Research Article

Configuration Design of Product Service System for CNC Machine Tools

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Product service system is a combination of product and services to meet the customer requirements. Configuration design is the key process of product service system development. This paper studies the configuration design of product service system for CNC machine tools. The research explores the configuration design process of product service system development, analyzes the retrieval method of product service system schemes, determines the configuration sequence of product modules and service modules by depth-first algorithm, uses fuzzy priority algorithm to produce product scheme, applies genetic algorithm to generate service scheme, and finally integrates product scheme and service scheme to obtain whole scheme of product service system. With CNC machine tools as an example, this paper verifies the feasibility and validity of proposed method.

1. Introduction

With the globalization of market economy, the world manufacturing industry is facing enormous challenges. The paradigm that manufacturers simply provide products has been unable to adapt to the increasingly fierce market competition. This situation forces manufacturing enterprises to shift from applying product design to submitting “product + service” solution. Product service system is the new paradigm to adapt to this strategic shift.

Product service system is a new kind of production system formed under the paradigm that the manufacturing enterprises are in charge of the lifecycle product and services (extended producer responsibility), which is highly integrated and globally optimized [1]. PSS is the combination of product and services to meet the customer requirements.

At present, the research on product service system mainly focuses on the macrolevel. The quantitative analysis and technology to realize the lifecycle-oriented scheme design are less to discuss. This paper presents the module division of configuration design and the realization of configuration design based on module division. At the end, this research uses CNC machine tools as an example to illustrate the integration process of configuration design of product and services and verifies the validity of proposed model and methods.

2. Literature Review

At present, the research on configuration design of product service system is less, which can be divided into two parts, namely, product service system research and configuration design research.

2.1. Product Service System Research. In the late 1990s, the United Nations Environment Programme put forward the concept of product service system [2]. So far, there are a lot of scholars studying in this field. The topics mainly include three aspects: the basic concept of product service system, the application of product service system, and the design methods of product service system.

In the aspect of concept research, Mont gave the definition of product service system, and analyzed the benefit that product service system brought to enterprise, customers, and environment. Manzini illustrated the shift from selling products to selling the integration of product and services from the essence.

In the aspect of application research, Besch studied the application of PSS in furniture industry, which made the furniture utility maximization through sharing and remanufacturing [3]. Rolls-Royce company provided PSS for airlines aircraft engine, in which the users bought several hours of
flying ability of aircraft engine to work rather than the aircraft engine [4].

In the aspect of design method research, Aurich et al. put forward the concept and frame architecture of product service system based on product lifecycle management (PSSPLM), which carried out product lifecycle system planning, design, and management in order to bring benefit to both manufacturers and customers [5]. Meier et al. proposed the architecture of industrial product service system, which was composed of three parts including design system, delivery system, and system improvement [6].

2.2. Configuration Design Research. Configuration design is one of the important means to realize scheme design of product service system, which mainly includes configuration modeling and configuration solving.

In the aspect of product configuration solving, there are a lot of methods such as method based on feature and option, method based on rule, method based on resource, method based on constraint, and method based on case. Simpson et al. proposed that configuration design was treated as dynamic constraint satisfaction problem to solve, by which the typical parameters were found out, and then product family was clustered [7]. In the respect of configuration based on knowledge, Kreuz put forward the method of relevant knowledge first (RKF) to realize product configuration [8]. Chandrasekaran proposed “proposal-evaluation-revision” method, in which the solving process included proposing configuration problem, retrieving configuration schemes with constraints and demand conditions, and modifying and eliminating configuration conflict [9].

The methods of product configuration design are gradually applied to service configuration design. Jiao discussed how design theory and methods were applied to the design of service execution system in mass customization and regarded service delivery system as product system rather than operating system. Meyer and Dalal developed new service using product family design platform and gave the definition of service platform in multinational insurance company [10]. Peters and Saidin studied the main factors of mass customization in service and used system modules to characterize the work and the process in process design of mass customization [11].

3. Configuration Design Process of PSS

For specific product, configuration design problem has multiple solutions. At present, there are three commonly used product configuration design strategies, which are rule reasoning-based strategy, model reasoning-based strategy, and instance based strategy [12]. Aimed at the specialties of product service system for CNC machine tools, single design method is difficult to solve the complex configuration design problem [13]. Therefore, this paper proposes a method to solve the configuration problem of product modules and service modules by combining instance matching solving technology, knowledge reasoning-based solving technology, and genetic algorithm-based optimization technology.

