Application of Fuzzy Comprehensive Evaluation Method Based on AHP in Product Materials

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Abstract. In order to research the material selection method of products more in line with consumer image, a fuzzy comprehensive evaluation method based on AHP is proposed to establish product material design system. Application software SPSS for factor analysis and cluster analysis, extract the perceptual image factor that affects the consumer to product material; Comparing the elements of product materials in pairs by using the tree hierarchical structure in the analytic hierarchy process, the fuzzy relation between consumer image and product material quality is presented in a quantitative form, establish a product material design system that meets the consumer's perceptual intentions; Using fuzzy comprehensive evaluation method to quantify product material design system, Verify the accuracy of the research results. Taking the material selection of lipstick as an example to verify and analyze, it is proved that the fuzzy comprehensive evaluation method based on AHP is an effective method for product material research, it can provide theoretical guidance for designers' material selection and decision making.

1. Introduction
With the progress of science and technology and the improvement of material level, Consumers' demands for products are no longer limited to basic functions, But tends to be perceptual [1]. The shape of the product is composed of three elements: shape, color and material, under normal conditions, Designers pay more attention to styling and color, and it is easy to ignore the study of materials [2]. Product material is the carrier that the designer conveys the emotion of the product to the consumer and resonates with it, it directly affects the consumer's perception of the product. The first feeling that consumers give consumers when they interact with products is the sense of touch. The perception of touch is generally the perception of the contact between the material of the product and the skin, it is through the skin to pass information to the brain to judge things [3]. Even for the same product, different materials will bring different feelings, How to accurately grasp the product material is an important content that designers can’t ignore. Based on this, this study uses SPSS (Statistical Product and Service Solutions) to deeply mine the main factors affecting consumers' perceptual image of product materials. Fuzzy comprehensive evaluation based on AHP to establish product material design system in accordance with consumers' sensibility, combined fuzzy comprehensive evaluation membership degree matrix, from a relatively objective point of view to quantify the product material design system, so as to provide theoretical guidance for the selection of product materials.
2. Main Research Technology of Product Material

2.1. Establishment of Fuzzy Comprehensive Evaluation Model of AHP

In this study, AHP based fuzzy comprehensive evaluation method is an organic combination of analytic hierarchy process and fuzzy comprehensive evaluation method to evaluate the selection of product materials [4]. Establishing the fuzzy comprehensive evaluation model of AHP can better solve the problems of fuzzy and quantification of evaluation, make the whole process of evaluation and analysis more systematic and clear, the model framework is shown in Fig.1.

![Figure 1. Fuzzy comprehensive evaluation model of AHP](image)

2.2. Analytic Hierarchy Process

Analytic Hierarchy Process is a hierarchical weight decision analysis method proposed by T. L. saaty to solve complex multi-criteria decision making problems [5], the process is as follows:

1. Establishment of evaluation index system. The problem of product material selection to be solved is constructed into a tree-like hierarchical structure based on the interaction between elements (target layer A, criterion layer B and measure layer C), establishing the corresponding evaluation index system.

2. Constructing judgment matrix. Establishment of judgment matrix of priority relation based on two-to-two comparisons, suppose there are N elements, then the matrix \( E = \{a_{ij}, \ i=1,2,...,n; j=1,2,...,m\} \), The importance of index \( i \) relative to index \( j \), the relative importance of two or two elements is constructed by the consumer's 1--9 scale method into a comparative matrix, when \( i=j \), \( a_{ij}=1 \);when \( i\neq j \), \( a_{ij}=1/a_{ji} \) [6].

3. Solving the judgment matrix. After obtaining the judgment matrix of each level of the product material, solving the contribution of two elements of each level to the target layer \( a \), that is weight vector, the calculation steps are as follows:

   1. normalize each column element of matrix \( E \) and add them separately by row:

   \[
   w_i = \frac{\sum_{j=1}^{n} a_{ij}}{n} \quad i = 1,2,...,n
   \]  

   In the formula, \( a_{ij} \) is the element of row \( i \) and column \( j \) in matrix \( E \), \( n \) is the number of elements, get the column vector \( w_i = \{w_1, w_2,...,w_n\}, i=1,2,...,n. \)
(2) Normalize the generated vector \( w_i \) in the previous step, get the largest eigenvector under a single criterion, in order to calculate the largest eigenvalue of the matrix \( E \):

\[
\lambda_{\text{max}} = \frac{1}{n} \sum_{i=1}^{n} \frac{E_{wi}}{\omega_i}, i = 1,2,\ldots,n
\]

(2)

In the formula, \( \lambda_{\text{max}} \) is the largest eigenvalue; \( E_{wi} \) is the vector; \( \omega_i \) is the largest eigenvector; \( n \) is the number of elements.

