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ORIGINAL ARTICLE

Embedded knowledge service in mechanical product development

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Abstract To develop competitive mechanical products, the enterprises should ask for external knowledge service. The concept of embedded knowledge service is presented to embed the independent technical activities of external resources unites as a part of the complete product development process of design entities. The mechanism of embedded knowledge service method is analyzed. Several key problems such as the decomposition of design tasks for cross-organizational assignment, the search of partners, the evaluation of the resources units, and the information transfer from the design entities to the resources units are analyzed point by point to make the embedded knowledge service easy to be applied. Finally, the effectiveness of the embedded knowledge service is illustrated with a case study on the development of an internal combustion engine.

Keywords Knowledge service · Product development · Design entity · Resource unit

1 Introduction

Most manufacturing enterprises in modern society face the keen competition. To have market dominance over others, the enterprise has to develop products with superior performance, lower cost, and faster delivery.

One perspective of the development process in the engineering design community is that it is largely a process marked and defined by a series of decisions [1]. To make rational choices that maximize the payoff for the predicted outcome, the domain knowledge is important for the designers. However, it is costly for one enterprise itself to hold all the knowledge needed in developing products with so many competitive factors. And in fact, now, more and more advanced domain knowledge is distributed in different organizations or even individual researching persons. In this situation, asking for external knowledge service, which means accessing knowledge from beyond the organizational boundaries, is maybe a shortcut for the enterprises to develop competitive products as soon and low cost as possible. The significance of knowledge service can easily be seen in small manufacturing enterprises [2]. For the research and development (R&D)-intensive enterprises, the traditional viewpoint deems that the significance of knowledge service is limited. However, in recent years, a more rational view has arisen [3–9]. In this view, the enterprises, no matter how large and R&D-intensive they are, can and should rely on not only the internal investments but also the important inputs from a variety of external sources.

Knowledge service can be seen as a kind of transactions between the knowledge demanders and the knowledge suppliers. To assist the achievement of the transactions, Zhuge and Guo [10] presented the concept of virtual knowledge service market based on the framework of knowledge grid. To promote the application of knowledge service in mechanical product development, Xie [7] built an internet platform named as "the modern design and product development network of China" (Website: http://www.chinamoderndesign.com) to allow for an opening registration of knowledge suppliers. In 2009, the authors presented the concept of "Embedded Knowledge Service" (EKS) to support the product development process [11]. However, up to now, it is still hard for the knowledge service to be extensively promoted in mechanical enterprises. To make

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the knowledge service easy to be applied, the mechanism of embedded knowledge service needs to be further analyzed. And several key problems, such as the decomposition of design tasks, the search of partners, the evaluation and selection of the resources units, and the information transfer from the design entities to the resources units, need to be analyzed in detail.

The paper is organized as follows. Section 2 relates the product development with knowledge service. In Section 3, the mechanism of EKS is presented, and several key problems are analyzed. Section 4 gives a case study to demonstrate the application of the EKS. Then, in Section 5, the credit problem which may block the application of the EKS is analyzed. Section 6 gives the conclusion.

2 Mechanical product development with knowledge service

Some essential factors of the product development can be described using Fig. 1. The input of the product development is the customer needs. The output is the design results. The product development process itself can be viewed as a series of design decision tasks. For mechanical products, the design decision-making should be based on the domain knowledge. So acquiring the right knowledge at the right place and the right time is crucial for the product development process.

As related above, two reasons induce the manufacturing enterprises asking for external knowledge service during their product development process. One is that the enterprise itself is costly to hold all the knowledge needed in mechanical product development. The second is that the advanced knowledge or the competence of acquiring the advanced knowledge is distributed in different organizations or even individual researching persons. Knowledge service can fill the gap between the enterprises who desire knowledge and the organizations that possess the professional knowledge or competence.

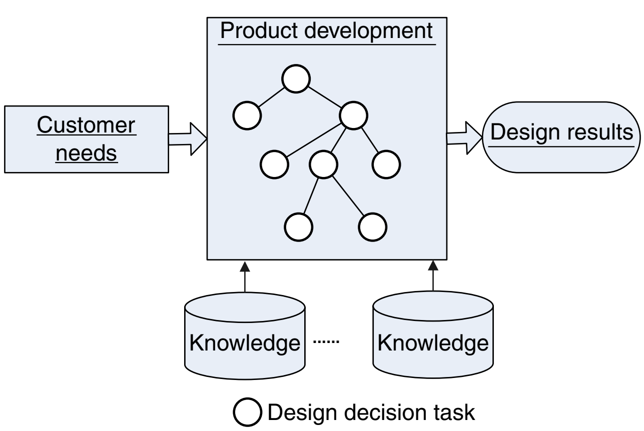

Fig. 1 Essential factors of product development

Two opposing roles in knowledge service should be classified first. One is named as Design Entities (DEs), which mean the enterprises or organizations that developing products with the help of external knowledge service. The other one is named as Resource Units (RUs), which mean the enterprises, organizations, or individuals that provide paid knowledge services to DEs and help the DEs to accomplish the product development tasks. There is a many-to-many relationship between the DEs and the RUs. That is, the DEs can ask for paid knowledge services from different RUs, and the RUs can serve to different DEs. Both these two kinds of roles can benefit from the paid knowledge service. However, it is still hard for the knowledge service to be popularized in mechanical products development. The concept of EKS may be helpful.

