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ORIGINAL ARTICLE

Key technologies for ASP-based product customization service system for SMEs: a case study

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Abstract Current product customization systems seldom consider the whole process of product customization, nor provide integrated application services for small to medium-sized enterprises (SMEs). In this paper, an ASP-based product customization service system with integrated application services is proposed for SMEs. A lifecycle-oriented customization service mode is presented to smoothly drive the whole process of product customization. For supporting product customization effectively and efficiently, key technologies on distributed product resource sharing, distributed product data reorganization, and product configuration are deeply studied. A dynamic resource publishing method and a general resource evaluation model with reward measures to promote resource sharing are given. A method of XML-based data mapping for product structure tree reorganization is proposed. A parameter gray correlation degree algorithm is established for quick product configuration. To greatly meet customers' individual requirements, an interactive virtual product configuration platform is designed. Finally, product customization service system orienting to construction machinery is developed and validates the above studies.

Keywords Product customization · Application service provider (ASP) · Small to medium-sized enterprises (SMEs) · Resource evaluation · Product configuration

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1 Introduction

Mass customization, which refers to the ability of providing customized products or services through flexible processes at reasonably low cost with high quality [1], has become a competitive strategy by an increasing number of companies in highly segmented global service market [2]. In recent years, product customization has attracted great interest due to the emergence of mass customization [3]. Networked product customization systems as the bridge connecting enterprises with customers are important for enterprises to bring out innovative and profitable products to the market quickly and cause mass customization (MC) enterprises increasing attention. Some MC enterprises have self-developed their own networked product customization system. For example, General Motors Corp. and Ford Motors Corp. developed their own Internet-based motor customization system, respectively; Dell Inc. provides a customization service in their own website; Haier Corp. developed a networked product order system. A successful networked product customization system needs an enterprise put in a great amount of capital, technology, manpower, and time into system development and maintenance. It is easy to drive MC enterprises away from concentrating on their efforts on core competence during self-developing and maintaining networked product customization system. Otherwise, configurable product resource on self-developed product customization system mainly came from the MC enterprise itself. The limited product resource is sometimes deficient to well satisfy customers' needs. However, customers are usually weary of logging in to different systems many times. Customers more intend to get their products or services on an integrated service platform, only logging in once.

In China, about 90% of registered companies are small to medium-sized enterprises (SMEs). Most of these SMEs may not make the socially optimal investment in product customization. It is even difficult for SMEs to develop Internet-based customization systems because of technology difficulties [4]. Fact reports [5] that SMEs in China can not keep up with new information technology, and most of them do have insufficient money to buy and no technical capability to utilize advanced software such as CAD, CAM, PDM, SCM, and CRM. It is difficult for SMEs to develop and maintain its own networked product customization system for lack of the capital, IT staffs, and specialists to manage product resource and to support sales personnel. It is necessary to find an easier and cheaper operation mode to implement networked product customization. An integrated service platform, which evolves e-business environment by integrating knowledge, technologies, and resources among customers, suppliers, and other business partners to improve SMEs' competitive capability and meet customers' individual demands efficiently, has been a trend in recent years [6].

The newly emerged mode of application service provider (ASP), which is viewed as a subset of e-commerce [7], in many cases, is a third party service organization to offer products of software and hardware through networks. ASP is also defined as a single point of contact for all the telecommunications, hardware, software, and consulting necessary to deploy, run, and maintain hosted applications remotely [8]. Its core value propositions are to lower total cost of ownership, make monthly fees predictable, reduce time-to-market, provide access to market-leading applications, and allow businesses to focus on their core competencies [9]. ASPs particularly target SMEs by providing applications that these firms need to adopt, but cannot afford or are commonly incapable of developing and maintaining [10]. The ASP mode is also helpful by setting up an ASP service platform that provides services such as system development, system integration, and technology support [11–13]. For above characteristics, ASP has been one of the high points of e-commerce in the twenty-first century and is increasingly welcomed by many SMEs which typically suffer from resource poverty and the lack of IT capabilities [14]. Software application using an ASP instead of the customer's local installation is expanding rapidly. For example, Zhou et al. [15] built up a remote ASP-oriented simulation tool on the World Wide Web. With the growth in the development of distributed manufacturing systems, Huang et al. [16] have developed an integrated network management framework based on mobile agent technology for SMEs to reduce complexity and expense in managing networked manufacturing devices.

However, the integration of the product customization system and ASP mode is seldom considered on current researches of product customization systems. After analyzing the status of existing networked product customization system and the features of ASP mode, the application predominance of ASP mode in product customization system can conclude as follows:

(a) Resource predominance. Information technology and management methods are two important aspects which have made mass customization a standard business practice [17]. Networked product customization system is, first, an information system. Networked product customization system running in ASP mode can promote distributive resource sharing. Product resource comes from different enterprises and even different industries and will be more abundant than that from single enterprise self-developed customization system.
(b) Cost predominance. ASPs can not only bear the cost on system development, system maintenance and software update, but also provide software service, technique support, and production equipment at low rent.
(c) Efficiency predominance. Since ASPs may serve a large customer base with different customization requirements, a product designed to facilitate customization may be easier to deliver through ASP.
(d) Market predominance. ASPs provide services to wide application fields, including geographically distributive enterprises and even differently industrial enterprises. Any users who can log in to Internet can access ASP services through the portal of ASP service platform. The more enterprises join in to ASP service platform, the more customers are attracted to log in to it, and, thus, it has a wide market.

So, we apply ASP mode in networked product customization systems and propose an ASP-based product customization service system for SMEs. The main motivation for developing ASP-based product customization service system is to provide a lifecycle-oriented product customization service to assist SMEs effectively conducting mass customization. The system structure is established and lifecycle-oriented product customization mode is presented. Key technologies for effective and quick product customization are deeply studied, i.e., resource sharing technology, product data transform technology, product configuration technology, and interactive virtual product configuration platform. To promote distributive product resource sharing, a general resource evaluation model is established. For integrated product, data from distributed SMEs are usually expressed in different file formats; an XML-based data mapping method for reorganizing product structure tree is presented. Considering the uncertainty and diversification of customers' demands, gray correlative technology is applied to product instantiation configuration and a parameter gray correlative-degree algorithm model is built to provide customers content products quickly. To meet customers' individual demands, an interactive virtual product configuration platform is designed. Finally, a system is developed using the above technologies and has been successfully applied in construction machinery.

2 System structure

ASP-based product customization service system mainly serves as a software resource rent center, a design/manufacture resource sharing center, and a technology consultation center. It provides open, reconfigurable, and web-enabled applications to support product customization for SMEs. The framework of ASP-based product customization service system includes four layers: resource support layer, management layer, application service layer, and user layer, as shown in Fig. 1. The four layers cover the total-life-cycle of product customization, from requirements analysis, product configuration, design, manufacture to managing and marketing.

As the foundation of ASP-based product customization service system, resource support layer provides data and resource for system running. It includes system database, sharing resource base, and product configuration knowledge base. The sharing resource base, which consists of a number of product development software, manufactured resources and enterprise information, is available to all enterprises in industry. System database are used to drive the whole service system running smoothly. Product configuration knowledge base is an important part of resource support layer and supplies sufficient knowledge of product configuration. It includes case base, rule base, graphics base, and products database.

