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Research on the Evaluation of Emergency Management Synergy Capability of Coal Mines Based on the Entropy Weight Matter-Element Extension Model

Chaolun Sun [1,2,3], Yu Hao [1,3,*], Jianping Wei [2] and Lijun Zhang [1,3]

[1] Emergency Management School, Henan Polytechnic University, Jiaozuo 454000, China; suncl@hpu.edu.cn (C.S.); zli13849117460@163.com (L.Z.)
[2] State Key Laboratory Cultivation Base for Gas Geology and Gas Control, Henan Polytechnic University, Jiaozuo 454000, China; weijianping@hpu.edu.cn
[3] Safety and Emergency Management Research Center, Henan Polytechnic University, Jiaozuo 454000, China
* Correspondence: haoyu_he@163.com

Abstract: Emergency management synergy capability is not only a "touchstone" to measure the operation effect of the emergency system of coal mine enterprises, it is an important symbol to reflect its level. In order to improve the level of emergency management in coal mines based on the PPRR theory of crisis management cycle, in this paper a hierarchical evaluation index system is constructed based on the emergency management process. A quantitative evaluation model of emergency synergy capacity is proposes based on the entropy–weighted elemental topology method to conduct evaluation and model validation for the case of J coal mine in Henan Province. The results show that the overall evaluation of the emergency management synergy capability of J Coal Mine is at a "good" level, with the emergency prevention synergy capability, emergency preparedness synergy capability, and recovery and reconstruction synergy capability at a "good" level and the emergency response synergy capability is at a "average" level. This indicates that the evaluation model is consistent with the current development of coal mining enterprises and has universal applicability. Therefore, this research can provide decision-making support for emergency management synergistic capacity building of coal mining enterprises to enhance the inherent driving force behind the early completion of the dual carbon task in the coal mining industry.

Keywords: coal mine accident; emergency coordination; the entropy weight matter-element extension model; level of emergency management; evaluation system

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1. Introduction

With carbon neutrality being one of the important topics of China's Twentieth Congress, in-depth exploration of the emission reduction potential of coal mining enterprises will be an important contribution [1]. As an indispensable part of carbon reduction, the effective evaluation of the emergency synergistic capability of coal mining enterprises will greatly enhance the overall work efficiency of coal mining enterprises and enhance the coal mining industry's early completion of the internal driving force behind the dual carbon task. Due to the complexity and variability of coal mining systems, emergency response capabilities are very important to coal mining enterprises. Effective accident prevention goes hand in hand with being able to handle crises, disasters, and post-disaster rehabilitation. Comprehensive assessment of the emergency response capability of coal mining enterprises is an effective way to ensure that coal mining enterprises have good emergency response capability.

With the continuous aging of coal mines and increasing mining depth, coal mines in China have to tackle a growing number of risk factors and a more severe emergency management situation in the production process [2]. In the face of unexpected disasters and accidents, a coal mine emergency management system is capable of minimizing property losses and casualties only if it responds quickly and if all of its subsystem emergency synergy capabilities function correctly and in unison. Therefore, the construction and evaluation of an emergency management synergy (hereinafter referred to as EMS) system has become a core issue.

In recent years, emergency synergy has been highly valued by emergency management and has become a focus of emerging research on disaster risk management as a security discipline [3]. Compared with Chinese coal mines, foreign ones have a much lower accident rate due to their objective advantages in terms of mechanization level and coal seam conditions. As a result, emergency synergy capability has only been reported in few studies abroad, although research results have been yielded over a long span of time. In the early stage, Ikeda et al. employed advanced communication technology to support emergency rescue and proposed an emergency rescue model [4]. In recent years, wireless sensing communication technology has greatly improved the emergency management level of coal mine accidents [5]. In addition to improving the incidence of coal mine accidents at various technical levels [6,7], the organizational management factors of coal mine accidents are gradually being paid attention to. Yeo and Comfort believed that the emergency organization synergy network is highly fragmented and presents weak horizontal and vertical interconnections [8]. Schipper et al. studied the interaction in emergency response actions and the information communication between different subjects. In the hope of preventing and reducing the occurrence of coal mine accidents [9], Kinilakodi and Grayson strengthened emergency synergy capability by introducing the reliability method [10].

