Article

Evaluation and Optimization of In-Vehicle HUD Design by Applying an Entropy Weight-VIKOR Hybrid Method

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Featured Application: HUD is of great significance to the development of automobile intelligent cockpit. The interface design of HUD has an impact on the cognitive load and situation awareness of drivers. Therefore, it is necessary to optimize and evaluate the interface design.

Abstract: Background: With the trend of intelligent display, the interface design of in-vehicle HUD is an expanding research field; Methods: To solve the subjectivity and uncertainty in the optimization of HUD interface design schemes, this paper proposed a hybrid scheme evaluation and optimization method based on entropy weight and VIKOR. The entropy weight method was used to reduce the subjectivity the decision-maker's weighting and obtain the objective weight of each indicator; The VIKOR method was used to obtain the best ranking of alternative schemes, and then the optimal interface design scheme was selected; Results: The evaluation of in-vehicle HUD interface design schemes were taken as an example for verification and calculation. The results showed that this method considers the subjectivity and uncertainty of the decision-making process in the optimization of design scheme, which can effectively improve the objectivity and accuracy of the evaluation results, and provide a reference for designers to optimize interface design schemes.

Keywords: Entropy weight; VIKOR method; Head-up display; Interface design; Design evaluation; Scheme optimization

1. Introduction

With the maturity and development of intelligent transportation, a large number of in-vehicle information systems (IVIS), such as smartphones, satellite radios, and head-up displays (HUD) are constantly pouring into the car, and the IVIS has developed from the early basic driving-related information to a multidimensional interaction system [1,2]. The all-over displays represent an important symbol in the digitalization of the future automobile [3]. Particularly, 80 percent of the driving information is visually perceived [4], so visual interface design is of great significance to the usability of the human-machine interface (HMI).

The issue of design evaluation and optimization is a complex multi-criteria decision-making problem [5,6]. The evaluation and decision-making of the design scheme exert the most obvious impact on the results of the later design stage. The early design information of the product is vague and incomplete, and the evaluation values of alternative design schemes under different indicators are often determined by experts subjectively based on their professional knowledge and experience. Thus, the evaluation process of product design schemes is ambiguous and subjective. The evaluation of the design scheme is an important part of the product research and development process, and whether the optimi-

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zation is reasonable serves as the key to subsequent product development, even determines the success of product research and development as well. Hence the evaluation and optimization of design schemes are hot topics in academia and industry fields [7-9].

There are a variety of methods commonly used in evaluation and optimization of design schemes, the multi-criteria decision making (MCDM) analysis can be an appropriate tool in these conditions [10], such as the Analytic Hierarchy Process (AHP), fuzzy comprehensive evaluation, The technique of order preference by similarity to ideal solution (TOPSIS), and Entropy weight method. Xu [11] proposed an evaluation method that combines AHP and fuzzy comprehensive evaluation and applied it to the decision-making of RV design schemes. Višekriterijumsko kompromisno rangiranje (VIKOR) method was employed by Simab et al. [12] to select the best condition in a pumped hydro-thermal scheduling problem. Anna [13] applied VIKOR method to calculate the parameters of the process based on entropy. Tiwari et al. [14] used soft set and entropy weight theory to obtain design specifications and customer needs qualitatively, and then applied entropy weight methods to determine the best solution. Sarina et al. [15] proposed a complex product scheme joint variable weight VIKOR group decision-making method to achieve a balanced evaluation process between product scheme performance indicators and cost indicators with uncertainty in the weight of evaluation indicators.

Most of the existing evaluation methods are the qualitative evaluations of the design schemes, and the review experts come from different professional fields and have different preferences for evaluation criteria, which may lead to a certain degree of subjectivity in the results of the product design scheme [16]. The VIKOR method has great advantages in obtaining the inevitability between the ideal scheme and data processing, and it is a multi-attribute decision-making method based on the ideal point [17], which has been widely used in multi-criteria decision-making problems.

