Distributed Resource Environment: A Cloud-Based Design Knowledge Service Paradigm

Zhinan Zhang, Xiang Li, Yonghong Liu and Youbai Xie

Abstract Design can be viewed as a knowledge intensive process, which requires more and more collaboration between design resources within and without an enterprise for product innovation. A company's capacity for product innovation essentially means the ability to discover, use, and manage different kinds of design resources. However, design resources are distributed unevenly within or across organizational boundaries. In order to benefit from the outsourcing of design knowledge within different design resources, with lower costs and within a shorter time, is a great challenge for enterprises. The design knowledge must flow quickly and reliably from when and where it is located to when and where it is needed for design activity. Unfortunately, there are many barriers having a negative influence on quick and reliable knowledge flow between knowledge owners and knowledge demanders. The lack of supporting mechanisms (e.g., a knowledge service platform) between service providers and consumers is one of the barriers. Thus, there is a need to develop mechanisms to overcome the barriers and thereby improve the performance of knowledge flow. This chapter introduces a cloud-based knowledge service environment, i.e., a distributed resource environment, which enables companies to utilize collective open innovation and rapid product development with reduced costs. The definition, function, structure, and characteristics of a distributed resource environment are presented. Then, the concept of a cloud-based

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knowledge service framework is proposed to organize the knowledge sources in a distributed resource environment. The knowledge sources are composed of design entities' knowledge cloud and resource units' knowledge cloud. The former is the knowledge consumer and latter is the knowledge provider in a distributed resource environment. Next, a cloud-based knowledge service framework is presented for the well effective operation of a distributed resource environment. Two agents, i.e., a knowledge service publishing agent (KSPA) and a knowledge service consuming agent (KSCA) are developed to implement the online knowledge service. KSPA can be used by knowledge providers to encapsulate and publish their design knowledge as a service into the service market, whereas KSCA can be used by knowledge consumers to request knowledge service from the service market. Finally, an inner-enterprise distributed resource environment is implemented to verify the proposed knowledge service paradigm.

Keywords Distributed resource environment · Cloud-based design · Knowledge cloud · Knowledge service · Knowledge flow

1 Introduction

The highly competitive nature of business in a global market economy is forcing companies to make continuous efforts to leverage their product innovation in order to gain or maintain their competitive edge. The design and development of products are becoming increasingly complex. In this scenario, manufacturing enterprises have to utilize just-in-time widespread knowledge resources to meet various customer requirements. There are many knowledge acquisition resources (e.g., experienced engineers, software, knowledge base, all kinds of test equipment and instruments), which belong to different organizations or enterprises. Generally, these knowledge acquisition resources are geographically distributed, and usually unknown to the seekers (i.e., enterprises or organizations who have a desire to utilize the outsourcing resources) outside organizational boundaries. This scenario makes the sharing of knowledge acquisition resource across organizational boundaries very complicated.

In recent years, new concepts about the cloud have emerged from computer science, such as cloud computing (Zhang et al. 2010), cloud service, service-oriented architecture (SOA), and grid computing. A constant infiltration of new techniques within a manufacturing industry, the concept of cloud-based design and manufacturing (CBDM) has become more and more popular as an enterprise-level design and manufacturing model (Wu et al. 2013a, b, c). As pointed by Dirk Schaefer in the *call for chapter proposals* of the book "*Cloud-Based Design and Manufacturing* (*CBDM*)*: A Service-Oriented Product Development Paradigm for the 21st Century,*" cloud-based design and manufacturing (CBDM) is "a new product realization model that supports open innovation through social networking and negotiation platforms between service providers and consumers. It is a type of parallel and distributed system consisting of a collection of inter-connected physical and virtualized service pools of design and manufacturing resources as well as intelligent search capabilities for design and manufacturing solutions." In this context, knowledge service bridges the gap between service providers and consumers, and thus facilitates knowledge flow and sharing among them.

Knowledge service is a knowledge flow intensive process to satisfy the users' requirement of specific knowledge (Li et al. 2009). As product design becomes more and more complicated and increasingly multidisciplinary knowledge dependent, any individual or enterprise will find it difficult to own all kinds of needed knowledge in the design process. Many researchers have done a lot of work in the knowledge service area. For example, in order to provide a semantically interactive environment for users, Li et al. (2009) proposed an approach of service-oriented knowledge modeling on an intelligent topic map. Chen and Chen (2009) proposed a novel product knowledge service model based on the product life cycle and its supply chain. Meng and Xie (2011) presented the concept of an embedded knowledge service to embed the independent technical activities of external resource units as a part of the complete product development process of design entities. Zhuge and Guo (2007) proposed a virtual knowledge service market based on a knowledge grid. Mentzas et al. (2007) introduced the concept of knowledge trading and analyzed an ontology-based approach for trading knowledge services using semantic technologies. In addition, according to Li et al. (2009), Schaefer et al. (2012), Wu et al. (2012, 2013a, b, c), Ding et al. (2012), Tao et al. (2011), and Xu (2012), scholars are working on defining, understanding, and discussing the framework of CBDM. For example, Wu et al. (2012, 2013a, b, c) and Schaefer et al. (2012) introduced a comprehensive definition and concept of CBDM as well as a first step towards understanding the key characteristics and fundamentals of it. As summarized by Wu et al. (2013a, b, c), they have proposed four kinds of services to cloud-based service consumers. The services are: (1) Hardware-as-a-service (HaaS) which delivers hardware sharing services (e.g., milling, lathe machines, CNC machining centers, hard tooling, and manufacturing processes) to cloud consumers, (2) Software-as-a-service (SaaS) which delivers software applications, e.g., CAD/CAM, FEA tools, and Enterprise Resource Planning (ERP) software to cloud consumers, (3) Infrastructure-as-a-service (IaaS) providing consumers and providers with computing resources, e.g., high performance servers and data centers, and (4) Platform-as-a-service (PaaS) offering a social networking media for cloud consumers and providers to communicate and collaborate, providing a new channel for mass collaboration and open innovation. Zhang et al. (2010) presented a survey of cloud computing, which provided a better understanding of the key concepts, architecture, and implementation of cloud computing. Ding et al. (2012) proposed an ontology-based cloud service integration model for the representation of manufacturing resources. A three-layer collaborative manufacturing resource sharing platform is proposed for manufacturing service integration. Tao et al. (2011) proposed a four-stage cloud manufacturing model where manufacturing resources are controlled through the internet via intelligent monitoring systems. Xu (2012) discussed the typical characteristics, architecture, core enabling technologies for cloud manufacturing, and the relationships between cloud manufacturing and cloud computing.