At present, emergency synergy capability of coal mines has not been extensively explored in China; the main representative studies are as follows. Hu studied the synergy between state-owned and local coal mines, emphasizing the necessity of signing synergy agreements between them [11]. Kong elaborated the necessity of strengthening the construction of disaster emergency rescue systems of coal mines in various regions [12]. Yang analyzed the current situation of coal mine disaster rescue and whether the establishment of mine rescue team cooperation is effective in solving coal mine emergency synergy capability [13]. Liang et al. used the AHP–fuzzy evaluation method to carry out grading evaluation of the coal mine emergency rescue capacity [14]. Qi et.al. discussed the coal mine emergency synergy capability system and capability in China [15–17]. Wang et al. analyzed an evolutionary game among emergency synergy capability subjects according to evolutionary game theory and the numerical simulation method [18], while Shi et al. focused on an evolution game between coal mining enterprises and local governments [19]. Yang et al. divided the development and evolution process of coal mine emergency management capability into four stages, i.e., the initial stage, the growth stage, the maturity stage, and the stability stage; they then comprehensively analyzed and evaluated the emergency capability of a coal mining enterprise using the logistic curve [20]. Lan et al. evaluated the emergency rescue capability of coal mine emergencies according to the RS-IPA method; their results were consistent with the actual rescue level of the enterprises [21]. Cheng et al. established a calculation model for the maturity of coal mine emergency rescue capability and introduced the improved catastrophe progression method to calculate the maturity of coal mine emergency rescue capability [22]. Yang used Unity 3D to integrate the coal mine emergency and rescue drill systems in order to improve emergency rescue capability in coal mine emergency coordination [23].

In summary, emergency management synergy has become a hot spot and focus of current theoretical research. Many scholars have presented different research perspectives to study emergency collaboration [24–26]. However, current research concerning coal mine emergency-related aspects remains shallow, and there is a lack of perfect system models. In addition, evaluations of the emergency synergy capability of coal mine enterprises have mostly adopted qualitative methods and focused their analysis on the level, elements, and connotations of the emergency synergy capability system. Few scholars have quantitatively analyzed and measured the emergency synergy capability of coal mine enterprises on the ground of an emergency synergy capability system. Therefore, from the perspective of synergy, in this study we built an index system and evaluation model of the emergency synergy capability of coal mine enterprises with reference to the matter-element extension theory. We selected a coal mine for use in an empirical case study. The results of our analysis lead to practical suggestions for rectification. These research results are expected to provide a relevant reference for improving the emergency synergy capability and level of coal mines. However, it is challenging to assess the emergency synergy capacity of coal mining businesses; several visits and professional guidance will be required in the future. In addition, the universality of the index system and the evaluation model obtained from the previous research results in the actual coal mine safety production has also met the challenge. Further improvements to the evaluation system are necessary in order to achieve the purpose applicable to the daily management decisions of all kinds of coal mining enterprises.

2. Evaluation Index System Construction and Classification of EMS Capability

2.1. Connotation of EMS Capability

The emergency synergy capability system, which is a collection of synergic relationships between the environment and the system, refers to various resources, organizations, processes, plans, personnel, and their interrelationships that are involved when coal mine enterprises respond to unexpected disasters and accidents. It is a multi-linked, nonlinear, and long-span system that runs through the four stages (i.e., preparation, prevention, response and recovery) of the emergency management life cycle. Specifically, the subsystem emergency synergy capabilities work independently and the synergy state is unordered in the production and management of coal mine companies in the absence of unanticipated disasters and accidents. The emergency synergy capability system's status changes instantly in the event of sudden disasters and accidents, and the supporting emergency synergy capability works properly and harmoniously to achieve synergistic management. Considering that the emergency synergy capability is both a "touchstone" to measure the operation effect of the emergency synergy capability system and an important symbol to reflect the emergency synergy capability and level, it was employed in this study to measure the synergic effect of the emergency synergy capability system of coal mine enterprises.

