Study on Tunnel Risk Assessment Based on Rough Set and Grey Theory

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Abstract. The surrounding environment of railway tunnel engineering is complex, and it is prone to major safety accidents. It is necessary to adopt feasible and accurate evaluation methods. The evaluation index system of tunnel is established. Rough set is used to quantify the evaluation index and form the reference index. The risk evaluation model of tunnel based on rough set and grey is established, and the risk of Sheguchong tunnel in Yunnan Province is validated to evaluate the validity of the model.

1. Introduction

The surrounding environment of railway tunnel project is complex, and unexpected events caused by external factors are easy to affect the progress of the project. Therefore, scientific tunnel risk assessment can provide construction worker with opportunities to prevent and recover losses in advance, reduce accidents in construction projects, avoid delays and even stoppages, and ensure the long-term effectiveness and safety of the tunnel.

Now, there are three kinds of methods for tunnel risk assessment: subjective weighting, objective weighting and subjective and objective integrated weighting. The first two kinds of algorithms have some shortcomings, such as ignoring the subjective information of decision makers, while the latter one has a high complexity, which affects its applicability to a certain extent.

2. Establishment of Tunnel Risk Assessment Model Based on Rough Set and Grey Theory

2.1 Establishment of Tunnel Risk Assessment Index System

The first step in risk assessment is to identify the source of risk, and establish different risk factors for different tunnel engineering risk assessment indicators according their characteristics.

2.2 Basic Principles of Rough Set and Grey Theory Model

Rough set theory based on data mining is used to extract the core indicators, calculate the attribute importance of each indicator, and then make a comprehensive evaluation of the research object. It is characterized by eliminating the interference of subjective factors without providing prior knowledge. Grey system theory is a forecasting model for the problem that both explicit information and uncertain information exist. In this paper, rough set theory and grey system theory are applied to tunnel risk assessment. According to the characteristics of tunnel accidents, a tunnel risk assessment index system is proposed. Experts engaged in tunnel risk assessment are invited to grade the importance of the index.
The objective weight of the evaluation index is determined by rough set theory and the grey system theory is used for qualitative evaluation, so that a tunnel risk assessment model is constructed.

2.3 Establishment of Evaluation Model

2.3.1 Establishment of Grey System Evaluation System
Risk assessment index information system $S= (U, R, V, f)$, $U$ is a finite object set, $R$ is a non-empty finite attribute set, $V$ is a set of attribute values, $f$ is the information function of $U$ and $R$. Conditional attributes are evaluation indexes, and the set of conditional attributes can be $C=\{c_{11}, c_{12}, \ldots\}$. The decision attribute is the risk score of each evaluation index, and the decision attribute can be $D=\{y\}$. Even if there is an evaluation relationship between the original index value and the index score, the risk importance of the index is expressed by the index risk score.

2.3.2 Rough Set to Determine Weight
(1) The knowledge expression system is constructed from the lower level to the higher level. The conditional attributes of each index are set as $C$. The higher level indicators constitute decision attributes. After the numerical system, the risk importance of $RD$ to $RC$, $\gamma_{RC}(RD)$ is calculated as follows:

$$\gamma_{RC}(R) = \frac{\sum_{[y]R \in U/R} \text{card}(R[y]R)}{\text{card}(U)}$$

Formula: $\text{card}(U)$ denotes the number of elements in the set $U$.

(2) The dependence of $RD$ on $RC-\{c_{ij}\}$ can be calculated as follows after removing the attribute

$$\gamma_{RC-\{c_{ij}\}}(RD) = \frac{\sum_{[y]R \in (U/RD)} \text{card}(R[y]R)}{\text{card}(U)}$$

(3) Get the importance of index $c_{ij}$.

$$\sigma_{ij}(c_{ij}) = \gamma_{RC}(RD) - \gamma_{RC-\{c_{ij}\}}(RD), (i, j = 1, 2, \ldots, n)$$

Find out the comprehensive weight of each index in the evaluation result.

$$\omega_{i} = \sum_{j=1}^{n} a_{ij}b_{ij}$$

Formula: $AJ$ is the weight of the first index relative to the system; $b_{ij}$ is the weight of the second index relative to the first index.

