Comprehensive Evaluation on Safety Management of Road Dangerous Goods Transportation Enterprises Based on Multi-level Gray Relational Analysis

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Abstract. It is helpful to improve the safety management level of enterprises to carry out the comprehensive evaluation on safety management of the road transport enterprises of dangerous goods, and to reduce road safety accidents. Based on the analysis of the risk factors of road transport of dangerous goods, this paper constructs a comprehensive evaluation index system for the safety of the road transport enterprise with the AHP method, and gives the weight of each evaluation index. Combined with the instance, the correlation size between each evaluated enterprise and the virtual "best enterprise" is calculated by using gray relational analysis model, so as to identify the pros and cons of the safety management level of each evaluated enterprise, and provide reference for comprehensive safety evaluation of road transportation enterprises of dangerous goods.

1. Introduction
Road transport of dangerous goods plays an important role in the development of national economy. Dangerous goods refer to those articles or substances which have the characteristics of explosion, flammability, poison, radioactivity, corrosiveness, etc. and which are easy to cause personal injury, property loss and environmental pollution and need special protection in transportation, storage, production, operation, use and disposal[1]. With the rapid development of China's economy, more and more dangerous goods transportation operations have been carried out, and the safety problems caused by them have become increasingly prominent, which has attracted the widespread attention of the whole society. It has developed into one of the disharmonious factors in the process of building a harmonious society, seriously endangering the safety of people's lives and property, social and public security, and even causing serious damage to the natural environment. Therefore, the research on the safety management evaluation of road transport enterprises of dangerous goods can effectively identify the sources of danger, and then take effective measures to control and reduce the incidence of accidents, minimize the economic loss and social impact caused by accidents, which is conducive to improving the safety management level of enterprises and promoting them to consciously establish and improve the long-term mechanism of safety production[2].
At present, there are many research results about the safety management evaluation of road dangerous goods transportation enterprises, such as using fuzzy comprehensive evaluation method, efficiency coefficient method to evaluate the safety management level of enterprises, using neural network as the model to evaluate the safety management level of enterprises. However, in general, these evaluation methods are either too simple and lose more information, which makes the evaluation results hard to be convincing; or they are too complex, operability is not strong, and lack of practical value. In fact, the safety management evaluation system for road transport enterprises of dangerous goods is a gray system. One is that there are many and complex influencing factors, and only some main indexes can be selected for analysis in the specific evaluation; the other is that some data of the indexes are known, but some are unknown and cannot be obtained from the statistical data[3]. Therefore, the system has the characteristics of incomplete information or "gray". In view of the gray characteristics of the system, it is very suitable to select the gray correlation analysis method to carry out safety management evaluation.

2. Establishment of evaluation index system
There are many factors that affect the safety management of road transport enterprises of dangerous goods, and the relationship between them is complex. Based on the field investigation and research of relevant materials, these factors can be summarized as six major aspects: system construction, safety investment, safety education and training mechanism, facility management, operation safety management, professional quality of employees, each of which includes specific indicators. The index system for safety management evaluation of dangerous goods road transportation enterprises is shown in Table 1.

Table 1. Evaluation index system of safety management of dangerous goods road transportation enterprises

| Target Layer | Criterion Layer (B) | Index Layer (C) |
|--------------|---------------------|-----------------|
| Safety management evaluation index system of dangerous goods road transport enterprises | System Construction B1 (0.11) | Complete safety production system C1 (0.25) |
| | | System in place C2 (0.31) |
| | | Rewards and punishments are reasonable C3 |
| | | Reasonable and perfect organization C4 (0.22) |
| | Safe investment B2 (0.12) | Safety investment fund C5 (0.55) |
| | | Full time safety management personnel C6 (0.45) |
| | Safety education and training mechanism B3 | Safety education and training C7 (0.55) |
| | | Lessons learned C8 (0.45) |
| | Facilities Management B4 (0.08) | Site environmental safety C9 (0.3) |
| | | Vehicle technical performance C10 (0.35) |
| | | Intrinsic safety of equipment C11 (0.35) |
| | Operation safety management B5 (0.43) | Safe job execution C12 (0.4) |
| | | Unsafe behavior intervention C13 (0.3) |
| | | Safe operation supervision C14 (0.3) |
| | Professional quality of practitioners B6 (0.16) | Personnel safety awareness C15 (0.4) |
| | | Personal safety skills C16 (0.6) |

3. Determination of index weight
There are many ways to determine the index weights. Here, the analytic hierarchy process (AHP) is used to determine the weight coefficients of the safety management level evaluation indicators of dangerous goods road transportation enterprises. The AHP method is a multi-criteria decision-making method that combines qualitative analysis and quantitative research. The specific steps are: firstly construct the judgment matrix, generally the judgment matrix of the evaluation index is given by the expert scoring method. After passing the consistency test, its maximum feature vector corresponding to the feature root is the weight vector of the element of this level relative to an element of the
previous level[4]. By analogy, the relative importance weight coefficient of the lower-level elements relative to the higher-level elements can be determined. The weight coefficient of each index is finally obtained by AHP method, as shown in Table 1 above.