2.2. Construction of the Evaluation Index System of EMS Capability

Mining accidents are sudden, serious, and random, and may cause serious casualties and economic losses. Therefore, the focus of emergency management in mining enterprises is to prevent accidents and reduce economic losses. Referring to the theory of PPRR put forward by the U.S. Federal Safety Commission, the emergency management process is divided into four stages: emergency prevention, emergency preparedness, emergency response, and emergency recovery. These four stages together form the dynamic cycle of the emergency management process. Based on the PPRR theory, this paper establishes four main indexes: emergency prevention synergy, emergency preparedness synergy, emergency response synergy, and emergency recovery synergy. It is found that complete and mature basic information data management is the link of communication and cooperation between the subjects of emergency management [27]. It is a prerequisite to better play the preventive role of periodic safety inspection, identify risks in a timely manner, and implement monitoring and control [28,29]. At the same time, this emergency management work more needs supporting emergency management mechanisms along with emergency management laws and regulations, supports and guarantees [30]. On the basis of this, third-level evaluation indicators such as safety prevention inspection, identification of major hazard sources, monitoring and control of hazard sources, institution-building for emergency management, emergency management regulations, and operator safety education were compiled and screened from the literature(As shown in Table 1). Relevant experts in the field of emergency response in coal mines were consulted on the selection of indicators and the ranking of importance in the tables. This selection process was followed for all indicators in Table 1.

Table 1. Evaluation index system of EMS capability of coal mine enterprises.

Evaluation Objectives	First-Level Evaluation Index Factors	Second-Level Evaluation Index Factors
EMS capability of coal mine enterprises(C)	Emergency prevention capability (C_1)	Completeness of basic data management C_{11}; Safety prevention inspection C_{12}; Identification of major hazard sources C_{13}; Hazard source monitoring and control C_{14}; Emergency management organization Construction C_{15}; Emergency management laws and regulations C_{16}; Safety education for operators C_{17}
	Emergency preparation capability (C_2)	Emergency rescue team construction C_{21}; Emergency rescue plan preparation C_{22}; Implementation of emergency drills C_{23}; Emergency supplies reserve C_{24}; Emergency aid equipment and technology C_{25}; Emergency rescue mutual aid agreement C_{26}
	Emergency response capability (C_3)	Emergency rescue response speed C_{31}; Emergency plan activation C_{32}; Emergency decision-making and command C_{33}; Emergency material allocation C_{34}; Synergy with government departments C_{35}; Synergy with relevant units C_{36}; Synergy with media C_{37}
	Emergency recovery capability (C_4)	Post analysis and summary C_{41}; Recovery and reconstruction C_{42}; Post emergency plan improvement C_{43}; Post emergency rescue system improvement C_{44}

2.3. Classification of EMS Capability

In view of the connotations of the EMS capability of coal mine enterprises, in this paper we used [0, 1] as the value range of variables of the EMS capability level and divided the coal mine emergency (CME) capability into five levels in accordance with the standard of the five-level evaluation method and expert opinions (Table 2).

Table 2. Grading standard for the EMS capability of coal mine enterprises.

Evaluation Result	Level	Eigenvalue Interval
Excellent	I	(0.8, 1.0]
Good	II	(0.6, 0.8]
Average	III	(0.4, 0.6]
Poor	IV	(0.2, 0.4]
Bad	V	[0, 0.2]

3. Construction of the Entropy Weight Matter-Element Extension Model

3.1. Determination of Classical Field, Joint Domain and Matter-Element to Be Evaluated

The matter-element extension theory can integrate the information of various factors in the emergency synergy system, transform the indexes of the problem to be evaluated into a compatibility problem, and finally express the evaluation results in quantitative numerical values. In this way, the level of emergency synergy capability of coal mine enterprises can be evaluated completely and objectively. The specific process is introduced as follows.

3.1.1. Determination of Classical Field

A matter element, also referred to as an ordered triple, generally includes matter, characteristics, and values [31]. The three elements are arranged in a fixed order and expressed as H = (matter N, characteristic C, value V). Therefore, the classical field can be expressed as follows:

$$H_j = (N_j, C_i, V_{ji}) = \begin{bmatrix} N_j & C_1 & V_{j1} \\ & C_2 & V_{j2} \\ & \ldots & \ldots \\ & C_n & V_{jn} \end{bmatrix} = \begin{bmatrix} N_j & C_1 & (a_{j1}, b_{j1}) \\ & C_2 & (a_{j2}, b_{j3}) \\ & \ldots & \ldots \\ & C_n & (a_{jn}, b_{jn}) \end{bmatrix} \quad (1)$$

In Formula (1), H_j is the classic domain, representing the value range of each evaluation index when the emergency synergies of coal mining enterprises are located at a certain level; N_j $(j = 1, 2, 3 \ldots m)$ indicates the coal mining enterprises emergency synergy capacity of the J evaluation level, belongs to the evaluation level; C_i $(i = 1, 2, 3 \ldots n)$ is different eigenvalues of N_j, which belongs to the evaluation index; V_{jn} indicates the range of values for the n feature indicator in the j rank; and (a_{ji}, b_{ji}) is the range of values of classical matter-element parameters, a_{ji} being the minimum value and b_{ji} being the maximum value. Moreover, i is introduced to explain the different eigenvalues expressed by indicators C_i, which belong to the evaluation indicators; j indicates each evaluation level of the emergency synergistic capability of coal mining enterprises, such as the range of values of the n feature index in the j grade; and n represents a subsequent taking of the associated value.

