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A methodology to construct warning index system for coal mine safety based on collaborative management

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ABSTRACT

Safety management is the most important issue in global coal mine enterprises. In order to effectively identify and control hazard sources, it's critical to establish a scientific and rational warning index system of coal mine safety on collaborative management. To this end, first, a basic structure of warning index system will be established. Second, a three-stage semiquantitative approach will be proposed, which utilizes AHP, Entropy method, and multi-granularity non-equilibrium semantic treatment method to determine the weights of indexes. Finally, the method will be applied to calculate the weights of warning index system for coal mine safety. This method will provide a good means to construct warning index system for coal mine safety based on collaborative management. By the method, coal companies can enhance the efficiency, improve the level and reduce the cost of security management.

1. Introduction

As one of the most widely used and important energy across the world, coal has provided an important driving force for global sustained economic growth during a long time. Statistics (BP, 2015) showed that the production of world coal was 3933.5 Million tonnes oil equivalent, what declined by 0.7% in 2014, while consumption of 3881.8 Million tonnes oil equivalent grew by 0.4%, coal is still one of global primary fossil fuels in the world. In China, coal production had reached to 3.66 billion tons in 2012, especially accounted for more than half of global coal consumption. However, with the continuous increasing of coal production in China, coal mine accidents still occur (Wen et al., 2016). The data (Li, 2010) indicates the number of roof and gas accident was 3372 and 1580, respectively accounting for 43% and 20% between 2001 and 2010.

Coal production is a complex process with multi-process and multi-section, and hazard sources always influence and restrict its safety, such as natural disasters or accidents. As data (Lu et al., 2011) shown, more than 80% of accidents in coal industry were caused by operations against rules and command against rules. Meanwhile gas explosion, coal spontaneous combustion, coal dust explosion, roof accidents and flooding accidents are common types. Cui proposed the types and primary characteristics of coal mine water disaster (Cui et al., 2013) and Wang set up a model for coal mine water disaster emergency logistics risk assessment (Wang et al., 2012). Fan analyzed the main reasons of the mine gas explosion accident (Fan et al., 2011). Dong developed the optimized seismic source location (Dong et al., 2014) and event classified methods (Dong et al., 2014). Zhang simulated the airflow conditions dynamically when fire broke out (Zhang et al., 2012).

According to accident-causing theory (Qian and Mu, 2008), if the hazard sources are in effective control state, the accidents do not occurs. To effectively identify and control hazard sources, it's critical to establish a scientific and rational warning index system, including determining warning indexes and calculating their weights.

In regard to warning indexes of coal mine safety, Qian proposed the multi level assessment system with environment, equipment, people and information safety management (Qian and Mu, 2008), and Zhou developed the assessment system from the points of human behavior, natural factor and management (Zhou and Wang, 2011). However, there is no unified standard to establish the index system, so that indexes of coal mine safety are less systematic.

As to the methods to determine the weights, subjective weight methods such as AHP and ANP are usually used. For example, an index system of capability of production safety in coal mine were studied (Jing et al., 2006), the influence factors of coal mine accidents based on AHP were analyzed (Wan and Song, 2014), and ANP was proposed (Nian et al., 2012) to analyze the interaction

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and influence factors of gas explosion in coal mine and calculate its mixture weights with super matrix, by which there may be deviations of indexes' weights due to subjective factors, and the process of repeated judgment is clunky. Besides, the objective weight method such as the Entropy method was applied to evaluate the weights of safety indexes in coal mine (Li et al., 2011; Yang et al., 2012). The weakness of the Entropy method is easy to ignore the subjective intention of decision making. With the development of mathematical theory and application, more methods were studied by researchers. For example, the fuzzy theory (Mojtaba et al., 2013; He et al., 2013) was applied to predict roof fall rate in underground coal mines and evaluating the safety management level of coal mines. But it's difficult to ensure the rationality of the membership function and fuzzy number, so that the data of objective information is easy to being lost. Furthermore, a new method of attribute weight assignment based on rough sets was studied (Bao and Liu, 2009), a disaster prediction way of coal mine gas based on rough sets theory was proposed (Shao, 2009) and so on. However, the limitation of the method based rough sets is that some indexes may be lost as redundant parts, especially in complex condition with multiple indicators.