Configuration design is essentially the process of concretization and instantiation of modules and the process of knowledge reasoning. The steps are as follows:

1. determining the selectivity of modules according to the customer requirements,
2. matching and solving the attributes of product modules according to the technical characteristics and traversing the modules according to the configuration sequence, until all the attributes of modules are being instantiated,
3. carrying out the configuration design of service modules based on genetic algorithm.

According to the above analysis, the problems needed to solve during configuration design process are as follows: (1) selecting the configuration scheme which matches or is similar to the configuration needs of customers from existing design scheme library, (2) determining the configuration sequence of product modules, (3) selecting the product modules according to the parameters of technical characteristics and determining the modules according to the configuration sequence, (4) configuring the service modules based on genetic algorithm, and (5) checking the configuration scheme to get feasible solution according to configuration constraints. The configuration process is shown in Figure 1.

The configuration process is as follows.

Step 1. Judge whether the scheme in product scheme library meets the requirements. If satisfied, directly go to Step 5, or turn to Step 2.

Step 2. Determine the variable values of product modules and match the product modules.

Step 3. Traverse and instantiate various modules according to configuration sequence. If there is no similar module, the module needs to redesign. Finally the product scheme is determined.

Step 4. Determine the service scheme based on genetic algorithm.

Step 5. Analyze the scheme feasibility according to constraint rules, and then get final configuration scheme.

According to the configuration steps, the rest of paper illustrates four aspects in detail, including the scheme retrieval of product service system, the determination of product scheme, the determination of service scheme, and the overall scheme determination of product service system.

4. Scheme Retrieval of Product Service System

4.1. Similarity Solving of Instances in Scheme Library

(1) Construction of the Scheme Library. First, the scheme library is built. Then the scheme having the highest similarity with the customer requirements is selected while configuring. The scheme which meets the customer requirements can
be directly selected as the design scheme. Scheme library saves all schemes that are delivered to customers successfully. Access 2007 database is selected as a carrier for scheme library of product service system, and the information of each scheme is saved in the Access tables. The information of concrete scheme includes the technical features of products and services. And product is characterized by parameters. While service is characterized by selected or not selected, the range of technology characteristics of the schemes in scheme library should be bigger than the technical features of specific customer requirements.

(2) Similarity Calculation by Similarity Function. Technical characteristic matrix is constructed by the data in scheme library. According to ideal technical characteristic vector \( Y_{ix} \) that the customer expects, the column corresponding to it is extracted from scheme library. For the text information in vector, digital symbol is used to express. For instance, if the technical characteristic meets the customer requirements, the value is set to 1. Otherwise, the value is set to 0. For example, there are 3 kinds of NC system including FANUC system, Siemens system, and FeiYang system. If the NC system that customer needs is FANUC system, the value of FANUC system is 1. At the same time, the value of Siemens system is set to 0, and the value of FeiYang system is also set to 0. Eventually the technical characteristic vector \( Y_{fa} \) is got:

\[
Y_{fa} = \frac{Y_{xa}}{Y_{x}} Y_{sa} \leq Y_{s}, \quad Y_{fa} = \frac{Y_{fa}}{Y_{fa}} Y_{sa} \geq Y_{s},
\]

where \( Y_{fa} \) is normalized by formula (1) to obtain normalized technical characteristic vector \( Y'_{fa} = (Y'_{1fa}, \ldots, Y'_{nfa}) \).

The generalized distance between \( Y'_{fa} \) and the unit vector is

\[
d(Y'_{fa}) = \left[ \sum_{i=1}^{n} (ai |Y'_{ia} - 1|)^p \right]^{1/p},
\]

where \( p \) is Minkowski distance parameter, \( p = 1 \) means hamming distance, and \( p = 2 \) means Euclidean distance. Due to different importance of each characteristic in vector, \( X \) is used to express the weights of technical characteristics.

