Evaluation Method of Roof Damage Degree and a Case Study in Maoping Lead-Zinc Mine, Yunnan

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With the continuous increase in the mining depth of underground mineral resources, the geological conditions encountered in mining have become more complex. The complex geological conditions have led to varying degrees of roof damage, especially the frequent occurrence of roof collapse accidents in metal mines, causing huge losses to mining enterprises. How to evaluate the risk of roof subsidence, falling, and even collapse under different geological conditions has become the primary issue. This article first selects the main evaluation indicators in the domestic and foreign roadway roof failure research literature for statistical analysis. Then, according to the statistical results, a classification approach of roof damage degree using the fuzzy comprehensive clustering method is established with roof rock strength, broken degree, roadway section size, buried depth, and roof sinking amount as evaluation indicators. The damage of the top plate is divided into five grades: minor damage, obvious damage, serious damage, extremely serious damage, and devastating damage. Finally, the established evaluation method was applied to the project site-supporting work of the 760 m main transport roadway in Yunnan Maoping Lead-Zinc Mine. The evaluation result is consistent with the actual situation on-site. The research results can provide a reference for the roof stability analysis under the background of this project and similar projects and at the same time help the next step in the classification control of different levels of roof stability and the design of the overall roadway support.

1. Introduction

The depth of underground mines continues to increase, and the number of roadway mileage is also increasing. Due to the instability of the roadway roof caused by the mining operation, the casualties, equipment damage, and the permanent shutdown of the mine caused by the falling or even collapse have brought huge damage to the people's health and economic construction. As a channel for mining and transportation of mineral resources, the roadway has the characteristics of sudden, instantaneous, destructive, and complex roof damage. The local stability assessment plays a decisive role in the overall stability assessment of underground engineering. The special position of the roof and its local stability directly affect the two sides and the floor and then become the key to the overall stability evaluation of the roadway [1].

Due to the complex and changeable geological features, the initial method of roof damage analysis is to use an engineering analogy. Based on the existing rock mass quality classification under similar engineering geological conditions, some adjustments will be made to the characteristics of this project. Rock mass quality classification is an evaluation method based on the combination of qualitative experience and quantitative field measurement [2]. Although this method can quickly distinguish some properties of rock masses, considering the single element, it cannot fully reflect the objective mechanical properties of rock masses. The American scholar Deer proposed the rock mass quality coefficient classification method in 1967 [3]. The
RQD value is obtained by comparing the collected core and the length of the borehole, and the rock mass is divided into 5 grades [4], which has been used until now. The American scholar Wickham proposed the Rock Mass Structure Evaluation Method (RSR) in 1972 [5], and the South African engineer Bieniawski proposed the Rock Mass Geomechanics Classification Method (RMR) in 1973, based on rock mass strength and rock mass quality index (RQD), joint spacing, joint conditions, and groundwater parameters, dividing the rock mass into 5 grades. In 1974, Norwegian scholar Barton proposed a more refined Q system method for grading rock mass, dividing the rock mass into 9 grades. The above rock mass classification methods have a far-reaching international influence and are widely used.

China’s rock mass quality classification began after 1970, and the Platts coefficient method has been used before. With the complexity of the engineering background and the shortcomings of the Platts coefficient method becoming more and more prominent, in 1979, scholars Gu Dezhen and Huang proposed the Z method for rock mass quality classification. In 1980, Wang Sijing proposed Za classification based on elastic wave index. In 1985, the Yangtze River Water Resources Commission proposed the YZP classification of the Three Gorges Project. In 1988, the Kunming Survey and Design Institute of the Ministry of Water Power proposed the classification of surrounding rock in underground chambers of large hydropower stations [6]. At the same time, the Ministry of Transport, Ministry of Water and Electricity, Ministry of Construction, and other relevant departments have successively proposed the quality classification of surrounding rock in their respective fields. The representative is the national standard rock mass quality evaluation BQ method promulgated and implemented in 1994. It has been revised, and it has become a widely used rock mass-quality grading evaluation method in China. In addition, there are many other methods for rock mass quality classification based on engineering analogy experience. However, the influencing factors considered by these methods are often too single, or some characteristic parameters are difficult to obtain. In addition, the damage of the roof has obvious temporal and spatial effects, and the rough classification of the degree of roof damage is completely replaced by the stability of the surrounding rock, which is not completely applicable to some specific projects [7–9].