The management layer aims to ensure that the platform is running smoothly and all function modules well-serving the SMEs. It consists of four main function modules which are used to manage this service system. They are configuring process management module, run control module, data transform module, resource management

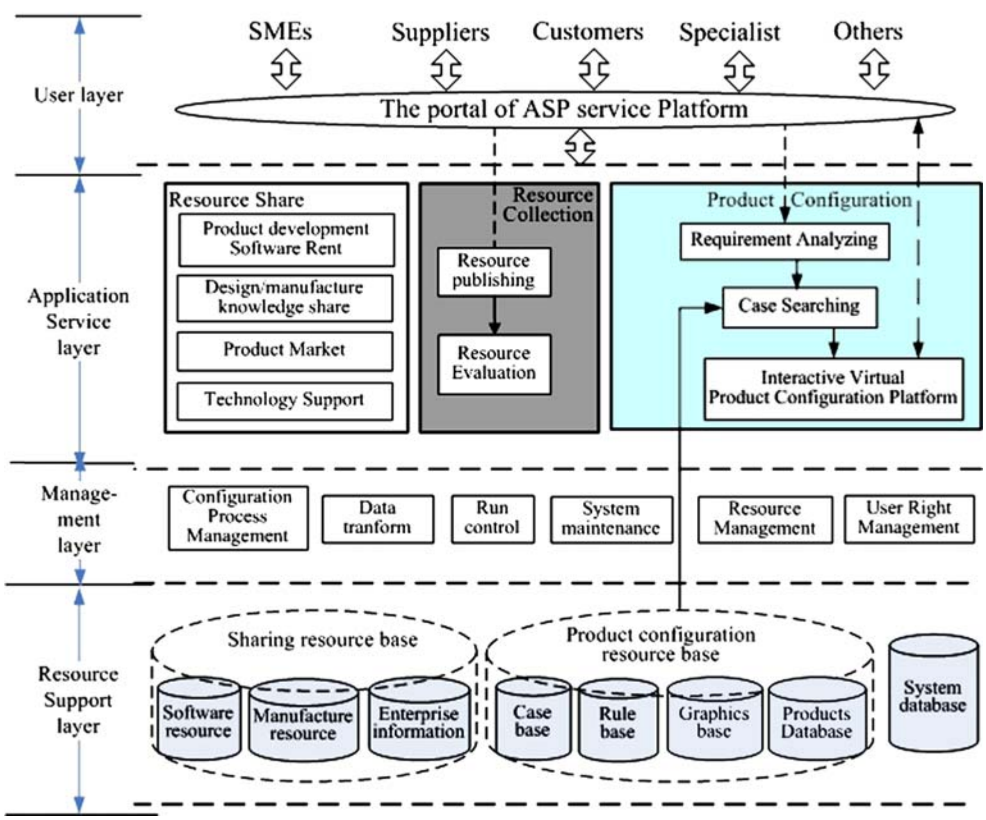

Fig. 1 Structure of ASP-based product customization service system

module, system maintenance module, and user right management module. Configuring process management module ensures that the configuring process smoothly and successfully provides products to satisfied customers. The resource management module serves mainly for product customization and emphasizes particularly on management of product hierarchy tree, product data, and product version. Run control and system maintenance modules are designed to make system and all function modules act smoothly. Isomeric/isomorphic product data from distributed customers or enterprises are transformed into uniform data format through data transform module. Any users who want to log in to the ASP service platform must be managed and controlled by user right management module.

Application service layer is the core layer of this platform and provides three kinds of services for three purposes. The first purpose is to meet SMEs' resource demands of design and manufacture, including advanced software sharing (e.g., Computer Aided Design (CAD), Computer Aided Manufacturing (CAM), Supply Chain Management (SCM), Customer Relationship Management (CRM)) lease, design/manufacture knowledge sharing, product marketing, and technology consultation. The second purpose is to integrate distributed resources owned by SMEs, scientific institutions, colleges and universities, etc. The third purpose is to provide users (SMEs or customers) product customization functions, including requirement analyzing, case searching, design type analyzing, virtual product configuration, and configuration validity analyzing, etc.

The user layer is the portal which users access services provided by ASP service platform. It presents users the following interactive function interfaces: information upload/download, software tools upload/download, resource evaluation, requirements analysis, product configuration, product assembly and disassembly, design validity analysis, configuration validity analysis, and so on. All the interfaces are embedded on ASP. Using these interfaces, SMEs, and other customers can access all the tools and application services provided by product customization service system.

High-tech process innovation (e.g., computer hardware and software) offers enterprises the potential of reducing production costs and enhancing product quality. The whole product customization service system is supported by scientific institutions, colleges and universities, and administrative organizations, which can well act as high-tech software and technology service center. In addition, it aims to provide not only quick product customization functions but also design/manufacture resources at low rent. SMEs could develop their Internet-based sales and customization effectively in a short time and at low cost by using this platform.

3 Lifecycle-oriented product customization service mode

Efficient customization service mode can shorten the time of product customization and reduce the cost consequently. So, we proposed a lifecycle-oriented product customization service mode that can help cut product customization time. The customization service mode is shown in Fig. 2.

Customer requirement parameters have strong correlation to enterprises' parameters requirements, and product customization is driven by customer requirements. When customers log on ASP-based product customization service system and input requirements' parameters, the data transform module parses them into XML documents. Then case-based searching module makes the first search (as

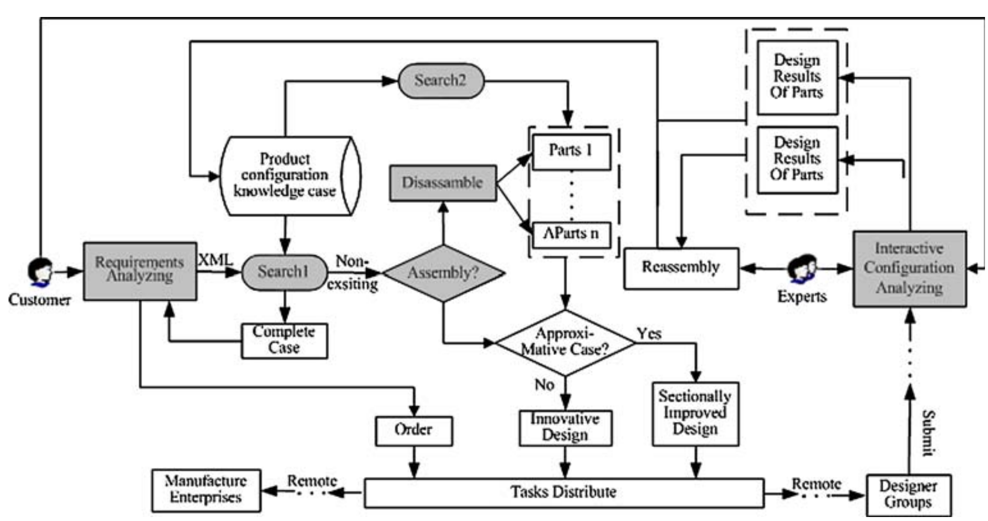

Fig. 2 Lifecycle-oriented product customization mode

search1 in Fig. 2) for counterpart case from resource support layer. If the counterpart is not found, the analyzer starts up and analyzes exported XML model documents from CAX scene. For assembly product, each child node in XML model documents is captured for next search. If there is no counterpart or similar counterpart and the child node can be divided further, the second search (as search2 in Fig. 2) continues until gaining the counterpart or similar, or until the node not being divided any more. When a similar product is achieved, the approach of partial improving design is adopted. If none of the counterpart or similar is found in the database, innovation design is appointed. Distributed design groups who receive design tasks can rent software tools of product development provided by the product customization service system weekly or monthly. Domain experts take part in evaluating the design results together with customers and designers in interactive virtual product configuration environment. Design results of assembly parts are reassembled and submitted to the analyzer for validity analysis. All finished parts and assembly parts are submitted into product configuration knowledge base for future reuse. While the customer is content with the results of the design, product orders are sent to remote distributed manufactories for production. The ASP-based product customization integrated service platform well provides information and technologies for distributed designers and manufacturers at low rent.

4 Key technologies

It can be seen from Figs. 1 and 2 that requirement analysis, distributed resource sharing, product data transform, and product configuration are four important aspects for supporting product customization effectively. Requirement analysis has been deeply studied in [18, 19]. In the following, resource sharing mechanism, XML data mapping for creating product structure tree, quick retrieving algorithm and interactive virtual product configuration platform for product configuration are focused on.