(4) Check consistency. According to the principle of analytic hierarchy process, to ensure the consistency of the thinking of the subject in the decision-making process and the compatibility of the matrix \( E \), consistency test is needed after calculating a hierarchical relative weight vector.

\[
CI = \frac{\lambda_{\text{max}} - n}{n - 1}
\]

(3)

\[
CR = \frac{CI}{RCI}
\]

(4)

In the formula, \( CI \) is the consistency indicator; \( CR \) is the consistency ratio; \( RC \) is the coefficient of consistency; \( n \) is the order [7]. When the consistency ratio \( CR<0.1 \), then the judgment matrix has consistency. The random consistency coefficient \( RCI \) corresponding to the order \( n \), shown in Tab.1.

| \( n \) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|-------|---|---|---|---|---|---|---|---|---|
| RCI   | 0 | 0 | 0.58 | 0.9 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 |

2.3. Fuzzy Comprehensive Evaluation Method

Fuzzy Comprehensive Evaluation Method is a comprehensive evaluation method based on fuzzy mathematics membership theory to transform qualitative evaluation into quantitative evaluation, introducing this method can better determine the advantages and disadvantages of factors.

(1) Determining factor set and evaluation set. Before using the fuzzy membership function to calculate the fuzzy evaluation, firstly, the factor set \( U = \{U_1, U_2, \ldots, U_n\} \) and the evaluation set \( V = \{V_1, V_2, \ldots, V_m\} \) of product material are determined.

(2) Determining the membership matrix. The evaluation indicators are divided into qualitative indicators and quantitative indicators. This study uses qualitative indicators to allow the judges to give a set of comments for the evaluation indicators to be assessed. Thus the membership matrix of fuzzy evaluation is constructed \( R=\{b_{ij},i=1,2,\ldots,n; j=1,2,\ldots,m\} \), \( n \) is the number of evaluation objects, \( m \) is the number of evaluation grades [6].

(3) Computational fuzzy synthesis matrix. When there are many evaluation elements, there is a problem that the weight coefficient is difficult to determine the problem, fuzzy comprehensive evaluation matrix can be obtained by combining the ranking weight calculated by fuzzy evaluation membership matrix \( R \) and analytic hierarchy process, the formula is as follows:

\[
P_i = W_i \times R_i
\]

(5)

In the formula, \( P_i \) is the comprehensive fuzzy value corresponding to each element under the \( i \) indicator, \( W_i \) is the weight value corresponding to each element under the \( i \) indicator, \( R_i \) is the fuzzy evaluation membership matrix [2].
Reference evaluation set value comparison table, quantitative fuzzy comprehensive evaluation matrix, can determine the pros and cons of the evaluation indicators, its formula is:

\[ U = \frac{P \times V}{n} \]

(6)

In the formula, \( U \) is the comprehensive assessment score; \( n \) is the number of people evaluated.

3. Application examples

The study found that China became the world's fourth largest cosmetics sales market in 2014. The majority of lipstick consumers are young women. However, there is no in-depth study on the sensory image of consumer lipstick materials in China. This article takes the choice of lipstick material as an example, exploring the main influence factors of Chinese young women's emotional imagery of lipstick materials, establish a lipstick material design system that meets the emotional requirements of young women in China.

