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Quantitative identification and analysis on hazard sources of roof fall accident in coal mine

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Abstract

The roof fall accident is one of the most frequent accidents in the coal mine and its frequency is ranked the first in various coal mine accidents. Hazard identification is a common method to prevent accidents. On the basis of predecessors` research, the concepts and identification indicators of the hazard sources in coal mine roof fall accident are defined initially. Hazard source of roof fall accident is analyzed quantitatively by the method which is combined triangular fuzzy theory and traditional fault tree to avoid the structural problems of the fault tree itself. Large area of empty-support is the greatest hazard sources in roof fall accident by the research.

Keywords: hazard source; fault tree; triangular fuzzy number

1. Introduction

The roof fall accident is one of the most frequent accidents in the coal mine. The number of casualties in the roof fall accident is not more than that in gas explosion accident, but its frequency is ranked the first in various coal mine accidents. The deaths and injuries by roof fall accident not only make the country and corporation suffered losses in the economy, but also bring misery to many families. In order to reduce and prevent occurrence of the roof fall accident, reasons of the roof fall accident have to be understood and mastered fully to provide a reference for further corrective measures.

Applying the concept of system security and theory of accident causation, hazard identification is the identification and analysis to the sources of danger which may cause an accident in the production system. After hazard identification, preventive measures can be established pertinently, which play a positive role in the prevention of accident. At present, the research of hazard identification to roof fall accident almost adopt the qualitative analysis of fault tree, sorting by the risk of hazard sources in accordance with structure importance [1-4]. The method plays a role in the process of hazard identification. But due to the effects of fault tree structure, the importance of small probability event would be big in the sorting process. Therefore, the small probability event would be considered as the key hazard sources to be controlled, and the established measures may lack of pertinence. Thinking about the probability of basic event, quantitative analysis is considered the fault tree structural problems synthetically, which makes identification in accordance with the actual situation better for all kinds of hazards.

2. Definition for hazard sources of roof fall accident in coal mine

In Chinese standard, hazard is defined as the dangerous matters which are produced, used or stockpiled permanently or temporarily, and the quantity of that is equal or greater than the critical amount. But this definition can just be applied to

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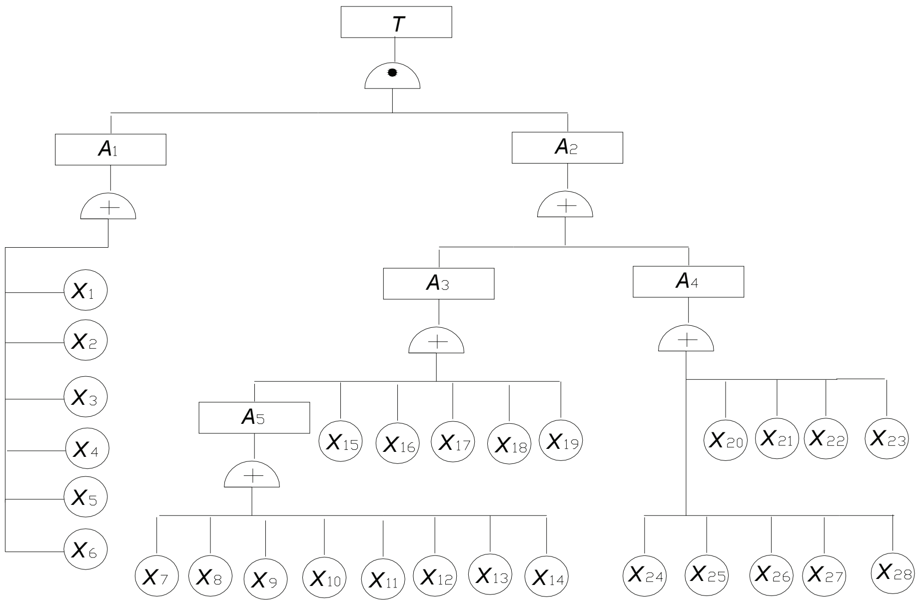
inflammable and explosive toxic materials, not to coal mine. It's unable to identify whether it's a hazard or not by the critical amount for the mine. For example, gas which is existed in coal mine belongs to the hazard, whether its content is high or low, it may blast. Consequently, referring to relevant standards and combining the complex and variable characteristic of coal mine hazard, some scholars define the coal mine hazards as the facilities or the locations which may lead to serious coal mine accident [5]. This concept defines the coal mine hazard directly. Based on previous study, this paper takes human unsafe behavior into account. The coal mine hazard is defined as all the insecurity factors about materials and human behavior which may result in serious coal mine accidents. Accordingly, hazard of roof fall accident is the total insecurity factors about materials and human behavior which may result in roof fall accident.

