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Research Article

Evaluation of Emerging Product Design Scheme Based on Multicriteria Decision-Making

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With the development of China's economy and the affluence of people's material life, there are more and more kinds of products around us. People have more and more kinds of products to choose from in similar needs, so the competition between similar products is becoming more and more fierce. In order to better win the competition, the current emerging products not only cover the basic functions of the same kind at the beginning of design, but also include many additional functions that can help the product position among consumers. The focus of product design has gradually changed from functional needs to emotional needs, so the product design method based on emotional needs has gradually attracted more and more attention. However, the traditional product design methods have some limitations in data research, product design scheme visualization and decision-making, and lack of theoretical support and data support. Aiming at the background of this problem, this paper studies and evaluates the design scheme of emerging products based on multi-criteria decision-making technology and big data analysis.

1. Introduction

The development of science and technology will have an impact on the industry. With the scheme implemented by the traditional product design method no longer applicable to people's demand for products at this stage, the traditional product design method is bound to be phased out. In order to meet people's emotional needs for products, it is bound to be explored in product design. Therefore, how to obtain the data that can be analyzed and used from the expected needs of consumers, and on this basis, carry out data mining, obtain the product design that consumers really like, and make accurate scheme decision is what should be considered in the current new product design scheme [1]. In the first ten-year manufacturing strategy plan of action made in China made 2025, it was clearly stated that we should encourage the deep excavation of modern computer technology in big data, Internet plus, and so on in product design, so as to design an innovative product design program [2]. The reason why the country takes innovation as the core of product design is determined by China's comprehensive national conditions. A country's comprehensive national strength and international competitiveness largely depend on the development level of the country's manufacturing industry, because the level of the country's manufacturing industry also directly reflects the country's basic productivity. Manufacturing industry belongs to the secondary industry in China's industrial structure. Compared with the agricultural structure of the primary industry, the manufacturing industry as the secondary industry gets rid of the restrictions of natural conditions, avoids the impact of the downturn of the primary industry caused by natural disasters such as natural disasters, and plays a great supporting role in the country's economic structure. At the same time, as the second industry, the manufacturing industry also avoided the foam economy phenomenon as the third industry. The tertiary industry refers to all walks of life except the primary industry and the secondary industry, such as transportation and cultural tourism. Compared with these industries, manufacturing, as an industry supported by

physical industries, has a more stable structure and greater resistance. Under the influence of COVID-19, transportation industry and culture and tourism industry have been hit hard by the third industry. While the manufacturing industry as a physical industry has suffered a certain impact, it remains relatively stable in the case of constant market demand. Therefore, although the tertiary industry is the leading industry of national economic growth, the measurement of a country's comprehensive strength depends more on the manufacturing industry as the secondary industry [3].

The development of China's manufacturing industry is closely dependent on product design. Product design is a key step for China to get rid of the label of "made in China" and successfully move toward "created in China." For today's consumers, the physical product is the concrete embodiment of their consumption demand, and product design is the emotional sustenance of consumers. For an enterprise, the physical product is the material basis for its survival and development, but the design behind the product is its own corporate positioning and brand culture that determines whether the enterprise can develop for a long time [4]. With the proposal of the concept of product design, product designers have gradually changed from the design concepts of "form follows function," "function first," and "product and technology as the center" to the design concepts of "form follows emotion," "people-oriented," and "user-centered." The design method has also changed from the traditional design experience relying on designers to the intelligent design and automatic design relying on advanced computer technology. At the same time, in the process of product design, we no longer focus on the scope of the industry where the product is located, but spread to various fields for multi-domain cross-design [5].

To sum up, at present, the difficulty of product design scheme in China is that consumers' demand for product design has become more and more diversified and personalized due to the transformation from materialization to spiritualization of product demand, which greatly increases the difficulty of enterprises in designing products [6].

