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Research on the risk forecast model in the coal mine system based on GSPA-Markov

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Abstract

Safety accidents in the coal mine occurred frequently, that how to reduce them became an important national task, which the hazards identification and the risk forecast work in the coal mine system can solve. In the process of risk forecast in the coal mine system, considering characteristics that system risk is different in different period, the IDO (identification, difference, opposition) change rule of the set pair which has element weight is analyzed, and on the basis of which, the system risk forecast model based on GSPA-MARKOV is put forward. The application example shows that the risk state in the coal mine system is forecasted by the transition probability and the ergodicity in the model, which embodies fully dynamic, predictable and so on , thus it provides a new method to determine the risk state in the coal mine system.

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Keywords: GSPA; Markov; risk forecast; transform matrix

Nomenclature

GSPA	Generalized set pair analysis
AHP	Analytic hierarchy process
$\mu_{hkl}(t)$	Connection degree to the grade h of the index k of the sample l
s_{kl}	Risk grade standard of the index k of the sample l
w_k	Weight of the index k

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I	Unit matrix.

1. Introduction

The risk forecast is more difficult in the production process of the coal mine system, because the influence risk factors which have uncertainty characteristics such as random, fuzzy are more, which GSPA can just solve. The certain and uncertain relationship of the risk in the coal mine system are knew from the systemic perspective by GSPA[1], and the coal mine system is looked as certain and uncertain system to research. The certain and uncertain is not absolutely, they can change into each other in certain conditions. In the same time, considering the Markov has characteristic such as ergodicity, GSPA and Markov are combined, and the forecast model based on GSPA-Markov which is used to forecast the risk in the coal mine system on the basis of exploration is researched.

2. System Risk Forecast Based on GSPA-MARKOV

2.1 MARKOV Process [2~8]

In the condition that system or process are known in the moment t_0, the process conditional distribution in the moment $t > t_0$ is irrelevant to the process conditional distribution before the moment t_0. In other words, the future state doesn't depend on the previous state in the condition present state is known.

Markov is provides with the character of Markov, which can be described by the distribution function. Suppose I is the state space of the stochastic process $\{X(t), t \in T\}$, for the distribution of the time $t_1 < t_2 < \cdots < t_n, n \geq 3$, $t_i \in T$, the condition distribution function of $X(t_n)$ equals exactly the condition distribution function of $X(t_{n-1}) = x_{n-1}$ in the condition $X(t_i) = x_i$, $x_i \in I$, $i = 1,2\cdots,n-1$, namely

$$P\{X(t_n) \leq x_n \mid X(t_1) = x_1, X(t_2) = x_2, \cdots, X(t_{n-1}) = x_{n-1}\} = P\{X(t_n) \leq x_n \mid X(t_{n-1}) = x_{n-1}\} \qquad (1)$$

The process is referred to as being provided with the characters of Markov or ineffectiveness, and the process is known as Markov process.

According to their state discrete or continuous, Markov process is divided into the Markov process in the discrete state and the Markov process in the continuous state respectively. The Markov process in the discrete time and state is known as Markov process chain, and it is also called for Markov chain which is called for $\{X_n = X(n), n = 0,1,2,\cdots\}$, which is viewed as the result that the Markov process in the discrete state is observed in the time set $T_1 = \{0,1,2,\cdots\}$.

2.2 System Risk Forecast Based on GSPA-MARKOV

All the connect components whose number is M are respectively $A(t)$, $B(t)$, $C(t)$, $D(t)$ and $E(t)$ in the moment t ,and $A(t) + B(t) + C(t) + D(t) + E(t) = N$. If the previous characters whose number are M are rearranged and numbered consecutively, the vector of the connect degree $\mu(t)$ is calculated as follows by the formula *(2)* or *(3)* in the condition that weights of all the characters (namely the assessment indexes) being considered.

