# A Study on Functional Analysis and Systematic Design Thinking of Car Front-end

Dan Li*[1], Tao Tao[2]

*ld_1777@163.com [1], 164291089@qq.com[2]

Dalian University, Dalian Liaoning 116622,China

**Abstract.** This study aims to solve the problem of the lack of functional analysis and systematic design thinking in the design of some existing automobile front faces, with the goal of reducing the loss of design time and shortening the design cycle. Firstly, each functional element of the automobile front face is extracted by inductive method and functional relationship is established to analyze the functionality of the automobile front face emphatically. Secondly, the evaluation index system of automobile front face is established by using hierarchical analysis method, and the scores of automobile front face at all levels are combined with consumer research and experts' opinions, and the comprehensive weights are determined in order to judge the importance of functionality in the design of automobile front face at all levels. It is found that the comprehensive weights obtained by using hierarchical analysis method, A, B grade automobile front face should consider more about functionality when designing, while C grade automobile front face needs to take into account the balance of functionality, experience and appearance, and D grade automobile front face needs to pay more attention to the appearance when designing; the comprehensive weights obtained by evaluating the results of consumers and professionals have improved the accuracy and objectivity of the data. Finally, the triangular fuzzy number is used to optimize the functionality of the morphological scheme, and the best functional principle scheme is selected. The triangular fuzzy number on the functional scheme preference quantifies the fuzzy indexes, and can judge the degree of its importance between the indexes. It is an important research to integrate the functionality evaluation into the automobile front face design, which provides a reference for the automobile front face design.

**Keywords:** Front of the car;programme evaluation;triangular fuzzy number;combined weights ;analytic hierarchy process

## 1 Introduction

In the research and development of automobiles, the front face design is an important component of automobile design. However, functional evaluation is rarely included in front face design, as the design process is usually carried out by designers for styling[1], and then technical personnel select the technical route, which can lead to communication conflicts between them. This linear relationship often results in the neglect of functionality as part of the evaluation of automobile front face design, resulting in a loss of research and development time and an extension of the design cycle. Based on analysis of existing literature, a combination of subjective and objective evaluations is used in the styling design to make the entire design process more scientific. However, besides the aesthetic requirements, the front face of an automobile also has certain

ADDT 2023, September 15-17, Xian, People's Republic of China

DOI 10.4108/eai.15-9-2023.2340898

functional requirements. Therefore, automobile companies and designers need to explore a more comprehensive method of evaluating front face functionality[2]. Through literature analysis[3], user demand analysis, and suggestions from professionals in relevant fields, it is difficult to find a standard for the importance of front face functionality that is suitable for all consumer groups. Furthermore, automobile functionality exists in the form of multiple parts with different functions, and these parts are interdependent[4]. Finally, exploring and comparing functionalities does not have a precise answer, and often there is ambiguity. To solve these problems, this article first establishes an automobile front face design analysis model using the Analytic Hierarchy Process[5]. Through the analysis of multi-brand automobile front face components at various levels, the weight values of each group of elements are determined, and consistency checks are completed. Then, the Triangular Fuzzy Number is used to optimize the best functional principle scheme, thus obtaining a more scientifically reasonable functional evaluation process and providing a reference for subsequent research and development of automobile front face design.

## 2 ANALYTIC HIERARCHY PROCESS

### 2.1 Construction of Evaluation Index System for Automotive Front End

Currently, there are many methods for evaluating product design and functionality. Common methods include analytic hierarchy process[6], information entropy evaluation, and triangular fuzzy number evaluation[7], which use mathematical and statistical analysis methods to select the optimal solution[8]. Triangular fuzzy number evaluation is often used for safety assessment, business selection[9, 10], environmental issues[11], product design[12], and other evaluations. The triangular fuzzy number can quantify the qualitative indicators and obtain a more intuitive result by comparing their proximity. Since the whole car is a huge system, if too many components of the car are analyzed, it will make the evaluation index biased, so the front face of the car, a more typical part, is selected for analysis and evaluation.

In order to make the established evaluation system for automobile front-end design convenient and scientific[13], a functional analysis of the many factors influencing automobile front-end design was carried out through literature and the collection of professional opinions[14]. The selected set of functions is then filtered and adjusted to remove some minor and repetitive functions. By extracting, collecting and analyzing different automobile front face elements, as shown in **Figure 1** Automobile front face element extraction. By extracting, collecting, and analyzing different elements of automobile front-end design, the elements were analyzed for their functional points, and four functional elements were extracted and generalized based on a functional element method: lighting and illumination, driving safety, driving assistance, and internal needs, as shown in **Figure 2**, the architecture of automobile front-end functional element analysis.

In constructing the hierarchy analysis model for automobile front-end design requirements, 10 industrial designers and vehicle engineers engaged in automobile design research and 10 drivers with extensive driving experience were selected and classified to discover that automobile front-end design mainly focuses on functional $B_1$, experiential $B_2$, and appearance $B_3$. Therefore, the target layer of automobile front-end design was divided into these three aspects as the criteria layer. Then, these three criterion layers were further divided into 10 sub-criterion layers: lighting and illumination $B_{11}$, driving safety $B_{12}$, driving assistance $B_{13}$, internal needs $B_{14}$, collision prevention level $B_{21}$, wide field of view $B_{22}$, driving assistance $B_{23}$, front-end material $B_{31}$, appearance design $B_{32}$, and color matching $B_{33}$. Based on this, an automobile front-end design evaluation system was established, as shown in **Figure 3**.

