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Research Article

Study on Measuring and Evaluating the Synergy Effect of Regional Coal Mine Emergency Management in China Based on the Composite System Synergy Model

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Emergency management of coal mines requires enhanced synergy among departments, institutions, and enterprises, which means overall efficiency in management. In this study, a regional coal mine emergency (CME) management synergy system was established; the synergy theory was adopted to construct the order parameter index system of the regional CME management synergy subsystems. Moreover, the order degrees and synergistic degrees of the regional CME management synergy subsystems in Henan Province, China, in the period 2015-2019 were quantitatively measured and analyzed using the composite system synergy model. The results show that the order degrees of regional CME management synergy subsystems and the synergistic degree of the composite system increase overall during the inspection period. With the gradual formation of the regional CME management synergy mechanism, this period has witnessed a steady improvement in both the synergy value and the considerable synergistic effect.

1. Introduction

Synergistic management is an effective way to build a strong force for the prevention and control of emergencies. In order to improve the overall managerial and cost efficiency of coal mine emergency (CME) management, synergy among departments, institutions, and enterprises is necessary. Therefore, the purpose of establishing a regional CME synergy mechanism is to achieve and promote synergistic effects among the subjects within the system. For a regional CME management system to become synergistic, it usually needs to experience a series of evolution including continuous diagnosis, adjustment, and evaluation of the original system. Before any improvement measure is made, an evaluation of the synergy status of the concerned regional CME management synergy system must be conducted, because it serves both as an evaluation of past systems and as the basis for improving or constructing new emergency synergy systems. Therefore, a scientific evaluation index system should be established to evaluate the system synergy, identify the weak points in the system, and take targeted measures for them. In this way, the synergy system and level of synergy can be improved as a whole, thus changing the system behavior and achieving better overall synergistic effects.

2. Current Situation of Emergency Management Synergy

The study on synergy can trace back to 1965; Igor Ansoff, a well-known American professor of strategic management, first introduced the concept of "synergy" in his paper "Corporate strategy: an analytic approach to business policy for growth and expansion" [1–3]. He pointed out that mutual promotion and mutual benefit can be achieved among multiple subjects on the basis of resource sharing. In 1971, a German physicist named Hermann Haken continued on that basis to propose a systematic theory, which is now known as the synergy theory [4]. With the development of society, the concept of synergy has been widely used in various research fields beyond physics. Although different scholars have different approaches and focuses on synergy research, a common understanding has been reached about the meaning of synergy, i.e., "1 + 1 > 2." Moreover, most of the scholars have recognized the significant value of synergy and have introduced a synergistic perspective to analyzing problems in their respective fields.

In addition to emphasizing prevention and preparedness, another obvious feature of the current academic research on emergency management theory is to focus on strengthening emergency synergy and cooperation. In recent years, foreign scholars' research on synergistic aspects of emergency management mainly focuses on emergency synergy cases, emergency synergy influencing factors, and emergency synergy roles.

On the role of emergency synergy, related scholars have studied the emergency synergistic response working mechanism from the perspective of the subject and pointed out the importance of achieving effective synergy among emergency subjects; for example, McMaster and Baber, Salama et al., Curnin et al. [5–7], and others explored the importance of emergency synergy among multiple departments in emergencies. Evers et al. viewed synergy as a collaborative approach [8]; Te Brake et al. argue that efficient allocation of emergency resources and resource interoperability are key factors for the synergy of emergency response teams [9]; Hemandez and Serrano propose that an optimized collaborative knowledge management model can be used to screen a large amount of raw information in the emergency management process, leading to an improved level of emergency response [10].

In terms of emergency synergy influencing factors, some scholars have studied the role of information, organizational structure, emergency resources, and other factors in emergency synergy, respectively. For example, Henstra proposed the concept of regional emergency management procedures as elements to provide a method for the evaluation of emergency management procedures. Henstra argued that adequate emergency funding can meet the needs and expectations of the public and ensure the continuity and depth of emergency cooperation among local governments [11].

For example, McEntire analyzed the tornado emergency in Fort Worth, Texas, and concluded that the amount of emergency information (lack or excess), the lack of emergency equipment, the lack of communication among new emergency personnel, organizational authority conflicts, and language barriers affect the efficiency of emergency response. The efficiency of emergency synergy is affected by the lack of communication among emergency personnel, conflicts in organizational competencies, and language barriers [12–14], arguing that organizational cooperation is a fundamental guarantee of an effective response to regional emergencies. Calixto and Larouvere, through their analysis of the Hurricane Katrina emergency, suggested factors that affect the efficiency of emergency synergy: differences in emergency norms and standards, differences in the phases of public emergency response, and relationships formed by organizations in advance [15].

