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Application of set pair analysis method on occupational hazard of coal mining

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ABSTRACT

As platforms age, there are increasing challenges to perpetuate their integrity. Currently, process of life extension and repair decision-making model in ageing offshore platforms which was based on DHGF algorithm was established built in order to make reasonable predictions about of life of ageing offshore platforms, and to make accurate repair decisions and to reduce their risks under uncertain and complicated environment. A decision on whether to install new equipment or recondition existing ones could then be taken in terms of optimal life-cycle cost, reliability, project budgets and safe state. There were 18 indicators based on Delphi method for evaluation system. Hierarchical structures were set up by analyzing and adjusting four dimensions - project factors, risk factors, load factors and structure factors which affect the ageing platform service state. Weighted subset was determined by Analytic Hierarchy Process (AHP). Then, we can calculate the gray weights using the gray model theory. The next step is that, it applied fuzzy mathematics to determine the grade evaluation of ageing platform. The evaluation criteria of life extension and repair decision-making model in ageing offshore platforms were established. The comprehensive score was calculated by a sequence of computational steps. Furthermore, life extension and repair decision-making reference table was set up and the period of life extension and repair grade in offshore platform was determined in the light of this table. Life extension and repair decisions for two platforms were made by using this new model and the results were compared with the traditional methods. Research results display that this model can describe the dynamic economic lifetime of ageing offshore platforms more accurately and give a new resolution for the research of life extension and repair decision-making under uncertain and complicated environment.

1. Introduction

Recent years have seen the significant improvement in the supervision, safety equipment, safety management, and safety status of China's coal mining industry. However, as the scale of production and depth of mining constantly expands, occupational hazards are growing increasingly severe. Occupational hazards associated with the coal production process include dust, toxic gas, and hazardous materials (Zhang et al., 2007). According to a recent survey, there were 13,243 cases of diseases associated with occupational hazards identified in China in 2014, including 9235 cases of pneumoconiosis (corresponding to 69.74% of the total cases) (Tong et al., 2016). Accordingly, preventing disease and other manner of coal mining occupational hazards has garnered considerable research attention.

Elaborate efforts have been and continue to be made by scholars, locally and abroad, to evaluate occupational hazards. Common evaluation methods include the Analytic Hierarchy Process (AHP), fuzzy comprehensive evaluation method (Tian et al., 2009; Tian et al., 2011a, 2011b, 2011c; He et al., 2009), comprehensive evaluation method (Zhang, 2010), matter element analysis (Tian et al., 2011a, 2011b, 2011c), and risk factors assessment (Spielholz et al., 2006). In practice, however, the results of these evaluation methods are restricted to a certain extent due to the randomness of the assessment process, the subjective uncertainty of the evaluator, and the ambiguity of perception.

For decision-makers, it is often the case that the assessment of occupational hazards in coal mines involves a number of unexpected factors of disparate nature, which makes the assessment multi-indexed and quite complex. Due to the large number of possible occupational hazards, of course, exist in the coal mine simultaneously. Assessment methodology itself is generally now considered the key to the sustainable management of occupational hazards. In this study, we built an evaluation and prediction model

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for occupational hazards in coal mines based on set pair analysis (SPA) that is intended to assist managers as they make decisions, improve the level of employee occupational health, and secure safety in production through the comprehensive evaluation and prediction of occupational hazards factors.

2. Set pair analysis (SPA) basics

SPA was originally proposed by Professor Zhao Ke-qin and has been since applied to several fields including system engineering, forecasting and multi-attribute risk assessment (Zhao, 1989). Zhang zhi-zhen, for example, utilized SPA to estimate rock burst risk in a coal mine (Zhang and Gao, 2011); Tan Fei-fei applied it to determine the coordinative ability of sustainable development (Tan and Zhang, 2014); Su Yue-feng used it to build an early warning for pollution emission reduction management (Su and Cheng, 2015); Wu Yao used to evaluate freeway traffic safety facilities (Wu et al., 2014); and Luo Jing-feng used it to create a tourism safety early warning model (Luo, 2015).

For the purposes of SPA, a set pair is a pair combined with two sets which have a certain degree of connection. The core concept of the SPA theory involves considering uncertainties and certainties as an uncertain-certain system by studying the relationship between the uncertainty and the certainty of a factor or event from three aspects of identity-discrepant-contrast (IDC). In such a system, the certainty is divided into two aspects, "similar" and "opposite", while the uncertainty is defined as the difference. They are interrelated, influenced, mutually restrained, and transformed to each other under certain conditions (Zhao, 1996).

This paper first presents the definition of set pair analysis theory and then moves on to discuss certain properties and concepts of them. Set pair analysis theory is defined below.

Definition 1. The connection degree, u, is given by Zhao (2000a, 2000b): $u = \frac{S}{N} + \frac{F}{N}i + \frac{P}{N}j$, where S is the sum of the identity of the two sets, N is the sum of the characteristics of the two sets, and P is the contrast of the sum of the two sets: $F = N - S - P$ is the sum of the discrepant characteristics of the two sets, $\frac{S}{N}$, $\frac{F}{N}$, $\frac{P}{N}$ are the degree of identity, degree of discrepancy and degree of contrast in the set pair under a certain condition. j is a contrast coefficient that usually equals -1, i is the uncertainty coefficient, and $i \in [-1, 1]$.

