A big data services platform framework towards cloud manufacturing system

Yongfeng Li*

School of Automation Science and Electrical Engineering,
Beihang University,
Beijing 100191, China
and
School of Mathematics and Information Engineering,
Taizhou University,
Zhejiang, 317000 Linhai, China
Email: lyfisgerly@163.com
*Corresponding author

Yongping Zhang

School of Automation Science and Electrical Engineering,
Beihang University,
100191, Beijing, China
Email: zyp904@126.com

Abstract: The source of big data in cloud manufacturing (CMfg) is analysed from two aspects. First, manufacturing cloud service lifecycle and manufacturing entire lifecycle, as well as its characteristics. Then, the classifications of big data resource and big data resource services in the CMfg are investigated respectively and the relationship between them as well. After analysing the requirements for big data technology in CMfg system, a framework for big data resource service platform is established, as well as its service operation model. The key technologies for implementing the proposed framework are studied and the application process of the platform is illustrated from the perspective of supply-demand matching of cloud services.

Keywords: big data; resource service; cloud manufacturing; CMfg; life cycle; service platform.

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Biographical notes: Yongfeng Li is a Lecturer at the School of Mathematics and Information Engineering, Taizhou University. He received his MS degree in Computer Application Technology from Wuhan University of Technology (WHUT), Wuhan, China, in 2006. He is a Visiting Scholar at the School of Automation Science and Electrical Engineering at Beihang University, Beijing, China, in 2015. His main research interests are the areas of manufacturing service management, service-oriented manufacturing, smart manufacturing, big data.

Yongping Zhang received his MS degree in Automation Control from Harbin Engineering University, Harbin, China, in 2014, and is working toward the PhD degree at the School of Automation Science and Electrical Engineering at Beihang University, Beijing, China. His main research interests are the areas of manufacturing service management, service-oriented manufacturing, smart manufacturing, decision-making and scheduling of distributed resource services in the cloud.

1 Introduction

In order to achieve full-scale sharing and collaboration of manufacturing resources and capabilities , a lot of advanced manufacturing systems and enterprise information technologies have been proposed during the past 20 years, such as networked manufacturing (NM) (Yang et al., 2000), application service provider (ASP) (Walsh, 2003), virtual manufacturing (VM) (Shukla et al., 1996), global manufacturing (GM) (Wang et al., 2001), manufacturing grid (MGrid) (Tao et al., 2011), intelligent manufacturing (IM), agile manufacturing(AM), cloud manufacturing (CMfg) (Tao et al., 2011), industrial product system (IPS2) (Meier et al., 2010), crowd sourcing(C-souring) (Estellés-Arolas and González-Ladrón-De-Guevara, 2012) and so on. As a new service-oriented NM model (Li et al., 2010; Zhang et al., 2010; Bohu et al., 2010), CMfg is developed from existing advanced manufacturing models (e.g., ASP, AM, NM and MGrid) and enterprise information technologies under the support of advanced computing technologies (ACTs) (e.g., grid computing and cloud computing), internet of things (IoT), virtualisation, service-oriented technologies (SOTs) and advanced management technologies. Since CMfg could provide cost-effective, flexible and scalable solutions to manufacturing companies by sharing manufacturing resources and capabilities, it has been widely studied by researchers recently at home and abroad and has made some typical researches in the concept, standards, architecture, operation mode, key technology and application platform.

In china, a series of research projects around the theme of CMfg has been set up by 863 plan of the ministry of science and technology of China in the “12th Five-Year” advanced manufacturing technology. This project has attracted more than 50 scientific research institutes in China (Li et al., 2011). At the same time, the National Natural Science Foundation of China (NSFC) has also established a major thematic project to support the CMfg research. As the most representative one of the research members, the CMfg research centre of Beihang University in China has made a lot of theoretical researches on the concept, architecture, core enabling technologies and characteristics of CMfg (Tao et al., 2011; Li et al., 2012; Tao et al., 2012; Cheng et al., 2013, 2014a, 2014b; 2014c).

In addition, the EU 7th Framework Program launched the manufacturing cloud project (ManuCloud) in August 2010, which purpose is to provide a configurable manufacturing capability services under the support of a set of software-as-a-service (SaaS) applications (Li et al., 2011). Wu and Schaefer (Tao et al., 2012) from Georgia Institute of Technology in USA proposed a cloud-based design and manufacturing (CBDM) model and studied the basic structure of the model. Xu et al. (Wu et al., 2013; Xu, 2013) from New Zealand presented some methodologies such as radio-frequency identification (RFID), wireless sensor networks and global positioning system (GPS) for identifying distributed resources. Wang and Xu (2013) and Wang (2013) from Sweden studied and developed an internet and web based service-oriented system for machine availability monitoring and process planning towards CMfg. Yip et al. (Wang et al., 2014) from UK studied the product configuration for CMfg.

It can be seen clearly that the manufacturing industry will develop towards integration, collaboration, agility, greening, service and intelligence. Among them, service-oriented manufacturing will play a leading role and IM will be the main feature. In order to realise service-oriented IM, it requires the instrumented, virtualisation, servitisation, collaborative and intellectualisation of hardware and software resources in CMfg and needs analysis and management of the massive data accumulated in the process. However, CMfg is still far from being able to meet the requirements of data collection, processing, storage and analysis. Fortunately, as the rise of big data (Yip et al., 2013; Li and Cheng, 2012; 2012; Wang et al., 2013; Liu and Zhang, 2014) and widely-used field in cloud computing, it has injected new vitality into the theory and application of CMfg. Accordingly, in order to enhance and expand the relevant theory and technology of CMfg, this paper will combine the theory and technology of big data, re-plan and design the application model for CMfg service platform from the perspective of data service.