With the deepening of the research on the quality evaluation of engineering rock masses, more and more researchers have introduced mathematical methods to the evaluation of rock mass damage degree. Established models such as artificial neural network, fuzzy mathematics model, game-extension theory analysis model, extension evaluation model connected to the cloud, extension matter-element model, unascertained measure, cloud model, and other evaluation methods have been well applied in the engineering site. These methods can analyze the roof stability more comprehensively, but the amount of data calculation is large and it is often necessary to rely on high-performance computing equipment and high-precision calculation methods, which are suitable for higher-level and more important projects [10–14].

In order to balance the contradiction between low-cost rough calculation and high-precision expensive calculation, this article first searches Web of Science and CNKI databases for the analysis of the factors affecting the stability of the roof and slab of underground engineering tunnels in the past ten years. Then, a classification and evaluation method of roof damage degree based on a fuzzy evaluation idea is proposed. Finally, the method was applied to the roof damage degree of the 760 m main transport roadway of the Maoping Lead-Zinc Mine in Yunnan Province. The research strives to provide some guidance for the key technical problems of roof stability control in the construction or repair of high-grade roadways.

2. Main Evaluation Indexes of Roadway Roof Damage Degree

In order to evaluate the degree of roof damage more objectively, it is first necessary to systematically understand the existing commonly used evaluation indicators and influencing factors. Therefore, this paper conducts a random investigation of the literature research on the roof stability of underground mine tunnels and subway tunnels at home and abroad in the past ten years. In total, 50 mine roadways and 50 subway tunnels were investigated, and the main indicators for the evaluation of the damage degree of the roof surrounding rock were counted. The sources of roadway roofs investigated include typical mine roadways, urban subway tunnels at home and abroad, mountain tunnels, state-owned large and medium-sized coal mines, open pit mines, and metal mines. The buried depth includes not only shallow mountain tunnels and subway tunnels, but underground water tunnels and coal mine tunnels. The surveyed roadway includes not only permanent chambers such as underground parking yards, substations, and water conveyance roadways but also temporary working roadways such as mining transportation roadways and power distribution rooms.

The survey results show that the degree of roof damage is mainly affected by five factors, two of which are direct factors due to the physical and mechanical properties of the roof rock mass itself [7], and the remaining three are indirect factors related to the engineering site conditions.

2.1. Direct Factors

2.1.1. Strength of Roof Rock Mass. The strength of the roof rock is different, and the damage degree of the roof is different. The stronger the integrity of roof rock, the lower the extent and scope of roof damage after excavation. For the roadway roof with low strength of surrounding rock, the stress of surrounding rock is greater than the strength of roof rock after excavation. The roof rock mass has a large degree
of damage and a large range of damage. The strength of rock mass can be tested by a uniaxial compressive strength test. It is obtained by the laboratory test of the load per unit area when the specimen is damaged by the axial force under unconfined conditions. The strength of the rock mass of the roof is different from the strength of the rock material of the roof [15], and it is difficult to conduct field tests accurately. Hence, laboratory test values of uniaxial compressive strength of roof rock are usually used to reflect the strength and softness of roof rock mass, as shown in Table 1.

If the equipment conditions are restricted and indoor tests cannot be carried out, point load tests can be carried out on-site. The following equation can be used to convert the two:

\[
R_c = 22.82I_S(50),
\]

where \(R_c\) is the uniaxial compressive strength of rock specimens measured by laboratory tests and \(I_S\) is the point load strength of the rock on-site; the rock point load strength index is 50.

2.1.2. The Integrity of the Surrounding Rock of the Roof.

After the excavation of the roadway, the roof surrounding rock is damaged and the degree of roof fracture and stability changes can be reflected by the integrity coefficient, which can be obtained through field tests. In the literature [16], the damage degree of the roof is classified according to the integrity coefficient of the roof. This article defines this indicator as \(K_v\). Also, we have the following:

(i) Basically complete (integrity coefficient above 0.95): the rock formation is complete, the roof has almost no risk of collapse, and only a small amount of reinforcement is required.

(ii) Slightly broken (integrity coefficient 0.85–0.95): the rock formation is slightly broken, and the risk of roof collapse is low, but it needs regular reinforcement and management.

(iii) Generally broken (integrity coefficient 0.75–0.85): the rock formation is generally broken, and the roof may collapse. Occasionally, roof fall events need to be overhauled regularly.