3 Embedded knowledge service

Associating with the characteristics of the embedded system in thinking, the EKS means a kind of knowledge service that is supplied by the RUs and embedded as a part of the complete product development process of DEs. It has the following characteristics:

First, the EKS is dedicated to specific tasks and generally consists of a series of related technical activities. As shown in Fig. 2, through EKS, some design decision task of the DE can be outsourced to the external RUs.

Second, the EKS orients to the product development processes and can be customized according to the requirements of different DEs. When the EKS is embedded to different product development processes, different design results can be obtained.

Third, the EKS maintain high independence between the DEs and the RUs. Although some information needs to be transferred between the DEs and RUs,

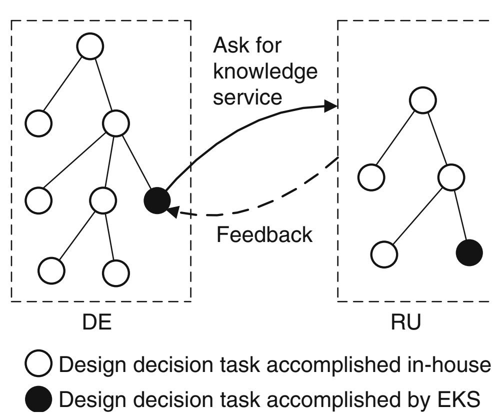

Fig. 2 EKS: Design decision task accomplished in-house (*empty circle*), Design decision task accomplished by EKS (*filled circle*)

the related technical activities included in the EKS are mainly accomplished by the RUs, which are independent of the DEs.

Further analysis can be made on Fig. 2. The design decision tasks of the DE in Fig. 2 can be classified into two types. Tasks of the first type, expressed as transparent circles in Fig. 2, are accomplished in-house because the DE is competent in these fields. Tasks of the second type, expressed as black circles in Fig. 2, are accomplished by the embedded RU, who is more competent or low costly in its field than the DE. By some decomposition principles, the "black" design tasks can be identified from the product development and outsourced to external RUs.

In fact, any organization relevant to product development has dual characters. On the one hand, it has its core competence. So, it is potential to provide the EKS to other organizations in the fields of its expertise. On the other hand, the organization has insufficiencies in some field. So if necessary, it needs to ask for external service in the fields of its insufficiency. The dual characters give the organization the embedded interfaces to interact with the other organizations, as shown in Fig. 3a. It can be imagined that different organizations can be chained together through EKS to collaboratively accomplish complex product development, as shown in Fig. 3b. This is beneficial to convert the mechanical product development from depending only one organization to the collaboration of some outstanding social organizations.

The advantages of the EKS are obvious from the above analysis. Firstly, high performance or quality of mechanical products can be expected because advanced knowledge from the professional external RUs is introduced into the product design decision-making process. Secondly, the time-to-market of products can be shortened because some

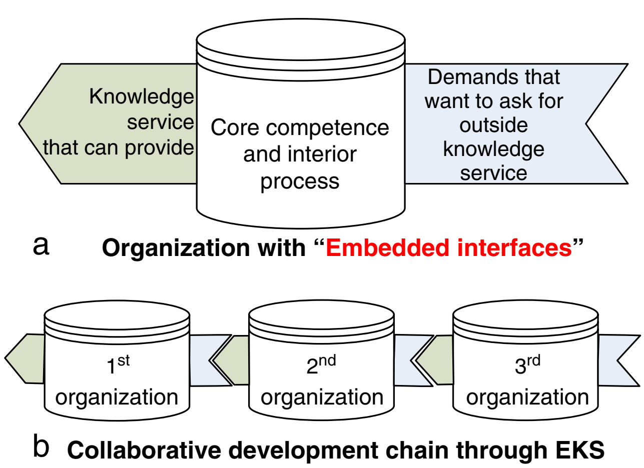

Fig. 3 Dual characters of organizations in product development. **a** Organization with "Embedded interfaces". **b** Collaborative development chain through EKS

R&D activities need not to start from scratch. Thirdly, The R&D costs of DEs can be reduced. Fourthly, the utilization ratio of each RU's knowledge can be improved because they can serve to different DEs. At the same time, the RU's competence can be strengthened through EKS. Fifthly, the EKS can be helpful to mobilize the social intelligence to participate in the complex mechanical products development. In fact, the advantages of knowledge service are not limited to the above. On the EKS mechanism, it can be expected that the DEs can easily ask for external knowledge service, and different organizations can form the powerful collaborative teams with flexibility and efficiency to accomplish complex product development. So the EKS is worth looking forward to. However, the following problems need to be solved first to apply the EKS in practice.

3.1 Design tasks decomposition by DEs

In EKS, the DEs undertake overall design and design decomposition of the product. Different from the traditional collaborative design [1, 12], the EKS allows for an opening collaboration and advocates more independent accomplishment of the design tasks by the RUs. This is beneficial for the DEs to access the most advanced knowledge distributed in different RUs. On this thinking, the authors have presented two principles for design decomposition for cross-organizational assignment of design tasks [13]. The first principle, which can be formulated as the following Eq. 1, is to minimize the coordination cost between the DE and the cross-organizational teams, namely RUs.

$$\min \text{total\_cost} = \sum_{i=1}^{N} \text{cost}(i) = \sum_{i=1}^{N} \left[\sum_{j=1}^{N} \left(r_{i,j} \times s_{i,j}\right)^2 + \sum_{k=1}^{N} \left(r_{k,i} \times s_{k,i}\right)^2 \right] \tag{1}$$

Where N is the total number of design tasks in the whole product development, total_cost means the total coordination cost of the N design tasks, cost (i) means the coordination cost of the ith design task, $r_{i,j}$ means the relative flux of information flow from the ith design task to the jth design task, $r_{k,i}$ means the relative flux of information flow from the kth design task to the ith design task, $s_{i,j}$ and $s_{k,i}$ denote the scale or scope of coordination.