The similarity function for similarity calculation is

\[
\min \left\{ Q(S_i) = x_i \left[ \sum_{i=1}^{n} (ai |Y'_{ia} - 1|)^p \right]^{2/p} \right. + \left. (1 - S_i)^2 \left[ \sum_{i=1}^{n} (aiY'_{ia})^p \right]^{2/p} \right\}.
\]

The derivative of similarity function is

\[
S_i = \frac{1}{1 + \left( \sum_{i=1}^{n} (ai |Y'_{ia} - 1|)^p \right) / \sum_{i=1}^{n} (aiY'_{ia})^p}^{2/p}.
\]

The scheme library is retrieved to find the scheme which meets the customer requirements completely by MATLAB programming. If there is expected scheme, the result is directly output. If not, it is needed to calculate the similarity \( S \) of all schemes. \( S_i \) means the similarity of the \( i \)th scheme.

4.2. Determination of the Similarity Threshold. Similarity calculation is made to existed schemes, and then the similarity of each scheme is got. The threshold value is needed to determine how to operate the scheme. If the similarity of one scheme is greater than threshold value, this scheme can
be used as alternative scheme in variant design; otherwise, the method based on module combination is used to obtain reasonable scheme.

Assume that the threshold value is \( K \), the number of modules is \( n \), and the possibility of each situation is the same when estimating module cost. The cost calculation is as follows:

\[
C_{\text{Modification}} = C_{\text{Scheme}} + (1 - K) \cdot n \cdot C_{\text{MM}}, \quad (5)
\]

\[
C_{\text{MM}} = (C_{\text{Material}} + C_{\text{Process}}), \quad (6)
\]

\[
C_{\text{Combining}} = C_{\text{Module}} + C_{\text{Assemble}}, \quad (7)
\]

where \( C_{\text{Modification}} \) is instance modification cost, \( C_{\text{Combining}} \) is combination module cost, \( C_{\text{Scheme}} \) is existing scheme cost, \( C_{\text{MM}} \) is modifying module cost, \( C_{\text{Material}} \) is modifying module material cost, \( C_{\text{Process}} \) is machining process cost, \( C_{\text{Module}} \) is module cost, and \( C_{\text{Assemble}} \) is assembly costs.

There are three kinds of module estimated costs [14].

1. If the instance module and demanded module are the same, the instance cost is the module cost.
2. If the similarity of instance module is in the scope of approximate estimate, take the lowest instance module cost.
3. If the instance module needs to redesign, the cost should be estimated after redesign.

Analyzing formulas (5) and (7), it is known that only scheme modifying cost associates with threshold value \( K \), and module combination cost has nothing to do with \( K \). Draw the diagram of the cost comparison as shown in Figure 2. The value of intersection point of two lines on similarity axis is the threshold value.

Let formula (5) be equal to formula (7) to solve the threshold value \( K \):

\[
C_{\text{Scheme}} + (1 - K) \cdot n \cdot (C_{\text{Material}} + C_{\text{Process}}) = \frac{1}{3} n (C_{\text{Module1}} + C_{\text{Module2}} + C_{\text{Module3}}) + C_{\text{Assemble}}. \quad (8)
\]

After simplification, we got

\[
(1 - K) \cdot n \cdot (C_{\text{Material}} + C_{\text{Process}}) = \frac{1}{3} n (C_{\text{Material}} + C_{\text{Process}}). \quad (9)
\]

At last it is got that \( K = 2/3 \). If the similarity of scheme \( S_i > K \), the scheme \( i \) can be used as the alternative scheme. On the other hand, the module combination is needed to produce new scheme.

5. Determination of Product Scheme Based on Module Retrieval and Configuration Sequence

5.1. Module Retrieval Based on Fuzzy Priority Decision

1. Module Retrieval Process. Set the target module for retrieval as \( M_i \). The number of modules of this kind in module library is \( n \), and the set is \( M = \{M_1, M_2, \ldots, M_n\} \).

2. Ranking Decision-Making Based on Fuzzy Priority Relation. Assume that the set \( U = \{x_1, x_2, \ldots, x_n\} \) contains \( n \) alternatives, and then define fuzzy set \( A \) on \( U \). Establish fuzzy priority relation using fuzzy mathematical method for \( n \) alternatives, and then sort them. This is ranking decision-making based on fuzzy priority relation.