(iv) Obviously broken (integrity coefficient 0.65–0.75): the rock layer is obviously broken, the roof has a great risk of collapse, and roof fall events occur frequently, so real-time monitoring of the surrounding rock of the roof is required.

(v) Seriously broken (integrity coefficient 0.55 and below): the roof rock layer is very broken. A devastating blow occurs to the overall stability of the roadway. Only after the personnel and equipment are removed from the site, professional teams and equipment are used to rebuild or renovate the roadway in order to ensure safety and normal use.

The integrity factor of the surrounding rock of the roof is generally judged by the acoustic velocity field test. The magnitude of the wave velocity in the rock reflects the degree of damage to the roof. Generally, it is believed that the magnitude of the wave velocity is proportional to the integrity of the surrounding rock. The more complete the surrounding rock, the faster the sound wave propagates in the rock. The relationship between wave speed and damage degree of surrounding rock is shown in Table 2.

The comparison between the field survey results and the previous literature further confirms that it is difficult to accurately evaluate the damage degree of the roof and to guide the construction of the on-site support by only relying on the rock mass strength and the integrity of the roof to classify the damage of the roof [17, 18]. When evaluating the degree of roof damage, it is also necessary to take the engineering factors into consideration and establish a comprehensive grading system that combines subjective and objective factors to provide references for roof support design and roadway stability control. Therefore, in the field survey, the engineering influence of the degree of roof damage was counted, including the buried depth of the roof of the roadway (B), the size of the roadway section (S), and the amount of roof subsidence (D). These factors are indirect indicators for evaluating the degree of roof damage.

2.2. Indirect Factors

2.2.1. Burial Depth (B). Generally speaking, the buried depth is positively related to the magnitude of the ground stress. The in situ stress level of deep engineering is higher than that of shallow engineering. Huge in situ stress is an important natural factor that causes separation or spalling of the roadway roof. The in situ stress is composed of the superposition of gravity stress and tectonic stress. The high initial stress mainly comes from the direct influence of complex regional geological structure, tunnel buried depth, valley topography, and rock strength. When excavating underground chambers under high ground stress conditions, the roof rock mass is more prone to a series of disasters. The disaster risk assessment table of engineering construction under different high and low ground stress conditions proposed by Zhang et al. [19] is shown in Table 3.

2.2.2. Roadway Section Size (S). The shape and size of the underground roadway section are various, and the section size can be described by the span or the area of the section. Span refers to the maximum value of the roadway section in the horizontal direction. When the span of the roadway is different, the risk of roof fall is also different. For a roadway with a small span, due to the small excavation area in the horizontal direction, the two sides have a higher supporting effect on the roof. The roof rock mass is more stable. Even in the absence of support, the surrounding rock of the roof can still carry out stress redistribution to achieve self-stability. Therefore, the deformation of the roof is relatively small, so the degree of damage is low and the stability is higher. For long-span roadways, the stress of the surrounding rocks after excavation is higher than the rock strength of the roof, and the roof support is difficult, which causes serious damage to the roof [16] and it even collapses. According to the
specifications, the current mine roadways in our country can be divided into categories according to the span or section area, as shown in Table 4.

2.2.3. The Amount of Roof Sinking (D). The change of roof subsidence displacement is an important manifestation of roof damage and initial support effect. After the excavation of the roadway is completed, the change of the roof displacement with time generally shows the characteristics of first increasing and then gradually becoming stable. Different types of underground roadways have great differences in the amount of roof subsidence. The urban subway tunnel is more important and its service life is longer than mine roadway, the roof stability is strong, and the amount of subsidence is small. Due to the short service life of temporary mining tunnels, considering the support cost, the support capacity is weak. At the same time, it is obviously affected by man-made operations, so the amount of sinking is relatively large.

In summary, this paper selects roof rock mass strength (Rc), rock wave velocity (V), ground stress (σv), tunnel span (S), and vault subsidence (D) as evaluation indicators. Using the fuzzy comprehensive evaluation method, comprehensively considering the principles of objective quantification and subjective qualitativeness, the damage degree of the roof is divided into five grades of 1 to 5. The evaluation indicators of each grade are shown in Table 5.