Aiming at the background of this problem, this paper studies and evaluates the design scheme of emerging products based on multi-criteria decision-making technology and big data analysis. The research structure is divided into five parts. The first part expounds the background of economic development and product selection of people's material life. The second part expounds the relevant research contributions of big data product design. The third part expounds the research methods and analyzes the optimized multi-criteria decision-making method. The fourth part analyzes the evaluation algorithm of emerging product design scheme based on multi-criteria decision-making and realizes the automation of product design scheme evaluation process. Finally, the full text is summarized. Research effectively improves product innovation ability and reduces product R & D cost and D cycle and cost. At the same time, it improves the competitiveness of products and users.

2. Related Work

Before the rise of the method of product design through big data, traditional product design was divided into two categories according to a different focus of objects concerned in the design process. One is the user-centered design method, which has sprung up in recent years. The user-centered product design focuses on the psychological feelings of users when using the product, so that users can place their spirit on the product and endow the product with the function of meeting users' emotion and spirit. The other focuses on the design method of product function concept. The design concept of this method is how to enrich the functions of products and better meet the use needs of users [7]. With the transformation of people's demand for emerging products from material demand to spiritual demand in recent two years, the concept of user-centered has become more and more popular, and its corresponding research methods have attracted more and more attention [8]. In the 1970s, Japanese scholar Yoji Akao first proposed the earliest user-centered research method—QFD method. This method divides the product functions according to the design requirements and the process requirements pursued by users, and pays careful attention to the characteristics of each part required by the product, so as to maximize the multi-level design from the perspective of users [9]. On this basis, Vinodh and other scholars have guided and designed the house of quality products of smartphones; on this basis, Yan et al. conducted relevant research on product improvement suggestions through competitive analysis. Chinese scholars Yang Qiang and others put forward the research on the consistency of decision-makers in view of the fuzziness and uncertainty of user demand information in the process of product design; based on the bionic theory, Chen Liang et al. obtained the abstract solution of contradictory characteristics from the abstract matching of the characteristics of biological clock in nature [10]. In addition, the commonly used user-centered product design methods include axiomatic design, perceptual engineering, emotional design, and Kano model. Due to the limitation of the length of the article, there is no more detail here.

After entering the era of big data, the amount of all kinds of data on the Internet has increased exponentially. Alvin Toffler, a famous American futurist, first proposed the concept of "big data era.". Later, Gartner institutions first found the massive, high growth rate and diversified information assets hidden behind big data. However, due to technical constraints in the early stage, it is temporarily impossible to effectively analyze the explosive growth of data. With the development of artificial intelligence technologies such as machine learning and deep learning, how to mine and analyze from big data has become the focus and hotspot of artificial intelligence technology research [11]. Chinese scholars Ren Yingli and fan Qiang first analyzed the possibility of product-related big data serving product design and put forward the process and limitations of using big data for product design research. So far, the data types commonly used in emerging product design are divided into structured data, semi-structured data, and unstructured data

[12]. Structured data refer to the collected survey related data, which is a kind of information with strong regularity and rigorous storage format. Chinese scholar flute and others obtained the user information from the customer relationship management system, analyzed the user requirements quantitatively based on the QFD model, and finally realized the mapping of mining user requirements from big data information and feeding back product design [13]. Li et al. explored and proposed a classification model between the perceptual words concerned by users in the use process and the product design elements concerned by designers in the design process based on the collected big data information in the form of questionnaire and machine learning algorithms such as vector regression, ridge regression, and classification number regression [14]. Semi-structured data are a kind of data between structured data and unstructured data. The distinguishing feature is mainly in the strictness of structure. The strictness of semi-structured data is between structured data and unstructured data. In daily data analysis, we usually classify semi-structured data as structured data. However, in the overall big data analysis, the probability that the analysis object is unstructured data is more, accounting for about 95% of the overall big data analysis. Therefore, the research on product design related to unstructured data has also attracted the attention of the majority of researchers. Stone and Choi analyzed the smartphone attributes preferred by users through more than 7000 keyword data related to smartphones on Twitter platform and using text mining technology and natural language processing technology [15]. In recent years, there are more and more Internet platforms. Users can express their views on product design on various platforms. The unstructured data have also become one of the important data sources for the study of product design schemes.

