Construction of Hydrogen Safety Evaluation Model Based on Analytic Hierarchy Process (AHP)

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With the large consumption of traditional primary energy, hydrogen as a clean and renewable energy has been widely studied by scholars around the world. Hydrogen is mainly used in hydrogen internal combustion engine and hydrogen fuel cell. Hydrogen internal combustion engine is the direct combustion of hydrogen as fuel, with the advantages of easy use. Alternatively, hydrogen fuel cell converts the chemical energy of hydrogen into electrical energy by electrochemical reaction, which has the advantages of high efficiency and zero pollution. Regardless of the use method, the safety of hydrogen use needs to be considered. However, in the whole life cycle of hydrogen, the process from hydrogen production to the use of hydrogen in automobiles is extremely complex. There are many factors affecting the safety of hydrogen use, and a single factor cannot be used as an evaluation. In order to make the evaluation of hydrogen safety more complete and accurate, the weight of four primary evaluation indexes and eight secondary evaluation indexes affecting hydrogen safety is determined by analytic hierarchy process, and a reliable hydrogen safety evaluation model is established.

Keywords: Analytic Hierarchy Process (AHP); Multi-objective evaluation; Hydrogen safety grade; Hydrogen fuel cell; Alternative energy sources

Introduction

Since the second industrial revolution, the emergence of internal combustion engines has accelerated the global industrial development. Various chemical energy sources have been consumed in large quantities. Oil, coal and natural gas are called the three major energy sources. These three energy sources are all non-renewable primary energy sources. Consumption in the long past can eventually lead to energy shortages. Various renewable clean energy sources have been widely studied as alternative energy sources, in which wind and solar energy account for a large proportion. Solar and wind energy are generally used for photovoltaic power generation and wind power generation, respectively. According to the results released by the World Energy Statistical Yearbook in 2019 [1], the solar and wind energy consumption in the seven regions of the world has increased compared with previous years. The solar and wind energy consumption in the Asia-Pacific region is the highest, reaching 225.4 million tons of oil equivalent, while the proportion of solar and wind energy consumption in the primary energy consumption in Europe is the highest, reaching 8.4 % (172.2 million tons of oil equivalent). Among many

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countries in the world, China's solar and wind energy consumption is 143.5 million tons of oil equivalent, ranking first in the world. The proportion of solar and wind energy consumption in primary energy consumption in Germany is the highest, which is 14.6 % (47.3 million tons of oil equivalent).

Solar energy and wind energy can be used to generate electricity as alternative energy as an alternative to coal. As the power device of many large and small machinery, internal combustion engines are mainly fueled by oil, and new alternative fuels for vehicles need to be found [2]. At present, vehicle alternative fuels can be divided into three categories, *i.e.,* gas (like natural gas, hydrogen) [3,4], battery (such as pure electric and fuel cells) [5,6], and alcohols (methanol, ethanol, butanol, dimethyl ether) [7,8]. Methane and alcohol alternative fuels are essentially hydrocarbon fuels. Compared with gasoline and diesel, they will reduce CO, CO_2 and unburned hydrocarbons (HC) emissions during combustion. When emission regulations are more stringent, these alternative fuels are no longer applicable. Hydrogen only contains hydrogen, and the product after combustion is water, which is a real clean energy.

Hydrogen as fuel has the advantages of high efficiency, no pollution, high calorific value and easy access. Hydrogen is an ideal alternative fuel for vehicles, but due to its low density, in order to improve its energy density per unit volume, it is necessary to use high-pressure storage technology. High pressure means high risk. From hydrogen production to storage and transportation to use, every step should consider the safety of hydrogen. Generally speaking, hydrogen security includes hydrogen supply station security, hydrogen supply system (equipment for storing and transporting hydrogen, combination of pipelines and accessories) security, hydrogen transportation system security, collision security and vehicle security. The hydrogen safety in this paper mainly refers to the hydrogen safety of hydrogen fuel cell vehicles. The safety problems of fuel cell vehicles mainly include four aspects: hydrogen storage safety, hydrogen transportation safety, hydrogen collision safety and hydrogen application. In order to make the evaluation of hydrogen safety more comprehensive and intuitive, this study established a hydrogen safety evaluation model.