The second principle, which can be formulated as the following Eq. 2, is to isolate the design tasks that the DE is not competent to complete from the other design tasks as far as possible.

$$\max \text{out\_index} = \frac{\sum_{i=1}^{N_G} \text{out\_index}(G_i)}{\sum_{i=1}^{N_G} f_{\max}[\text{out\_index}(G_i)]} \tag{2}$$

Where N_G is the number of design tasks groups, out_index (G_i) is the outsourcing index of the group G_i and can be calculated as following.

$$\text{out\_index}(G_i) = \sum_{j=1}^{n(G_i)} w_j \cdot \text{out\_necessity}(j) \quad (3)$$

Where $n(G_i)$ is the number of design tasks included in the group G_i, out_necessity(j) is the necessity of outsourcing of the jth design task in the group G_i, w_j is the relative weight of the jth design task in the group G_i; out_necessity(j) can be valued according to the DE's competence to complete the jth design task. If the DE cannot complete the design task, out_necessity(j) should be valued as 1.0. Otherwise, out_necessity(j) should be valued as 0.0. The $f_{\max}$[out_index(G_i)] in Eq. 2 is the maximal possible value of out_index(G_i).

With quantitative formulation of the above two principles, the design decomposition problem can be solved using some optimization methods such as the genetic algorithm method used in references [13, 14]. By the above two principles, the design tasks can be reasonably decomposed into different groups. This can be illustrated using Fig. 4. From Fig 4, it can be seen that not only the minimizing of the coordination cost between groups but also the isolation of the design tasks that the DE is not competent to complete from the other design tasks are considered during the design decomposition.

3.2 Requirements to RUs

The particular competence of the RUs can make up for the insufficiencies of the DEs in product development. By requests of the DEs, the RUs should provide knowledge service well, fast, and competently. So the following several conditions for the RUs need to be satisfied.

3.2.1 Close to needs of the DEs

In EKS, the DEs are customers of the RUs. To provide embedded service to the DEs, it is not enough for the RUs to be competent in its field. They must close to the needs of the DEs and strengthen their comprehensive competence relevant to the needs. In fact, it is often the bottleneck that blocks the organizations with special technique to serve the DEs intimately.

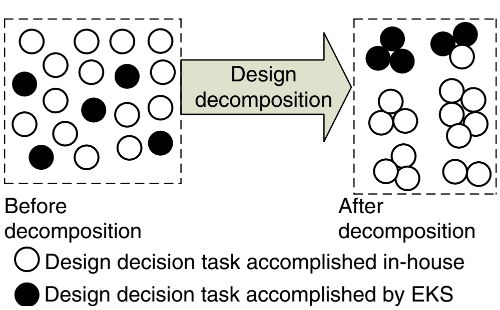

Fig. 4 Design decomposition for EKS: Design decision task accomplished in-house (*empty circle*), Design decision task accomplished by EKS (*filled circle*)

3.2.2 Rapid response

The second requirement to the RUs is their rapid response to the demands of the DEs. This is determined by the time requirement of the product development. Theoretically, each research organization has potential to provide knowledge service to the DEs when their competent fields are needed. However, sometimes, the quality of knowledge service is poor for two reasons relevant to the time requirement of the DEs. One reason is that the capability of the organization is insufficient yet. The other reason is that many research organizations lack the consciousness to serve to the DEs.

3.2.3 Professional competence

The third while the most important requirement to the RUs is their professional competence in their fields. Any organization who wants to provide EKS should focus on some certain field and be expert in the related technical activities.

3.3 Description and search of partners

The search of partners is important for both the DEs and the RUs. There is no denying that there are a great amount of potential demands and supplies of knowledge service in mechanical products development. However, the information barriers block the application of EKS. In recognition of this, the authors have been studying the communication between the DEs and the RUs, and an internet platform has been developed to allow for the registration and searching of the RUs [7]. In the era of internet, the proper internet platform is necessary for the search and selection of the RUs. Moreover, not only the DEs can search potential RUs but also the RUs can search the demands of DEs by the platform. This needs a proper description of the DEs and the RUs firstly.

As shown in Fig. 3a, any organization relevant to the EKS can be described using three kinds of information. The first is about the general information of the organization such as its identification, specialized field, and contact information. The second is about the organization's capability of knowledge service. The third is about the organization's demands of knowledge service. So a concise description of the organizations in the EKS can be given as Table 1, in which a company named as "BoTong Piston Technical Company" (BTPTC) is illustrated. The meaning of each item in Table 1 is explained as following.

Table 1 Universal description of an engine piston technical organization

General information	Identification	*BoTong Piston Technical Comp.(BTPTC)*
	Specialized field	*..[Automobile]. [ICEs]. Piston*
	Contact information	*Dr. MENG, E-mail: xhmeng@sjtu.edu.cn, Telephone: 86-21-34207167, Fax: 86-21-34207167*
Capability of knowledge service	Core competence	*Piston design, evaluation, and optimization*
	Cases of knowledge service	*5 cases (see detailed information)*
	Appraisal from DEs	*4.7 points (5 appraisals, total is 5 points)*
Demands of knowledge service	Demands	*1, new material or surface treatment technology to improve the lifetime of piston*
		2, ……
	Remarks	……

"Identification" is used to uniquely identify the organization. "Specialized field" describes the field the organization specialized in according to some classification system such as a system shown in Fig. 5. "Contact information" is used to tell the potential partners how to contact. "Core competence" describes the organization's competence or capability of knowledge service. "Cases of knowledge service" describes how many cases of knowledge service the organization has completed and the brief information about each case. "Appraisal from DEs" records the appraisals from the organization's previous partners. By this information, other DEs can evaluate the qualification of the organization as a RU. "Demands" records the organization's demands of knowledge service. By this information, the potential RUs can forwardly search the potential DEs. It should be mentioned that some information such as the demands information in Table 1 may be omitted in reality.

