Impact risk assessment based on Grey accident tree

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Abstract. The impact ground pressure is currently restricted mine production and safety of one of the typical dynamic disasters, this paper USES the two-dimensional evaluation method from two dimensions of risk and possibility analysis of the impact of the situation in a coal mine in shandong province, using fault tree (FTA) to determine the impact, with grey correlation analysis to find out the key factors that affects the risk impact and to improve the traditional fault tree analysis method, effectively solve the traditional fault tree in uncertain complex system are not suitable for as a quantitative analysis of the defects Combined with the field mining simulation of Shendong Group to judge the stress concentration and migration, to assist in verifying the impact risk of Shendong Coal Mine, the multi-parameter early warning system combining geological factors and mining factors is established, and the key factors of impact risk are corrected.

1. Introduction
With the deep extension of coal mining, rock faces three highs a disturbance of complex mechanical environment, a variety of disasters increasing coupling problem, severe natural environment and production conditions to mine deep mining of rock bursts is facing more risk factors threatening because of the rock mass or geological structure in the elastic energy reaches limit, the internal storage of stress release abruptly, instantaneous displacement of rock mass damage, may also cause gas outburst roof caving and other mine safety accidents.

Rock burst is a typical dynamic disaster in China's mine production and safety at present, posing a great threat to mine safety production. Because the mechanism and factors of rock burst are very complex, it is difficult to predict quantitatively. In 2018, the State Administration of Coal Mine Safety issued the Rules for the Prevention and Control of Coal Mine Rockburst in Article 45, which stipulates that regional prediction and local prediction can give priority to the comprehensive index method to determine the impact risk according to the geological and mining technical conditions, and other methods that have been proved effective in practice can also be adopted. At present, the research on rock burst in China mainly focuses on the mechanism and anti-impact measures, and the research on the risk assessment of rock burst is still in its initial stage without a unified identification model. Based on different mining disturbance conditions, Zhang Kai, Gu Stain et al used neural network model to carry out risk ANN evaluation on influencing factors of rock burst. Bi Juan and Li Xijian applied the TPPIsis analysis method of combinatorial weighting to Yanshitai Coal Mine, and calculated the relative attachment progress of 20 groups of selected samples, and the accuracy was 2.64% higher than that of the entropy-weight-approximation ideal solution. Fu Jianhua and Li Tao et al used the accident tree method (FTA) to establish the rock burst accident tree, and the Boolean algebraic algorithm was used to solve the minimum cut set. According to the importance ranking of cut set, the factors affecting rock
burst were divided into three grades. However, the evaluation indexes are numerous and correlated, and it is difficult to overcome the one-sidedness of diagnosis sequence by using fault tree only for single detection and prediction. The existing quantitative analysis methods of fault tree can not meet the requirements of rock burst risk assessment with complex mechanism.

In view of this, this paper adopts the two-dimensional evaluation method to analyze the impact situation of a coal mine in Shandong Province from two dimensions of risk and possibility. Using the improved gray FTA fault tree to view the risk factor of percussive ground pressure analysis method of combining the judging shock hazard, make up the defects of fault tree quantitative analysis, and by considering the effects of mining parameters more early warning system to replace the traditional single parameter, using mining simulation stress transfer and stress concentration, thus modified impact risk early warning system parameters.

2. Coal mine rock burst accident tree

Accident tree analysis (FTA) is widely applied in the complex system reliability diagnosis and safety risk assessment, and other fields, mainly in the form of graphic interpretation to logical reasoning system events, will be the cause of the failure from the overall to local layers of track, and the potential risk of system identification, is an effective method for safety assessment.

