OPTIMIZATION OF PRODUCT CONFIGURATION DESIGN WITH SERVICE FUSION BASED ON THE COMBINATION OF EMOTIONAL WORD ANALYSIS AND ANT COLONY ALGORITHM

Hang LIU[1]

Customization has become the core content to maximize customer value while on the other hand it also brings a challenge to enterprise companies when conducting product design. The tendency of service fusion makes the product scheme design even more complicated. Therefore, this paper proposes a flexible product configuration optimization method when considering the influence of service. After extracting useful information, the service requirements are mapping to the relevant function modules. All the selected modules will be weighted to acquire the priority. The ant colony algorithm is then applied to obtain the optimal product configuration scheme. The MATLAB software is used to simulate the result and prove it. Finally, a case study of a packing machine is conducted to prove the effectiveness of the proposed method.

Keywords: demanded service, product configuration optimization, ant colony algorithm, mapping

1. Introduction

Maximization of customer value has become the core content of enterprise competitiveness. The introduction of service opens a new way to achieve it. Starting from the late 20^{th} century, the boundaries between manufacturing system and service system are getting blurred. The manufacturers are no longer mere producers of physical products, but providers of products as well as additional services. Similarly, rather than simply buying products, customers require the overall solutions that can meet their needs and help them create the greatest value. Because of the ability of achieving higher customer demands, the service has important influence on the final determination of the scheme.

The introducing of service has impacted on the traditional design theory, especially the most important configuration design process. The configuration design, which is in the early stage of the whole design process, takes the customer demand as the basis, stipulates the main function and determines the realization plan of all functions. Combining the service into consideration in configuration

[1] School of Management Engineering, Zhengzhou University of Aeronautics, Zhengzhou, Henan, China; e-mail: liuhang@zua.edu.cn

stage is a quite new issue and often brings difficulties to engineers. Modularization is an effective way to address this problem. The significance of applying modularization theory to product service system is to use modules to encapsulate complex product and service components so as to improve the controllability of the system. Through the packaging of module internal structure and the standardization of external interface, modules can be used to serve different products and service systems to improve the universality and reuse rate of component modules. The modular product and service system consists of "semi-autonomous" modules, each of which can be independently innovated without interfering with the overall and other modules. Therefore, the modular structure not only makes the system open, but also has the ability of self-adaptation and self-organization. It is easy to form an innovation platform that can support the modification of subsequent new product design. Modular design can achieve personalization at the cost of mass production through the reorganization of product structure and design process to, and then accomplish the best balance between product variety, cost and performance [1].

Since Sabin and Weigel [1] summed up the concept of configuration in 1998, the research in this field has a sustainable growth. Gu et al. [2] designed a configuration method based on the potential functions of key services. Nimbin et al. [3] applied fuzzy multi-attribute decision theory to solve the configuration problem. Wang et al. [4] improved grey correlation method to evaluate the configuration options of complex products. Zhang et al. [5] puts forward the reconstruction technology of product configuration with the combination of grey correlation and weight order. Although many literatures have discussed the configuration theory and methods, the integration of the service elements is still rare and need to be further studied.

In product-service activity area, Aurich et al. [6] put forward a product and service integration program according to the product life cycle characteristics. Bustinza et al. [7] studied the complex relationship between external collaborative service development and industrial R&D intensity and product service innovation. Mourtzis et al. [8] studied the design and evaluation of product service system in industry 4.0 environment and proposed a method to quantify the complexity of PSS (Product Service System, PSS) customization. Li et al. [9] used the product quality segmentation method to conduct the longitudinal analysis of product and service modules. Dan et al. [10] compared the differences between products and services and tried to integrate these differences. Obviously, the current studies of product-service system mainly concentrate on the concept stage of qualitative analysis and lack effective quantitative method.

In modularization design area, Stone et al. [9] described product functions by functional elements and time series functional chains uniformly and proposed a three-stage heuristic algorithm for module recognition. Erixon [11] proposed the application of module incidence matrix to express the correlation between components quantitatively. Helmer et al. [12] proposed a comprehensive DSM clustering algorithm including data collection, clustering algorithm and post-processing to solve the problem of module division, and comprehensively summarized the DSM based module division method. Teng [13] discussed a hierarchical module division method framework for complex product systems. By establishing a multi-agent simulation model for complex product system design, Wang [14] used simulation method to study the dynamic adaptability of different modular modes of complex product system to customer demands. Fan [15] put forward to a modular analysis method based on the statistical characteristics of complex networks. Gui [16] constructed a research model of key factors identification and mechanism path analysis for modular complex product system innovation, and the results showed that key elements such as system architecture design, interface and standards, and resource arrangement should be emphasized in product innovation. In general, the research on product modularization is mainly focused on modularization division technology, product module division program evaluation and modularization innovation mechanism, but there is still a lack of effective theory and method on how to realize the integration design of products and services by modularization.