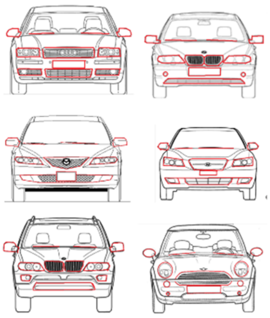

**Fig. 1.** Extraction of elements from the front of the car

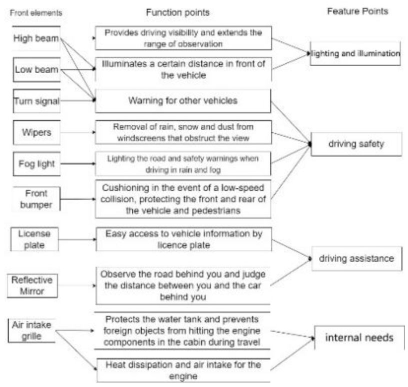


**Fig. 2.** Functional meta-analysis architecture for the front of the car

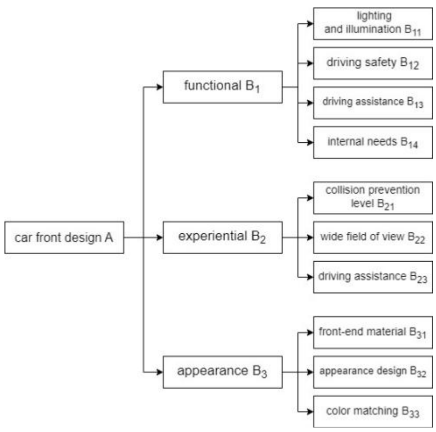


**Fig. 3.** Car front design evaluation system

## 2.2 Construction of Evaluation Index System for Automotive Front End

(1) Construct a judgment matrix. Due to different opinions on the evaluation criteria among different consumer groups, the front faces of cars with different sizes are first divided into four groups: A-level cars, B-level cars, C-level cars, and D-level cars, according to the classification method used by Volkswagen in Germany based on car wheelbase and size. In each market level, the price and sales volume of each brand differ significantly. Therefore, when selecting samples of front faces of cars at each level, the 2022 car sales rankings and recommended prices compiled by CarRankings.net were used as reference criteria, and front faces of cars with a price difference of no more than 50,000 and a top-five sales volume were selected as reference samples as much as possible. The selected vehicles are divided into A-level car group, which includes Sagitar, Lavida, and Qin PULS, B-level car group, which includes Camry, Accord, and Passat, C-level car group, which includes BMW 530, Audi A6, and Mercedes-Benz E-Class, and D-level car group, which includes BMW 740 series, Audi A8, and Mercedes-Benz S-Class. In addition, a survey was conducted on the sports car group, but due to the relatively small number of sports car consumers and the extreme results, the sample was insufficient. Then, a questionnaire survey was conducted on consumers at each level to score each criterion and describe its relative importance. Using the 1-9 scale method to analyze the criteria, the mutual comparison of each evaluation criterion element in each level was constructed to form a judgment matrix. Then, the criteria were calculated to construct the evaluation matrix for front face design at each level, as shown in **Tables 2-5.**

**Table 1.** Judgement matrix scales

| Relative importance assignment (i/j) | Meaning | Scale description |
|---|---|---|
| 1 | Equally important | Indicator i is equally important compared to indicator j |
| 3 | Slightly more important | Indicator i is slightly more important than indicator j |
| 5 | Obviously important | Indicator i is significantly more important than indicator j |
| 7 | Strongly Important | Indicator i is strongly more important than indicator j |
| 9 | Extremely important | Extreme importance of indicator i compared to indicator j |
| 2, 4, 6, 8 | Use when compromising | Determination of importance based on adjacency scale |

**Table 2.** A-Class front design judgement matrix and weights

| A | B1 | B2 | B3 | Weighting w11 |
|---|---|---|---|---|
| B1 | 1.000 | 1.250 | 1.429 | 40.036% |
| B2 | 0.800 | 1.000 | 1.042 | 31.057% |
| B3 | 0.700 | 0.960 | 1.000 | 28.908% |

**Table 3.** B-Class front face design judgement matrix and weights

| A | B1 | B2 | B3 | Weighting w12 |
|---|---|---|---|---|
| B1 | 1.000 | 1.250 | 1.250 | 38.459% |
| B2 | 0.800 | 1.000 | 1.042 | 31.189% |
| B3 | 0.800 | 0.960 | 1.000 | 30.352% |

**Table 4.** C-Class front face design judgement matrix and weights

| A | B1 | B2 | B3 | Weighting w13 |
|---|---|---|---|---|
| B1 | 1.000 | 1.111 | 1.111 | 35.705% |
| B2 | 0.900 | 1.000 | 1.087 | 33.041% |
| B3 | 0.900 | 0.920 | 1.000 | 31.255% |

**Table 5.** D-Class front face design judgement matrix and weights

| A | B1 | B2 | B3 | Weighting w14 |
|---|---|---|---|---|
| B1 | 1.000 | 0.909 | 0.870 | 30.727% |
| B2 | 1.100 | 1.000 | 0.833 | 32.280% |
| B3 | 1.150 | 1.200 | 1.000 | 36.993% |

(2) Consistency test. The consistency test is mainly to avoid errors caused by the subjectivity of decision-makers. The CR is used as an indicator to test the consistency of the judgment matrix. Generally, the smaller the CR value, the better the consistency of the judgment matrix, and the higher the usability, as shown in the formula . In this study, SPSS software was used for data analysis to obtain the average random consistency indicators for each level of car group, as shown in **Tables 6**. The calculation results are shown in **Tables 7** where $RI_1$ is the value for A-level cars, $RI_2$ is the value for B-level cars, $RI_3$ is the value for C-level cars, and $RI_4$ is the value for D-level cars.

$$CR = \frac{\lambda_{max} - n}{(n-1)RI} \leq 0.1 \tag{1}$$

**Table 6.** Table of average random consistency indicators

| nth order | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RI1 | 0 | 0 | 0.52 | 0.89 | 1.12 | 1.26 | 1.36 | 1.41 | 1.46 | 1.49 | 1.52 | 1.54 |
| RI2 | 0 | 0 | 0.52 | 0.89 | 1.12 | 1.26 | 1.36 | 1.41 | 1.46 | 1.49 | 1.52 | 1.54 |
| RI3 | 0 | 0 | 0.52 | 0.89 | 1.12 | 1.26 | 1.36 | 1.41 | 1.46 | 1.49 | 1.52 | 1.54 |
| RI4 | 0 | 0 | 0.52 | 0.89 | 1.12 | 1.26 | 1.36 | 1.41 | 1.46 | 1.49 | 1.52 | 1.54 |