3. Establishment of the Fuzzy Comprehensive Evaluation Model for Roof Damage Degree

3.1. Principle and Engineering Application of Fuzzy Comprehensive Clustering. The fuzzy comprehensive clustering method is an important application of fuzzy mathematics in engineering disciplines in recent years. According to the transformation principle and membership theory in fuzzy mathematics, the rough qualitative judgment is transformed into scientific quantitative analysis. In particular, fuzzy mathematics theory can comprehensively analyze and evaluate objects restricted by a variety of influencing factors and has a wide range of applications in
the field of geotechnical engineering. Applying it to the evaluation of the damage degree of the roadway roof not only considers the physical and mechanical properties of the rock mass itself [20] but also draws on the engineering field experience, which can more scientifically and accurately reflect the damage degree of the underground roadway roof.

3.2. Membership Function and Fuzzy Relation Matrix. The roof is broken, and its damage mechanism is complicated and affected by multiple factors. The fuzzy comprehensive clustering method comprehensively considers multiple key factors and can give a quantitative evaluation. The fuzzy comprehensive clustering method is used to carry out the evaluation of the damage degree of the roadway roof. First, the factors affecting the damage degree determined previously \( U = (U_1, U_2, U_3, \ldots, U_n) \) and all the evaluation grades of the influencing factors \( V = (V_1, V_2, V_3, \ldots, V_m) \) are given. And, the weight of each influencing factor is designated as the fuzzy subset \( A \) on \( U \), which is expressed as weighted fuzzy.

Set the weights as \( W_1, W_2, W_3, W_4, \) and \( W_5 \) occupied by the influencing factors, and then, obtain the fuzzy relationship matrix \( R(rij)_{n \times m} \) through the affiliation relationship of each influencing index to the damage degree of the roadway roof, as shown in matrix (6). Then, according to equation (2), fuzzy calculation and normalization are performed on the fuzzy relationship matrix and the index weight. Finally, the fuzzy comprehensive evaluation result is given and \( U \) is the fuzzy clustering matrix on \( V \). The following matrix is used to determine the type of roof damage.

\[
B = A \cdot R. \tag{2}
\]

After determining the influencing factors and standards of roof damage classification, according to the indoor test results of each index and the on-site situation, the fuzzy set composed of the index is determined, that is, the membership function of the index. Since the units and evaluation scales of the five influencing factors are completely different, the dimensionlessness of the influencing factors should be obtained before determining the value of the degree of membership. Here are function expressions (3)–(5) of the three kinds of membership functions, which can be used to determine the value of the membership. The abscissa \( x \) in each membership function expression is the actual value, \( a_1 \) and \( a_2 \) are the critical values between two adjacent levels of the index, and the ordinate is the membership \( \mu(x) \).

From left to right, these three membership functions are divided into three categories: small, medium, and large, as shown in Figure 1. According to these three functional relations, \( U_{ij} \) in the fuzzy relation matrix \( R \) can be determined, that is, the membership degree of the actual value of the \( i \)-th influencing factor to the class \( j \) [21].

\[
\mu(\chi) = \begin{cases} 
1, & 0 \leq x \leq a_1 \\
\frac{a_2 - x}{a_2 - a_1}, & a_1 < x < a_2 \\
0, & x > a_2 
\end{cases}, \quad \tag{3}
\]

\[
\mu(\chi) = \begin{cases} 
0, & 0 \leq x \leq a_1 \\
\frac{x - a_1}{a_2 - a_1}, & a_1 < x \leq a_2 \\
1, & a_2 < x \leq a_3 \\
0, & x > a_4 
\end{cases}, \tag{4}
\]

\[
\mu(\chi) = \begin{cases} 
0, & 0 \leq x \leq a_1 \\
\frac{x - a_1}{a_2 - a_1}, & a_1 < x < a_2 \\
1, & x > a_2 
\end{cases}, \tag{5}
\]

\[
R = (r_{ij})_{n \times m} = \begin{bmatrix} 
\mu_{11} & \mu_{12} & \ldots & \mu_{1m} \\
\mu_{21} & \mu_{22} & \ldots & \mu_{2m} \\
\mu_{n1} & \mu_{n2} & \ldots & \mu_{nm} 
\end{bmatrix}, \quad \tag{6}
\]
3.3. Determining the Factor Weight Vector. There are many ways to determine the weight, such as the expert questionnaire survey method, analytic hierarchy process (AHP), and entropy weight method. This paper chooses the excess weighting method to determine the weight vector. This weighting method is simple and efficient, that is, the farther a parameter value is from the critical average value, the greater the impact on the roof damage and therefore the greater the weight. This is given by