In Kuan Gou Coal Mine W1123, the corresponding surface elevation of fully mechanized caving working face is +1660 -- +1820m, the slope length of working face is 192m, the strike length is 1468m, the mining height is 3.2m, the caving thickness is 6.3m, the minable area is 282048m2, and the average dip angle of working face is 14.0m. Taking the data of rock burst in Kuangou Coal Mine provided in literature as an example, according to statistics, there have been many rock burst accidents in this coal mine, causing huge casualties and financial losses. According to the statistics of rock burst events over the years and relevant results of previous studies on rock burst accident tree, a relatively complete rock burst accident tree is constructed as follows:

| Serialnumber | Occurrence time | Occurrence place | Accident description |
|--------------|----------------|-----------------|---------------------|
| 1            | 2010.10.8      | W1143           | The coal outburst of W1143 working face was 247m3, causing casualties. |
| 2            | 2011.7.4       | E1146           | The accident occurred about 5m behind the heading face of the return air roadway, and the roadway section contracted sharply. |
| 3            | 2011.7.6       | E1146           | A similar accident happened again. Rock burst occurs when tunneling reaches 910m, accompanied by explosion, the coal wall deforms sharply. |
| 4            | 2013.1.9       | E1148           | A similar accident happened again. |
| 5            | 20.13.1.12     | E1148           | A similar accident happened again. |
Figure 1. Rock burst accident tree.

The production technology $A$, Geological factors $B$, Coal mining method $B$, Geological structure $B$, Physical and mechanical properties of coal seams $B$, Coal seam roof $C$, Underestimation of risk $C$, Human disturbance $X$, Mining sequence $X$, Roadway layout $X$, Cross section of roadway $X$, Face mining $X$, Fault $X$, Fold $X$, Coal quality $X$, Elastic deformation moisture content $X$, The thickness of the roof $X$. The direct roof and floor above the coal pillar are unstable.

2.1. Model Building

2.1.1. Grey accident tree analysis principle.
First of all, the time, place and circumstances of the occurrence of historical events are discussed. Then the rock burst accident tree of Shendong Group is drawn to calculate the minimum cut set and the smallest path set to analyze the impact possibility.

Grey relational analysis is used to improve the defect that the accident tree is difficult to judge quantitatively. Grey relational analysis can process a small amount of data for relational degree analysis, and indicate the importance of things with the magnitude of relational degree, so as to improve the disadvantage of the accident tree. The mathematical method mentioned above is used to calculate the weight of the impact data collected. To judge the impact risk and find out the key factors that affect the impact risk.

2.1.2. Solving steps of grey correlation method.
The assumption premise of accident tree analysis method is that the probability of occurrence of basic events is not considered or the probability of occurrence of basic events is equal, which makes the current accident tree analysis method stay in the qualitative stage, the relationship between basic events is difficult to determine, and is often not suitable for quantitative analysis. The grey correlation analysis method is used to determine the primary and secondary influences of each basic event on the top event, and the grey correlation analysis is combined with the traditional accident tree analysis to make a deep analysis of rock burst accidents from both qualitative and quantitative perspectives, which can effectively solve the shortcomings of the traditional accident tree in the analysis of uncertain complex system.

The solving steps of the grey correlation method are as follows:

(1) Set a group of original data as

$$
\chi^{(0)} = \{\chi^{(0)}(1), \chi^{(0)}(2), \ldots, \chi^{(0)}(n)\}
$$

(1)
(2) For the \( \chi^{(0)} \) volatility and randomness of the accumulatively weakened random sequence, a new number is obtained as follows:

\[
\chi^{(1)} = (\chi^{(0)}(1), \chi^{(0)}(2), \ldots, \chi^{(0)}(n)) \tag{2}
\]

Among them, \( \chi^{(0)}(k) = \sum_{i=1}^{k} \chi^{(0)}(i) \quad k = 1, 1, \ldots, n \)

Equal weight column of the \( \chi^{(0)} \) generated mean value of the nearest neighbors.

\[
Z^{(0)}(k) = 0.5\chi^{(0)}(k - 1) + 0.5\chi^{(0)}(k), k = 2, 3, \ldots, n \tag{3}
\]

(3) According to the grey theory, a first-order unitary differential equation about the whitening form of \( T \) is established.

\[
\frac{d\chi^{(1)}}{dt} + a\chi^{(0)} = u \tag{4}
\]

Where, \( a \) and \( u \) are unsolved coefficients, development coefficient and grey action respectively, the effective interval of \( a \) is \((-2, 2)\), and the matrix constituted by \( a \) and \( u \) is the grey parameter \( \hat{\alpha} = \begin{pmatrix} a \\ u \end{pmatrix} \) If you just take the parameter \( a \) and \( u \), then you can get, and then you can get the predicted value.