In the research of emergency synergy in coal mines, scholars such as Ikeda et al. [16] studied the use of advanced communication technology to support emergency rescue and proposed an emergency rescue model; Yeo and Comfort concluded that the collaborative network of emergency organizations showed a high degree of fragmentation and weak interconnection between horizontal and vertical [17]; Schipper et al. studied the emergency response collaborative action interaction in emergency response, and information communication between different subjects was studied [18]; Kinilakodi and Grayson studied the prevention and reduction of coal mine accidents by introducing a reliability approach to enhance the collaborative management of coal mine safety emergencies [19].

An analysis of the past researches reveals that both China and the international community are in a primary stage of exploring the emergency management synergy mechanism, where few fruits have been yielded, especially those in the CME management area. In this research, the synergy theory was employed to study the degree of synergy in the regional CME management synergy system and analyze its composition. Besides, an order parameter index system of the regional CME management synergy subsystems was constructed, and the composite system synergy model was introduced for the quantitative measurement and empirical evaluation of the order degrees and synergy level of the regional CME management synergy subsystems in Henan Province, China. Based on research results, relevant suggestions were made.

3. Composition of Regional CME Management Synergy System

At present, the overall CME management system in China is divided into several sections according to the administrative division. Regional CME management synergy is not about simply superimposing various synergistic subsystems or elements of different regions. Instead, it involves using certain synergistic mechanisms to generate synergistic effects among various subsystems or elements in meeting emergencies, thus achieving the goal of controlling and optimizing the distribution of information, capabilities, and materials. According to the current division criterion of coal mines in China, regional CME management synergy is generally divided into three levels: province, municipality, and mining areas. Provincial emergency management synergy plans and uses limited emergency resources on an interprovincial basis to realize maximum effectiveness. Municipal synergy refines and implements provincial decisions at the municipal level. Mining area synergy refers to the integration of emergency business processes among coal mining enterprises, which is aimed at removing obstacles among various processes and facilitating smoother business docking. In dealing with regional coal mine emergencies, the emergency synergy system is at work in four stages: emergency recovery, preparation, prevention, and response. At the abovementioned three levels, the CME synergy management system is able

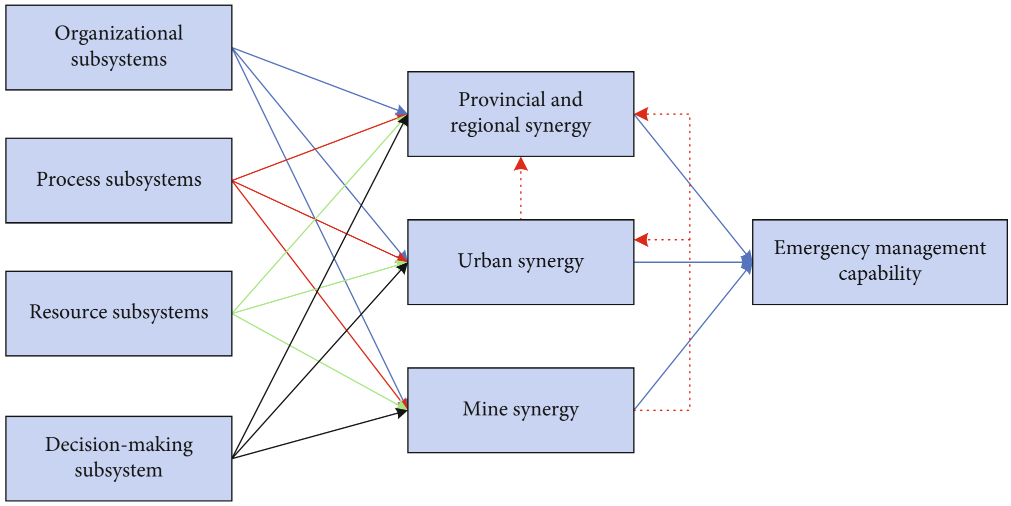

FIGURE 1: Mechanism of regional CME management synergy.

to form a more orderly structure in function, space, and time dimensions, thus contributing to the effective improvement of CME management capabilities (Figure 1).

Subjects within a regional CME management synergy system mainly include the mine itself, government institutions, regional coal mine cooperation bodies, and social service institutions. Each synergistic subject has multiple subsystems, such as resource, decision, organization, and process subsystems. Meanwhile, they interact with each other in the regional CME management synergy process to induce subsystem behavior changes and internal synergy. Moreover, the synergistic subjects also affect each other through the exchange of material, information, and energy and produce synergistic effects under a synergistic mechanism, so that the system can develop in an orderly manner. Ultimately, the regional CME management synergy system can achieve an overall synergistic effect. That is, the elements in the system exchange energy and materials with the outside world through interaction, thus forming an overall orderly structure with respect to function, space, and time, which then evolves into a new orderly state. Therefore, for the regional CME management synergy system, in response to coal mine emergencies, all subjects should enhance mutual collaboration and communication with each other through organization systems, emergency response plans, laws, regulations, etc. This can improve the overall order level of the emergency synergy system that is composed of relevant subsystems, conduce to a more efficient and coordinated response to coal mine emergencies, and finally reduce casualties and property damage.

