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Risk Evaluation of Road Transportation of Dangerous Chemicals Based on FAHP and Fuzzy Comprehensive Evaluation

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Based on fuzzy analytic hierarchy process (FAHP) and fuzzy comprehensive evaluation (FCE), the risk evaluation model of road transportation of dangerous chemicals is established. The model uses FAHP to determine the subjective weights of evaluation indexes at all levels and the evaluation rating set. Then it obtains the fuzzy evaluation matrix of evaluation target by FCE and work out the comprehensive evaluation vector of evaluation target level, as well as the evaluation results according to the principle of maximum membership degree. The example proves that the risk evaluation of road transportation of dangerous chemicals can be effectively solved.

1. Introduction

Dangerous chemicals are inflammable, explosive, toxic, corrosive, and radioactive goods that are liable to cause personal injury and death, property damage and environmental pollution in the process of production, storage, transportation, use and disposal (Zhu and Jiang, 2007). With the acceleration of industrialization, the dangerous chemicals have been widely used and the transportation volume of the dangerous chemicals has been increasing year by year. According to statistics, 80% of the dangerous chemicals are transported by road every year in China. With the increase of transportation volume of dangerous chemicals, the transportation accident rate of dangerous chemicals continues to rise, which makes the transportation safety of dangerous chemicals gradually become a social problem. How to effectively evaluate the transportation safety of dangerous chemicals and prevent the occurrence of accidents has become an important issue in the field of dangerous chemicals logistics transportation.

The safety evaluation of dangerous chemicals transportation belongs to the multi-index comprehensive evaluation. The solving method can be divided into subjective method and objective method according to the index weight (Wang and Sun, 2011). Subjective method mainly includes analytic hierarchy process (AHP), expert survey method and fuzzy evaluation method. Objective method mainly includes entropy evaluation method, grey correlation analysis method and cluster analysis method. AHP has been widely used in the multi-index evaluation because of its simplicity and flexibility. However, it is difficult to test and adjust the consistency of judgment matrix in AHP and the judgment standard CR<0.1 lacks scientific basis and has great limitations (Oberkampf and Roy, 2010). FAHP improves the defect of AHP (Chen and Yan, 2012) and is widely used. There are many factors in risk evaluation of road transportation of dangerous chemicals and the fuzzy characteristics are obvious, so FAHP which overcomes many shortcomings and limitations of AHP is used to determine the index weight, and to carry out the comprehensive rating evaluation of target combined with FCE (Wu et al., 2009; Tirmizi and Tirmizi, 2017).

2. Risk evaluation index system for road transportation of dangerous chemicals

According to the analysis of the main factors affecting the vehicle transportation risk of dangerous articles, the main factors are determined to be human factors, vehicle factors, road factors, environment factors and the

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transported dangerous chemicals factors. The evaluation index system for determining the risks is shown in Table 1 (Yang and Lv, 2013).

Table 1: Risk evaluation index system for road transportation of dangerous chemicals

Evaluation target	First-level index B	Second-level index C
Risk evaluation index system for road transportation of dangerous chemicals	Human factors B_1	Driver's skill level C_1
		Driver's mental quality C_2
		Driver's physical condition C_3
		Effectiveness of emergency mechanism C_4
	Vehicle factorsB_2	Safety performance of vehicle braking C_5
		Anti-seismic performance of vehicles C_6
		Communication and emergency equipment C_7
	Dangerous chemical factors B_3	Species of dangerous chemicals C_8
		Loading safe operation C_9
		Quantity of dangerous chemicals C_{10}
		Risk of active reaction C_{11}
	Road environment B_4	Road conditions C_{12}
		Traffic flow C_{13}
		Sensitive area C_{14}
		Road warning signs C_{15}
	Natural environment B_5	Rain and snow weatherC_{16}
		Foggy weather C_{17}
		Area temperature C_{18}

3. Evaluation method and route

3.1 Subjective weight determination method based on FAHP

Analytic Hierarchy Process (AHP) is a decision-making method that decomposes elements related to decision-making into goals, criteria, and programs, and then conducts qualitative and quantitative analysis. This method was proposed in the early 1970s. This method is characterized by the in-depth analysis of the nature of complex decision-making problems, its influencing factors and its internal relationships, and the use of less quantitative information to mathematicalize the thinking process of decision-making, thus providing a simple decision method for complex decision-making problems of multi-objective, multi criteria or unstructured characteristics.