(1)The ascertained method on IDO connection degree of the single index is as follows if the assessment index x_{kl} increases with the increase of assessment grade:

$$\mu_{1kl}(t)=\begin{cases}1 & x_{kl}\in[-\infty,s_{1k}]\\ \cos\left[\left(\dfrac{x_{kl}-s_{1k}}{s_{2k}-s_{1k}}\right)\pi\right] & x_{kl}\in[s_{1k},s_{2k}]\\ -1 & x_{kl}\in[s_{2k},+\infty]\end{cases}\quad \mu_{2kl}(t)=\begin{cases}-1 & x_{kl}\in[-\infty,s_{0k}]\\ \cos\left[\left(\dfrac{s_{1k}-x_{kl}}{s_{1k}-s_{0k}}\right)\pi\right] & x_{kl}\in[s_{0k},s_{1k}]\\ 1 & x_{kl}\in[s_{1k},s_{2k}]\\ \cos\left[\left(\dfrac{x_{kl}-s_{2k}}{s_{3k}-s_{2k}}\right)\pi\right] & x_{kl}\in[s_{2k},s_{3k}]\\ -1 & x_{kl}\in[s_{3k},+\infty]\end{cases}$$

$$\mu_{3kl}(t)=\begin{cases}-1 & x_{kl}\in[-\infty,s_{1k}]\\ \cos\left[\left(\dfrac{s_{2k}-x_{kl}}{s_{2k}-s_{1k}}\right)\pi\right] & x_{kl}\in[s_{1k},s_{2k}]\\ 1 & x_{kl}\in[s_{2k},s_{3k}]\\ \cos\left[\left(\dfrac{x_{kl}-s_{3k}}{s_{4k}-s_{3k}}\right)\pi\right] & x_{kl}\in[s_{3k},s_{4k}]\\ -1 & x_{kl}\in[s_{4k},+\infty]\end{cases}\quad \mu_{4kl}(t)=\begin{cases}-1 & x_{kl}\in[-\infty,s_{2k}]\\ \cos\left[\left(\dfrac{s_{3k}-x_{kl}}{s_{3k}-s_{2k}}\right)\pi\right] & x_{kl}\in[s_{2k},s_{3k}]\\ 1 & x_{kl}\in[s_{3k},s_{4k}]\\ \cos\left[\left(\dfrac{x_{kl}-s_{2k}}{s_{3k}-s_{2k}}\right)\pi\right] & x_{kl}\in[s_{4k},s_{5k}]\\ -1 & x_{kl}\in[s_{5k},\infty]\end{cases}$$

$$\mu_{5kl}(t)=\begin{cases}-1 & x_{kl}\in[-\infty,s_{33}]\\ \cos\left[\left(\dfrac{s_{4k}-x_{kl}}{s_{4k}-s_{3k}}\right)\pi\right] & x_{kl}\in[s_{3k},s_{4k}]\\ 1 & x_{kl}\in[s_{4k},+\infty]\end{cases}\tag{2}$$

(2)The ascertained method on IDO connection degree of the single index is as follows if the assessment index x_{kl} decreases with the increase of assessment grade:

$$\mu_{1kl}(t)=\begin{cases}1 & x_{kl}\in[s_{1k},+\infty]\\ \cos\left[\left(\dfrac{s_{1k}-x_{kl}}{s_{1k}-s_{2k}}\right)\pi\right] & x_{kl}\in[s_{2k},s_{1k}]\\ -1 & x_{kl}\in[-\infty,s_{2k}]\end{cases}\quad \mu_{2kl}(t)=\begin{cases}-1 & x_{kl}\in[s_{0k},\infty]\\ \cos\left[\left(\dfrac{x_{kl}-s_{1k}}{s_{0k}-s_{1k}}\right)\pi\right] & x_{kl}\in[s_{1k},s_{0k}]\\ 1 & x_{kl}\in[s_{2k},s_{1k}]\\ \cos\left[\left(\dfrac{s_{2k}-x_{kl}}{s_{2k}-s_{3k}}\right)\pi\right] & x_{kl}\in[s_{3k},s_{2k}]\\ -1 & x_{kl}\in[-\infty,s_{3k}]\end{cases}$$