Therefore, this paper proposes a flexible complex product configuration method when considering product and service fusion in order to provide a theoretical support for manufacturing enterprises to adapt the newly developing tendency. In the proposed method, useful information will be first extracted through quantifying customer emotion words for the service requirements, the required service are then mapping to the relevant function modules. All the selected modules will be weighted to acquire the priority. The ant colony algorithm will be finally applied to obtain the optimal product configuration scheme.

2. The relationship between physical product and service

With the introduction of ICT, many computer technologies have been developed to improve the quality of product design, while downstream aspects of the product life cycle, such as services, are also considered in the product design phase. Enterprises are increasingly aware that their competitiveness lies in whether they can create greater perceived value for customers. The perceived value of a product includes physical product value and service value. Products produced by enterprises have their own service functions. The total utility of the product that can be released from the physical product and the consumer can be obtained from the service. When the overall product quality is unchanged, the relationship between physical product quality and service quality is negatively related. Decrease in physical product quality will increase the demand for services, and vice versa.

In the initial stage of product development, the tangible products are the key competition points. The physical functions of products are the direction of enterprise improvement. When the product comes to the mature stage, the physical products gradually show a high similarity, the competition of products will be achieved through the service differentiation. The internal relationship between the physical product and the product service is structured as Fig. 1.

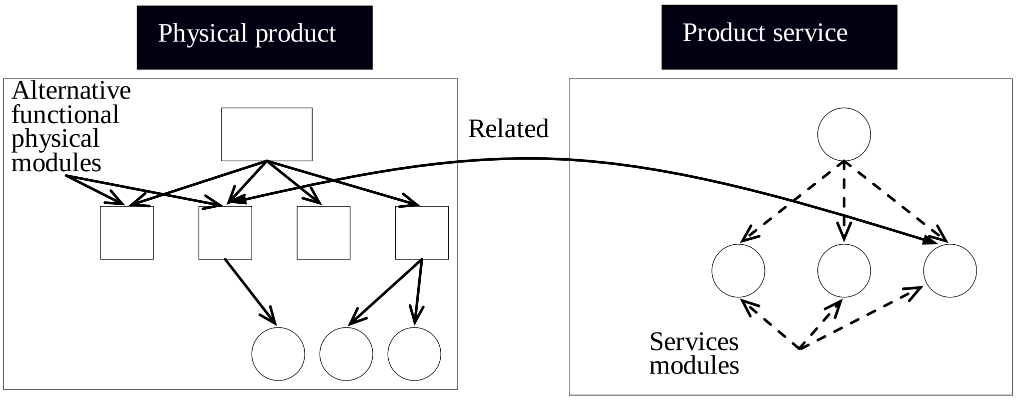

Fig. 1. The relationship between physical product and product service

Among various issues considered in product configuration design stage, serviceability plays an important role to improve competitiveness of products for manufacturers as well as for consumers from engineering perspective. With the intention of conducting certain service, the relevant physical modules need to be equipped in final product and to be considered in early design stage. For example, in order to provide users the services of sleep quality report, calorie consumption and personal exercise plan suggestions, the smart bracelet needs to equip a built-in three-dimensional rhythmic motion state sensor. For another example, the smart gloves, Tacit Project, an intelligent product to help the blind to avoid obstacles, need to configure the transceiver signal capture the obstacles ahead and the microprocessor to convert the received signal to a virtual map [17]. Therefore, designing and configuring products based on service planning to meet personalized, dynamic and rapidly iterative customer needs has become one of the key capabilities for manufacturing enterprises to improve product competitiveness.