3. After retrieval, and the scheme satisfies the dimension constraints and assembly constraints.

4. Figure 2: Cost comparison of two methods.

The matrix \( R = (r_{ij})_{n \times n} \), which consists of \( r_{ij} \) that meets formula (10), is called fuzzy priority relation matrix. And the relationship that the matrix \( R \) determines is called fuzzy priority relation. \( r_{ij} \) is called fuzzy priority ratio. Fix threshold value \( \lambda \in [0, 1] \), and lambda-cutting matrix is

\[
R_{\lambda} = (r_{ij}^{(\lambda)})_{n \times n}, \quad (11)
\]

where

\[
r_{ij}^{(\lambda)} = \begin{cases} 
1, & r_{ij} \geq \lambda \\
0, & r_{ij} < \lambda.
\end{cases} \quad (12)
\]
6. Determination of Service Scheme Based on Genetic Algorithm

In service scheme, the characteristics of service module are different from those of product module. So configuration design of service modules becomes combinatorial optimization problem. Genetic algorithm has global search ability and is widely used in combinatorial optimization. This paper uses genetic algorithm to determine the service scheme.

(1) Chromosome Encoding of Service Module. Encoding is the first problem in using genetic algorithm and a key step of genetic algorithm. The link between the practical representation of target problem and the chromosome structure of genetic algorithm must be constructed first when using genetic algorithm to solve the problem. Common encoding methods include binary encoding, real-number encoding, orderly encoding, structured encoding, matrix encoding and quantum bit encoding, and so forth.

Different scale number coding is used in this paper: \( X = (x_1, x_2, \ldots, x_p) \). \( x_i \) means the number of sub-modules that each module contains and then randomly generates initial population.

(2) Population Initialization. After determining the chromosome code of service module, this paper uses random method to generate initial population as initial solution and sets the population size to 40.

(3) Fitness Function. In this paper, service value coefficient, service quality level, and customer relative satisfaction are used as optimization goal to establish fitness function. Configuration function \( y_{ij} \) is defined to represent whether a child module is selected, in which 1 means that the module is selected and 0 means no matching.

(i) Construction of Service Cost Matrix \( C = [c_{11}, c_{12}, c_{13}, \ldots, c_{ij}, \ldots, c_{mn}]^T \). \( c_{ij} \) is the cost to realize the function of \( j \)th submodule of \( i \)th module. \( N = [n_{11}, n_{12}, n_{13}, \ldots, n_{ij}, \ldots, n_{mn}]^T \) represents the actual cost of this module. So the objective function is as follows:

\[
\min C_s = \sum_{i=1}^{n_{12}} \sum_{j=1}^{n_{i1}} n_{ij} \cdot c_{ij},
\]

where \( C_s \) represents the total service cost.

Service cost is calculated by

\[
C = C_1 + C_2 + C_3 + C_4,
\]

where \( C_1 \) is relevant personnel costs, \( C_2 \) is information management costs, \( C_3 \) is logistics cost, and \( C_4 \) is processing cost.

For manufacturers, they can produce some products themselves and produce some services in the form of outsourcing. Considering the risk, when the self-made products have the same utility with the outsourcing products, people prefer to select the former. Therefore, the price of outsourcing product is lower than that of product. So a coefficient \( Y \) is
added before the unified price $P_s$. And the range of $Y$ is $(1/3, 1/2)$.
Therefore, the relationship is got as $(C_1 + C_2 + C_3 + C_4)(1 + r) \leq p \leq YP_s$, in which $r$ is target profit rate, $p$ is service price, and $P_s$ is unified price.

(ii) Construction of Module Quality Level Matrix $Q = \{q_{11}, q_{12}, q_{13}, \ldots, q_{1n}, \ldots, q_{m1}, q_{m2}, q_{m3}, \ldots, q_{mn}\}^T$. $q_{ij}$ is the correlation degree of service quality level of $i$th submodule of $j$th module. In order to calculate conveniently, $Q' = \{q'_{11}, q'_{12}, q'_{13}, \ldots, q'_{1n}, \ldots, q'_{m1}, q'_{m2}, q'_{m3}, \ldots, q'_{mn}\}^T$ is defined as the reciprocal of the correlation degree of service quality level. Then the objective function is given as follows:

$$\min Q = \sum_{i=1}^{m} \sum_{j=1}^{n} y_{ij} \cdot q'_{ij}.$$  \hspace{1cm} (17)

(iii) Construction of Customer Relative Satisfaction Matrix $S = \{s_{11}, s_{12}, s_{13}, \ldots, s_{ij}, \ldots, s_{mn}\}^T$. $s_{ij}$ is the customer relative satisfaction of $j$th submodule of $i$th module. In order to calculate conveniently, $S' = \{s'_{11}, s'_{12}, s'_{13}, \ldots, s'_{ij}, \ldots, s'_{mn}\}^T$ is defined as the reciprocal of the customer relative satisfaction. Then the objective function is given as follows:

$$\min S = \sum_{i=1}^{m} \sum_{j=1}^{n} y_{ij} \cdot s'_{ij}.$$  \hspace{1cm} (18)