$$\mu_{3kl}(t)=\begin{cases}-1 & x_{kl}\in[s_{1k},+\infty]\\ \cos\left[\left(\dfrac{x_{kl}-s_{2k}}{s_{1k}-s_{2k}}\right)\pi\right] & x_{kl}\in[s_{2k},s_{1k}]\\ 1 & x_{kl}\in[s_{3k},s_{2k}]\\ \cos\left[\left(\dfrac{s_{3k}-x_{kl}}{s_{3k}-s_{4k}}\right)\pi\right] & x_{kl}\in[s_{4k},s_{3k}]\\ -1 & x_{kl}\in[-\infty,s_{4k}]\end{cases}\quad \mu_{4kl}(t)=\begin{cases}-1 & x_{kl}\in[s_{2k},+\infty]\\ \cos\left[\left(\dfrac{x_{kl}-s_{3k}}{s_{2k}-s_{3k}}\right)\pi\right] & x_{kl}\in[s_{3k},s_{2k}]\\ 1 & x_{kl}\in[s_{4k},s_{3k}]\\ \cos\left[\left(\dfrac{s_{4k}-x_{lk}}{s_{4k}-s_{5k}}\right)\pi\right] & x_{kl}\in[s_{5k},s_{4k}]\\ -1 & x_{kl}\in[-\infty,s_{5k}]\end{cases}$$

$$\mu_{5kl}(t)=\begin{cases}-1 & x_{kl}\in[s_{3k},+\infty]\\ \cos\left[\left(\dfrac{x_{kl}-s_{4k}}{s_{3k}-s_{4k}}\right)\pi\right] & x_{kl}\in[s_{3k},s_{4k}]\\ 1 & x_{kl}\in[-\infty,s_{4k}]\end{cases}\tag{3}$$

Where
$k = 1,2,\cdots,m$ ， $l = 1,2,\cdots,n$ 。

The total connection degree of every sample is calculated as follows after the IDO connection degree and the weight of every index are obtained:

$$\mu_{hl}(t) = \sum_{k=1}^{m} w_k \mu_{hkl}(t) \tag{4}$$

Judge Rule Based on the Biggest Connection Degree: For the connection grade vector $\mu_{hl}(t) = [\mu_{1l}(t), \mu_{2l}(t), \cdots, \mu_{cl}(t)]$ of the risk grade of the sample l in the moment t, if

$$\mu_{jl}(t) = \max\{\mu_{hl}(t), h = 1,2,\cdots,c\} \tag{5}$$

So the risk grade of the sample l is the grade j.

The risk grade of the previous assessment index changes in the period from t to $t+T$. And some grades changes, others doesn't change. In the characters whose number is $A(t)$ of the period, characters whose number is $A(t1)$ doesn't change, and characters whose number is $A(t2)$ are transformed into the grade B , and characters whose number is $A(t3)$ are transformed into the grade C, and characters whose number is $A(t4)$ are transformed into the grade D, and characters whose number is $A(t5)$ are transformed into the grade E, so the transform vector is obtained as follows in the period from t to $t+T$:

$$\vec{P_A} = (p_{11} \quad p_{12} \quad p_{13} \quad p_{14} \quad p_{15}) \tag{6}$$

Where:

$$p_{11} = \left[1 + \sum_{k=1}^{A(t1)} \left(\omega_k^{(t)} \mu_{hk}^{(t)}\right)\right] / 2\alpha(t), \quad p_{12} = \left[1 + \sum_{k=A(t1)+1}^{A(t1)+A(t2)} \left(\omega_k^{(t)} \mu_{hk}^{(t)}\right)\right] / 2\alpha(t),$$

$$p_{13} = \left[1 + \sum_{k=A(t1)+A(t2)+1}^{A(t1)+A(t2)+A(t3)} \left(\omega_k^{(t)} \mu_{hk}^{(t)}\right)\right] / 2\alpha(t), \quad p_{14} = \left[1 + k \sum_{k=A(t1)+A(t2)+A(t3)+1}^{A(t1)+A(t2)+A(t3)+A(t4)} \left(\omega_k^{(t)} \mu_{hk}^{(t)}\right)\right] / 2\alpha(t),$$

$$p_{15} = \left[1 + \sum_{k=A(t1)+A(t2)+A(t3)+A(t4)+1}^{A(t)} \left(\omega_k^{(t)} \mu_{hk}^{(t)}\right)\right] / 2\alpha(t), \quad \alpha(t) = \left[\sum_{k=1}^{A(t)} \left(\omega_k^{(t)} \mu_{hk}^{(t)}\right) + 5\right] / 2 \text{。}$$