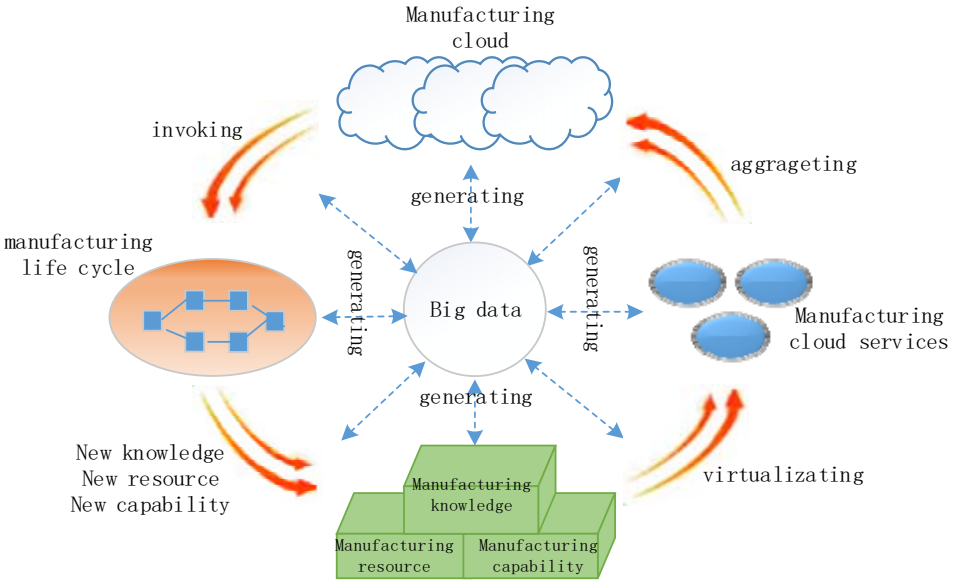
2 Big data in CMfg

2.1 Source of Big Data in CMfg

As shown in Figure 1, the CMfg system is mainly composed of manufacturing resources, manufacturing capabilities, manufacturing cloud and manufacturing life cycle (Bohu et al., 2010).

Based on the technologies such as IoT and virtualisation, distributed CMfg resources and manufacturing capabilities could be virtually encapsulated and access to the CMfg platform. Virtualised cloud resources could be provided to users with product manufacturing life cycle applications in the form of services (Li et al., 2011). There are a lot of data in this process, as shown in Figure 1. According to Figure 1, this paper describes the origin of big data in CMfg system from the following two perspectives.

Figure 1 Big data sources in the CMfg system (see online version for colours)



2.1.1 From the perspective of CMfg services

The lifecycle of manufacturing services in CMfg includes the description, release, storage, matching, composition, transaction, execution, scheduling, settlement, evaluation and other processes of manufacturing resources and capabilities (Li et al., 2011). In order to facilitate the analysis of big data in CMfg, manufacturing lifecycle is divided into three stages, namely beginning-of-service (BOS), middle-of-service (MOS), end-of-service (EOS). BOS is the stage that manufacturing cloud provides a large amount of manufacturing resource services by the virtualisation and servitisation of manufacturing resources and capabilities. MOS is the transaction process between service providers and service customers to ensure the reliability, security and maintainability. EOS mainly includes the knowledge optimisation process after the service transaction evaluation, as shown in Figure 2. Table 1 describes the data sources from each service phase. This paper introduces data flow, information flow, resource flow, logistics flow, value flow, knowledge flow, capital flow and service flow.

Figure 2 Business flow of the CMfg service life cycle (see online version for colours)

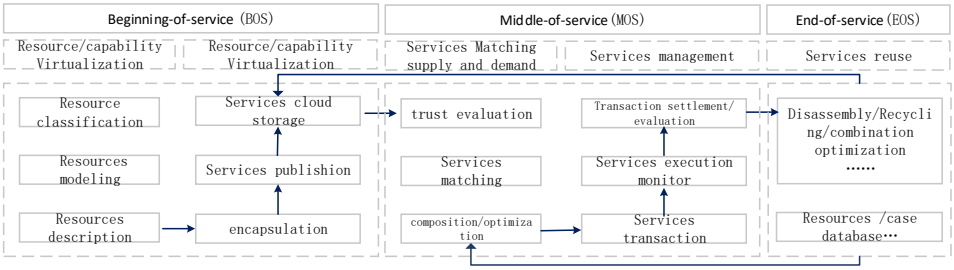


Table 1 Big data sources in the CMfg service life cycle

Service phase	*Input*	*Output*	*The big data sources*
BOS	Manufacturing resources and capabilities	Resources services	Static and dynamic manufacturing resource/capability classification standard, sensor interface and sensor acquisition standard and specification, adapter construction technology standard and specification, virtual access technology standard, resource service dynamic mapping rule, service encapsulation, registration and release standard and specification, resource service pool construction technology standards, service dynamic deployment standards and resource providers in accordance with these standards for unified modelling, packaging, registration, publishing, deployment of various types of resource services and related documents collection.
MOS	Resource services	Resource services Services evaluation	Trust assessment standards o f supply and demand, transaction and evaluation of manufacturing resource services, tasks decomposition and combination of manufacturing resources, service matching and optimal combination of manufacturing resources, services, optimal configuration and fault-tolerant management, manufacturing cloud platform operation monitoring and management, transaction process management, credit assessment and analysis of supply and demand, transaction billing and evaluation management of supply and demand.
EOS	Resource services Services evaluation	New resource services New sources	After the completion of the resource service, it decomposes the data flow in the resource pool. Resource service based on the effect of the service to the business process optimisation analysis to form new knowledge and cases