**Table 7.** Consistency test results

| Grouping | A-Class | B-Class | C-Class | D-Class |
|---|---|---|---|---|
| λmax | 3.001 | 3.000 | 3.001 | 3.002 |
| CI | 0.000 | 0.000 | 0.000 | 0.000 |
| RI | 0.520 | 0.520 | 0.520 | 0.520 |
| CR | 0.001 | 0.000 | 0.001 | 0.002 |

### 2.3 Calculation of weighting factors

The weights obtained through the above method were obtained by surveying consumers, who were the targeted group of the respective cutting-edge automotive industry. However, this only considers the perspective of consumers and lacks the professional opinions of designers and relevant professional developers. Therefore, this article also surveyed and obtained questionnaires from automotive design practitioners and related professional teachers, and calculated the second weight vector through their constructed judgment matrix. Then, according to expert guidance, a linear composite weight vector was formed with a 6:4 importance ratio.

$$\omega = 0.6\omega_1 + 0.4\omega_2 \tag{2}$$

The weight vectors for each set of car fronts were then compared, as shown in **Figure 4**:

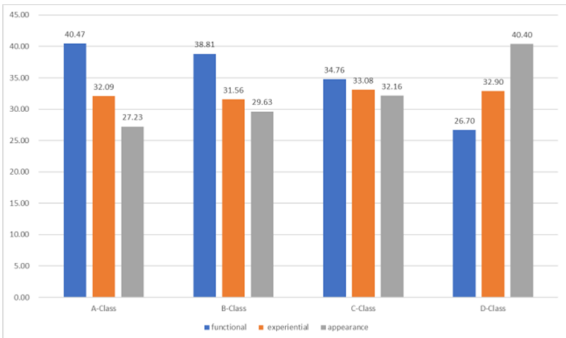


**Fig. 4.** Distribution of target weights

## 3 TRIANGULAR FUZZY EVALUTION METHOD

### 3.1 Triangular fuzzy numbers

In practical problems, decision makers often provide evaluations of relevant factors and their corresponding weights using imprecise language, such as "around m". To address this issue, Dutch scholars F.J.M.VanLaarhoven and W.Pedrycz proposed the use of triangular fuzzy numbers (l,m,u) to represent fuzzy comparative judgments. Triangular fuzzy numbers have unique advantages in expressing imprecise evaluations that fall within a range of values[15, 16].

The triangular fuzzy number is the number of theoretical domains $R$ the fuzzy number on $\widetilde{M}$ and its affiliation function $\mu_{\widetilde{M}}: R \to [0,1]$ is denoted as

$$\mu_{\widetilde{M}}(x) = \begin{cases} \dfrac{x-l}{m-l} & x\epsilon[l,m] \\ \dfrac{x-u}{m-u} & x\epsilon[m,u] \\ 0 & \text{others} \end{cases} \tag{3}$$

Where $l \leq m \leq u$ ,$l$ and $u$ denote the lower and upper bounds of $\widetilde{M}$ the lower and upper bound values ofm is the $\widetilde{M}$ the median of the subordinate degree of 1, whose function image is shown in **Figure 5**, and the triangular fuzzy number can be $\widetilde{M}$ is denoted as $\widetilde{M}(l,m,u)$ [17, 18].

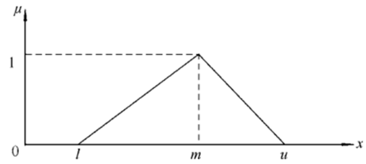


**Fig. 5.** Plot of the triangular fuzzy number affiliation function

### 3.2 The process of the triangular fuzzy number evaluation method

Step 1: Construct k rater's decision evaluation values for each alternative

To select the optimal functional principle solution, the functional class evaluation indicator $u_n$ are the evaluation objectives. First select $k$ a number of evaluators $e_k(k = 1,2,3 \ldots k)$ for $i$ options $x_i(i = 1,2,3)$ according to the previously defined indicators $u_n$ The corresponding evaluation values are given. and by $u_n$ calculating the weight vector $\omega^n$ [19].

Step 2: Construct a triangular fuzzy decision matrix

The fuzzy decision matrix of the k-th evaluator is $\tilde{A}^k = \left[\tilde{a}_{ij}^k\right]_{m\times n}$ ,where $\tilde{a}_{ij}^k = \left(\tilde{a}_{ij}^{kL},\ \tilde{a}_{ij}^{kM},\ \tilde{a}_{ij}^{kU}\right)$ represents the average value of the k-th evaluator's decision on the solution $x_i$ under the objective $u_j$ under the objective.

$$\tilde{A}^k = \begin{array}{c} \\ x_1 \\ x_2 \\ \cdots \\ x_m \end{array} \begin{array}{c} \begin{matrix} u_1 & u_2 & \cdots & u_n \end{matrix} \\ \begin{bmatrix} \tilde{a}_{11}^k & \tilde{a}_{12}^k & \cdots & \tilde{a}_{1n}^k \\ \tilde{a}_{21}^k & \tilde{a}_{22}^k & & \tilde{a}_{2n}^k \\ & \vdots & \ddots & \vdots \\ \tilde{a}_{n1}^k & \tilde{a}_{n2}^k & \cdots & \tilde{a}_{mn}^k \end{bmatrix} \end{array} \quad k = 1,2,\ldots,k \tag{4}$$

Step 3: Normalize the decision matrix

To exclude decision outcomes from being influenced, the decision matrix $\tilde{A}^k$ is normalised to a decision matrix $\tilde{R}^k$ , as the functional evaluation indicators are all benefit-based evaluation indicators. The j-th benefit-based indicator, the i-th option, and the k-th expert normalised formula is shown in equation (5).

$$b_{ij}^{kL} = \frac{a_{ij}^{kL}}{\sum_{i=1}^{m}\left(a_{ij}^{kU}\right)}, b_{ij}^{kM} = \frac{a_{ij}^{kM}}{\sum_{i=1}^{m}\left(a_{ij}^{kM}\right)}, b_{ij}^{kU} = \frac{a_{ij}^{kU}}{\sum_{i=1}^{m}\left(a_{ij}^{kL}\right)} \tag{5}$$