AHP has been widely used in the multi-index evaluation because of its simplicity and flexibility. However, it is difficult to test and adjust the consistency of judgment matrix in AHP and the judgment standard CR<0.1 lacks scientific basis and has great limitations. One of the main advantages of FAHP is the fuzzy consistent matrix, which can automatically satisfy the consistency condition so that it is not necessary to check the consistency when FAHP is used to determine the index weight. The specific steps of the FAHP are:

1) Establishing priority relation matrix

Table 2: Scale method of 0.1~0.9 and its significance

Scale	Definition	Description
0.5	Equally important	The comparison of the two factors is equally important.
0.6	A little more important	Comparing the two factors, one factor is a little more important than the other.
0.7	Obviously more important	Comparing the two factors, one factor is obviously more important than the other.
0.8	Much more important	Comparing the two factors, one factor is much more important than the other.
0.9	Extremely more important	Comparing the two factors, one factor is extremely more important than the other.
0.1, 0.2, 0.3, 0.4	Anti comparison	If the factor a_i is compared with the factor a_j to obtain the judgment f_{ij}, then the factor a_j is compared with the factor a_i to obtain the judgment f_{ji}=1-f_{ij}.

The 0.1-0.9 scale (Du, 2001) in Table 2 is used to establish the priority judgment matrix:

$$F = (f_{ij})_{n\times n} \tag{1}$$

The judgment matrix is a fuzzy complementary matrix.
2) The priority relation matrix is transformed into a fuzzy consistent matrix (Tian et al., 2013):

$$R = (r_{ij})_{n\times n} \tag{2}$$

Where,

$$r_{ij} = \frac{(r_i - r_j)}{2n} + 0.5 \text{ ,} \quad r_i = \sum_{j=1}^{n} f_{ij},\ j = 1, 2, ..., n \text{ .}$$

3) The weight vector is calculated by the linear regression method:

$$W_1^{(0)} = \left[\frac{\sum_{j=1}^{n} r_{1j}}{\sum_{i=1}^{n}\sum_{j=1}^{n} r_{ij}}, \frac{\sum_{j=1}^{n} r_{2j}}{\sum_{i=1}^{n}\sum_{j=1}^{n} r_{ij}}, ..., \frac{\sum_{j=1}^{n} r_{nj}}{\sum_{i=1}^{n}\sum_{j=1}^{n} r_{ij}} \right]^T \tag{3}$$

4) Power method (Xu and Sun, 2007) is used to solve higher precision weight vector
The fuzzy consistent matrix (2) is transformed into a reciprocal matrix:

$$E = (e_{ij})_{n\times n} \tag{4}$$

Where, $e_{ij} = r_{ij}/r_{ji}$。

The weight vector $W_1^{(0)}$ obtained by the sum-line normalization method is taken as the initial vector $V^{(0)}$, the following formula is used to iterate:

$$V^{(k+1)} = E \frac{V^{(k)}}{\left\| V^{(k)} \right\|_\infty} \tag{5}$$

In formula (5), $V^{(k)} = (v_1^{(k)}, v_2^{(k)}, \ldots, v_n^{(k)})$, $\|V^{(k)}\|_\infty = \max_{1\le i\le n}(|v_i^{(k)}|)$, *k*=0,1,2…The above iteration process is as follows: if $\left|\|V^{(k+1)}\|_\infty - \|V^{(k)}\|_\infty\right| \le \varepsilon$ is true and ε is a given error, then $\lambda_{max} = \|V^{(k+1)}\|_\infty$, and λ_{max} is the largest eigenvalue of the fuzzy consistent matrix, and $V^{(k+1)}$ is normalized to obtain the vector

$$\left(\frac{v_1^{(k+1)}}{\sum_{i=1}^{n} v_i^{(k+1)}}, \frac{v_2^{(k+1)}}{\sum_{i=1}^{n} v_i^{(k+1)}}, \ldots, \frac{v_n^{(k+1)}}{\sum_{i=1}^{n} v_i^{(k+1)}}\right),$$

namely weight vector obtained by FAHP method; otherwise, continue to iterate. After the calculation of the subjective weights of all the first-level indexes and he second-level indexes in each group is completed, the subjective weights of the second-level indexes in each group are multiplied by the corresponding subjective weights of the first-level indexes to obtain the subjective comprehensive weights *W* of the second-level indexes.