3.1.2. Determination of Joint Domain

Assuming that the joint domain of emergency synergy capability is H_p, it can be expressed as

$$H_P = (N_p, C_i, V_{pi}) = \begin{bmatrix} N_p & C_1 & V_{p1} \\ & C_2 & V_{p2} \\ & \ldots & \ldots \\ & C_i & V_{pi} \end{bmatrix} = \begin{bmatrix} N_p & C_1 & (a_{p1}, b_{p1}) \\ & C_2 & (a_{p2}, b_{p3}) \\ & \ldots & \ldots \\ & C_i & (a_{pi}, b_{pi}) \end{bmatrix} \quad (2)$$

where H_P is the joint domain matter-element, representing the combination of the classical field and the overall range; N_p is all levels of the object to be evaluated; V_{pi} is the range of value of C_i corresponding to each level N_p; and $V_{ji} \subset V_{pi}$; i is the number of second-level indexes.

3.1.3. Determination of Matter-Element to Be Evaluated

$$H_0 = (N_0, C_i, V_i) = \begin{bmatrix} N_0 & C_1 & V_1 \\ & C_2 & V_2 \\ & \ldots & \ldots \\ & C_n & V_n \end{bmatrix} \quad (3)$$

where H_0 is the matter-element to be evaluated; N_0 is the evaluation level; C_i is the index to be evaluated; and V_i is the measured value of the index to be evaluated.

3.2. Determination of Weights of Indexes

To enhance the accuracy and objectivity of index weight assignment, the entropy method is adopted to determine the weight of the index system. The calculation steps are as follows:

(1) Calculate the proportion of the ith object in the jth index:

$$\theta_{ji} = \frac{x_{ji}}{\sum_{i=1}^{n} x_{ji}} \ (i = 1,\ 2,\ 3 \ldots m,\ j = 1,\ 2,\ \ldots n) \quad (4)$$

(2) Calculate the entropy value of the jth index. Set e_j as the entropy value of the jth evaluation index; the calculation process is:

$$e_j = -\frac{1}{lnm}\sum_{\mathrm{i}=1}^{m}(\theta_{ji}x_{ji}),\ \ e_j \in [0,\ 1] \tag{5}$$

(3) Calculate the coefficient of variation:

$$g_j = 1 - e_j \tag{6}$$

(4) Calculate the weight of the index j:

$$\theta_{ji} = \frac{g_j}{\sum_{\mathrm{j}=1}^{\mathrm{n}} g_j} \tag{7}$$

3.3. Determination of Correlation Degree and Evaluation Level

3.3.1. Determination of Correlation Degree

The correlation degree refers to the degree of correlation between two things; a higher correlation degree means that the two things are correlated more closely. The correlation function is a functional relation expression used to represent the degree of correlation between the objective to be evaluated and a standard evaluation value. It is generally expressed by the correlation function value defined by the moment. The formulas for calculating the correlation degree of a single index are as follows:

$$K_j(V_i) = \begin{cases} \frac{-\rho(V_i, V_{ji})}{|V_{ij}|}, & V_i \in V_{ij} \\ \frac{\rho(V_i, V_{ji})}{\rho(V_i, V_{pi}) - \rho(V_i, V_{ji})}, & V_i \notin V_{ij} \end{cases} \tag{8}$$

$$\rho(v_i, V_{ji}) = \left| V_i - \frac{a_{ji} + b_{ji}}{2} \right| - \frac{b_{ji} - a_{ji}}{2} \tag{9}$$

$$\rho(v_i, V_{pi}) = \left| V_i - \frac{a_{pi} + b_{pi}}{2} \right| - \frac{b_{pi} - a_{pi}}{2} \tag{10}$$

In Equation (8), Kj (V_i) is the correlation degree of a single index; $\rho(v_i, V_{ji})$ is the distance between the point v_i and the classical field of the evaluation index; and $\rho(v_i, V_{pi})$ is the distance between the point v_i and the joint domain.