Construction of Hydrogen Safety Evaluation Model

The main construction idea of hydrogen safety evaluation model is as follows. Firstly, hydrogen safety is divided into five safety levels according to the gradient theory, and then the appropriate primary and secondary evaluation indexes are selected according to the linear correlation degree. Then, the weight of each evaluation index is calculated by analytic hierarchy process (AHP). Finally, the membership matrix of power following energy management strategy is determined according to the official statistics, simulation data and entity store survey data under power following strategy, and the hydrogen safety level of power following strategy is obtained.

Hydrogen Safety Grade

Hydrogen safety means that there is no danger, harm or loss in the process of using hydrogen. There are no hidden dangers in storage and use, which are exempt from unacceptable hazards. Hydrogen safety is the control of the damage to human life, material and the environment that the operating level of the system may cause to an acceptable level. Therefore, hydrogen safety is subjective dynamic fuzzy. If we want to accurately evaluate hydrogen safety, we must well define the safety levels of storage, use, and collision. Hydrogen safety experts believe that the safety state of hydrogen can be divided into grades according to the cascade theory. Hydrogen safety can usually be divided into five or seven grades. Among them, the five levels mainly include very safe, safe, general, unsafe and very unsafe. The seven grades are divided into seven levels as very safe, safe, safer, general, less safe, unsafe and very unsafe. This paper chooses the first classification system.

Hydrogen Safety Evaluation Principles

To establish a comprehensive evaluation index system of hydrogen safety, a set of representative indicators that can reflect the impact of various aspects of hydrogen safety (such as storage, transportation, collision and application) is selected first. These indicators can accurately show the quantitative judgment of the evaluation objectives of hydrogen safety [9]. Therefore, the selection of hydrogen safety comprehensive evaluation index should follow the following principles:

(1) Scientific: When selecting hydrogen safety evaluation indexes, the number of typical representative indexes should be appropriate and reasonable. On the other hand, must be able to accurately reflect the evaluation objectives, scientific basis for support.

(2) Distinguishing independence: Each factor and sub-factor should not only have its own independence, but also have a certain correlation with other factors and sub-factors. There are levels and depths between evaluation factors and sub-factors, forming a complete and independent system.

(3) Comparative quantitative practice: The indicators can be compared with each other. Qualitative analysis and quantitative analysis can be conducted. In addition, the selected indicators must be simple and easy to take, practical operability, for us to carry out statistics and analysis.

(4) Practical and effective: The purpose of hydrogen safety evaluation is to better serve the safety of energy management strategy of extended range fuel cell car, and ultimately achieve the purpose of optimizing energy management strategy. Therefore, we should choose those indicators that can actually help us effectively improve the hydrogen safety of automobiles.

(5) Objective and reliable: In order to make the final evaluation results accurate and effective, and truly have reference value, all selected indicators must ensure the reliability of data sources and the objectivity of evaluation indicators.

The design and determination of evaluation indicators should follow the above principles. The common methods of screening indicators are: qualitative analysis, sorting, correlation analysis and so on. Qualitative analysis method is based on the selected indicators of evaluation principles for qualitative analysis, and deletes some indicators with poor practicability and scientific objectivity [10]. The ranking method ranks all indicators according to importance, practicality and quantifiable degree, and the former is the optional indicator. Correlation analysis needs to classify the indicators, analyze the correlation of the same type of indicators, merge the indicators with high correlation, and finally obtain a relatively reasonable and comprehensive evaluation index system [11].