4. Establishment of Assessment Model

4.1. Order Degree Model for Subsystems. Based on the synergistic evaluation method, the regional CME management synergy system in this study is expressed as $M = \{M_1, M_2, M_3, \cdots, M_n\}$, where M_j is the j^{th} subsystem of system M, $j = 1, 2, \cdots, n$, and $M_j = \{M_{j1}, M_{j2}, M_{j3}, \cdots, M_{jn}\}$, which means that M_j is composed of several order parameters or several subelements. As mentioned in the previous analysis, the regional CME management synergy system consists of four main subsystems, namely, resource, organization, decision, and process subsystems. Hence, $M = \{M_1, M_2, M_3, \cdots, M_n\}$ $(n \leq 4)$.

Set the order parameter of subsystem M_j as $X_j = (x_{j1}, x_{j2}, \cdots, x_{ji})$, $i \in [1, n]$. "$x_{j1}, x_{j2}, \cdots, x_{ji}$" are parameters for describing the operating status of subsystems, and $n \geq 1$. x_{ji} and β_{ji} are the stability caps and collars of subsystems, respectively, $\alpha_{ji} \leq x_{ji} \leq \beta_{ji}$. Considering the difference in the properties of the order parameter x_j, different order degree evaluation methods are adopted. Specifically, when the order degree of the subsystem changes in the same direction as the value of the order parameter x_j, the order parameter x_j is a positive indicator. In this case, the order degree of the component parameter x_{ji} of the order parameter x_j in the regional CME management synergy subsystem M_j is

$$\varphi_j(x_{ji}) = \frac{x_{ji} - \alpha_{ji}}{\beta_{ji} - x_{ji}}. \tag{1}$$

When the order degree of the subsystem changes in the opposite direction to the value of the order parameter x_j, the order parameter x_j is a negative indicator. In that case, the order degree of the component parameter x_{ji} of the order parameter x_{ji} in the regional CME management synergy subsystem M_j is

$$\varphi_j(x_{ji}) = \frac{\beta_{ji} - x_{ji}}{\beta_{ji} - \alpha_{ji}}. \tag{2}$$

The order degree φ_j of the order parameter x_j lies in the range of $[0, 1]$. φ_j reflects the influence of the component parameter x_{ji} of the order parameter x_j on the order degree of the subsystem. The larger the value of φ_j, the greater the contribution of x_{ji} to the order degree of the subsystem.

Table 1: Evaluation standard of SRCMEMCS.

Synergistic degree	$0 < \text{SRCMEMCS} \le 0.4$	$0.4 < \text{SRCMEMCS} \le 0.6$	$0.6 < \text{SRCMEMCS} \le 0.8$	$0.8 < \text{SRCMEMCS} \le 0.9$	$0.9 < \text{SRCMEMCS} \le 1$
Synergy level	Nonsynergy	Mino nonsynergy	Basic synergy	Good synergy	Excellent synergy

The contribution of x_{ji} to the overall order degree of the subsystem can be obtained by arithmetic averaging or geometric averaging, i.e., the order degree of the regional CME synergy subsystem (abbreviated as ODRCMESS) can be expressed as or

$$\text{ODRCMESS} = \varphi_j(x_j) = \frac{1}{n}\sum_{i=1}^{n}\varphi_j(x_{ji})\ (j = 1, 2, 3, 4) \tag{3}$$

$$\text{ODRCMESS} = \varphi_j(x_j) = \sqrt[n]{\prod_{i=1}^{n}\frac{1}{n}\varphi_j(x_{ji})}\ (j = 1, 2, 3, 4). \tag{4}$$

From Equations (3) and (4), it is known that $\text{ODRCMESS} = \varphi_j(x_j) \in [0, 1]$. The larger the value of ODRCMESS, the higher the order degree of the subsystem; the smaller the value of ODRCMESS, the lower the order degree of the subsystem. When $\text{ODRCMESS} = \varphi_j(x_j) = 0$, the subsystem M_j has the lowest order degree; when $\text{ODRCMESS} = \varphi_j(x_j) = 1$, the subsystem M_j has the highest order degree.