The above objective functions need to solve the minimum value as the optimization target, which can be mapped into a single objective function. There are many mapping methods including constraint method, linear weighting method, and ideal point method. This paper uses the linear weighted method to construct the fitness function as

$$f(x) = \omega_1 \cdot \sum_{i=1}^{m} \sum_{j=1}^{n} y_{ij} \cdot c_{ij}$$

$$+ \omega_2 \cdot \sum_{i=1}^{m} \sum_{j=1}^{n} y_{ij} \cdot q'_{ij} + \omega_3 \cdot \sum_{i=1}^{m} \sum_{j=1}^{n} y_{ij} \cdot s'_{ij},$$

where $\omega_1 + \omega_2 + \omega_3 = 1$.

(4) Genetic Operations. Genetic operations include selection operation, crossover operation, and mutation operation. For selection operation, random selection operator is used to traverse samples. For crossover operation, single point crossover operator is used. For mutation operation, mutation operator is generated based on certain probability to randomly select mutant gene. This paper adopts the operation parameters of genetic algorithm as shown in Table 1.

This paper uses genetic algorithm to solve combinatorial optimization problem, namely, to solve the problem of service module configuration, in order to establish the service scheme of product service system.

7. Case Analysis

7.1. Configuration Case of Product Scheme

(1) Configuration Sequence of Product Modules. The pure physical modules and integrated service modules are numbered as shown in Table 2. Considering the assembly relationship between modules and the relevance between integrated service products, the undirected graph is obtained as shown in Figure 3, which shows the configuration sequence of pure physical modules and integrated service modules.

The configuration sequence is got by depth-first algorithm as $1 \rightarrow 3 \rightarrow 6 \rightarrow 10 \rightarrow 13 \rightarrow 15 \rightarrow 16 \rightarrow 14 \rightarrow 7 \rightarrow 4 \rightarrow 12 \rightarrow 8 \rightarrow 5 \rightarrow 2 \rightarrow 9 \rightarrow 11$.

(2) Determination of Product Scheme. According to the configuration sequence, no. 1 module is selected as the first module to retrieve until all complete matching modules or similar modules are retrieved. This step is carried out according to configuration sequence until the attributes of all modules have been instantiated. The attribute values of object module can be got by the case analysis of customer requirements as shown in Table 3.

The property parameters of lathe bed module are acquired from lathe bed module library, as shown in Table 4, in which $M_{i1}$ means the no. $i$ module of the first class module and $M_{i2}$ represents the target property of the first class module.

Take the module set $M$ as the domain, and select two modules from $n$ modules at a time in turn, and then find out all the fuzzy priority ratio $r_{ij}$. Finally the fuzzy priority relation matrix $R$ is obtained as follows:

$$R_{(i)} = \begin{bmatrix}
1 & 1 & 1 & 1 & 1 \\
0 & 1 & 0.78 & 0.79 & 0.86 & 0.87 & 0.91 \\
0 & 0.22 & 1 & 0.52 & 0.63 & 0.66 & 0.75 \\
0 & 0.21 & 0.48 & 1 & 0.62 & 0.64 & 0.74 \\
0 & 0.14 & 0.37 & 0.38 & 1 & 0.53 & 0.64 \\
0 & 0.13 & 0.34 & 0.36 & 0.47 & 1 & 0.61 \\
0 & 0.09 & 0.25 & 0.26 & 0.36 & 0.39 & 1
\end{bmatrix}. \hspace{1cm} (20)$$
Table 1: Operation parameters of GA.

| Population size | Maximum number of generations | Binary digits | Crossover rate | Mutation rate | Generation gap |
|-----------------|-------------------------------|---------------|----------------|---------------|----------------|
| 40              | 20                            | Depending on the number of modules | 0.8            | 0.01          | 0.95           |

Table 2: Pure physical modules and integrated service modules.

| No. | Module name       |
|-----|-------------------|
| 1   | Lathe bed         |
| 2   | Protection        |
| 3   | Spindle           |
| 4   | Feed              |
| 5   | Lubrication       |
| 6   | NC system         |
| 7   | Turret            |
| 8   | Tailstock         |
| 9   | Refrigeration     |
| 10  | Electric          |
| 11  | Chip removal      |
| 12  | Hydraulic         |
| 13  | Remote monitoring |
| 14  | Quality assurance |
| 15  | Remote service    |
| 16  | Detection         |

By the method described above, the attribute "X axial stroke" should be at the first order corresponding to the first module. Then delete the first row and the first column, and continue to calculate. Take different $\lambda$, and get the next order. Finally, the priority order of every quantitative attribute of lathe bed module is obtained as shown in Table 5.