Hydrogen Safety Evaluation Method

There are many factors in the hydrogen safety evaluation system of extended-range hydrogen fuel cell vehicles. How to select the indicators is a multi-objective and multi-criteria problem. Therefore, the conventional linear structure was unable to clearly express the internal relationship of each index and the various evaluation objectives and needs of each evaluation object [12]. In this paper, the extended range fuel cell vehicle hydrogen safety evaluation is prepared to apply AHP three-level hierarchical analysis. The evaluation object is divided into several objectives according to the logical relationship classification, and then each objective is divided into several sub-objectives in turn, forming a complete tree structure of the target layer, the criterion layer and the index layer, until the object can be quantitatively and qualitatively analyzed. There are many methods for hydrogen safety evaluation, such as BP neural network method, multi-objective comprehensive evaluation method, analytic hierarchy process, fuzzy comprehensive evaluation method, and expert evaluation method. Each method has its own advantages and disadvantages [13]. According to the characteristics of hydrogen security, the analytic hierarchy process is finally selected.

Analytic Hierarchy Process (AHP) can deal with complex and fuzzy problems simply and effectively, which is suitable for the problems that cannot be quantitatively analyzed. This is a simple, effective and practical multi-criteria decision-making method proposed by Professor T. L. Saaty [14]. Usually there are many factors in a system, and the evaluation of the system is composed of the weight ratio of each target. The objective evaluation results of the system are composed of the evaluation results of each sub-objective according to the weight ratio, so a complete multi-level tree evaluation model is obtained. The establishment of multi-level tree evaluation model often uses analytic hierarchy process (AHP). Analytic hierarchy process has the following characteristics [15]:

(1) Not complex and understandable. AHP analytic hierarchy process is simple, and four steps are clear. The analysis process is clear and easy to understand. Moreover, the analytic hierarchy process software can help us establish the model, which uses the root method or sum product method for weight calculation, making the calculation results more scientific and effective.

(2) Flexible and practical. AHP analytic hierarchy process can not only quantitatively analyze but also qualitatively analyze. It can use the relative scale to consider the non-quantifiable factors and theoretical factors. All the factors are organically combined. It breaks the traditional thinking mode and proves that it can be used not only for quantitative analysis but also for qualitative analysis. It is widely used in material distribution, overall analysis, program evaluation and planning scenarios.

(3) Systematic. There are three types of decision-making: The first is to treat the problem as a whole system, so as to make decisions in the research environment of the target system, including all components of the system and the relationship between them. The second is the causal inference. In most of the less complex decisions, the causal logic is basic, simple and convenient, making it the basis of thinking for people to judge and choose things in daily life. The last one is the way of decision-making thinking, because most of the systems have hierarchical relationships. AHP can reflect the decision-making characteristics of such systems, and can be extended and studied more complex systems.

The analytic hierarchy process is modeled according to the following four steps:

(1) The first step is to establish a hierarchical structure model;

(2) The second step constructs all the judgment matrix of each level;

(3) The third step is to conduct hierarchical single sorting and consistency test according to the judgment matrix;

(4) The fourth step is hierarchical sorting and consistency test.

Hydrogen Safety Index

In general, hydrogen safety evaluation includes four aspects: hydrogen storage, hydrogen transportation, hydrogen collision safety and hydrogen application. According to these four first-level hydrogen safety evaluation indexes, the following four first-level hydrogen safety evaluation indexes and eight second-level evaluation indexes are set up.

Hydrogen Storage

Hydrogen storage is divided into hydrogen storage in hydrogenation station and vehicle storage. At present, there are three main hydrogen storage methods, including high pressure hydrogen storage method, liquid hydrogen storage method and solid hydrogen storage method. High-pressure hydrogen storage method, also known as gaseous hydrogen storage method, is to store hydrogen in a specific container with high pressure, similar to CNG cylinders of natural gas vehicles. Its advantage is that compared with the other two storage methods, it has low cost and high hydrogen storage density, and its disadvantage is relatively low security. The second method of liquid hydrogen storage is to liquefy hydrogen at the ultra-low temperature of 20.28 K (− 252.77 ℃), and then it is stored in a specific cryogenic vessel. Its hydrogen storage density is the largest of the three methods, but it is high cost and has a large subsidiary system, so it is not suitable for vehicles. The third solid hydrogen storage method, according to the physical adsorption or chemical reaction mechanism of solid hydrogen, hydrogen is stored in some specific solid materials, and then released through the corresponding reaction when used. Solid-state storage is often safe, efficient and high-density, which is the most promising storage method after gaseous storage and liquid storage. At present, the common solid hydrogen storage materials include alloys, nanoparticles and other materials. Its advantages are relatively safe and have good stability, and the disadvantage is high cost [16].