2.1.2 From the perspective of manufacturing lifecycle

Manufacturing cloud services in CMfg are applied to the whole lifecycle from product manufacturing to manufacturing as a service. The whole life cycle of product manufacturing is mainly consists of argumentation, design, production, processing, experiment, simulation and management (Li et al., 2012). In order to facilitate the analysis of big data in the manufacturing lifecycle, based on the comprehensive literatures (Li et al., 2011; Huang et al., 2014; Hu et al., 2012), this paper divides the whole life cycle into three stages: beginning-of-life (BOL), middle -of-life (MOL), end-of-life (EOL). Jun et al. (2007) defines BOL as each link between product design and manufacturing stage and the main purpose is to realise the tight coupling of material and information flow. MOL is defined as the process from product purchase to usage by customer, as well as product maintenance. The main purpose is to achieve loose coupling of material and information flow and give the feedback of the relevant information to the BOL stage. EOL is defined as the process, namely customer goes to complete the use of the product to the product recovery and discard and provides feedback to the BOL and MOL stage for optimising product design, product manufacturing and product maintenance. According to these definitions, the information flow of BOL, MOL and EOL phases can be considered as a closed-loop structure. BOL, MOL and EOL are

further described in this paper. In other words, BOL is mainly concerned the stage with the products from the concept to the drawings and finally into the physical product. MOL is mainly concerned the stage with the product sales to after-sales service and repair. EOL is mainly concerned with the recycling of products. All kinds of data flow in each stage form the closed-loop structure. The data flow generated by the manufacturing process is shown in Figure 3. Table 2 lists the major data sources generated by each phase.

Figure 3 Business flow of the product manufacturing life cycle (see online version for colours)

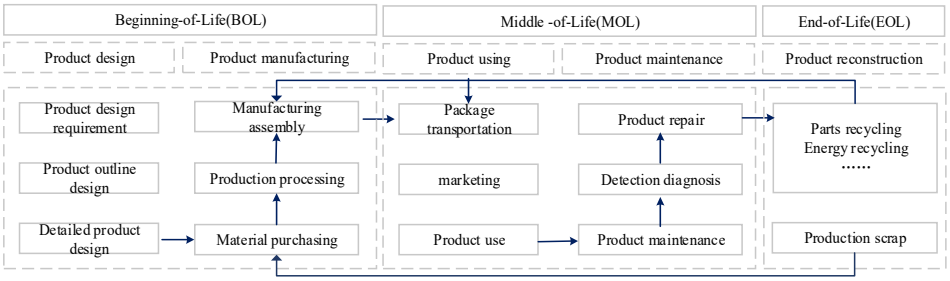


Table 2 Big data sources in the product manufacturing life cycle

Phase	*Input*	*Output*	*The big data sources*
BOS	Product requirement	Product	Market data, design knowledge, simulation data, auxiliary analysis data, product standardised data, experimental data and manufacturing data, and so on. The process of the original/source material data, supplier information, process planning data, product manufacturing data, equipment information, fault repair data, quality management data, energy management data, sensor acquisition, inventory changes data; the required financial data of design and processing, personnel information, all aspects of historical experience data and other logistics, information flow, capital flow and other data.
MOS	Product	Service feedback	Product related information, product sales related information, product use tracking related data, product maintenance related data, customer feedback data, customers use evaluation related data.
EOS	Product recycle	Parts waste product	Product life information, product re-use standards, product dismantling specifications, product retirement standards, parts re-furnace standards, parts assembly recycling standards, product exit market standards, product scrap and recycling related data.

2.2 Characteristics of big data in CMfg

From the analysis above, characteristics of big data resources in CMfg can be concluded as follows.

2.2.1 Coexistence

It refers that big data in manufacturing industry has shown both centralised and decentralised characteristics. From the perspective of resource providers, big data concentrates on the manufacturing-scale group enterprises, industrial clusters and government departments, especially in semiconductor, electronics, aircraft, aviation, aerospace, shipbuilding, automotive, equipment manufacturing and other fields. From the perspective of manufacturing process, big data concentrates on product design, process design, manufacturing processing, simulation, fault detection and other processes. From the perspective of cloud service, big data focuses on the dynamic invocation of manufacturing cloud pool and manufacturing resource services. However, big data is actually scattered in the various parts and components, production lines, manufacturing equipment and sensors from the microscopic point of view.

2.2.2 Multi-source

Big data in CMfg may be located both in the pool of corporate public resources and private enterprise resources. And it may be stored in relational distributed database, distributed real-time database, distributed file system. In additional, these databases and file systems are different in operating system, operation languages and storage methods.