4.2. Composite System Synergistic Degree Model. The synergistic degree of the regional CME composite synergy system is measured based on the dynamic remeasurement of the subsystems' order degree. Assuming that a subsystem's order degree $\text{DRCMESS} = \varphi_j^{\,0}(x)$, $j = 1,2,3,4$, at the initial time t_0 and that the subsystem's order degree $\text{DRCMESS} = \varphi_j^{\,k}$, $j = 1,2,3,4$, at a certain time t_k, then the synergy of regional coal mine emergency management coordination subsystem (abbreviated as SRCMEMCS) for that time period can be expressed as or

$$\text{SRCMEMCS} = \theta^{1/4}\left|\sum_{i=1}^{4}\left[\varphi_j^k(x_j) - \varphi_j^0(x_j)\right]\right| \tag{5}$$

$$\text{SRCMEMCS} = \theta^{4}\sqrt{\left|\prod_{i=1}^{4}\left[\varphi_j^k(x_j) - \varphi_j^0(x_j)\right]\right|}, \tag{6}$$

where

$$\theta = \frac{\min\left[\varphi_j^k(x_j) - \varphi_j^0(x_j)\right]}{\left|\min\left[\varphi_j^k(x_j) - \varphi_j^0(x_j)\right]\right|}\ (j = 1, 2, 3, 4). \tag{7}$$

As can be seen from Equations (3), (5), and (6), the regional CME management synergy model can be used to characterize the changing trend of the regional CME management synergy system and the quantification of its synergistic degree in a certain period of time, while SRCMEMCS can be used to evaluate the overall synergistic degree of the regional CME synergy system in the time period t. The value of SRCMEMCS lies within the range of $[0, 1]$. The greater the value of SZMECS, the stronger the synergistic ability of the synergy system; the smaller the value, the weaker the synergy ability.

When it comes to evaluating the synergistic degree of a composite system, this classifies SRCMEMCS into five levels by drawing from relevant practical experience in China and abroad and following the principle that a large number of evaluation data must conform to reasonable normal distribution (Table 1).

4.3. Establishment of Order Parameter System. The synergy effects of the regional CME management synergy system depend on the synergistic actions among subsystems. According to the synergy theory, order parameters are the main variables responsible for the structural and functional changes of the system, and they determine the process and direction of the system evolution. Hence, choosing correct order parameters is crucial [7, 8]. Based on analysis of the elements of the regional CME management synergy system and the review of relevant information and research results of related scholars, and by combining the Delphi method, this study compiled the order parameter system that can indicate the order degree of the regional CME management synergy subsystem (Table 2).

4.4. Weight Assignment of Order Parameter Index. There are generally subjective and objective methods of assigning index weights, each of which has its own advantages and disadvantages. Considering the difficulty in collecting raw information by using the subjective assignment method and the influence of subjective factors, this paper adopts the entropy weighing method to calculate the weight of each index. The calculation steps are as follows.

(1) Calculate the weight of the i^{th} subject of the j^{th} index:

$$\theta_{ji} = \frac{x_{ji}}{\sum_{i=1}^{n} x_{ji}}\ (i = 1, 2, 3 \cdots, m,\ j = 1, 2, \cdots, n) \tag{8}$$

(2) Calculate the entropy value of the j^{th} index:

If e_j is the entropy value of the j^{th} evaluating index, its calculation is as follows:

$$e_j = -\frac{1}{\ln m}\sum_{i=1}^{m}\left(\theta_{ji}x_{ji}\right),\ e_j \in [0, 1] \tag{9}$$

Table 2: Synergistic degree evaluation index system of the regional CME management synergy system.

Subsystem	Order parameter	Index	Code	Type
Decision-making subsystem (M_1)	Synergy among subjects	Synergy with government departments	x_{11}	Positive
		Synergy with coal mining enterprises	x_{12}	Positive
		Agreement in decision-making among subjects	x_{13}	Positive
	Information synergy	Information convey quality	x_{14}	Positive
		Information convey speed	x_{15}	Positive
		Degree of information sharing	x_{16}	Positive
Organization subsystem (M_2)	Structure synergy	Structure order degree	x_{21}	Positive
		Differentiation among levels	x_{22}	Negative
	Synergy among departments	Departmental management span	x_{23}	Negative
		Cross-departmental synergy level	x_{24}	Positive
		Occupational synergy level	x_{25}	Positive
	Authority synergy	Completeness of emergency response agreement among organizations	x_{26}	Positive
		Rationality of emergent assignment of authority and responsibility	x_{27}	Positive
Process subsystem (M_3)	Precaution synergy	Completeness of basic data	x_{31}	Positive
		Difference in criterions and standards among organizations	x_{32}	Negative
		Safety check times	x_{33}	Positive
		Accident predicting and warning capacity	x_{34}	Positive
	Preparation synergy	Emergency rescue crew	x_{35}	Positive
		Mutual aid agreement in emergency rescue	x_{36}	Positive
		Interorganizational planning adaptability	x_{37}	Positive
		Average annual trainings for emergency response personnel	x_{38}	Positive
		Emergency drilling times	x_{39}	Positive
	Response synergy	Emergency rescue technologies and professional equipment	x_{310}	Positive
		Involvement of emergency experts	x_{311}	Positive
		Emergency response speed	x_{312}	Positive
		Effectiveness of emergency equipment and facilities	x_{313}	Positive
	Recovery synergy	Reliability of medical services	x_{314}	Positive
		Reliability of emergency telecommunication	x_{315}	Positive
		Accident investigation and report	x_{316}	Positive
		Effectiveness of recovery plan	x_{317}	Positive
Resource subsystem (M_4)	Reservation synergy	Applicability of emergency equipment	x_{41}	Positive
		Sufficiency of emergency supply	x_{42}	Positive
	Distribution synergy	Complementarity of different resources	x_{43}	Positive
		Timeliness of resource acquisition	x_{44}	Positive