Hydrogen Transportation

There are many commonly used hydrogen production methods. The most commonly used methods are steam reforming of natural gas and electrolysis of water. Large quantities of hydrogen production need to transport hydrogen from the hydrogen station to the hydrogenation station. The most common way of hydrogen transportation is through the pipeline, that is, from the hydrogen storage equipment through the pipeline, gas valve, pressure relief valve and other devices to the fuel cell hydrogen supply. The material and pressure of hydrogen transmission pipeline are the two most critical factors in the process of hydrogen transmission. Due to the small volume energy density of hydrogen itself and the need for high pressure transportation, it is easy to produce "hydrogen embrittlement" phenomenon on the pipe in this process [17].

Hydrogen Collision

Hydrogen is likely to collide whether in the process of transportation or in the process of vehicle use. Hydrogen storage or transmission device is easily damaged to produce hydrogen leakage.

(1) Leakability: Hydrogen is the lightest gas, which is more prone to small pore leakage than other fuel gases. Once leakage occurs, hydrogen will rapidly diffuse.

(2) High voltage: For extended-range hydrogen fuel cell vehicles, the vehicle is equipped with a high voltage power circuit, and the voltage of the energy storage system

composed of power batteries is far beyond the safety voltage. Therefore, accidents such as electric shock, short circuit and electrolyte leakage may occur.

(3) Personnel protection: The different structure of extended-range hydrogen fuel cell vehicle has an impact on the activity space and body characteristics of personnel in the vehicle.

(4) Hydrogen storage vessel protection: High-pressure hydrogen storage vessels should use sufficient strength of fixed brackets and seatbelts. When subjected to impact, high-pressure hydrogen storage vessels will not have a large displacement, resulting in fracture deformation of the transmission line and a large amount of hydrogen leakage.

Hydrogen Applications

Hydrogen application safety refers to the safety of hydrogen when the vehicle is running. The use of hydrogen fuel in the clearing of vehicles and other transport vehicles will increase hydrogen in the atmosphere, leading to an expansion of the ozone hole. However, the continuous development of new fuel cell technologies and land absorption are considered to eliminate this effect. This article mainly refers to the safety in the automobile application process.

Calculation of Index Importance and Determination of Weight in Hydrogen Safety Model

According to the selection of four first-level rating indicators and eight second-level rating indicators, the comprehensive evaluation structure of hydrogen security is shown in the figure 1:

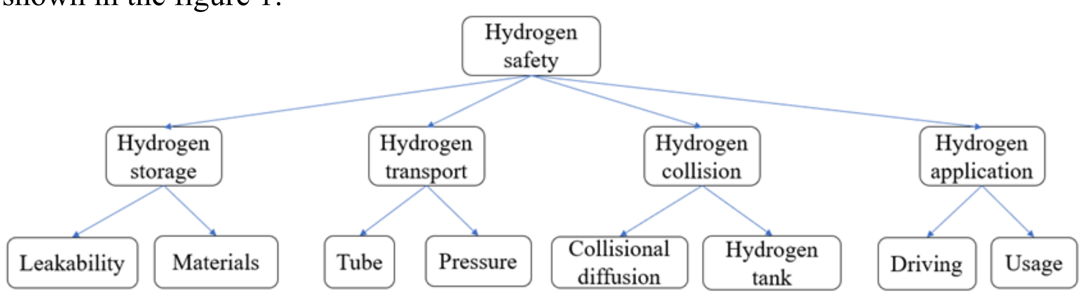

Figure 1. Comprehensive evaluation system diagram of hydrogen safety

The determination of weight has a direct impact on the final research results. Hydrogen safety is the target level A, and the four influencing factors of hydrogen storage, hydrogen transportation, hydrogen collision and hydrogen application are selected as the quasi-target level B, while its sub-factor leakage, hydrogen storage material, pipe material, pressure, collision diffusion, hydrogen tank protection, driving and use are selected as the sub-factor level C. The first step is to determine the weight of B to A, and then determine the weight of C to B. Finally, the weight of C to A is comprehensively determined to obtain the final weight of each sub-factor layer and determine their importance. The calculation of importance can directly use the software AHP to input the target layer, and the single-level sorting is used to judge the matrix consistency, and the calculation results are directly obtained and then the results are exported. The importance calculation can also normalize the matrix without software, and the weight of the index can be obtained after normalization. Each column is normalized.