2.2.3 Complexity

There are many information technologies such as internet, IoT, wireless sensor, network physical system, global position system (GPS), indoor positioning, 3D printing and some others, which are widely used in manufacturing lifecycle. Therefore, the way of data generation and data structure have changed, the data type and the noise of data have increased exponentially and the way of data services modelling are continually increased, which leads to the complexity of service feature extraction, semantic modelling and knowledge base construction. For example, the monitoring data of the equipment operation status in the workshop includes video data, positioning data, working temperature, running time, loss degree and so on. These kinds of data need to be compared with the full load peak and maintenance records of the equipment to determine the best working time of the equipment. Therefore, the data of a device becomes multidimensional and complex.

2.2.4 Uncertainty

Big data in CMfg comes from different companies, different departments, different manufacturing activities and different terminal equipment. The way of producing, recording and collecting data is uncertainty. The description of the granularity and feature of the service encapsulation is uncertainty. The data representation in different spatial and dimensions is uncertainty. These lead to uncertainties in data description, encapsulation, mining and visualisation. As the force analysis of a part, it is related to the material, metal content, casting process, forging process, trial process, workshop environment and workers' familiarity. According to their own needs, users' requirements are different. Moreover, when qualified parts are used under different conditions, it may also occurs some uncertain fault in use stage.

2.2.5 Emergence

At present, the manufacturing of many complex parts requires sophisticated production technology, manufacturing process and assembly process. At the same time, there are many unpredictable environment issues in the used process, but these parts and components lead an important role in the assembly of the entire product. Once a minor fault occurs on one part, serious consequences will appear. Therefore, this kind of seemingly insignificant data does have an important value, showing the emergence of the overall. A small crack in the turbine of an aircraft engine may threaten the safety of the aircraft flight. The environmental changes in the production shop-floor may affect the accuracy of the machining process.

2.3 Classification of resources and services of big data in CMfg

2.3.1 Classification of big data resources

Although big data mainly utilises the big data technology to collect, process and analyse, it is not suitable for big data processing analysis in CMfg (Jun et al., 2007). Therefore, the big data resources in CMfg are divided into three categories (traditional resources, new resources and infrastructure resources), as shown in Table 3. Traditional resources mainly refer to the management systems and software which exists in manufacturing enterprises, as well as the knowledge resources and services in the manufacturing lifecycle. New resources mainly refer to the generated data resources in manufacturing activities by utilising the network technologies, such as IoT, mobile networks, social networks, internet application and so on. Infrastructure resources mainly refer to the hardware and software resources needed to deploy and use big data technology in CMfg.

Table 3 Classification of big data resources in the CMfg

Traditional resources	Application system resources (ASR)	Refers to all the data in the application management system and software used in the traditional CMfg, such as PDM, ERP, CAPP, SCM, CRM, transaction system, design system, analysis system, image processing system, simulation system, simulation traditional software, etc.
	Knowledge resources (KR)	Refers to the technical, information and knowledge data generated in the CMfg, such as standards, models, experience, documentation, combinatorial optimisation algorithms, etc.
News resources	IoT resources (PR)	Refers to all the data acquisition devices, sensors, terminal tools and data collected in the CMfg, such as RFID, wireless sensor, temperature sensor, positioning terminal, monitoring equipment and data acquisition, etc.
	Network resources (NR)	Refers to the network data sources required for the CMfg. Such as web data, social commentary, mobile internet data, etc.
Infrastructure resources	Computing resources (CR)	Refers to all the servers, storage devices, network devices and computer terminals used in traditional CMfg, such as server clusters, disk arrays, routers, and management software, etc.
	Analysis resources (AR)	Refers to the platform and algorithm model for data mining and analysis in the CMfg, such as Hadoop platform, NoSql database, Hive, etc.

2.3.2 Classification of big data resources services

Big data resource service is to provide users with CMfg service resources which are the encapsulation and servitisation of all kinds of big data resources and capabilities. According to the above classification, this paper divides the big data resource services into infrastructure resource service, manufacturing resource service and big data analysis resource service.

Infrastructure resource services refer to a set of computing resources for cloud computing in CMfg.

1 Infrastructure-as-a-service (IaaS) refers to the infrastructure services for the construction of big data resource services platform in CMfg, such as computing server clusters, database server clusters, communication networks and their service capabilities and so on.

2 Platform-as-a-service (PaaS) refers to a set of application platforms that can provide processing, analysis, modeling, testing and deploying for big data resource services, such as Hadoop, NoSQL and so on. In this platform, users can manage and host their deployed applications without knowing the underlying infrastructure and environment.

3 SaaS refers to the application platform and management system for big data processing and analysis in CMfg, such as ERP, PDM, CRM, etc. Users can use specific softwares for free or lease without buying.

Manufacturing resource services refer to a set of big data resource services encapsulated as service in CMfg. Compared with cloud computing, CMfg includes not only cloud computing resources, but also manufacturing resources, such as product design-related resource services, production-related resource services, logistics-related resource services.

1 *Product design-related resource services* refer to encapsulating the data resources and capabilities for feasibility demonstration, market research, product design, process design, simulation analysis in product process to services. Then the encapsulated services are provided for upper-level analysis service.

2 *Production-related resource services* refer to encapsulating the data resources and capabilities for material procurement, production and processing, inventory storage, quality inspection and testing, fault diagnosis in product process to services. Then the encapsulated services are provided for upper-level analysis service.