In the characters whose number is $B(t)$ in the period from t to $t+T$, and characters whose number is $B(t_1)$ are transformed into the grade A , characters whose number is $B(t_2)$ doesn't change, and characters whose number is $B(t_3)$ are transformed into the grade C, and characters whose number is $B(t_4)$ are transformed into the grade D, and characters whose number is $B(t_5)$ are transformed into the grade E, and there is the equation of $B(t_1)+B(t_2)+B(t_3)+B(t_4)+B(t_5)=B(t)$, so the transform vector is obtained as follows in the period from t to $t+T$:

$$\vec{P_B} = (p_{21} \quad p_{22} \quad p_{23} \quad p_{24} \quad p_{25}) \tag{7}$$

Where:

$$p_{21} = \left[1 + \sum_{k=1}^{B(t1)} \left(\omega_k^{(t)} \mu_{hk}^{(t)}\right)\right] / 2\beta(t), \quad p_{22} = \left[1 + \sum_{k=B(t1)+1}^{B(t1)+B(t2)} \left(\omega_k^{(t)} \mu_{hk}^{(t)}\right)\right] / 2\beta(t),$$

$$p_{23} = \left[1 + \sum_{k=B(t1)+B(t2)+1}^{B(t1)+B(t2)+B(t3)} \left(\omega_k^{(t)} \mu_{hk}^{(t)}\right)\right] / 2\beta(t), \quad p_{24} = \left[1 + \sum_{k=B(t1)+B(t2)+B(t3)+1}^{B(t1)+B(t2)+B(t3)+B(t4)} \left(\omega_k^{(t)} \mu_{hk}^{(t)}\right)\right] / 2\beta(t),$$

$$p_{25}=\left[1+\sum_{k=B(t1)+B(t2)+B(t3)+B(t4)+1}^{B(t)}\left(\omega_k^{(t)}\mu_{hk}^{(t)}\right)\right]/2\beta(t),\quad \beta(t)=\left[\sum_{k=1}^{B(t)}\left(\omega_k^{(t)}\mu_{hk}^{(t)}\right)+5\right]/2\text{。}$$

In the characters whose number is $C(t)$ in the period from t to $t+T$, and characters whose number is $C(t_1)$ are transformed into the grade A , and characters whose number is $C(t_2)$ are transformed into the grade B, characters whose number is $C(t_3)$ doesn't change, and characters whose number is $C(t_4)$ are transformed into the grade D, and characters whose number is $C(t_5)$ are transformed into the grade E, and there is the equation of $C(t_1)+C(t_2)+C(t_3)+C(t_4)+C(t_5)=C(t)$, so the transform vector is obtained as follows in the period from t to $t+T$:

$$\vec{P}_C=\begin{pmatrix}p_{31} & p_{32} & p_{33} & p_{34} & p_{35}\end{pmatrix} \tag{8}$$

Where:

$$p_{31}=\left[1+\sum_{k=1}^{C(t1)}\left(\omega_k^{(t)}\mu_{hk}^{(t)}\right)\right]/2\gamma(t),\quad p_{32}=\left[1+\sum_{k=C(t1)+1}^{C(t1)+C(t2)}\left(\omega_k^{(t)}\mu_{hk}^{(t)}\right)\right]/2\gamma(t),$$

$$p_{33}=\left[1+\sum_{k=C(t1)+C(t2)+1}^{C(t1)+C(t2)+C(t3)}\left(\omega_k^{(t)}\mu_{hk}^{(t)}\right)\right]/2\gamma(t),\quad p_{34}=\left[1+\sum_{k=C(t1)+C(t2)+C(t3)+1}^{C(t1)+C(t2)+C(t3)+C(t4)}\left(\omega_k^{(t)}\mu_{hk}^{(t)}\right)\right]/2\gamma(t),$$

$$p_{55}=\left[1+\sum_{k=C(t1)+C(t2)+C(t3)+C(t4)+1}^{C(t)}\left(\omega_k^{(t)}\mu_{hk}^{(t)}\right)\right]/2\gamma(t),\quad \gamma(t)=\left[\sum_{k=1}^{C(t)}\left(\omega_k^{(t)}\mu_{hk}^{(t)}\right)+5\right]/2\text{。}$$