When the above universal description of organizations is registered online, it is easy to find each other for the DEs and the RUs.

3.4 Evaluation and selection of RUs

How to select the suitable RU from numerous organizations is an important issue for the DEs. Generally, the selection of the RUs should be based on the following evaluation.

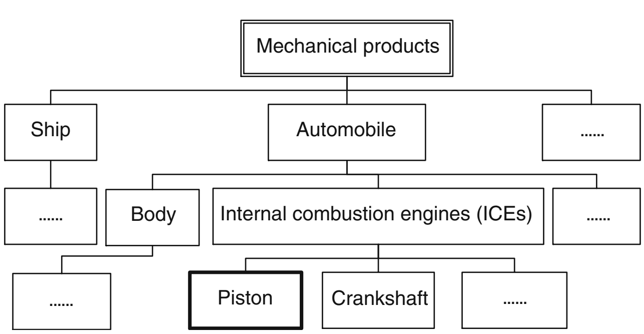

Fig. 5 Classification system used to describe the specialized field of organizations in the EKS

First, evaluate the status of the organization to confirm that it is a partner or a competitor. One organization seldom asks for knowledge service of its competitors. So the status of the organization should be evaluated first. A simple and feasible method is to evaluate it using the "specialized field" information and the "core competence" information in Table 1 when every organization is described according to the same classification system. For example, suppose four organizations A, B, C, and D in evaluation. The "specialized field" information of each organization is "..[Automobile]. ICEs," "..[Automobile]. ICEs," "..[Automobile]. [ICEs]. Piston," and "..[Automobile]. [ICEs]. Crankshaft," respectively. Then, it can be concluded that the organizations C and D are each other's neither competitors nor partners. But C and D can provide knowledge service to A and B because the specialized field of C and D subordinates that of A and B. The organizations A and B may be each other's competitors because their specialized fields are the same. Further evaluation can be made using the "core competence" information of A and B. When their core competence is also the same or similar, it can be concluded that A and B are each other's competitors.

Second, evaluate the qualification of the organization as a RU. Undoubtedly, this is important for the success of the EKS. As related in Section 3.3, some information associated with the qualification evaluation has been included in the description of the organization. The information such as "core competence," "cases of knowledge service," and "appraisal from DEs" can be used to synthetically evaluate whether the organization is a qualified RU or not. Based on the information, proper evaluation tool can be developed to online help the DEs find the qualified RU. The evaluation tool can be developed using the Case-Based Reasoning (CBR) theory. CBR is the process of solving new problems based on the solutions of similar past problems. In traditional CBR, it has been formalized as a four-step process, namely retrieve, reuse, revise, and retain [15]. The case generally consists of a problem, its solution, and, typically, annotations about how the solution was derived.

The first step of CBR is to retrieve cases from memory that are relevant to solving the given problem. The second step is to map and adapt the solution from the previous case to the target problem. The third step is to test the new solution in the target situation and, if necessary, revise it. The final step is to store the resulting experience as a new case in memory after the solution has been successfully adapted to the target problem.

For the problem in this paper, the case and the process of CBR is much different with the traditional relation. Here, the case consists of three parts: (1) a problem or a demand of the DEs, (2) the RU who provides the knowledge service to respond to the demand, and (3) the appraisal of the knowledge service. Then a three-step process can be followed, namely retrieve, redo, and retain. The first step is to retrieve cases from memory that are relevant to the demand of the DEs. The cases are sorted according to their relevance with the given demand. The second step is to select the RU relevant to the most relevant case to respond to the target demand of the DEs. Then, the third step is to retain the knowledge service case as a new case in memory.

Third, evaluate the organization's total quality of knowledge service. The other aspects except the status and qualification, such as price, speed, and quality of knowledge service, collectively referred to as the total quality of knowledge service here, should be evaluated to decide whether the organization is selected as a RU or not. This subject will not go into here.

3.5 Information transfer between DEs and RUs

By the decomposition method in Section 3.1, it can minimize the communication between the DEs and the RUs. After decomposition of design tasks, the DE just transfers its demands to the selected RU. Then, the RU can work independently according to the DE's demands. However, in reality, it is not easy to make the RU understand the DE's demands clearly. In most situations, the DEs tend to tell the RUs as little as possible for the reason of keeping secrets. Any misunderstanding of the demands or information insufficiency will lead to an unsuccessful or time-consuming knowledge service. So, there should be a balance for the information transfer from the DEs to the RUs.

For some regular knowledge service, the kind of information needed by the RUs is nearly immovable. Take the piston, which is a part of the internal combustion engines (ICEs), for example. When the engine developers ask for the RUs that specialized in the piston field to develop a piston, the demands in different cases of knowledge service may be different. However, the kind of information needed by the RUs when accomplishing the development of pistons is nearly the same. In each case of knowledge service, the information such as the engine displacement and the cylinder diameter must be told by the DEs to the RUs. To message clearly and minimize the communication between the DEs and the RUs, a framework of information transfer as shown in Table 2 can be used by the DEs. It can be seen that two parts of information is included in the framework. One part is the given information which is necessary for the RUs to work. The other part is about the demands of DEs.