In this paper, the sum product method is used to calculate, and the AHP results are used to make the index weight (Table 1).

Table 1. First level index weight table

Hydrogen safety	Hydrogen storage	Hydrogen transport	Hydrogen collision	Hydrogen application
Hydrogen storage	1	3	5	7
Hydrogen transport	1/3	1	3	7
Hydrogen collision	1/5	1/3	1	3
Hydrogen application	1/7	1/7	1/3	1
Single layer weights	0.507	0.296	0.144	0.053

The satisfaction judgment matrix is:

$$A = \begin{bmatrix} 1 & 3 & 5 & 7 \\ 1/3 & 1 & 3 & 5 \\ 1/5 & 1/3 & 1 & 3 \\ 1/7 & 1/5 & 1/3 & 1 \end{bmatrix} \quad B_1 = \begin{bmatrix} 1 & 3 & 5 & 7 \\ 0.333 & 1 & 3 & 5 \\ 0.2 & 0.333 & 1 & 3 \\ 0.143 & 0.2 & 0.333 & 1 \end{bmatrix}$$

Normalized processing

$$k_1 = \begin{bmatrix} 1+3+5+7 \\ 0.333+1+3+5 \\ 0.2+0.333+1+3 \\ 0.143+0.2+0.333+1 \end{bmatrix} = \begin{bmatrix} 16 \\ 9.333 \\ 4.533 \\ 1.676 \end{bmatrix}$$

$$K_1 = \begin{bmatrix} 0.507 \\ 0.296 \\ 0.144 \\ 0.053 \end{bmatrix}$$

The weight vector set of B_1 is K_1 = (0.507, 0.296, 0.144, 0.053). The above is the weight of target layer B to target layer A, and the weight of sub-factor layer C to target layer B can be obtained. Tables 2 - 5 are the weight for secondary indicators.

Table 2. Weight of hydrogen storage

Hydrogen storage	Leakability	Materials
Leakability	1	3
Materials	1/3	1
Single layer weights	0.75	0.25

Table 3. Weight of hydrogen transportation

Hydrogen transport	Tube	Pressure
Tube	1	4
Pressure	1/4	1
Single layer weights	0.8	0.2

Table 4. Weight of Hydrogen collision

Hydrogen collision	Collisional diffusion	Hydrogen tank
Collisional diffusion	1	2
Hydrogen tank	1/2	1
Single layer weights	0.667	0.333

Table 5. Weight of hydrogen application

Hydrogen application	Driving	Usage
Driving	1	2
Usage	1/2	1
Single layer weights	0.667	0333

The weight solving process of sub-factor layer C to target layer B is similar to that of target layer B to target layer A. In order to highlight the research focus, each weight vector set is given directly.

The weight vector set of hydrogen storage is: K_2 = (0.75, 0.25);

The weight vector set of hydrogen transportation is: K_3 = (0.8, 0.2);

The weight vector set of hydrogen collision is: K_4 = (0.667, 0.333);

The weight vector set of hydrogen application is: K_5 = (0.667, 0.333);

According to the weight of sub-factor layer C to target layer B and the weight of target layer B to target layer A, the weight of each sub-factor set C to target layer A can be determined. The results are shown in Table 6:

Table 6. Weight summary table

Target layer A	Quasi-target layer B	The weight of B in A	Sub-factor C	The weight of C in B	The weight of C in A
Hydrogen safety evaluation index	Hydrogen storage	0.507	Leakability	0.75	0.3803
			Materials	0.25	0.1267
	Hydrogen transport	0.296	Tube	0.8	0.2368
			Pressure	0.2	0.0592
	Hydrogen collision	0.144	Collisional diffusion	0.667	0.0960
			Hydrogen tank	0.333	0.0480
	Hydrogen application	0.053	Driving	0.667	0.0354
			Usage	0.333	0.0176

Hydrogen Safety Level under Power Following Strategy

This paper obtains the statistical results (Table 7) by consulting literature and online data, investigating the physical stores in Zhengzhou City, Henan Province, China, and simulating the model under the power following strategy.