For the evaluation index of efficiency type in this article, the normalized triangular fuzzy decision matrix is obtained as shown in (6):

$$\tilde{R}^k = \begin{matrix} & u_1 & u_2 & \cdots & u_n \\ x_1 & \tilde{r}_{11}^k & \tilde{r}_{12}^k & \cdots & \tilde{r}_{1n}^k \\ x_2 & \tilde{r}_{21}^k & \tilde{r}_{22}^k & & \tilde{r}_{2n}^k \\ \cdots & & \vdots & \ddots & \vdots \\ x_m & \tilde{r}_{n1}^k & \tilde{r}_{n2}^k & \cdots & \tilde{r}_{mn}^k \end{matrix} \quad k = 1,2,\dots,k \tag{6}$$

Step 4: Calculate the average similarity and relative similarity

According to equation (7) and the formula for calculating average similarity (8) and relative similarity (9), the similarity of evaluation values of any two evaluators for a certain alternative under objective can be calculated:

$$S_{ij} = (p,q) = 1 - \frac{1}{3}\left[\left|r_{ij}^{pL} - r_{ij}^{qL}\right| + \left|r_{ij}^{pM} - r_{ij}^{qM}\right| + \left|r_{ij}^{pU} - r_{ij}^{qU}\right|\right] \tag{7}$$

$r_{ij}^{p} = \left[r_{ij}^{pL}, r_{ij}^{pM}, r_{ij}^{pU}\right] . r_{ij}^{p} = \left[r_{ij}^{qL}, r_{ij}^{qM}, r_{ij}^{qU}\right]$

Average similarity:

$$AS_{ij}(e_k) = \frac{1}{k-1}\sum_{\substack{l=1 \\ l \neq k}}^{k} S_{ij}(k,l) \quad j = 1,2,\dots,n; i = 1,2,\dots,m \tag{8}$$

Relative similarity:

$$RS_{ij}(e_k) = \frac{AS_{ij}(e_k)}{\sum_{i=1}^{K} AS_{ij}(e_k} \quad k = 1,2,\dots,k \tag{9}$$

Step 5: Comprehensive importance coefficient of evaluator

Based on the average similarity and relative similarity of the rater's opinions, the scheme can be obtained $x_i$ In the evaluation indicators $u_j$ rater $e_k$ The combined degree of importance is

$$w_{ij}(e_k) = \alpha w_k^j + (1-\alpha) \cdot RS_{ij}(e_k) \tag{10}$$

$$j = 1,2,\dots,n; i = 1,2,\dots,m; k = 1,2,\dots,k$$

where is the weight coefficient and . The size of reflects the final preference of the evaluator. The larger it is, the more the evaluator tends to the authority of the individual evaluator; the smaller it is, the more the evaluator tends to the opinions of the entire evaluator group.

Where $\alpha$ is the weighting factor . $\alpha \in [0,1]$ .$\alpha$ The larger the coefficient, the more the rater prefers the individual rater's authority; the smaller the coefficient, the more the rater prefers the opinion of the rater as a whole.

Step 6: Gathering of assessors' opinions

The triangular fuzzy number decision matrix of n evaluation indicators is obtained by assembling the evaluators' evaluation values of the programme :

$$\tilde{B}^k = \left[\tilde{b}_{ij}\right]_{m\times n} = \begin{matrix} \\ \text{programme } x_1 \\ \text{programme } x_2 \\ \cdots \\ \text{programme } x_m \end{matrix} \begin{matrix} u_1 & u_2 & \cdots & u_n \\ \end{matrix} \begin{bmatrix} \tilde{r}_{11}^k & \tilde{r}_{12}^k & \cdots & \tilde{r}_{1n}^k \\ \tilde{r}_{21}^k & \tilde{r}_{22}^k & & \tilde{r}_{2n}^k \\ \vdots & & \ddots & \vdots \\ \tilde{r}_{n1}^k & \tilde{r}_{n2}^k & \cdots & \tilde{r}_{mn}^k \end{bmatrix} \tag{11}$$

Set up experts $e_k$ For programmes $x_i$ in the evaluation indicators $u_j$ The evaluation value of

$$\tilde{b}_{ij}^k : \tilde{b}_{ij} = \sum_{k=1}^{k} w_{ij}(e_k) \cdot \tilde{b}_{ij}^k \tag{12}$$

A normalized triangular fuzzy decision matrix can be obtained from the above two equations $\tilde{B} = \left[\tilde{b}_{ij}\right]_{m\times n}$

Once the collection of opinions is complete, the rater gives a vector of fuzzy attribute weights based on subjective preferences, taking into account the fuzzy and complex nature of human thinking $\widetilde{w_j} = \left(w_j^L, w_j^M, w_j^U\right), (j = 1,2, \dots, n)$ . The rater normative weighted triangular fuzzy number decision matrix is

$$\tilde{Z} = \left[\tilde{Z}_{ij}\right]_{m\times n}, \ \tilde{z}_{ij} = \widetilde{w}_j \cdot \tilde{b}_{ij} \tag{13}$$

The normalised weighted triangular fuzzy number decision matrix is then obtained by taking the fuzzy attribute weight values given by the rater as

$$\tilde{Z} = \left[\tilde{Z}_{ij}\right]_{m\times n}, \ \tilde{z}_{ij} = \widetilde{w}_j \cdot \tilde{b}_{ij} \tag{14}$$

Step 7 Application of the closeness to the ideal solution for solution selection

Remember that the evaluation value is $U^* = \left(\tilde{u}_j^{+L}, \tilde{u}_j^{+M}, \tilde{u}_j^{+U}\right)$ of the positive ideal programme, as the evaluation indicator is benefit-based, where

$$\tilde{u}_j^+ = \left(\tilde{u}_j^{+L}, \tilde{u}_j^{+M}, \tilde{u}_j^{+U}\right) = \left[\max_{1\le i\le m} w_j^L b_{ij}^L, \ \max_{1\le i\le m} w_j^M b_{ij}^M, \ \max_{1\le i\le m} w_j^U b_{ij}^U, \ \right] \tag{15}$$

Remember that the evaluation value is $U^* = \left(\tilde{u}_j^{-L}, \tilde{u}_j^{-M}, \tilde{u}_j^{-U}\right)$ of the negative ideal programme, as the evaluation indicator is benefit-based, where

$$\tilde{u}_j^- = \left(\tilde{u}_j^{-L}, \tilde{u}_j^{-M}, \tilde{u}_j^{-U}\right) = \left[\min_{1\le i\le m} w_j^L b_{ij}^L, \ \min_{1\le i\le m} w_j^M b_{ij}^M, \ \min_{1\le i\le m} w_j^U b_{ij}^U, \ \right] \tag{16}$$