3. Confirmation of roof fall accident hazard and structure of fault tree

According to the definition of roof fall accident hazard, some relevant information and statistics are consulted and analyzed [6-8]. Finally, hazards indexes are shown in Table 1, and the fault tree is established according to causes of the accidents in Fig 1.



T roof accidents X basic event A_1 huge roof pressure A_2 roof fall

A_3 maladministration A_4 Support Technology ineffectively A_5 peccancy working

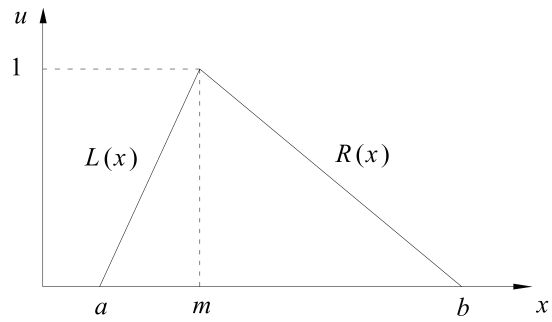
Fig. 1. The tree graph of roof fall accident.

4. Quantitative analysis method of hazard identification

The traditional fault tree analysis is based on Boolean algebra, which requires accurate probability of events when making quantitative analysis. Therefore, lots of data is needed, which might cause some errors. Meanwhile, lots of data couldn't be obtained in some occasion when accident frequency is not high enough. What's more, coal mine hazard has the dynamic characteristic, which makes it difficult to use mathematical model or formula to calculate and analysis uncertain factors of the system by traditional fault tree method. The dynamic characteristic brings on unneglectable weakness in the traditional accident tree analysis. The fuzzy theory could solve the problems which the probability theory could not deal with. So it is the best tool to deal with these problems. The fuzzy mathematics theory would be used for those bottom events which can't get precise value of the occurrence probability, and the occurrence probability of bottom events could be considered as a fuzzy number. The fault behavior of system and its component unit are depicted by using the fuzzy probability.

4.1. Triangular fuzzy number

Common fuzzy fault tree mainly includes the trigonometric, normal and cuspate type [9-11]. As triangular fuzzy number's algebraic operation is simple, it is widely used in engineering. The graph for membership functions of fuzzy triangle is shown in Fig 2.



μ membership function x real number a left boundary
b right boundary m expectation of probability

Fig. 2. Figure of fuzzy triangular membership function.

The mathematical expression is:

$$u_{\tilde{A}}(x) = \begin{cases} 0 & (x < a) \\ \dfrac{x-a}{m-a} & (a \le x \le m) \\ \dfrac{b-x}{b-m} & (m < x \le b) \\ 0 & (x > b) \end{cases} \quad (1)$$

$\tilde{A}$ is called Triangular fuzzy number, and expressed as $\tilde{A} = (a, m, b)$ [12]. *u* is membership degree, the m is mathematical expectation of probability. The *a* and *b* are left and right boundary respectively. They have the same meaning in the following.