3. Method

Multi-criteria decision-making refers to the selection decision when there are multiple alternatives, and each alternative conflicts with each other and cannot exist at the same time. Multi-criteria decision theory is also one of the important contents of analytical decision theory. In the market, when enterprises make actual scheme decisions for a new product, they often collect multiple design schemes from the design side for final selection. These design schemes conflict with each other and cannot coexist. When enterprises choose a design scheme for mass production, it means that other design schemes are abandoned. The whole period is a process of screening and selection. Usually, we will regard this screening process as a sort. The product design scheme finally adopted will rank first, and other schemes will continue to rank down according to the alternative order. In the traditional product design methods, TOPSIS and extended decision-making method are usually used to make the decision of product design scheme, but this method does not pay enough attention to the investigation of users' personalized preferences, and some ignore the opinions of product users. Therefore, on this basis, this paper combines the online review data-driven perceptual engineering method (tf-epa) and analytic hierarchy process to construct the perceptual evaluation system of product users, and puts forward a new multi-criteria decision-making method for emerging product design scheme which can meet the personalized preferences of product users. Through the follow-up experimental verification, we prove that the evaluation result of the product design scheme made by the method proposed in this paper is the highest user satisfaction compared with the traditional multi-criteria decision algorithm. The problem of overfitting of decision tree is solved. The decision tree is easy to ignore the correlation of attributes in the data set. It unifies the data with inconsistent sample numbers in various categories. When dividing attributes in the decision tree, different judgment criteria will lead to different attribute selection tendencies. The specific method of this paper is shown in Figure 1.

In the traditional ranking technology method of approaching the ideal solution, when facing the selection of multiple product design schemes, the "attribute value" brought behind the product design is usually selected as the "criterion" for decision-making. For example, when measuring the design scheme of a power station, the influence of each design scheme on the power generation will be ranked. With the change of the power generation, the criterion used to measure the ranking order will change. However, when this method is applied to the user-centered product design, we find that there is no good or bad difference in the user's personalized needs, only whether they are satisfied and the degree of satisfaction. Therefore, the traditional approximate ideal solution ranking technology cannot be directly extended to the current user-centered product design. Due to the great uncertainty of users' personalized needs and sensibility, in modern new product design schemes, we usually measure users' uncertainty sensibility as the criterion in multi-criteria decision-making. As a whole, GRA-TOPSIS method and perceptual engineering are used to evaluate and rank the design schemes of emerging products. Here, we first construct a perceptual decision matrix H as the weight parameter in multi-criteria decision-making. The specific expression is shown in

$$H = \{h_{ij}\} = \begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1n} \\ h_{21} & h_{22} & \cdots & h_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ h_{m1} & h_{m2} & \cdots & h_{mm} \end{bmatrix}, \quad i = 1, 2, \cdots m, \; j = 1, 2, \cdots, n. \tag{1}$$

The matrix H determines the importance of each criterion in multi-criteria decision-making in emerging product design scheme evaluation. Generally speaking, the larger the value, the greater the evaluation of the criterion for the product design scheme. From this, we can obtain the weight value of each parameter, as shown in Figure 2.

From Figure 2, we can see that there is a large difference in entropy between different parameter values, and the greater the entropy, the smaller the parameter weight and vice versa, because the larger the entropy value, the higher

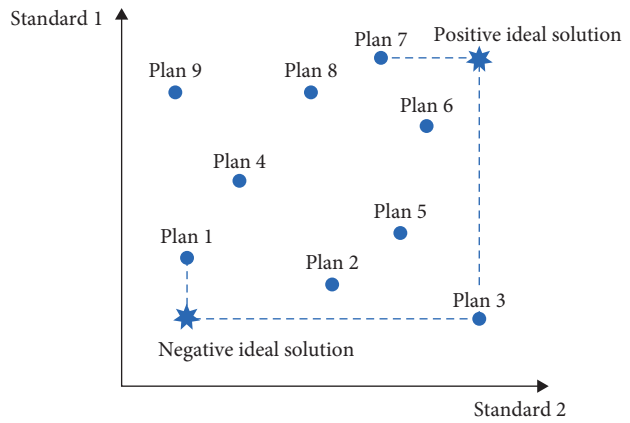

Figure 1: The basic idea of multi-criteria decision-making method after optimization.

