Risk Evaluation of Railway Coal Transportation Network Based on Multi Level Grey Evaluation Model

Wei Niu* and Xifu Wang*
School of Traffic and Transportation, Beijing Jiaotong University, Beijing, China

*Corresponding author: wsnw1123@163.com
*xifuwang1@bjtu.edu.cn

Abstract. The railway transport mode is currently the most important way of coal transportation, and now China's railway coal transportation network has become increasingly perfect, but there is still insufficient capacity, some lines close to saturation and other issues. In this paper, the theory and method of risk assessment, analytic hierarchy process and multi-level gray evaluation model are applied to the risk evaluation of coal railway transportation network in China. Based on the example analysis of Shanxi railway coal transportation network, to improve the internal structure and the competitiveness of the market.

1. Introduction
At present, China's railway transport capacity in general cannot be compatible with the national economic and social development needs, coal supply and consumption regional distribution is not balanced. Some of our sales channels on the capacity of a serious shortage, cannot meet the needs of the corresponding regional coal consumption market.

This paper will analyze the possible risk factors in the railway coal transportation network and estimate the probability of each risk and the possible loss of the risk, so as to find the key risk of the mode of transport, determine the overall risk level and how to deal with these risk, to provide a scientific basis to ensure the smooth progress of railway coal transportation.

2. Risk evaluation index of railway coal transportation network
Railway coal transportation network is a complex system inside, and its risk evaluation should be based on the analysis of the internal risk factors, so as to establish the risk evaluation index system of railway coal transportation network.

2.1. Analysis on risk factors of railway coal transportation network
The analysis of risk index of railway coal transportation network needs to analyze the internal structure and function of the network from the aspects of society, economy and technology, so as to verify the rationality of the scheme and provide the technical basis for optimization and decision. Include indicators such as network invulnerability, accessibility, network availability, transport capacity and network suitability.
2.1.1. Network invulnerability. Network invulnerability refers to the ability of the network to maintain its operation when the nodes or edges of the network fail or are attacked intentionally. Network invulnerability mainly includes 3 indicators, namely node density, link density and network connectivity.

2.1.2. Accessibility. Accessibility includes node accessibility and network accessibility, In a railway coal transportation network, the accessibility of a node is expressed by the average distance from the node to the other nodes. The network accessibility can be expressed by the distance, the travel time or the cost traveled from any node in the planning area.

2.1.3. Network availability. Network availability refers to the ability of the network to meet the transport demand in a certain period of time, that is, the probability of the normal use of the railway coal transportation network. Network availability indices include section availability and OD availability.

2.1.4. Transport capacity. Transport capacity is the maximum capacity of the traffic system to meet the traffic demand under the service and quality requirements of the traffic user and resource environment, which reflects the actual carrying load status of railway coal transportation network. It includes the average transportation turnover, the average haul distance and the cargo transport density.

2.1.5. Network suitability. Network suitability refers to the ability of the rail coal transportation network to allocate limited resources reasonably, to meet the demand of the transportation with minimal resource consumption. It includes line efficiency and transport capacity saturation.

2.2. Risk evaluation index system of railway coal transportation network

According to the qualitative and quantitative analysis of the risk evaluation indexes of railway coal transportation network, the risk evaluation index system is established, as shown in Table 1.

| Target | Criterion | Index |
|--------|-----------|-------|
| The risk of railway coal transportation network A | Network invulnerability B1 | Node density C11, Link density C12, Network connectivity C13 |
| Accessibility B2 | Node accessibility C21, Network accessibility C22 |
| Network availability B3 | Section availability C31, OD availability C32 |
| Transport capacity B4 | Average transportation turnover C41, Average haul distance C42, Cargo transport density C43 |
| Network suitability B5 | Line efficiency C51, Transport capacity saturation C52 |

3. Multi-level grey evaluation model

There are many methods for risk assessment. Through comparative analysis, this paper uses multi-level grey evaluation model as evaluation method, and uses analytic hierarchy process to determine the index weight.