In this paper, an entropy weight-based VIKOR method is proposed for evaluating and optimizing the in-vehicle HUD design schemes. The entropy weight method was used to reduce the subjective factors of decision-makers entrusting with the weight, and the objective weight of each indicator was obtained; the VIKOR method was applied to attain the best ranking of the alternatives, and then the best product design scheme was optimized. This hybrid method determines the weight unbiasedly and effectively, avoids the subjectivity and randomness of weight decision-making, and can evaluate the design scheme by the preference of decision-makers, thus providing a mathematical basis for product design scheme optimization.

2. Theory background

2.1. Entropy weight

The entropy weight method was first transferred from the field of thermodynamics to the information domain [18]. The entropy weight method is based on the difference in data, and the weight of each indicator is obtained by the entropy calculation formula, which is widely used in various fields [19]. While subjective methods (e.g. Delphi and AHP) are used to determine subjective weights of criteria, objective methods such as the entropy weight method are utilized to eliminate man-made instabilities and yield more realistic results [20]. The entropy weight method can reflect the utility value of sample information entropy value, without introducing subjective assumptions, and the obtained indicator weight is more objective[21]. Subjective weights could be obtained directly from the decision makers' opinions like many other MCDM processes [22]. When the method is applied, firstly, experts are invited to score the actual situation of the project, and the scoring matrix is obtained; then the score matrix is normalized, the entropy value of each indicator is solved, and the weight of each indicator is calculated.

2.2. VIKOR method

Like the MCDM problem, there are many influencing factors in the process of product design, TOPSIS and VIKOR are two typical multi-criteria compromise methods [23].

Among them, the VIKOR method can maximize group utility, and its compromise solution can be accepted by decision-makers. VIKOR is a multi-attribute optimization decision-making method put forward by Opricovic in 1998 [24-26]. It introduces the multi-criteria ranking index based on the particular measure of "closeness" to the "ideal" solution [27]. It is an optimization compromise solution in multi-attribute decision-making, and it is also a decision-making method based on the rational point method [26]. In the process of ranking, the VIKOR method completes the ranking of the advantages and disadvantages of the schemes to be evaluated according to the comparison of group utility value, regret value, and comprehensive utility value, and the optimal scheme obtained by this method is closest to the ideal scheme.

VIKOR is a helpful tool in MCDM, particularly in a situation where the decision-maker is not able or does not know to express his/her preference at the beginning of system design [28], however, it has great defects when used independently, and it can solve different problems by combining with other methods. In this paper, the entropy weight method and VIKOR method are combined, and the objective weight of each indicator is obtained by the entropy weight method. By applying the VIKOR method, the best order of alternative schemes that maximize group benefits and minimize individual regrets is obtained, and the best product design scheme is obtained.

3. Proposed methodology

Through the entropy weight system, the subjective factors of decision-makers in weighting are excluded, and the objective weights of each indicator are obtained. By using the VIKOR method, the best order of compromise candidate schemes to maximize group benefits and minimize individual regrets is obtained, and the best product design scheme is obtained. The evaluation and optimization process of the design scheme based on entropy weight and the VIKOR method is shown in Figure 1.