4.1 Distributed resource sharing mechanism

Regardless of which category is focused on and which method or logical structures are adopted, the base and core element determining the failure or success of product customization is product resources [20] including design resources, manufacturing resources, product cases, product data, etc. Lack of sufficient resource is also one of the important factors that the business mode of application service providers in China cannot diffuse effectively as expected [21]. Since a product platform on the proposed product customization service platform is structured from distributed enterprises, how to promote geographically distributed enterprises to submit their product resources onto the integrated ASP service platform is a bottleneck problem of the product. Current researches in the field of distributed resource sharing are mainly focused on resource integration system design, information extraction technology, and knowledge resource management. For example, Wang et al. [22] proposed a resource integration framework of regional networked manufacturing ASP service platform. Zha [23] developed a web-enabled database system for micro electro-mechanical system which can provide the networked design and manufacturing services over the Internet. Reinoso-Castillo [24] presents a novel ontology-driven approach to support customizable information extraction and integration in scientific discovery. To integrate the legacy of manufacturing resources into networked manufacturing systems, Zhou and Jiang [25] develop a novel platform for the configuration and encapsulation of legacy manufacturing resources in networked manufacturing systems. Knowledge resource management has experienced two waves. Through the first wave of knowledge management and the second wave of knowledge management, large numbers of researches have focused on knowledge resource management [26]. But few researches target establishing resource sharing mechanism to promote resource-holders to actively submitting their product resources. To achieve that, a “win–win” strategy for ASPs and SMEs is expected to be a good measure, i.e., submitted resource must be useful for ASPs and SMEs who submit useful resources should obtain certain rewards.

Based on the above analysis, following this paper, a dynamic resource publishing method for distributed resource sharing is given (see Fig. 3). Original resources on the resource support layer are collected by administrators from typical members, relative domain institutions, ongoing Internet resources, and relative technique books and periodicals. Most product resources and the update of service resources need to be done dynamically on clients by users. Platform administrators have the highest right to operate the whole resource, involving constructing initial resource database and integrating distributed resources. All non-members must register and pay certain money for special resources or for resource space to deposit their private resources into database. Any uploaded resource will be taken into the database when it is evaluated to be useful. When the added resource is evaluated to be a value-added resource, a certain reward is given to the resource provider. It can be seen from the resource publishing process that resource evaluation model and certain award measures are important aspects to promote resource sharing.

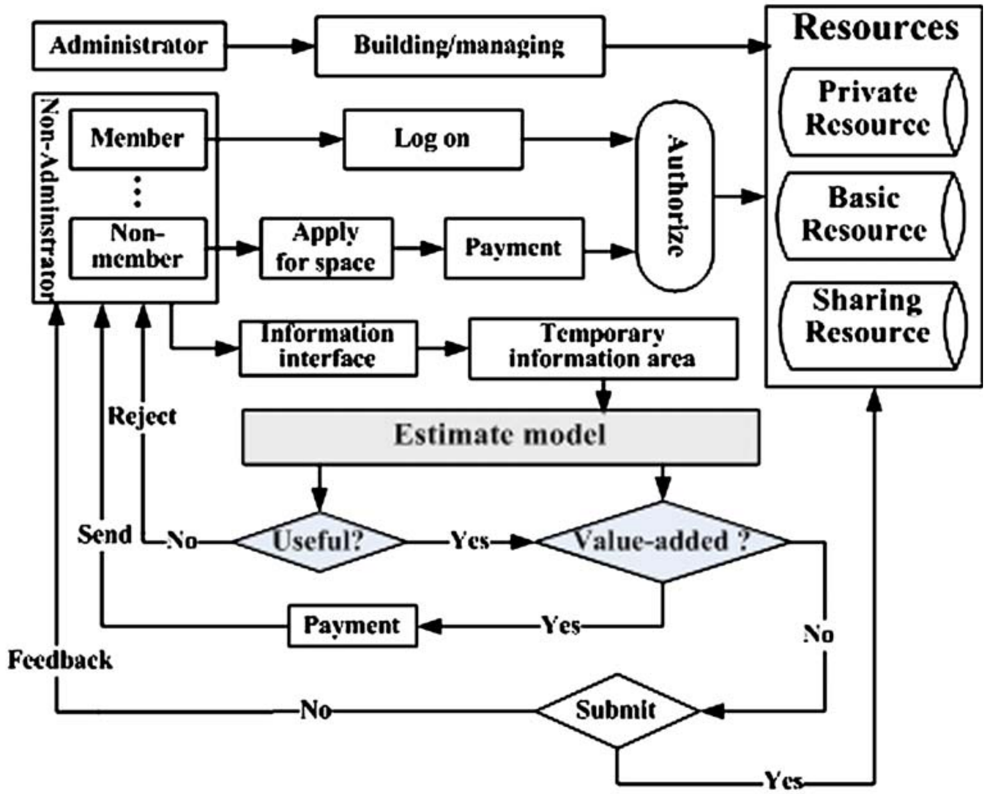

Fig. 3 Dynamic resource publishing

4.1.1 General resource evaluation model

Existing resource evaluation models are established for a special resource with certain evaluation indices, such as collaborative design resource evaluation [27], manufacturing resource selection evaluation [28], Web information resource evaluation [29], and injection mould cost evaluation [30], so on. Product resources on ASP service platform comes from different enterprises and even different industries. The category and quantity of product resources are abundant. Establishing an evaluation model for each category of product resource is not practical. So, a general resource evaluation model is established to evaluate the value of resources submitted from clients. Evaluation indices and evaluation algorithm are established as follows:

Hypothetically set U is an evaluation index,

$$U = (u_1, u_2, \cdots, u_k),$$

where u_i (i=1, 2,…, k) is assigned by evaluation experts. If set W is a relevant weight aggregate of U and ω_i is the weight of element u_i, then $W = (\omega_1, \omega_2, \cdots, \omega_k)$, and $\sum_{i=1}^{k} \omega_i = 1$. Each index can be divided into different grades according resource categories. Each grade is marked by evaluation experts. Let R^* be the mark matrix of U and P be the matrix of the number of evaluation experts, then

$$R^* = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \cdots & \cdots & \vdots & \cdots \\ r_{k1} & r_{k2} & \cdots & r_{km} \end{bmatrix}, \quad P = \begin{bmatrix} N_{11} & N_{12} & \cdots & N_{1m} \\ N_{21} & N_{22} & \cdots & N_{2m} \\ \cdots & \cdots & \vdots & \cdots \\ N_{k1} & N_{k2} & \cdots & N_{km} \end{bmatrix}$$

Let A be the evaluation matrix, then

$$A = W \oplus R^* \oplus P = W \bullet \left(R^* \bullet P^T\right) = (a_1, a_2, a_3, a_4, a_5).$$

Log files memorize the frequency τ of submitting resource and the number of resource provided by each resource-holder at a time. The context of resources and other information are memorized in temporary information area. Domain experts and task-assigner mark each item. Generally, the sum of resources provided by each resource-holder changes along with time t. Let $g(t,\tau)$ be number of resources per second at a time and G_j (j=1, 2,…, k) be the total quantity of the j^{th} kind of resource, then

$$G_j = \iint g(t,\tau)\, d\, t\, d\, \tau,$$

Suppose ξ_i (i=1, 2,…, k) is the value of unit mark and N is the number of experts who attend evaluation. ξ_i is appointed by task-assigner. Let Val be the evaluation result of resource value, then

$$N = \sum\sum N_{ij}, i = 1, \cdots, k, j =, \cdots, m,$$
$$\text{Val} = (\xi_1 G_1, \xi_2 G_2, \cdots, \xi_k G_k) \bullet A/N \circ$$

Set λ=(λ_1, λ_2, λ_3) represents the grade of useful degree, where λ_1, λ_2, and λ_3, respectively, represent very useful, useful, and useless. Therein, $0 \leq \lambda_i \leq 1$ and $\sum_{i=1}^{3} \lambda_i = 1$. Hypothetically, relative useful degree $\text{Vper} = \text{Val} \Big/ \left(\sum_{i=1}^{k} (\xi_i G_i) \right)$, and the lower limit of value-added resource is δ, which is appointed by experts, then

If Vper≥λ_1, the resource is very useful;
If λ_2≤Vper≤λ_1, the resource is useful;
If Vper≤λ_3, the resource is useless;
If the resource is useful and Vper≤δ, the resource is value-added.