3.2 Establishment of fuzzy evaluation matrix

First, it is necessary to determine an evaluation rating set. The evaluation set is the evaluation expression of the evaluation target with the fuzzy language, which ensures the consistency of the fuzzy judgment matrix. According to the fuzzy expression of general risk evaluation rating, *V* = (low, relatively low, general, high, relatively high) is set for to the risk evaluation set of transportation of dangerous chemicals. According to the fuzzy evaluation set, the indexes in the evaluation index system are evaluated by a single factor, that is, the fuzzy relation between the single factor and the evaluation set *V* is established to obtain the fuzzy matrix of the upper indexes, which is expressed by R.

$$R = \begin{pmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{pmatrix}$$

3.3 Calculation of comprehensive evaluation results

Firstly, the comprehensive evaluation set E_i, $E_i = W_i \cdot R_i$ of each single factor index set B_i is obtained by fuzzy evaluation of the second-level index set, where W_i is the weight set of each second-level index set to the first-level index set, and R_i is the fuzzy evaluation matrix of each second-level index set to the first-level index set. Taking single factor index set B_1 as an example, its fuzzy comprehensive evaluation set is E_1, $E_1 = W_1 \cdot R_1$. Similarly, if E_2, E_3, E_4, E_5 can be obtained, then the target comprehensive fuzzy evaluation matrix R = $(E_1, E_2, E_3, E_4, E_5)^T$. Finally, the target fuzzy evaluation vector E = W·R is obtained, and the corresponding evaluation value is judged by the evaluation set according to the principle of maximum membership degree to get the analysis result.

4. Example analysis

According to the risk evaluation index system, this study takes the risk evaluation of vehicle transportation of dangerous chemicals as an example, and takes Chengdu to Deyang road section as the research object, and uses the FAHP to verify the validity of the evaluation method.

4.1 Determination of weight

In the FAHP, the priority judgment matrix of the target layer and the index layer is established by using the scale of 0.1~0.9. The priority judgment matrix is transformed into a fuzzy consistent matrix according to the formula (2), and then the transformation and calculation are carried out according to the formulas (3), (4) and (5) to obtain the weights of the first-level indexes and the second-level indexes. The product of the first-level index weight and the second-level index weight is the comprehensive weight of the second-level index to the target layer, as shown in Table 3.

Table 3: Weight results obtained by FAHP for risk evaluation index of road transportation of dangerous chemicals

First-level index	First-level index weight	Second-level index	Second-level index weight	comprehensive weight
B_1	0.081	C_1	0.119	0.010
		C_2	0.150	0.012
		C_3	0.186	0.015
		C_4	0.545	0.044
B_2	0.219	C_5	0.551	0.121
		C_6	0.243	0.053
		C_7	0.206	0.045
B_3	0.380	C_8	0.114	0.043
		C_9	0.415	0.158
		C_{10}	0.316	0.120
		C_{11}	0.155	0.059
B_4	0.115	C_{12}	0.152	0.017
		C_{13}	0.348	0.040
		C_{14}	0.152	0.017
		C_{15}	0.348	0.040
B_5	0.205	C_{16}	0.175	0.036
		C_{17}	0.522	0.107
		C_{18}	0.303	0.062

4.2 Establishment of fuzzy comprehensive evaluation matrix

The risk evaluation rating is set as *V* = (low, relatively low, general, high, relatively high). By using the risk evaluation index system of transportation of dangerous chemicals, 10 experts are asked to score the second-level indexes according to the evaluation rating, and the evaluation matrix is obtained by statistics.
The fuzzy matrix R_1 corresponding to the index B_1 is obtained by conducting a single factor evaluation on the four factors under the first-level index B_1:

$$R_1 = \begin{pmatrix} 0.1 & 0.4 & 0.3 & 0.1 & 0.1 \\ 0 & 0.2 & 0.5 & 0.2 & 0.1 \\ 0.1 & 0.2 & 0.2 & 0.5 & 0 \\ 0 & 0.1 & 0.4 & 0.4 & 0.1 \end{pmatrix}$$

According to $E_1 = W_1 \cdot R_1$, the single factor fuzzy comprehensive evaluation set E_1 = [0.031, 0.169, 0.366, 0.353, 0.081] is obtained under the first-level index B_1. Similarly, the other four comprehensive evaluation vectors can be obtained. Finally, the fuzzy evaluation matrix of the target is obtained:

$$R = (E_1, E_2, E_3, E_4, E_5)^T = \begin{pmatrix} 0.031 & 0.169 & 0.366 & 0.353 & 0.081 \\ 0.155 & 0.196 & 0.245 & 0.279 & 0.125 \\ 0.071 & 0.091 & 0.272 & 0.337 & 0.229 \\ 0.149 & 0.186 & 0.291 & 0.265 & 0.112 \\ 0.159 & 0.170 & 0.149 & 0.321 & 0.201 \end{pmatrix}$$