the degree of confusion of the parameter, and the greater the regularity and consistency, the lower the weight and responsibility in the ranking of emerging product design schemes in multi-criteria decision-making. At the same time, considering that multi-criteria decision-making needs to consider the uncertainty of user-personalized experience in the process of product design, we set the positive ideal solution and negative ideal solution of user preference in the matrix. See formulas (2) and (3) for specific expressions.

$$B = \{b_{ij}\} = \begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1n} \\ b_{21} & b_{22} & \cdots & b_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ b_{m1} & b_{m2} & \cdots & b_{mm} \end{bmatrix}, \quad i = 1, 2, \cdots m, \; j = 1, 2, \cdots, n, \tag{2}$$

$$b_{ij} = N - \left| U_j - h_{ij} \right|, \quad i = 1, 2, \cdots m, \; j = 1, 2, \cdots, n. \tag{3}$$

The positive ideal solution of user preference is obtained by matrix B in formula (2), which represents the value farthest from user preference; formula (3) represents the value closest to the user preference in the negative ideal solution representing the user preference.

Through the above formula, we can determine the weight of objective parameters, but the emerging product design scheme of multi-criteria decision-making contains not only objective criteria, but also subjective criteria in the process of product use. Therefore, next, we need to calculate the weight of subjective parameters. Here, we use analytic hierarchy process to obtain the weight of subjective parameters. Analytic hierarchy process is a decision-making method combining qualitative and quantitative. The specific expression is shown in

$$O = \{o_{ij}\} = \begin{bmatrix} o_{11} & o_{12} & \cdots & o_{1j} \\ o_{21} & o_{22} & \cdots & o_{2j} \\ \vdots & \vdots & \ddots & \vdots \\ o_{i1} & o_{i2} & \cdots & o_{ij} \end{bmatrix}, \quad i, j = 1, 2, \cdots, n. \tag{4}$$

Through formula (4), we construct the subjective parameter index judgment matrix, but in the overall process of analytic hierarchy process, the construction of the competent parameter index judgment matrix is only the operation process of the first layer. In the calculation process of the next several layers, each layer needs to compare the value of the upper layer with the numerical index of the layer and make a decision. We call it the judgment matrix. See formulas (5) and (6) for the specific judgment process.

$$w_i = \frac{\prod_{j=1}^{n} \sqrt[n]{o_{ij}}}{\sum_{i=1}^{n} \prod_{j=1}^{n} \sqrt[n]{o_{ij}}}, \quad i, j = 1, 2, \ldots, n, \tag{5}$$

$$\lambda_{\max} = \sum_{i=1}^{n} \frac{(Ow)_i}{n w_i}, \quad i, j = 1, 2, \ldots, n. \tag{6}$$

Formulas (5) and (6), respectively, obtain the eigenvector and maximum eigenvalue in the subjective function index judgment matrix. This is because each subjective parameter may have a different emphasis on product indicators. Two different cup designs, the former may focus on the appearance of the cup, while the other may focus on the dexterity of the cup. In this case, the obtained subjective function index values need to be normalized to make them comparable. The maximum eigenvalue obtained by formula (6) is to solve the weight vector by the square root method. Finally, we test the index values of subjective decision-making parameters in multi-criteria decision-making, and the results are shown in Figure 3.

Through Figure 3, we can see the corresponding subjective decision-making parameter index values of different samples and the comparison before and after normalization. It is obvious that the index of each sample after normalization is higher than that before normalization. This also lays a data foundation for our subsequent decision-making of emerging product design scheme in multi-criteria decision-making algorithm through subjective parameters.