It is obvious that the contents of "given information" and "demands" in Table 2 are different for the knowledge service in different fields. However, the framework in Table 2 is still meaningful for the following reasons. Firstly, it helps to transfer the necessary and minimum information from the DEs to their RUs clearly. Secondly, the mature framework of information transfer can spread in similar cases of knowledge service. So more and more standard frameworks of information transfer can take shape in different fields. Take the case in Table 2, for example, the same framework can be used by the other engine developers when they ask for the knowledge service of pistons development, only some detailed information needs to be replaced.

Comparatively speaking, the information transfer from the RUs to the DEs is easy to carry out. So it will not go into here.

4 Case study

Here, a case study is conducted to illustrate the above relation. Suppose an ICE developing enterprise intends to develop a single cylinder gasoline engine after analyzing the customers' requirements. Then, it divides the entire product development into the design tasks as shown in Fig. 6, and the relationship among the design tasks is shown in Table 3. Then, the product development process based on the EKS can be as following.

Table 2 Information transfer from an engine developer to a piston developer

Given information	Demands
The engine displacement is 1.251 L The number of cylinders is 4, and the cylinder diameter and stroke is 71 and 79 mm, separately	The design of a piston for the gasoline engine to meet the requirements of low friction loss and long life
The highest rotation speed of engine is 6,500 rpm	
The cylinder peak pressure is 8.0×10^6 Pa	
The maximum power is 65 kW	

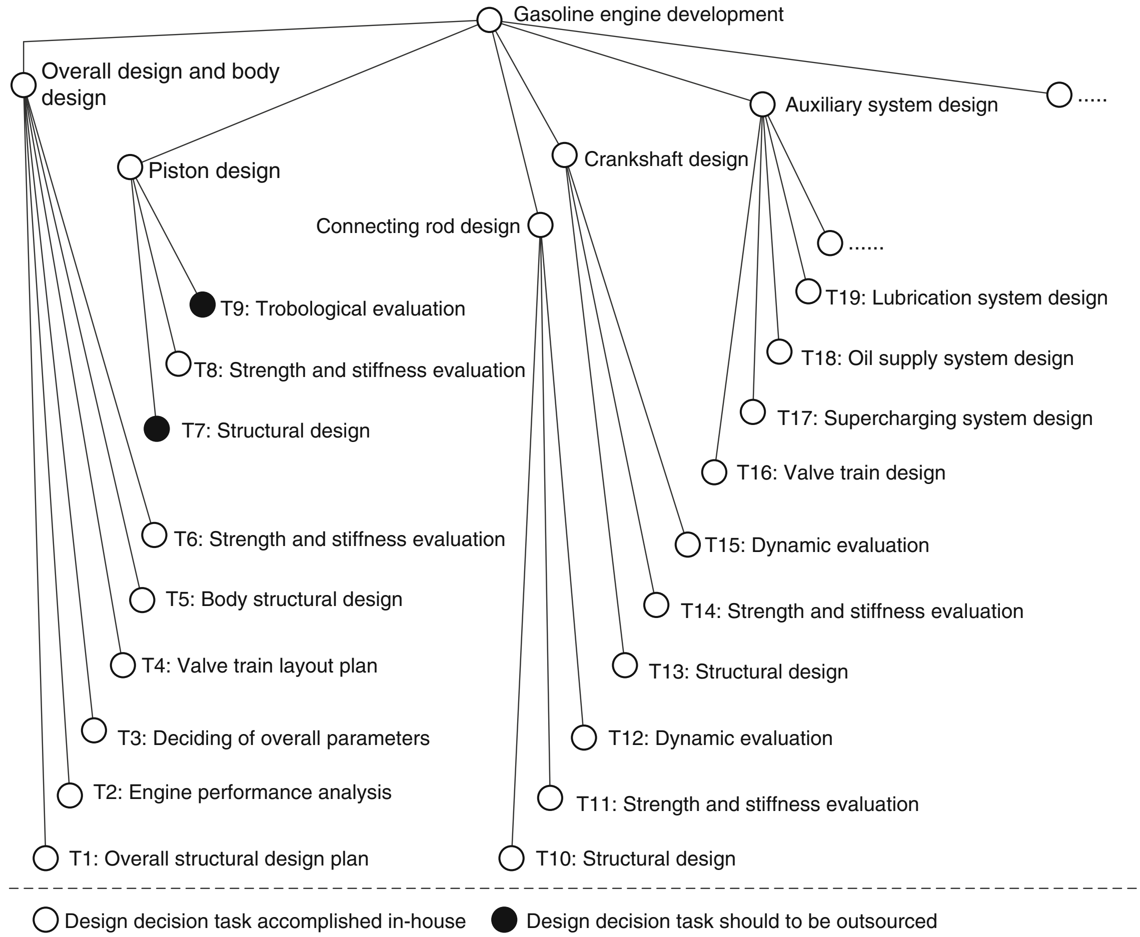

Fig. 6 Design tasks of the gasoline engine

4.1 Decomposition of design tasks

According to the decomposition principles related in Section 3.1 and the decomposition method presented by the authors in paper [13], the design tasks shown in Fig. 6 and Table 3 can be clustered into five groups. The decomposition result can be shown in Table 4. It can be seen that the decomposition considers not only the interdependencies among the design tasks but also the isolation of the design tasks that the enterprise is not competent to complete. For example, design tasks T7 and T9 are remained with T8 but isolated from others.