Uploaded resource information from non-administrators is first deposited in a temporary information area. Task-assigners and experts start up resource evaluation module to evaluate uploaded resources and give the results of useful degree and value-added degree. Useful resources are accepted and deposited in sharing resource base, product configuration knowledge base, or system database respectively according to resource characters.

4.1.2 Awarding measures

To encourage and attract resource-holders to submit product resources and more customers to feedback helpful information, three reward measures are presented according to the value of Val.

(a) Payment

Pay cash or mail goods to resource supplier directly according the rate of exchange of Val which assigned by task distributor.

(b) Awarded marks

Every time when the published resource is evaluated by estimation module, the calculated value is added to Val and deposited as a type of awarded marks. The resource supplier can use the rewarded marks to exchange services which are provided by ASP service platform at any time until the awarded marks equal to zero.

(c) Widen authorization

When Val is large enough and exceeds a certain value appointed by the administrator, the resource supplier has the following choices:

- To be a member if his/her present status is non-member
- To be an advanced member if he/she has been a general member
- To prolong period of validity to operate the ASP-based product customization service system

The rate of exchange for the above-three award measures is assigned by ASPs after forecasting the future value of relevant resource. ASP service platform backups and evaluates the resource submitted from client in real time. The Val is termly updated and possible reward information is timely sent to resource-holders. Resource providers are free to select permissive reward measures.

4.2 XML-based data mapping for product structure tree

Integrated product data from distributed SMEs are usually expressed in different file formats. It is necessary to transform these isomeric product data into uniform format. Product hierarchy structure tree is an intuitive organization form of product data and convenient for users querying and browsing. Current researchers mainly focus on product family design [31] and product information representation for effective case retrieval [32]. Few studies emphasize on product data reorganization.

On ASP-based product customization service system, relational database is used as back-end database. To realize data mapping between different file formats, XML document is used to exchange and search among different modules. The main benefit of adopting XML format is that there are powerful parsers to process XML files and XML format has a clear structure to organize data [33]. Furthermore, it is because of its feature of standard language and its interoperability, XML would allow, by means of eXtensible Stylesheet Language Transformations (XSLT), the generation of eXtensible HTML (XHTML) pages which are visualized on a browser with a representation of any other document that includes their elements [34].

There are two types of data mapping for creating and depositing product hierarchy structure tree. One is the data mapping between relational database and product hierarchy structure. The other is data mapping between relational database and product data connecting with tree nodes of product hierarchy structure. For the two types of data mapping, two XML-based mapping methods are proposed:

XML template-driven mapping and object-oriented XML table mapping. The two proposed mapping methods are realized by following pre-designed XML template and object-oriented XML table.

For data-mapping principle, see Fig. 4. According to the XML template, data are retrieved from a relational database and expressed in XML. On the front-end browser, the XML document displays in the user interface as a product

XML template :

```
<?xml version="1.0">
<Rootnode Text="ProductName">
 <Fathernode1 Text="Assembly 1">
   <childnode11 Text="Part A1">
       <Instruction>Description</Instruction>
       <Name>Object A1</name>
       <Operation>SELECT Sub-objects FROM Object A</
SelectStmt>
       <Conclusion>Description</Conclusion>
   </childnode11>
  <childnode12 Text="Part B1">
       .....
  </childnode12>
       .....
 </Fathernode1>
    ......
<FathernodeN Text="Assemblyn">
    ......
<FathernodeN>
       .....
</Rootnode>
```

Object-oriented XML table:

Sub-object1	Sub-object2	Sub-object3
NodeA	NodeB	NodeC
description	description	description

```
<Object>
  <Sub-object1>NodeA</Sub-object1>
  <Sub-object2>NodeB</Sub-object2>
  <Sub-object3>NodeC</Sub-object3>
  ... ...
</Object>
  Object Frame{
  Sub-object1=" NodeA" ;
  Sub-object2=" NodeB" ;
  Sub-object3=" NodeC" ;
  ... ...
   }
Object Description{
<Object NodeA>description<Object NodeA>
<Object NodeA>Attribute Item1<Object NodeA>
... ...
}
... ...
```

hierarchy structure tree. According to object-oriented mapping, data in the table or nodes of hierarchy tree are transformed into XML documents and deposited into relational database. Fig. 5 illustrates the above-mentioned mapping relationships in reorganizing product hierarchy structure tree of Road-surface Machinery. When the 1220MAXI-PAV Paver meets a customer's needs, product data of 1220MAXI-PAV Paver is mapped to a product hierarchy structure tree driven by an XML template. Product data of performance parameters or others are mapped into the data table by object-oriented XML table and connects with relevant tree nodes, such as Extension

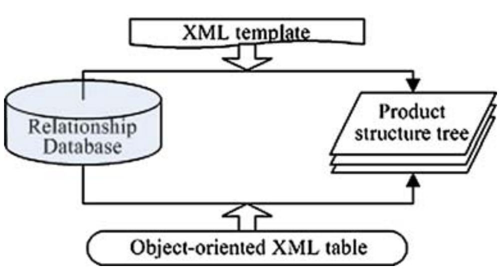

Fig. 4 XML-based data mapping for product structure tree

Frame of 1220MAXI-PAV Paver. If modifications are made, product hierarchy structure tree and data connecting with tree nodes can also be deposited in a relational database driven by XML template and XML table.

4.3 Product configuration

4.3.1 Case-based product configuration algorithm

To solve the product configuration problem, several different approaches have been adopted. For example, the generic bill of material (GBOM) concept to solve the problem of product configuration management [35], Product Family Structure (PFA) [1] and the object-oriented concept [36] to organize and express product configuration model, and Constraint Satisfactory Problem (CSP) Algorithm [37] to solve rapid configuration problem. These researches in the field mostly focus on the issues about creating product configuration information system environment and solving optimization-based problem for product family design. Reusing precious successful cases can lower the error rate of configuration design and case-based reasoning (CBR) can help solve the problem through the retrieval of similar previous cases [38]. In the domain of product design and development, case-based reasoning algorithm is used to quickly help generate