(3) Calculate the differentiation coefficient:

$$g_j = 1 - e_j \tag{10}$$

(4) Calculate the weight of the j^{th} index:

$$\theta_{ji} = \frac{g_j}{\sum_{j=1}^{n} g_j} \tag{11}$$

According to the above equations, the weights of all indexes in Table 2 are calculated step by step, and the results are shown in Table 3.

5. Analysis on Empirical Results

5.1. Sample Selection and Data Processing. In this study, the provincial-level CME management system in Henan Province was taken as the sample for empirical analysis, and

Table 3: Regional coal mine emergency system synergistic degree evaluation index weights.

Subsystem	Weights	Order parameter	Weights	Index	Code	Weights
Decision subsystem (M_1)	0.3	Synergy among subjects	0.54	Synergy with government departments	x_{11}	0.31
				Synergy with coal mining enterprises	x_{12}	0.28
				Agreement in decision-making among subjects	x_{13}	0.41
		Information synergy	0.46	Information convey quality	x_{14}	0.21
				Information convey speed	x_{15}	0.33
				Degree of information sharing	x_{16}	0.46
Organization subsystem (M_2)	0.25	Structure synergy	0.37	Structure order degree	x_{21}	0.45
				Differentiation among levels	x_{22}	0.55
		Synergy among departments	0.32	Departmental management span	x_{23}	0.42
				Cross-departmental synergy level	x_{24}	0.58
		Authority synergy	0.31	Occupational synergy level	x_{25}	0.38
				Completeness of emergency response agreement among organizations	x_{26}	0.21
				Rationality of emergent assignment of authority and responsibility	x_{27}	0.41
Process subsystem (M_3)	0.31	Precaution synergy	0.21	Completeness of basic data	x_{31}	0.18
				Difference in criterions and standards among organizations	x_{32}	0.12
				Safety check times	x_{33}	0.16
				Accident predicting and warning capacity	x_{34}	0.54
		Preparation synergy	0.23	Emergency rescue crew	x_{35}	0.25
				Mutual aid agreement in emergency rescue	x_{36}	0.22
				Interorganizational planning adaptability	x_{37}	0.20
				Average annual trainings for emergency response personnel	x_{38}	0.15
				Emergency drilling times	x_{39}	0.18
		Response synergy	0.42	Emergency rescue technologies and professional equipment	x_{310}	0.22
				Involvement of emergency experts	x_{311}	0.16
				Emergency response speed	x_{312}	0.21
				Effectiveness of emergency equipment and facilities	x_{313}	0.41
		Recovery synergy	0.14	Reliability of medical services	x_{314}	0.13
				Reliability of emergency telecommunication	x_{315}	0.14
				Accident investigation and report	x_{316}	0.32
				Effectiveness of recovery plan	x_{317}	0.41
Resource subsystem (M_4)	0.14	Reservation synergy	0.46	Applicability of emergency equipment	x_{41}	0.44
				Sufficiency of emergency supply	x_{42}	0.56
		Distribution synergy	0.54	Complementarity of different resources	x_{43}	0.38
				Timeliness of resource acquisition	x_{44}	0.62

the regional CME synergistic degree evaluation index system and model constructed in Section 3 were used to perform the actual measurement, evaluation, and result analysis. Henan Province, which is endowed with rich coal resources and boasts a long history of coal mining, is a key coal-producing province in China [20–22]. At present, the backbone coal mining enterprises in Henan mainly include the Yima Coal Group, China Pingmei Shenma Group, Henan Energy and Chemical Industry Group, and Zhengzhou Coal Industry Group. In addition, there are also a few local coal mining enterprises. The Henan Coal Mine Safety Supervision Bureau is a direct subsidiary of the State Coal Mine Safety

Table 4: Order degree of the CME management synergy decision-making subsystem in Henan Province.

