

INTERACTIONS AND INFLUENCES ON COAL MINERS' SAFETY ATTENTION: AN EVALUATION USING IMPROVED DEMATEL-ISM

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Abstract. *In coal mining, the myriad of factors influencing miners' attention to safety necessitates deeper exploration. Particularly, discerning the significance and interplay of these factors offers crucial insights into the actual disparities in miners' safety attentiveness. Yet, a limited number of comprehensive studies address this dimension. Thus, an advanced Decision Making Trial Evaluation Laboratory-Interpretive Structural Model (DEMATEL-ISM) has been employed to probe the determinants impacting coal miners' safety focus and the mechanisms underpinning these interactions. The objective is to provide strategies that could diminish the occurrence of minor accidents. Results revealed that there are 9 causative factors and 6 resultant factors shaping the coal miners' attention to safety. Within the structural model of these factors, three layers and seven levels were identified. Notably, the intricacy of relationships among these factors was found to be profound. Emphasis is recommended on the management of these intricate deep-level causative factors boasting high driving power, and mid-level resultant factors characterized by both substantial driving force and dependence.*

Key words: *Minor injury accidents, Coal miners, Safety attention, Influencing determinants*

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1. INTRODUCTION

In recent years, a steady improvement in coal mine safety has been observed in China, attributed largely to consistent investments and enhancements in safety technologies and equipment within coal mine enterprises. This enhancement has resulted in a notable decline in major accidents. Yet, minor injury accidents, accounting for >90% of all accidents [1], persist as a prevalent concern. Such accidents, apart from posing a significant threat to miner safety, also jeopardize the economic well-being and production of coal mines. Mainly attributed to miners' unsafe behaviors, minor injury accidents have been found to predominantly stem from a decline in coal miners' attention to safety [2-4].

Emphasis on the factors that influence coal miners' attention to safety is underscored by its potential in mitigating these unsafe behaviors and consequently reducing minor injury accidents. Several scholars have diligently studied these influences. It has been frequently postulated that a decrease in coal miners' attention to safety contributes to human error, and a strong correlation exists between safety attention and unsafe behaviors [5,6]. Recent studies have highlighted relationships between individual characteristic factors and coal miners' safety attention [7-9]. Mathematical methods have also been employed to elucidate the determinants of miners' safety attention [10,11]. The prevailing research predominantly focuses on the influence mechanism of various factors on coal miners' safety attention [12-14]. It is well-acknowledged that diverse factors impact miners' safety attention [15-17]. A comprehensive understanding of the significance and interplay of these factors provides insights into actual disparities in safety attention among miners. Nevertheless, a scarcity of in-depth studies on this crucial aspect limits the fulfillment of scientific requirements for coal mine safety management. The resulting challenge for practical management is the vast array of influencing factors and the evolving nature of safety information. These complexities make comprehensive control countermeasures elusive, potentially overlooking pivotal factors requiring attention in safety management.

The combined usage of Decision Making Trial Evaluation Laboratory (DEMATEL) and Interpretive Structural Modeling (ISM) offers a framework to discern the importance and causal attributes of system factors, thereby shedding light on the intricate interactions between them [18-20]. Moreover, the Matrix Impacts Cross-reference Multiplication Applied to a Classification (MICMAC) delves deeper, analyzing the driving force and dependencies among system factors [21, 22]. Given their unique characteristics, an integration of the MICMAC method with DEMATEL-ISM has been proposed. Such a methodological convergence can effectively rank each influencing factor, elucidate the multi-layered interpretation structure of the system, and through rigorous analysis of driving forces and dependencies, unveil the interplay mechanism among these factors. Employing this improved approach can streamline the overwhelming workload in minor injury accident safety management and mitigate the potential oversight of key determinants. Ultimately, the aim is to enhance safety management efficiency, providing mining companies with a solid foundation to address strategic challenges in minor injury accidents by bolstering miners' safety attention.

2. IMPROVED DEMATEL-ISM METHOD

2.1 Value assignment of influencing factors

The assignment of values to influencing factors predominantly relies on expert evaluations, fundamentally characterized by a systematic aggregation of expert opinions. Subsequent processing of their responses culminates in the consolidation of results. A questionnaire-based approach was adopted for this expert evaluation. Twenty experts, affiliated with three distinct research institutions in Henan province and specializing in the study of coal miners' safety behavior, were solicited for their insights.