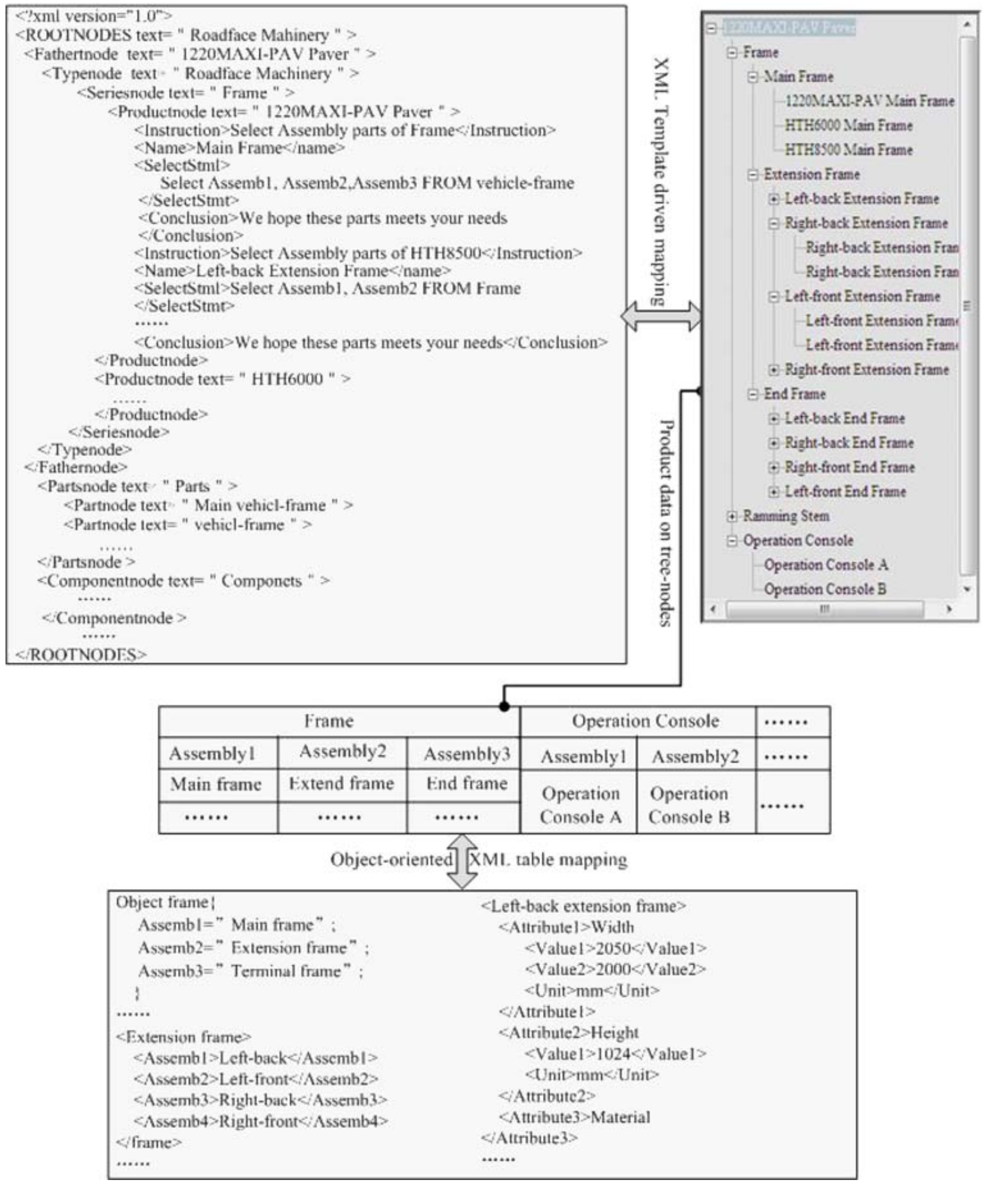

Fig. 5 Creating product structure tree of road-surface machine

a right new BOM [39] or new product ideas [40] when solving a new problem. The preconditions of the above product configuration methods are that customers' needs must be transformed into coincidence expression with configurable attribute.

As a matter of fact, customers' needs take on uncertainty and diversification. The transformation of customers' needs will not only add load to the system but sometimes be hard to be unified. The goal of case-based product configuration is to find the most similar cases which meet with customers' needs. Case-based product configuration process is also a process of sorting cases by the similar degree. Due to the uncertainty and diversification of customers' needs, product configuration process, as a system, is actually a gray system according to the theory of gray correlative technology [41]. If taking attributes of customers' needs as referent sequence and attributes of cases as comparable sequence, case-based product configuration can be realized using gray correlative-degree algorithm model [42]. Usually, attributes of customers' needs and attributes of cases are discrete. Here, point gray correlative degree [42] is adopted and parameter gray correlative-degree algorithm is established as follows:

Set the p_0 attribute aggregate of customers' needs, $p_0(k)$ the kth attribute among attribute aggregate of customers' needs, then

$$p_0 = \{p_0(1), p_0(2), \cdots, p_0(l)\}$$

Set p_i as the attribute aggregate of the ith case, $p_i(k)$ the kth attribute among attribute aggregate of the ith case. If one attribute is absent in the attribute aggregate of a case, the value of the attribute item is set to zero. All the attribute aggregates of cases are expressed as follows:

$$\begin{aligned} p_1 &= \{p_1(1), p_1(2), \cdots, p_1(l)\}, \\ p_2 &= \{p_2(1), p_2(2), \cdots, p_2(l)\}, \\ &\cdots\cdots \\ p_m &= \{p_m(1), p_m(2), \cdots, p_m(l)\}. \end{aligned}$$

Taking p_0 as the reference sequence and p_i (i=1, 2,…,m) as the comparable sequence, parameter gray correlative degree p_0 between p_i and is

$$\begin{aligned} r(p_0, p_i) &= \sum_{k=1}^{l} \omega_k r(p_0(k), p_i(k)) \\ &= \sum_{k=1}^{l} \omega_k \frac{\Delta \min_i \min_k \left| p_0(k) - p_i(k) \right| + 0.5\, \Delta \max_i \max_k \left| p_0(k) - p_i(k) \right|}{\left| p_0(k) - p_i(k) \right| + 0.5\, \Delta \max_i \max_k \left| p_0(k) - p_i(k) \right|} \end{aligned}$$

(Formula 4.1)

where ω_k is the weight of performance parameter k, $0 \leq \omega_k \leq 1$, and $\sum_{k=1}^{n} \omega_k = 1$

In order to make all attributes to be compared and ensure retrieving correct results, dimensions of attributes need to be eliminated. From attributes of customers' needs and attributes of cases exist three types of expression, i.e. text, numerical value, and range value. Existing data transform methods in gray correlative technology can not be directly used. The following defines gray distances between attributes by different type of attributes:

(a) Text gray distance

For text attributes among referent sequence and comparable sequence, the improved algorithm model of text similarity [43] is as follows

$$\mathrm{sim}(\mathrm{OT}_0, \mathrm{OT}_i) = \frac{\mathrm{count}(\mathrm{OT}_0 \cap \mathrm{OT}_i)}{\mathrm{count}(\mathrm{OT}_0) + \mathrm{count}(\mathrm{OT}_i) - \mathrm{count}(\mathrm{OT}_0 \cap \mathrm{OT}_i)}$$

(Formula 4.2)

And define text gray distance

$$|\mathrm{OT}_0, \mathrm{OT}_i| = \frac{\mathrm{count}(\mathrm{OT}_0 \cap \mathrm{OT}_i) \times \omega_0 \times \sigma_i^T}{|\omega_0| \mathrm{count}(\mathrm{OT}_0) + |\omega_i| \mathrm{count}(\mathrm{OT}_i) - \mathrm{count}(\mathrm{OT}_0 \cap \mathrm{OT}_i) \times \omega_0 \times \omega_i^T}$$

(Formula 4.3)

Where OT_0, OT_i are text attributes of p_0 and text attributes of p_i respectively, the function of *count* is used to compute the quantity of text attributes, ω_0 and ω_i, are the weight of test attribute of p_0 and the weight of test attribute of p_i respectively.

(b) Range gray distance

Set the attribute item of reference sequence $p_0(k)$=[d_1, d_2], attribute item of comparable sequence $p_i(k)$=[e_1, e_2], $\omega_{a_0,k}$ and $\omega_{a_i,k}$ are the weight of $p_0(k)$ and the weight of $p_i(k)$, respectively, $0 \leq \omega_{a_0,k} \leq 1, 0 \leq \omega_{a_i,k} \leq 1$. Improve the definition 2.2.2 [42] and define the following range gray distance with weight

$$|P_0(k), p_i(k)| = \sqrt{2} \Big/ 2\sqrt{\left(\omega_{a_0,k} \times d_1 - \omega_{a_i,k} \times e_1\right)^2 + \left(\omega_{a_0,k} \times d_2 - \omega_{a_i,k} \times e_2\right)^2}$$

(Formula 4.4)

(c) Numerical value gray distance

Set the attribute item of reference sequence $p_0(k)$=d, attribute item of comparable sequence $p_i(k)$=e and define numerical value gray distance

$$|p_0(k), p_i(k)| = \left| \omega_{a_0,k} \times d - \omega_{a_i,k} \times e \right| \Big/ \left| \omega_{a_0,k} \times d + \omega_{a_i,k} \times e \right|$$

(Formula 4.5)

While computing gray correlative degree between reference sequence and comparable sequence, gray distance between attributes is calculated using the above Formula 4.3, Formula 4.4, or Formula 4.5 according to the type of attribute.