After determining the index calculation method of subjective decision parameters and objective decision parameters, we need to determine the comprehensive weight of the final emerging product design scheme. Customer demand plays an important role in the evaluation and decision-making of product conceptual design scheme. Customers' cognition of the overall attributes of products is a process of gradual perception. Therefore, customer demand should have the characteristics of gradual evolution with time; that is, it is dynamic, and the dynamic is based on the time event model, taking full account of the dynamic characteristics of customer demand. Therefore, it is necessary to predict the customer demand after obtaining the customer demand. On this basis, analytic hierarchy process (AHP) is used to determine the importance of customer demand, that is, the weight. The judgment matrix is analyzed and modified to improve the efficiency of weight determination and obtain more objective weight. This is because there is more or less subjective or objective irrational influence whether the emerging product scheme decision is made according to the subjective decision-making

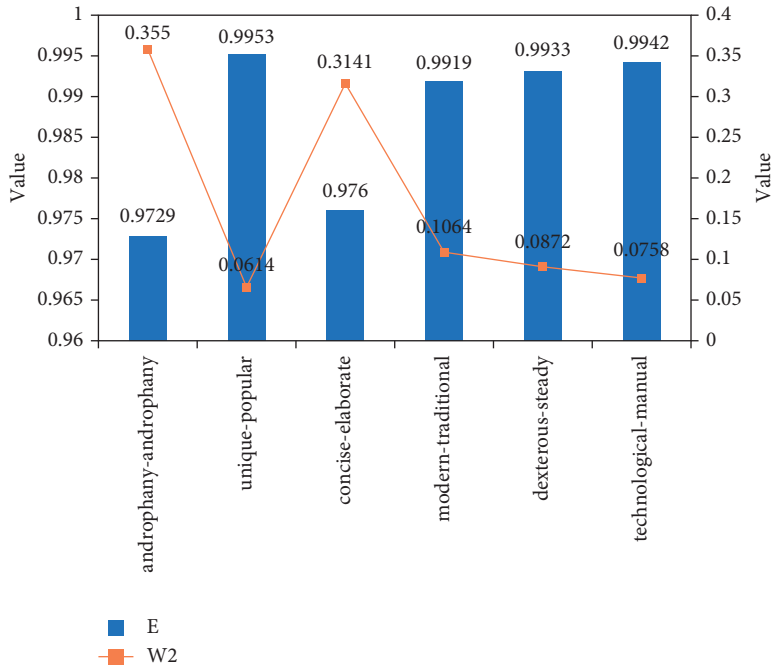

Figure 2: different parameter entropy value and objective weight value.

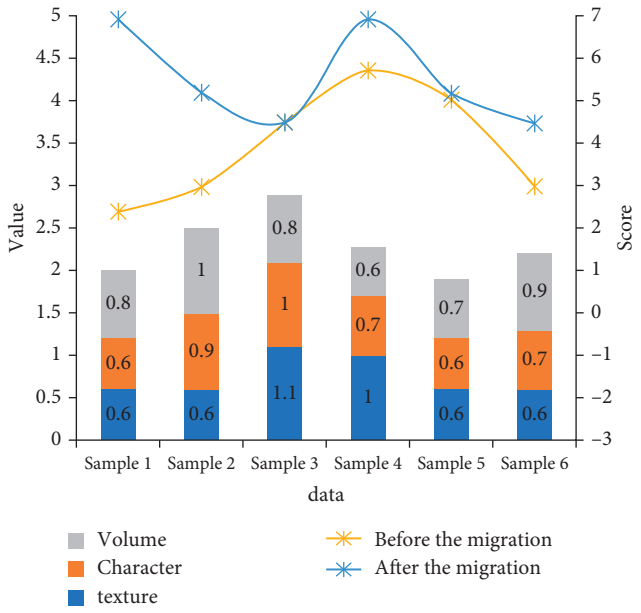

Figure 3: Different parameter entropy value and subjective weight value.

parameters or the objective decision-making parameters. If the decision is too objective, the final product design will ignore the personalized needs of product users, while if the decision is too subjective, the internal relationship between various indicators will be ignored. Therefore, to sum up, in the final parameter decision, we choose to combine the subjective parameter weight and objective parameter weight according to some law, which is called comprehensive parameter weight. The weight value of comprehensive parameters is shown in

$$W = \sum_{k=1}^{l} \alpha_k w_k^T \left(\alpha_k > 0\right). \tag{7}$$

In order to obtain the optimal equilibrium weight vector, the comprehensive weight value of minimizing the deviation is usually taken. The specific expression is shown in

$$\min \left\| \sum_{k=1}^{L} \alpha_k w_k^T - \omega_i \right\|_2, \quad i = 1, 2, \ldots, L. \tag{8}$$