Year	2015	2016	2017	2018	2019
Synergy among subjects	0.557	0.682	0.754	0.841	0.915
Information synergy	0.662	0.724	0.853	0.819	0.896

Table 5: Order degree of the CME management synergy organization subsystem in Henan Province.

Year	2015	2016	2017	2018	2019
Structure synergy	0.627	0.728	0.859	0.834	0.912
Synergy among departments	0.658	0.724	0.846	0.845	0.947
Authority synergy	0.654	0.741	0.826	0.831	0.887

Table 6: Order degree of the CME management synergy process subsystem in Henan Province.

Year	2015	2016	2017	2018	2019
Precaution synergy	0.573	0.668	0.832	0.815	0.921
Preparation synergy	0.628	0.724	0.843	0.911	0.947
Response synergy	0.684	0.735	0.847	0.854	0.828
Recovery synergy	0.657	0.726	0.816	0.851	0.893

Table 7: Order degree of the CME management synergy resource subsystem in Henan Province.

Year	2015	2016	2017	2018	2019
Reservation synergy	0.654	0.748	0.846	0.851	0.912
Distribution synergy	0.641	0.654	0.749	0.849	0.848

Table 8: Order degrees of the CME management synergy subsystems in Henan Province.

Year	2015	2016	2017	2018	2019
Decision subsystem	0.653	0.715	0.832	0.745	0.821
Organization subsystem	0.627	0.696	0.743	0.721	0.847
Process subsystem	0.584	0.653	0.687	0.692	0.729
Resource subsystem	0.657	0.726	0.836	0.847	0.896

Supervision Bureau. It has five branch bureaus: Zhengzhou, West Henan, East Henan, North Henan, and South Henan Supervision Branch. This research took as examples Henan Provincial Coal Mine Safety Supervision Bureau and relevant institutions, including the Jiaozuo Coal Industry Group, Zhengzhou Coal Industry Group, and China Pingmei Shenma Group, to carry out an empirical study on the synergistic degree of provincial-level CME management system.

In terms of data sources, a total of 70 representatives (including government staff from the Henan Provincial Coal Mine Safety Supervision Bureau; senior and junior managers from coal mining enterprises such as Jiaozuo Coal Industry Group, Yima Coal Group, Zhengzhou Coal Industry Group, and China Pingmei Shenma Group; and scientific researchers from research institutes such as Henan University of Technology) were invited to score relevant indexes according to a 10-point scale with a minimum score of 0 and a maximum score of 10. After these experts gave their marks to the indexes in the regional CME management synergy system in Henan Province in the period 2015-2019 according to the actual situation, an averaged result was obtained.

With respect to data processing, since the indexes correspond to different directions and dimensions, the raw data cannot be used directly for evaluation and comparison. Therefore, an appropriate method is needed to standardize these data so that the final score results of each index fall within the $[0, 1]$ interval. For convenience concern, the raw data collected in this study were processed dimensionless using the deviation standardization method. The calculation is as follows.

Assume that x_{ji} is the nondimensional value of the j^{th} index in the i^{th} stage and that v_{ji} is the nondimensional value of the j^{th} index in the i^{th} stage, where n refers to the stage. Then, Equations (12) and (13) are adopted, respectively, for the standardization of positive and negative indexes:

$$\text{Positive index}: x_{ji} = \frac{v_{ji} - \min_{1\le i\le n} v_{ji}}{\max_{1\le i\le n} v_{ji} - \min_{1\le i\le n} v_{ji}} \quad (i = 1, 2, \cdots, m, \ j = 1, 2, \cdots, n), \tag{12}$$

$$\text{Negative index}: x_{ji} = \frac{\max_{1\le i\le n} v_{ji} - v_{ji}}{\max_{1\le i\le n} v_{ji} - \min_{1\le i\le n} v_{ji}} \quad (i = 1, 2, \cdots, m, \ j = 1, 2, \cdots n). \tag{13}$$

5.2. Calculation of the Order Degrees of Order Parameters. Based on weights of each index, all the standardized dimensionless data were substituted into the previously constructed equations for calculating the order degrees of order parameters in subsystems. Afterwards, the order degrees of order parameters in regional CME management synergy subsystems in Henan Province were obtained (Tables 4–7).