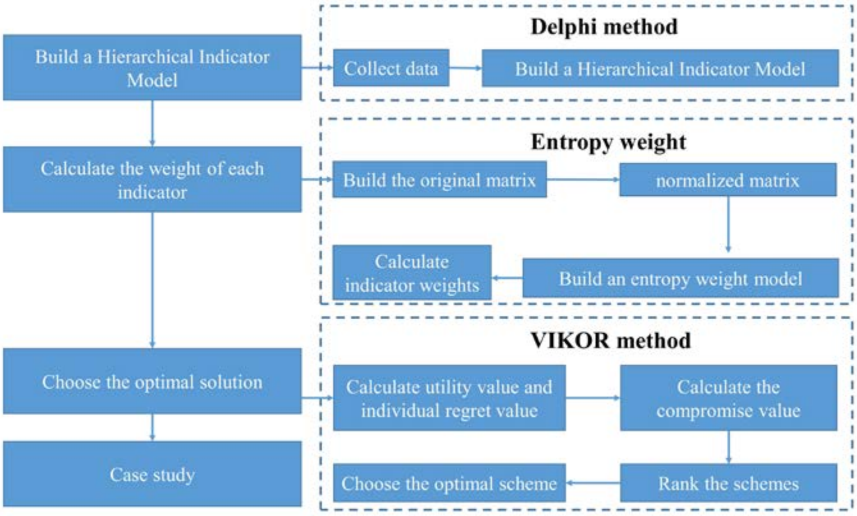

Figure 1. Design scheme evaluation and optimization process based on entropy weight and VIKOR method.

3.1. Establishment of evaluation indicator model

The optimization and evaluation of the interface design scheme is a complex multi-indicator decision-making problem, and the selection of evaluation indicators has the characteristics of integrity and non-overlap. Interface design is an integrated system design, including function, layout, human factors, and aesthetic aspects [29,30]. Taking the design of the in-vehicle HUD interface as an example, field research, online questionnaire survey, and user interviews are conducted to explore the factors affecting the design points of HUD interface [31,32]. In-vehicle HUD should first meet the basic functional

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requirements of information display and navigation, and then increase the auxiliary functions of non-driving related tasks (NDRT) such as entertainment systems to improve product added value. When the driver interacts with HUD, the interface needs to be visible enough and easy to read. Therefore, readability is also an evaluation indicator that cannot be ignored [33,34]. The ultimate goal of the design is to provide a better user experience. Aesthetic considerations in design can improve user experience, and aesthetics can be analysed from the colour application, symbol design, and interface layout.

Through the multi-round Delphi method [35], the collected data and evaluation indicator factors are analysed and discussed. Combined with the PSSUQ (Post-Study System Usability Questionnaire)[36], 3 evaluation indicators of the level 1 criteria layer and 15 evaluation indicators of the level 2 criteria layer for the evaluation of in-vehicle HUD interface design scheme are finally obtained. The level 1 layer has three criteria: usability, information quality, and interface quality. It has the requirements of independence, non-overlap, and integrity. At the same time, it has a certain degree of progression in the experience level. A_1-A_4 represents the level 2 criterion layer of availability; B_1-B_4 represents the level 2 criterion layer of information quality; C_1-C_4 represents the level 2 criterion layer of interface quality, as shown in Table 1.

Table 1. In-vehicle HUD interface design evaluation indicator system.

Layer 1	Layer 2
Usability	A_1: Generally, I think this interface is easy to operate. A_2: The interface is useful for completing my task. A_3: I can use this product to complete tasks quickly. A_4: Good display effect (appropriate brightness, no ghost shadow and no dizziness). A_5: This interface is easy to learn how to use. A_6: The error prompt on the interface can guide me on how to solve the problem. A_7: When the operation is wrong, I can quickly and simply start over.
Information quality	B_1: The interface provides clear information (such as help and tips) B_2: The information provided is easy to understand. B_3: This information is useful to complete the task. B_4: The information organization structure on the interface is clear.
Interface quality	C_1: The information of the interface will not cause visual obstruction. C_2: The interface makes me feel happy and comfortable. C_3: I like the interface of this product. C_4: The product has all the functions expected.