2.4 Application of Grey System Theory
(1) Establish the numerical matrix of tunnel and divide the risk assessment grades into $E=\{E1, E2, E3, E4\}=\{\text{extremely high, high, medium, low}\}$ according to table 1. The tunnel risk assessment experts are requested to evaluate the project indicators appropriately and form the evaluation matrix $H$ according to the results.

$$H = \begin{bmatrix}
H_{11} & H_{12} & \cdots & H_{1n} \\
H_{21} & H_{22} & \cdots & H_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
H_{m1} & H_{m2} & \cdots & H_{mn}
\end{bmatrix}$$
Table 1. Evaluation Scores and Corresponding Grading Criteria

| Evaluation results | [4,3) | [3,2) | [2,1) | [1,0) |
|--------------------|-------|-------|-------|-------|
| Level              | extremely high | height | moderate | low degree |

(2) Establishing Whitening Weight Function

In this paper, tunnel risk is classified as extremely high risk, high risk, medium risk and low risk. According to the grading criteria, the whitening weight function is as follows:

Table 2. ash classes and corresponding whitening weight functions

| Grey classifications | Grey number | definite weight functions |
|----------------------|-------------|---------------------------|
| e=1                  | $\otimes 1\epsilon(0,4,+\infty)$ | $f(z(h_{ij})) = \begin{cases} 
 h_{ij} / 4, & h_{ij} \in [0, 4] \\
 1, & h_{ij} \in [4, +\infty] \\
 0, & h_{ij} \in [0, 4] 
\end{cases}$ |
| e=2                  | $\otimes 2\epsilon(0,3,6)$ | $f(z(h_{ij})) = \begin{cases} 
 h_{ij} / 3, & h_{ij} \in [0, 3] \\
 (6 - h_{ij}) / 3, & h_{ij} \in [3, 6] \\
 0, & h_{ij} \in [0, 6] 
\end{cases}$ |
| e=3                  | $\otimes 3\epsilon(0,2,4)$ | $f(z(h_{ij})) = \begin{cases} 
 h_{ij} / 2, & h_{ij} \in [0, 2] \\
 (4 - h_{ij}) / 2, & h_{ij} \in [2, 4] \\
 0, & h_{ij} \neq [0, 4] 
\end{cases}$ |
| e=4                  | $\otimes 4\epsilon(0,1,2)$ | $f(z(h_{ij})) = \begin{cases} 
 1, & h_{ij} \in [0, 1] \\
 2 - h_{ij}, & h_{ij} \in [1, 2] \\
 0, & h_{ij} \in [0, 2] 
\end{cases}$ |

(3) Weight Vector Matrix of Grey Evaluation

The weight of grey evaluation is as follows:

\[
\bar{r}_{ije} = \frac{1}{\sum_{e=1}^{4} \sum_{c=1}^{n} X_{ije}} \sum_{k=1}^{4} f_{c}(h_{ik})
\]

(6)

In formula: $X_{ije}$ is the grey evaluation coefficient.

The weight vector of grey evaluation is $R_{ij} = r_{ije}$, then the weight matrix of each grey class corresponding to the secondary index is:

\[
R_i = \begin{bmatrix}
\Gamma_{i1} \\
\Gamma_{i2} \\
\Gamma_{i3} \\
\Gamma_{i4}
\end{bmatrix} = \begin{bmatrix}
\Gamma_{i11} & \Gamma_{i12} & \Gamma_{i13} & \Gamma_{i14} \\
\Gamma_{i21} & \Gamma_{i22} & \Gamma_{i23} & \Gamma_{i24} \\
\vdots & \vdots & \vdots & \vdots \\
\Gamma_{i41} & \Gamma_{i42} & \Gamma_{i43} & \Gamma_{i44}
\end{bmatrix}
\]

(7)

(4) Comprehensive evaluation

The results of secondary indicators should be operated as follows:

\[
Z_{C} = R_i \cdot E^T
\]

(8)

The results of the first-level indicators should be operated as follows:

\[
Z_i = C_i \cdot Z_{C}
\]

(9)

The evaluation results can be obtained as follows:
3. Case Study on Risk Assessment of Sheguchong Tunnel

3.1 Project Survey
The Sheguchong Tunnel in Yunnan Province is located in Sheguchong Village, Xinxian Township, Pingbian County. The tunnel site is a low-mountain topography of erosion. The surface vegetation of the tunnel body is well developed, mostly wooden bushes, and the entrance and exit of the tunnel are early slopes. Only the rural convenience road communicates with the outside world, and the convenience road often collapses in the rainy season, resulting in poor traffic conditions.

3.2 Model Application

3.2.1 Establishment of Index System
This study divides tunnel engineering safety risk into three first-level indicators: environmental risk, technology and management risk, and other risks.
First, the environmental risk is mainly the geological and hydrological impact of tunnel engineering. Among them, collapse, mud burst, water burst, plastic deformation and broken ring, gas emission are the main sources of tunnel environmental risk. Secondly, the risk of technology and management, i.e. the behaviour of construction technology and management personnel, may hinder the construction during the construction process. Third, other risks are the third-party risks excluded from link risks and technology management risks, which are manifested in investment and economic market changes.

| Environmental risk | Water and mud inrush | Landslide | large deformation | Gas |
| Technology and Management risks | Technical staff level | Material Science | transport | equipment |
| Other risks | Design and construction methods | Market Changes in Investment Economy |