4.Mathematical model of multi-level gray correlation analysis
The safety management evaluation system of dangerous goods road transportation enterprises is a gray system (the relevant information is inaccurate and not completely known), and gray correlation analysis is very suitable for analyzing the degree of correlation between any two factors in the gray system.

4.1 Construct a reference sequence
For a gray system consisting of m evaluation objects and n evaluation indicators, the following matrix exists:

$$V=(V_{ik})_{m \times n} = \begin{bmatrix} V_{i1} & V_{i2} & \ldots & V_{in} \\ V_{i1} & V_{i2} & \ldots & V_{in} \\ \vdots & \vdots & \ddots & \vdots \\ V_{im} & V_{i2} & \ldots & V_{in} \end{bmatrix}$$

among them, i=1,2,..., m; k=1,2,..., n. Vik is the evaluation value of the k-th evaluation index of the i-th evaluation plan. Set reference sequence V0=(V01,V02,...,V0n), Among them, v0k = optimum (V0k), that is, the optimal value v0k is selected from m schemes and N indexes to form a virtual reference sequence with "optimal" indexes.

4.2 Standardize the evaluation index value
Standardizing the index value is helpful for pairwise comparison of various indexes, which can be carried out according to formula (1).

$$X_{ik} = \frac{V_{ik} - \min_{i} V_{ik}}{\max_{i} V_{ik} - \min_{i} V_{ik}}$$

Normalized matrix: $$X=(X_{ik})_{m \times n} = \begin{bmatrix} X_{i1} & X_{i2} & \ldots & X_{in} \\ X_{i1} & X_{i2} & \ldots & X_{in} \\ \vdots & \vdots & \ddots & \vdots \\ X_{im} & X_{i2} & \ldots & X_{in} \end{bmatrix}$$

4.3 Calculate the correlation coefficient between each evaluation index and the optimal index
The sequence Xi=(Xi1,Xi2,...,Xin) (i=1,2,...,m) as comparison sequence, X0=(X01,X02,...,X0n) as a reference sequence, the correlation coefficient ζik of them can be calculated by formula (2).

$$\zeta_{ik} = \frac{\Delta_{\min} + \rho \Delta_{\max}}{X_{ik} - X_{0k}}$$

Among them: $$\Delta_{\min} = \min_{i,k} \frac{\Delta_{\min}}{X_{ik} - X_{0k}}$$, $$\Delta_{\max} = \max_{i,k} \frac{\Delta_{\max}}{X_{ik} - X_{0k}}$$, ρ is the resolution coefficient, generally ρ = 0.5.

Then the matrix of correlation coefficient is obtained: $$E=(\zeta_{ik})_{m \times n} = \begin{bmatrix} \zeta_{i1} & \zeta_{i2} & \ldots & \zeta_{in} \\ \zeta_{i1} & \zeta_{i2} & \ldots & \zeta_{in} \\ \vdots & \vdots & \ddots & \vdots \\ \zeta_{im} & \zeta_{i2} & \ldots & \zeta_{in} \end{bmatrix}$$

4.4 Calculation of single-layer correlation
W is the weight of a certain level of indicators relative to the upper level, W=(w1,w2,...,wn) (among
\[ \sum_{i=1}^{T} w_i = 1 \]  \( T \) is the total number of indicators in this layer), then the correlation degree of the level indicator

\[ R = (r_1, r_2, \ldots, r_m) = W \cdot E^T \quad (3) \]

4.5 Calculate the final correlation of multi-layer systems

Suppose a multi-layer system has a total of \( L \) layers. The calculation method of the final correlation degree is as follows: firstly, the correlation coefficients of the indicators of the \( k \)-th layer are synthesized to obtain the correlation degree of the upper layer (\( k-1 \)) to which these indicators belong. On the basis of the correlation degree of this layer, continue to perform the synthetic calculation to the upper layer (\( k-2 \)) layer, and so on, until the correlation degree of the highest layer index is obtained. According to the order of the finally calculated correlation degree \( r_i \) \((i=1,2,\ldots,m)\), the order of merits of each evaluation scheme can be determined, so as to achieve the purpose of scheme optimization.