As mentioned above, current knowledge service work focuses on how to supply consumers with organizations' existing knowledge in a plug-in and plug-out pattern. In fact, since design is full of uncertainty, knowledge service providers have to do certain knowledge acquisition activities ahead of providing knowledge to meet the consumers' knowledge needs. Therefore, a design knowledge service should be a knowledge flow intensive iterative process. To the best of our knowledge, a few studies on knowledge service and CBDM focus on how to organize knowledge acquisition resources to form a distributed resource environment (DRE) and represent their knowledge service capability for providing design knowledge services. The demands of a distributed resource environment are more owing to today's competitive nature of the global marketplace and increasing complexity of products. This phenomenon requires that companies design products right-the-first-time and for shorter time-to-market. A distributed resource environment can help companies by reducing the cost of product design and development, accelerating time-to-market for new products, and improving product performance. This is an evolution of the design transition away from traditionally depending on research and design (R&D) in-house towards more open innovation by integrating knowledge from distributed resources. Core competencies, i.e., knowledge integration competency for design entities (i.e., knowledge service consumers) and knowledge acquisition competency for resource units (i.e., knowledge service providers), rather than physical assets, increasingly define competitiveness of companies in the market.

In this study, a DRE aims at realizing a service-based design knowledge flow and paid sharing among enterprises or organizations. A well operated distributed resource environment means that design resources can be integrated and the flow of knowledge is manageable. Manufacturing enterprises can rapidly integrate different kinds of knowledge from professional design resources based on their dynamic and various design requirements. In short, the manufacturing enterprises and individuals enabled by the more efficient cooperative capability of enterprise cloud service systems could obtain diverse design and manufacturing services from the internet and intranet more conveniently. This chapter introduces a cloud-based knowledge service environment, i.e., a distributed resource environment, which enables companies to utilize collective open innovation and rapid product development with reduced costs. The outline of the chapter is as follows. Section 1 presents the background of this study. Section 2 presents the concept of the distributed resource environment. Section 3 proposes a cloud-based knowledge service framework. Section 4 introduces the implementation of the proposed framework via an illustrative case study. Finally, the conclusions are presented in Sect. 5.

2 Distributed Resource Environment

2.1 Concept of Distributed Resource Environment

The aim of a distributed resource environment is to effectively organize all kinds of knowledge service providers (e.g., design entities) and knowledge services consumers (e.g., resource units) through a knowledge service platform. Based on a distributed resource environment, any design entity or resource units could easily obtain the knowledge to solve their problem by knowledge services. Its concept is introduced as follows.

The Oxford English Dictionary http://oxforddictionaries.com/page/oxfordenglishdictionary defines the noun *environment* as

> The surroundings or conditions in which a person, animal, or plant lives or operates.

The essentials of this definition are *surroundings* or *conditions*, and *object* (referring to person, animal, or other things). Thus, the concept of *distributed resource environment* also includes elements as surroundings and object. Therefore, the key factor to define the concept of a *distributed resource environment* is to clarify the surroundings and the object.

In order to solve the problem, a brief review of the development of this concept should be discussed first. The concept of a distributed resource environment is presented in the background that design plays a critical role for improving the competitive power of Chinese manufacturing enterprises, and that most of Chinese manufacturing enterprises lack knowledge and knowledge acquisition resources to help design products with shorter time-to-market. The concept of a distributed resource environment was first presented by Xie (1998), which aimed at organizing distributed resources in China through service-based knowledge flow for the purpose of improving their competitive power http://www.chinamoderndesign.com .

As mentioned above, the *surroundings* are distributed knowledge service providers and consumers, i.e., design entities and resource units, respectively. The *object* is an intelligent, sustainable internet-based platform (e.g., a kind of knowledge) that enables design entities (fulfilling the role of knowledge service or knowledge acquisition service consumers) and resource units (fulfilling the role of knowledge service or knowledge acquisition service providers) to effectively capture, publish, share, and manage knowledge services, or knowledge acquisition service resources. Therefore, the distributed resource environment is the *Internet of Knowledge*.

Thus, a DRE can be defined as an ecosystem of design entities and resource units, supporting networks and infrastructure that is designed to be: competitive, satisfy customer needs, and create value for both design entities and resource units. This ecosystem refers to companies in the system where orderly competition instead of the current disorderly competition is exhibited.

For resource units (*knowledge service providers*), DRE means a shift from producing and offering products to providing services and system solutions that will intensively meet customers' needs. With traditional R&D cooperation in China, R&D means one organization that provides services for one company for a certain period, and the fruit will be owned by the company or shared by both. However, DRE emphasizes on open innovation that has the potential for one resource units servicing many design unities and many resource units to service one design unit. This requires resource units to continuously improve their knowledge service and knowledge acquisition (abbreviated as knowledge service later) service level to maintain their competitive edge.

For design entities (*knowledge service consumer*), DRE means a shift from long time-based R&D cooperation to buying just-in-time services and system solutions that have a potential to minimize the risk for short-to-market product development due to failed or delayed R&D projects.

2.2 Function of a Distributed Resource Environment

For both resource units and design entities (*provider and consumer*), a distributed resource environment is a knowledge flow facilitator designed to support cross-organizational intense flow of knowledge. Both resource units and design entities will benefit from knowledge flow. On the one hand, design entities can fulfill their design-led innovation by integrating knowledge from outside knowledge resources. On the other hand, resource units can provide knowledge services to different design entities to enlarge their profit, and this will in turn encourage permanent investment in maintaining the knowledge acquisition edge.

A paramount purpose of the DRE should be to minimize the impact of lack of knowledge acquisition resources or insufficiently utilizing existing knowledge in improving the design-led competitiveness of manufacturing enterprises, especially Chinese manufacturing enterprises.

2.3 Structure of a Distributed Resource Environment

As is shown in Fig. 1, a distributed resource environment is the *internet of knowledge*, which includes three main constitutional elements, i.e., design entities, resource units, and an internet-based knowledge service platform. Figure 1 may provide a cognitive understanding of the distributed resource environment. It is the platform that bridges design entities and resource units and fulfills the function as knowledge flow facilitator.

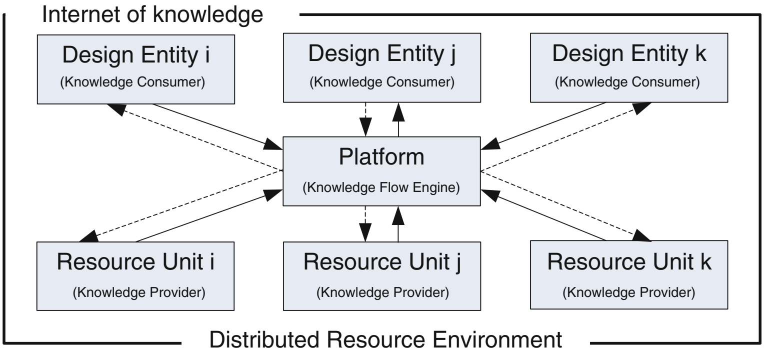


Fig. 1 Structure of distributed resource environment

- *Design entity: knowledge service consumer*

Design entities refer to organizations, which have the capacity to integrate domain knowledge to perform the innovative product design and development process, and which know what knowledge is needed to accomplish their tasks. Within DRE, many design entities focus on the integration of knowledge, and in their product design process, they will consume knowledge services and knowledge acquisition services to overcoming the barriers of lack of time and money spent on new knowledge acquisition. For example, internal combustion engines OEMs are design entities. In their engine design and development process, design entities will consume knowledge services from outside organizations, for example, they may ask universities to do fundamental research on a frontier field, or they may ask component suppliers (e.g., piston OEM, bearing OEM, etc.) to develop engine elements to meet their needs.