After the correlation functions for individual first- and second-level indexes are obtained, the comprehensive correlation degree can be calculated in a sequential and recursive manner based on the evaluation indexes in accordance with the hierarchical structure. The formula for calculating the comprehensive index correlation is

$$K_j(N)\ \sum_{i=1}^{n} \omega_i K_j(V_i) \tag{11}$$

where $K_j(N)$ is the correlation degree of the target to be evaluated with the jth level; $K_j(V_i)$ is the correlation degree of the index C_i to be evaluated with the risk level j; and ω_i is the weight of the evaluation index C_i. According to the affiliation relationship, the comprehensive correlation degree is more accurate and objective because it takes into account the degrees of influence of all evaluation indexes on the overall evaluation results.

3.3.2. Determination of Evaluation Levels

The specific evaluation level of the evaluation object can be determined according to the comprehensive correlation degree. Assuming that the level of the object N is evaluated as m, then:

$$\overline{K_j(N)} = \frac{K_j(N) - minK_j(N)}{maxK_j(N) - minK_j(N)} \tag{12}$$

$$j^* = \frac{\sum_{j=1}^{m} \overline{jK_j(N)}}{\sum_{j=1}^{m} \overline{K_j(N)}} \tag{13}$$

where j^* is the eigenvalue of the variable of the emergency synergy capability level, that is, the degree to which the emergency synergy capability falls into this level. The deviation degree between the target to be evaluated and its adjacent emergency synergy capability level can be judged by j^*.

4. Empirical Case Analysis

In this section, an empirical evaluation was conducted on J Coal Mine in Henan Province, China using the evaluation index system and model of the emergency synergy capability of coal mine enterprises constructed in the above section. The evaluation results verify the rationality of the theoretical model, which boasts strong practical significance.

4.1. Data Sources and Collection

The research data came from relevant staff from various departments of J Coal Mine, including the safety and environmental protection supervision and management department, the production technology department, the ventilation management department, and the mechanical and electrical management department. A total of 185 questionnaires were issued, of which 180 were recovered. After eight invalid questionnaires were removed, the effective return rate was 92.97%.

4.2. Determination of Evaluation Index Weight

Twenty experts in the fields of safe coal production and emergency management, including university researchers, leaders of government emergency management departments, and managers of coal mine enterprises, were invited to score the index weights using a Likert scale. The second-level evaluation index weights obtained after normalization are listed in Table 3.

Table 3. Evaluation index weights of emergency coordination capacity of coal mines.

Level 1 Indicator	Weighting of First-Level Indicators	Level 2 Indicator	Scores	Secondary Indicator Entropy Value	Secondary Indicator Weights
Emergency prevention synergy capability (C_1)	0.168	Completeness of basic data management C_{11}	88	0.0439	0.0286
		Safety prevention inspection C_{12}	86	0.1032	0.0223
		Identification of major hazard Sources C_{13}	72	0.0824	0.0256
		Hazard source monitoring and control C_{14}	89	0.0891	0.0236
		Emergency management organization Construction C_{15}	87	0.1552	0.0223
		laws and regulations C_{16}	85	0.1817	0.0237
		Safety education for operators C_{17}	77	0.1322	0.0219
Emergency preparation synergy capability (C_2)	0.335	Emergency rescue team constructionC_{21}	75	0.0504	0.0491
		Emergency rescue plan preparation C_{22}	70	0.1276	0.0471
		Implementation of emergency drills C_{23}	68	0.0975	0.0494
		Emergency supplies reserve C_{24}	75	0.1228	0.0573
		Emergency aid equipment and technology C_{25}	75	0.0506	0.0852
		Emergency rescue mutual aid agreement C_{26}	64	0.1272	0.0469

Table 3. *Cont.*

Level 1 Indicator	Weighting of First-Level Indicators	Level 2 Indicator	Scores	Secondary Indicator Entropy Value	Secondary Indicator Weights
Emergency response synergy capability (C_3)	0.338	Emergency rescue response speed C_{31}	70	0.1082	0.0693
		Emergency plan activation C_{32}	75	0.1325	0.0389
		Emergency decision-making and command C_{33}	80	0.1789	0.0598
		Emergency material allocation C_{34}	75	0.1278	0.0472
		Synergy with government departments C_{35}	65	0.0976	0.0478
		Synergy with relevant units C_{36}	68	0.1621	0.0381
		Synergy with media C_{37}	65	0.1026	0.0369
Emergency recovery synergy capability (C_4)	0.159	Post analysis and summary C_{41}	85	0.1078	0.0375
		Recovery and reconstruction C_{42}	75	0.1857	0.0482
		Post emergency plan improvement C_{43}	70	0.1582	0.0365
		Post emergency rescue system improvement C_{44}	80	0.1451	0.0368