3.1. AHP and its steps

The first step of application of AHP for system analysis is to stratify the problem, and form a multi-level analytical structure model. Comparing the factors in pairs at each level to determine the judgment matrix. We can calculate the single ordering weights for a layer of factors relative to the previous level by calculating the maximum eigenvalue of the judgment matrix and its corresponding eigenvector. Finally, calculate the weight of each factor relative to the overall goal.
3.2. Multiple grey model evaluation method and its steps

The gray evaluation method is designed to determine the gray correlation between the reference series and each comparison sequence. Its steps are as follows:

Organizational evaluators rate the qualitative indicators of the railway coal transport network, the greater the risk, the greater the score of the experts. According to the evaluation results of the evaluator, obtain the evaluation sample matrix $G$.

$$
G = \begin{pmatrix}
g_{11} & \cdots & g_{1m} \\
\vdots & \ddots & \vdots \\
g_{n1} & \cdots & g_{nm}
\end{pmatrix} = \begin{pmatrix}
C_{11} \\
\vdots \\
C_{nj}
\end{pmatrix}
$$  \hspace{1cm} (1)

Determine the index rating table. According to the railway coal transportation network, to establish qualitative and quantitative indicators of grading scoring criteria.

Determine the gray scale and calculate the gray rating. According to the grading standard level, the gray whitening right function take in this paper is shown in Fig 1.

![Figure 1. The gray-type albinio weight function](image)

For the evaluation index $C_{ij}$, the grey evaluation number which belongs to the grey evaluation of $n$ is recorded as $X_{ijn}$.

$$
X_{ijn} = \sum_{i=1}^{m} f_{e}(d_{ij})
$$  \hspace{1cm} (2)

For the evaluation index $C_{ij}$, the total grey evaluation rates belongs to the grey class each evaluation number is recorded as $X_{ij}$.

$$
X_{ij} = \sum_{n=1}^{p} (X_{ijn})
$$  \hspace{1cm} (3)

Calculating grey evaluation weight vector and weight matrix, all the evaluators advocate that the gray evaluation of the $n^{th}$ evaluation gray class is recorded as $r_{ijn} = \frac{X_{ijn}}{X_{ij}}$. Gray evaluation weight vector $r_{ij} = (r_{ij1}, r_{ij2}, \ldots, r_{ijn})$, then,

$$
R_{i} = \begin{pmatrix}
r_{i1} \\
r_{i2} \\
\vdots \\
r_{ij}
\end{pmatrix} = \begin{pmatrix}
r_{11} & \cdots & r_{1in} \\
r_{21} & \cdots & r_{2in} \\
\vdots \\
r_{ijn}
\end{pmatrix}
$$  \hspace{1cm} (4)
Calculate the comprehensive evaluation value. The results of the comprehensive evaluation of $B_i$ is $\beta_i$. Then,

$$\beta_i = A \bullet R = A \begin{bmatrix} A_1 \bullet R_1 \\ \vdots \\ A_m \bullet R_m \end{bmatrix} = (b_1, b_2, \ldots, b_n)$$

Thus, the grey evaluation weight matrix $R$ of each index for each evaluation grey class is obtained. Divide all levels according to “gray level”, get a variety of evaluation gray class rank value vector $Z = (d_1, d_2, \ldots, d_n)$.

And then obtain a comprehensive evaluation value $Z = B \bullet C^T$. From this we can derive the risk level of the network system and compare it with other network system risk levels.

4. Case analysis

Taking Shanxi railway coal transportation network as an example, prove the model and method of risk assessment by the case analysis.

4.1. The calculation of the index weight

According to the above established index system, and comparison of importance of the value at the same level, to determine the weight of evaluation index system at all levels, as shown in Table 2.

| Weight | Relative to criterion layer weight | Relative to target layer weight |
|--------|-----------------------------------|--------------------------------|
| 0.5070 | 0.6301                            | 0.3195                         |
| 0.2184 | 0.2184                            | 0.1107                         |
| 0.1515 | 0.1515                            | 0.0768                         |
| 0.7500 | 0.7500                            | 0.1841                         |
| 0.2500 | 0.2500                            | 0.0614                         |
| 0.6667 | 0.6667                            | 0.1051                         |
| 0.3333 | 0.3333                            | 0.0526                         |
| 0.1692 | 0.1692                            | 0.0104                         |
| 0.4434 | 0.4434                            | 0.0272                         |
| 0.3874 | 0.3874                            | 0.0238                         |
| 0.4650 | 0.4650                            | 0.0224                         |
| 0.4135 | 0.4135                            | 0.0199                         |