Drawing from an array of studies and accident case analyses [7-11], these questionnaires distilled and highlighted 15 pivotal factors impacting miners' safety attention. These factors were compartmentalized into three distinct categories, as illustrated in Table 1: Individual factors, environmental factors, and management factors. Leveraging the index system for these factors, experts were prompted to designate values to the interaction intensity among these 15 determinants, rooted in their professional acumen and prior experiences. To counteract potential individual biases in the evaluations, mean values were computed for each factor.

Table 1 The index system of influencing factors pertinent to coal miners' safety attention

Classification	Influencing factors
Individual factors	Safety cognition S_1 , Safety consciousness S_2 , Behavioral habit S_3 , Safety self-control S_4 , Risk perception S_5 , Educational level S_6 , Working years S_7 , Work pressure S_8 , Job burnout S_9
Environmental factors	Working environment S_{10} , Working strength S_{11} , Safety information stimulus S_{12}
Management factors	Safety supervision S_{13} , Safety education and training S_{14} , Safety atmosphere of the organization S_{15}

The results from the value assignments were manifested as a matrix, denoted as the direct influence matrix A . This matrix, represented as $A=(a_{ij})_{n \times n}$, is delineated in Eq. (1). Within this matrix, each constituent element a_{ij} signifies the potency of influence exerted by factor S_i on factor S_j . The guiding metric for experts to designate these values is further elucidated in Eq. (1). Consequently, upon assimilating the experts' value designations, the direct influence matrix A was derived, as detailed in Eq. (2).

$$a_{ij} = \begin{cases} 0 & S_i \text{ has no influence on } S_j \\ 1 & S_i \text{ has a weak influence on } S_j \\ 2 & S_i \text{ has a moderate influence on } S_j \\ 3 & S_i \text{ has a strong influence on } S_j \end{cases} \quad (1)$$

where, when $i = j$, $a_{ij} = 0$.

$$A = \begin{bmatrix} 0 & 3 & 3 & 3 & 3 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 3 & 3 & 3 & 0 & 0 & 0 & 2 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 2 & 0 & 2 & 2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 2 & 2 & 0 & 2 & 0 & 0 & 0 & 2 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 2 & 2 & 2 & 0 & 0 & 0 & 0 & 2 & 0 & 0 & 0 & 0 & 0 & 0 \\ 3 & 3 & 3 & 3 & 3 & 0 & 0 & 0 & 2 & 0 & 0 & 0 & 0 & 0 & 0 \\ 3 & 3 & 3 & 3 & 3 & 0 & 0 & 0 & 2 & 0 & 0 & 0 & 0 & 0 & 0 \\ 3 & 3 & 3 & 3 & 3 & 0 & 0 & 0 & 3 & 0 & 0 & 0 & 0 & 0 & 0 \\ 3 & 3 & 3 & 3 & 3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 2 & 2 & 2 & 2 & 2 & 0 & 0 & 3 & 3 & 0 & 0 & 0 & 0 & 0 & 0 \\ 2 & 2 & 2 & 2 & 2 & 0 & 0 & 3 & 3 & 0 & 0 & 0 & 0 & 0 & 0 \\ 3 & 3 & 3 & 3 & 3 & 0 & 0 & 2 & 3 & 0 & 0 & 0 & 0 & 0 & 0 \\ 3 & 3 & 3 & 3 & 3 & 0 & 0 & 2 & 3 & 0 & 0 & 3 & 0 & 0 & 0 \\ 3 & 3 & 3 & 3 & 3 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 3 & 3 & 3 & 3 & 2 & 0 & 0 & 2 & 2 & 0 & 0 & 3 & 3 & 3 & 0 \end{bmatrix} \quad (2)$$

2.2 Enhanced DEMATEL-ISM analysis technique

Post the expert-driven value assignment of influential determinants, a pressing need emerges to determine both the centrality and cause degrees of each constituent factor using the refined DEMATEL-ISM analysis procedure. In initial phases, the method seeks to elucidate the significance and causative characteristics of each factor. Successive stages demand the partitioning of system levels founded upon the centric and causative degrees of each variable. Consequently, a multi-layered, recursive interpretative structure model is crafted to decipher intricate interactions between said factors. Ultimately, the analytical procedure is harnessed to discern the drive and dependency values of each factor. An in-depth analysis of these values unravels the intricate interplay mechanisms among them. The ensuing subsections provide an exhaustive breakdown of the refined DEMATEL-ISM technique.