3. Module weighting based on the mapping from demanded service to function modules

3.1 The acquisition of service requirements through customer emotion word quantification

Collecting and processing customer demand data, and then analysing customers' preferences based on those data is the crucial step for successful service identification and configuration design. Addressing customer demands accurately is the beginning issue. At present, the two main methods of customer demand analysis are market survey and online review. The market survey is the traditional and the most commonly used method of demand analysis. With the popularity of online shopping, customers can easily express their opinions and requirements for products online freely. Therefore, online comments become another important channel to obtain customer needs. However, no matter which data collecting method is chosen, end users usually do not have professional knowledge and cannot use technical language to describe the service they want. They tend to give personalized and emotional description. The information collected from the customers cannot be used directly and need to be extracted to obtain product attributes.

Attribute emotion word quantification refers to the calculation of the total polarity value of emotion of each attribute keyword after extracting product attributes, and then calculating the average value of the total polarity value [18]. Through the average value of attribute emotion word, the product attributes that users are satisfied with and unsatisfied with can be found out. If the average value is exactly equal to 0, it means that users are evenly split on the attributes. If the average value is less than 0, the user is not satisfied with the property and needs to improve it. The formulas for calculating the affective value of attributes are listed below.

Let the product attribute set be D = { D_1, D_2, D_3…… D_n }, where Di denotes the *i*th attribute of the product. D_{ij} represents the *j*th emotion polarity value of the *i*th attribute (*i* = 1, 2, 3, ..., n, *j* = 1, 2, 3, ..., m), and E+ represents a positive emotion tendency, E- represents a negative emotional tendency. The total emotional polarity calculation formula is:

$$C_i = \sum_{j=1}^{n} D_{ij} \times E_{\pm} \tag{1}$$

where {*i* = 1,2, 3................n; *j* = 1,2,3................m}

The average value is:

$$\overline{C_i} = \frac{1}{n} \sum_{j=1}^{n} D_{ij} \times E_{\pm} \tag{2}$$

3.2 The mapping between customer service requirements and product modules

Matrix analysis is the most popular method to study customer requirements to product structure mapping [19,20]. The mapping relationship between customer demanded service and product functional modules is illustrated as Fig. 2 below:

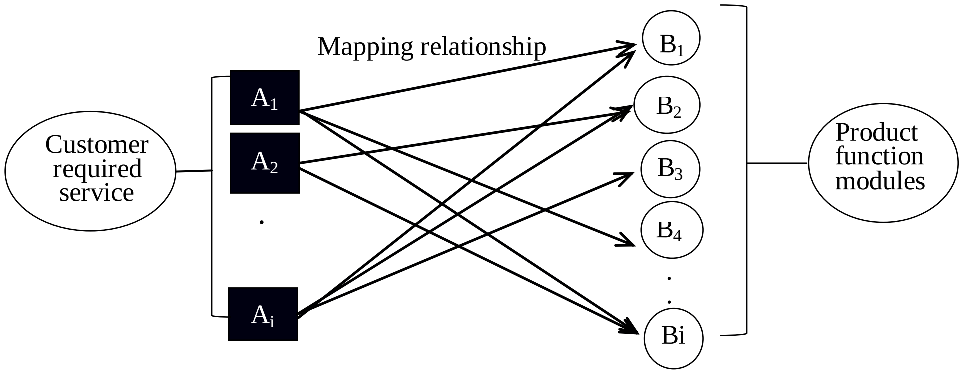

Fig. 2. The mapping relationship between demanded service and product functions

$A=\{A_1, A_2, \cdots A_i\}$ represents the customer demanded service set; $B=\{B_1, B_2, \cdots, B_i\}$ represents the product function module set; f is the mapping relationship between A and B, which is determined by customer demanded service. Through mapping model, the service requirements can be transformed into product function modules. The mapping relationship f includes two types: $1:1$ relationship and $1:n$ relationship (n is positive integer).

3.3 The weighting model of required function modules

According to the mapping relationship between customer demanded service and product function modules, the required function set Bf can then be obtained, $Bf=\{Bf_1, Bf_2, \cdots, Bf_n\}$. Comparing each of the two subsets to obtain a judgment matrix C:

$$C=\begin{pmatrix} c_{11} & c_{12} & \cdots & c_{1n} \\ c_{21} & c_{22} & \cdots & c_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ c_{n1} & c_{n2} & \cdots & c_{nn} \end{pmatrix} \tag{3}$$

The eigenvector w_i represents weighting value of the i^{th} required function module in accordance with customer demands [20]. Calculate the eigenvector $w=(w_1, w_2, \ldots w_n)$ by using Square Root Method and is expressed as equation (4) and (5):

$$\overline{w_i} = \sqrt[n]{\prod_{j=1}^{n} c_{ij}}, i = 1, 2, \cdots n, j = 1, 2, \cdots, n \tag{4}$$

$$w_i = \frac{\overline{w_i}}{\overline{w_1} + \overline{w_2} + \cdots + \overline{w_n}}, i = 1, 2, \cdots, n \tag{5}$$

w_i is the weight value of the i^{th} functional module required by customers.