4.2 Outsourcing of design task groups

As shown in Table 4, the design task group G_2 should be outsourced to the external RU that is competent to complete the structural design, strength and stiffness evaluation, and tribological evaluation of pistons. So a sheet of information transfer from the DE to the RU can be adapted as Table 5 from Table 2.

4.3 Process of knowledge service

The DE searches and selects the most competent RU on the internet platform, in which numerous RUs are registered. Here, a piston design company named as BTPTC is selected to assume the tasks according to the principles related in Section 3.4. After awarding a contract, the design task group G_2 will be conducted within the RU of BTPTC according to the information listed in Table 5. And finally, some results will be fed back to the DE. Part of the results can be seen in Fig. 7.

It can be seen that necessary results related with the piston development have been included in the feedback. For example, Fig. 7a gives the most important detailed design of the piston. The design contains nearly all the fruits of mental labor of BTPTC. Some other information is also necessary to prove that the design is successful, such as the feedback in Fig. 7b, which proves that the design is reliable in strength. Furthermore, some other proofs to prove the success of the design such as low friction loss and long life can be evaluated by the DE itself or by a third-

Table 3 Relationship among design tasks

	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16	T17	T18	T19
T1		1	1	1	1	1										1	1	1	1
T2	1		1																
T3					1	1	1			1			1			1			
T4	1				1											1			
T5	1			1		1							1			1		1	1
T6			1		1														
T7			1					1	1	1									
T8							1		1										
T9							1	1											
T10			1								1	1							
T11										1		1							
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T14													1		1				
T15													1	1					
T16				1	1														
T17					1														
T18	1				1														
T19	1				1														

party certification. With this design feedback, the DE can organize the production of the piston. Of course, the production tasks can also be outsourced to some external manufacturers.

It should be mentioned that the knowledge service cannot be accomplished in one move. It may need several iterations to reach the goal. Take the above case, for example: if the DE finds that the piston designed by BTPTC cannot work smoothly in experiment, it will ask BTPTC to improve the design. So the second sheet of information transfer from the DE to the RU should be made up as Table 6. For this time, some other necessary information, such as the testing conditions, and two pieces of physical pistons are given to aid the RU to improve the design. Then, with the information and physical pistons, the RU works on the design to improve its reliability. After solving the problem, the RU feeds back the design results and necessary proof. Then, the DE evaluates the design again. If it is successful to meet the requirements, the knowledge service process can be ended. The above iterative process can be described in Fig. 8.

5 Discussion

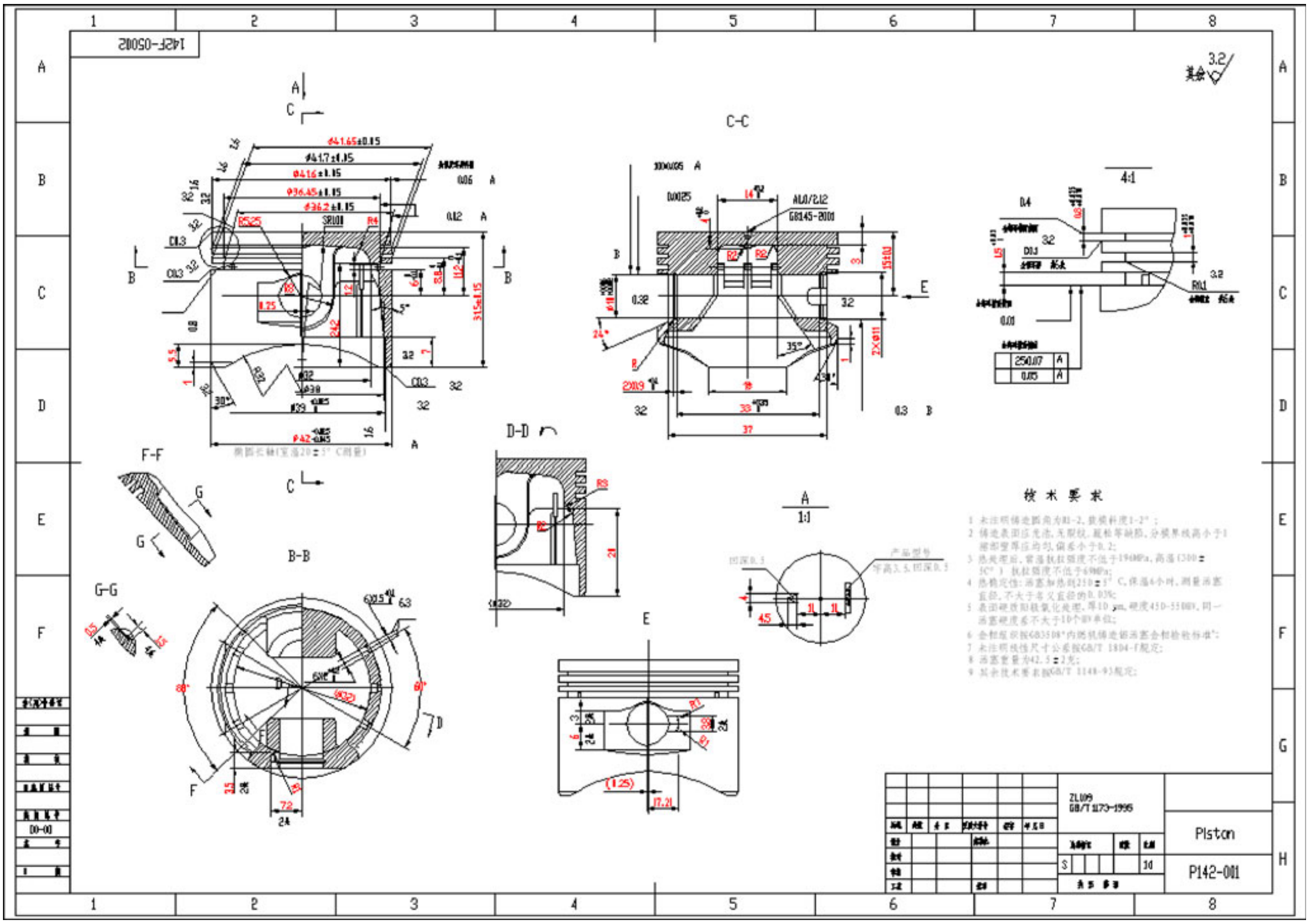
It can be illustrated by the above case study that the success of EKS mainly benefits from the DEs' capability of design tasks decomposition and design evaluation, the RUs' competence in their specific field, and the introduction of proper information transfer framework. However, there are still some other problems that may block the application of the EKS.