From requirement-driven product customization process graph (Fig. 2), it is obvious that searching counterparts or similar cases from resource support layer is one key technology for product customization to proceed smoothly. There are two main strategies that are used for retrieval, namely, generalization hierarchy strategy and parallel strategy [44]. Here, we integrate generalization hierarchy strategy and parallel strategy according to product hierarchy tree, and apply two searching algorithms for quick product configuration: the text similar degree algorithm (Formula 4.2) [43] and the proposed parameter gray correlative-degree algorithm (Formula 4.1).

When a product is required to be configured, text similar degree algorithm (Formula 4.2) is applied in nodes of the product hierarchy structure tree. Text-name relevant to tree node is regarded as text attribute of the retrieving object. The process of retrieving starts from the root-node and downwards when none of the counterpart or similarity is retrieved at the current level and ends when the node is a leaf-node. When multi-similarities of a retrieving object are found, customer requirements are decomposed into performance parameters. A further search based on parameter gray correlative-degree algorithm (Formula 4.1) is done according to performance parameters. When a text-type parameter is met within a parameter table, text gray distance (Formula 4.3) is utilized and the value of $|\mathrm{OT}_0, \mathrm{OT}_i|$ is added into Formula 4.1. When one parameter item is a range value, range gray distance (Formula 4.4) is used to calculate the similar degree of two performance parameters. The similar degree of two parameters of numerical value type is computed by numerical value gray distance (Formula 4.5)

Table 1 Performance parameters of multi-function bitumen-concrete paving machine put forward by customer

Multi-function bitumen–concrete paving machine						
Basic working width (ω_1)	Max working width (ω_2)	Max paving thickness (ω_3)	Paving speed (ω_4)	Traveling speed (ω_5)	Theoretic productivity (w_6)	Hopper capacity (ω_7)
3.0	7.5~9.5	380	0~15	0~3.0	600~650	18~22
Gradient ability (ω_8)	Engine type (ω_9)	Rated output (ω_{10})	Generator power (ω_{11})	Weight (ω_{12})	Overall dimension (w_{13})	
20	–	110~120	20~25	16~25	Not exceed 6,300×3,000×3,900	

(ω_1=ω_2=ω_3=ω_4=ω_5=ω_7=ω_7=ω_8=ω_{10}=ω_{11}=ω_{12}=ω_{13}=0.076, ω_9=0.088,$\sum_{i=1}^{13}\omega_i = 1$)

For example, a Cement–Concrete Paving Machinery is required by customers (Table 1). The text-name "Cement–Concrete Paving Machinery" is an object to be retrieved. First, text similar degree algorithm is applied and multi-similar products are retrieved (Table 2). In order to get the most similar product from Table 2, parameter gray correlative-degree algorithm is used for further search by performance parameters. When the item of Engine type is met, text similar degree algorithm is utilized and the text item is replaced by sim(OT_0, OT_9). Results indicate that RP802 is the most similar. Improvement design or innovation design can be performed upon RP802. Tests show that case-based product configuration by use of proposed retrieval method can significantly improve retrieval efficiency.

4.3.2 Interactive virtual product configuration platform

At present, end users often want to configure the product with individual preferences and are allowed to choose product specifications with real-time update in the product appearance or overall shape. Only, supplying a bill of product configuration or 2D image for showing customer's configurations may not be effective when the product styling (shape, color, and appearance in 3D space) is a key factor that influences the purchase decision. There is a need for web-based interactive visualization environment. Lots of Web VR-supported interactive or collaborative systems have been studied and developed in recent years. Kan et al. [45] employ virtual reality modeling language (VRML) for synchronized 3D-viewing of a product design over the Internet and developed a web VR collaborative environment. Cera et al [46] employ Java and Java 3D to develop a collaborative 3D environment for designers separated geographically to author design semantics. Huang [47] employs VRML to construct a whiteboard to display design information. Lau et al. [48] employ VRML to develop an interactive environment for sharing product design data and the visualization of design changes in real time. Zhang et al. [49] propose a Web-based framework for product information sharing and visualization. Gierach et al. [50] present an approach for managing networked hardware devices and

Table 2 Performance parameters of multi-function bitumen-concrete paving machine cases retrieved from case base

Item/parameter	Product-type					
	RP955	RP800J	RP951A	RP751	RP802	…
Basic working width	3.0	3.0	3.0	3.0	3.0	…
Max working width	9.5	8.0	9.5	7.5	8.0	…
Max paving thickness	350	330	350	380	380	…
Paving speed	0~18	2.0~5.5	0~18	0~10	0~14	…
Traveling speed	0~2.4	0~2.4	0~2.4	0~3.5	0~3.0	…
Theoretic productivity	700	500	700	600	600	…
Hopper capacity	14	14	14	13	13	…
Gradient ability	20	20	20	20	20	…
Engine type	BF6M1013E	D6114ZG1B	BF6M1013	BF4M1013C	BF4M1013C	…
Rated output	137/2300	140/2300	133	112	112	…
Generator power	28	28	28	20	20	…
Weight	21.3~28.8	22~25	21.3~28.6	16.5~19.5	16.5~23.5	…
Overall dimension	6,731×3,000×3,850	6,636×3,000×3,880	6,757×3,000×3,650	6,130×3,000×3,815	6,230×3,000×3,855	…

software services in the field of virtual manufacturing and have applied it for dynamically monitoring and controlling remote facilities in virtual manufacturing.

The activities and functions involved in product design and manufacturing on the above systems or methods are different from those for configuration design. Functions related to product design may include generation and editing of new shapes, measurement of dimensions, specification of manufacturing parameters such as tolerances, surface finish, etc. Functions for configuration design of customized products include quick selection of proper base products and components from part database, configuration of a virtual product similar to the customized product, 3D visualization of the virtual product, and interactive improvement of the virtual product. For interactive configuration design, Sun and Chiang [51] presented a Web-based collaborative VR environment for customer–company interaction support. But it is mainly designed to acquire customer's requirements through the communication between the company's salesperson and customer. It only provides a simple function of the 3D display of the virtual product. Both customers and company can not mark, modify, and partially reconfigure the 3D model of the virtual product.

In this paper, in order to allow users to participate in product configuration vividly and make the configuration product meet the customer's individual requirements as possible as it can, an interactive virtual product configuration platform is presented. By analyzing the content of product configuration, successful configuration products are based upon valid organization of product structure, sufficient product data, and 2D/3D models of the virtual product. Thus, the platform consists of five major modules: product configuration hierarchy organization module, virtual configuration scene, color module, PDM module, intercommunication module, and collaborative configuration design module. Configuration product hierarchy tree is structured by product configuration hierarchy organization module. Each node of the hierarchy tree corresponds to a configurable product function module. If a customer is discontented with some function modules of the configured product, he/she can start up the product configuration hierarchy organization module and re-organize the hierarchy of the configured product using a new replaceable product function module. Product data are managed by PDM module and are well-integrated with the product hierarchy tree by the keywords of tree nodes. Participants in product configuration, including the customer, designers, and experts, air their opinions by intercommunication module and change colors of 3D model by color module to meet individual favor. When customers expect partially modifying or improving some product function modules, customers mark it out and inform product designers. Product designers and even customers carry collaborative design through collaborative configuration design module.