4. Product configuration model based on ant colony algorithm

A product can be divided into several function modules and each function module has various parameters. This paper uses the different walking paths of one ant to one destination to simulate the function module configurations [21].

Set the target function as $\min Z$, $\min Z$ shows the minimum deviation to the goal of customer requirements, w_v is the weight, v is the number of customer requirements, d_{ij} is the absolute value of the difference between the current module and the desired module required by customer requirements.

$$\min Z = \left\{ w_1 d_{ij}^1 + w_2 d_{ij}^2 + \cdots w_v d_{ij}^v \right\} \tag{6}$$

Assuming there are m ants starting to walk at the same time, the ant k will choose the next path based on the amount of pheromones on each path during the walk. The probability function of the ant's path selection can then be set up as follows:

$$f(P_{ij}^k(t)) = w_1 P_{1ij}^k(t) + w_2 P_{2ij}^k(t) + \cdots + w_v P_{vij}^k(t) \tag{7}$$

$$P_{ij}^k(t) = \begin{cases} \dfrac{\left[\tau_{ij}(t)\right]^\alpha \cdot \left[\eta_{ij}(t)\right]^\beta}{\sum_{c \subset allowedk} [\tau_{ic}(t)]^\alpha \cdot \left[\tau_{ic}(t)\right]^\beta} & j \in allowed\, k \\ 0 & otherwise \end{cases} \tag{8}$$

In the above formula, $f(P_{ij}^k(t))$ represents the probability of the kst ant from the module node i to the module node j in the moment; $\tau_{ij}(t)$ shows the pheromone size; $\eta_{ij}(t)$ is the heuristic function, which represents the different parameters of the function module in the complex product configuration, $\eta_{ij}(t) = \frac{1}{b_{ij}}$. α is the information heuristic factor, expressing the importance of the path. β is the desired heuristic factor, which indicates the degree of desire to choose the shortest path. $c \in allowed\, k$ is the set of module nodes that the ants will walk through.

$\Delta\tau_{ij}^{k}(t)$ stands for the pheromone quantity the k[th] ant left when it walks through the path (i, j).

$$\Delta\tau_{ij}^{k}(t) = \begin{cases} G & \text{if the k}^{\text{th}}\text{ ant go through this path during time (t,t+1)} \\ 0 & \text{others} \end{cases} \quad (9)$$

G is the intension of pheromone, i.e. the relative importance of product schemes. The pheromone will be updated timely. The updating equation is:

$$\tau_{ij}(t+n) = (1-\phi)\times\tau_{ij}(t) + \Delta\tau_{ij}(t), \quad \Delta\tau_{ij}(t) = \Delta\tau_{ij}^{1}(t) + \Delta\tau_{ij}^{2}(t) + \dots + \Delta\tau_{ij}^{m}(t) \quad (10)$$

ϕ is the pheromone volatilization coefficients, $0<\phi<1$ When the product is configured, the weights of the function modules determine the position that the ant is going to arrive next. Under this circumstance, as long as the ant selects one function module node, there will be a random number within [0, 1]. The direction of the ant's movement can be predicted in accordance with this random number by using the equation below:

As the parameters in ant colony algorithm are usually obtain by experience, this paper uses the value in literature [22]: $\alpha\in[0,5]$, $\beta\in[0,5]$, $\phi\in[0.1, 0.99]$, $G\in[10,10000]$.

The Product configured procedures based on customer information extraction can then be summarized as follows:

Step1: Quantify the customer requirements by using equation (1)-(2) and finish the mapping from customer service requirement to product modules;

Step2: Set m ants based on assigned product function modules to start computation;

Step3: Using equation (3)-(5), determining the objective function in accordance with the weight of customer requirement modules;

Step4: Assign the m ants into n module nodes. Calculate the probability by using equation (6)-(8), recording the optimal path for the walk.

