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Research Paper

Roof Failure Risk Assessment in Longwall Mining Using Fuzzy Event Tree Analysis

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Abstract: In longwall mining, after extracting each slice from the coal seam and advancing the face, a severe stress concentration is formed in the vicinity of the roof and coalface due to the stress disturbance and also the caving of the immediate roof, which resulted in roof displacement, cracks propagation, and roof failure. Due to the caving of the immediate roof and the displacement of the overburden layers by face advancement, there is a possibility of propagating the fractures and instability of the roof in the coalface. The roof failure in a longwall face will bring adverse consequences such as the stoppage of mining operations, damage to equipment, injuries, and fatalities. In this research, the critical events that are effective on the roof failure in the E_3 panel at the Tabas coal mine were identified, and the risk of roof failure was evaluated using the fuzzy event tree analysis approach through filling out the questionnaire by the mining experts and faculties. In this way, ten scenarios were examined to analyze the risk of roof failure by checking the roof failure or non-failure, and then the probability of critical events was calculated. Based on the results, the probabilities of roof failure in the fourth, tenth, and seventh scenarios are respectively 5.68, 4.21, and 1.70 percent, and the risk values in these three scenarios are respectively 28.42, 21.05, and 8.51. Therefore, the most critical scenario in this research is the fourth one, in which the preventive measures should be taken through the timely control of critical events to reduce or prevent the risk of roof failure.

Keywords: Roof failure risk, Fuzzy event tree analysis, Longwall mining method, Tabas coal mine.

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INTRODUCTION

Roof failure in underground coal mines is affected by many factors such as geological structures, regional stress field, thickness and strenght of the immediate roof strata and the coal seam, depth of the mine, the rate of face advancement, the mine layout, and the mechanism of mining operations. Although it is not possible to accurately predict the cause of roof failure, it may be determined to a large extent after the roof collapse by examining the collapsed dome, the conditions of the roof strata, and the geotechnical conditions [1]. Therefore, in order to control the roof stability in a coalface, it is necessary to assess the risk of roof failure by knowing the geological and geomechanical conditions, and then design a suitable support system to protect the immediate roof strata [2].

The continuous monitoring of the roof stability and the timely caving of the immediate roof by face advancement may lead to an increase in productivity of the mining operations. The unexpected roof failures not only endangers the safety of miners, but also may postpone the coal extraction by causing damage to the coalface and mining equipment. The fuzzy event tree analysis as a quantitative risk analysis model is presented in this research to assess the risk of roof failure in longwall mining. In the proposed model, all kinds of sequences or scenarios resulting from the occurrence of the initial event (roof failure) are quantitatively analyzed in a tree structure to identify high-risk events and consequently provide a practical solution for the timely control of the roof failure.

METHODS

In order to analyze the risk of roof failure in longwall face and identify the main factors affecting the instability of the roof strata, in this research, the fuzzy set theory and the event tree analysis are combined to develop the fuzzy event tree analysis model.

Fuzzy set theory was proposed in order to quantitatively express the subjective and ambiguous concepts in human judgments [3]. One of the simplest ways of expressing a fuzzy set is the triangular fuzzy numbers, in which the fuzzy number $A=\left(a,b,c\right)$ is defined as a fuzzy subset with left membership function f_A^L and right membership function f_A^R. In this way, by defining λ as the cut set of the triangular fuzzy number A, then $A^\lambda=\left\{A_L^\lambda,A_R^\lambda\right\}=\left[\left(b-a\right)\lambda+a,\left(b-c\right)\lambda+c\right]$ [4,5].

In general, the occurrence of any incident is the result of the occurrence of consecutive events. Therefore, in order to identify critical events in Tabas underground mine, the research method is carried out as follows:

1) Defining the initial event: The roof failure in the longwall face is selected as the initial event.

2) Investigating the records of roof failures: To identify the critical events, it is necessary to understand the entire development process of the events that have already occurred. Therefore, a questionnaire was designed in our research, which was filled out by the faculties and mine engineers as experts, based on the reports related to the roof failure in the E_3 panel.

3) Identifying the critical events: According to the field investigations and the experiences of the technical office of the mine, five critical events influencing the occurrence of roof failure were identified as the presence of water flow, the immediate roof strength, the immediate roof thickness, the instability of the intersections, and the support systems resistance.