3.2. *Weight calculation of each indicator*

3.2.1. Create an initial evaluation matrix

According to the theoretical research of VIKOR [25], there are m solutions in the evaluation system, and each solution has n evaluation indicators. The evaluation value of each indicator of the solution m is expressed by a_{ij}, to establish the original matrix of $m \times n$.

$$\mathbf{A}=\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{12} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix} \tag{1}$$

3.2.2. Normalized evaluation matrix

The matrix is normalized by the vector normalization method [37]. According to Eq. (2) and Eq. (3), the cost type and beneficial type are normalized, and the matrix X can be calculated as follows:

$$x_{ij}=\frac{a_{ij}}{\sqrt{\sum_{i=1}^{m} a_{ij}^2}} \quad (j \in \text{benificial type}) \tag{2}$$

$$x_{ij}=\frac{\frac{1}{a_{ij}}}{\sqrt{\sum_{i=1}^{m} \left(\frac{1}{a_{ij}}\right)^2}} \quad (j \in \text{cost type}) \tag{3}$$

$$\mathbf{X}=\begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{12} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}$$

3.2.3. Establishing entropy weight model

Based on the calculation model of the entropy weight method [21], after defining the $m \times n$ evaluation matrix, the attribute value proportion of the j-th decision indicator of the i-th scheme can be computed as:

$$p_{ij}=\frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \tag{4}$$

Then calculate the entropy of the j-th decision indicator:

$$e_j=-k\sum_{i=1}^{m} p_{ij} \ln p_{ij} \tag{5}$$

where k is constant, $k = {}^{1}/_{\ln m}$.

Finally, the entropy weight value of each indicator is expressed by the following equation:

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$$w_j = \frac{1-e_j}{\sum_{j=1}^{n}(1-e_j)} \tag{6}$$

3.3. Optimize the design scheme

3.3.1. Computation of utility value S_i and individual regret R_i

$$S_i = \sum_{j=1}^{n} \frac{w_j(x_j^+ - x_{ij})}{x_j^+ - x_j^-} \tag{7}$$

$$R_i = \max_j \left\{ \frac{w_j(x_j^+ - x_{ij})}{x_j^+ - x_j^-} \right\} \tag{8}$$

Where: x_j^+ is the positive ideal solution, $x_j^+ = \max_j\{x_{ij}\}$;

x_j^- is the negative ideal solution, $x_j^- = \min_j\{x_{ij}\}$.

3.3.2. Determine the compromise value of the candidate schemes Qi:

In the last stage, the compromise value Qi can be calculated on the basis of the equation:

$$Q_i = \varepsilon \frac{S_i - S^-}{S^+ - S^-} + (1-\varepsilon)\frac{R_i - R^-}{R^+ - R^-} \tag{9}$$

Where: $S^+ = \max_i\{S_i\}$;

$S^- = \min_i\{S_i\}$;

$R^+ = \max_i\{R_i\}$;

$R^- = \min_i\{R_i\}$;

ε- compromise coefficient, which is held as 0.5 [38], $\varepsilon \in [0,1]$. When $\varepsilon > 0.5$, it means taking the maximization of group interests as the decision basis; when $\varepsilon < 0.5$, the decision is based on individual regret minimization;

3.3.3. Determination of optimal scheme

The determination of the optimal scheme is divided into two steps:

1. The alternatives are arranged in descending order by the values of Si, Ri, and Qi ;
2. Ranked by Q from small to large, option a1 at position 1 is the best option if it satisfies the following two conditions:

- Condition 1: $Q(a_2) - Q(a_1) \geq 1 / (m-1)$, a_2 is the second scheme by Qi value, and m represents the number of alternative schemes.
- Condition 2: Acceptable decision stability, option a_1 must be ranked first in Si or Ri values and remain stable in decision making.

If both conditions 1 and 2 are satisfied, a1 is the best scheme; If only condition 1 is satisfied, there is a compromise solution set $\{a_1, a_2\}$; If only the condition 2 is satisfied, there is a compromise solution set $\{a_1, a_2, \ldots, a_m\}$, and the maximum value of m is determined by the $Q(a_2) - Q(a_1) \geq 1 / (m-1)$, to determine the compromise solution set.

4. Case study

4.1. HUD interface design

In this paper, three in-vehicle HUD interface designs were introduced to verify the proposed methodology. Based on the features of the HUD interface which has been mass-produced in the market at present [31], some key information was extracted for interface design, and an evaluation indicator system was set up (Table 1). HUD experts in human factors and display technology applied 9-level scales to assign the evaluation indicators and make reliability and validity analysis of each indicator score in SPSS. The Cronbach α (0.860) and KMO coefficient (0.812) are both greater than 0.80, which showed the high reliability and rationality of these evaluation indicators.