Step5: Update the pheromone by using equation (9)-(10). Repeat the process until the maximum iteration is reached.

Step6: Calculating the final results. The optimal product configuration is determined according to the optimal ant path.

5. Case study

This paper takes the packing machine of Changyu Packing Ltd as the example to prove the effectiveness of the proposed method. By using the consumer review information, the customer demanded services can be obtained. As aforementioned, by mapping the demanded services into relevant function modules, the weighting of all modules in terms of customer satisfaction can then calculated after determining the proportion of those function modules. Finally, the MATLAB programming is used to simulate the optimal packing machine.

5.1 The weighting of required functional modules

In this case, a total of 1658 pieces of customer desired service information have been obtained through customer interview, online review information and customer service feedback information. After eliminating worthless and duplicate messages, 308 pieces of useful information are finally selected. Synthesizes the mapping from customer required service to product functional modules, three functional modules are finally selected to be customized to achieve customer satisfaction: the maximum lumen dimension, packing efficiency and gas consumption. The current parameter options are illustrated in Fig. 3.

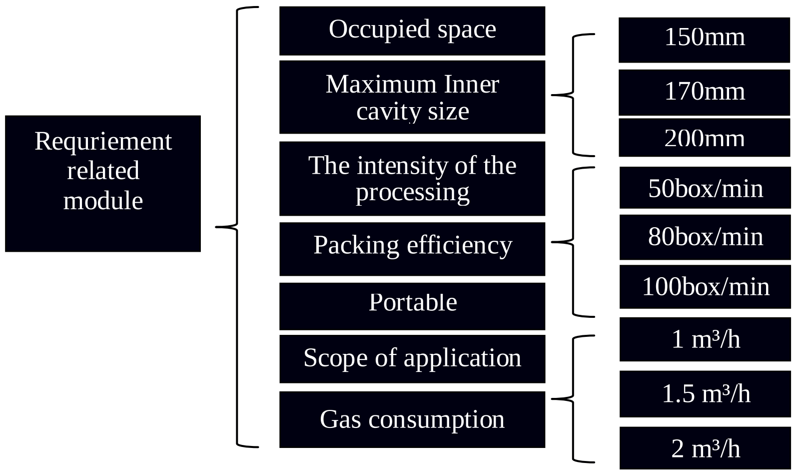

Fig. 3. Current parameter options of Chanyue Packing machine

Suppose the desired configuration option of one customer is:

$$\{\text{maximum Inner cavity size170mm, Packing efficiency 70 cases/minute, gas consumption } 1.3\text{m}^3/\text{h}\}$$

As the current parameters of product modules cannot meet the customer requirement directly, an evaluation process need to be proceeded for obtaining the optimal configuration result to achieve the maximum customer satisfaction. Set B = (size, efficiency, consumption), the judgment matrix A is:

$$A = \begin{bmatrix} 1 & 2 & 3 \\ 1/2 & 1 & 2 \\ 1/3 & 1/2 & 1 \end{bmatrix}$$

By using equation (4)-(6), the weight set of customer required function can be calculated as $W = (0.54, 0.30, 0.16)$.

5.2 Optimization of product configuration based on ant colony algorithm

According to customer requirements, set the target function as $\min Z = \{0.54b_1 + 0.30b_2 + 0.16b_3\}$, b_1, b_2, b_3 represents the absolute value of difference between the ant selected module and the desire module respectively. Let the maximum number of the iterations $N_{c\max} = 120$, $m = 50$, $\tau_{ij}(t) = 1$, $\eta_{ij}(t) = 0.5$, $p = 0.1$, the intension of pheromone $G = Q = 10$.

Using the equation (7)-(11) and conducting a MATLAB programming based on the ant colony algorithm, all possible configuration results are shown in Table 1 and the simulation result is shown in Fig. 4.