2.2.1 Determining centrality and cause degrees

The pivotal initiation step in the refined DEMATEL-ISM analysis method hinges on the calculations of the centrality and cause degrees. These degrees offer preliminary insights into the relative significance of each influencing factor. The methodical steps are delineated below:

(1) System components are identified, denoted as S_1 - S_n , wherein S_1 - S_n pertain to the factors enumerated in Table 1.

(2) The direct influence matrix A is constructed. Guided by expert insight and acumen, the degree of influence exerted by factor S_i on factor S_j is assessed, resulting in the formation of the direct influence matrix $A=(a_{ij})_{n \times n}$, as given in Eq. (2).

(3) The normalized direct influence matrix C , represented as $C=(c_{ij})_{n \times n}$, is computed as follows:

$$c_{ij} = \frac{a_{ij}}{\max(\sum_{j=1}^n a_{ij})} \quad (3)$$

where, a_{ij} is an element of matrix A .

(4) The comprehensive influence matrix T is deduced, with the matrix presented as $T=(t_{ij})_{n \times n}$:

$$T = C(I - C)^{-1} \quad (4)$$

Herein, C stands for the normalized direct influence matrix, and I symbolizes the unit matrix. The unit matrix I is characterized by diagonal elements equating to 1, with the remaining being 0.

(5) For each factor, both the influential degree F_i and affected degree E_i are calculated. F_i , representing the aggregate value of row i in T , mirrors the encompassing value of the influence factor S_i on its counterparts. Conversely, E_i , reflecting the summation of the value of column i in T , signifies the aggregate influence borne by factor S_i due to other factors. Eqs. (5) and (6) represent F_i and E_i respectively:

$$F_i = \sum_{j=1}^n t_{ij}, (i = 1, 2, \dots, n) \quad (5)$$

$$E_i = \sum_{j=1}^n t_{ji}, (i = 1, 2, \dots, n) \quad (6)$$

where, t_{ij} is an element of the matrix T .

(6) Subsequently, for each factor, the centrality degree M_i and the cause degree N_i are computed. M_i , the cumulative value of both influential and affected degrees for each factor, pinpoints the prominence of factor S_i within the system. N_i , the differential between the influential and affected degrees, sheds light on the causality dynamics among factors. Eqs. (7) and (8) give M_i and N_i , respectively:

$$M_i = F_i + E_i \quad (7)$$

$$N_i = F_i - E_i \quad (8)$$

where, a positive N_i denotes S_i as a causative factor, while a negative N_i classifies S_i as a resultant factor.

2.2.2 Formulation of the multi-layer recursive interpretation structure model

In the subsequent phase of the enhanced DEMATEL-ISM analysis method, the focus shifts to the conceptualization of a multi-layer recursive interpretation structure model. The processes entailed in this establishment are elucidated below.

(1) The global influence matrix H is computed. This matrix, represented as $H=(h_{ij})_{n \times n}$, is derived by incorporating the comprehensive influence matrix T with the unit matrix I .

(2) The threshold value λ , essential for discerning the reachable matrix K , is derived from the comprehensive influence matrix T . Following this determination, elements within the global influence matrix H undergo processing, leading to the acquisition of the reachable matrix $K=(k_{ij})_{n \times n}$. The component K_{ij} is given in Eq. (9):

$$k_{ij} = \begin{cases} 1 & h_{ij} \geq \lambda \\ 0 & h_{ij} < \lambda \end{cases} \quad (9)$$

In this context, the threshold value λ is expressed as the sum of α and β , where α and β respectively denote the mean and standard deviations of the elements encapsulated in T .

(3) Stratification of the reachable matrix K is performed. From the matrix, both the reachable set $R(S_i)$ and the antecedent set $A(S_i)$ for factor S_i are extracted. Here, $R(S_i)$ represents $\{S_j | S_j \in S, k_{ij}=1\}$ and $A(S_i)$ denotes $\{S_l | S_l \in S, k_{li}=1\}$. Subsequently, the stratification aligns with Eq. (10). The initial tier of factors is discerned, followed by the elimination of its corresponding row and column from K , aiding in the identification of the secondary tier of factors. This procedure is replicated iteratively until all system levels are demarcated.

$$R(S_i) \cap A(S_i) = R(S_i), (i = 1, 2, \dots, n) \quad (10)$$

(4) Depiction of the interconnected framework of influencing factors across diverse tiers is executed. This is premised on the prior stratification of the system, culminating in the illustration of the multi-layer recursive interpretation structure model for the system.