Mean value of alternative options to the evaluation value of the positive ideal option $U^+$ and the evaluation value of the negative ideal option $U^+$ Euclidean distance $d_{ij}^+$ and $d_{ij}^-$ :

$$d_i^+ = \sqrt{(d_{i1}^+)^2 + (d_{i2}^+)^2 + \cdots + (d_{in}^+)^2}, d_i^- = \sqrt{(d_{i1}^-)^2 + (d_{i2}^-)^2 + \cdots + (d_{in}^-)^2} \tag{17}$$

$$d_{ij}^+ = d\left(\tilde{z}_{ij}, \tilde{u}_j^+\right) = \left[\frac{1}{3}\left(\left|w_j^L b_{ij}^L - \tilde{u}_j^{+L}\right|^2 + \left|w_j^M b_{ij}^{LM} - \tilde{u}_j^{+M}\right|^2 + \left|w_j^L b_{ij}^U - \tilde{u}_j^{+U}\right|^2\right)\right]^{\frac{1}{2}} \tag{18}$$

$$d_{ij}^- = d\left(\tilde{z}_{ij}, \tilde{u}_j^-\right) = \left[\frac{1}{3}\left(\left|w_j^L b_{ij}^L - \tilde{u}_j^{-L}\right|^2 + \left|w_j^M b_{ij}^{LM} - \tilde{u}_j^{-M}\right|^2 + \left|w_j^L b_{ij}^U - \tilde{u}_j^{-U}\right|^2\right)\right]^{\frac{1}{2}} \tag{19}$$

Based on: $L(x_i) = \frac{d_i^-}{d_i^- + d_i^+}$ , the proximity of each option is calculated $L(x_i)$ , by comparing the closeness, the larger is the higher rated option.

## 4 TRIANGULAR FUZZY EVALUTION METHOD

Here are three Audi front grille design concepts, each of which was generated using Disco Diffusion technology by extracting keywords related to technology, high-end, and business, and based on the front of a D-class car. The functional features of each concept are explained, and wireframes are provided with design highlights marked, as shown in **Figures 6-8**.

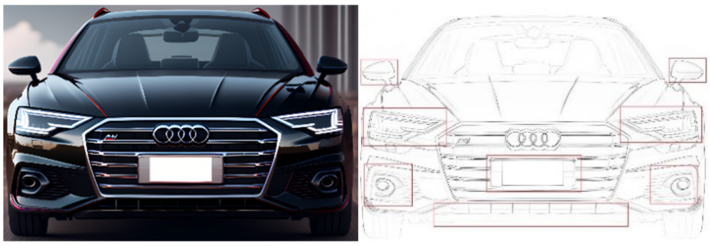

**Fig. 6.** frontal form scheme S1

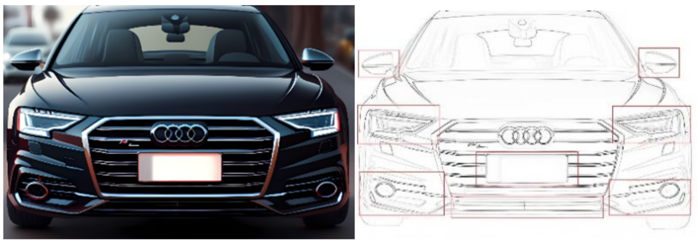

**Fig. 7.** frontal form scheme S2

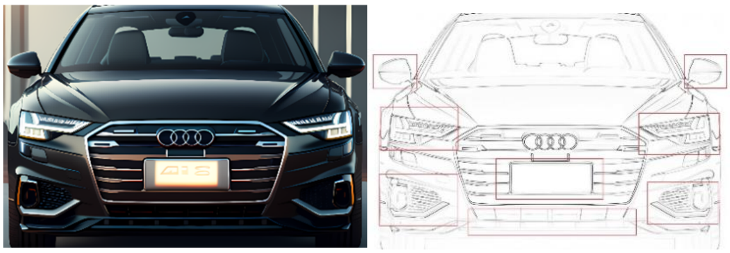

**Fig. 8.** frontal form scheme S3

A normalized triangular fuzzy decision matrix is then obtained according to equation (5) $\tilde{B} = [\tilde{b}_{ij}]_{3\times4}$ : By applying the method of triangular fuzzy number to it, a solution is preferred by the following process: to use light illumination $u_1$ , driving safety $u_2$ , driver assistability $u_3$ and vehicle interior requirements $u_4$ Five professional assessors were selected as the evaluation objectives $e_k(k = 1,2,3,4,5)$ The three front face options were $x_i(i = 1,2,3)$ according to the previously defined indicators $u_1$ , $u_2$ , $u_3$ , $u_4$ The corresponding evaluation values are given. The assessor is then asked to calculate the indicators $u_1$ , ,$u_2$ , $u_3$ , $u_4$ The calculated weight vectors are respectively $\omega^1 = (0.3,0.2,0.1,0.2,0.2)$ . $\omega^2 = (0.2,0.1,0.3,0.2,0.2)$ . $\omega^3 = (0.2,0.2,0.2,0.2,0.1)$ . $\omega^4 = (0.3,0.3,0.2,0.2,0.2)$ . The evaluators' ratings of the Functional Principles Program under each indicator are shown in the following table 8-12.