4.2. Calculation of the sample matrix and the weight matrix of gray evaluation

Organize five experts to rate the rest of the qualitative risk assessment factors, then calculate the sample matrix. Finally, the expert scoring matrix and the corresponding evaluation weight matrix are obtained. As shown in Table 3.
Table 3. The expert scoring matrix and the evaluation weight matrix

| Expert scoring matrix | Evaluation weight matrix |
|-----------------------|--------------------------|
| \( D_{in} = \begin{bmatrix} 5.0 & 4.0 & 5.0 & 5.0 & 4.0 \\ 4.0 & 5.0 & 5.0 & 4.0 & 4.0 \end{bmatrix} \) | \( R = \begin{bmatrix} 0.4329 & 0.3680 & 0.1991 & 0.0000 \\ 0.4329 & 0.3680 & 0.1991 & 0.0000 \end{bmatrix} \) |

4.3. Calculation of the gray evaluation matrix

Calculate the risk assessment index of Shanxi railway coal transportation network index layer belongs to the gray evaluation weight vector of each evaluation gray class. As shown in Table 4.

Table 4. The expert scoring matrix and the evaluation weight matrix

| The gray evaluation weight vector | Matrix value |
|----------------------------------|-------------|
| \( B_1 \)                       | \begin{bmatrix} 0.3074 & 0.3329 & 0.3075 & 0.0219 \end{bmatrix} |
| \( B_2 \)                       | \begin{bmatrix} 0.3771 & 0.3200 & 0.0640 & 0.0000 \end{bmatrix} |
| \( B_3 \)                       | \begin{bmatrix} 0.4110 & 0.3791 & 0.1978 & 0.0000 \end{bmatrix} |
| \( B_4 \)                       | \begin{bmatrix} 0.2901 & 0.3863 & 0.2901 & 0.0289 \end{bmatrix} |
| \( B_5 \)                       | \begin{bmatrix} 0.2616 & 0.3133 & 0.2616 & 0.0384 \end{bmatrix} |

The gray class of this paper is divided into four grades: high risk, high risk, medium risk and low risk. Determine the evaluation of gray class rank assignment vector \( C = (4.5, 3.5, 2.5, 1.5)^T \), Calculate the comprehensive evaluation of railway coal transportation network risk.

\[
Z = B \cdot C^T = \begin{bmatrix} 4.5 \\ 3.5 \\ 2.5 \\ 1.5 \end{bmatrix} \begin{bmatrix} 0.34 & 0.35 & 0.23 & 0.01 \end{bmatrix} = 3.35
\]

Shanxi Railway coal transport network risk comprehensive evaluation value of 3.35, combined with the above set of reviews, the network system is between the medium risk and higher risk.

The influence of the five factors of the index layer on the evaluation value of the total risk of the coal transportation network in Shanxi railway is the network survivability, the network adaptability, the network availability, the network carrying capacity, the network accessibility.

5. Conclusion

Railway coal transportation network is a complex system, the scientific evaluation of its risk is also a complex work. The multi-level gray evaluation model of this paper has a clear meaning and has some validity and practicability for risk assessment. This approach is not only very operational, but also allows risk management decision makers based on the risk level to make targeted control and emergency measures.

And it is undeniable that the theoretical system and practical application of the application for the multi-level gray evaluation model in the railway coal transportation network risk assessment needs to further improve and expand.
References

[1] Li Zhang. Solving Railway Routing and Scheduling Problems in an Intermodal Freight Transportation System [D]. Concordia University.

[2] Maruri, L. Simulation of a container transport system between port and inland terminal depots [J]. 1st Industrial Simulation Conference 2003.

[3] Teng-Fei Rang, Kevin Cullinane. The Efficiency of European Container Terminals and Implications for supply Chain Management [J]. Economics & Logistics. 2006 (8).

[4] Limonov, E. L. Organization of multimodal container transportation [J]. Tselliuloza, Bumaga, Karton/Pilp, Paper, Board, n3-4, 2003.

[5] Y. H. V. Lun, K.-H. Lai, T. C. E. Cheng. Shipping & Logistic Management [M].

[6] Williams C A, Heine 1985 R M. Risk management and Insurance [M]. New York.

[7] Information on http://www.sxcoal.gov.cn.