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Research on Coupling Coordination Degree of Security Emergency Management in Coal Mine

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Abstract

Aiming at lack of the initiative to coordinate in the coal mine security emergency management, the easy consequence in coal mine accident, the security emergency management of the coupling coordination degree is put forward based on hierarchical network analysis process (ANP) and order parameter method. According to the literatures at home and abroad, the coupling coordination of emergency management processes in coal mine security is summarized; whose measure index system includes five sub-systems, eleven order parameters and thirty-three secondary indexes. With super decision software to determine the weight of each index, the four steps of prevention, preparation, response and recovery of coal mine security emergency management are calculated by using the order parameter method. The results show that the coordination is the highest between the coal mine security emergency management preparation and response of the two parts of the sub-system, while the overall coordination of the system is relatively low.

Keywords: *Emergency management; coal mine security; coupling synergy; order parameter; analytic network process (ANP)*

1. Introduction

In January 2016, a total of more than sixty types of accidents occurred in China, causing 270 of deaths and the missing [1]. In Qian'an coal mine in Yulin of Shanxi Province, "1•6" serious coal dust explosion caused eleven deaths due to illegal explosion, for which the main reason is the disordered security management, the unfulfillment of security training and emergency drills, the employees' low quality, the weak security awareness, and "management loopholes" existing in coal mine security supervision and monitoring, and so on. Therefore, how to solve the "management loopholes", to identify the cause chains of the accident, and to improve the coordination of coal mine security emergency management are urgent. In addition, measuring and determining the dynamic coordination between the coal mine system and the sub system of the coal mine is a difficult problem to be tackled in the emergency management of the coal mine security production.

2. Literature Review and Comment

The integration and summarization of the literature reveals that the research on coal mine security emergency management is still in the initial stage. Lv, Qi [2] constructed the prediction equations to indicate the relationship between the death toll and employees in coal mines by using model of Grey theory and Complementary simulation prediction level test, and thought that model is more useful in measuring the relationships among the elements in coal mine security management system. Onuscheck, E.J. recalled the causes of the coal mine accidents in Pennsylvania in USA from 1907 to 1923 and he thought that the main causes

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concerning coal mining were lack of sufficient ventilation, coal dust and light etc. Zhao Yanqin [4], taking into account the coal mine security noise test, adopted the spatial domain-based and self-adaptive multi-level noise reduction median filter to denoise the image, which effectively reduce the impulse noise in coal mine and thus enhance the intelligibility of the lowlight image. SUN Jiping [5] studied the coal mine security production management information system based on 3DGIS for the detection and location of life in the underground coal mine. CHEN Zhaobo [6], owing to the analysis of different people, made use of HFACS to conduct the Cochran-Q test and designed the open loop and closed loop analysis method for the security accidents of coal mine. TAN Bin [7] maintained that the system is not sound, the training is not standardized, management is not systematic, and the punishment is not reasonable etc, all being the main organization mistakes in the coal mine security management, and revealed the evolution path and law of various organization errors. XI Yuchen [8] constructed the coal mine emergency management system according to the situation of our country from the eight aspects of security planning, emergency organization, resources etc. QI Qi [9] discussed the correlation between the coal mine accident causal variables and the level of enterprise emergency management, and he in addition, set up the evaluation system of emergency management capability of coal mine in terms of causes of accident. From the perspective of coal mine LAN environment, WANG Lingding et al [10] designed the mine emergency resources management and command aided system for pre-arranging planning drills and disaster reliefs; and applied the emergency rescue system to Mu Cheng Jian coal mine. From five aspects such as people, equipment, environment, management and technology, CAI Wenfei [11] developed an emergency management index system, and employed fuzzy AHP to assess the risk of coal mine emergency management. Using system dynamics theory and method, HE Gang [12] explored the impact of security investment growth rate on security management capacity of coal mine security management. FU Gui [13] used the accident causing chain “2-4” behavior model analysis the coal mine security management loopholes, among which, the “2” represented the organization behavior and individual behavior and the “4” stood for guidance, operation, habits and one time behavior. MA Xiaoping [14], through the application of ant colony clustering algorithm for clustering analysis from the four levels of the miners’ quality, organization and management, work environment, psychology and physiology, concluded that the organization and management were the key causes of the accident of coal mine.