3 *Logistics-related resource services* refer to encapsulating the data resources and capabilities for product sales, logistics distribution, after-sales maintenance, product evaluation and stock in product process to services. Then the encapsulated services are provided for upper-level analysis service.

Big data resource analysis services refer to providing on-demand big data analysis services for customers through the various terminals in the product lifecycle, such as statistical analysis, intelligence analysis, recommendation analysis, reasoning analysis, predictive analysis and so on.

2.3.3 The mapping relationship of the big data resources and resources services

Big data resource service is registered in the service resource pool after the virtualisation and servitisation of the big data resources. The big data resource services used by customers will eventually be mapped to the underlying big data resources. It can be said that the big data resource services are the result of the logicalisation of the big data resources on the physical level. The mapping relationships of the big data resource services and the big data resources exist as follows:

- *One-to-one* refers to an analysis task only need to call one data set or analysis method.
- *Many-to-one* refers to an analysis task needs to call two or more data sets or analysis methods.
- *One-to-many* refers to multiple analysis tasks need to call the same data set or analysis methods.
- *Many to many* refers to an analysis task need to the invocation of multiple data sets or analysis methods and a data set or analysis method may be called by multiple analysis tasks.

3 A big data resource service platform in CMfg

3.1 Demand for big data resource services

In order to deal with the emergence of big data in CMfg and realise the precision, high efficiency and IM service, the following requirements are needed.

1 Achieve the integration of multiple data and knowledge resources

There are different kinds of data and knowledge in CMfg, such as mature product design templates, graphics, experience, standards, specifications, protocols, processes, fault diagnosis methods, service processes, service composition cases, semantic cases, domain standards, service quality standards and so on. As these resources are often located in different enterprises and management systems, they are limited to search and reuse by the management system itself and can not rise to the macro level. Therefore, it is urgent to establish a unified and coordinated data collection, filtering and integration mechanisms, which can integrate the decentralised data and knowledge resources to provide customers with accurate knowledge services.

2 Build personalised recommendation and collaboration services system

Nowadays, the globalisation of manufacturing makes the competition among manufacturing enterprises increasingly fierce. ‘Just-in-time (JIT)’ is gradually replaced by the ‘want-to-get (WTG)’ and ‘need-to-participate (NTP)’. WTG refers to the manufacturing enterprise that can scan and capture the interest, habits, work nature and other data information of a certain kind of user groups and take the

initiative to push the personalised product to the users. NTP refers to a manufacturing enterprise that allows users to participate in product design, manufacturing process and product experience according to the needs of users and can quickly organise cooperative enterprises for rapid mass production, to achieve high efficiency and low cost product delivery. The realisation of these functions requires the support of big data technology.

3 Build efficient information and manufacturing networks

With IoT and information physical network are widely used in manufacturing workshop and logistics, manufacturing enterprises are not only to collect the traditional production and processing data, but also to collect equipment data, perception data, material data and other data. Hence, the interaction between materials and information is frequent. Inefficient network bandwidth and storage capacity will seriously affect the efficiency of product manufacturing. Therefore, it is necessary to establish an efficient information and logistics network to integrate the multi-objective data in the manufacturing process to ensure the accuracy of the manufacturing process. In addition, in order to speed up the application of 3D printing technology in product collaborative design, it is necessary to optimise the manufacturing network.

4 Realise the total quality control of manufacturing process

At present, many manufacturing enterprises focus on the design and manufacture of core products, while the parts and processes are outsourced or crowd sourced to the cooperative enterprises. In order to ensure the quality of the external processed parts without affecting the schedule of the main production units, it is necessary to monitor the quality of external parts timely and accurately, so as to obtain the relevant information of production and processing. The dynamic, stochastic and uncertain factors that affect the quality of the product should be accurately predicted and adjusted scientifically to maintain stable and continuous production capacity and ensure the quality of the products.