5.3. Calculation of the Synergistic Degrees of Subsystems. Based on the calculated synergistic degree values of order parameters and their weights, the orderliness values of all subsystems in the regional CME management synergy system were calculated in turn (Table 8). Overall, from 2015 to 2019, the synergistic degrees of all CME management synergy subsystems in Henan Province have improved significantly, which means that the system has been heading for a more synergistic direction. Moreover, by comparing the order degree values of the four subsystems, it can be seen that the order degree of the process subsystem is relatively low for two main reasons: First, the average annual training frequency for emergency personnel in Henan Province is relatively low, barely meeting the basic requirement for training (i.e., once a year). Second, the coal market is in the downward phase in recent years, yet Henan Province has not added to its emergency response teams, which falls short to the synergy needs with other elements.

5.4. Calculation of the Synergistic Degree of the Composite System. The previously constructed SRCMEMCS model

Table 9: Overall synergistic degree of the CME management synergy system in Henan Province.

Year	2015	2016	2017	2018	2019
Overall synergistic degree	0.563	0.615	0.732	0.759	0.802

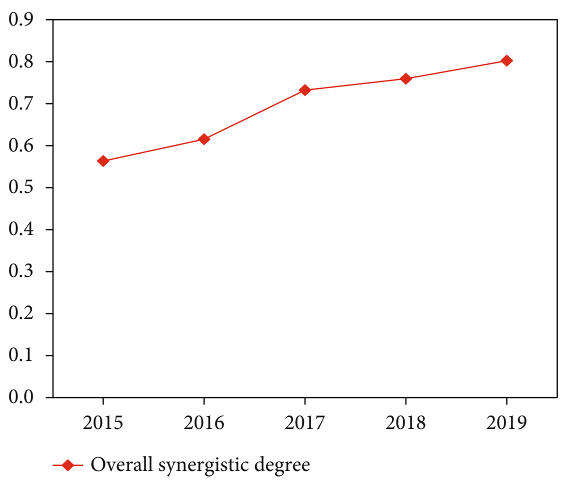

Figure 2: Overall synergistic degree of the CME management synergy system in Henan Province (2015-2019).

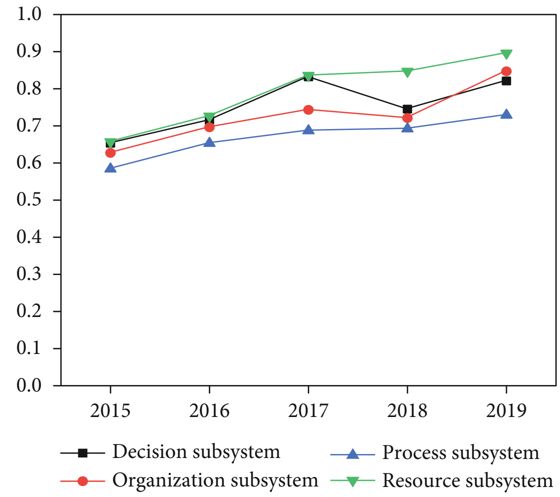

Figure 3: Synergistic degrees of CME management synergy subsystems in Henan Province (2015-2019).

was used to calculate Equations (5)–(11), and the overall synergistic degree of the regional CME management synergy system in Henan Province in the period 2015-2019 was obtained (Table 9).

The following is the findings acquired from the analysis on each subsystem: The decision subsystem was in the basic synergy stage from 2015 to 2017 and stayed there from 2017 to 2018 with the synergistic degree declined; subsequently, from 2018 to 2019, it entered a primary stage of good synergy where its synergy began to grow rapidly. The organization subsystem had a similar development trajectory to that of the decision subsystem, which also started from the basic synergy stage (2015-2017), then experienced a growth slowdown stage (2017-2018), and finally entered the primary stage of good synergy (2019). The resource subsystem had stayed in the basic synergy stage with a low growing rate since 2015, and it started to enter the primary stage of good synergy in 2018. However, the process subsystem exhibited relatively poor synergy compared with the other three subsystems; it started from the mild nonsynergy stage and entered the primary stage of basic synergy in 2016; although the emergency synergy state was gradually improving in these years, the growth rate was low and it remained in the advanced stage of basic synergy by the year 2019.