In the characters whose number is $D(t)$ in the period from t to $t+T$, and characters whose number is $D(t_1)$ are transformed into the grade A , and characters whose number is $D(t_2)$ are transformed into the grade B, and characters whose number is $D(t_3)$ are transformed into the grade C, characters whose number is $D(t_4)$ doesn't change, and characters whose number is $D(t_5)$ are transformed into the grade E, and there is the equation of $D(t_1)+D(t_2)+D(t_3)+D(t_4)+D(t_5)=D(t)$, so the transform vector is obtained as follows in the period from t to $t+T$:

$$\vec{P}_D=\begin{pmatrix}p_{41} & p_{42} & p_{43} & p_{44} & p_{45}\end{pmatrix} \tag{9}$$

Where:

$$p_{41}=\left[1+\sum_{k=1}^{D(t1)}\left(\omega_k^{(t)}\mu_{hk}^{(t)}\right)\right]/2\tau(t),\quad p_{42}=\left[1+\sum_{k=D(t1)+1}^{D(t1)+D(t2)}\left(\omega_k^{(t)}\mu_{hk}^{(t)}\right)\right]/2\tau(t)$$

$$p_{43}=\left[1+\sum_{k=D(t1)+D(t2)+1}^{D(t1)+D(t2)+D(t3)}\left(\omega_k^{(t)}\mu_{hk}^{(t)}\right)\right]/2\tau(t),\quad p_{44}=\left[1+\sum_{k=D(t1)+D(t2)+D(t3)+1}^{D(t1)+D(t2)+D(t3)+D(t4)}\left(\omega_k^{(t)}\mu_{hk}^{(t)}\right)\right]/2\tau(t)$$

$$p_{45}=\left[1+\sum_{k=D(t1)+D(t2)+D(t3)+D(t4)+1}^{D(t)}\left(\omega_k^{(t)}\mu_{hk}^{(t)}\right)\right]/2\tau(t),\quad \tau(t)=\left[\sum_{k=1}^{D(t)}\left(\omega_k^{(t)}\mu_{hk}^{(t)}\right)+5\right]/2$$

In the characters whose number is $E(t)$ in the period from t to $t+T$, and characters whose number is $E(t_1)$ are transformed into the grade A , and characters whose number is $E(t_2)$ are transformed into the grade B, and characters whose number is $E(t_3)$ are transformed into the grade C, and characters whose number is $E(t_4)$ are transformed into the grade D, characters whose number is $D(t_5)$ doesn't change, and there is the equation of $E(t_1)+E(t_2)+E(t_3)+E(t_4)+E(t_5)=E(t)$, so the transform vector is obtained as follows in the period from t to $t+T$:

$$\vec{P_E} = \begin{pmatrix} p_{51} & p_{52} & p_{53} & p_{54} & p_{55} \end{pmatrix} \tag{10}$$

Where:

$$p_{51} = \left[1 + \sum_{k=1}^{E(t1)} \left(\omega_k^{(t)} \mu_{hk}^{(t)}\right)\right] / 2\xi(t), \quad p_{52} = \left[1 + \sum_{k=E(t1)+1}^{E(t1)+E(t2)} \left(\omega_k^{(t)} \mu_{hk}^{(t)}\right)\right] / 2\xi(t)$$