Table 7. The number of vehicles in each index under the power tracking strategy

	Evaluation set				
	Very unsafe	Unsafe	General	Safe	Very safe
Hydrogen storage	23	37	46	74	40
Hydrogen transport	32	23	44	75	26
Hydrogen collision	24	64	46	53	13
Hydrogen application	11	39	68	23	59
Leakability	30	44	52	39	35
Materials	33	55	52	37	23
Tube	37	11	75	29	48
Pressure	36	15	45	65	39
Collisional diffusion	45	62	48	33	12
Hydrogen tank	25	48	35	69	23
Driving	26	60	58	42	14
Usage	23	36	69	47	25

The membership degree can be obtained by applying fuzzy mathematics method through quantitative indicators, as shown in Table 8:

Table 8. The satisfaction evaluation set of each level index

	Evaluation set				
	Very unsafe	Unsafe	General	Safe	Very safe
Hydrogen storage	0.115	0.135	0.18	0.37	0.2
Hydrogen transport	0.16	0.115	0.22	0.375	0.13
Hydrogen collision	0.12	0.32	0.23	0.265	0.065
Hydrogen application	0.055	0.195	0.34	0.115	0.295
Leakability	0.15	0.22	0.26	0.195	0.175
Materials	0.165	0.275	0.26	0.185	0.115
Tube	0.185	0.055	0.375	0.145	0.24
Pressure	0.18	0.075	0.225	0.325	0.195
Collisional diffusion	0.225	0.31	0.24	0.165	0.06
Hydrogen tank	0.125	0.24	0.175	0.345	0.115
Driving	0.13	0.3	0.29	0.21	0.07
Usage	0.115	0.18	0.345	0.235	0.125

According to Table 8, the single factor evaluation matrix R_1 of hydrogen safety evaluation index can be obtained:

$$R_1 = \begin{bmatrix} 0.115 & 0.135 & 0.18 & 0.37 & 0.2 \\ 0.16 & 0.115 & 0.22 & 0.375 & 0.13 \\ 0.12 & 0.32 & 0.23 & 0.265 & 0.065 \\ 0.055 & 0.195 & 0.34 & 0.115 & 0.295 \end{bmatrix}$$

Similarly, the single factor evaluation matrix of hydrogen storage (R_2), hydrogen transportation (R_3), hydrogen collision (R_4) and hydrogen application (R_5) safety indicators can be obtained:

$$R_2 = \begin{bmatrix} 0.15 & 0.22 & 0.26 & 0.195 & 0.175 \\ 0.165 & 0.275 & 0.26 & 0.185 & 0.115 \end{bmatrix}$$

$$R_3 = \begin{bmatrix} 0.185 & 0.055 & 0.375 & 0.145 & 0.24 \\ 0.18 & 0.075 & 0.225 & 0.325 & 0.195 \end{bmatrix}$$

$$R_4 = \begin{bmatrix} 0.225 & 0.31 & 0.24 & 0.165 & 0.06 \\ 0.125 & 0.24 & 0.175 & 0.345 & 0.115 \end{bmatrix}$$

$$R_5 = \begin{bmatrix} 0.13 & 0.3 & 0.29 & 0.21 & 0.07 \\ 0.115 & 0.18 & 0.345 & 0.235 & 0.125 \end{bmatrix}$$