Table 1

All possible configuration results

1	150	50	1	17.152
2	150	50	1.5	17.232
3	150	50	2	17.312
4	150	80	1	14.152
5	150	80	1.5	14.232
6	150	80	2	14.312
7	150	100	1	20.152
8	150	100	1.5	20.232
9	150	100	2	20.312
10	180	50	1	11.552
11	180	50	1.5	11.632
12	180	50	2	11.712
13	180	80	1	8.552
14	180	80	1.5	8.632
15	180	80	2	8.712
16	180	100	1	14.552
17	180	100	1.5	14.632
18	180	100	2	14.712
19	180	50	1	11.552
20	200	50	1.5	22.832
21	200	50	2	22.912
22	200	80	1	19.752
23	200	80	1.5	19.832
24	200	80	2	19.912
25	200	100	1	25.752
26	200	100	1.5	25.832
27	200	100	2	25.912

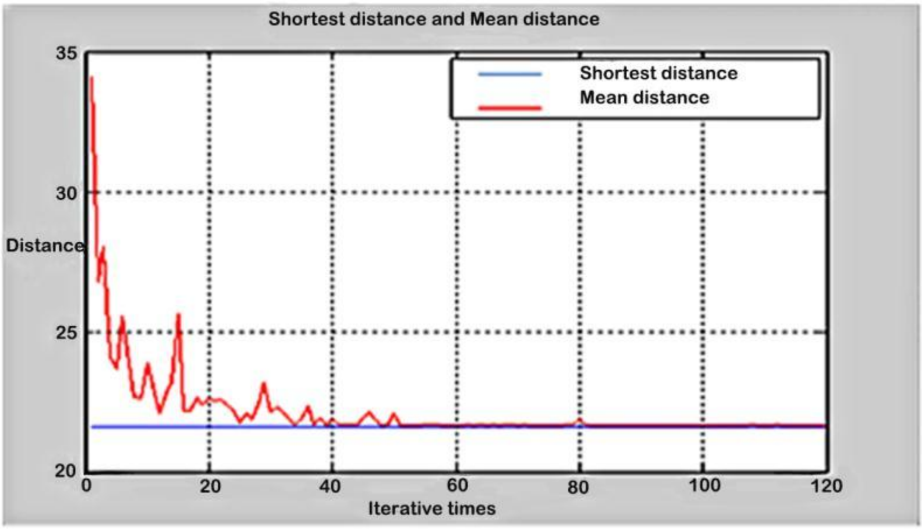

Fig. 4. Simulation result

Based on the result shown in Table 1, the minimum deviation value is 8.552, and the corresponding parameter value is (180, 80, 1). According to the evolution curve of ant colony algorithm shown in Fig. 4, the average distance curve tends to be stable when the iteration time is about 55 times, which indicating that the ant colony has found the optimal path.

From above results, it is clear that the optimal configuration option is:

$\{\text{maximum Inner cavity size180mm, Packing efficiency 80 cases/minute, gas consumption } 1\text{m}^3/\text{h}\}$

The company can then confirm the product configuration scheme to meet the maximize customer satisfaction.

6. Conclusion

This paper proposed an approach that combines attribute emotion word quantization and ant colony algorithm to solve the complex product configuration. The ideas as follows: calculating the polarity value of each attribute keyword emotion to find out the product attributes that the customer is not satisfied with and then to be optimized; dividing the product to be optimized into multiple function module with different parameters. The process of selecting the configuration of function modules is simulated as the process of ants choosing the path to the destination. The calculation process of ant colony algorithm can be expressed here as: determine the parameters of different module nodes according to different consumer needs. Those parameters can be explained as the different lengths of road sections that the ants walk in, resulting in different pheromones left on different sections. The colony can determine the next road section to walk until the end, thus realizing the configuration of complex products. From the simulation results of above case study, the optimal ordering of the configuration schemes is achieved. The company can obtain the optimal product configuration scheme to meet the maximize customer satisfaction. If the product module library of the company has no such ‘desired’ modules, the company can then have the configuration of the product that is closest to consumer demand based on the configuration scheme from the optimal order. It is clear that this method can satisfy the demand of the consumer as much as possible. The simulation results of the case demonstrate also confirms the effectiveness of proposed method that uses the combination of emotion word quantization and ant colony algorithm to solve the configuration of complex products.

Despite the progress, some issues still need to be addressed to further improve the developed approach. In this paper, customer requirement data are obtained from online review. Although comparing with market survey, online review is more objective and trusted as people are willing to express their opinions online freely, subjective and fuzzy information cannot be avoided completely. With the popularity of Internet of Thing, acquiring accurate and absolute objective customer requirements from the product processing data collected through embedded sensors directly rather than customers’ personal expression become possible. More efficient and effective simulation methods then need to be developed.