$$p_{53} = \left[1 + \sum_{k=E(t1)+E(t2)+1}^{E(t1)+E(t2)+E(t3)} \left(\omega_k^{(t)} \mu_{hk}^{(t)}\right)\right] / 2\xi(t), \quad p_{54} = \left[1 + \sum_{k=E(t1)+E(t2)+E(t3)+1}^{E(t1)+E(t2)+E(t3)+E(t4)} \left(\omega_k^{(t)} \mu_{hk}^{(t)}\right)\right] / 2\xi(t)$$

$$p_{55} = \left[1 + \sum_{k=E(t1)+E(t2)+E(t3)+D(t4)+1}^{E(t)} \left(\omega_k^{(t)} \mu_{hk}^{(t)}\right)\right] / 2\xi(t), \quad \xi(t) = \left[\sum_{k=1}^{E(t)} \left(\omega_k^{(t)} \mu_{hk}^{(t)}\right) + 5\right] / 2$$

The transformed matrix P of system is obtained by the above calculation in the period from t to $t+T$:

$$P = \begin{bmatrix} p_{11} & p_{12} & p_{13} & p_{14} & p_{15} \\ p_{21} & p_{22} & p_{23} & p_{24} & p_{25} \\ p_{31} & p_{32} & p_{33} & p_{34} & p_{35} \\ p_{41} & p_{42} & p_{43} & p_{44} & p_{55} \\ p_{51} & p_{52} & p_{53} & p_{54} & p_{55} \end{bmatrix} \tag{11}$$

Then the connection degree vector $\mu(t+T)$ of the system risk grade is calculated as follows in the moment $t+T$

$$\begin{bmatrix} (\mu_1(t+T)+1)/2 \\ (\mu_2(t+T)+1)/2 \\ (\mu_3(t+T)+1)/2 \\ (\mu_4(t+T)+1)/2 \\ (\mu_5(t+T)+1)/2 \end{bmatrix} = \begin{bmatrix} p_{11} & p_{12} & p_{13} & p_{14} & p_{15} \\ p_{21} & p_{22} & p_{23} & p_{24} & p_{25} \\ p_{31} & p_{32} & p_{33} & p_{34} & p_{35} \\ p_{41} & p_{42} & p_{43} & p_{44} & p_{55} \\ p_{51} & p_{52} & p_{53} & p_{54} & p_{55} \end{bmatrix} \bullet \begin{bmatrix} (\mu_1(t)+1)/2 \\ (\mu_2(t)+1)/2 \\ (\mu_3(t)+1)/2 \\ (\mu_4(t)+1)/2 \\ (\mu_5(t)+1)/2 \end{bmatrix} \tag{12}$$

Supposed the transformed matrix is identical in each period, namely the transformed matrix P is a constant matrix, the connection degree vector of the system risk grade is calculated as follows:

$$\begin{bmatrix} (\mu_1(t+nT)+1)/2 \\ (\mu_2(t+nT)+1)/2 \\ (\mu_3(t+nT)+1)/2 \\ (\mu_4(t+nT)+1)/2 \\ (\mu_5(t+nT)+1)/2 \end{bmatrix} = P^{nT} \bullet \begin{bmatrix} (\mu_1(t)+1)/2 \\ (\mu_2(t)+1)/2 \\ (\mu_3(t)+1)/2 \\ (\mu_4(t)+1)/2 \\ (\mu_5(t)+1)/2 \end{bmatrix} \tag{13}$$

And thus the above formula meets the famous Chapman-Kolmogorov. After more periods that the time is infinite, P^{nT} will stabilize. In other words, for Markov chain, the transformed probability vector whose step is n is of the one step transformed vector. Therefore, the stabilization connection vector of the system risk grade is calculated as follows:

$$\begin{cases} ((\mu_1+1)/2 \quad (\mu_2+1)/2 \quad (\mu_3+1)/2 \quad (\mu_4+1)/2 \quad (\mu_5+1)/2) \bullet (I-P) = 0 \\ (\mu_1+1)/2 + (\mu_2+1)/2 + (\mu_3+1)/2 + (\mu_4+1)/2 + (\mu_5+1)/2 = 1 \end{cases} \tag{14}$$