5. Application examples

Now it is necessary to evaluate the safety management level of five road transport enterprises of dangerous goods in a certain place.

5.1 Calculation of single-layer correlation

By using the expert scoring method, several experts are invited to use the 10 point system to score the 16 three-level indicators \( V_1, V_2, V_3, V_4 \) and \( V_5 \) of these five enterprises one by one. The evaluation scores of each indicator and the optimal value \( v_{0k} \) of each indicator are obtained as shown in Table 2 below.

| Index | Scheme | The Optimal Value \( V_{0k} \) |
|-------|--------|-----------------------------|
|       | \( V_1 \) | \( V_2 \) | \( V_3 \) | \( V_4 \) | \( V_5 \) |
| C_1   | 8      | 7      | 8      | 6      | 8      | 8 |
| C_2   | 6      | 8      | 7      | 6      | 7      | 8 |
| C_3   | 8      | 7      | 7      | 6      | 6      | 8 |
| C_4   | 6      | 8      | 8      | 6      | 7      | 8 |
| C_5   | 5      | 8      | 5      | 7      | 6      | 8 |
| C_6   | 5      | 7      | 8      | 6      | 6      | 8 |
| C_7   | 7      | 6      | 7      | 6      | 7      | 7 |
| C_8   | 5      | 6      | 7      | 8      | 5      | 8 |
| C_9   | 6      | 8      | 7      | 5      | 6      | 8 |
| C_10  | 8      | 7      | 6      | 7      | 5      | 8 |
| C_11  | 7      | 9      | 6      | 5      | 6      | 9 |
| C_12  | 8      | 7      | 5      | 6      | 8      | 8 |
| C_13  | 7      | 7      | 5      | 7      | 6      | 7 |
| C_14  | 7      | 5      | 7      | 5      | 6      | 7 |
| C_15  | 5      | 8      | 6      | 7      | 8      | 8 |
| C_16  | 8      | 5      | 6      | 8      | 7      | 8 |

Then reference sequence \( V_0=(8,8,8,8,8,8,8,8,8,8,8,8,8,7,7,8,8) \). According to formula(1), normalize the evaluation value of each index in Table 2, and then calculate the value of the correlation coefficient \( \zeta_k \) of each index and the best value in the reference sequence according to formula(2), as shown in Table 3.
Table 3. Correlation coefficient values of safety management evaluation indexes for road transport enterprises of dangerous goods

| Index | Scheme | V1 | V2 | V3 | V4 | V5 |
|-------|--------|----|----|----|----|----|
| ζi1   |        | 1  | 1/2| 1  | 1/3| 1  |
| ζi2   |        | 1/3| 1  | 1/2| 1  | 1/3| 1/2|
| ζi3   |        | 1  | 1/2| 1  | 1/3| 1  |
| ζi4   |        | 1/3| 1  | 1  | 1  | 1/3| 1/2|
| ζi5   |        | 1/3| 1  | 1/3| 3/5| 3/7|
| ζi6   |        | 1/3| 3/5| 1  | 3/7| 3/7|
| ζi7   |        | 1  | 1/3| 1  | 1/3| 1  |
| ζi8   |        | 1/3| 3/7| 3/5| 1  | 1/3|
| ζi9   |        | 3/7| 1  | 3/5| 1/3| 3/7|
| ζi10  |        | 1  | 3/5| 3/7| 3/5| 1/3|
| ζi11  |        | 1/2| 1  | 2/5| 1/3| 2/5|
| ζi12  |        | 1  | 3/5| 1/3| 3/7| 1  |
| ζi13  |        | 1  | 1  | 1/3| 1  | 1/2|
| ζi14  |        | 1  | 1/3| 1  | 1/3| 1/2|
| ζi15  |        | 1/3| 1  | 3/7| 3/5| 1  |
| ζi16  |        | 1  | 1/3| 3/7| 1  | 3/5|