4.3. Determination of Classical Field, Joint Domain, and Matter-Element to Be Evaluated

4.3.1. Determination of Classical Field

According to the five levels of emergency synergy capability established above, the classic field is determined as follows:

$$H_1(B_1) = (N_1, B_1, V_{1j}) = \begin{bmatrix} N_1 & B_{11} & [85,100] \\ & B_{12} & [70,85) \\ & B_{13} & [55,70) \\ & B_{14} & [40,55) \\ & B_{15} & [0,40) \end{bmatrix}$$

The classical field matter-elements of other second-level indexes B_2 and $B_3 \ldots B_7$ under the first-level index are determined in the same way; thus, their determination is not elaborated here.

4.3.2. Determination of Joint Domain

The joint domain is determined in a similar way as the classical field. With the above index as an example, if the union of score ranges of all five levels of the index B_1 is [0, 100], the joint domain can be obtained according to the definition of the joint domain:

$$H_P(B_1) = (N_p, B_1, V_{1p}) = \begin{bmatrix} N_p & B_{11} & [0,\ 100] \\ & B_{12} & [0,\ 100] \\ & \ldots & \ldots \\ & B_{15} & [0,\ 100] \end{bmatrix}$$

4.3.3. Determination of Matter-Element to Be Evaluated

According to the scores of various indexes of J Coal Mine in the questionnaire survey, it is confirmed that the matter-element to be evaluated is

$$H_1(B_1) = (N_1, B_1, V_{1j}) = \begin{bmatrix} N_1 & B_{11} & 88 \\ & B_{12} & 72 \\ & B_{13} & 63 \\ & B_{14} & 54 \\ & B_{15} & 39 \end{bmatrix}$$

4.4. Calculation of Correlation Degree

According to Equations (8)–(10), the correlation degrees of individual evaluation indexes at the two levels are calculated by Matlab 7.0 software. Subsequently, the comprehensive correlation degree is calculated. Taking the second-level index "completeness of basic data management" under the first-level evaluation index "emergency prevention capability" as an example, the correlation degrees of the indexes is calculated as follows:

$$\rho(v_1, V_{11}) = \left|88 - \frac{85+100}{2}\right| - \frac{100-85}{2} = -3$$

$$\rho(v_1, V_{12}) = \left|88 - \frac{70+85}{2}\right| - \frac{85-70}{2} = 3$$

$$\rho(v_1, V_{13}) = \left|88 - \frac{55+70}{2}\right| - \frac{70-55}{2} = 18$$

$$\rho(v_1, V_{14}) = \left|88 - \frac{40+55}{2}\right| - \frac{55-40}{2} = 33$$

$$\rho(v_1, V_{15}) = \left|88 - \frac{0+40}{2}\right| - \frac{40-0}{2} = 48$$

$$\rho(v_1, V_{1p}) = \left|88 - \frac{0+100}{2}\right| - \frac{100-0}{2} = -12$$

It can be calculated by Equations (8)–(10) that = 0.74610; = −0.74512; = −0.8284; = −0.4026; and = −0.5270.

The correlation degrees of all second-level indexes can be obtained by repeating the above steps. Afterwards, the comprehensive correlation degrees of the first-level indexes can be calculated by Equation (7); the results are shown in Tables 4 and 5.

Table 4. Correlation values of secondary indicators of emergency synergy capacity of coal mines.