Through the related literature, we can know that many of the coal mine accident developmental processes are applied to study the security and emergency management; the variables are different in expression, but mostly similar in essence. Research on the coupling coordination of security emergency management is relatively rare. Based on the literature review, this article, starting from the coal mine security emergency management, establish a coupling coordination degree model for coal mine security emergency management using ANP and order parameter method. This model provides measures for the degree of coordination of the four stages, namely, prevention, preparation, response and recovery for the coal mine security emergency management, which contribute to a new research perspective in this field.

3. Extracting the Degree Index of Coal Mine Security Emergency Management Coupling Coordination

The coordinated operation of coal mine security emergency management is a complicated systematic project. The integration of the four sub-systems, namely, information resources, organization, and process, is then integrated into the established target sub-system of coal mine security emergency management, forming the organic whole consisting of emergency management objectives coordination, emergency management process coordination, emergency management organization coordination, emergency management information coordination and emergency management resource coordination. The operation of five emergency management sub-system co-ordinations can cause the coal mine emergency management coordination system to play the overall

dynamic synergy, produce coordinated innovation, and promote group dynamics.

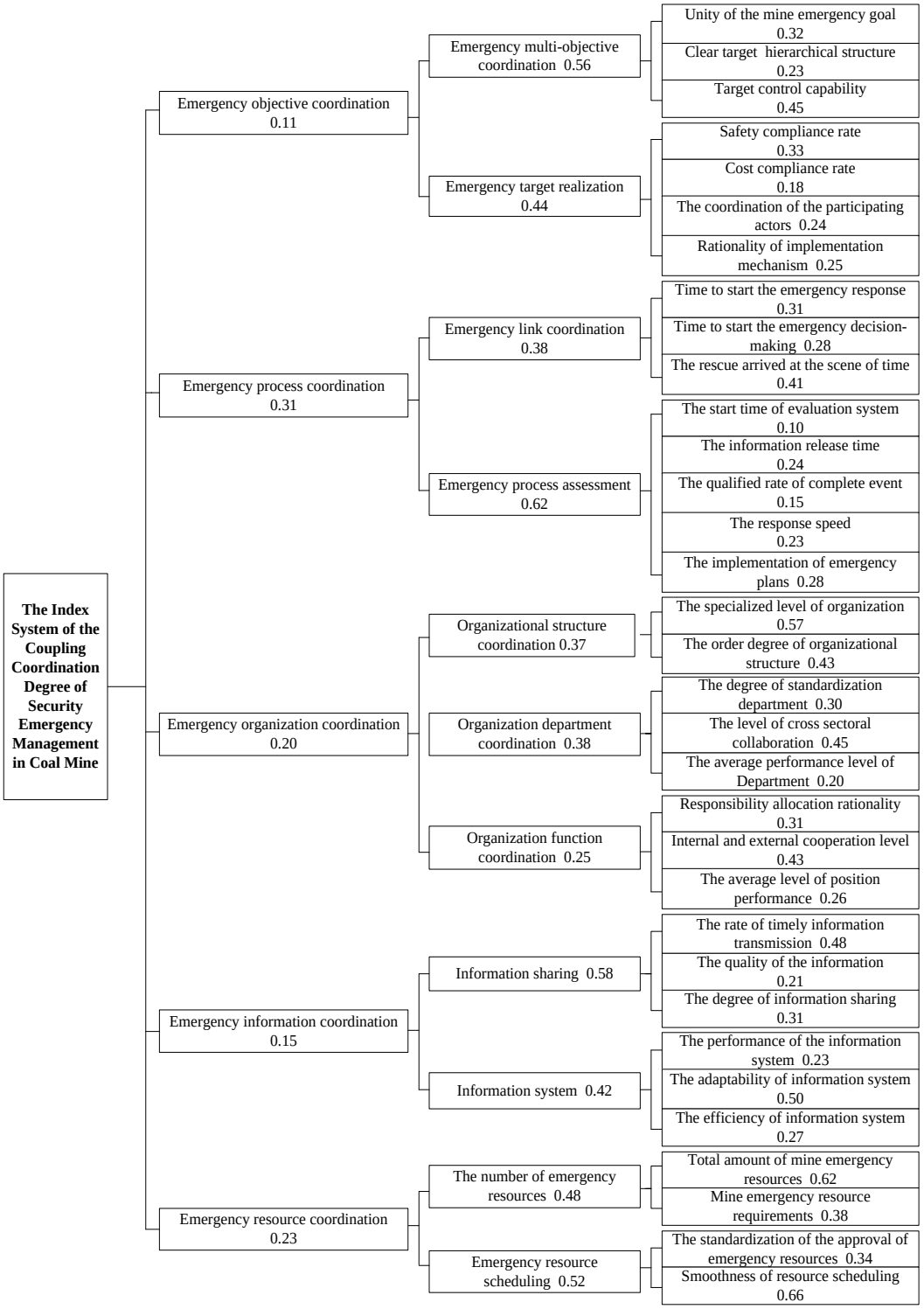

Figure 1. The Index System of the Coupling Coordination Degree of Security Emergency Management in Coal Mine

By referring to the research results of the relevant literature, with combination of the practice of coal mine security emergency management practice with behavior security management theory, the coordination framework of coal mine security emergency management will be designed in this research. By means of expert consultation, questionnaire and other methods, we will extract the indicators and transfer them to coal mine security management experts for further consultation. According to the experts' opinions, we eliminate the index variables that does not conform to the subject or overlap with each other and thus construct the coupling coordination degree measurement system of coal mine security emergency management. The index system is determined as shown in Figure 1.

In Figure 1, the coordination modes, coordination effect, hidden conflict and cost of the different sub-systems are not the same. Coal mine security emergency management process es coordinate with each other in order to realize the coordination modes of coal mine emergency response with emergency process assessment, to realize the coupling coordination effect caused by shortening the start-up time of emergency response system, the time of emergency decision and the release time of information, and to effectively control the event response rate so as to achieve high quality