$$W_i = \frac{C_i}{C_0}$$  \( (7) \)

where \( C_i \) is the actual value of index \( i \) and \( C_0 \) is the average allowable critical value of each level of classification index. The weight calculated according to formula (7) is regarded as a single-factor weight. The comprehensive weight is determined under the condition of considering the influence of multiple factors, after the calculation of each single-factor influence weight, and the data normalization process shall be performed using (8), calculate the comprehensive weight of each influencing factor. The way to check whether the comprehensive weight is calculated correctly is to ensure that the sum of the calculation results of the comprehensive weight of each indicator is 1.

$$A = \sum_{i=1}^{n} W_i \quad (i = 1, 2, 3, \ldots, n).$$  \( (8) \)

Finally, the calculation result of the comprehensive weight matrix is obtained.

$$A = (W_1, W_2, \ldots, W_n) = (W_1, W_2, W_3, W_4).$$  \( (9) \)

3.4. Fuzzy Clustering Decision. Substituting equations (6) and (9) into (2) can obtain the fuzzy clustering evaluation matrix, as shown in the following equation:

$$B = A \cdot R = (u_1, u_2, u_3, \ldots, u_n) = (u_1, u_2, u_3, u_4, u_5).$$  \( (10) \)

According to the principle of maximum membership, if the result vector of the fuzzy comprehensive clustering matrix \( B \) is \( U_r \), the object belongs to the class \( R \).
\[
\mu_r = \max_{1 \leq j \leq n} \{B\}. \tag{11}
\]

4. Example Analysis of Evaluation of Roof Damage Degree of the Roadway in the Maoping Lead-Zinc Mine

4.1. Project Overview of the Research Site. The Maoping Lead-Zinc Mine is located about 70 km southeast of Zhaotong City, Yunnan Province. The administrative division is subordinate to Luozehe Town, Yiliang County, Zhaotong City. It is the main production mine of Chihong Mining Co. Ltd. The geographic location is shown in Figure 2.

The roof of a 760 m layered roadway was selected to evaluate the damage degree. This roadway was originally a material transportation roadway. The roadway as a whole is in the Carboniferous strata, dominated by carbonaceous sandstone and mudstone. The roof of the roadway at the sampling position passes through the coal seam at the same time, as shown in Figure 3.

Due to the roof conditions of the deep mine and complex environmental factors, the roof of the roadway is broken and the vault is an obvious sink, as shown in Figure 4.

Due to the roof conditions of the deep mine and complex environmental factors, the roof of the roadway is broken and the vault is an obvious sink, as shown in Figure 4.

4.2. Laboratory Test of Roof Rock Mass of the Maoping Lead-Zinc Mine. For more accurate analysis, after sampling the roadway roof rock on-site, it is processed in the laboratory for a uniaxial compression test of the rock sample [23, 24]. The YZW-100 testing machine used for the test is shown in Figure 5.

The in situ stress measurement was carried out in the borehole of the roadway roof. In order to complete the research work of this article, the borehole strain gauge was used to carry out the engineering field stress test and the borehole was selected in the roof of the main transportation roadway of 760 m to be studied. Its working principle is to place the probe in a rock borehole and rigidly connect it with the rock with a binder. The change of ground stress acts on the probe. First, the volume of the probe changes accordingly, and then, the oil pressure in the probe changes. Finally, the pressure sensor in the probe converts the pressure change into electrical signal output. After passing through
the preamplification circuit in the probe, it is sent to the ground electronic instrument through the cable [25–29]. The in situ stress test tool is shown in Figure 6.

An ultrasonic detection analyzer is used to detect the integrity of the roof. When in use, the standard rock specimen must be fixed between the two ends of the probe to ensure the complete propagation of sound waves in the specimen [30]. The built-in software of the NM-4A ultrasonic detection analyzer can directly read the test results. Its structure is shown in Figure 7.

Based on the test results of the above experimental methods, the measured values of the five influencing factors of the roof damage of the 760 m main transportation roadway in the Maoping Lead-Zinc Mine are summarized, as shown in Table 6.

The weight calculation results of each indicator are shown in Table 7.