The three candidate schemes are shown in Figures 2-4 and we apply the Entropy Weight-VIKOR method to evaluate and optimize the design schemes. Each scheme includes the Classic, Minimalism, and Sport mode, and the design elements and complexity of each mode are different. Here are three schemes as follows:

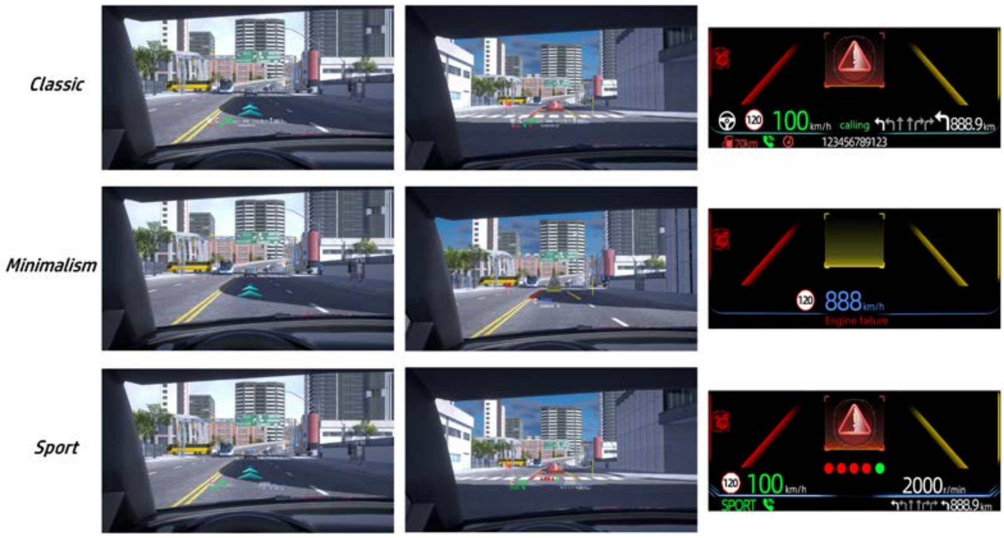

Figure 2. HUD interface design scheme 1. This scheme adopts the solid boomerang navigation icon. The arrow thickness is appropriately increased in the design, and the light and shadow effect is added to make it more stereoscopic visually. As for WSP (Warning System for Pedestrians) and FCWS (Forward Collision Warning System) design, the icons are designed in the form of squares as a whole, and the specific presentation forms change with the different HUD system modes. e.g. In minimalism mode, only one semi-transparent warning rectangle is displayed.