(4) Make the mean value of the accumulated data to generate vector \( B \) and constant term.

\[
B = \begin{bmatrix}
-\chi^{(0)}(2) \\
-\chi^{(0)}(3) \\
\vdots \\
-\chi^{(0)}(n)
\end{bmatrix}, \quad Y = \begin{bmatrix}
\chi^{(0)}(2) \\
\chi^{(0)}(3) \\
\vdots \\
\chi^{(0)}(n)
\end{bmatrix}
\tag{5}
\]

(5) The least square method is used to solve the ash parameters, so

\[
\hat{\alpha} = (B^T B)^{-1}B^T Y_n \tag{6}
\]

I’m going to substitute in the grey parameter \( \frac{d\chi^{(1)}}{dt} + a\chi^{(0)} = u \). And to solve, get

\[
\hat{\chi}^{(1)}(t + 1) = \left(\chi^{(0)}(1) - \frac{u}{a}\right)e^{-at} + \frac{u}{a}
\]

The predicted value can be obtained by reducing the above results

\[
\hat{\chi}^{(0)} = (\hat{\chi}^{(0)}(1), \ldots, \hat{\chi}^{(0)}(n), \hat{\chi}^{(0)}(n + 1), \ldots, \hat{\chi}^{(0)}(n + m)) \tag{7}
\]
From what has been discussed above:
First, the reference sequence and comparison sequence are established.
Set reference sequence: \( \chi^{(0)}(i) = \{ \chi^{(0)}(1), \chi^{(0)}(2), \chi^{(0)}(3), ..., \chi^{(0)}(n) \} \)
Comparison sequence: \( \hat{\chi}^{(0)}(i) = \{ \hat{\chi}^{(0)}(1), \hat{\chi}^{(0)}(2), \hat{\chi}^{(0)}(3), ..., \hat{\chi}^{(0)}(n) \} \)
Then, the initial value of the index is processed. \( \chi(i) = \chi^{(0)}(i)/\chi^{(0)}(1) \),
Then, the correlation coefficient is solved.

\[
\eta(i) = \frac{\min \min |\chi^{(0)}(i) - \chi^{(0)}(i)| + \rho \max \max |\chi^{(0)}(i) - \chi^{(0)}(i)|}{|\chi^{(0)}(i) - \chi^{(0)}(i)| + \rho \max |\hat{\chi}^{(0)}(i) - \chi^{(0)}(i)|}
\] (8)

Where, \( \rho \) is the resolution coefficient, and the value interval is [0,1]. Usually, 0.5 is the correlation coefficient.
Finally, the grey relational degree is solved.

\[
r(\hat{\chi}^{(0)}(i), \chi^{(0)}(i)) = \frac{1}{n} \sum_{i=1}^{n} \eta(i)
\] (9)

2.2. Analysis principle of grey accident tree
In the rock burst risk accident tree model, it is assumed that there are \( n \) basic events and \( m \) minimum cut sets (typical faults) in the accident tree. Any minimum cut set is composed of \( n \) characteristic parameters, and a total of \( m \) groups of eigenvectors constitute the eigenmatrix of rock burst risk accident:

\[
X_{R} = \begin{bmatrix}
X_{R1} \\
X_{R2} \\
\vdots \\
X_{Rm}
\end{bmatrix} = \begin{bmatrix}
X_{R1}(1) & X_{R1}(2) & \cdots & X_{R1}(n) \\
X_{R2}(1) & X_{R2}(2) & \cdots & X_{R2}(n) \\
\vdots & \vdots & \ddots & \vdots \\
X_{Rm}(1) & X_{Rm}(2) & \cdots & X_{Rm}(n)
\end{bmatrix}
\] (10)