Table 4 Decomposed groups of design tasks for the gasoline engine

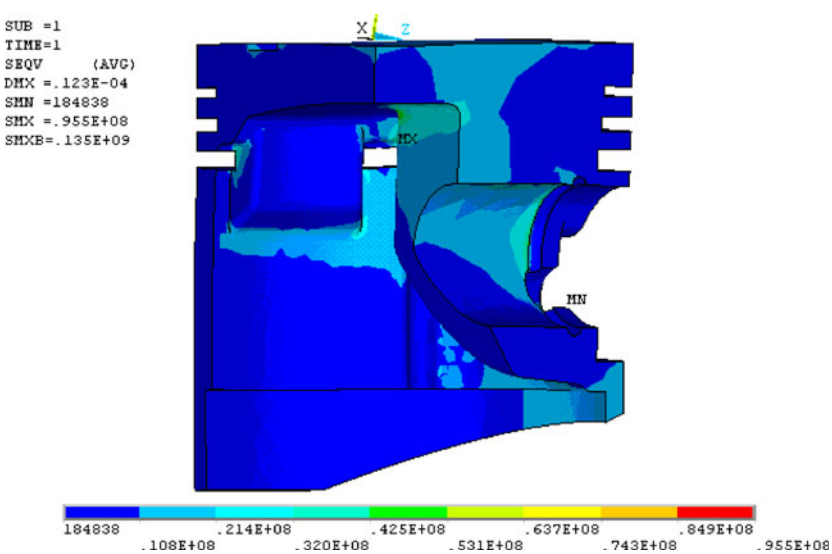
Group	Design tasks included	out_index (G_i)
G_1	T1, T2, T3, T4, T5, T6, T16, T18, T19	0
G_2	T7, T8, T9	0.667
G_3	T10, T11, T12	0
G_4	T13, T14, T15	0
G_5	T17	0

Table 5 Information transfer from the engine developer to RU of pistons

Given information	Demands
The engine displacement is 0.051 L The number of cylinders is 1, and the cylinder diameter and stroke is 42 and 37 mm, separately The highest rotation speed of engine is 5,500 rpm The cylinder peak pressure is 4.0×10^6 Pa The maximum power is 1.4 kW	The design of a piston for the gasoline engine to meet the requirements of strength, stiffness, low friction loss and long life.



a **Detailed Design**



b **Strength analysis results**

Fig. 7 Part of feedback from the RU of BTPTC. **a** Detailed design, **b** Strength analysis results

Table 6 Information transfer from the engine developer to BTPTC for design improvement

Given information	Demands
Version of piston design: P42-001	Improve the design of piston to reach a better reliability.
Two pieces of pistons as samples to be reviewed. One is not used. The other one is tested	
Testing conditions: rotation speed of engine is 5,000 rpm, effective power is 1.2 kW, operation cycle time is 3,000 h	

Although the EKS can be seen as a paid transaction of knowledge, it is different with traditional transactions of goods. During the knowledge service, not only the DEs acquire knowledge or design results from the RUs but also the RUs learns much from the DEs. And the working schedule of any side will be influenced by the other side. In this situation, the credits of any side may block the EKS. It mainly comes from two aspects. The first is that whether one side can transfer the necessary information or results to the other side within the prescribed time and with high quality. The other is that whether the intellectual properties of both sides can well be protected.

Legal means is the first thought and the final step to handle disputes in the EKS. So a legal contract should be signed by both sides before the beginning of knowledge service. Several