**Table 8.** Rater e1 's evaluation of the functional principles programme under each indicator

| Reviewer e1 | u1 | u2 | u3 | u4 |
|---|---|---|---|---|
| x1 | (0.80,0.80,0.80) | (0.80,0.90,0.95) | (0.75,0.85,0.85) | (0.80,0.90,0.90) |
| x2 | (0.70,0.80,0.90) | (0.75,0.85,0.98) | (0.70,0.85,0.95) | (0.90,0.90,0.95) |
| x3 | (0.75,0.85,0.90) | (0.90,0.90,0.95) | (0.80,0.90,0.90) | (0.75,0.85,0.85) |

**Table 9.** Rater $e_2$ 's evaluation of the functional principles programme under each indicator

| Reviewer e2 | u1 | u2 | u3 | u4 |
|---|---|---|---|---|
| x1 | (0.80,0.92,0.92) | (0.85,0.90,0.95) | (0.75,0.85,0.85) | (0.80,0.85,0.98) |
| x2 | (0.90,0.92,0.90) | (0.75,0.85,0.90) | (0.70,0.85,0.95) | (0.80,0.80,0.80) |
| x3 | (0.85,0.90,0.90) | (0.80,0.80,0.85) | (0.80,0.95,0.95) | (0.70,0.80,0.90) |

**Table 10.** Rater $e_3$ 's evaluation of the functional principles programme under each indicator

| Reviewer e3 | u1 | u2 | u3 | u4 |
|---|---|---|---|---|
| x1 | (0.80,0.91,0.91) | (0.85,0.90,0.95) | (0.75,0.85,0.85) | (0.86,0.90,0.90) |
| x2 | (0.90,0.92,0.94) | (0.75,0.85,0.92) | (0.70,0.85,0.95) | (0.80,0.80,0.90) |
| x3 | (0.75,091,0.90) | (0.80,0.91,0.85) | (0.80,0.95,0.94) | (0.75,0.80,0.85) |

**Table 11.** Rater $e_4$ 's evaluation of the functional principles programme under each indicator

| Reviewer e4 | u1 | u2 | u3 | u4 |
|---|---|---|---|---|
| x1 | (0.80,0.90,0.90) | (0.85,0.90,0.85) | (0.80,0.90,0.95) | (0.80,0.92,0.90) |
| x2 | (0.80,0.85,0.95) | (0.70,0.81,0.88) | (0.75,0.95,0.92) | (0.90,0.90,0.95) |
| x3 | (0.85,0.88,0.95) | (0.80,0.90,0.90) | (0.80,0.82,0.90) | (0.75,0.85,0.85) |

**Table 12.** Rater $e_5$ 's evaluation of the functional principles programme under each indicator

| Reviewer e5 | u1 | u2 | u3 | u4 |
|---|---|---|---|---|
| x1 | (0.82,0.84,0.79) | (0.82,0.90,0.95) | (0.75,0.85,0.85) | (0.83,0.80,0.98) |
| x2 | (0.70,0.80,0.90) | (0.85,0.80,0.93) | (0.70,0.87,0.95) | (0.93,0.92,0.85) |
| x3 | (0.75,0.85,0.85) | (0.92,0.88,0.90) | (0.83,0.95,0.90) | (0.88,0.85,0.95) |

Triangular model decision matrix based on the data in Tables 1, 2, 3, 4 and 5 $\tilde{A}^k(k1, 2, 3, 4, 5)$:

$$\tilde{A}^1 = \begin{bmatrix} [0.80\ 0.80\ 0.80] & [0.80\ 0.90\ 0.92] & [0.75\ 0.85\ 0.85] & [0.80\ 0.90\ 0.90] \\ [0.70\ 0.80\ 0.90] & [0.75\ 0.85\ 0.95] & [0.70\ 0.85\ 0.95] & [0.90\ 0.90\ 0.95] \\ [0.75\ 0.85\ 0.85] & [0.90\ 0.90\ 0.92] & [0.80\ 0.90\ 0.90] & [0.75\ 0.85\ 0.85] \end{bmatrix}$$

$$\tilde{A}^2 = \begin{bmatrix} [0.80\ 0.92\ 0.92] & [0.85\ 0.90\ 0.95] & [0.75\ 0.85\ 0.85] & [0.85\ 0.85\ 0.98] \\ [0.90\ 0.92\ 0.95] & [0.75\ 0.85\ 0.90] & [0.70\ 0.85\ 0.95] & [0.80\ 0.80\ 0.80] \\ [0.85\ 0.90\ 0.90] & [0.80\ 0.80\ 0.85] & [0.80\ 0.95\ 0.95] & [0.70\ 0.80\ 0.90] \end{bmatrix}$$

$$\tilde{A}^3 = \begin{bmatrix} [0.80\ 0.91\ 0.91] & [0.85\ 0.90\ 0.91] & [0.75\ 0.85\ 0.85] & [0.86\ 0.90\ 0.90] \\ [0.90\ 0.92\ 0.94] & [0.75\ 0.85\ 0.92] & [0.70\ 0.85\ 0.95] & [0.80\ 0.80\ 0.90] \\ [0.75\ 0.90\ 0.90] & [0.80\ 0.80\ 0.85] & [0.80\ 0.94\ 0.94] & [0.75\ 0.80\ 0.85] \end{bmatrix}$$

$$\tilde{A}^4 = \begin{bmatrix} [0.80\ 0.90\ 0.90] & [0.85\ 0.85\ 0.85] & [0.80\ 0.90\ 0.95] & [0.80\ 0.92\ 0.95] \\ [0.80\ 0.85\ 0.95] & [0.70\ 0.81\ 0.88] & [0.88\ 0.90\ 0.92] & [0.90\ 0.90\ 0.95] \\ [0.85\ 0.88\ 0.95] & [0.80\ 0.90\ 0.90] & [0.80\ 0.82\ 0.90] & [0.75\ 0.85\ 0.85] \end{bmatrix}$$

$$\tilde{A}^5 = \begin{bmatrix} [0.82\ 0.84\ 0.84] & [0.82\ 0.90\ 0.95] & [0.75\ 0.85\ 0.85] & [0.80\ 0.85\ 0.98] \\ [0.70\ 0.80\ 0.90] & [0.85\ 0.85\ 0.93] & [0.70\ 0.87\ 0.95] & [0.92\ 0.93\ 0.95] \\ [0.75\ 0.85\ 0.85] & [0.88\ 0.88\ 0.90] & [0.83\ 0.90\ 0.90] & [0.85\ 0.88\ 0.95] \end{bmatrix}$$

