the newly generated module parameters are input into the corresponding model database to modify and generate a three-dimensional (3D) model of the new product and two-dimensional (2D) engineering drawings.

3.2.3 Product configuration technology

Cloud manufacturing product configuration technology is composed of five main modules: visualization engine, user interface, product evaluation, configuration engine, and cloud manufacturing service [14]. The relationship between product configuration and cloud manufacturing services is shown in Fig. 4. After responding to the system request, the cloud manufacturing service sends the required product-related data to the system to support the product configuration. After the product configuration is completed, the final product specifications and related information are submitted for the next step. The purpose of the configuration engine is to refer to mandatory configuration rules and constraints and then generate effective product specifications based on user input requirements. The visualization engine provides web-based dynamic product visualization, viewing, and 3D product model operations to support product configuration. The interaction between the user and system is primarily used to receive user requirements and view the configuration feedback.

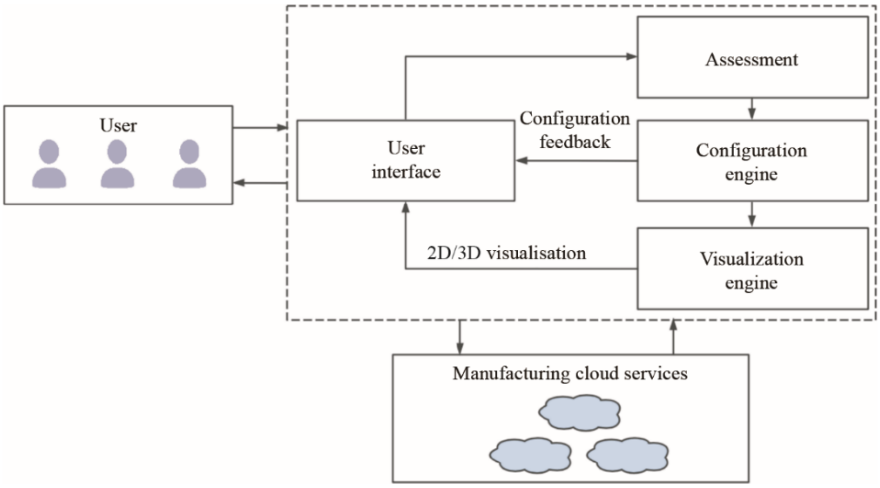

Fig. 4. Relationship between product configuration and manufacturing cloud services.

3.3 Key technologies of product collaborative design

3.3.1 Dynamic monitoring technology

In the product collaborative design platform of cloud manufacturing services, dynamic monitoring technology enable the service status of resources to be monitored comprehensively to ensure the smooth and efficient operation of cloud manufacturing services. The main detections performed by dynamic monitoring technology are as follows: (1) Cooperative process monitoring. To ensure the efficient and rapid completion of complex design tasks, the intelligent conflict detection model of the cloud manufacturing environment is used to monitor the data, process, and authority conflicts in the collaborative design process in real time. Conflict resolution services are called promptly to improve collaboration efficiency; (2) resource dynamic monitoring, where efficient resource monitoring strategies, real-time dynamic monitoring of resource allocation and invocation process, timely detection, and processing of resource failures are adopted; hence, resource allocation and invocation requirements are minimized for system hardware and monitoring efficiency is improved; (3) system failure monitoring and real-time monitoring of the system’s software and hardware; emergency plans are devised for system failures to avoid the complete collapse of the system and the loss of design tasks and design resources.

3.3.2 System security technology

In a highly open collaborative design platform for cloud manufacturing products, security is key for ensuring the smooth operation of the system. The main problems solved by system security technology are as follows: (1) Platform security test—the platform can dynamically add and delete users when performing tasks; (2) the platform user permissions are granted—during task coordination, the platform grants user permissions reasonably and appropriately to ensure that users can not only complete the design tasks, but will not interfere with matters beyond the design permissions.

4 Case analysis of cloud manufacturing product collaborative design platform system

Product demand changes rapidly and hence a good product design model is essential. Based on analyzing the architecture of the product collaborative design platform, a cloud manufacturing product collaborative design

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platform system developed by a certain enterprise (Fig. 5) is presented as an example herein to describe the application of the cloud manufacturing product collaborative design platform. Subsequently, the functions of the system are analyzed. The company's platform system performed well throughout the product lifecycle.