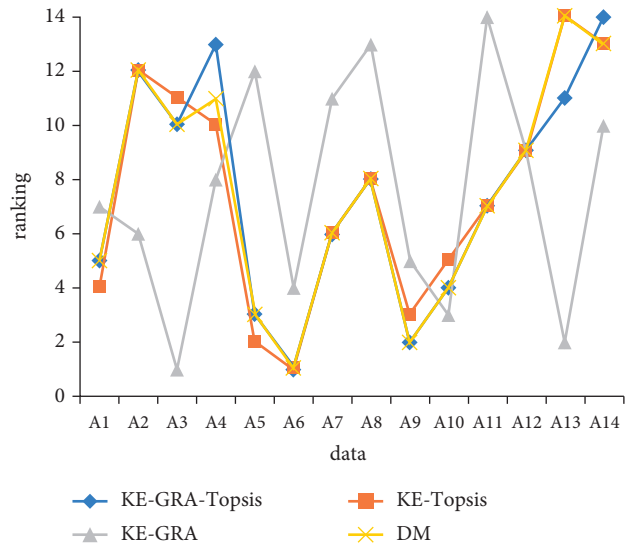

Figure 4: The decision result of emerging product design scheme based on multi-criteria decision.

Formula (9) can be obtained by calculating the deviation minimization value:

$$\sum_{k=1}^{L} \alpha_k w_k^T = w_i w_i^T, \quad i = 1, 2, \ldots, L. \tag{9}$$

The equations corresponding to the above formula are shown in

$$\begin{bmatrix} w_1 w_1^T & w_1 w_2^T & \cdots & w_1 w_L^T \\ w_2 w_1^T & w_2 w_2^T & \cdots & w_2 w_L^T \\ \vdots & \vdots & \ddots & \vdots \\ w_L w_1^T & w_L w_2^T & \cdots & w_L w_L^T \end{bmatrix} \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \vdots \\ \alpha_L \end{bmatrix} = \begin{bmatrix} w_1 w_1^T \\ w_2 w_2^T \\ \vdots \\ w_L w_L^T \end{bmatrix}. \tag{10}$$

The comprehensive parameter value of each sample can be obtained from formula (10). Finally, we normalize it to obtain the optimal comprehensive parameter weight value for multi-criteria decision-making. See formulas (11) and (12) for the specific formula.

$$a_k^* = \frac{\alpha_k}{\sum_{k=1}^{L} \alpha_k}, \quad k = 1, 2, \ldots, L, \tag{11}$$

$$w^* = \sum_{k=1}^{L} \alpha_k w_k^T. \tag{12}$$

Considering the influence of positive ideal value and negative ideal value in the matrix, we need to first calculate the distance of positive and negative ideal solutions, and then remove the influence from the comprehensive parameters. See formulas (13)–(14) for specific expressions.

$$z_j^+ = \max z_{ij}, \quad i = 1, 2, \cdots m, \; j = 1, 2, \cdots, n, \tag{13}$$

$$z_j^- = \min z_{ij} \, (i = 1, 2, \cdots m, \; j = 1, 2, \cdots, n). \tag{14}$$

In addition, considering the uncertainty of users' personalized needs, we also sort out the alternative emerging product design schemes. See formula (15) for the specific expression.

$$C_i = \frac{s_i^+}{s_i^+ + s_i^-}, \quad i = 1, 2, \ldots, m. \tag{15}$$

Finally, in order to verify the effectiveness of the emerging product design scheme based on multi-criteria decision-making proposed in this paper, we evaluate different schemes and rank the scheme decisions according to the comprehensive parameter values. The results are shown in Figure 4.

Figure 4 shows four different methods: KE-GRA-TOPSIS, KE—TOPSIS, KE-GRA, and DM. We can see that the product ranking obtained by using different product design methods is different. According to the general product design decision-making habits, we will choose the first product design scheme as the final scheme, so different product design methods make different decisions. Combined with the end-user feedback, the multi-criteria decision-making emerging product design scheme proposed in this paper ranks the most suitable for the user's real feedback on product design.