assessment system qualified rate as the goal of the implementation coordination mechanism of emergency plan. In addition, as the main mode of coordination, emergency information coordination is to share the mine information to improve information transmission rate and quality, to solve the problem of retardant information sharing, and to realize the effective coordination of information system performance, adaptability and efficiency. Due to space constraints, the rest of the security management emergency mechanism would not be elaborated in this paper.

4. Construction of Coupling Coordination Degree Model for Coal Mine Security Emergency Management

4.1. To determine the Weight of Each Index

In view of the feedback links between the order parameters and the two-level indexes, the ANP method is adopted to calculate the weight of the indexes at different levels of the coal mine security emergency management coordination mechanism. By drawing on the relevant literature and previous research results, we were to develop the questionnaire firstly. Under the guidance of teachers, our teammates interviewed and investigated twenty experts and scholars in the field of coal mine security emergency management. In addition, we apply 0-1 interval scoring method to extract the views of these twenty experts. The bigger the index data is, the greater the degree of it being recognized. With the aid of super decision (Super-Decisions, SD) software and ANP model, the weight of each index and the weight of order parameter in the coupling coordination degree of coal mine security emergency management are calculated, and the corresponding weight value is shown in Figure 1.

4.2. Security Management Coordination and Order Parameter Method

The coupling coordination degree of coal mine security emergency management mainly refers to the degree of mutual coordination and interaction coordination between the sub-systems of the mine security emergency management system and the components of the system [15].The coordination function between order parameters within the system is the whole evolution process from disorder to order, from low-level coordinated evolution to high-level coordination. Coordination degree is the measure of the coordination effect, which reflects the mutual dependence between the development speed and direction of the system.

Owing to the relative complexity of the coupling coordination process of coal mine

security emergency management, suppose the coal mine sub-system is S_j, $j=1,2,\cdots,n$, and the order parameter of the sub-system is $e_j=(e_{j1},e_{j2},\cdots,e_{jn})$ which is used to describe the variable of the system running statement, and $n\geq 1$, $\alpha_{ji}\geq e_{ji}\geq\beta_{ji}$, $i\in[1,n]$, in which the upper and lower bounds of order parameter e_{ji} are respectively represented by α_{ji} and β_{ji}. Assuming $i\in[1,k]$, then, the greater the value of $e_{j1},e_{j2},\cdots,e_{jk}$, the higher the level of the emergency management system; when $i\in[k+1,n]$, the greater the value of $e_{jk+1},e_{jk+2},\cdots,e_{jn}$,the lower the level of the coal mine security emergency management system, which is in accordance with the usual normal analysis principle.