2.2.3 Determination of driving force and dependence degrees

In the progression of the advanced DEMATEL-ISM method, an essential step involves quantifying the driving force and dependence degrees of each factor. The subsequent delineation outlines the processes involved.

The driving force degree, represented as P_i , and the dependence degree, denoted as Q_j , for every factor are calculated. The quadrant classification diagram, a critical visual representation, is then constructed based on these values. Derived from the reachable matrix K , the expressions for P_i and Q_j are given by Eqs. (11) and (12), respectively:

$$P_i = \sum_{j=1}^n K_{ij} (i = 1, 2, \dots, n) \quad (11)$$

$$Q_j = \sum_{i=1}^n K_{ij} (j = 1, 2, \dots, n) \quad (12)$$

Within this context, K_{ij} is recognized as an element of matrix K . The promotional degree of factor S_i influencing other factors is signified by P_i , whereas the degree to which factor S_j is influenced by other factors is represented by Q_j . In the quadrant diagram, the positions of factor S_i on the abscissa and ordinate are represented by P_i and Q_j , respectively.

The quadrant diagram, an essential analytical tool, is partitioned into four distinct quadrants. Each quadrant epitomizes a unique cluster: the autonomous cluster (Quadrant I), the independent cluster (Quadrant II), the connection cluster (Quadrant III), and the dependent cluster (Quadrant IV).

3. ANALYSIS OF RESULTS DERIVED FROM THE ENHANCED DEMATEL-ISM TECHNIQUE

3.1 Centrality and cause degrees

Upon obtaining the direct influence matrix A , normalization was performed in accordance with Eq. (3). Subsequently, the comprehensive influence matrix T was deduced

as per Eq. (4). With reference to the comprehensive influence matrix T , various degrees – namely the influential degree F_i , the affected degree E_i , the centrality degree M_i , and the cause degree N_i – associated with each influencing factor were computed, as detailed in Eqs. (7) and (8). Table 2 provides the calculated results concerning the centrality and cause degrees. Further elucidation on the causal relationships among the factors shaping miners' safety attention can be discerned from Fig. 1. Notably, these results reveal a distinction between 9 causative factors and 6 resultant factors. Moreover, an elevated centrality degree is observed among the resultant factors.

Table 2 Calculation results of centrality degree and cause degree

<i>Factors</i>	F_i	E_i	M_i	N_i	<i>Sort by M_i</i>	<i>Type</i>
S_1	0.571	1.197	1.768	-0.627	6	Resultant factor
S_2	0.484	1.743	2.227	-1.259	1	Resultant factor
S_3	0.265	1.812	2.077	-1.546	4	Resultant factor
S_4	0.402	1.812	2.214	-1.409	2	Resultant factor
S_5	0.358	1.774	2.132	-1.417	3	Resultant factor
S_6	0.758	0.000	0.758	0.758	12	Causative factor
S_7	0.758	0.000	0.758	0.758	13	Causative factor
S_8	0.806	0.482	1.288	0.323	8	Causative factor
S_9	0.661	1.333	1.994	-0.672	5	Resultant factor
S_{10}	0.740	0.000	0.740	0.740	14	Causative factor
S_{11}	0.740	0.000	0.740	0.740	15	Causative factor
S_{12}	0.909	0.222	1.131	0.687	10	Causative factor
S_{13}	1.073	0.111	1.184	0.962	9	Causative factor
S_{14}	0.761	0.111	0.872	0.650	11	Causative factor
S_{15}	1.312	0.000	1.312	1.312	7	Causative factor