4. Result Analysis and Discussion

Finally, combined with the algorithm analysis of emerging product design scheme evaluation based on multi-criteria decision-making, we automate the process to serve designers to make product design scheme decision and meet the needs of users' personalized experience. The main function of the system is to collect the user's voice and generate the original design scheme of emerging products that meet the designer's requirements and meet the user's personalized experience to the greatest extent according to the basic demand description of the design. Finally, the generated final scheme can be sorted and exported with other alternative schemes, so that the designer can choose independently. Here, the user voice is divided into the big data of user active feedback and unstructured user experience or demand feedback automatically captured by the system on the network. The specific operation process is shown in Figure 5.

In order to further explore the evaluation of the emerging product design scheme based on multi-criteria decision-making proposed in this paper, we explore the current mobile phone product design. At present, with the development of the Internet, mobile phones gradually play more and more roles in our lives, and the frequency of mobile phone updates is faster and faster. Major mobile phone manufacturers are constantly launching new product designs in order to obtain more market share. At present, the basic functions of mobile phones are similar among major mobile phone manufacturers. At the same time, in recent two years, mobile phone brand enterprises will pay more attention to additional functional innovation in mobile phone design, such as the size of mobile phone screen, durability, thickness, and refinement of mobile phone. Therefore, this paper evaluates the design scheme of emerging mobile phone products based on multi-criteria

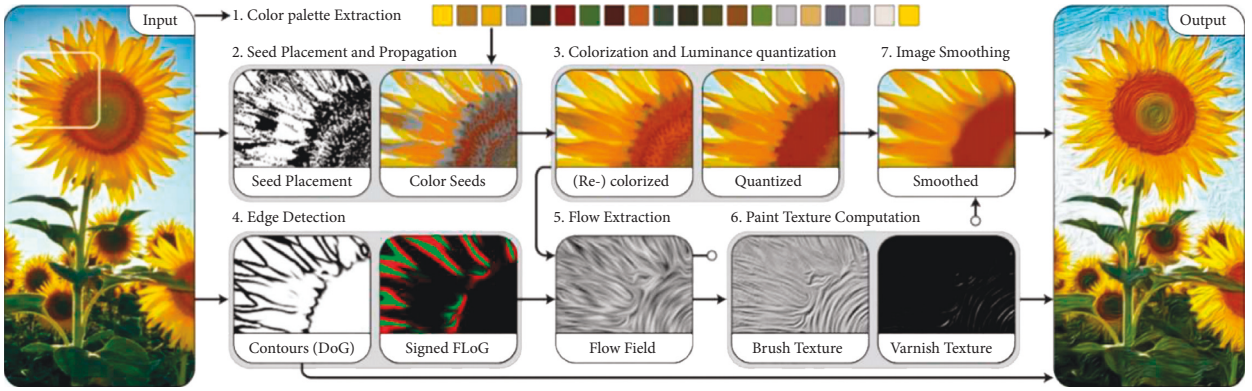

Figure 5: Big data-driven product innovation design assistant prototype system.