For the benefit-based evaluation indicators, the normalized triangular fuzzy number decision matrix is obtained$\tilde{R}^k(k = 1, 2, 3, 4, 5)$ as shown below:

$$\tilde{R}^k = \begin{matrix} & u_1 & u_2 & \cdots & u_n \\ x_1 & \tilde{r}_{11}^k & \tilde{r}_{12}^k & \cdots & \tilde{r}_{1n}^k \\ x_2 & \tilde{r}_{21}^k & \tilde{r}_{22}^k & & \tilde{r}_{2n}^k \\ \cdots & & \vdots & \ddots & \vdots \\ x_m & \tilde{r}_{n1}^k & \tilde{r}_{n2}^k & \cdots & \tilde{r}_{mn}^k \end{matrix} \quad k = 1,2,\ldots,k$$

$$\tilde{R}^1 = \begin{bmatrix} [0.31\ 0.33\ 0.36] & [0.29\ 0.33\ 0.38] & [0.28\ 0.33\ 0.38] & [0.30\ 0.34\ 0.37] \\ [0.27\ 0.33\ 0.40] & [0.27\ 0.35\ 0.39] & [0.26\ 0.33\ 0.42] & [0.33\ 0.34\ 0.39] \\ [0.29\ 0.35\ 0.38] & [0.32\ 0.33\ 0.38] & [0.30\ 0.35\ 0.40] & [0.28\ 0.32\ 0.35] \end{bmatrix}$$

$$\tilde{R}^2 = \begin{bmatrix} [0.29\ 0.34\ 0.36] & [0.31\ 0.35\ 0.40] & [0.27\ 0.32\ 0.42] & [0.32\ 0.35\ 0.42] \\ [0.32\ 0.34\ 0.37] & [0.28\ 0.33\ 0.38] & [0.25\ 0.32\ 0.42] & [0.30\ 0.33\ 0.34] \\ [0.31\ 0.33\ 0.35] & [0.30\ 0.31\ 0.35] & [0.29\ 0.36\ 0.42] & [0.26\ 0.33\ 0.38] \end{bmatrix}$$

$$\tilde{R}^3 = \begin{bmatrix} [0.29\ 0.33\ 0.37] & [0.32\ 0.35\ 0.38] & [0.27\ 0.32\ 0.38] & [0.32\ 0.36\ 0.37] \\ [0.33\ 0.34\ 0.38] & [0.28\ 0.33\ 0.38] & [0.26\ 0.32\ 0.42] & [0.30\ 0.32\ 0.37] \\ [0.27\ 0.33\ 0.37] & [0.30\ 0.31\ 0.35] & [0.29\ 0.36\ 0.42] & [0.28\ 0.32\ 0.35] \end{bmatrix}$$

$$\tilde{R}^4 = \begin{bmatrix} [0.20\ 0.32\ 0.39] & [0.31\ 0.33\ 0.36] & [0.29\ 0.34\ 0.38] & [0.28\ 0.32\ 0.38] \\ [0.29\ 0.34\ 0.39] & [0.29\ 0.35\ 0.42] & [0.32\ 0.34\ 0.37] & [0.38\ 0.33\ 0.34] \\ [0.29\ 0.33\ 0.37] & [0.29\ 0.32\ 0.37] & [0.29\ 0.31\ 0.36] & [0.32\ 0.35\ 0.41] \end{bmatrix}$$

$$\tilde{R}^5 = \begin{bmatrix} [0.32\ 0.34\ 0.37] & [0.29\ 0.34\ 0.37] & [0.28\ 0.32\ 0.37] & [0.28\ 0.32\ 0.38] \\ [0.270.32\ 0.40] & [0.31\ 0.32\ 0.36] & [0.26\ 0.33\ 0.42] & [0.32\ 0.35\ 0.37] \\ [0.29\ 0.34\ 0.37] & [0.32\ 0.33\ 0.35] & [0.31\ 0.34\ 0.39] & [0.30\ 0.33\ 0.37] \end{bmatrix}$$

Based on the average similarity and relative similarity of the rater's opinion set, the scheme can be obtained $x_i$ In the evaluation indicators $u_j$ rater $e_k$ .The combined degree of importance, here set $\alpha = 0.5$ .

A normalized triangular fuzzy decision matrix is then obtained according to equation (5)$\tilde{B} = [\tilde{b}_{ij}]_{3\times4}$ :

$$\tilde{B} = \begin{bmatrix} [0.28\ 0.33\ 0.37] & [0.30\ 0.34\ 0.38] & [0.28\ 0.33\ 0.38] & [0.30\ 0.34\ 0.38] \\ [0.30\ 0.33\ 0.39] & [0.29\ 0.34\ 0.39] & [0.27\ 0.33\ 0.41] & [0.33\ 0.33\ 0.36] \\ [0.29\ 0.34\ 0.37] & [0.31\ 0.32\ 0.36] & [0.30\ 0.34\ 0.40] & [0.29\ 0.33\ 0.37] \end{bmatrix}$$

Here the values of fuzzy attribute weights given by the rater are :

$\omega_1(0.30,0.36,0.45), \omega_2(0.35,0.40,0.50), \omega_3(0.20,0.24,0.30), \omega_4(0.31,0.34,0.40)$

The normalized weighted triangular fuzzy number decision matrix is then obtained as$\tilde{Z} = [\tilde{Z}_{ij}]_{3\times4}$

$$Z = \begin{bmatrix} [8.46\ 11.95\ 16.65] & [10.64\ 13.60\ 18.90] & [5.56\ 7.86\ 11.34] & [9.3\ 11.49\ 15.36] \\ [8.88\ 12.02\ 17.46] & [10.01\ 13.44\ 19.30] & [5.39\ 7.90\ 12.33] & [10.11\ 11.36\ 14.48] \\ [8.7\ 12.10\ 16.56] & [10.71\ 12.80\ 18.00] & [5.90\ 8.24\ 11.99] & [8.93\ 11.22\ 14.88] \end{bmatrix} \times 10^{-2}$$

Based on the above analysis the positive and negative ideal scenarios are:

$$X^+ = [[8.88,12.10,17.46][10.71,13.60,19.30][5.90,8.24,12.33][10.11,11.49,15.36]] \times 10^{-2}$$

$$X^- = [[8.46,11.95,16.56][10.01,12.80,18.00][5.39,7.86,11.34][8.93,11.22,14.48]] \times 10^{-2}$$

The final Euclidean distance is obtained

$$d^+ = [[0.96][0.51][1.20]] \times 10^{-2}, d^- = [[0.94][0.62][1.19]] \times 10^{-2}$$

Based on:$L(x_i) = \frac{d_i^-}{d_i^- + d_i^+}$ , calculate the proximity of the three options$L(x_i)$ as:

$$L(x_1) = 0.496\ , L(x_2) = 0.550\ , L(x_3) = 0.498$$

The proximity calculation shows that S2 has the highest proximity. Therefore, the S2 is rated relatively high in the overall evaluation of the car front.