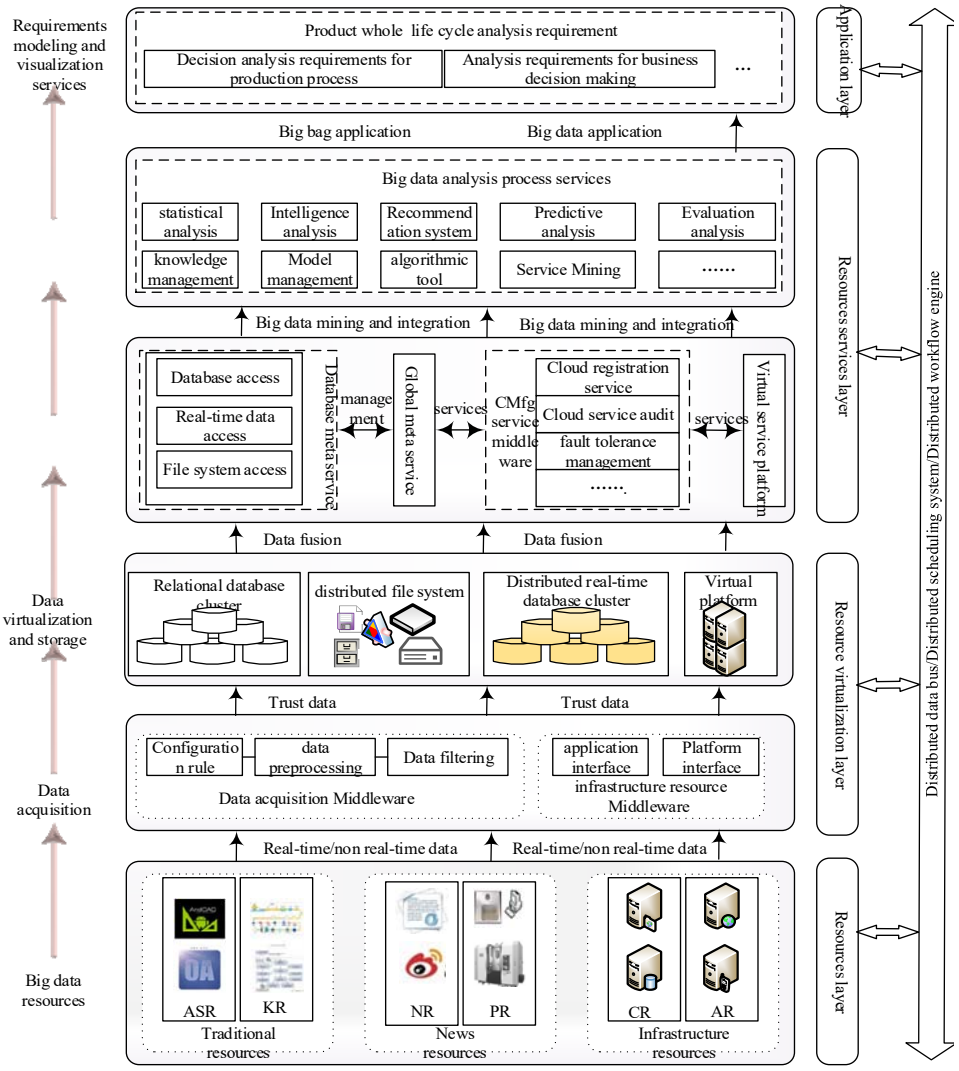
5 Achieve product re-design and innovation

The key point of the application of big data in CMfg is to achieve product reconfigurable design and innovative product design. The production process can speed up through the reconstruction of the history of the product model, product design, production processes. In order to achieve the innovation of product design, production process and manufacturing, market research, user experience analysis and product history data analysis will work.

3.2 A big data resource service platform architecture for CMfg

According to the above requirements, this paper presents a big data resource service platform model based on CMfg, as shown in Figure 4. This model mainly includes resource layer, resource virtual layer, resource service layer and application layer. The layers are described in detail as follows.

Figure 4 The architecture of the big data resource services platform for the CMfg (see online version for colours)



Resource layer refers to the big data resources generated from the product manufacturing life cycle and manufacturing cloud services processes and the basic resources needed to analyse these resource. It includes traditional manufacturing resources, new manufacturing resources and other manufacturing resources. The details are shown in Table 3.

Resource virtualisation layer mainly includes two parts: big data acquisition and virtualisation storage. Big data acquisition means multilevel denoising and filtering for the accessed data in CMfg service platform. According to certain domain configuration rules, the excess or low value data will be gradually removed to achieve the sequential convergence of data, which can ensure the accuracy of the data. Virtualisation storage is to handle the collected data with the ways such as classification, feature extraction,

formal description and modelling according to the semantic field and ontology. Then the handled data is stored in different database clusters according to the data storage format and timeliness requirements. As for the strong relationship data in product design stage and product data management, it will be stored in the distributed relational database cluster. The distributed real-time database cluster is used for managing the real-time manufacturing process data. For Unstructured data in the product manufacturing cycle such as pictures, videos, documents, experience and other knowledge, etc., the distributed file system will be required for management.

Resource service layer refers to the servitisation of the virtualisation resources and the big data analysis resources by utilising the key middleware technology in CMfg services platform. It mainly includes the servitisation of virtual storage resources and the servitisation of data analysis function model. The former is to register the virtualised storage resources into the manufacturing cloud pool, establish the different distributed database access engine and map them to the global metadata management model. The latter is to establish and manage data analysis model according to the demand analysis of the whole life cycle of product manufacturing, in order to provide analysis services for users. The analysis mainly includes knowledge management analysis services, model management analysis services, mining algorithm management service, statistical analysis management services and other functional modules.

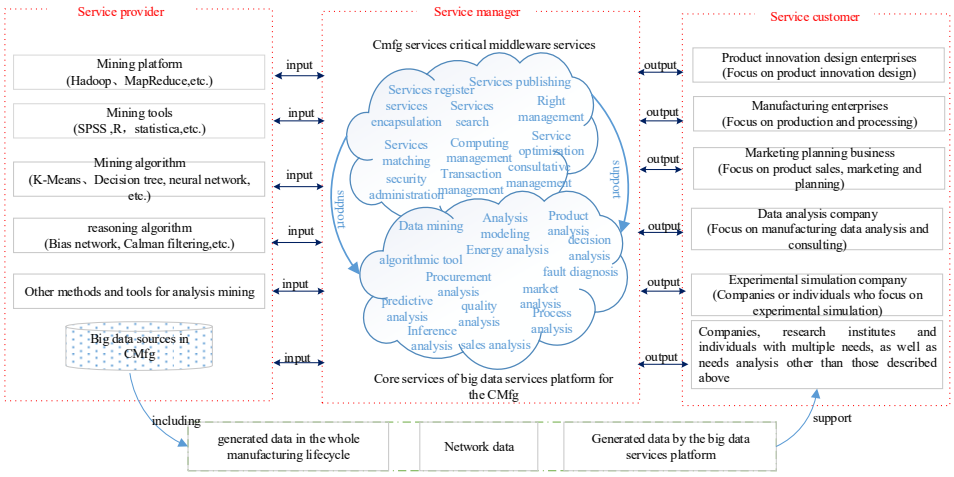
Application layer provides analysis services for the business and personal application requirement of the product manufacturing life cycle, enabling the product analysis to be universalised and visualised. It mainly includes requirements analysis, procurement analysis, product analysis, process analysis, sales analysis, reporting centre, etc.