3. Application Example

The coal mine is assessed for a year by the risk assessment index system in the coal mine from the reference [9], and the coal mine is assessed every two months. The system risk assessment indexes are divided into five levels, which include the grade I which is from 8 to 10, the grade II which is from 6 to 8, the grade III which is from 4 to 6, the gradeIV which is from 2 to 4, the gradeV which is from 0 to 2, the result of the risk assessment is as follows:

Table1 Risk assessment index results of some coal mine

month / index	February	April	June	August	October	December
Coal Seam Occurrence	3	3	5	6	6	8
Hydrogeology	2	3	4	5	7	9
Roof and floor structure	1	3	4	6	6	7
Gas conditions	3	4	5	6	7	7
Mechanization level	2	3	4	5	6	8
Equipment equipped with status	3	4	4	6	7	8
Equipment maintenance	1	2	3	4	6	6
Scientific research innovation	3	3	4	5	7	8
Staff structure	3	3	4	6	7	8
Technology level	2	4	5	6	5	9
Culture Level	3	3	4	5	7	8
Safety Consciousness	2	4	4	4	5	9
Education plan	3	3	6	5	5	8
Post safety training	1	3	4	4	7	8
Post safety training	3	3	3	5	7	7
Special profession’s training	3	3	4	5	7	8
Noise control	1	3	3	5	7	7
Lighting	3	3	4	5	7	8
Prevention and control of coal seam	4	4	5	6	7	7
Temperature, humidity	3	3	4	5	7	7
Air quality	2	3	4	5	7	8
Leadership’s Safety Consciousness	3	3	4	5	5	7
Safety Input	2	3	4	5	5	8
Safety Culture	3	3	4	5	7	7
Security warning	1	3	4	5	5	8
Accident treatment	2	3	5	5	6	8

Step1: The risk connection degree vector is for the different moments calculated as follows by the formula from *(2)* to *(5):*

$$\mu(t_1)=[-0.9413,-0.6762,0.1689,0.4197,-0.1056]$$

$$\mu(t_2)=[-0.8803,-0.5432,0.2953,0.3805,-0.4336]$$

$$\mu(t_3)=[-0.7611,-0.2945,0.6124,0.3360,-0.7151]$$

$$\mu(t_4)=[-0.8086,0.3150,0.7558,-0.3055,-0.8986]$$

$$\mu(t_5)=[-0.0037,0.5825,0.0144,-0.8354,-0.9315]$$

$$\mu(t_6)=[0.4754,0.5996,-0.4294,-1.0000,-1.0000]$$

According to **Judge Rule Based on the Biggest Connection Degree**, the biggest connection degree of the coal mine in February is the grade IV, and the biggest connection degree of the coal mine in April is the grade IV, and the biggest connection degree of the coal mine in June is the grade III, and the biggest connection degree of the coal mine in August is the grade III, and the biggest connection degree of the coal mine in October is the grade II, and the biggest connection degree of the coal mine in December is the grade II.

Step2: According to AHP, the connection degree weight for the five assessments by four experts is [0.0210, 0.0822,0.1331,0.2001,0.2526,0.3110] by principle of laying more stress on the present than on the past, and the average risk connection vector of the coal mine in a year is calculated as follows:

$$\bar{\mu}=[-0.2083,0.2986,0.1307,-0.4983,-0.8591]$$

Step3: Each transformed matrix is calculated as follows by the formula from *(6)* to *(10)*:

$$P_{2\sim4}=\begin{bmatrix}0.3117 & 0.1793 & 0.5090 & 0.0000 & 0.0000\\ 0.7910 & 0.2090 & 0.0000 & 0.0000 & 0.0000\\ 0.0000 & 0.0913 & 0.8174 & 0.0913 & 0.0000\\ 0.0000 & 0.0000 & 0.6842 & 0.3158 & 0.0000\\ 0.0000 & 0.0000 & 0.0000 & 0.0000 & 1.0000\end{bmatrix}$$