4) Defining success or failure: Success of an event means preventing the occurrence of the initial event (roof stability), and failure of an event means the occurrence of the initial event (roof failure). After determining the critical events affecting the initial event, the event tree is created. Each of the critical events is divided into two opposite branches, each of which has a certain probability that indicates the success or failure of that event (S: Success and F: Failure). If the probability of success or failure of a critical event is expressed by P_S and P_F, respectively, then $P_S=1-P_F$ [6].

In order to evaluate and calculate the probability of each of the critical events, five steps have been taken as follows:

A) Defining the fuzzy linguistic terms for experts: Fuzzy linguistic terms are used in the form of triangular fuzzy number and cut set (λ) to evaluate the probability of occurrence of each of the critical events [7].

B) Weighing the opinions of experts: Since the results of the evaluation of experts are subjective, to avoid the possible mistakes, the opinions of at least three experts have been used in each subject. Also, the experts record, especially their age, work experience, education level, etc., have been taken into consideration to evaluate their viewpoints.

C) Cut set for experts' judgment: The cut sets correspond to the fuzzy linguistic terms and the general relation are defined as $e_i\lambda + f_i, g_i\lambda + h_i$, where e_i, f_i, g_i, and h_i are real numbers ($1 \le i \le n$).

D) Probability of occurrence of any critical event: After calculating $I_L\left(A\right)$ and $I_R\left(A\right)$, the probability of occurrence of any critical event ($P_{U_i} = I_i, 1 \le i \le n$) will be obtained.

E) Calculating the risk in each scenario: Finally, the risk $R = P \times L$ is calculated in each scenario, taking into account the conditional probability of the occurrence of any critical event in each scenario (P) and the severity of its probable consequences (L).

RESULTS AND DISCUSSION

By determining the critical events affecting the initial event, the event tree is developed based on the probability of success and the probability of failure. To evaluate the probability of occurrence of each of the critical events, the triangular fuzzy numbers and the cut sets are used. Considering that the maximum eigenvalue in the judgment matrix is 11.2559, the consistency index will be 0.139544, and the random consistency index is equal to 1.49. The consistency ratio will then be equal to 0.093654, which is less than 0.1, indicting the consistency of the judgment matrix. The probability of failure of each of the critical events ($P_{U_i}^{\lambda}$) is now calculated based on the fuzzy linguistic expressions $I_L\left(F_i\right)$ and $I_R\left(F_i\right)$ for each event, and is summarized in Table 1. In the next step, the probability of each scenario, which is obtained from the product of the probability of each of the critical events involved in that scenario, is calculated as shown in Table 2.

Table 1. Fuzzy expressions related to the probability of failure in each event

Probability of failure	$I_R(F_i)$	$I_L(F_i)$	$P_{F_i}^{\lambda} = I(F_i)$
F_1	0.57506	0.37506	0.47506
F_2	0.72264	0.54687	0.63476
F_3	0.68479	0.48684	0.58582
F_4	0.65680	0.46160	0.55920
F_5	0.80674	0.61995	0.71335
F_6	0.54938	0.34938	0.44938
F_7	0.53797	0.33797	0.43797
F_8	0.49913	0.29912	0.39913
F_9	0.59040	0.39039	0.49040

Table 2. Probability of occurance in each of the scenarios

Scenario	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
Probability	0.5249	0.0719	0.0448	0.0568	0.0476	0.0218	0.0170	0.1293	0.0438	0.0421

As shown in Figure 1, ten scenarios are created in the event tree, which are related to the roof failure or the roof stability. As seen, the result for the fourth, seventh, and tenth scenarios is the roof failure, while for the other ones is the roof stability. The most critical situation was observed in the fourth scenario, in which the risk of roof failure will be 28.42 provided that the probabilities of four critical events including the presence of water flow, the immediate roof strength, the instability of the intersections, and the support systems resistance, are equal to 0.47506, 0.36524, 0.58582, and 0.55920, respectively. In the tenth scenario, the risk of roof failure will be 21.05 provided that the probabilities of five critical events including the presence of water flow, the immediate roof strength, the immediate roof thickness, the instability of the intersections, and the support systems resistance, are equal to 0.47506, 0.63476, 0.71335, 0.39913, and 0.49040, respectively. Also, in the seventh scenario, the risk of roof failure will be 8.51 provided that the probabilities of five critical events including the presence of water flow, the immediate roof strength, the immediate roof thickness, the instability of the intersections, and the support systems resistance, are equal to 0.47506, 0.63476, 0.28665, 0.44938, and 0.43797, respectively.