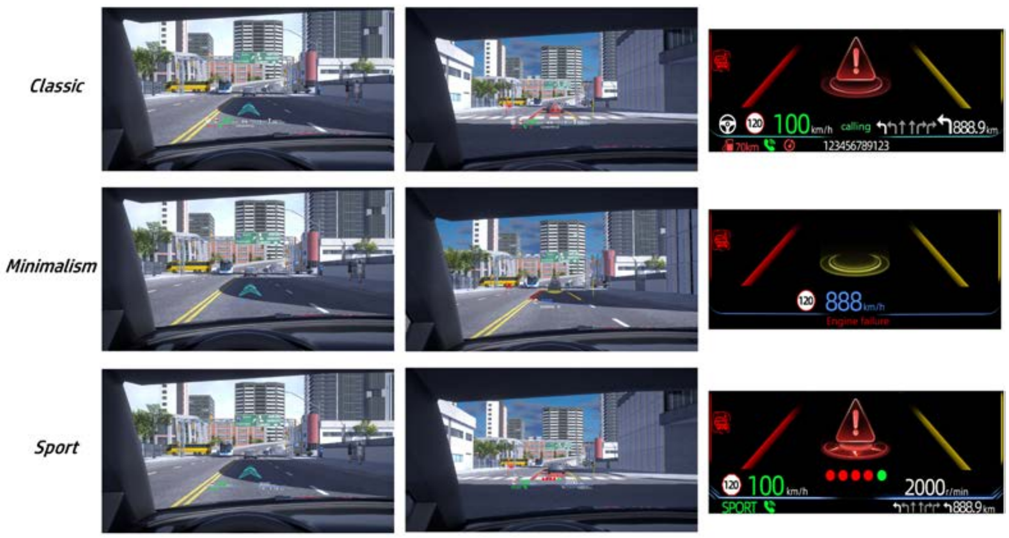

Figure 3. HUD interface design scheme 2. Scheme 2 adopts hollow navigation arrows, which enhance the integration of AR icons and the real environment and avoids visual obstruction to road

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conditions. Cyclic annular warning icons are designed for the WSP and FCWS. To be specific, icons in sport mode are designed to be more dynamic and powerful.

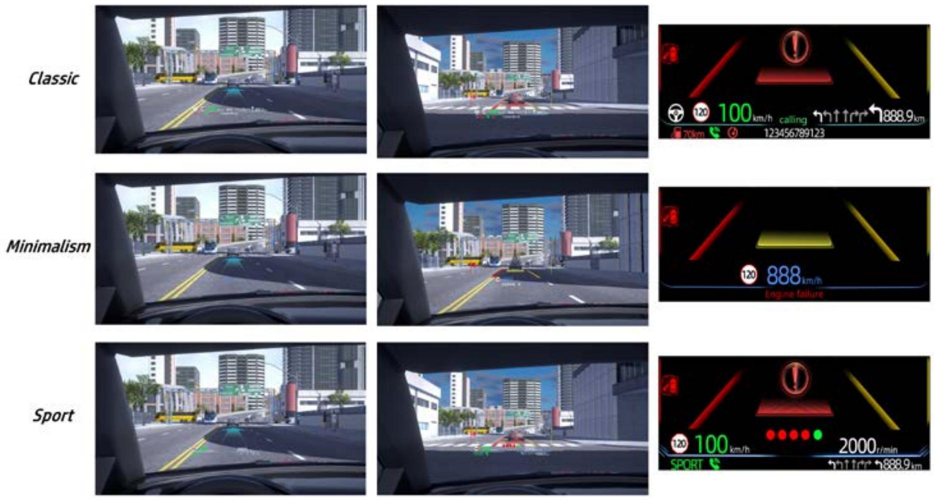

Figure 4. HUD interface design scheme 3. The plane navigation arrow is used in scheme 3. Although it seems to occupy a lot of visual space, the plane arrow is fading to transparent at its back end, so it is actually like a solid arrow with a tail outlined. Semi-transparent triangle background and circular warning icon are used for FCWS.

4.2. Optimizing design schemes

4.2.1. Establish an initial evaluation matrix

A total of 20 R&D staff (designers and system testers) were recruited, including 10 males and 10 females ($Mean_{age}$=32.5, SD_{age}=4.17). In accordance with the in-vehicle HUD interface design evaluation indicator system (Table 1), we used the 9-level scale (1-terrible, 9-excellent) to assign values to each evaluation indicator of the 3 design schemes, calculated their mean value, and thus obtained the initial evaluation value of the scheme, as shown in Table 2, and established the initial evaluation matrix A based on Table 2.

$$\mathbf{A} = \begin{bmatrix} 8.2 & 8.0 & 8.2 & 8.2 & 8.3 & 8.0 & 8.0 & 8.3 & 7.6 & 8.0 & 8.0 & 8.1 & 7.8 & 7.3 & 7.7 \\ 7.9 & 8.0 & 7.8 & 7.9 & 7.9 & 7.5 & 7.3 & 4.0 & 7.4 & 7.6 & 7.7 & 7.9 & 7.6 & 7.3 & 7.4 \\ 7.8 & 8.0 & 7.7 & 7.2 & 7.8 & 7.6 & 7.6 & 3.0 & 7.1 & 7.5 & 3.0 & 8.0 & 7.2 & 7.0 & 7.2 \end{bmatrix}$$

Table 2. Initial evaluation value of schemes.