5.5. Results and Discussion. According to Table 9 and Figures 2 and 3, the synergistic degree of the regional CME management system in Henan Province shows a steady upward trend. The elements of the CME management synergy system have been effectively collaborated and improved year by year. However, the speed of improvement slowed down from 2017 to 2018, with a slight decrease in adaptability of interorganizational plans, average frequency of emergency personnel training, emergency drills, and preventive safety inspections. Furthermore, the structural order degree and departmental management span also scored slightly lower in 2018 than in 2017. This phenomenon can be explained as follows: In 2018, the Chinese government underwent an institutional reform of the State Council, in which the former State Administration of Work Safety was replaced by the Ministry of Emergency Management. As a constituent department of the State Council, the newly formed Ministry of Emergency Management integrated relevant responsibilities of the previous nine units of State Administration of Work Safety, National Flood and Drought Control Headquarters, National Disaster Reduction Committee, State Council Earthquake Relief Headquarters, Headquarters of China Forest Fire Prevention, etc. With an extremely wide range of departments involved, this reform can be said to be a stripped-down rebuilding and reconstruction. On March 21, 2018, the Central Committee of the Communist Party of China issued the Program for Deepening the Reform of Party and State Institutions, and local departments in various provinces and cities started institutional reforms in accordance with the requirements. On November 29, 2018, the Emergency Management Department of Henan Province was inaugurated, and local emergency management departments at all levels were established subsequently as institutional reform continued to accelerate. Therefore, 2018-2019 was in a special phase of mechanism transition, responsibility handover, and power conversion. It was also a crucial period of function integration, friction, and convergence. The scoring of the organization subsystem negatively affected the synergistic degree of the whole system in this special period of reform and run-in period. However, from a holistic perspective, the synergistic degree of the regional CME management synergy system in Henan Province in the period 2015-2019 has achieved significant growth from basic synergy to the primary stage of good synergy via a brief period of good synergy. From 2018 to 2019, the growth of synergistic degrees slowed down.

6. Conclusions and Suggestions

In this paper, first of all, the composition and elements of the regional CME management synergy system in China were systematically analyzed according to the characteristics of China's emergency management system. Afterwards, the order parameter index system of each subsystem of the regional CME synergy system was constructed based on synergy theory. In the next part, the composite system synergy model was adopted to quantitatively measure and analyze the order degrees of regional CME management synergy subsystems and the synergistic degree of the composite system in Henan Province in the period 2015-2019. The following conclusions were drawn: The order degrees of regional CME management synergy subsystems and the synergistic degree of the composite system in Henan Province have shown an overall upward trend, with synergistic degrees ranging from -0.563 to 0.802. All the elements involved in the CME management synergy system have seen annually deepening improvements in the synergistic degree as a synergistic development mechanism is established step by step. However, the synergistic degree in Henan grew relatively slow from 2018 to 2019, indicating sluggish synergistic development. In the end, through analysis of each subsystem, it can be drawn that among the four subsystems, the process subsystem shows a relatively lower synergistic degree compared with the other three subsystems. It started from a mild nonsynergy stage and entered the basic synergy stage in 2016, but with a slow-growing rate, which only led it to the advanced stage of basic synergy in 2019.

Therefore, the following suggestions are made.

(1) Promote the construction of CME-management-synergy-related laws and regulations

In this era of frequent emergencies, each department, which is considered a subsystem, needs to establish guidelines that apply to its emergency management efforts. Therefore, the development of CME management synergy requires the support of laws and regulations, and it is suggested to actively promote the construction of China's emergency legal system; develop emergency synergy-related laws, regulations, systems, and standards; clearly stipulate the principles, disciplines, and responsibilities of relevant departments; and regulate emergency synergy in the form of legislation, so as to achieve the rule of law in emergency synergy.

(2) Construct a province-municipality-mine synergy model

It is suggested to actively adapt to the new normal of China's coal mine safety and emergency management work, give full play to the organizational coordination and comprehensive supervision role of emergency management agencies, and construct a three-level synergistic emergency response model of provincial, municipal, and mining areas. In a specific work context, the participating subjects in this model need to further enhance communication and scientific decision-making; give full play to the role of departments such as safety supervision, land and resources, public security, trade unions, industry and commerce, environmental protection and electricity to strengthen communication and coordination, and close cooperation and timely consultation; and actively explore the resource sharing mechanism and emergency response linkage between military force, local government, and coal mines and resource.

(3) Strengthen synergy between emergency plans

At present, most of the coal mining enterprises in China have emergency plans prepared according to national requirements, but those plans, made by different synergistic subjects, turn out to be poorly connected, so they expose insufficient synergy coordination effects in actual practice. Therefore, in a regional CME management synergy system, each coordinating subject should pay attention to the connection and cooperation of the emergency plans with other subjects when formulating the emergency plans and ensure that the emergency plans prepared can be connected with the relevant emergency plans in the system from both horizontal and vertical levels in accordance with the principle of "strong coherence within and across department and coordination between local governments and enterprises."

(4) Establish supervision mechanism for regional emergency management synergy

As a complex collective action involving multiple departments, emergency management synergy is inherently challenging. The absence of clear organizational design and institutional norms could easily lead to the phenomenon of "free-riding," which then brings difficulty to collective action. Therefore, it is necessary to establish and improve regional emergency synergy supervision mechanism and improve regional synergistic emergency management capability by holding accountable those who do not perform their duties faithfully and facilitating sound cooperation among all subjects in effectively responding to all kinds of emergent disasters and accidents.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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