3.2.2 Rough Set to Determine Weight
Seven tunnel risk assessment experts are invited to grade the importance of risk indicators points. The weights and weight vectors of 12 indicators are obtained by calculation. Processing as follows:

\[
Z = Z \cdot \omega^T
\]  
(10)

| B1 | B2 | B3 | C11 | C12 | C13 | C14 | C21 | C22 | C23 | C24 | C25 | C31 | C32 | C33 |
|----|----|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1  | 4  | 3  | 2   | 4   | 4   | 3   | 2   | 2   | 4   | 2   | 3   | 3   | 1   | 1   | 1   |
| 2  | 3  | 3  | 2   | 3   | 4   | 3   | 2   | 2   | 3   | 2   | 3   | 3   | 1   | 2   | 2   |
| 3  | 4  | 2  | 2   | 4   | 4   | 4   | 4   | 2   | 4   | 2   | 3   | 3   | 2   | 1   | 1   |
| 4  | 3  | 2  | 2   | 4   | 3   | 3   | 3   | 2   | 3   | 2   | 3   | 3   | 1   | 3   | 1   |
| 5  | 4  | 3  | 4   | 4   | 4   | 4   | 4   | 2   | 4   | 2   | 2   | 3   | 1   | 1   | 1   |
| 6  | 3  | 4  | 3   | 4   | 3   | 3   | 3   | 3   | 3   | 3   | 2   | 2   | 3   | 1   | 1   |
| 7  | 4  | 2  | 2   | 4   | 4   | 4   | 4   | 3   | 4   | 3   | 2   | 2   | 1   | 1   | 1   |

Table 3 uses rough sets to determine the weights of indicators and gets them according to (1), (2), (3) and formula (4), the weights of the second-level indicators are as follows.
Table 5. Weights of Specific Indicators

| Bi in the system | The proportion of Cij in Bi | Cij in the system |
|------------------|---------------------------|------------------|
| 0.5              | 0.3182                    | 0.1951           |
|                  | 0.2273                    | 0.1137           |
|                  | 0.2273                    | 0.1137           |
|                  | 0.2273                    | 0.1137           |
| 0.3752           | 0.1739                    | 0.0621           |
|                  | 0.2609                    | 0.0932           |
|                  | 0.2174                    | 0.0776           |
|                  | 0.1739                    | 0.0621           |
| 0.1428           | 0.25                      | 0.0357           |
|                  | 0.3333                    | 0.0476           |
|                  | 0.4167                    | 0.0595           |

3.2.3 Grey System Evaluation

The grey weight matrix of the index is determined according to the ranking matrix and formula (6)(7). According to formula (8) (9) (10), the following table results are obtained.

Table 6. Comprehensive assessment results

| Overall evaluation results | Level indicators | The weight | The evaluation results | The secondary indicators | The weight | The evaluation results |
|----------------------------|------------------|------------|------------------------|--------------------------|------------|------------------------|
| 2.4258                     | B1                | 0.5        | 2.5996                 | C11                      | 0.1591     | 3.0588                 |
|                            |                  |            |                        | C12                      | 0.1137     | 3.2572                 |
|                            |                  |            |                        | C13                      | 0.1137     | 3.1236                 |
|                            |                  |            |                        | C14                      | 0.1137     | 3.1172                 |
|                            |                  |            |                        | C21                      | 0.0621     | 2.2179                 |
|                            |                  |            |                        | C22                      | 0.0932     | 2.5713                 |
|                            |                  |            |                        | C23                      | 0.0621     | 2.8496                 |
|                            |                  |            |                        | C24                      | 0.0776     | 2.1524                 |
|                            |                  |            |                        | C25                      | 0.0621     | 2.2347                 |
|                            | B2                | 0.3572     | 2.4121                 | C31                      | 0.0595     | 1.4956                 |
|                            |                  |            |                        | C32                      | 0.0476     | 2.1474                 |
|                            |                  |            |                        | C33                      | 0.0357     | 2.05                  |

From the results of the above rough set and grey theory comprehensive model calculation, it can be seen that the risk assessment grade of the Sheguchong tunnel in Yunnan Province is high, and the value is 2.4258. Level 1 indicator B1 environmental risk is dominant. The risk of C11 collapse, C12 water inrush and mud inrush, C13 soft rock large deformation in the secondary index under B1 is very obvious, which should be paid great attention to and corresponding control measures should be taken. The capability risk of C23 technicians and the assessment level of C14 gas explosion risk are also high, which should be paid close attention to.

4. Conclusion

In this paper, grey system theory and rough set theory are applied to tunnel risk assessment. The tunnel risk assessment system independently completes the risk assessment of tunnel engineering projects. Its evaluation results are more concise and effective, and overcome the lack of objective scientific theory support for tunnel safety risk assessment and the subjective evaluation method. The problem has achieved ideal results. The combination of rough set and grey theory enriches and improves the research methods in this field, and provides a new prediction model and ideas for the study of Tunnel Risk assessment.
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