The feature matrix is composed of the data to be examined:

\[
X_{T} = \begin{bmatrix}
X_{T1} \\
X_{T2} \\
\vdots \\
X_{Tm}
\end{bmatrix} = \begin{bmatrix}
X_{T1}(1) & X_{T1}(2) & \cdots & X_{T1}(n) \\
X_{T2}(1) & X_{T2}(2) & \cdots & X_{T2}(n) \\
\vdots & \vdots & \ddots & \vdots \\
X_{Tm}(1) & X_{Tm}(2) & \cdots & X_{Tm}(n)
\end{bmatrix}
\] (11)

Due to the contribution degree of each basic event of the top event is different, with different importance, in the impact ground pressure hazard accidents, importance of basic events is a probability of basic events caused the occurrence probability of top event rate, the rate of change of the certain impact ground pressure causes events on the whole the influence degree of the impact ground pressure hazard accidents.

\[
P_{S} = 1 - \prod_{i}^{m} \left( 1 - \prod_{R \in c} P_{Q} \right)
\] (12)
\[ e_j = \sum_{i=1}^{\infty} P_{ij} / P_j \quad i = 1, 2, \ldots, m \quad j = 1, 2, \ldots, n \]  

(13)

Where, \( e_j \) represents the importance of each basic event, \( P_{ij} \) represents the probability of occurrence of top event, \( P_j \) represents the probability of occurrence of basic event, \( P_{ij} \) represents the probability of occurrence of the minimum cut set, and \( P_j \) represents the probability of occurrence of the minimum cut set. The above feature matrix composed of test data can be transformed into a set of mode vectors to be checked:

\[ M = \{ M(1), M(2), \ldots, M(n) \} = \{ e_1, e_2, \ldots, e_n \} \]  

(14)

The correlation degree between the mode vector \( M \) to be detected and the characteristic matrix of the ground burst dangerous accident is calculated, and the correlation degree interval is \([0, 1]\). The more the calculation result approaches 0, the less sensitive its influence is, and the more sensitive the result approaches 1. According to the order of size, the influence of various basic events on top events can be obtained, and targeted effective prevention and control can be carried out.

3. Case Analysis

In coal mine W1123, the corresponding surface elevation of the fully mechanized caving working face is +1660 -- +1820m, the working face incline length is 192m, the strike length is 1468m, the mining height is 3.2m, the caving thickness is 6.3m, the mining area is 282048m², and the working face inclination is 14.0m on average. Taking the data of rock burst in Kuangou Coal Mine provided in literature as an example, according to statistics, there have been many rock burst accidents in this coal mine, causing huge casualties and financial losses. According to the statistics of rock burst events over the years and relevant results of previous studies on rock burst accident tree, a relatively complete rock burst accident tree is constructed as follows:

![Rock burst accident tree](image)

Figure 2. Rock burst accident tree.

FLAC3D was used for mining simulation to simulate the stress law, and the dynamic information was fed back to the qualitative determination and grey prediction of the accident tree in the early stage.

Working face: the mining height is 1.7 meters, the burial depth is 79 meters, the working face inclination length is 340 meters, and the pushing length is 2199 meters. (2) The X-axis direction of the model is set to represent the advancing direction of the working face. The open-off cut is set at 980m and pushed forward to 300m to express the two-square direction of the working face. The Y axis is set to represent the tilt direction of the working face. The length is 1 to 940m, and the length is 300 to 640 m to represent the tilt length of the working face. (3) The Z axis of the model represents the rock layer, and the thickness of the rock layer is 79 meters. See the table for specific information.
Table 2. Parameter data sheet.