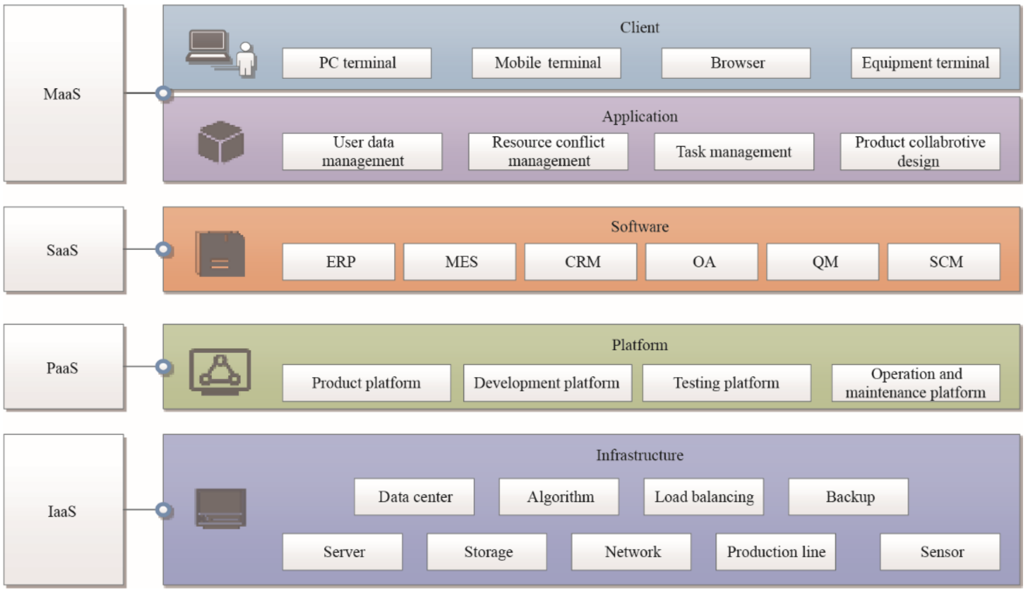

Fig. 5. Cloud manufacturing product collaborative design platform system.

4.1 System function introduction

The cloud manufacturing product collaborative design platform system homepage developed by the company, as shown in Fig. 6, primarily comprises five functional modules: user data management, product management, resource management, conflict resolution, and system security services. A user data management service refers to the authorization and management of user permissions. Users with different roles are granted strict permission levels to ensure the safe and successful completion of tasks; product management services are used for product lifecycle management, including collaborative design, collaborative modeling, and collaborative simulation and production. Resource management services are used to describe, encapsulate, manage, and apply resources such that users can use resources promptly and effectively. The main applications of conflict resolution services are the formulation of detection classification, resolution strategies, task assignment, and intelligent processing during system operation. The main application of the system security service is to dynamically monitor all the parameters of the system during the operation of the system to ensure the safety of real-time product design data, historical design cases, and various design resources in the product platform.

Fig. 6. Home page of product platform for cloud manufacturing.

This section primarily introduces the product management services of the cloud manufacturing product collaborative design platform system. Based on a CNC milling machine as an example, the applications of product collaborative design, product collaborative modeling, and product collaborative simulation are explained.

(1) The product collaborative design application can call the computer-aided design software (Pro/ENGINEER) through the cloud server to read the 3D structure drawing and 2D engineering drawing of the selected component to realize parameter-driven product design. The relevant parameters of the product model are obtained by reading the 3D model, and the size modification of the 3D structural model is realized using a parameter-driven method; subsequently, its model storage database is updated.

(2) The procedures involved in the product collaborative modeling application are as follows: Determine the CNC milling machine series based on the user's requirements; determine the parameters, structure, and auxiliary structure characteristics of each module of the CNC milling machine and select different structural module codes; select the combination of various modules to promptly design new CNC milling machine products; modify and save the main structural modules of the CNC milling machine, and assemble the structural modules into a CNC milling machine to satisfy customer requirements.

(3) In the product co-simulation application, the CNC milling machine model is imported, and the application of loads, constraints, and post-processing can be realized through the command stream. The user can edit the task number, task name, and other information, as well as set the end time of the task. The system dynamically calls related resources based on the end time of the task, such as the number of central processing units used by the server during the calculation process, to ensure that the task is completed on time. After the task is completed, the results of the simulation analysis are displayed on the interface, and the analysis result can be output as a hypertext markup language file.