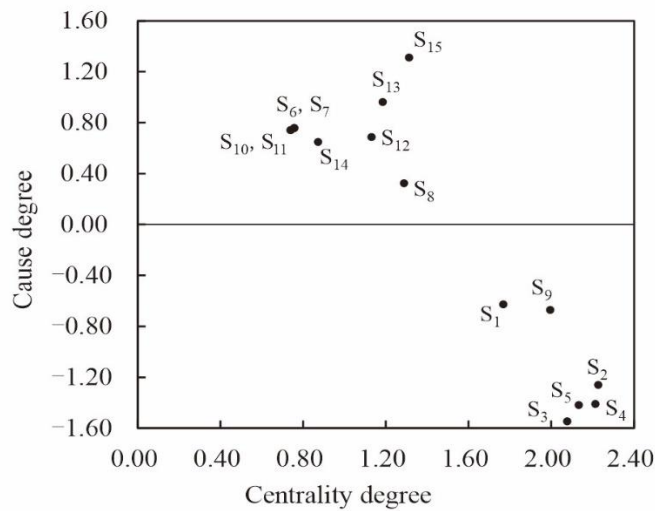


Fig. 1 Causal relationship of influencing factors

3.2 Recursive structural interpretation of influencing factors

The global influence matrix H was derived by integrating the unit matrix I with the comprehensive influence matrix T . With the introduction of the threshold value λ , elements within H were adjusted following Eq. (9). Consequently, the reachable matrix K , characterized in Eq. (13), was formulated. The threshold λ was discerned from the summation of the average value α and the standard deviation β stemming from the elements in matrix T , yielding a computed threshold value of 0.107.

$$K = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 1 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 1 & 1 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 1 & 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 \\ 1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & 1 & 0 & 0 \\ 1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & 1 & 1 & 1 \end{bmatrix} \quad (13)$$

With the aid of the reachable matrix K , both the reachable set $R(S_i)$ and the antecedent set $A(S_i)$ pertaining to factor S_i were identified. Factors of the primary level were extracted based on Eq. (10). By eliminating corresponding rows and columns of level 1 factors within K , the level 2 factors were discerned. This methodological approach facilitated the classification of influencing factors into seven distinct levels, as cataloged in Table 3.

Table 3 Results of division of levels of the influencing factors

Level division	Element set	Level specification
L ₁	S ₃ , S ₄ , S ₅	Surface-level direct factor
L ₂	S ₂	Middle-level indirect factor
L ₃	S ₁	Middle-level indirect factor
L ₄	S ₆ , S ₇ , S ₉ , S ₁₄	Middle-level indirect factor
L ₅	S ₈ , S ₁₂	Deep-level fundamental factor
L ₆	S ₁₀ , S ₁₁ , S ₁₃	Deep-level fundamental factor
L ₇	S ₁₅	Deep-level root factor

Fig. 2 visually represents the multi-layer recursive interpretation structure delineating the factors influencing miners' attention to safety. An in-depth examination of the constructed model indicates a three-tiered structure comprising seven levels. Furthermore, the presence of 12 intermediate and profound factors is evident, accounting for a significant 80% of the total influential factors. The intricate internal relationships and dynamic mechanisms linking these deep-level factors underscore the complexity inherent to this domain.

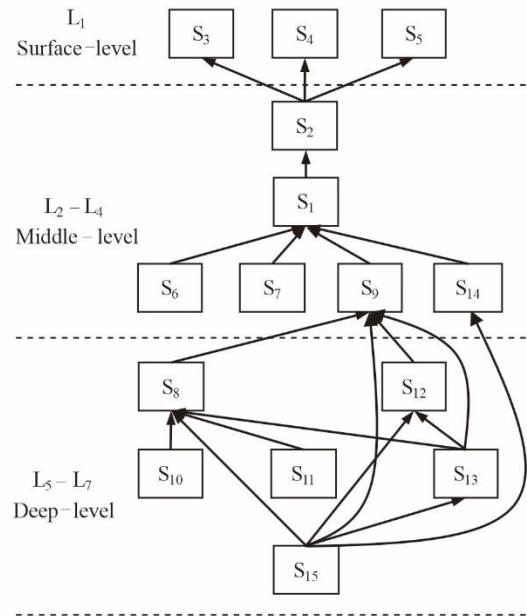


Fig. 2 Multi-layer recursive interpretation structure of influencing factors

3.3 Driving force and dependence degrees of influencing factors

Drawing from the reachability matrix K , calculations for the driving force and dependence degrees of each influencing factor were meticulously executed, as delineated in Eqs. (11) and (12). Table 4 presents the computed values for both driving force and dependence degrees. The quadrant distribution map, showcased in Fig. 3, plots the influencing factors based on their calculated degrees.