3.3 Platform operation model

In order to implement efficient and intelligent share of data analysis and mining resources by improving the innovation of product design, controllability of manufacturing processes, agility of fault diagnosis, visualisation of experimental simulation, realisation of manufacturing precision, the big data service platform for CMfg is data-centric and integrates the methods of data services and data mining needed by the manufacturing lifecycle and supply chain enterprises. The big data service platform model is shown in Figure 5. There are three participants in the model: service provider, service customer and service manager. Service providers include manufacturing enterprises, scientific research institutes, information technology companies or individuals. They release their data resources, mining tools, analysis platforms, mining algorithms and mining models to the service platform and get a certain reward through service transactions in the platform. Service customers mainly include enterprises, research institutes, information technology companies, manufacturing consulting companies or individuals. They can get various analysis services by the way of lease or purchase such as market analysis, product design, product sales analysis, product quality analysis and so on. As for the service manager, it is mainly responsible for managing the data, mining algorithms and analysis capabilities provided by the service provider by the way of review, screening, modelling, evaluation, monitoring, registration, release and other services on the one hand and on the other hand it is responsible for managing the analysis demands of service customers by screening, labelling, search, services decomposition, services matching and optimisation services. At the same time, it is responsible for monitoring the entire service process between

service provider and service customer, as well as hardware and software environment in CMfg service platform to ensure the timeliness and security of the platform.

Figure 5 The operation model of the platform (see online version for colours)



3.4 Key technologies

The big data resource service platform for CMfg is a service system with big data analysis technologies under the support of big data resource storage cluster, CMfg and cloud computing. In the system, it is necessary to solve the key technologies and problems of the platform, such as collection and integration of big data, classification and organisation of big data, virtual access of big data resources, storage of big data resources and services, management of big data resources and services and so on. Details are shown in Table 4.

4 Comparison with the CMfg service platform

The CMfg service platform, which is a new model of service-oriented IM (Li et al., 2011), is to provide the platform for network interconnection, resource sharing and collaboration between manufacturing enterprises, so as to provide on-demand services according to the needs of manufacturing resources and capabilities for users whenever and wherever possible. It can be said that the CMfg service platform is the deepening of the manufacturing network and MGrid and the landing and extension of cloud computing in the manufacturing field (Li et al., 2011). Compared with the existing information technology, the technical characteristics of the CMfg service platform are embodied in the combination of manufacturing resources and capabilities, virtualisation, servitisation, coordination and intelligence (Li et al., 2011).

Table 4 Key technologies of the platform

Key technology	*Research contents*	*Problem solving*
Framework	The operating mechanism and service mode of the platform, the connotation and characteristics of the big data of the platform, the connotation and the relationship between the large data resources and services of the platform, the development and application of the standard specification of the platform, the architecture of the platform and so on	To solve what is the big data, where it exists, what is the significance of the classification criteria in the CMfg. How to manage big data, how virtualisation of these big data, how to conduct transactions and evaluation and so on a series of standard, guidelines and specifications to create a multi-user, multi-task large data analysis environment.
Big data acquisition technology	Dynamic collection, analysis and pre-processing technology of mass IoT and Information physical sensing data, real-time acquisition, analysis and pre-processing technology of mass production cycle data, acquisition, analysis and pre-processing of mobile networks, social networks and Internet data	To solve the problem of data collection and pre-processing in the product life cycle, to ensure the data consistency and correctness of the data source of the big data analysis.
Virtualisation and storage technology of big data resources	Organisation, classification and formal description of emerging data Semantic description techniques for subject and domain knowledge Integration of traditional application system resources Real-time data virtualisation and storage technology Virtualisation and storage technology of knowledge-based unstructured data	To solve the problem of data fusion and unification representation of heterogeneous data sources and application systems. To solve the problem of unified representation of knowledge and technology of semi structured and structured data, so as to form a unified data access interface. To solve the problem of data organisation, classification, data association, model extraction and formal description in the platform. At the same time, according to the different application requirements, the hierarchical storage is used to optimise the layout of the distributed storage cluster and improve the efficiency of data scheduling.
Service technology of big data resources	Service technology of mining algorithm, mining tools and mining platform Mapping and transformation between analytical services and physical data sets Task decomposition, optimisation, matching, composition and evaluation of analytical services Encapsulation technology of service capability of data set and mining method Joint scheduling techniques for global and local resource metadata sets	To solve the big data resources and service package, constructed to meet the analysis of the data of different scale demand, realise the reasonable scheduling analysis algorithm and parallel operation strategy, realise resource scheduling ecosystem processes to the analysis task.
Security and privacy protection	Access to data and data sets security and privacy technologies Access enterprise and its terminal equipment security technology Transaction payment credit protection technology Credible and reliable analytical techniques	Ensure that data security of the data mining process, to ensure that the user's privacy is not compromised. The process of data analysis is virtual, controllable and reliable, and the feedback analysis results are objective and real.
Interactive visualisation technology	On demand personalised interactive view technology for pervasive users Multimodal natural interaction technology for pervasive computing Display technology for supporting multi source multi dimensional analysis	Solve the visualisation, interactive, personalised, diversified, timely, dynamic, intelligent needs of the big data analysis.