4.2. Algebraic operation of triangular fuzzy number

If fuzzy number p_1 and p_2 are represented by three parameters (a_1, m_1, b_1) and (a_2, m_2, b_2) respectively, algebra operational rules of fuzzy Numbers p_1 and p_2 is shown below:

$$p_1 \oplus p_2 = (a_1, m_1, b_1) + (a_2, m_2, b_2) = (a_1 + a_2, m_1 + m_2, b_1 + b_2) \quad (2)$$

$$1 \oplus p_1 = 1 - (a_1, m_1, b_1) - (1 - a_1, 1 - m_1, 1 - b_1) \quad (3)$$

$$p_1 \otimes p_2 = (a_1, m_1, b_1) \times (a_2, m_2, b_2) = (a_1 a_2, m_1 m_2, b_1 b_2) \quad (4)$$

4.3. Fuzzy operator

Gate operator of the traditional fault tree analysis is $p_{AND} = \prod_{i=1}^{n} p_i$, p_i is the occurrence probability of event *i*, which is an exact value. If the occurrence probability of event *i* is a fuzzy number p_i, $p_i = (a_i, m_i, b_i)$. According to formula (4), the fuzzy and gate operator can be recorded as follows,

$$P_{AND} = \prod_{i=1}^{n} p_i = p_1 \times p_2 \times \cdots p_n = \left[\prod_{i=1}^{n} a_i, \prod_{i=1}^{n} m_i, \prod_{i=1}^{n} b_i \right] \tag{5}$$

Or gate fuzzy operator of the traditional fault tree analysis is $p_{OR} = 1 - \prod_{i=1}^{n}(1-p_i)$, if p_i is a fuzzy number, and according to formula (3), the fuzzy and gate operator can be recorded as follows,

$$P_{OR} = 1 - \prod_{i=1}^{n}(1-p_i) = \left\{ 1 - \prod_{i=1}^{n}(1-a_i), 1 - \prod_{i=1}^{n}(1-m_i), 1 - \prod_{i=1}^{n}(1-b_i) \right\} \tag{6}$$

4.4. Analysis of fuzzy probability importance

Fuzzy probability importance is the decrement of fuzzy unreliability from some kind of fuzzy fault state B_j to another certain state A_j of fuzzy function in the system, and the mathematical definition is expressed as follows:

$$I_k = Fs(''S'' = A_i \left| ''k'' = B_j \right.) - Fs(''S'' = A_i \left| ''k'' = A_j \right.) \tag{7}$$

According to formula (7) and using the fuzzy importance method which Hideo Tanaka has proposed, when the structure function of fault tree T is $\Phi(x_1, x_2, \cdots, x_n)$, the triangle possibility distribution of basic events is $P_{X_i} (i = 1, 2 \cdots, n)$. While all basic events happen and event x_i doesn't occur, the possibility distribution of top events T are as follows:

$$\tilde{P}_T = \tilde{P}(\tilde{P}_{x_1}, \cdots, \tilde{P}_{x_i} \cdots, \tilde{P}_{x_n})$$

$$\tilde{P}_{T_i} = \tilde{P}(\tilde{P}_{x_1}, \cdots, \tilde{P}_{x_{i-1}}, 0, \cdots, \tilde{P}_{x_n})$$

As the discussed system is humdrum and coherent, $\tilde{P}_{T_i} < \tilde{P}_T$, and the importance degree of event x_i is as follow:

$$V(\tilde{P}_T, \tilde{P}_{T_i}) = (m_L^T - m_{L_i}^T) + (m^T - m_i^T) + (m_R^T - m_{R_i}^T) > 0 \tag{8}$$

If $V(\tilde{P}_T, \tilde{P}_{T_i}) > V(\tilde{P}_T, \tilde{P}_{T_j})$, event x_i is more important than x_j for the system. Therefore, x_i should be considered to change firstly, when the system is improved.

5. Quantitative analysis of mine roof fall accident

In Table 1, the name and probability value of each basic event are obtained through 146 roof fall accidents counted and arranged from 1980 to 2000 years.