Evaluation layer	Evaluation indicator	Scheme 1	Scheme 2	Scheme 3	Indicator type
Usability	A1	8.1	7.9	7.8	beneficial
	A2	8.0	8.0	8.0	beneficial
	A3	8.2	7.8	7.7	beneficial
	A4	8.2	7.9	7.2	beneficial
	A5	8.3	7.9	7.8	beneficial
	A6	8.0	7.5	7.6	beneficial
	A7	8.0	7.3	7.6	beneficial
Interface quality	B1	8.3	4.0	3.0	beneficial
	B2	7.6	7.4	7.1	beneficial
	B3	8.0	7.6	7.5	beneficial
	B4	8.0	7.7	3.0	beneficial
	C1	8.1	7.9	8.0	beneficial
	C2	7.8	7.6	7.2	beneficial

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Information quality	C3	7.3	7.3	7.0	beneficial
	C4	7.7	7.4	7.2	beneficial

4.2.2. Normalized evaluation matrix

According to the calculation method of VIKOR decision, all evaluation indicators in the evaluation system are of beneficial type, so they were normalized by Eq. (2) to obtain matrix ***X***:

$$\mathbf{X}=\begin{bmatrix} 0.594 & 0.577 & 0.599 & 0.609 & 0.599 & 0.600 & 0.605 & 0.857 & 0.595 & 0.600 & 0.696 & 0.585 & 0.597 & 0.585 & 0.598 \\ 0.572 & 0.577 & 0.570 & 0.586 & 0.570 & 0.562 & 0.551 & 0.412 & 0.580 & 0.570 & 0.669 & 0.570 & 0.582 & 0.585 & 0.575 \\ 0.565 & 0.577 & 0.563 & 0.534 & 0.563 & 0.570 & 0.574 & 0.310 & 0.556 & 0.562 & 0.260 & 0.577 & 0.552 & 0.561 & 0.559 \end{bmatrix}$$

4.2.3. Computation of the weight of each indicator w_j

Calculate the weight w_j value of each indicator through Eq. (6), as shown in Table 3.

Table 3. Calculation of each indicator weight w_j.

Indicator	w_j	Indicator	w_j
A1	0.000	B2	0.0057
A2	0.000	B3	0.0057
A3	0.0057	B4	0.4425
A4	0.000	C1	0.000
A5	0.0057	C2	0.0057
A6	0.0057	C3	0.000
A7	0.000	C4	0.0057
B1	0.5057	-	-

4.2.4. Optimizing the design scheme

On the basis of Eq. (7) and Eq. (8), we calculated the S_i, R_i, and Q_i of the three schemes respectively, and arranged them in ascending order. The calculated values of scheme evaluation are shown in Table 4.

Table 4. S_i, R_i, and Q_i of each scheme.

No.	S_i	R_i	Q_i
1	0.141	0.119	0.000
2	0.541	0.377	0.628
3	0.932	0.463	1.000

According to the evaluation VIKOR method best scheme, the schemes are arranged in ascending order of their compromise value Q_i and are sorted into scheme 1, scheme 2, and scheme 3. Condition 1 is satisfied due to inequality $Q(a_2) - Q(a_1) \geq 1 / (m-1)$; a_1 is the best ranking among S_i and R_i values, and the order of group utility value and individual regret value is the same as the compromise value, so condition 2 is satisfied. As a consequence, scheme 1 is the optimized scheme.