According to the analysis on customer requirements, the weight of three attributes is $[0.44, 0.15, 0.41]$. Use the data in Table 5 to weighted sum, and the similarity degree of each module is got. The smaller the value is, the higher the similarity degree is. As shown in Table 6, the module $M_{11}$ is the closest module with the target module.

The selected module is M00201040124001. The $X$ axial stroke of this module can meet the customer requirements, but the $X$ axial fast-forward speed is lower than the customer requirements. It is needed to adjust the motor. The original motor for the module is Y112M-2. Y160M1-2 is used to replace it.

According to the configuration sequence, the next selection module is the main shaft module. Repeat the above process, and the product configuration scheme can be obtained.

7.2. Configuration Case of Service Scheme

(1) Module Configuration Constraints. The service modules in the module library should satisfy service constraints in order to meet the customer requirements. It is needed to build a configuration model of service modules to illustrate the configuration knowledge to make sure all different service configuration schemes can be reused and ensure the sharing ability of configuration knowledge. And some appropriate service constraints are added to illustrate the validity of the model.

According to the division result of service modules, the constraint relationship between the modules and the submodules can be described to ensure the rationality and feasibility of module combination scheme. The model for the configuration constraints of service modules is shown in Figure 4, in which $[1]$ means this module must be chosen, and $[0, 1]$ means this module is an optional module. Through the description of this model, the configuration knowledge can be obtained. The example of knowledge representation is as follows:

\[
\text{If } S_i = S_{12} \text{ or } S_i = S_{14}, \text{ then } S_{42} = 0; \\
\vdots \\
\text{If } S_{ij} \in S_i, \text{ then } \sum_{j=1}^{n} S_{ij} = 1, i, j = 1, 2, \ldots, n, \\
S_{ij} = 0 \text{ or } 1, i, j=1,2,\ldots,n.
\]

(2) Calculation Results and Analysis. According to the customer requirements, the matching condition of service modules is $[\text{sale module M1, quality assurance module M2, installation module M3, maintenance module M4, supply module M5, recovery module M6, CNC programming service M7, and training service M8}] = [1 1 1 1 1 1 1 0 0 1]$. Service value coefficient, service quality level, and customer relative satisfaction of each submodule are shown in Table 7.

Encode the module by the notation number $[4, 2, 3, 2, 3, 2]$. The weight is set to $\omega_1 = \omega_2 = 0.33$ and $\omega_3 = 0.34$. MATLAB is used to solve this question, and two kinds of schemes are eventually obtained as shown in Figure 5. It can be seen that convergence appears in the sixth generation, and the convergence speed is fast. The computational result is as follows:

\[
F_1 = [0.7310, 0.7690, 0.7670, 0.7310, 0.7010, 0.6980], \\
F_2 = [0.7310, 0.8000, 0.7670, 0.7310, 0.7010, 0.6980].
\]
Table 4: X axial attribute parameters of lathe bed module.

| Attribute | Stroke | Power of motor | Feed speed | Mount rail type | Bending strength |
|-----------|--------|----------------|------------|----------------|------------------|
| M_{11}   | 360    | 3.5            | 9.6        | Multiplex rail | Better           |
| M_{12}   | 400    | 3.7            | 16         | Multiplex rail | Good             |
| M_{13}   | 500    | 10             | 20         | Linear rail    | Good             |
| M_{14}   | 510    | 12             | 24         | Multiplex rail | Better           |
| M_{15}   | 600    | 20             | 32         | Multiplex rail | Good             |
| M_{16}   | 630    | 20             | 36         | Linear rail    | Good             |
| M_{17}   | 780    | 20             | 36         | Multiplex rail | Better           |

Table 5: Priority order of every quantitative attribute.