1) The order degree of coal mine security emergency management coupled sub-system S_j and order parameters e_{ji} can be expressed as:

$$u_j(e_{ji})=\begin{cases}\dfrac{e_{ji}-\beta_{ji}}{\alpha_{ji}-\beta_{ji}}, i\in[1,k]\\ \dfrac{\alpha_{ji}-e_{ji}}{\alpha_{ji}-\beta_{ji}}, i\in[k+1,n]\end{cases} \quad (1)$$

In the formula (1), $u_j(e_{ji})\in[0,1]$, the larger the value of $u_j(e_{ji})$, the stronger the effect of order parameter e_{ji} on the coupling coordination of the system.

2) The contribution of order parameter e_j to the coupling coordination of the emergency management sub-system S_j is obtained by the $u_j(e_{ji})$ integration. In this paper, the entropy weight method is used to calculate the coupling coordination degree of order parameters e_j, as shown in the formula (2).

$$u_j(e_j)=\sum_{i=1}^{n}\lambda_i u_j(e_{ji}) \quad (2)$$

At this time, the weight coefficient is greater than 0, the sum of the weight coefficient is equal to 1. The weight coefficient is expressed as $\lambda_i\geq 0,\sum_{i=1}^{n}\lambda_i=1$.

In the formula (2), $u_j(e_j)\in[0,1]$, the larger the value of $u_j(e_j)$, the higher the level of the emergency management system. On the contrary, the system disorder will be higher.

3) The coupling coordination process of coal mine security emergency management mainly takes place in the four stages: prevention, preparation, response and recovery. If there is no security accident, the system runs independently, and the coupling coordination state is in the form of disorder. If there is an emergency, emergency coordination system status will be instantly changed; proper coordination and harmony between the systems will appear, and then begin to coordinate management. According to this process, the first stage of the security emergency management is regarded as the response time of the coupling coordination process. If the initial point is t_0, the order degree of S_j system is $u_j^0(e_j)$, $j=1,2,\cdots,m$, that is, the coupling coordination degree of coal mine security emergency management can be expressed as:

$$D = \theta \sum_{i=1}^{n} \lambda_i \left| u_j^1(e_j) - u_j^0(e_j) \right| (j = 1,2,\cdots,n)$$

(3)

Among them, D is used to explain the coal mine security emergency management coupling coordination degree. $D \in [-1,1]$, the value of D is positively correlated with the overall coupling coordination degree of the emergency system.

$$\theta = \begin{cases} 1, u_j^1(e_j) - u_j^0(e_j) > 0 \\ -1, u_j^1(e_j) - u_j^0(e_j) < 0 \end{cases}$$

5. Empirical Analysis

Coal mine security emergency management coordination system is a nonlinear, multi-link, and long-span system. From the investment of material capital and human capital into efficiency to the formation of a decentralized index returns, and ultimately to the achievement of the overall coordination of the system would go through a long process. In addition, different aspects of investment which are related to each other constitute a typical complex closed system. A typical coal mine in Anhui province is selected to calculate the coordination degree of security emergency management, in which the system variables were simplified as application examples. On this basis, the weight of the eleven order parameters and thirty-three sub indexes of the security emergency management are determined, and the weight of the index is in the closed range of 0 to 1.

1) Dimensionless data processing. Considering that the initial data dimension is quite different, and the direct conversion is more complicated, dimensionless treatment of initial data is carried out.

The greater the index is, the better the judgment, as shown in the formula (4).

$$x_j^{'} = \frac{x_j - \min(x_j)}{\max(x_j) - \min(x_j)}$$

(4)

The smaller the index is, the better the judgment, as shown in the formula (5).

$$x_j^{'} = 1 - \frac{x_j - \min(x_j)}{\max(x_j) - \min(x_j)}$$

(5)

Among them, $x_j^{'}$ is the dimension of value, $\max(x_j)$ is the maximum value of the j variable, and $\min(x_j)$ is the minimum value of the j variable.