The m is the mean of probability. m-a=m-b=0.0556m [14]

Weightiness of fuzzy probability:

$I(2) > I(4) > I(1) > I(15) = I(20) > I(13) > I(14) = I(19) > I(3) > I(23) > I(5) > I(7) > I(8) = I(10) > I(9) = I(11) = I(12) = I(17) = I(18) > I(21) = I(22) > I(25) > I(6) > I(28) > I(24) = I(26) = I(27) > I(16)$

According to the weightiness of fuzzy probability, X_2, X_4, X_1, X_{15}, X_{20} and X_{13} are of particular importance in accidents, and they should be taken strict precautions against.

6. Conclusions

(1) On the basis of fuzzy theory applied to hazard identification, the structural problems of fault tree is overcome. The influence effects of probability randomness and human errors are solved. Therefore, the distribution of dangerous source can be manifested well.

Table 1. The name and probability value of each basic event

Code	Name of basic event	*a*	*m*	*b*	Fuzzy important
X_1	long time of roof suspension	0.0582	0.0616	0.0651	0.0923918
X_2	large area of empty-support	0.3105	0.3288	0.3470	0.690206
X_3	periodic weighting or rock burst	0.0194	0.0205	0.0217	0.0294551
X_4	meeting geologic tectonic zone	0.1035	0.1096	0.1157	0.173264
X_5	partition coal pillarsor rock is small	0.0129	0.0137	0.0145	0.0195487
X_6	Heavy of Dropping	0.0065	0.0068	0.0072	0.0096355
X_7	Empty-Support work	0.0776	0.0822	0.0868	0.0156729
X_8	foolhardy work	0.0712	0.0753	0.0795	0.0142503
X_9	no or not give the proper method of wall tapping and roof sounding	0.0647	0.0685	0.0723	0.0128689
X_{10}	find the hidden trouble but not give treatment	0.0712	0.0753	0.0795	0.0142503
X_{11}	Not tell the hidden trouble when duty shift	0.0388	0.0411	0.0434	0.0128689
X_{12}	unscientific of recovering billers and roof caving	0.0647	0.0685	0.0723	0.0128689
X_{13}	violative command	0.1682	0.1781	0.1880	0.0379163
X_{14}	not make operation rules or it's don't meet to the requirement	0.1423	0.1507	0.1591	0.0310487
X_{15}	bad safety consciousness and diathesis of leaders and workers	0.2393	0.2534	0.2675	0.0593858
X_{16}	maintenance of roadway not in time	0.0129	0.0137	0.0145	0.00243097
X_{17}	unstable of roof characteristic	0.0647	0.0685	0.0723	0.0128689
X_{18}	not obtain activity rhythm of roof	0.0647	0.0685	0.0723	0.0128689
X_{19}	does not strictly of supervision and inspection	0.1423	0.1507	0.1591	0.0310487
X_{20}	bad engineering quality (support system)	0.2393	0.2534	0.2675	0.0593858
X_{21}	bad quality of support material	0.0582	0.0616	0.0651	0.0114877
X_{22}	support holding power is poor	0.0582	0.0616	0.0651	0.0114877
X_{23}	poor stability of support system	0.0970	0.1027	0.1085	0.0200285
X_{24}	mining height is large	0.0194	0.0205	0.0217	0.0036628
X_{25}	operation mode of advancing supportin a wrong way	0.0517	0.0548	0.0578	0.0101461
X_{26}	The post setting not in advance of Solid crib timbering in heading face	0.0194	0.0205	0.0217	0.0036628
X_{27}	support not be reinforced when met old roadway	0.0194	0.0205	0.0217	0.0036628
X_{28}	Emergency unit of support is scarcity	0.0323	0.0342	0.0362	0.0040445

(2) By quantitatively analyzing the hazard sources in coal mine roof fall accident, the following factors are found as main hazard sources for coal mine accidents, which must be taken strict precautions against, such as large area of empty-support, meeting geologic tectonic zone, long time of roof suspension, low safety consciousness and diathesis of leaders and workers, bad engineering quality (support system) and violative command.

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