| The serial number | The lithology                  | Strata thickness (m) | The density (kg·m⁻³) | The resistance strength (MPa) | Modulus of elasticity | Poisson's ratio | Angle of internal friction |
|-------------------|--------------------------------|----------------------|----------------------|------------------------------|-----------------------|-----------------|---------------------------|
| 8                 | The loess Medium grained sandstone | 8.06                 | 2540                 | 2.08                         | 5                     | 0.34            | 32.7                      |
| 7                 | Medium grained sandstone         | 5.87                 | 2550                 | 3.31                         | 25                    | 0.35            | 26.5                      |
| 6                 | siltstone                        | 7.47                 | 2472                 | 1.42                         | 6                     | 0.31            | 30.4                      |
| 5                 | mudstone                         | 0.3                  | 2540                 | 2.08                         | 5                     | 0.34            | 32.7                      |
| 4                 | coal                             | 3.7                  | 2540                 | 2.08                         | 5                     | 0.34            | 32.7                      |
| 3                 | mudstone                         | 3.85                 | 2540                 | 2.08                         | 5                     | 0.34            | 32.7                      |
| 2                 | Fine grained sandstone           | 22                   | 2430                 | 3.05                         | 20                    | 0.33            | 2                         |
| 1                 | mudstone                         | 1                    | 2540                 | 2.08                         | 5                     | 0.34            | 32.7                      |
| 0                 | 4-3coal                          | 1.7                  | 2540                 | 2.08                         | 5                     | 0.34            | 32.7                      |
| -1                | siltstone                        | 1                    | 2540                 | 2.08                         | 5                     | 0.34            | 32.7                      |
| -2                | mudstone                         | 3                    | 2540                 | 2.08                         | 5                     | 0.34            | 32.7                      |

Figure 3. Numerical analysis drawing of 170 m advance of working face.
As can be seen from the figure), when the working face advances to 170 meters (that is, half of the inclined length of the working face), the stress isoline above the stope reaches the surface. Figure 4.3 (b) to express is the contour map and the vertical displacement nephogram, advancing the 170 meters, vertical deformation of rock 130 mm contour through to the surface, thus, under the condition of thin bedrock, shallow buried depth of stope overburden fracture zone development soon, little slowly sinking area, the forward distance under the condition of small surface can achieve full mining, it is thin bedrock with typical characteristics of shallow buried deep stope in the three zones.

When the working face is advanced to 340 meters, that is, one square, the abutment pressure distribution range of stope in front of the advancing direction of the working face and on both sides of the inclined direction is simulated, as shown in the figure.

Describing the distribution law of abutment pressure in the coal wall in front of the coal face, it can be seen from the figure that the vertical stress appears an inflection point at 9 meters in front of the coal wall, and the leading distance of the peak abutment pressure in front of the coal wall can be basically determined to be 9 meters. The figure describes the distribution law of abutment pressure on both sides of the coal face, and its peak reaches 11 meters into the coal wall. According to Equation (3.93), its correlation value is, the peak abutment pressure is 3.28m, the revised coefficient of mining height and buried depth should be added, and the revised coefficient is estimated to be between 2.5-3.

Shows the vertical displacement isoline, 100 mm obvious in the graph on the deformation contour, the measurement of the distance, because of the coal seam is 22 meters above 2 meters of the existence of fine grained sandstone, fine sandstone overall deformation, coal rock deformation of 10 meters above the impact Angle is greater than the coal seam of 40 metres above the impact Angle, the surface subsidence impact Angle of working face in 60 degrees or so.

4. Conclusion
The fault tree is used to list the causes of rock burst, and the qualitative analysis is carried out. The minimum cut set and the minimum path set are obtained from the qualitative point of view. Because the fault tree is suitable for qualitative judgment in use, it can not meet the accuracy, so the gray correlation analysis is introduced to improve the fault tree, and the gray correlation analysis method is used to determine the primary and secondary influence degree of each basic event on the top event Combining grey correlation with traditional fault tree analysis, the deep analysis of rock burst accident from qualitative and quantitative perspectives can effectively solve the shortcomings of traditional fault tree analysis in uncertain complex system analysis. In addition, FLAC3D is used to simulate the impact risk assessment.

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