According to the formula (4) and (5), the initial data is handled by dimensionless; the results are shown in Table 1.

Table 1. The Dimensionless Data

Sub-system																				
Emergency target coordination					Emergency process coordination				Emergency organization coordination				Emergency information coordination				Emergency resource coordination			
0.3	0.7	0.8	0.5		0.5	0.6	0.7	0.5	0.4	0.6	0.6	0.5								
0.5	0.7	0.7	0.4		0.5	0.7	0.7	0.5	0.5	0.6	0.7	0.5								
0.5	0.8	0.7	0.4		0.4	0.7	0.8	0.4	0.6	0.6	0.7	0.6	0.6	0.7	0.7	0.5				
0.6	0.8	0.9	0.6		0.7	0.4	0.6	0.6	0.6	0.5	0.7	0.6	0.3	0.7	0.7	0.4				
0.5	0.6	0.6	0.4		0.7	0.5	0.6	0.5	0.3	0.7	0.8	0.5	0.7	0.7	0.8	0.6	0.7	0.8	0.6	0.5
0.5	0.8	0.6	0.4		0.5	0.6	0.7	0.6	0.4	0.6	0.9	0.7	0.5	0.8	0.8	0.6	0.8	0.6	0.7	0.4
0.6	0.8	0.7	0.5		0.6	0.7	0.8	0.7	0.4	0.6	0.9	0.6	0.5	0.6	0.7	0.5	0.6	0.6	0.8	0.5
					0.6	0.7	0.8	0.6	0.3	0.8	0.8	0.6	0.4	0.6	0.7	0.7	0.5	0.7	0.6	0.4

2) The order degree calculation of order parameter in the sub-system. Combined with the formula (2) and the weight of Figure 1, we calculate the order degree of the order parameter in the five sub-systems. The order degree of the order parameter is shown in Table 2.

Table 2. The Order Degree of Order Parameter

Sub-system	The order parameter	Prevention stage	Preparation stage	Response stage	Recovery stage
Emergency target coordination	Emergency multi-objective coordination	0.436	0.745	0.732	0.432
	Emergency target realization	0.558	0.764	0.748	0.515
Emergency process coordination	Emergency link coordination	0.459	0.669	0.741	0.459
	Emergency process assessment	0.619	0.607	0.717	0.599
Emergency organization coordination	Coordination of organizational structure	0.443	0.600	0.643	0.500
	Departmental coordination	0.510	0.545	0.685	0.550
	Coordination of functions	0.374	0.652	0.874	0.631
Emergency information coordination	Information sharing	0.568	0.700	0.731	0.510
	Information system	0.473	0.646	0.723	0.577
Emergency resource coordination	The number of emergency resources	0.738	0.724	0.638	0.462
	Emergency resource scheduling	0.534	0.666	0.668	0.434

3) Calculating the order degree of the sub-system. According to the data of Table 1, Table 2 and Figure 1, the calculation result of the order degree of the sub-system is shown in Figure 2.

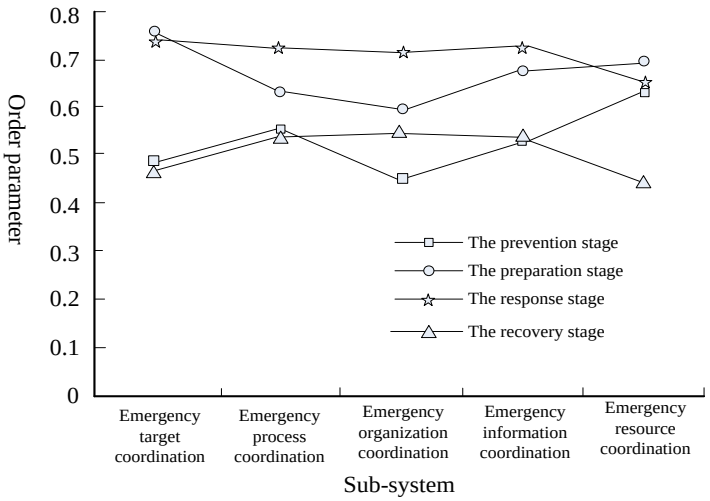

Figure 2. The Order Degree of the Emergency Management Sub-system

The order degree of each sub-system of coal mine emergency management ranged from 0.4 to 0.8, and the level of emergency management in different stages is relatively stable. From emergency target coordination, emergency process coordination, emergency organization coordination to emergency information coordination the front of the four sub-systems in the process, the highest degree of order is at the response stage. In the emergency resource coordination sub-system, the order degree of the highest stage is at the preparation stage. We can see from Figure 2, the overall high degree of order is emergency process coordination and emergency information coordination, which reflects the two sub-systems play a decisive role in the coal mine security emergency management coordination.