The hydrogen safety level 1 evaluation is as follows:

$$K_1R_1 = (0.507,\ 0.296,\ 0.144,\ 0.053) \begin{bmatrix} 0.115 & 0.135 & 0.18 & 0.37 & 0.2 \\ 0.16 & 0.115 & 0.22 & 0.375 & 0.13 \\ 0.12 & 0.32 & 0.23 & 0.265 & 0.065 \\ 0.055 & 0.195 & 0.34 & 0.115 & 0.295 \end{bmatrix}$$
$$= (0.1259, 0.1589, 0.2075, 0.428, 0.1649)$$

Hydrogen storage:

$$K_2R_2 = (0.75, 0.25) \begin{bmatrix} 0.15 & 0.22 & 0.26 & 0.195 & 0.175 \\ 0.165 & 0.275 & 0.26 & 0.185 & 0.115 \end{bmatrix}$$
$$= (0.154,\ 0.234,\ 0.26,\ 0.193,\ 0.16)$$

Hydrogen transport:

$$K_3R_3 = (0.8, 0.2) \begin{bmatrix} 0.185 & 0.055 & 0.375 & 0.145 & 0.24 \\ 0.18 & 0.075 & 0.225 & 0.325 & 0.195 \end{bmatrix}$$
$$= (0.184,\ 0.059,\ 0.181,\ 0.345,\ 0.231)$$

Hydrogen collision:

$$K_4R_4 = (0.667,0.333)\begin{bmatrix}0.225 & 0.31 & 0.24 & 0.165 & 0.06\\ 0.125 & 0.24 & 0.175 & 0.345 & 0.115\end{bmatrix}$$
$$= (0.192,\ 0.287,\ 0.218,\ 0.225,\ 0.078)$$

Hydrogen application:

$$K_5R_5 = (0.667,0.333)\begin{bmatrix}0.13 & 0.3 & 0.29 & 0.21 & 0.07\\ 0.15 & 0.18 & 0.345 & 0.235 & 0.125\end{bmatrix}$$
$$= (0.125,\ 0.26,\ 0.308,\ 0.218,\ 0.085)$$

According to the principle of maximum membership degree and the first-level fuzzy evaluation, under the power following strategy, the membership degree of hydrogen storage index corresponding to "general" is the highest with a value of 0.26. The membership degree of hydrogen transport index corresponding to "safety" is the highest, which is 0.345. The membership degree of hydrogen collision safety corresponding to "unsafe" is the highest, which is 0.287. The membership degree of hydrogen application corresponding to "general" is the highest with a value 0.308.

According to the secondary fuzzy comprehensive evaluation matrix:

$$B = (0.507,\ 0.296,\ 0.144,\ 0.053)\begin{bmatrix}0.154 & 0.234 & 0.260 & 0.193 & 0.160\\ 0.184 & 0.059 & 0.181 & 0.345 & 0.231\\ 0.192 & 0.287 & 0.218 & 0.225 & 0.078\\ 0.125 & 0.260 & 0.308 & 0.218 & 0.085\end{bmatrix}$$
$$= (0.1654,\ 0.1922,\ 0.2353,\ 0.2407,\ 0.168)$$

From the comprehensive evaluation matrix B, it can be seen that the value of "relatively safe" is 0.2407, which is the maximum value, and the value of "general" is 0.2353, which is second only to the maximum value. The evaluation of hydrogen storage index is general, the evaluation of hydrogen transportation index is safe, the evaluation of hydrogen collision safety index is unsafe, and the evaluation of hydrogen application index is general safety. Therefore, the comprehensive evaluation of hydrogen safety under power following strategy is "relatively safe" and tends to "general safety".

CONCLUSIONS

(1) According to the linear correlation, four first-level evaluation indexes and eight second-level evaluation indexes affecting the hydrogen safety level are determined to establish the structural system.

(2) The selected evaluation indexes are stratified by objectives, and the judgment matrix is constructed. The root method is used to obtain the feature vector of the judgment matrix. The consistency test is used to calculate the weight of the second level. Finally, the hydrogen safety evaluation model is constructed.

(3) The hydrogen safety evaluation model is constructed by using the analytic hierarchy process, and the software simulation and the investigation results of the physical store are analyzed. Finally, the hydrogen safety level under the power following strategy is determined to be relatively safe and biased towards general safety.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this paper.

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