Therefore, in order to succeed in mining operations in a longwall face, it is necessary to control the interaction between the hydraulic support systems, the roof stability especially at the intersections, the abutment pressures, and the coal seam strength through the continuous monitoring of the rock displacements and deformations, and the mechanism of roof caving by face advancement.

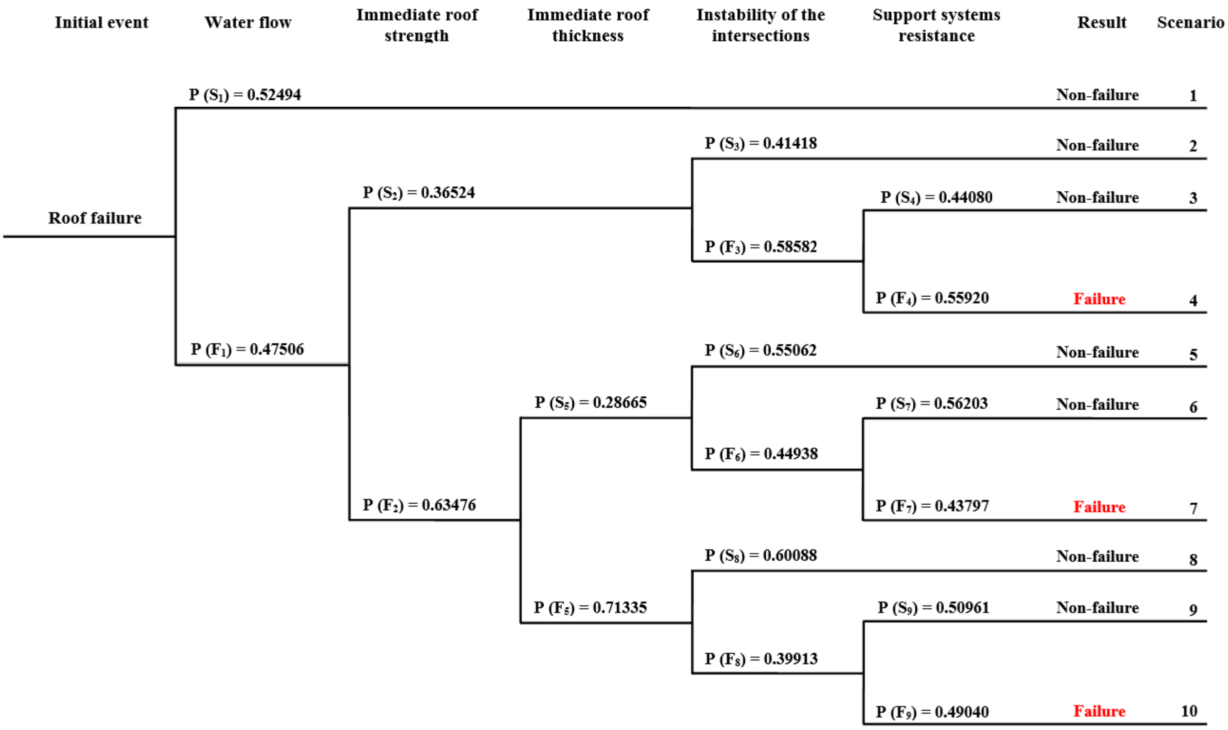

Figure 1. Diagram of the event tree analysis related to the roof failure

CONCLUSIONS

In order to assess the risk of roof failure in the E_3 panel at Tabas coal mine, a fuzzy event tree analysis model was presented. At first, a questionnaire was prepared based on the reports related to the roof failure and the roof falling in this panel, which was filled out by ten experts including faculties and mine engineers. Thereafter, the qualitative responses were converted into quantitative values using the fuzzy sets, and the risk of roof failure in the coalface was investigated. Ten scenarios were created in the fuzzy event tree to check the roof failure or the roof stability. According to the results, the fourth, tenth, and seventh scenarios resulted in roof failure, while the other ones showed stable conditions. The most critical situation was observed in the fourth scenario, in which the risk of roof failure will be 28.42 provided that the probabilities of four critical events including the presence of water flow, the immediate roof strength, the instability of the intersections, and the support systems resistance, are equal to 0.47506, 0.36524, 0.58582, and 0.55920, respectively. The instability of the intersections and the thickness of immediate roof will play a key role in the fourth and tenth scenarios, respectively. The proposed fuzzy event tree analysis method introduced a practical risk index to describe the priority level of scenarios based on the identified risks and critical events affecting them. Consequently, it will be possible to develop a proper planning to respond to the high risk events and reduce the severity of adverse consequences.

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