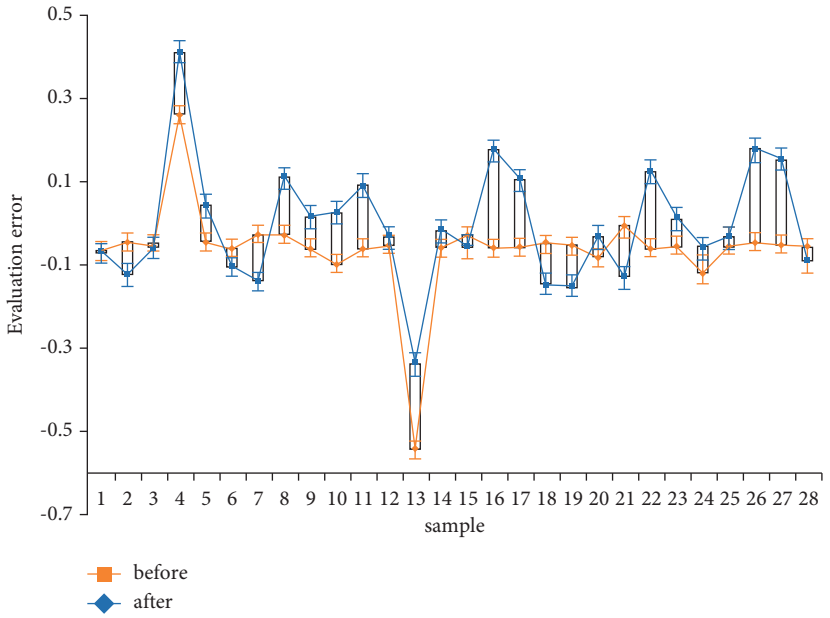

Figure 6: Comparison of error values before and after optimization.

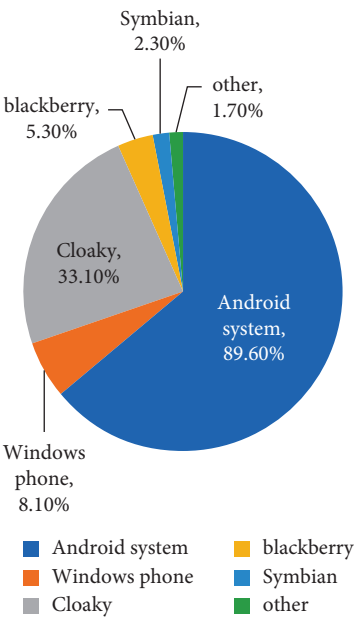

Figure 7: Mobile operating system market share in China in 2021.

decision algorithm. Among them, the data of users' personalized experience are taken from the online comment data such as the feedback of users' language or pictures on various platforms, and the emotional color represented by the combination of word clustering, adverbials, and degree adverbs in the comments is extracted through BP neural network, so as to analyze the users' personalized experience needs. The multi-criteria decision algorithm is used to predict and score different product designs, and compared with the actual value of users in the process of actual product use. The results show that the difference between the two is small, indicating that the algorithm proposed in this paper has good accuracy, as shown in Figure 6.

The data source of this experiment is Zhongguancun mobile phone data evaluation. It was originally planned to capture and analyze the commodity comments of e-commerce platform through crawler technology. However, due to the incomplete mobile phone models captured by e-commerce platform, it may affect the calculation of subsequent data, so we finally chose Zhongguancun mobile phone data evaluation with the same complete data.

However, considering the proportion of the main operating systems of mobile phones in the market, due to the large difference in the proportion of different operating systems in China, Figure 7 shows the statistical results of various operating systems in the mobile phone market in 2021. It can be seen that the Android operating system is the main operating system in China at present. This will lead to a small number of sample comments in some systems, resulting in an inaccurate number of samples. Therefore, the influence of this factor can be removed and explored in the follow-up research. Due to the length of this paper, there is no more detail.

5. Conclusion

To sum up, traditional designers usually use empirical and intuitive methods to judge. In this way, the designed products have strong subjectivity, long design cycle, slow response time to the rapidly changing needs of users, and small interpretation space. Affected by the level of play of designers, the success rate is also relatively unstable. Therefore, how to accurately identify and capture the product needs of consumers and visually display the product design is the focus and difficulty in the current emerging product design scheme and evaluation process. In this paper, through the big data sources such as the real feedback of consumers on various platforms in the era of We Media, the algorithm technology based on multi-criteria decision-making can quickly and accurately locate the needs of consumers and accurately reflect the needs in the design scheme of emerging products, which effectively improves the product innovation ability and reduces the product R & D cycle and cost. At the same time, it improves the competitiveness of products and users. Based on multi-criteria decision-making technology and big data analysis, this paper studies and evaluates the design scheme of emerging products. It solves the limitations of traditional product design methods in data research, product design scheme visualization, and decision-making, and supplements theoretical support and data support. The research still has some limitations. In this paper, the random domination rule is extended to the treatment of grey random variable criterion value, and the random domination relationship between schemes is not obtained. In future research, it is also necessary to use general criteria to transform the stochastic dominance relationship.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest or personal relationships that could have appeared to influence the work reported in this paper.

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