For the structure of interactive virtual product configuration platform, see Fig. 6. It adopts three layers of B/S

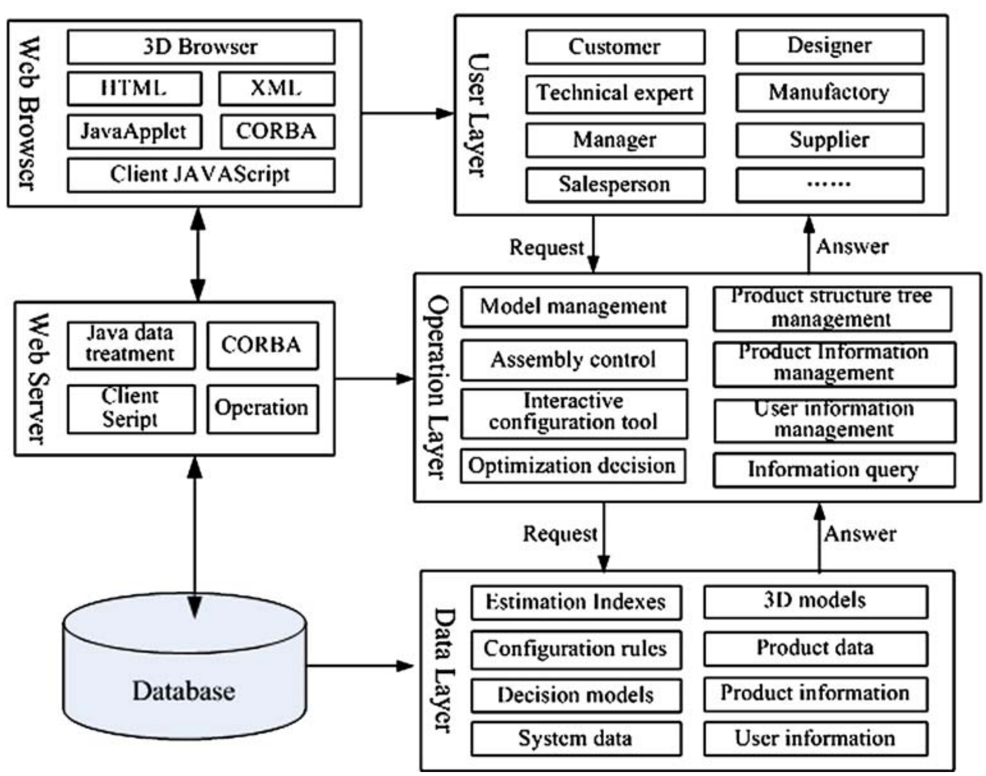

Fig. 6 Structure of interactive virtual product configuration platform

structure and developed on modular thought. The user layer is an interactive interface connecting users and interactive configuration design system. Users can browse the information of parts, product, and product structure tree through Web browser and 3D browser. Users can also carry out actions, such as loading virtual product models, disassembling products, and assembling parts, so on. The operational logic layer takes charge of the following operations: (1) handling information and data uploaded by users; (2) querying, browsing, and modifying configurable parts of a product; (3) controlling assembly process of 3D models; configuration optimizing and making decision. The data layer stores and manages system data, users' information, product data, 2D/3D product models, and configuration rules.

The interactive configuration process between customers and designers shows in Fig. 7. After the authentication of users, users can query and browse all the virtual product information provided by the ASP service platform through Web browser. If some modifications are needed, they can inform remote designers through Publish Questions & Suggestions module. Users and designers cooperatively carry out interactive configuration design using offered interactive configuration tools, such as Create Product Structure Tree, Modify Product Structure Tree, Modify Performance Parameter, Mark 2D Drawing, etc.

Design communication can be implemented using FTP, VRML, E-mail, Net-meeting, or video conferencing. The 3D display is controlled and responds to an outside event through the self-defined feeling nodes and script nodes on the VRML scene, comprising adding scene nodes, changing the appearance, color, location, and motion track of nodes on the VRML scene. Real-time interactive operation between users and VRML scene is realized by not only utilizing Script nodes of VRML itself, but Java Applet and EAI. To achieve product resource reuse, virtual products modeled on CAD tools or other 3D modeling software can be exported into VRML files for display on the VRML scene. For direct exported VRML files from CAD tools and other 3D modeling software are commonly large and difficult for transport and coloration, a method of optimization and reconstruction of VRML files [52] is given and resolves the above problems.

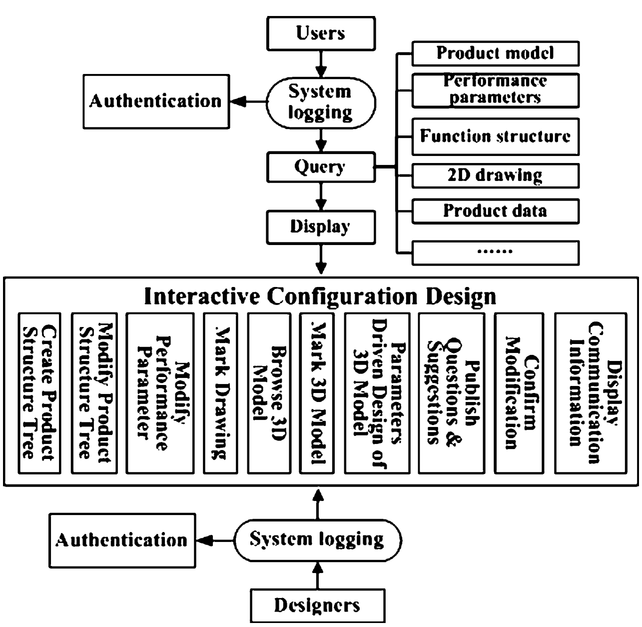

Fig. 7 Interactive configuration design process

5 A case study

Based on aforementioned studies, a prototype of ASP-based product customization service system is developed by utilizing object-oriented technology, module design method and Internet technology. Resource support layer is built upon the SQL Server 2000 system. All modules are implemented in .NET framework by making use of technologies of ASP.NET with Visual Basic and Java Script. The interactive virtual product configuration platform is developed by improving a self-developed web-based interactive virtual assembly system [53]. The virtual configuration scene is developed by use of EAI technologies of Cortona [54] on Java development platform. The virtual configuration environment is developed based on VRML and embedded in an IE6.0 browser that allows clients to access the environment over the Internet. The developed product customization system has been diffusively applying in construction machinery. Road-surface pavers in construction machinery are adopted to verify and demonstrate above studies. Fig. 8 shows several typical interfaces developed based on above studies.

Fig. 8(a) is a typical interface of resource evaluation system for collecting product configuration resource of a road-surface paver. It is developed on the proposed dynamic resource collecting method with certain reward measures. The evaluation object is the manufacture resource for a Frame of 1220MAXI PAV Paver. Experts log in to the system to assign evaluation indices and mark the relevant weight of evaluation indices. Here, the indices aggregate *U* specialization degree, innovation degree, credit degree, quality level, forecast-value respectively. Each index is divided into six grades, i.e. very high, high, general, low, very low, and none. The grade of useful degree is set as, γ_1=0.8, γ_2=0.5, γ_1=0.1 and the lower limit to be value-added resource is δ=0.75. Through statistically computing and analyzing, the resource value is Val=68 and the relative useful degree is Vper=0.779. Evaluated results