According to the research literatures, it can be realized that weights of safety warning indexes cannot be accurately determined just by any of above methods. Mine safety warning system is a complex integrated system. At present, in the process of building the warning index system, the main problems include the following two aspects.

For the first problem, evaluation indexes and assessment methods are usually formulated by a number of different administrative departments or agencies, which leads to repeated evaluation, inconsistent results and deviation of evaluation.

For the second one, weights of indexes are usually set to determined value, and unable to make reasonable adjustments to the specific characteristics of a particular mine, which makes safety evaluation management less targeted and systematic.

Therefore, to effectively identify and control hazard sources, it's critical to establish a scientific and rational warning index system of coal mine safety. In this paper, a basic structure of warning index system for coal mine safety is established to ensure integration and objectivity. Then, a three-stage semiquantitative approach is proposed to ensure the weights of indexes more scientific and reasonable in the collaborative environment.

2. The basic framework of coal mine safety warning index system

Coal mine safety management in collaborative environments, collaborative management bodies can be generally divided into three main types, higher-authority supervision subject, industry cooperation subject and internal management subject, which play an important role in safety management of coal mining.

In the process of coal mine safety management, every subject has a different focus to build coal mine safety warning index system. According to the theory of system safety (Gou et al., 2014), insecure condition of coal production system is mainly caused by incongruity between human behaviors and mechanical features. Therefore, mine safety warning index system includes the following dimensions: Environment Disaster, Safety Management, Facility Performance, Behavior Monitor and Emergency Rescue.

The identification and discrimination of disasters in mine is very important works before establishing the warning index system for coal mine safety. The identification of disasters is the process in which potential disasters are identified by the methods of perception, judgment or classification, and its main task is to analyze the possibility of disasters and judge the severity (Dong et al., 2016a,b). Only on the basis of correctly identify disasters, scientific and reasonable safety management activities will be carried out. Therefore, the judgment result will become the most important Ref. factor when management bodies construct warning index system. Based on this, the framework of mine safety management is proposed, as shown in Fig. 1.

Fig. 1.shows that the process of disasters identification consists of information acquisition, pretreatment, characteristics selection and extraction, classification decision and so on. The essence of which is using trained classifier to identify disasters of the research samples.

Specifically, the process includes three steps: (1) Collect and pretreat the original data from coal mines as training sample, where disaster events had happened before, then select and extract the date of characteristic variables. After inputting the data into the classifier and debug parameters, the classification decision model can be obtained. (2) Collect and pretreat the original data from the coal mine as research sample, which is a certain coal mine. Then select and extract the date of characteristic variables and input them into the classification decision model obtained. (3) According to data comparison, we can recognize types of disaster will possibly happen.

As Fig. 1 shown, the variables definition as follows.

e	index of Environment Disaster dimension
e'	number of Environment Disaster dimension index
s	index of Safety Management dimension
s'	number of Safety Management dimension index
f	index of Facility Performance dimension
f'	number of Facility Performance dimension index
b	index of Behavior Monitor dimension
b'	number of Behavior Monitor dimension index
r	index of Emergency Rescue dimension
r'	number of Emergency Rescue dimension index

Based on indexes proposed (Qian and Mu, 2008; Zhou and Wang, 2011), combined with the characteristics of coal mine production and requirements of safety management, warning index system for coal mine safety is established, as shown in Fig. 2.

To ensure versatility and universality of warning index system for coal mine safety, the weights of indexes need to be determined, by which safety knowledge and experience of different management bodies can be used better, and potential risks of coal mine can be recognized.

3. Quantitative analysis of index weight

The purpose of coal mine safety warning is that the potential risks of accidents can be effectively identified. However, there is diversity in the environment, type and condition for different coal mines, so that focuses of security warning index are not entirely consistent. Therefore, it's important to determine weights of warning indexes. A three-stage semiquantitative approach are proposed as follows.

(1) In the first stage, based on AHP and Entropy method, calculate the weights of indexes in the first layer, so as to give prominence to coal features by taking full advantage of collaborative bodies' management knowledge. (2) In the second stage, based on multi-granularity non-equilibrium semantic treatment method, determine the weights of indexes in the second layer, in order to ensure consistency of complex multi-role cooperative subjects' language decision information. (3) In the third one, the weights of indexes can be obtained by normalization process.