## 5 CONCLUSIONS

In the evaluation of automobile front face design, a more comprehensive evaluation of the automobile front face is needed in conjunction with its functionality. This paper tries to establish a model based on hierarchical analysis to evaluate the front face of a car from the perspective of its functionality. The front face design of class A and B cars can focus more on functionality, while the front face of class D cars should focus on recognisability. This provides some reference for the judgement of incorporating functionality in the design of car fronts. The functional principle solution is selected by using the triangular fuzzy number to calculate the closeness of the three solutions, and finally a more suitable and scientific functional principle solution for the front of the car is selected. The use of the triangular fuzzy number to evaluate the functionality of the car's front face reduces the uncertainty of human judgement to a certain extent. By combining functionality and aesthetics to analyse the front face design of a car from a systematic perspective, it provides scholars and designers with a more comprehensive and scientific solution in the design of the front face of a car, which can be used as a reliable design support. However, this paper only provides a comprehensive analysis of the front face of a car, which is only a part of the car design and lacks a comprehensive analysis of its entire car.

## References


[1] J.-B. Bluntzer, E. Ostrosi, and J.-C. Sagot: Styling of cars: is there a relationship between the style of cars and the culture identity of a specific country?. Proceedings of the Institution of Mechanical Engineers Part D-Journal of Automobile Engineering. Article vol. 229, no. 1, pp. 38-51 (2015)

[2] G. Calabrese: Structure and transformation of the Italian car styling supply chain. International Journal of Vehicle Design. Article vol. 57, no. 2-3, pp. 212-229 (2011)

[3] H. K. Min: A Study on Car Interior Design by User Interface. Journal of Cultural Product & Design. research-article vol. 58, pp. 319-328 (2019)

[4] N. Meng and Y. J. Bum: Research on the Influence of Visual Attention in “Fractal” Visual Design -Focus on Car Poster Design. Journal of the Korean Society of Design Culture. research-article vol. 27, no. 3, pp. 151-161 (2021)

[5] M. Tavana, M. Soltanifar, and F. J. Santos-Arteaga: Analytical hierarchy process: revolution and evolution. Annals of Operations Research. Article; Early Access (2021)

[6] D. Yu, G. Kou, Z. Xu, and S. Shi: Analysis of Collaboration Evolution in AHP Research: 1982-2018. International Journal of Information Technology & Decision Making. Article vol. 20, no. 01, pp. 7-36 (2021)

[7] X. Zhang, W. Ma, and L. Chen: New Similarity of Triangular Fuzzy Number and Its Application. Scientific World Journal. Article 2014, Art no. 215047 (2014)

[8] Y. Du, W. Chen, K. Cui, and K. Zhang: Study on Damage Assessment of Earthen Sites of the Ming Great Wall in Qinghai Province Based on Fuzzy-AHP and AHP-TOPSIS. International Journal of Architectural Heritage. Article vol. 14, no. 6, pp. 903-916 (2020)

[9] S. H. Zyoud and D. Fuchs-Hanusch: Comparison of Several Decision-Making Techniques: A Case of Water Losses Management in Developing Countries. International Journal of Information Technology & Decision Making. Article vol. 18, no. 5, pp. 1551-1578 (2019)

[10] B. Buran and M. Ercek: Public transportation business model evaluation with Spherical and Intuitionistic AHP and sensitivity analysis. Expert Systems with Applications, Article vol. 204 (2022)

[11] R. B. Mudashiru, N. Sabtu, R. Abdullah, A. Saleh, and I. Abustan: A comparison of three multi-criteria decision-making models in mapping flood hazard areas of Northeast Penang, Malaysia. Natural Hazards. Article vol. 112, no. 3, pp. 1903-1939 (2022)

[12] M. A. Hapsari and S. Subiyanto: Fuzzy AHP Based Optimal Design Building-Attached Photovoltaic System for Academic Campus. International Journal of Photoenergy. vol. 2020, Jan (2020)

[13] X. Chen, Y. Fang, J. Chai, and Z. Xu: Does Intuitionistic Fuzzy Analytic Hierarchy Process Work Better Than Analytic Hierarchy Process?. International Journal of Fuzzy Systems. Article vol. 24, no. 2, pp. 909-924 (2022)
[14] W. Hou and C. Niu: A consumer-oriented car style evaluation system based on fuzzy mathematics and neural network. International Journal of Circuits. Systems and Signal Processing, vol. 15, pp. 986-995 (2021)
[15] F. Kutlu Gundogdu and C. Kahraman: A novel spherical fuzzy analytic hierarchy process and its renewable energy application. Soft Computing, Article vol. 24, no. 6, pp. 4607-4621 (2020)
[16] F. Amin, A. Fahmi, and M. Aslam: Approaches to multiple attribute group decision making based on triangular cubic linguistic uncertain fuzzy aggregation operators: Soft Computing. Article vol. 24, no. 15, pp. 11511-11533 (2020)
[17] K. Yin, B. Yang, and X. Jin: Grey Fuzzy Multiple Attribute Group Decision-Making Methods Based on Interval Grey Triangular Fuzzy Numbers Partitioned Bonferroni Mean. Symmetry-Basel. Article vol. 12, no. 4 (2020)
[18] H. M. Lyu, W. J. Sun, S. L. Shen, and A. N. Zhou. Risk Assessment Using a New Consulting Process in Fuzzy AHP. Journal of Construction Engineering and Management. vol. 146, no. 3 (2020)
[19] S. Faizi, W. Salabun, S. Ullah, T. Rashid, and J. Wieckowski: A New Method to Support Decision-Making in an Uncertain Environment Based on Normalized Interval-Valued Triangular Fuzzy Numbers and COMET Technique. Symmetry-Basel. vol. 12, no. (2020)