Table 5 Comparison with the CMfg service platform

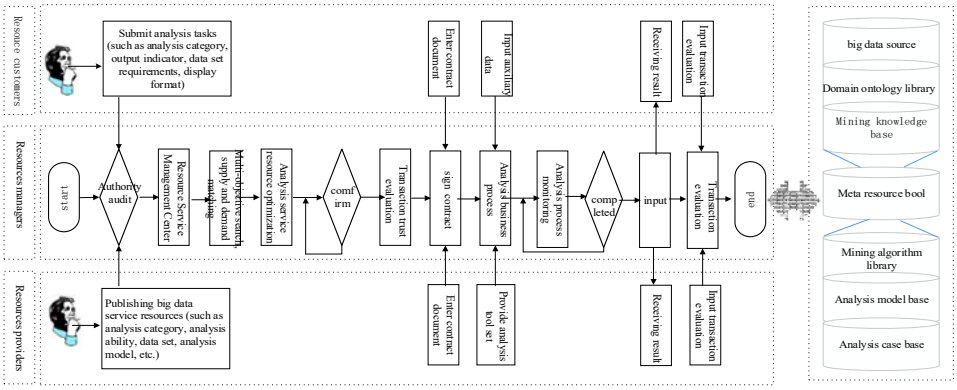
Contents	*CMfg service platform*	*Big data resource service platform for the CMfg*
Data form	Structured and unstructured data (structured data)	Structured and unstructured data (non-structural, sequential data)
Data type	Complexity	Very complexity
Data sources number	Many	Great many
Data feature	Record data	Flow data
Timeliness	Ordinary	Real-time
Application purpose	Process monitoring, optimal scheduling and allocation of resources	Advanced prediction, data processing and decision analysis
Service type	On demand service/mass customisation service	Individuation/intelligent recommendation/precision service
System requirement	High storage capability	High storage/analyzing ability/high throughput
Unit data increment	Stabilisation	Geometric growth
Visualisation mode	Single	Complex diversity
Data processing and analysis method	Little	Many
Information integration scope	Enterprise integration	Integration of enterprise and society extended to the entire supply chain

The big data resource service platform for CMfg aims at providing decision support for all aspects of the product life cycle, such as the real-time perception of manufacturing resources, the optimisation control of manufacturing process, the optimal allocation of manufacturing services, agile business in supply chain and so on, utilising the technologies (such as data collection, data fusion, data processing, data analysis and data visualisation, etc.) of the big data. The big data resource service platform for CMfg is the deepening of the CMfg service platform. From the perspective of service-orientation, data resources and analytics resource in the big data resource service platform for the CMfg still need to be encapsulated to the manufacturing cloud through virtualisation technology, servitisation technology and cooperative technology and still need follow the related protocols and standards of the CMfg services platform. From the system level, the big data resource service platform for the CMfg needs more reliable hardware and software resources to meet the requirements of real-time processing and analysis of massive data. For the purpose of application, the big data resources service platform for the CMfg is to provide the agile and accurate decision-making services for production operations and businesses by obtaining the valuable information of different levels of the CMfg service platform. Table 5 lists the comparison of the big data resource service platform for the CMfg and the CMfg service platform from different angles.

5 The application process of big data service platform based on CMfg

The platform has three users: service provider, service customer and service operator. Service provider provides big data resources and analysis methods. Service customer uses the services in the platform. Service operator manages the services in the platform and ensures the security of the platform. A detailed flow chart is shown in Figure 6.

Figure 6 Application process of the platform (see online version for colours)



6 Conclusions

In recent years, with the rapid development of IT and communication technologies such as internet, IoT, cloud computing and tri-networks integration, data has become a serious challenge faced by many industries. However, it is still a valuable opportunity for many industries. The emergence of big data not only changes the way of people's life and work, but also changes the operation mode of enterprises and even leads to fundamental changes in the mode of scientific research (Li and Cheng, 2012). At present, many manufacturing enterprises have carried out production facilities projects based on big data to help them achieve a shorter time to market, higher production flexibility and asset utilisation, lower ownership costs and more controllable corporate risk (Hu et al., 2006).

After analysing the origin and characteristics of big data in CMfg, this paper carries out the classification for these data, so as to provide a reference for the feasibility of application based on big data technology in CMfg. After analysing the demand for analysis resource of big data in CMfg, the big data resources service platform model for CMfg is proposed. The platform enriches the theory of CMfg. Finally, the key technologies of building a big data resource service platform for CMfg are summarised, which is helpful for further study. However, as the research and application of cloud-based manufacturing is still in the infancy, it is far from being able to realise the processing and analysis requirements of big data in CMfg. Therefore, further researches are needed from various aspects such as model, technology and application. With the big data technology maturing, it is bound to create a new world of CMfg in-depth study.

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