- *Resource unit: knowledge service provider*

Resource units are organizations or individuals, which have a competitive advantage in certain domains and which may offer knowledge services and have the ability to acquire new knowledge to meet the need of knowledge service requirements from design entities. Many resource units (having the capacity of acquiring new knowledge in given regions) will provide knowledge services and new knowledge acquisition services for design entities in order to obtain their rewards. As for the engine design case, if an Engine OEM is a design entity, then suppliers, such as a piston OEM and piston ring OEM are resource units, which will provide service to the engine OEM. On the other hand, if the piston OEM asks for knowledge services (e.g., evaluate piston skirt tribological performance) provided by others, then the role of the piston OEM is as a design entity. Therefore, there are no clear boundaries between design entity and resource unit. To name an organization as a design entity or a resource unit depends on the functional role of the organization.

- *Knowledge service platform*

As shown in Fig. 1, the platform is a hub for knowledge service consumers and providers in a distributed resource environment (Zhuge and Guo 2007; Choy et al. 2007). Design entities and resource units in design related domains find their needed information and knowledge here to solve their problem. They therefore help both design entities and resource units through knowledge services to obtain design-led competitiveness, which is at the heart of the platform. A platform with many instruments is good enough to support a highly efficient, highly reliable, and very cheap internet-based cooperation between design entities and resource units.

2.4 Characteristics of a Distributed Resource Environment

- *Internet of knowledge*

The internet of knowledge refers to design entities and resource units that have the potential in knowledge services, and both design entities and resource units are taken as knowledge flow nodes being connected by the internet within a distributed resource environment. The concept of internet of knowledge means that the internet bridges the time and space gaps between design entities and resource units, and meets the need for the just-in-time supply of knowledge and information. The Internet of Knowledge can possibly enable manufacturing enterprises to compete in the knowledge economy, especially Chinese manufacturing enterprises. DRE can help manufacturing enterprises to strategically manage its limited knowledge resources and focus on core capabilities for sustainable development. On the other hand, manufacturing enterprises may depend on knowledge services to gain faster insights into new business opportunities, and compete on knowledge to drive productivity and innovation.

- *Partial self-organization of design entities and resource units*

Distributed resource environments emphasize an open innovation instead of a closed innovation through knowledge service. A key element of DRE is a well operated platform. As mentioned above, the platform is a hub for integrating information about distributed design resources. Hence, the platform fulfills the role of organizer and manager for organizing and managing distributed resources. However, both design entities and resource units have the right to determine whether joint DRE or not.

- *Power of the many*

One resource unit serves for one design entity on a traditionally project-based R&D pattern, and all the knowledge acquired should be transferred to the project founder. A resource unit is forbidden to use the knowledge acquired in one project to serve another consumer. Therefore, this pattern will not allow improvements in design-led Chinese manufacturing enterprises' competitive power due to limited knowledge flow. On the other hand, using a one-to-one service pattern, design entities may lose the chance to ask more powerful resource units to provide better knowledge service or knowledge acquisition services.

Within a distributed resource environment, any design entity or resource unit has the chances to ask many to provide or consume knowledge services or knowledge acquisition services. The one which can provide better service will have more chances to serve the many and thus to make more profits.

3 A Cloud-Based Knowledge Service Framework

The cloud-based knowledge service framework consists of knowledge service, working platform, and resources. The key technology of this framework mainly includes the service management technology, service providers and consumers management technology, safety and reliable security technology, and cloud technology. This study focused on the development of knowledge service platform and related key technology, e.g., development of tools to help knowledge providers encapsulate and publish their design knowledge as a service (i.e., SaaS). The platform consists of a collection of knowledge service pools, i.e., simulation related knowledge service, test-related knowledge service, consulting-related knowledge service, and component of system design related knowledge service.

3.1 Architecture of Knowledge Service Platform

According to the definition and structure of the distributed resource environment, the architecture of a knowledge service platform is shown in Fig. 2. The platform is also a type of knowledge service provided by a certain resource unit. The platform has three key components. The universal discovery, description, and integration of knowledge (i.e., KUDDI) component deals with the publishing and searching of knowledge service. All the publishing services and requirements will be included in the service and requirements list, respectively. Using this component, both knowledge service providers and consumers will obtain business opportunity. The negotiation component helps both the knowledge service provider and demander to negotiate and produce contracts to protect the intellectual property and patent rights within the knowledge flow. It should be noted that an inner-enterprise distributed resource environment is able to avoid the intellectual property rights disputes. The trade management component deals with the management of complaints, payment, and trust for services and offers a system to evaluate the knowledge service provider. The functions of the management component can be refined with reference to *www.taobao.com*.