Definition 2. $a = \frac{S}{N}$, $b = \frac{F}{N}$, $c = \frac{P}{N}$ represent the identity, discrepancy and contrast degrees of the set pair, respectively, and $a + b + c = 1$ (Zhao, 2000a, 2000b). u is also defined as follows:

$$u = a + bi + cj \tag{1}$$

If "safety" is expressed as a_i, the "medium between safety and danger" is expressed as b_i, and "danger" is expressed as c_i. If W is the weight vector of the evaluation index, then the connection degree is given by:

$$u = WRE = (W_1, W_2, \ldots, W_n)\begin{pmatrix} a_1 & b_1 & c_1 \\ a_2 & b_2 & c_2 \\ \vdots & \vdots & \vdots \\ a_k & b_k & c_k \end{pmatrix}\begin{pmatrix} 1 \\ i \\ j \end{pmatrix} \tag{2}$$

where W denotes the weight coefficient vector, R is the identity-discrepant-contrast (IDC) evaluation matrix, and E is the connection degree matrix.

Definition 3. When $c \neq 0$, the set pair trend is represented conceptually as a/c and denoted as $shi(H) = a/c$ (Hu et al., 2008). The set pair trend sequence is acquired according to the set pair potential.

Table 1
Grade and sort of set pair trend.

Relationship of a, b and c	Grade	Set pair trend
$a/c > 1, b = 0$	Similar trend	Super similar Set-Pair-Trend
$a/c > 1, b/c < 1$		Strong similar Set-Pair-Trend
$a/b > 1, b/c > 1$		Weak similar Set-Pair-Trend
$a/c > 1, a/b < 1$		Slight similar Set-Pair-Trend
$a = c, b = 0$	Balanced trend	Super balance Set-Pair-Trend
$a = c, a/b > 1$		Strong balance Set-Pair-Trend
$a = c, b = a$		Weak balance Set-Pair-Trend
$a = c, a/b < 1$		Slight balance Set-Pair-Trend
$a/c < 1, b = 0$	Contrary trend	Super contrary Set-Pair-Trend
$a/c < 1, a/b > 1$		Strong contrary Set-Pair-Trend
$a/c < 1, a/b < 1, b/c < 1$		Weak contrary Set-Pair-Trend
$a/c < 1, b/c > 1$		Slight contrary Set-Pair-Trend

When $a < c$, $shi(H)$ is an opposite trend which indicates that there are contrast trends in this set pair; when $a > c$, $shi(H)$ is a similar trend which indicates that there are similar trends in this set pair; when $a = c$, $shi(H)$ is a balance trend which indicates that the similar and opposite trends are well-matched in this set pair. The set pair trend made $shi(H) = 1$ as the dividing line between the similar and opposite trends. The relation type and grade of the set pair trend are shown in Table 1 (Zhao, 2000a, 2000b).

3. Modeling procedure

Occupational hazards involve many complicated factors and aspects. As discussed in the Introduction, it is imperative to develop methods for more effectively managing these complex factors and gathering and analyzing relevant data; doing so effectively can help secure the lives and livelihoods of coal mining personnel. Essentially, occupational diseases that occur due to workplace hazards in the coal mining industry are very serious and incurable; general uncertainty regarding occupational hazards inherent to working in underground coal mines poses a serious problem. As mentioned above, this study adopted the AHP method and SPA theory to develop a system for evaluating coal mine occupational hazards. The proposed system can be described in a stepwise manner as follows.

Step 1: Determine the evaluation index set.

First, experts in the field join the project's team. Each expert independently participates by putting forward a series of evaluation indices, collecting and analyzing data, and screening out unimportant indices. In this step, a scientific and reasonable evaluation index system is built.

$$O = [O_1, O_2, \ldots, O_n] \tag{3}$$

where O is the evaluation indices and n is the number of indices.

Step 2: Determine the weighted subset via AHPThe AHP is a structured, multi-attribute decision-making method (Satty, 1994) which has been extensively used to solve problems that have multiple criteria (Satty, 2005). The main goal of using AHP is to decompose a complex system into goals, principles, and programs, thus allowing for both quantitative and qualitative decisions. The main advantage of this method is its ability to identify and reduce inconsistencies among expert judgments.

The AHP consists of the following four steps:

(1) Construct the hierarchical structure.
(2) Construct the judgment matrix to be completed by the experts.
(3) Calculate the weight of index W_i, given by $W_i = \frac{1}{n}\sum_{j=1}^{n}\left(a_{ij}/\sum_{k=1}^{n}a_{kj}\right)$, a_{ij} is the element of the judgment matrix, and $\sum_{i=1}^{n}W_i = 1$, $0 < W_i < 1$.