5.2 Multi level structure association degree synthesis

According to formula (3), the correlation degree of B-layer index can be obtained:

\[
R_{B_i} = W_{B_{LC}} \cdot E_{B_{LC}}^\tau = (0.25,0.31,0.22,0.22)\cdot \\
\begin{bmatrix}
1 & 0.5 & 1 & 1/3 & 1 \\
1/3 & 1 & 0.5 & 1/3 & 0.5 \\
1 & 0.5 & 0.5 & 1/3 & 1/3 \\
1/3 & 1 & 1 & 1/3 & 0.5 \\
\end{bmatrix}
\]

\[= (0.5967,0.765,0.735,0.3333,0.5883)\]

\[
R_{B_i} = W_{B_{LC}} \cdot E_{B_{LC}}^\tau = (0.55,0.45)\cdot \\
\begin{bmatrix}
1/3 & 1 & 1/3 & 0.6 & 3/7 \\
1/3 & 0.6 & 1 & 3/7 & 3/7 \\
\end{bmatrix}
\]

\[= (0.3333,0.82,0.6333,0.5229,0.4286)\]

\[
R_{B_i} = W_{B_{LC}} \cdot E_{B_{LC}}^\tau = (0.55,0.45)\cdot \\
\begin{bmatrix}
1 & 1/3 & 1 & 1/3 & 1 \\
1/3 & 3/7 & 0.6 & 1 & 1/3 \\
\end{bmatrix}
\]

\[= (0.7,0.3762,0.82,0.6333,0.7)\]

\[
R_{B_i} = W_{B_{LC}} \cdot E_{B_{LC}}^\tau = (0.3,0.35,0.35)\cdot \\
\begin{bmatrix}
3/7 & 1 & 0.6 & 1/3 & 3/7 \\
0.5 & 1 & 0.4 & 1/3 & 0.4 \\
\end{bmatrix}
\]

\[= (0.6536,0.86,0.47,0.4267,0.3852)\]

\[
R_{B_i} = W_{B_{LC}} \cdot E_{B_{LC}}^\tau = (0.4,0.3,0.3)\cdot \\
\begin{bmatrix}
1 & 0.6 & 1/3 & 3/7 & 1 \\
1 & 1/3 & 1 & 1/3 & 0.5 \\
\end{bmatrix}
\]

\[= (1,0.64,0.5333,0.5714,0.7)\]

\[
R_{B_i} = W_{B_{LC}} \cdot E_{B_{LC}}^\tau = (0.4,0.6)\cdot \\
\begin{bmatrix}
1/3 & 1 & 3/7 & 0.6 & 1 \\
1 & 1/3 & 3/7 & 1 & 0.6 \\
\end{bmatrix}
\]

\[= (0.7333,0.6,0.4286,0.84,0.76)\]
Furthermore, the correlation degree of the highest level indicator $a$ can be obtained,

$$
R_a = (r_1, r_2, r_3, r_4, r_5, r_6) = W_{AB} \cdot (R_{B_1}, R_{B_2}, R_{B_3}, R_{B_4}, R_{B_5}, R_{B_6})^T
$$

$$
= (0.11, 0.12, 0.10, 0.08, 0.43, 0.16) \cdot \begin{bmatrix}
0.5967 & 0.765 & 0.735 & 0.3333 & 0.5883 \\
0.3333 & 0.82 & 0.6333 & 0.5229 & 0.4286 \\
0.7 & 0.3762 & 0.82 & 0.6333 & 0.7 \\
0.6536 & 0.86 & 0.47 & 0.4267 & 0.3852 \\
1 & 0.64 & 0.5333 & 0.5714 & 0.7 \\
0.7333 & 0.6 & 0.4286 & 0.84 & 0.76
\end{bmatrix}
$$

$$
= (0.775, 0.660, 0.584, 0.577, 0.617)
$$

5.3 Evaluation results

According to the calculation results of RA, the order of safety management level of these five road transport enterprises is: $V_1 > V_2 > V_5 > V_3 > V_4$.

6. Conclusion

At present, with the continuous acceleration of China's industrialization process, the number of dangerous goods transportation is increasing. Carrying out the safety management evaluation of dangerous goods road transport enterprises will help to improve the safety management awareness and level of enterprises, and then enhance the core competitiveness and comprehensive strength of enterprises. In this paper, a virtual "optimal" objective vector is constructed by using the theory of gray relation analysis. The "optimal" objective vector represents a virtual "optimal" enterprise with "optimal" indexes. The approach degree between the evaluated enterprise and the virtual "optimal enterprise" is calculated by mathematical method to determine the management level of the evaluated enterprise[5]. This method makes the qualitative analysis quantitative, improves the accuracy and scientificity of the analysis, reduces the possible negative impact on the evaluation results due to personal subjective reasons, and has certain reference significance for similar evaluation problems.

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