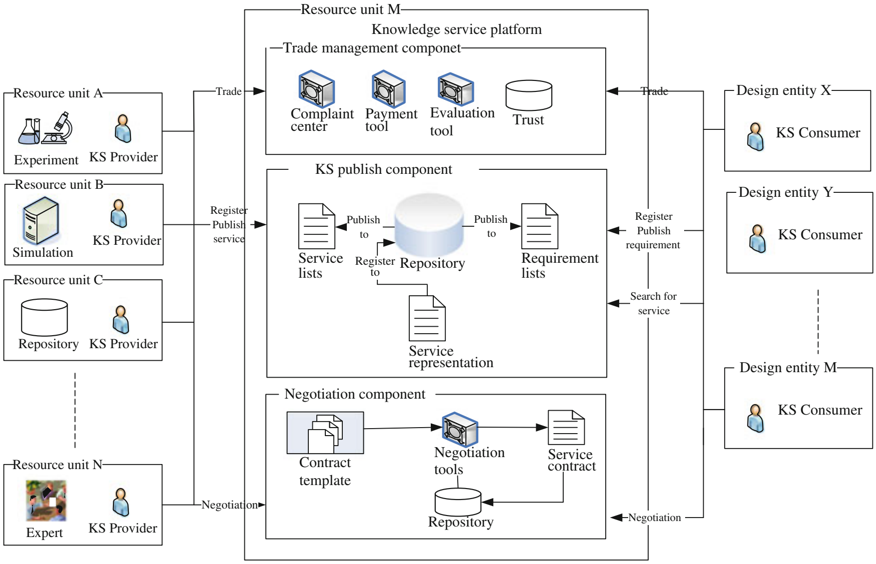


Fig. 2 Architecture for a knowledge service platform in DRE

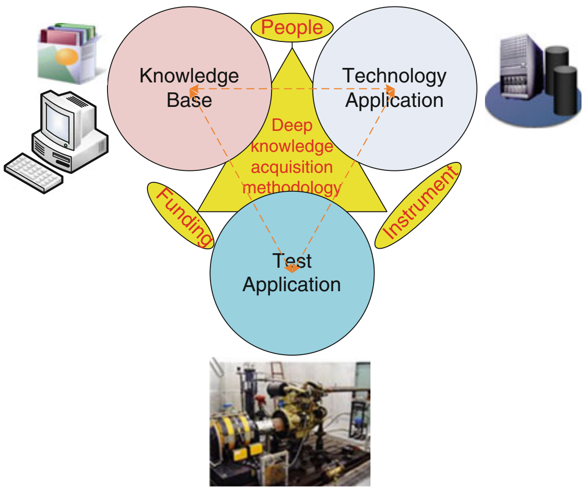
3.2 *Represent the Knowledge Service Capacity of a Resource Unit*

In the architecture of a knowledge service platform, one of the key issues is the representation of the knowledge service capacity of a resource unit and the service requirements of a design entity. In this subsection, the capacity model of a resource unit and an ontology based modeling approach was proposed to represent the knowledge service providers' knowledge service capacity and the consumers' knowledge service requirement.

- *Capacity model of resource unit*

The capacity model of a resource unit consists of four main aspects: (1) People with knowledge and experience that are able to acquire extensive knowledge in a certain domain. (2) The knowledge base that stores the knowledge and experience of a resource unit. (3) Instruments including software and hardware, which supports knowledge acquisition. (4) Sufficient investment of time and money to improve and maintain a resource unit's innovation and competitiveness. With the support of its knowledge acquisition resource, a resource unit has to develop its own broad knowledge acquisition methodology and be able to develop technology-based knowledge services and/or test-based knowledge services. Figure 3 illustrates a schematic diagram of the capacity model of a resource unit.

Fig. 3 Capacity model of a resource unit



- *Modeling of service providers' capacity*

As shown in Table 1, the provider, product, discipline, tools, and provision compose the ontologies of resource units, and each ontology consist of one or more attributes. For instance, the provider ontology has the attributes of contact information, finance information and human information, and all the attributes have determined descriptions. Using the provider ontology, the basic information of a knowledge service provider will be represented and ready for being discovered in the KUDDI component. Suppose each resource unit provides two kinds of knowledge services, i.e., product-oriented services and discipline-oriented services. For the product ontology, all or some of the six attributes have to be quantitative or qualitative descriptions. For the discipline ontology, the provider needs qualitative description application domains and their capacity of new knowledge acquisition and knowledge services, such as tribology design. Our approach also provides ontology for the description of tools that might be used to acquire new knowledge. The provision ontology includes the trust attribute, where intellectual property and the quality of service are defined; the price ontology, which specifies price and payment issues; and the delivery ontology, where transfer issues are represented.

- *Capacity model of resource unit*

Table 2 provides the design entities with four kinds of ontologies, i.e., the demander ontology, the product ontology, the discipline ontology and the provision ontology, to represent their knowledge requirements. As the attributes and descriptions of those ontologies are similar with those presented in Table 1, those will not be detailed here.

Negotiation among providers and demanders will be assisted by a conference system or other negotiation tools, such as Skype, Microsoft MSN, Tencent QQ et al.

Table 1 Ontology based modeling of resource units' knowledge service capacity

Vendor	Ontology	Attributes	Description
Resource units (Service providers)	Provider	Contact	Name, address, tel, fax, e-mail, reputation, and so forth
		Finance	Financial information
		Human	Human resource
	Product	Function	What is for?
		Structure	For physical products
		Constraint	Must or Must not
		Context	In which context the product can be used
		Process	Describes how to use the service object
	Discipline		Describes the application domain that can offer knowledge service, i.e., tribology design
	Tools	Test instrument	Name, vender, specialty, purpose
		Software	Name, vender, specialty, purpose
		Hardware	Name, vender, specialty, purpose
	Provision	Trust	How to protect the rights of both parties
		Price	Price for different kinds of service
		Delivery	How to transfer the knowledge object
		Time	Time to customer

Table 2 Ontology based modeling of design entities' knowledge requirements

Vendor	Ontology	Attributes	Description
Design entities (Service consumers)	Demander	Contact	Name, address, tel, fax, e-mail, reputation, and so forth
		Finance	Financial information
	Product	Function	Requirement for function
		Behavior	Requirement for behavior
		Structure	Requirement for structure
		Constraint	Must and must not
	Discipline		Describes the requirement of discipline knowledge service
	Provision	Price	Price for the service
		Delivery	How to transfer the knowledge object
		Time	Time to demander

After successful negotiation, a contract will be produced to protect the intellectual property and patent rights within the knowledge flow.

Using knowledge flow, even if a company lacks some domain knowledge, it can also design a new product through integrating domain knowledge. Thus, to facilitate knowledge flow within DRE by the proposed architecture, both service provider and service demander will benefit from the flow of knowledge. In the next section, a brief case is given to show how a DRE facilitates the flow of knowledge and how a manufacturer benefits from KF.

3.3 Modeling Knowledge Service Process

The process of knowledge service is shown in Fig. 4, which includes two kinds of stakeholders (i.e., knowledge service provider and knowledge service consumer), nine kinds of actions and five kinds of states.

Figure 5 shows the actions and the variation of states in a knowledge service process. After the knowledge service provider published his knowledge service, the status of the service becomes *ready*. If knowledge service consumer requests knowledge service from a knowledge provider, the status of service enters *proposed*. The knowledge service provider needs to evaluate its capability to decide whether it can provide knowledge service. If not, the knowledge service provider rejects the request, and gives feedback to the knowledge service consumer; the status of service will be *closed*. If yes, the status of service becomes *active*. The active status indicates the service is beginning. When a knowledge service provider solves the requested problem, it will give the solution to the knowledge service consumer. The status of service becomes *resolved*. The knowledge service consumer evaluates the result to decide whether the service satisfied his requirements. If not, it will ask the knowledge service provider to rework; the status of service becomes *active* again. If yes, it indicates that the solution provided by the knowledge service provider meets the requirement of knowledge demander, the service is *closed*, and then a total knowledge service process is done.

3.4 Classification of Knowledge Services

In a distributed resource environment, there are four major kinds of knowledge services. The detailed information about each type of knowledge service is as follows.