4) Measuring system coupling coordination degree. According to the order degree of each sub-system, the prevention stage of coal mine safe emergency management is taken as the base, combined with the formula (3) to calculate the overall coordination level of emergency management system for coal mine security, as shown in Figure 3.

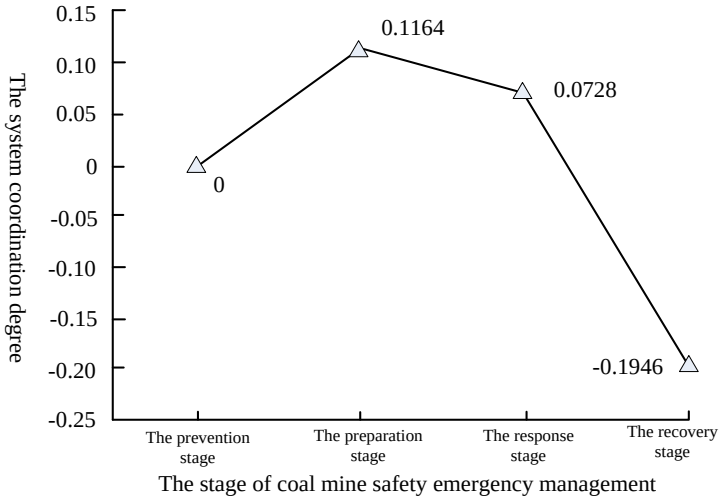

Figure 3. Safety Emergency Management System of Coupling Coordination in Coal Mine

According to Figure 3, we can know the overall coordination degree of the coal mine security emergency management system. The coupling coordination degree at the

preparation stage is 0.1164; the coupling coordination degree at the response stage of is 0.0728, and the overall system coordination degree is very high, indicating that the emergency work at these stages are more complex and it is an important link to solve the accident. The overall system coordination degree at the recovery stage is -0.1946, which indicates that the indexes at this stage have not been reasonably coordinated resulting in the state of disharmony. Therefore, the coal enterprises and the relevant government departments should further optimize the coordination level of each stage, to achieve the overall coordination of the coal mine security emergency management.

6. Conclusions and Prospects

1) Through the analysis of the coupling coordination degree of coal mine security emergency management of the five sub-systems, taking the prevention stage as coal mine security emergency management in the initial period, we obtained the results of the analysis: from sub-systems of emergency target coordination, emergency process coordination, emergency organization coordination to emergency information coordination in the process, the highest degree of order is at the response stage. In the emergency resource coordination sub-system, the order degree of the highest stage is at the preparation stage. Moreover, we can know the overall coordination degree of the coal mine security emergency management system. At the preparation stage, the coupling coordination degree is 0.1164, the coupling coordination degree at the response stage is 0.0728, and the overall system coordination degree is very high. The recovery phase reveals the state of disharmony. Therefore, it is urgent to assort with the coordination degree of each stage of the coal mine security emergency management and the corresponding sub-system.

2) Actively responding to “The Thirteenth Five-Year Plan” on security production emergency management, we should consider the coal mine security emergency management into the security in production planning process and take the coal mine security emergency management into the overall planning process of security production. Combined with the characteristics of coal mine security risk management, we can select one or two areas to carry out the pilot work of coal mine security emergency management, and take the security management of dangerous situations and typical accident rescue as the focus to improve and perfect the emergency coordination and orderly management, to carry out emergency warning education. In practical application, we should strengthen the research of emergency management and optimize the management method of coal mine emergency. In the end, it is equally important to test and revise the coupling coordination degree of emergency response. It also puts forward a plan for the establishment of the emergency management system in order to create a safe environment for the coal mine enterprises and promote its healthy development.

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