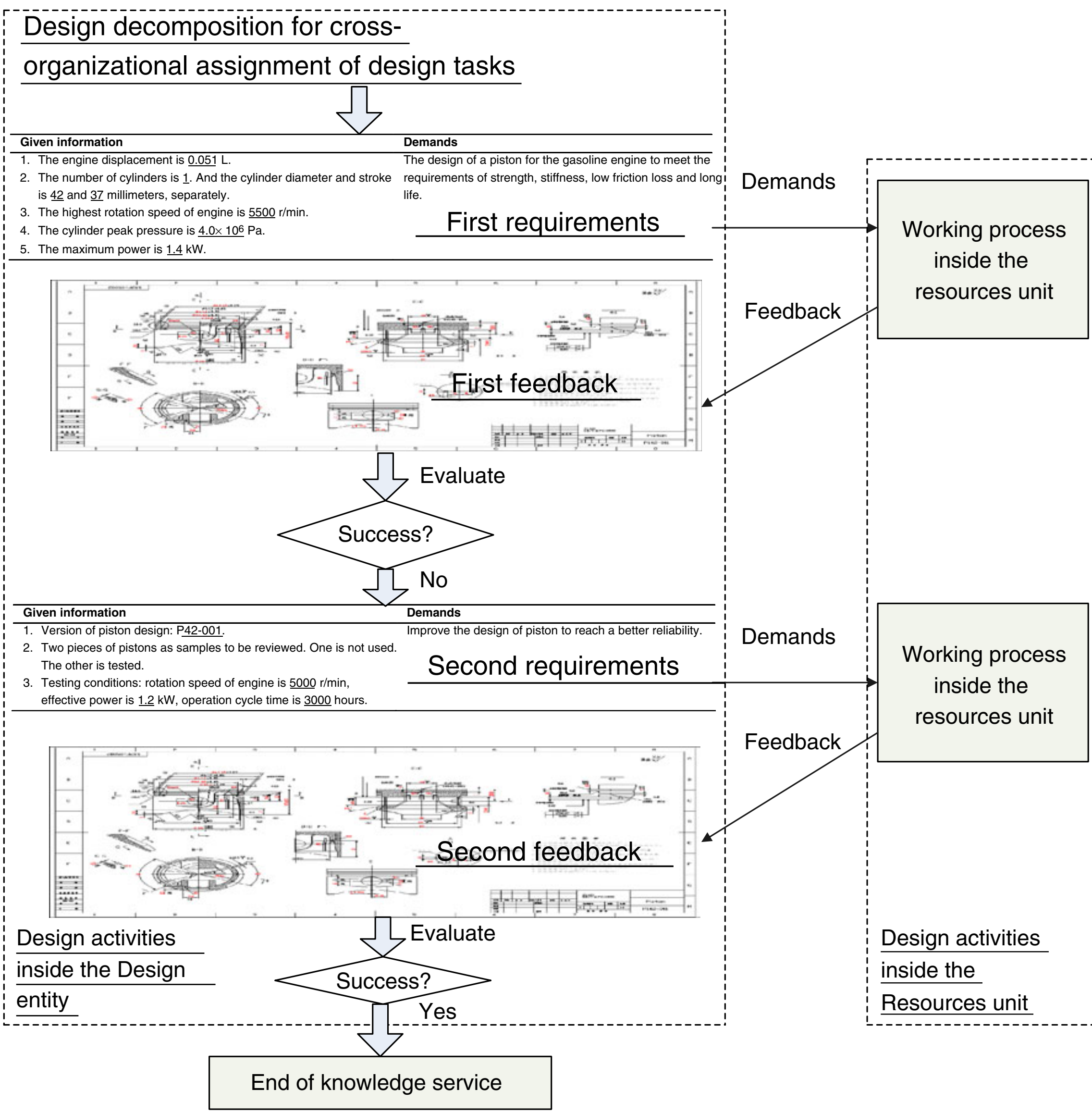


Fig. 8 Iterative information transfer between the DE and the RU

items such as keeping secrets, information transfer on-time, and quality of service should be made on the contract. In perfect legal environment, the signing of knowledge service contract can effectively regulate the behaviors of both sides.

The improvement of the internet platform, in which the DEs and the RUs are registered, is another important means to regulate the knowledge service. With the description of one organization as Table 1, the other organizations can learn about its performance and appraisals in previous cases of knowledge service. In the era of internet, good reputation and history of the things is crucial to one organization to get chances in the future. So in order to be selected in future knowledge service, each organization must do its best in current knowledge service and strive to leave behind a good reputation.

Furthermore, the organizations themselves also have some means to keep their secrets. For the DEs, by decomposition of design tasks into small groups, the communication with the RUs can be minimized. It is beneficial for not only the application of knowledge service but also the keeping of secrets. When the design tasks group is small to some extent, the intention of the DEs about the entire product development is hard to be guessed correctly by its partners. Comparing with the DEs, it is easier for the RUs to keep secrets. In each knowledge service, what the RU provided or sold is the specific results related with the demands of the DEs. The core knowledge and competence about how to get the results are retained within the organization.

Another problem that may block the application of the EKS is the price of knowledge service. Reasonable price level is beneficial for not only the DEs but also the RUs themselves. According to the basic principles of economics, the reasonable price derives from competition rather than monopoly. So in each specific field, there should be a group of RUs rather than only one to serve to the DEs. Moreover, this kind of competition can encourage the technical development in each specific field.

So with proper means, the EKS can be applied smoothly and both the DEs and the RUs can benefit from it.

6 Conclusion

EKS is a kind of knowledge service that supplied by the RUs and embedded as a part of the complete product development process of DEs. Through EKS, higher performance or quality of mechanical products can be expected because advanced knowledge from the professional external RUs is introduced into the product design decision-making process. Several problems are analyzed to support the application of EKS. The presented methods of design tasks decomposition can help the DEs to determine the design task group to be outsourced. And the information communication between the DEs and the RUs can be minimized. With the presented universal description of the organizations relevant to product development, it is easy to find and evaluate each other for the DEs and the RUs. Although the credits of both sides may block the EKS, it can be avoided through proper means. The case study on the development of an internal combustion engine shows that the EKS is feasible, and both the DEs and the RUs can benefit from the knowledge service.

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