- *Simulation-related knowledge service* Knowledge service providers have simulation tools, methods, and engineering applications. Based on these resources, they can provide simulation-related knowledge services to the service consumers.
- *Test-related knowledge service* Knowledge service providers have instruments, equipment, and experiment devices, and the knowledge of how to use these resources to acquire new knowledge.
- *Consulting-related knowledge service* Knowledge service providers have domain experts and fruitful knowledge and experience. Providers can use these resources to solve consumers' problems.
- *Component of system design related knowledge service* Knowledge service providers are often component suppliers with the capabilities to offer the service of design and development of new component to consumers.

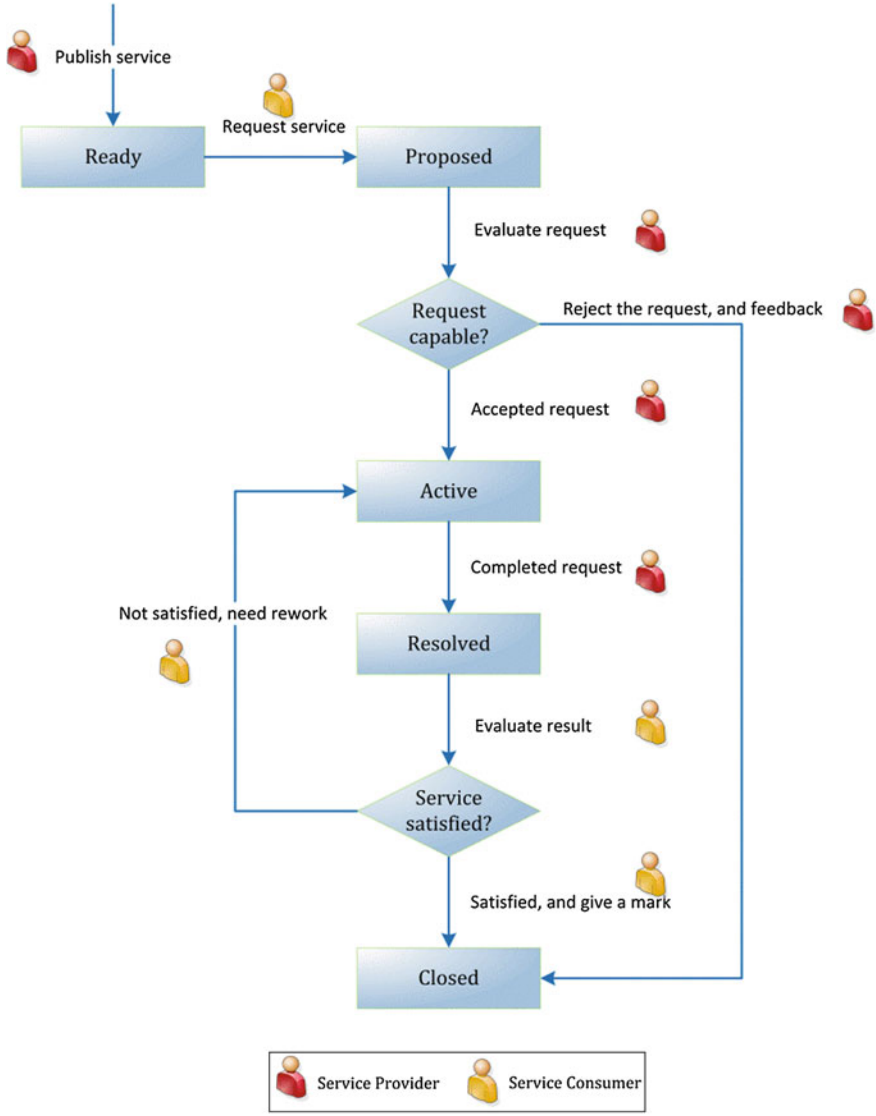


Fig. 4 The planning for knowledge service process

3.5 The Framework of Knowledge Service Agents

Two knowledge service agents are designed for supporting the cloud-based knowledge service environment, i.e., knowledge service publishing agent (KSPA) and knowledge service consuming agent (KSCA). The function of KSPA is to help knowledge providers encapsulate and publish their design knowledge as a service.

Action	State	Role	Info.
Publish service	Ready	SP	SP is ready for providing service to customers.
Request service	Proposed	SC	SC wanna request a relay test service.
Evaluate request		SP	SP will evaluate your request.
- Accepted	Active	SP	Okay, SP decides to accept SC's request.
- Reject	Closed	SP	Sorry, SP decides to reject SC's request.
Completed service	Resolved	SP	SP told SC that he has completed the request, and waiting for SC's evaluation.
Evaluate result		SC	SC evaluates the result of service.
- Satisfied, and give a mark	Closed	SC	Very good, SC satisfies the result of service, and give a five-star mark to SP's service.
- Not Satisfied, need rework	Active	SC	Not very good, SC does not satisfied with the result of service, and tell SP to rework.

Service Provider (SP) Service Consumer (SC)

Fig. 5 The state variation during knowledge service process

KSCA will help the knowledge consumers use the knowledge service. An overall framework of the two knowledge service agents is shown in Fig. 6. The framework has five layers, i.e., knowledge encapsulation layer, knowledge representation layer, knowledge service layer, knowledge contract layer, and knowledge application layer.

In the knowledge encapsulation layer, design knowledge is encapsulated as the knowledge application part with its input and output files. The knowledge application part includes design knowledge, such as finite element analytical files, or procedures written in any programming language, or which kinds of know-how knowledge to apply and use to obtain the design result. At the same time, knowledge providers can always extract necessary knowledge elements from the input and output files regardless of the format of them. For example, a CAE analysis process generally includes input and output files, where the input files include the three-dimensional model, and the output files include analytical result.

In the knowledge contract layer of knowledge providers, KSPA provides a file parsing function to extract input and output knowledge into input and output frame sets. The frame set is a parameter set, which is based on the frame-based knowledge representation. Each parameter in the input and output frame set has its name, data type, assigned value, and location where it is in the knowledge input and output file. The function of the knowledge representation layer, so the service consumers can give the values for their structured questions according to the input frame set, then KSPA would rewrite these values into the knowledge input file. The knowledge application part is conducted by knowledge providers based on the input knowledge that comes from the knowledge consumers. KSPA would extract the result knowledge from the output files into an output frame sent back to the