Level 1 Indicators	Level 2 Indicators	Relevance				
		j = 1	j = 2	j = 3	j = 4	j = 5
Emergency prevention synergy capability (C_1)	c_{11}	0.746	0.745	0.828	0.403	0.527
	c_{12}	0.356	0.059	0.452	0.307	0.472
	c_{13}	0.253	0.452	0.268	0.504	0.638
	c_{14}	0.300	0.290	0.472	0.512	0.560
	c_{15}	0.322	0.210	0.360	0.482	0.243
	c_{16}	0.737	0.650	0.547	0.052	0.045
	c_{17}	0.086	0.027	0.813	0.750	0.625
Emergency preparation synergy capability (C_2)	c_{21}	0.255	0.061	0.925	0.910	0.850
	c_{22}	0.079	0.016	0.776	0.100	0.312
	c_{21}	0.025	0.185	0.093	0.916	0.045
	c_{22}	0.038	0.230	0.712	0.617	0.415
	c_{23}	0.119	0.153	0.812	0.750	0.625
	c_{24}	0.096	0.936	0.915	0.900	0.750
	c_{25}	0.875	0.833	0.750	0.500	0.167
	c_{26}	0.688	0.582	0.375	0.250	0.167
Emergency response synergy capability (C_3)	c_{31}	0.186	0.260	0.585	0.866	0.128
	c_{32}	0.495	0.625	0.390	0.278	0.095
	c_{33}	0.712	0.592	0.308	0.820	0.918
	c_{34}	0.038	0.626	0.538	0.732	0.829
	c_{35}	0.498	0.600	0.308	0.762	0.810
	c_{36}	0.766	0.029	0.198	0.646	0.828
	c_{37}	0.351	0.782	0.324	0.566	0.914
	c_{38}	0.403	0.780	0.306	0.642	0.788

Table 4. *Cont.*

Level 1 Indicators	Level 2 Indicators	Relevance				
		j = 1	j = 2	j = 3	j = 4	j = 5
Emergency recovery synergy capability (C_4)	c_{41}	0.875	0.832	0.753	0.500	0.489
	c_{42}	0.625	0.612	0.258	0.480	0.250
	c_{43}	0.870	0.833	0.750	0.500	0.500
	c_{44}	0.682	0.583	0.376	0.248	0.178

Table 5. Correlation of primary indicators of emergency management capacity of coal mining enterprises.

Projects		j = 1	j = 2	j = 3	j = 4	j = 5	Eigen-Value j*	Level
Level 1 Indictors	Emergency prevention synergy capability	0.412	0.705	0.456	−0.46	−0.62	0.76	Good
	Emergency preparation capability	−0.02	0.09	−0.42	−0.63	−0.70	0.68	Good
	Emergency response synergy capability	−0.01	0.09	−0.42	−0.61	−0.65	0.53	Average
	Emergency recovery synergy capability	−0.06	0.09	−0.38	−0.57	−0.68	0.72	Good

According to the correlation degrees of first-level indexes and the determined weights in Table 4, the eigenvalue j* of variables of the emergency synergy capability level can be calculated. According to the eigenvalue, the overall emergency synergy capability level is evaluated as "good", that is, the emergency synergy capability of J Coal Mine is generally good though it can be improved. The evaluation result agrees with the actual production and operation situation of the mine.

4.5. Analysis of Evaluation Results

With the aid of the matter-element extension comprehensive evaluation model, the evaluation results of various evaluation indexes of the emergency synergy capability of J Coal Mine can be obtained (Table 6).

According to the evaluation results in Table 6, the comprehensive evaluation level of the emergency synergy capability of J Coal Mine is "good". To be more specific, the first-level index emergency prevention synergy capability is "good". All its second-level indexes are "good" or "excellent" except for emergency management laws and regulations, which is "average". The first-level index emergency preparation synergy capability is "good"; among the second-level indexes, the implementation of emergency drills, emergency aid equipment and technology, and emergency rescue mutual aid agreement are "average" and the others are "good" or above. The first-level index emergency response synergy capability is "average"; among the second-level indexes, emergency material allocation, synergy with government departments, and synergy with relevant units are "average", while the others are "good". The first-level index recovery and reconstruction capability is "good"; all the second-level indexes are "good" except for post-emergency plan improvement, which is "average".

Table 6. Evaluation results of emergency management capacity of coal mining enterprises can be improved.