3.1. Sample determination

Search the official websites of domestic and foreign brands and relevant fashion books to collect samples of lipstick materials, choose 267 lipstick pictures taken clearly. To preserve the common shape and material universality, sample screening based on eliminate the principle of similar shape and high repetition rate, get 97 samples. Based on the appearance material as benchmark, classify 97 samples as: plastics, metals, leather, and paper. Considering the color and shape will affect the analysis results, four materials with identical shapes were selected as representative samples, and the gray level was processed, as shown in Fig.2:

![Figure 2. Represents the sample](image)

3.2. Determining Image Factor

Retrieval lipstick materials related websites, fashion magazines and Literature, brings together 103 words from lipstick material, remove words that are inaccurate and overly similar, get 36 words. Inviting 50 subjects aged 18 to 30 in the form of a questionnaire, select the 10 words that best represent the lipstick material from 36 words. Combine the 10 vocabulary initially selected with 4 representative samples, making the Fifth-order LiKert Scale, invite the above 50 subjects to evaluate the image of lipstick material, summarize and average the assessment, get the emotional rating scale, shown in Tab.2:

| Materials | Expensive | Unique | Dignity | Environment | Simply | Fashion | Durables | Light | Modern | Temperament |
|-----------|-----------|--------|---------|-------------|--------|---------|----------|-------|--------|-------------|
| Plastics  | 2.36      | 2.45   | 3.55    | 2.36        | 4      | 3.27    | 3.18     | 4.09  | 3.73   | 2.9         |
| Metals    | 3.73      | 3.82   | 3.72    | 2.9         | 3.18   | 3.55    | 4.18     | 1.73  | 3.55   | 3.45        |
| Leather   | 4.36      | 3.9    | 4.82    | 2.27        | 2.73   | 3.9     | 3.36     | 2.64  | 4.09   | 4.27        |
| Paper     | 1.82      | 3.73   | 2.09    | 4.36        | 3.55   | 2.82    | 1.73     | 4.27  | 2.81   | 3.36        |

Table 2. Emotional rating scale of vocabulary

Factor analysis of perceptual assessment score table using SPSS, get 2 sets of factor load values, shown in Tab.3. The cumulative contribution of the two groups of factors is 91.572%, and explain that
two sets of factors are sufficient to explain all images. The contribution ratio was 67.196%:24.376%, about 3:1, to provide the basis for selecting the final image factors. Cluster analysis of two groups of factor using SPSS, combine the ratio of the two groups of factor contributions in Tab.3 and the factor value of each vocabulary, 4 image factors were selected as: modern, unique, light and environment.

| Vocabulary | Factor 1 | Factor 2 |
|------------|----------|----------|
| Environment | -0.986 | 0.104 |
| Modern | 0.965 | 0.112 |
| Dignity | 0.924 | 0.331 |
| Fashion | 0.874 | 0.480 |
| Durables | 0.843 | 0.157 |
| Expensive | 0.744 | 0.667 |
| Unique | -0.219 | 0.969 |
| Simply | -0.297 | -0.949 |
| Temperament | 0.266 | 0.885 |
| Light | 0.266 | -0.63 |
| Contribution Ratio | 67.196% | 24.376% |

3.3. Product Material Decision and Analysis

The product material hierarchy is decomposed into: Target Layer A, Criterion Layer B and Measure Layer C, constructing evaluation index system for lipstick material, as shown in Fig.3.A total of 30 decision makers are composed of graduate students with industrial design learning background and consumers without any design background. The perceptual vocabulary of the criterion level B is compared in pairs and scaled in proportion. Perform a pairwise comparison to construct a priority relationship judgment matrix E.1~5 scale table for taking into account the fatigue of decision makers.

| Material A |
|-----------|
| Modern B1 | Unique B2 | Environment B4 | Light B5 |
| ... | ... | ... | ... |
| Plastics C1 | Metals C2 | Leather C3 | Paper C4 |

Calculate the formula according to the AHP (1)~(4), Order n=4,Take RCI=0.9,Calculate the weight values of each index of $E$ matrix and check the consistency, it is concluded that: $\omega_E=(0.115,0.497,0.246,0.142); \lambda_{max}=4.125; CI=0.072; CR=0.08<0.1$, then the $E$ matrix satisfies the consistency, can be accepted. Invite the above 30 decision makers based on different image factors of the B layer of the criterion layer, contrast method and 1~5 scale method are used for different materials of C layer of measure layer. Performing a pairwise comparison to construct a priority relationship judgment matrix, $E_1$~$E_4$, calculate the material weight of each indicator, shown in Tab.4.
As can be seen from Tab.4, the best choice for environment lipstick material is paper (0.508); The best choice for Light lipstick material is plastic (0.466); The best choice for modern lipstick materials is leather (0.349); The best choice for a unique lipstick material is paper (0.45); The plastic composite weight in the lipstick material is the highest (0.305). According to the analysis results, for young female consumers aged 18 to 30, the best choice for lipstick material in lipstick design is plastic.