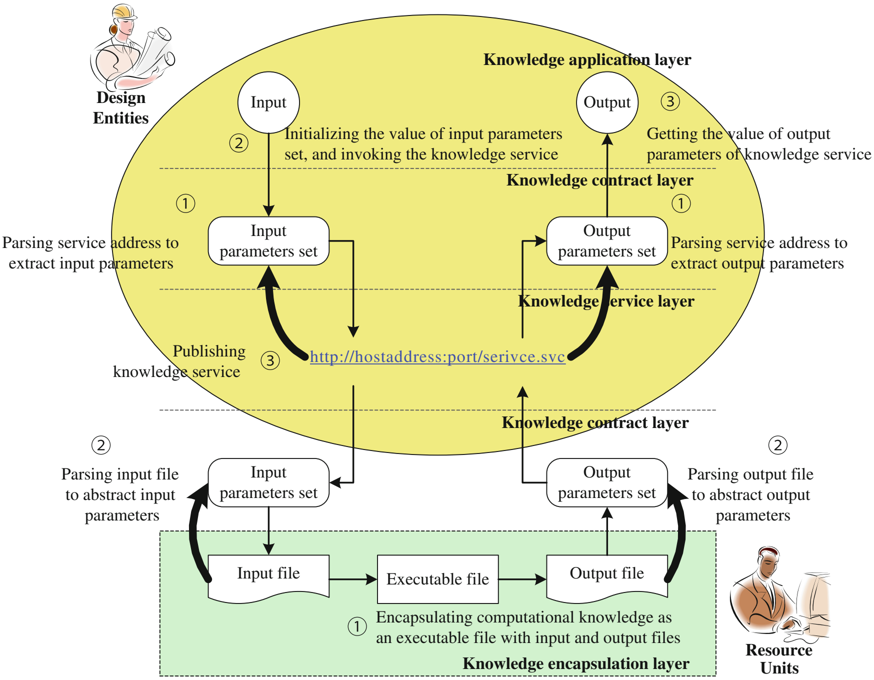


Fig. 6 Overview framework of knowledge service agent (from Li et al. 2012)

service consumers. The goal of this layer is to transform the irregular knowledge from the input and output files to the regular input and output frame set.

In the knowledge service layer, the knowledge providers can publish the knowledge encapsulated in the bottom layer as a service. Each knowledge service has its service address, which comprises a host address, port number, and service name. The service address is a bridge for connecting knowledge suppliers and knowledge demanders.

Knowledge suppliers are responsible for receiving the input knowledge from knowledge demanders, then performing knowledge applications, and giving the output knowledge back to the knowledge demanders.

In the knowledge contract layer of knowledge consumers, KSCA helps knowledge consumers parse the input and output frame set from the service address that published by knowledge suppliers. The frame set is a knowledge interface transferring from knowledge providers to knowledge consumers, which include the slot name, data type, value, and data structure, etc. KSCA will help knowledge consumers understand what knowledge he must give to the knowledge providers, and what knowledge it will get back from the knowledge providers.

In the knowledge application layer, knowledge consumers will set input knowledge according to the input frame set for requesting service from the knowledge suppliers. KSCA will obtain the output knowledge what he wanted through the service address of the knowledge providers. The knowledge service has been completed through KSCA and KSPA.

4 Implementation and Illustrative Case

The implementation of an inner-enterprise distributed resource environment is employed to illustrate how the proposed approach can be applied to real industrial practices. For the sake of commercial secrets, the name of the enterprise (abbreviated as AA later) is omitted here. Since AA is very large and its subcompanies are geographically distributed all over the world, AA is selected as a focal scenario for developing a cloud-based knowledge service paradigm to support knowledge service driven open innovation. The content of the construction of a distributed resource environment includes two main parts, i.e., the construction of a distributed resource environment and the development of a knowledge service platform.

4.1 Background

AA is a global company in the construction machinery industry with a vast product range of concrete machinery, excavators, hoisting machinery, pile driving machinery, road construction machinery, port machinery, and etc. The company is comprised of nine product divisions, one central R&D institute and 31 product R&D institutes. The divisions and R&D institutes are geographically distributed throughout China and other countries. The knowledge and knowledge acquisition resources are distributed unevenly within or across organizational boundaries. Generally, these resources are unknown to the seekers (i.e., enterprises or organizations who have a desire to utilize the resources) outside organizational boundaries. This scenario makes the sharing of knowledge and knowledge acquisition resources across organizational boundaries very difficult and complicated.

However, the highly competitive nature of business in a global market economy is forcing AA to make continuous efforts to leverage their product innovation in order to gain a competitive edge. In order to benefit from the latest fruit of outsourcing design knowledge in different design resources at lower cost and shorter time is a big challenge for enterprises. The design knowledge must flow quickly and reliably from when and where it is located to when and where it is needed for design activity. Unfortunately, there are many barriers having a negative influence on quick and reliable knowledge flow between knowledge providers and knowledge consumers. The lack of supporting mechanisms (e.g., a knowledge service platform) between service providers and consumers is such a barrier. Thus, there is a need to develop mechanisms to overcome the barriers, thereby improving the performance of knowledge flow.

4.2 Construction of Resource Units

In AA group, we have constructed six different domain resource units. Another five resource units are in the construction. A four-step model is used to frame the construction progress of resource units.

Step 1 *Functional planning of a resource unit* First, long-term goals and short-term goals are primarily determined, and then according to the goals, the investment of time and money, knowledge acquisition capabilities, and knowledge service items are planned.

Step 2 *Construction of a resource unit* Based on the planning schedule, resource units are constructed.

Step 3 *Providing knowledge service to consumers* In this stage, there are two kinds of knowledge service patterns. One is the offline service pattern, in which service providers and service consumers often utilize face-to-face communication and will be based on a project contract to realize a successful knowledge service. The other is the online service pattern. This is a real cloud-based pattern. Providers and consumers will use a knowledge service platform to cooperate on a knowledge service.

Step 4 *Managing the acquired new knowledge* Any resource units have to construct their own knowledge base and establish knowledge management mechanisms.

Based on the above four steps, we have planned 12 resource units, and currently six of them are providing knowledge services now. An overview description of the six resource units is shown in Table 1. A case of the Noise, Vibration, and Harshness (NVH) unit is briefly given for the demonstration of resource units (Table 3).

- *Description of the NVH resource unit*

Planning the long-term goal is built a 20-person professional service group to provide NVH service to the whole enterprise, and the short-term goal is to build an 8–10 people professional service group to provide knowledge service to several divisions.

Construction Currently, two senior engineers with Ph.D. degree and eight engineers with Master's degrees are taking charge of the total knowledge service to the whole group of AA. The investment of money, the NVH stimulation, and testing facility is more than 3.7 million Chinese Yuan (CNY). The knowledge service capacities include CAE software applications, the fault identification of vibration and noise; the design and analysis noise and vibration reduced facility.

Service Advanced Simulation of the cab; Vibration and noise control; NVH control of concrete machinery, excavator, hoisting machinery, pile driving machinery, road construction machinery, port machinery, etc.

Management of knowledge Build database; develop structured documents; organize knowledge community.