Acknowledgement

This paper is supported by the following Foundation items:
1. Key Scientific and Technological Project of Henan Province (202102310311, 182102210442);
2. 2019 Higher Institution Youth Scholar Supporting Program of Henan Province (2019GGJS179);
3. 2020 Key Scientific Research Projects of Henan Higher Institutions (20A630035).

R E F E R E N C E S

[1]. *D. Sabin, R. Weigel,* Product configuration frameworks-a survey, IEEE Intelligent Systems, Vol. 13, No. 4, 1998, pp. 42-49.

[2]. *J. Gu, Z. Yang, W. Zhu,* Research of product configuration design, China Mechanical Engineering, Vol. 14, No. 16, 2003, pp. 1394-1396.

[3]. *R. Bin, S. Zhang, G. Yin,* Complex product configuration method based on fuzzy multi-attribute decision, Journal of Mechanical Engineering, Vol. 46, No. 19, 2010, pp. 108-116.

[4]. *Y. Wang, X. Li, D. Liu, B. Wang,* Research on intelligent configuration system of complex products based on knowledge engineering, Modular Machine Tool & Automatic Manufacturing Technique, No. 2, 2014, pp. 156-157.

[5]. *L. Zhang, S. Zhang, X. Liu,* Reconstruction of complex product configuration scheme based on grey correlation and weight sequence, Computer Integrated Manufacturing System, Vol. 21, No. 10, 2015, pp. 2565-2575.

[6]. *J. C. Aurch, C. Fuchs,* C. Wagenknecht, Life cycle-oriented design of technical product service system, Journal of Cleaner Production, Vol. 14, No. 17, 2006, pp. 1480-1494.

[7]. *O. F. Bustinza, E. Gomes, F. Vendrell-Herrero, T. Baines,* Product-service innovation and performance: the role of collaborative partnerships and R&D intensity, R&D Management, Apr. 2017.

[8]. *D. Mourtzis, S. Fotia, N. Boli, P. Pittaro,* Product-service system (PSS) complexity metrics within mass customization and Industry 4.0 environment, International Journal of Advanced Manufacturing Technology, Vol. 97, No. 2, Mar. 2018, pp. 91-103

[9]. *H. Li, Y. J. Ji, X. J. Gu, G. Qi, R. Tang,* Module partition process model and method of integrated service product, Computers in Industry, Vol. 63, No. 4, Feb. 2012, pp. 298-308.

[10]. *B. Dan, M. Liu, B. Shao,* "Internet +" product service integration business model of fresh produce supply chain, Journal of Business Economics, No. 9, 2017, pp. 5-14.

[11]. *R. B. Stone, K. L. Wood, R. H. Crawford,* A heuristic method for identifying modules for product architectures, Design studies, Vol. 21, No. 1, 2000, pp. 5-31.

[12]. *G. Erixon, A. von Yxkull, A. Arnstroem,* Modularity-the basis for product and factory reengineering, CIRP Annals-Manufacturing Technology, Vol. 45, No. 1, 1996, pp. 1-6.

[13]. *R. Helmer, A. Yassine, C. Meier,* Systematic module and interface definition using component design structure matrix, Journal of Engineering Design, Vol. 21, No. 6, 2010, pp. 647-675.

[14]. *X. Teng,* Study on module division method of complex product system, Harbin Engineering University, 2011.

[15]. *W. Wang, W. Kong, J. Chen,* Research on the adaptability of modular model of complex product design system to customer dynamic demand, Journal of Management, Vol. 3, No. 4, 2006, pp. 395-399.

[16]. *B. Fan, G. Qi,* Product family structure modeling and module analysis method based on complex network, Journal of Mechanical Engineering, Vol. 43, No. 3, 2007, pp. 187-198.

[17]. X. *Zhang*, H. Tang, A preliminary study on personalized service design of "intelligent products" in the era of big data, The Chinese Newspaper, No. 14, 2016, pp. 10-11.

[18]. H. *Liu,* Optimization of module granularity based on online review-in case of vacuum packaging machine, Paper Asia, No.4,2018,pp.125-128.

[19]. *B. Gui,* Research on innovation factors and action path of complex product system based on modularization, Zhenjiang University, 2006.

[20]. *L. Su,* Research on optimization of the configuration of product service system under mass customization, Shanghai Jiaotong University, 2010.

[21]. *H. Duan*, Theory and application of ant colony algorithm, Science Publication, 2015.

[22]. *H. Li*, Research on the key technology of generalized product module division and integration, Zhejiang University, 2013.