$$P_{4\sim6}=\begin{bmatrix}0.2848 & 0.7152 & 0.0000 & 0.0000 & 0.0000\\ 0.0000 & 0.4807 & 0.2313 & 0.2880 & 0.0000\\ 0.0000 & 0.0000 & 0.9419 & 0.0581 & 0.0000\\ 0.0000 & 0.0000 & 0.0000 & 1.0000 & 0.0000\\ 0.0000 & 0.0000 & 0.0000 & 0.5593 & 0.4407\end{bmatrix}$$

$$P_{6\sim8}=\begin{bmatrix}0.0000 & 0.2421 & 0.7579 & 0.0000 & 0.0000\\ 0.0446 & 0.2108 & 0.7446 & 0.0000 & 0.0000\\ 0.0000 & 0.0000 & 1.0000 & 0.0000 & 0.0000\\ 0.0000 & 0.0000 & 0.1389 & 0.8611 & 0.0000\\ 0.0000 & 0.0000 & 0.0000 & 0.0000 & 1.0000\end{bmatrix}$$

$$P_{8\sim10}=\begin{bmatrix}0.0000 & 1.0000 & 0.0000 & 0.0000 & 0.0000\\ 0.0000 & 0.0000 & 1.0000 & 0.0000 & 0.0000\\ 0.0000 & 0.0210 & 0.3939 & 0.5851 & 0.0000\\ 0.0000 & 0.0000 & 0.0000 & 1.0000 & 0.0000\\ 0.0000 & 0.0000 & 0.0000 & 1.0000 & 0.0000\end{bmatrix}$$

$$P_{10\sim12} = \begin{bmatrix} 0.0000 & 0.0000 & 0.0000 & 1.0000 & 0.0000 \\ 0.0000 & 0.0000 & 0.0000 & 1.0000 & 0.0000 \\ 0.0000 & 0.0000 & 0.3926 & 0.2954 & 0.3120 \\ 0.0000 & 0.0000 & 0.0000 & 0.8870 & 0.1130 \\ 0.0000 & 0.0000 & 0.0000 & 0.0000 & 1.0000 \end{bmatrix}$$

Step4： According to AHP, the weight of transformed matrix by four experts is [0.0910,0.1563,0.2100,0.2501,0.2926] by principle of laying more stress on the present than on the past, and the average weight transformed matrix of the coal mine in a year is calculated as follows:

$$\overline{P} = \begin{bmatrix} 0.0729 & 0.4290 & 0.2055 & 0.2926 & 0.0000 \\ 0.0813 & 0.1384 & 0.4426 & 0.3377 & 0.0000 \\ 0.0000 & 0.0136 & 0.6450 & 0.2502 & 0.0913 \\ 0.0000 & 0.0000 & 0.0914 & 0.8755 & 0.0331 \\ 0.0000 & 0.0000 & 0.0000 & 0.3375 & 0.6625 \end{bmatrix}$$

Step5：Supposed the transformed matrix $\overline{P}$ remaining unchanged, the risk connection degree vector in the coal mine after a year is calculated as follows by the formula *(12)*:

$$[0.0091,-0.0463,0.1281,-0.6536,-0.5737]$$

According to **Judge Rule Based on the Biggest Connection Degree**, the risk grade of the coal mine is the grade III after a year.

Step6：Supposed the transformed matrix $\overline{P}$ remaines unchanged, the final risk connection degree vector in the coal mine after a period of adjustment is calculated as follows by the formula *(13)* and the formula *(14)*:

$$[-0.9527,0.5390,-0.5938,-0.9931,-0.9994]$$

According to **Judge Rule Based on the Biggest Connection Degree**, the final risk grade in the coal mine is the grade II.

4. Conclusions

Generalized set pair analysis and Markov are combined in the article, which make full use of the advantages of them. In allusion to connection degree level vector of the coal mine risk grade in different periods, according to **Judge Rule Based on the Biggest Connection Degree** to get the risk level at the different period. In the same time, according to the principle of laying more stress on the present than on the past, the average weight risk connection degree vector and average weight transformed matrix are obtained. On the basis of the average weight transformed matrix being supposed to be unchanged, the risk grade of the coal mine in any year will be forecasted, which can provide the theory basis to the risk state in the coal mine.

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