4.3 Evaluation results

It is known from Table 3 that the first-level index weight set *W*=(0.081, 0.219, 0.380, 0.115, 0.205). And the comprehensive evaluation vector E=*W*·*R*=(0.120, 0.140, 0.255, 0.320, 0.165) for the risk evaluation rating of road transportation of dangerous chemicals is calculated. From the risk evaluation rating *V*=(low, relatively low, general, high and relatively high) and according to the principle of maximum membership degree, the transportation risk rating of dangerous chemicals in this road section is relatively high, and measures need to be taken to prevent accidents. It should be highly valued by the transportation department, chemical goods transportation enterprises and drivers to prevent the occurrence of vehicle accidents.

5. Conclusions

The FAHP and fuzzy comprehensive evaluation method has strong adaptability to the multi objective and multi-level vehicle transportation risk assessment problem involved, which can be used both for comprehensive evaluation of subjective factors and for comprehensive evaluation of objective factors. At the same time, according to the different characteristics of each person, vehicle, road and natural environment, the weight of the safety risk evaluation index can be adjusted accordingly. It can obtain more accurate risk assessment results with the actual situation, and provide more reliable traffic safety information for the transportation department, the chemical goods transportation enterprise and the driver.

The evaluation index system has been established based on the evaluation standard of the main factors of transportation risk of dangerous goods, such as man, vehicle, road, environment and transported dangerous goods. The subjective weights of evaluation indexes at all levels are determined by FAHP, and the evaluation rating set is determined. The fuzzy evaluation matrix of evaluation target is obtained by fuzzy comprehensive evaluation method, and the comprehensive evaluation vector of evaluation target rating is obtained. Besides, evaluation result is obtained according to the principle of maximum membership degree. It is proved by examples that the model can effectively solve the risk evaluation of road transportation of dangerous chemicals.

At the same time, the evaluation results are limited to specific regions and time. There are too few evaluation indicators, and there are too many subjective factors. They are not general in all regions of China and may not be completely consistent with the actual situation.

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Reference

Chen Y.H., Yan C.L., 2012, A Model for Traffic State Recognition Based on FAHP and Fuzzy Comprehensive Evaluation, Journal of Chongqing University of Technology (Natural Science), 26(11), 109-114.

Du D., 2001, Study on 0.1~0.9 Scale in AHP, Systems Engineering and Electronics, 5(5), 36-38.

Oberkampf W.L., Roy C.J., 2010, Verification and Validation in Scientific Computing, Cambridge University Press, 1(1), 183-198, DOI 10.1017/CBO9780511760396

Tian L.G., Jin C.C., Chao B.A., 2013, Application of Improved Fuzzy AHP To Safty Evaluation of Seawall Engineering, Engineering Journal of Wuhan University, 46(3), 317-320, 327,

Tirmizi S.T., Tirmizi S.R.U.H., 2017, Hierarchical linear modelling of risk assessment of petroleum installations, Mathematical Modelling of Engineering Problems, 4(4), 139-144, DOI: 10.18280/mmep.040401

Wang S.Y., Sun Y., 2011, Evaluation of the emergency response capacity of the city public based on the AHP-Entropy integrated method, Journal of Harbin Engineering University, 32(8), 992-996, DOI: 10.3969/j.issn.1006-7043.2011.08.005

Wu J., Wu X.Y., Gao Z.C., 2009, FAHP-Based Fuzzy Comprehensive Evaluation of M&S Credibility, Communications in Computer and Information Science book series (CCIS), 51, 285-294.

Xu C.W., Sun S.W., 2007, Computer methodology, Beijing: Higher Education Press, 185-191.

Yang J.W., Lv J.X., 2013, Research of vehicle transport hazardous chemical risk assessment, Journal of Chinese Agricultural Mechanization, 34(3), 68-70, DOI: 10.3969/j.issn.2095-5553.2013.03.017

Zhu Z.H., Jiang S., 2007, Safety technology of dangerous chemicals storage and transportation workers, Beijing: Chemical Industry Press, 2007.