| X axial attribute | M_{11} | M_{12} | M_{13} | M_{14} | M_{15} | M_{16} | M_{17} |
|------------------|--------|--------|--------|--------|--------|--------|--------|
| Stroke           | 1      | 2      | 3      | 4      | 5      | 6      | 7      |
| Power of motor   | 3      | 4      | 2      | 1      | 7      | 6      | 5      |
| Feed speed       | 4      | 3      | 5      | 2      | 7      | 6      | 1      |

Table 6: Similarity degree between modules.

| Module | M_{11} | M_{12} | M_{13} | M_{14} | M_{15} | M_{16} | M_{17} |
|--------|--------|--------|--------|--------|--------|--------|--------|
| Similarity | 2.54 | 2.72 | 3.68 | 2.72 | 6.13 | 6.01 | 4.23 |

The corresponding module combination schemes are as follows: scheme 1 \([M_{14} M_{32} M_{41} M_{51} M_{62} M_{83}]\), scheme 2 \([M_{14} M_{32} M_{42} M_{51} M_{62} M_{83}]\), scheme 3 \([M_{14} M_{31} M_{42} M_{51} M_{62} M_{83}]\), and scheme 4 \([M_{14} M_{32} M_{42} M_{51} M_{62} M_{83}]\).

Check the service constraint for four schemes. It is found that scheme 2, scheme 3, and scheme 4 do not conform to rule if \(S_{42} = 1\), then \(S_{83} = 0\). So scheme 1 is the service scheme that satisfies the customer requirements.

7.3. Configuration Case of Overall Scheme. According to Sections 7.1 and 7.2, the product scheme and service scheme are obtained, the relationship between which is weak at this time. The product scheme and service scheme can be directly combined to configure several kinds of overall schemes that meet customer requirements. Check the constraints of overall schemes to guarantee the feasibility and the rationality of the schemes. For the convenience of check procedure, the configuration constraints of overall schemes are translated into character description that MATLAB can identify, which is expressed as a \(n \times 2\) matrix. And the corresponding constraints of every scheme are described in the same way. If there are \(i\) schemes, a matrix with \(n \times 2i\) elements is formed:

\[
\begin{bmatrix}
C_5 & M_5 \\
M_{103} = 1 & M_{112} = 1 \\
\vdots & \vdots \\
M_{15} = 800 & M_{36} \leq 800
\end{bmatrix}_{\text{nc2}}
\]

in which the number of lines with data 0 is \(j\) in \(n\) lines (it shows that target constraint is different from constraint rules), and the number of lines with data 1 is \(n - j\) (it shows that target constraint is the same as constraint rules). That means the scheme is reasonable. Finally the products service system scheme for CNC machine tools that meets customer requirements is obtained by this method. A specific description of the result is listed as shown in Table 8.

8. Conclusions

Product service system is a kind of overall solution to meet the customer requirements, which includes product and services. The focus of current research of product service system is shifting from basic theory to industrial application. The offering of product service system is a big challenge for configuration design system, which needs to meet higher requirements and has higher efficiency. This paper discussed the configuration design process of product service system, analyzed the scheme retrieval of product service system, determined the configuration sequence of product modules and service modules by depth-first search algorithm, and generated the product scheme by fuzzy priority algorithm and the service scheme by genetic algorithm. And on this basis, this paper integrated product scheme with service scheme and obtained the product service system as overall...
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Figure 4: Configuration constraints model between service modules.

Table 7: Related date of submodules.

|   |   |   |   |   |   |   |   |   |   |   |
|---|---|---|---|---|---|---|---|---|---|---|
|   |   |   |   |   |   |   |   |   |   |   |
|   |   |   |   |   |   |   |   |   |   |   |

Table 8: PSS Scheme of CNC machine tools.

| No. | Product module Code | Service module Code |
|-----|---------------------|---------------------|
| 1   | M00201040533001     | S1080213            |
| 2   | M0020101024007      | S1090103            |
| 3   | M00201060236004     | S1040303            |
| 4   | M0020100123002      | S1040304            |
| 5   | M00201130324001     | S0010400            |
| 6   | M00201030724003     | S0030200            |
| 7   | M0020112012001      | S0040100            |
| 8   | M00201070624002     | S0050100            |
| 9   | M00201080633005     | S0060200            |
| 10  | M00201050324001     | S0080300            |
| 11  | M0020120524002      |                     |
| 12  | M00201090314001     |                     |
Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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