Table 3 Overview on the construction of professional resource units

Unit name	Knowledge acquisition resource			Service type
	People	Software	Hardware	
Unit of NVH	2 Ph.D. 8 MS	EDM Sysnoise VA One	e.g. Ncode/NI/LMS data collection system; Sensors	Simulation test
Unit of material R&D	5 MS	ANSYS	e.g. MTS fatigue test machine; Metallographic microscope	Test consulting
Unit of environment simulation	5 MS	None	e.g. Temperature test chamber; Salt spray test chamber	Test consulting
Unit of electronic and electrical	5 MS	EDA PCB	e.g. CAN bus test system; Switch performance test system;	Test consulting
Unit of Industry design	5 MS	CATIA PRO/E	Design review facilitate	Design consulting
Unit of product development	7 MS	PRO/E ANSYS	e.g. Bearing test system; product performance test system	Design consulting

4.3 Development of a Knowledge Service Platform

Based on the architecture of a knowledge service platform, we have developed a knowledge service platform to meet the needs of the inner-enterprise knowledge service in AA Group. Figure 7 shows the login page. Users can login or register on this page.

The platform has three key components, i.e., a service market management component, a resource unit management component, and a business management component. Figure 8 exhibits the elements of all the published services in this platform. The services are broken down into four types, i.e., test service, simulation service, design service, and consulting service. Knowledge service consumers can browse and obtain summary or detailed information about a service.

Figure 9 presents the summary information about the seven registered resource units. These units provide four kinds of knowledge services to the whole enterprise.

Figures 10 and 11 show the key functions of the knowledge service management component. As shown on the left side of Fig. 10, users can create a new resource unit and manage their knowledge service information. Using the *My Service* function module, resource units can review and manage their service profile. The right side of Fig. 10 shows the abstract information of a test service. Detailed information can be found after clicking on the *Detail button*.

Figure 11 shows the detailed information of a service interaction process. The rationale to support decision making in the service process can be recorded, and can be traced in later business.

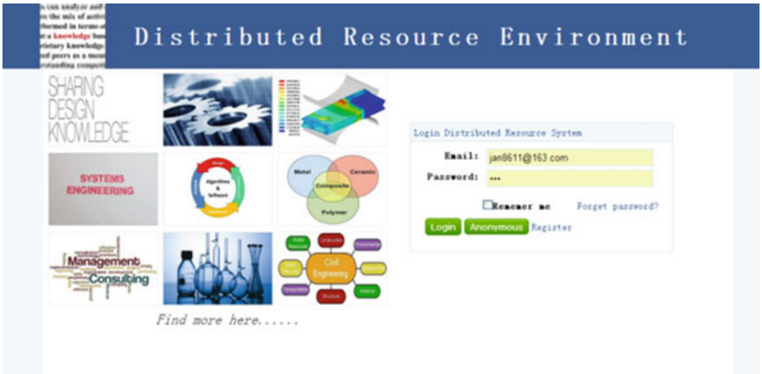


Fig. 7 Distributed resource environment

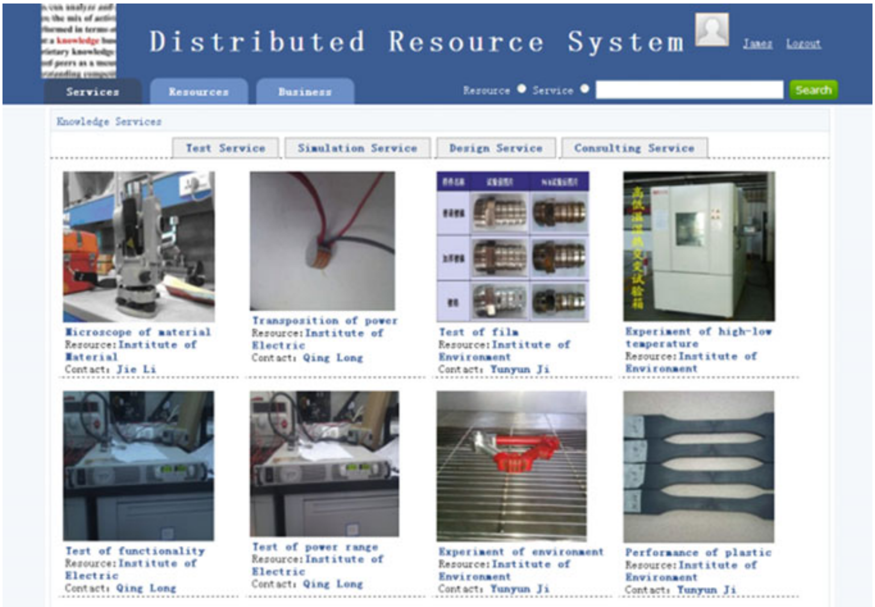


Fig. 8 Knowledge service market

4.4 Results and Discussions

The concept of the distributed resource environment is applied to real industry practice. A one-and-a-half year industry practice has constructed a small scale distributed resource environment in AA group. The environment includes six professional resource units (i.e., knowledge service providers), a knowledge service platform, and numerous knowledge service consumers. The six resource units