After the data collection is completed, the fuzzy comprehensive method is used to classify the damage degree of the roof of the 760 m transportation roadway in the Maoping Lead-Zinc Mine. First, calculate the membership degree of each parameter according to formulas (3)–(5) and substitute (6) to obtain the following fuzzy evaluation matrix:

\[
R = \begin{bmatrix}
0 & 0 & 0 & 0 & 1 \\
0.29 & 0.71 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 \\
0.42 & 0.58 & 0 & 0 & 0 \\
0.11 & 0.89 & 0 & 0 & 0 \\
\end{bmatrix}
\]

(12)

Then, calculate the weight of each index according to formulas (7)–(9) and normalize it (Table 7) to obtain the following weighted fuzzy set:

\[
A = (0.42, 0.14, 0.14, 0.19, 0.11).
\]

(13)

According to formula (2), the following fuzzy clustering matrix can be obtained:
According to the principle of maximum membership degree in fuzzy mathematics theory, it belongs to the model which has the largest degree of membership. Matrix $A$ is the standard model, matrix $R$ is the evaluation matrix of engineering examples, and the calculation result matrix $B$ is the membership degree. We select the largest column vector of matrix $B$, i.e., 0.56, as the maximum membership degree, which belongs to the fifth degree of damage. This is a roof that has experienced near-destructive damage and requires the highest-level, logically rigorous support countermeasures to ensure the safety of personnel and equipment and prevent roof disasters that affect safe production.

5. Conclusion

In this paper, the research on the evaluation of roof damage degree, based on the research results of relevant high-level literature in recent years, not only considers the strength and fracture degree of the roof rock mass itself but also adds engineering background factors such as buried depth and roadway section size. The vault subsidence is also considered in this paper. The five factors are comprehensively analyzed, and finally, the roof damage level is obtained, which aims to lay the foundation for the next support design of the mine. At the same time, it also provides a kind of technical support for roof stability analysis and roadway repair under the background of similar projects. The main conclusions obtained are as follows:

1. Based on the literature research on roof stability of 100 roadways of various types at home and abroad, five indexes for the evaluation of roof damage degree have been established, which are the strength of the roof rock mass, the degree of rock fragmentation, the depth of burial, the size of the roadway section, and the roof subsidence quantity.

2. We obtain the measured values and average values of the five indicators by means of on-site measurement and give the value range of the single-factor indicator for judging the degree of roof damage. A method of a fuzzy comprehensive evaluation is proposed to determine the degree of roof damage. The result of the discrimination divides the degree of roof damage into five grades: light type, obvious type, severe type, destructive type, and extreme type.

3. Based on the engineering example of this article, the damage degree of the roof of the 760 m main transportation roadway in Maoping Lead-Zinc Mine is evaluated. According to the principle of the maximum degree of membership, the damage of the roof of the 760 m main transport roadway in Maoping Lead-Zinc Mine belongs to the fifth category. This is a very serious roof damage. The site survey of the project also verified the accuracy and rationality of the method.

In addition, it should be noted that during the study period, the 760 m main transportation lane was closed due to severe damage and vehicles and personnel were prohibited from passing. Therefore, this article does not discuss the disturbance effect of man-made construction work on the roof rock mass. Therefore, in the next step, such as large-scale equipment and long-term manual operations, it is recommended to refine or adjust on the basis of this evaluation.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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\[ Table 7: \text{Weight table of the classification index for measured value of roof damage degree.} \]

| Category                              | Rc (MPa) | V (m/s) | $\Sigma v$ (MPa) | S (m) | D (mm) |
|---------------------------------------|----------|---------|-----------------|-------|--------|
| Measured value, Ci                    | 12.61    | 2185    | 6.62            | 2.62  | 74     |
| Critical value average, $C_{0i}$       | 7.98     | 4012    | 12.94           | 3.55  | 187    |
| Weight value, $W_i$                   | 1.580    | 0.545   | 0.512           | 0.738 | 0.396  |
| Normalized weight coefficient, $\overline{W_i}$ | 0.42    | 0.14    | 0.14            | 0.19  | 0.11   |

\[ B = A \cdot R = \begin{bmatrix} 0.42 & 0.14 & 0.14 & 0.19 & 0.11 \end{bmatrix} \]

\[ = (0.13, 0.31, 0, 0, 0.56). \]

\[ (14) \]
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