5. Discussion

In this paper, an entropy weight-based VIKOR method is proposed to optimize the scheme of in-vehicle interface design. A case study involving a HUD concept design was employed to demonstrate the proposed method. To verify the correctness of entropy weight and VIKOR design scheme evaluation and optimization method, we compare the proposed method with other decision-making methods. e.g. the FCE (fuzzy comprehensive evaluation) [39], the GRA (grey relational analysis) [40], the TOPSIS method [28]. And the schemes' evaluation values and ranking results obtained by the three methods are shown in Table 5.

Table 5. Evaluation result using different methods.

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Method	Scheme 1	Scheme 2	Scheme 3	Ranking
Proposed method	0.00	0.63	1.00	1>2>3
FCE	0.78	0.13	0.22	1>3>2
GRA	0.81	0.47	0.39	1>2>3
TOPSIS	0.15	0.39	0.48	1>2>3

Where FCE is expressed by comprehensive evaluation value. The larger the evaluation value, the better the scheme; the TOPSIS method is expressed by the degree of closeness to the positive ideal scheme. The smaller the evaluation value, the better the scheme; The GRA method is expressed by grey correlation degree, the larger the evaluation value, the better the scheme. It can be seen from Table 5 that scheme 1 is the first-rate all along. Except for the deviation in ranking between scheme 2 and scheme 3 of the FCE method, the ranking of other schemes is consistent, which proves the feasibility and rationality of the proposed method. Next, we will discuss the advantages of this proposed method and the other three MCDM methods respectively.

Compared with the fuzzy comprehensive evaluation method, the evaluation of the relative importance of each indicator element in the fuzzy comprehensive evaluation method has a degree of subjective uncertainty, and cannot solve the problem of repeated evaluation information caused by the correlation between indicator factors; In this paper, the entropy weight method was used to reduce the subjective factors in the weighting, and a more objective weight model for design scheme evaluation was established to make the evaluation results more accurate. In addition, we found very little differences between the values of each scheme in the fuzzy comprehensive evaluation method, and there will be ranking deviation (Table 5), and the order of scheme 2 and scheme 3 is opposite.

Compared with the TOPSIS method, the difference between the evaluation values calculated by the TOPSIS method is quite minor, and the distribution is dense. However, the excessively accurate ranking would appear in reverse order, and the final result is not necessarily the optimal scheme. In the ranking process of the VIKOR method, the advantages of evaluation schemes are ranked by the comparison of group utility value, regret value, and comprehensive utility value. The optimal scheme obtained by this method is the closest to the ideal scheme. As shown in Table 5, the difference between the scheme values calculated by the TOPSIS method is small, which may not be suitable for the decision-making of mass schemes, and the VIKOR method will show greater advantages on this occasion.

When it comes to the grey relational analysis method, we generally invite several industry experts to score the schemes and obtain the grey correlation value, which is highly subjective [41], and the difference between the decision-making values of each scheme is small. As shown in Table 5, the difference between the maximum value and the minimum value is only 0.42. When there are many schemes, however, it is not conducive for the decision-makers to make more objective judgments.

6. Conclusions

Aiming at the subjectivity and uncertainty of product design schemes optimization, a design scheme evaluation and optimization method based on entropy weight and VIKOR was proposed. Taking the in-vehicle HUD interface design as an example, the results showed that the method can be applied to the evaluation and optimization of design schemes of related products.

Using the entropy weight method, a more objective weight model for design scheme evaluation was established. VIKOR method was used to get the best ranking of alternatives, and then the best product design scheme is screened out. The evaluation and optimization method of design schemes based on entropy weight and VIKOR can effectively improve the objectivity and accuracy of scheme evaluation results, and provide a reference for designers to optimize product design schemes. The entropy weight method is used to determine the weight value of the scheme, which excludes the subjective preference of the decision-maker, and ignores the auxiliary and corrective effect of the decision-maker on the design scheme to a certain extent. In further work, it is worth considering the combination of physiological factors, e.g. eye tracking, EEG (Electroencephalogram), EDA (Electrodermal activity) [42], when evaluating and optimizing the design schemes.

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