4.2 System analysis

In this study, task allocation time and task completion time were used as indicators to measure the efficiency of traditional and cloud manufacturing models. Three manufacturing companies located in Beijing, i.e., A, B, and C, were selected as the research objects. With permission, the research team accessed the company's MES system and database; subsequently, relevant data regarding the time required to allocate tasks as well as to complete tasks before and after the application of the cloud manufacturing product collaborative design platform system by the three companies were obtained. The average task time was used as the basis for evaluation. However, owing to the significant amount of data, the two manufacturing modes were compared by selecting key node data and drawing charts.

The time difference between the assignment and completion of tasks based on the two manufacturing modes is shown in Fig. 7. Fig. 7a shows the average task allocation time of the three companies; the dotted line in Fig. 7b was obtained by the scatter coordinates of the task completion time of the three companies. The fitted line shows the difference in the time required for the company to complete tasks in the two manufacturing modes. In the initial stage, owing to the complex operating mechanism of the cloud manufacturing model, its response speed was not on par with that of the traditional manufacturing model. When the task volume reached a certain value, the computing advantages of the cloud manufacturing model were revealed.

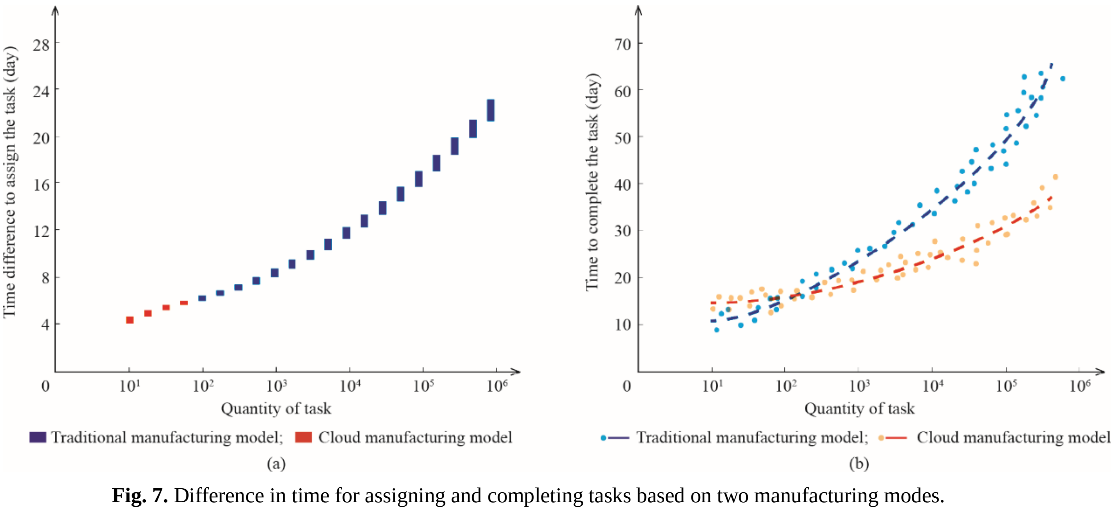

Fig. 7. Difference in time for assigning and completing tasks based on two manufacturing modes.

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5 Conclusion

Based on the investigation and analysis of the status quo in the field of collaborative design as well as the use and sharing of resources in traditional manufacturing models, a five-layer architecture of a product collaborative design platform for cloud manufacturing was proposed herein; the architecture organically combined cloud manufacturing technology, product family, product platform technology, and product collaborative design technology. Furthermore, a cloud manufacturing product collaborative design platform prototype system was established; the system is used in related manufacturing companies for application verification via a comprehensive comparison with the traditional manufacturing model. Additionally, the time difference between the assignment and completion of tasks based on the two manufacturing models was analyzed, and the effectiveness and superiority of the cloud manufacturing model were verified.

In the future application of the product collaborative design platform based on cloud manufacturing, it is recommended to combine the actual situation of the project, use the agile and intelligent characteristics of the cloud manufacturing model, and fully utilize the advantages of the cloud manufacturing model throughout the product life cycle. Designers, customer demanders, product suppliers, and other entities should collaborate to complete the product design and manufacturing process as well as improve product design efficiency and product quality.

Owing to the continuous development of cloud manufacturing technology, this study was limited by technology and time. The following can be considered in future investigates: (1) In-depth study of different cloud service architectures, where the effectiveness of each cloud service architecture is compared; optimization of cloud technologies, such as resource packaging and dynamic monitoring, and improvement in the product collaborative design platform; (2) the support of additive manufacturing and big data analysis, as well as improvement in system functions of the cloud manufacturing product collaborative design platform to further realize the functions of rapid product manufacturing and market demand forecasting.

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