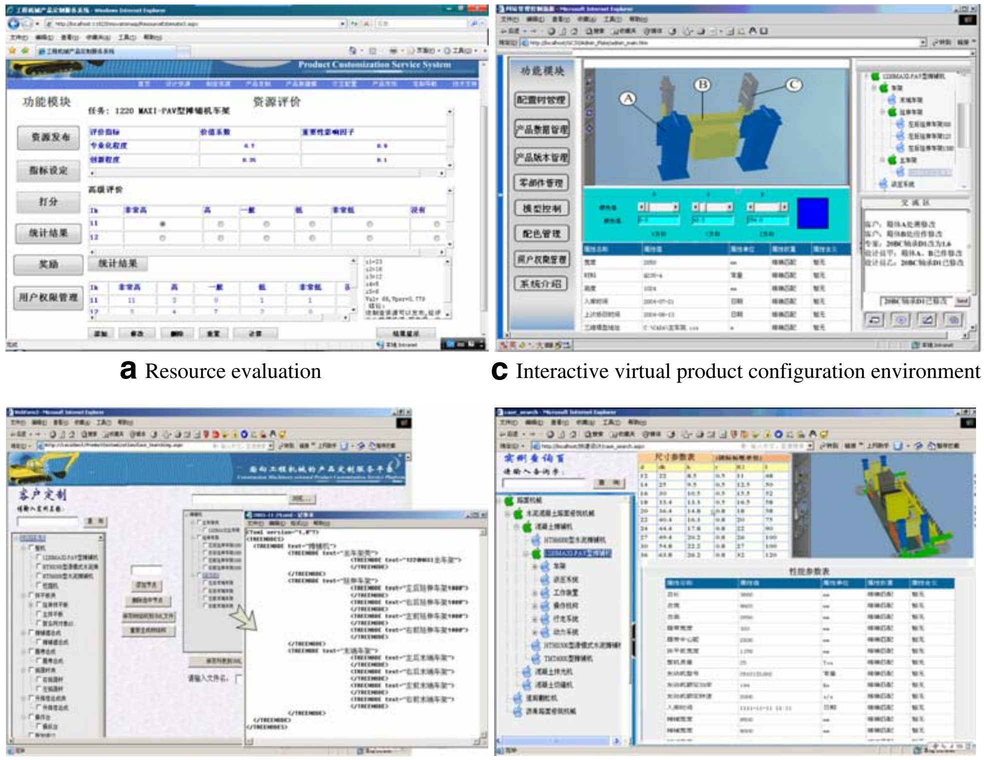

Fig. 8 Typical interfaces of construction-machinery-oriented product customization service platform (in Chinese)

a Resource evaluation **c** Interactive virtual product configuration environment

b Product customization **d** Configuration results display

show that the submitted manufacturing resource is a value-added resource.

Fig. 8(b)~(d) are typical interfaces of product customization. Fig. 8(b) provides customers rapid configuration functions of primary case search by keywords. Retrieved assembly is organized as a product structure tree and mapped into XML files for storage. Customers can reconstruct the product structure tree by adding nodes, deleting nodes, replacing a module with a configurable module or parts on a node. Fig. 8(c) is the typical interface of interactive virtual product configuration platform which offers all users functions of product models preview, collaborative configuration analysis, and collaborative configuration design. The platform includes seven main modules shown at the left of Fig. 8(c). The Configuration Structure Tree Management module takes charge of organizing and maintaining configuration product hierarchy structure tree. The Product Data Management module, the Product Version Management module, and the Parts Management module are responsible for managing and maintaining detailed information of products or parts linked on tree nodes. The 3D Model Control module bears two functions: one is to control 3D model assembly/disassembly and movement, the other is to mark the 3D model when any modification is demanded. The Match Colors Management module provides customers' auto-match the colors function of the 3D model according to customers' favorites. Customers, experts, designers, and ASPs have different authorizations respectively in operation, management, and maintenance. Their authorizations are managed by Users Authorization Management module. The interface of interactive virtual product configuration environment is divided into four display plats. The center consists of above-part and under-part. The above-part is a virtual scene of the 3D model display and the under-part lists the performance parameters of configuration product. The right is divided into the display area of product structure tree and communication area. Detailed information of the configured product, including product hierarchy structure tree, performance parameters table, dimension parameter table, and 3D model can be queried and provided to further design or manufacture (Fig. 8(d)). Product hierarchy structure trees in Fig. 8(b), (c), and (d) are created by XML template mapping. Parameter tables in Fig. 8(c) and (d) are retrieved by the combination of text similar degree algorithm and parameter gray correlative-degree algorithm, and created by object-oriented XML table mapping. ASPs are responsible for system maintenance and management.

When a client inputs keywords of required product, parts of counterparts or similarity are organized as a hierarchy tree by using text similar degree algorithm and listed at the left of Fig. 8(b). When multi-counterparts or similarity are retrieved, the client switches to parameter configuration by using combined algorithm of text similar degree and parameter gray correlative degree. Initial configuration product is organized as hierarchy tree (at the center of

Fig. 8(b)) and deposits on product knowledge resource base in XML format as a new case for future use (at the left of Fig. 8(b)). While further modification for meeting individual requirements or configuration validity analysis is required, clients (customers, designers, experts and manufacturers) can enter into interactive virtual product configuration environment (Fig. 8(c)) and carry collaborative analysis, design, and modification (color, shape, and appearance in 3D). Detailed information of configuration product, including product hierarchy organization, performance parameters table, dimension parameter table and 3D model, can be queried and provided to further design or manufacture (Fig. 8(d)). Any further modification of the configuration product can be carried on through switching to interactive virtual product configuration environment.

For example, a customer wants to customize a multi-function cement–concrete paver produced. The customer logins onto the product customization system through the portal of ASP service platform and first inputs keywords of paver, machinery, and cement concrete for primary search. Fifteen counterparts and some selections of relevant parts list at the left of Fig. 8(b). The customer is asked to continue inputting detailed parameters; then the customer inputs parameters of basic paving width 4~4.5 m, max paving width 8 m, paving thickness 360 mm, paving speed 0~6 m/min, and so on. When the customer taps the button of searching, product text similar degree algorithm and parameter gray correlative-degree algorithm model start up. Product listing is immediately updated and only the hierarchy structure of 1220MAXI-PAV remains. According to different paving width, each kind of frames of 1220MAXI-PAV has several selections. For instance, Right-front End Frame has three selections, i.e. Right-front End Frame1, Right-front End Frame2, and Right-front End Frame3. The customer can select favorite or more suitable parts to form assembly through function modules of Add Nodes, Delete Selected Nodes and reconstruct structure Tree (see at the center of Fig. 8(b)). After primary product configuration, the customer switches to interactive virtual product configuration environment to preview and carry out individualized design. If the customer expects Cabinet A and C to be coffee color, Cabinet B with chamfer angle of 30°, relevant location of 3D model in virtual scene can be labeled and modification information can be published on communication area. The customer himself can modify the color of Cabinet A and Main Frame C through the function module of Match Colors. Designers and experts execute collaborative design and validity analysis, and feed back results to the customer. If the customer put forward further individuation needs, the same process can continue till the configuration product meets with the customer's requirements completely.

The construction-machinery-oriented product customization service platform has been applied to some SMEs in construction machinery in Jiangsu Province, People's Republic of China. Feedback information shows that after using this service platform, these SMEs are able to conduct their Internet-based sales and product customization effectively in a shorter time and at a lower cost than before.

6 Conclusion and future work

In this paper, we have proposed an ASP-based product customization service system operating in lifecycle-oriented customization service mode. With the ASP mode, the product customization service system offers significant commercial and organizational benefits such as easy software maintenance and future upgrade, low cost of entry into the business for SMEs. Key technologies for supporting lifecycle-oriented product customization service effectively are deeply studied. A general resource evaluation model with reward measures for facilitating distributed resource sharing is established. XML template-driven mapping and object-oriented XML table mapping for product hierarchy structure tree reorganization are presented. Considering the uncertainty and diversification of customers' demands, a new case-based retrieving algorithm of parameter gray correlative-degree algorithm is established to speed product configuration. In order to meet customers' individual requirements and allow customers to participate in product configuration vividly, an interactive virtual product configuration platform is designed. A construction-machinery-oriented product customization service system is developed. Road-surface pavers in construction machinery are taken as a case and the above studies are verified.

In the future, we intend to constitute a set of uniform evaluation criterion through statistical analysis of history data to make resource evaluation more effective. In addition, product configuration validity analysis, system service mechanism, and data safety need further investigation.

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