### 3.4. Fuzzy Evaluation of Product Material

Theoretical knowledge based on fuzzy comprehensive evaluation, determine the factor set $U =$ Environment, Light, Modern, Unique; comment set $V =$ very suitable, appropriate, general, inappropriate, very inappropriate, the value of its comment set is shown in Tab.5.

### Table 5. Assessment set of valuation reference table

| Comment Set      | Very Inappropriate | Inappropriate | Indifferent | Appropriate | Very Appropriate |
|------------------|---------------------|---------------|-------------|-------------|------------------|
| Score (0,20]     | (20,40]             | (40,60]       | (60,80]     | (80,100]    |                  |

Research on lipstick material selection, let the nine judges give a set of comments on the environment friendly, light, modern and unique evaluation indicators, thus constructing fuzzy evaluation matrices $R_1$ $\sim$ $R_4$.

| $R_1$ | $R_2$ | $R_3$ | $R_4$ |
|-------|-------|-------|-------|
| 0 3 2 3 1 | 0 2 3 3 1 | 0 4 4 0 1 | 6 2 0 1 0 |
| 5 3 1 0 0 | 0 1 1 5 2 | 1 3 4 1 0 | 6 2 0 1 0 |
| 4 2 2 0 1 | 4 3 1 1 0 | 2 4 3 0 0 | 0 4 2 3 0 |
| 0 3 4 1 1 | 2 4 2 1 0 | 5 3 1 0 0 | 5 2 1 1 0 |

According to the fuzzy comprehensive evaluation formula (5), Combine the fuzzy evaluation matrices $R_1$ $\sim$ $R_4$ with the measure layer C layer weights $\omega_{E1}$ $\sim$ $\omega_{E4}$, the fuzzy comprehensive evaluation matrix $R$ is obtained as:

$$R = \begin{bmatrix} 3.048 & 2.559 & 1.648 & 1.213 & 0.492 \\ 4.18 & 2.585 & 1.287 & 0.81 & 0.138 \\ 2.846 & 3.247 & 2.028 & 0.663 & 0.216 \\ 4.05 & 2.74 & 1.418 & 0.716 & 0.076 \end{bmatrix}$$

Similarly, Using formula (5), Combine the fuzzy comprehensive evaluation matrix $R$ with the weight $\omega_{E}$ of the hierarchical analysis matrix $E$, calculate the overall comprehensive evaluation vector of the export red material $P = \{3.703, 2.77, 1.53, 0.807, 0.189\}$.

In order to facilitate the calculation of the comprehensive assessment score, take the middle value of the score of the comment set, then the value of the comment set is $V = \{90, 70, 50, 30, 10\}$. According to formula (6), $n=9$, its comprehensive evaluation score $U = 69.974$ in $[60, 80]$, the result of fuzzy evaluation of lipstick material is qualified. Explain that the above analysis of lipstick materials for young female
consumers aged 18 to 30 is reasonable, the best material selection for environment and unique lipsticks is paper; the best material selection for Light lipsticks is plastic; the best material selection for modern lipsticks is leather. Consideration of Four Image Factors, the best material selection scheme is plastic.

4. Conclusion
Through the study of the material of the products on the market, using software SPSS to obtain the index of representative perceptual image; based on AHP fuzzy comprehensive evaluation model, product material design system is established. Combining with expert comment set, the fuzzy qualitative evaluation of product material is transformed into quantitative evaluation. Take the lipstick material selection as an example, the validity of the research method is verified. This research method can optimize the traditional design method based on subjective experience, help designers acquire consumers image factors of product materials, Provide reference and reference for the selection of other product materials. Limited to research time and space, this study did not investigate a large amount of data for statistics and analysis, in follow-up studies, the author will work with lipstick design companies to conduct large-scale research, get enough sample data, and combined with the company's user feedback, we can better develop products that meet the consumer's perceptual requirements.

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