Evaluation Object	Ability Level	Level 1 Indicators	Evaluation Level	Level 2 Indicators	Evaluation Level
Coal Mine Emergency Management Capability	Good	Emergency prevention synergy capability (C_1)	Good	Completeness of basic data management C_{11}	Good
				Safety prevention inspection C_{12}	Good
				Identification of major hazard sources C_{13}	Good
				Hazard source monitoring and control C_{14}	Good
				Emergency management organization Construction C_{15}	Good
				Emergency management laws and regulations C_{16}	Average
				Safety education for operations C_{17}	Good
		Emergency preparation synergy capability (C_2)	Good	Emergency rescue team construction C_{21}	Excellent
				Emergency rescue plan preparation C_{22}	Good
				Implementation of emergency drills C_{23}	Average
				Emergency supplies reserve C_{24}	Good
				Emergency aid equipment and technology C_{25}	Average
				Emergency rescue mutual aid agreement C_{26}	Average
		Emergency response synergy capability (C_3)	Average	Emergency rescue response speed C_{31}	Good
				Emergency plan activation C_{32}	Good
				Emergency decision-making and command C_{33}	Good
				Emergency material allocation C_{34}	Average
				Synergy with government departments C_{35}	Average
				Synergy with relevant units C_{36}	Average
				Synergy with media C_{37}	Good
		Emergency recovery synergy capability (C_4)	Good	Post analysis and summary C_{41}	Good
				Recovery and reconstruction C_{42}	Good
				Post emergency plan improvement C_{43}	Average
				Post emergency rescue system improvement C_{44}	Good

4.6. Rectification Suggestions

Our comprehensive evaluation of the emergency synergy capability of J Coal Mine aimed to find any deficiencies in its emergency management and take corresponding rectification measures to improve its overall emergency capability. According to the evaluation results, the following rectification suggestions are proposed:

(1) In terms of emergency prevention, J Coal Mine should vigorously promote the construction of a dual prevention system for safety production risk and hidden danger, improve the prediction and early warning technology for coal mine accidents, continuously and effectively promote preventive safety inspections, and strengthen the source control of coal mine safety. A sound emergency plan should be formulated to ensure coordination with relevant plans of local government departments to form a joint force with local government and relevant departments.

(2) With respect to emergency preparedness, it is suggested to intensely enhance the intelligent construction of coal mines and governance according to law, strengthen the education of coal mine employees by means of safety training, and promote the overall improvement of the emergency response capability of employees. Meanwhile, it is necessary to increase investment and research and development of emergency rescue equipment, strengthen the signing of emergency rescue agreements with surrounding coal mines, and boost rescue cooperation.

(3) With regard to emergency response, importance should be attached to building an emergency rescue team, enhancing the emergency synergy capability, raising the level of the emergency communication guarantee system, and strengthening the synergistic interaction between "Internet plus" and coal mine emergency management. In addition, collaboration between the government and other units should be stressed for achieving on-site emergency linkage synergy and multiparty emergency synergy capability within the region.

(4) For emergency recovery, the post-emergency recovery and reconstruction plan should be further improved and production recovery should be accelerated through scientific

and comprehensive formulation of the accident recovery plan, to ensure minimal loss due to unexpected disasters while ensuring safety.

5. Conclusions

(1) Based on engineering practice and experts' experience, from the perspective of synergy and considering factors affecting the coal mine emergency response synergy ability in various aspects, the evaluation index system of coal emergency prevention synergy capability, emergency preparedness synergy capability, emergency response synergy capability, and recovery synergy capability was constructed, and 24 factors such as hazard source monitoring and control, emergency rescue plan preparation, emergency decision-making and command, and post-emergency plan improvement were used as indexes. The evaluation index system of coal mine emergency response synergistic capability is scientific, reasonable, and comprehensive. Moreover, the index system is scientific, reasonable, comprehensive, and in line with the engineering reality.

(2) An empirical evaluation of the emergency synergy capability capacity of J coal mine in Henan Province was carried out as an example. According to the evaluation results, the overall evaluation of the emergency synergy capability of J Coal Mine was "good". Among the four first-level evaluation indexes, the levels of emergency prevention synergy capability, emergency preparedness synergy capability and recovery and reconstruction synergy capability were "good", while the emergency response synergy capability was "average", which is in line with the actual situation. These results indicate that the evaluation model constructed in this paper has good practical significance and can scientifically and effectively evaluate emergency synergy. The successful practice of the J Coal Mine demonstrates the feasibility of popularizing this method of evaluation of emergency synergistic capability in China and even other mining enterprises around the world.

(3) Emergency management is an important means of effectively reducing accident losses by taking scientific precautionary measures according to the idea of system theory, organically combining micro- and macro-level factors inducing accidents while taking into full consideration the inducing effect, linkage effect, and superposition effect of each factor. The improvement of the emergency response synergy of coal mining enterprises is due to the influence of many factors, and requires the people, machines, environment, and management of the whole emergency management system of coal mining enterprises to cooperate with each other and respond synergistically to ensure the sustainable operations on the scale of individual coal mines.

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