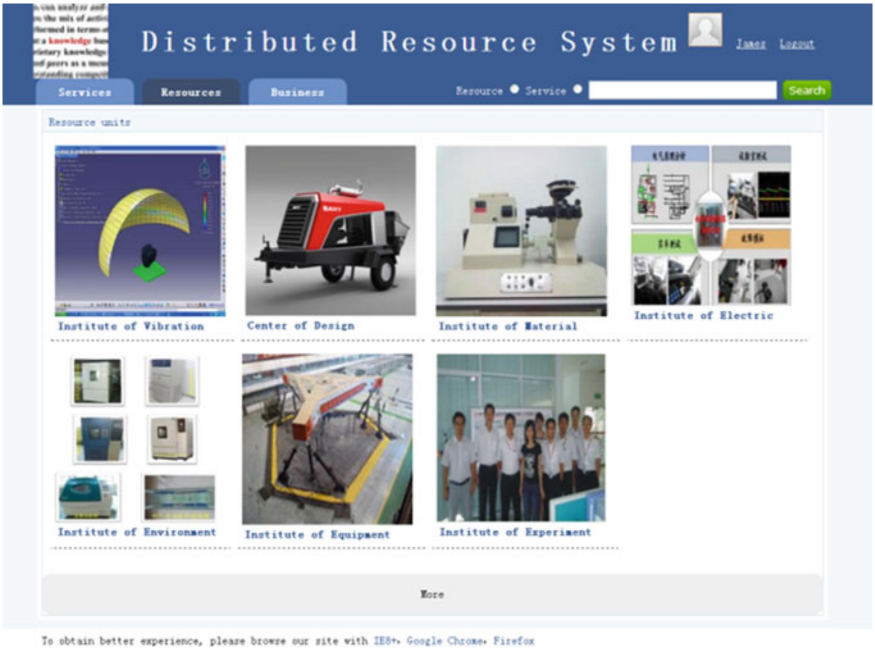


Fig. 9 Resource units management

Fig. 10 Knowledge service management

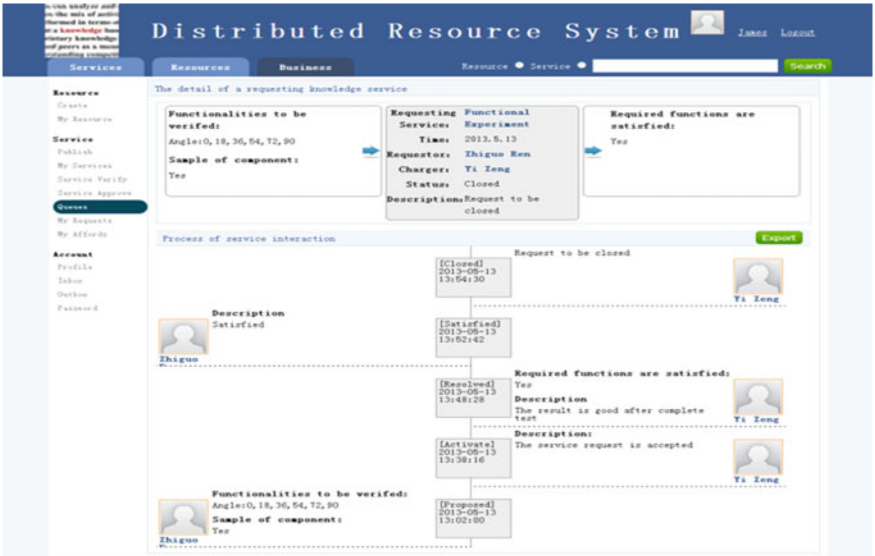


Fig. 11 Process of service interaction

can provide simulation, testing, consulting, and product design services to the whole AA group. The knowledge service platform is a knowledge service market that has bridged the gap of information asymmetry and reduced the communication cost between knowledge consumers and providers in AA group.

Through inner-enterprise knowledge services within a distributed resource environment, the following specific effects were achieved.

- *Better profit*

The outcome of knowledge services shows that the construction of an inner-enterprise distributed resource environment in AA group has generated the following merits: (1) The cost-saving effect is obvious. As shown in Fig. 12, compared with outsourcing knowledge services, a half-year inner-enterprise knowledge service has saved about ¥6.461 million in R&D investment. (2) Improved resource unit deep domain knowledge acquisition capability. (3) Speed enterprise product innovation. (4) Well-managed knowledge for better sharing and reuse.

- *Better social influence*

As shown in Fig. 13, a half-year operation of a distributed resource environment has provided more than 3,100 test services to more than 31 R&D institutes all over the enterprise. For example, the NVH unit has provided 44 noise and/or vibration tests services; the environment simulation unit has provided 1,051 test services. Since July 2012, the industry design unit has provided 23 design services, the other five units have provided more than 7,600 test services and 270 consulting

Unit	People	Income (Completed Services)	Income (Ongoing services)	Spending (Outside service)
NVH	10	617K	360K	1900K
Material R&D	5	282K	170K	900K
Product development	7	630K	50K	1400K
Environment simulation	5	775K	140K	3000K
Electronic and electrical	6	417K	200K	1500K
Industry design	5	428.5K	1695K	2000K
Total	38	3149.5K	1089.5K	10700K

Note: the unit of the currency is CNY, inner-enterprise service will save ¥6461K

Fig. 12 The benefit of a half year inner-enterprise knowledge service

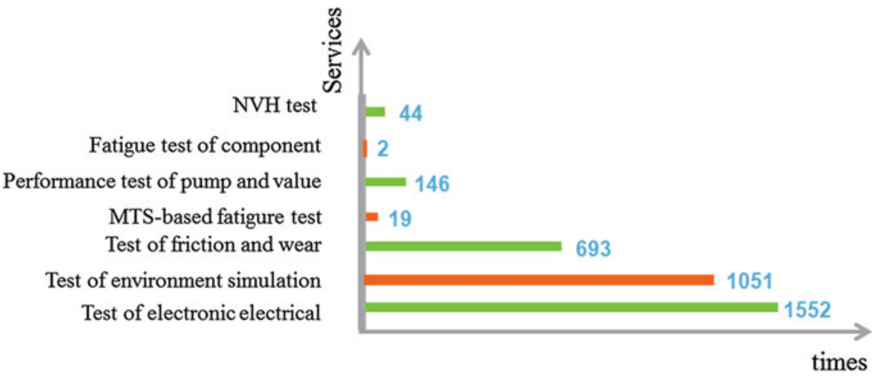


Fig. 13 Overview of half a year knowledge service

services to the whole group. The small scale distributed resource environment has solved a lot of problems within several months. The effect of knowledge service to AA group has been widely acknowledged by knowledgeable service consumers. For example, consumers published thank-you letters through the enterprise's office automation (OA) system. It can be concluded that in the foreseeable future, the distributed resource environment will be a strong driver of product innovation in AA group.

Although we have applied the concept of a distributed resource environment and this small scale distributed resource environment has achieved good results in AA group, there is still a need for further improvement. For example, the concept of a distributed resource environment will be constantly evolving. The development of a theoretical framework for effective design knowledge service will become increasingly important as moving to the next generation of design innovation.

In this case study, there remain several questions still to be answered. For example, (1) How to improve the affordance of the platform? The platform should provide a step-by-step tool for service providers to easily encapsulate their design computing service. The platform should provide an automated mapping mechanism between knowledge service providers and consumers. (2) How to construct more resource units? There are only six design knowledge service providers in this small scale distributed resource environment, therefore how to design organizational mechanisms, which can support the development of more resources units and facilitate knowledge service and knowledge management in AA group would be an interesting direction for future work.

5 Conclusion

In this chapter, the concept of a distributed resource environment (DRE) was presented. The function and structure of a distributed resource environment was proposed and the characteristics of a distributed resource environment were also identified. We proposed a cloud-based knowledge service framework. The architecture of a knowledge service platform was proposed to integrate the knowledge service providers and consumers. A capacity model of a resource unit and the knowledge service process model were presented to support the construction of knowledge service providers and planning their knowledge service processes. Two agents, i.e., a knowledge service publishing agent (KSPA) and a knowledge service consuming agent (KSCA) are developed to implement the online knowledge service. KSPA can be used by knowledge providers to encapsulate and publish their design knowledge as a service into the service market, whereas KSCA can be used by knowledge consumers to request knowledge service from the service market. The concept of a distributed resource environment was applied to a real industry practice. The efficiency and effectiveness of a distributed resource environment as a knowledge flow and innovation facilitator was validated by the industry practice. The results of this study provide a background for setting future research directions on developing a distributed resource environment. However, there are some important questions unanswered and also some disadvantages that need to be overcome. For example, why should resource units provide their knowledge to the platform, when providing their know-how to only one customer is more profitable? Why resource units should provide their knowledge to customers via the platform, even if there is a strong protection of intellectual property? There is also a need to further explore issues like how to reduce the resistance to develop a distributed resource environment from the view of design and how to develop such an environment as a social, technical, and cognitive integrated process.

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