Table 4 Driving force values and dependence values of influencing factors

Influencing factor	Driving force	Dependence
S ₁	5	9
S ₂	4	10
S ₃	1	11
S ₄	1	11
S ₅	1	11
S ₆	6	1
S ₇	6	1
S ₈	7	3
S ₉	6	7
S ₁₀	3	1
S ₁₁	3	1
S ₁₂	7	3
S ₁₃	8	2
S ₁₄	6	2
S ₁₅	10	1

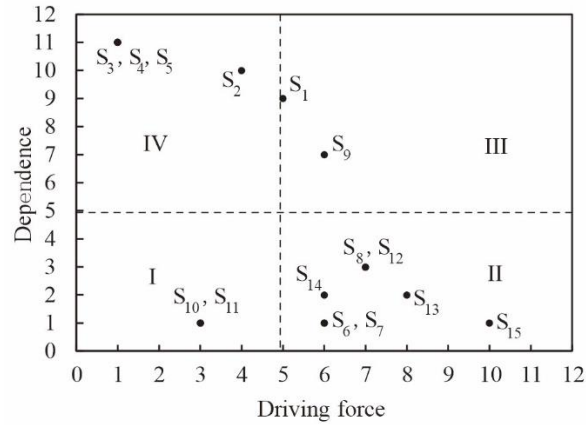


Fig. 3 Classification of driving force and dependence of influencing factors

The spatial distribution of influencing factors within the quadrant map conveys compelling insights. A striking 73% of the total influencing factors, amounting to 11 distinct factors, are situated within quadrants II and IV. Notably, these factors exhibit pronounced values in either driving force or dependence degrees. A significant observation concerns the positioning of safety cognition S_1 and job burnout S_9 within quadrant III, suggesting a pronounced concurrent driving force and dependence for these two factors.

Further research could delve deeper into the underlying reasons for such classifications, offering a more nuanced understanding of the roles and interactions of these influencing factors within the mining safety landscape. This could pave the way for more targeted interventions and strategic policies to enhance miners' safety awareness and practices.

4. DISCUSSION

4.1 Assessment of influencing factors' importance degrees

In the system depicted in Table 2, the centrality degree serves as an indicator of the relative importance of the influencing factors. From the data, a specific hierarchical sequence regarding the factors' influence on miners' safety attention is discerned: $S_2 > S_4 > S_5 > S_3 > S_9 > S_1 > S_{15} > S_8 > S_{13} > S_{12} > S_{14} > S_6 = S_7 > S_{10} = S_{11}$. This hierarchy can be compartmentalized into three distinct levels.

Notably, factors such as safety consciousness S_2 , safety self-control S_4 , risk perception S_5 , behavioral habits S_3 , job burnout S_9 , and safety cognition S_1 are classified under the first tier. As per Fig. 1, the centrality degrees for these factors surpass 1.5, signifying their heightened importance within the system. These factors are thus inferred to exert a substantial impact on miners' attention to safety.

The second echelon encompasses the safety atmosphere of the organization S_{15} , work pressure S_8 , safety supervision S_{13} , and safety information stimulation S_{12} . These factors exhibit centrality degrees ranging between 1 and 1.5, denoting a medium level of systemic importance.

Conversely, the education level S_6 , working years S_7 , working environment S_{10} , and work intensity S_{11} are relegated to the third tier, characterized by their comparatively diminished importance. Their centrality degrees, all falling below 1, suggest a relatively minor influence on coal miners' safety attentiveness.

4.2 Examination of causative factors

Within the system presented in Table 2, nine causative factors are identified. Their hierarchical significance unfolds as follows: $S_{15} > S_8 > S_{13} > S_{12} > S_{14} > S_6 > S_7 > S_{10} > S_{11}$. It is posited that these causative elements play an instrumental role in shaping resultant factors and miners' emphasis on safety.

However, an intricate scrutiny reveals that factors such as the education level S_6 , working years S_7 , and safety education and training S_{14} are situated within the mid-tier of the system as depicted in Fig. 2. In Table 2, a lower degree of significance is attributed to these elements. Furthermore, as discerned from Fig. 3, these factors are categorized within quadrant II and are perceived as independent clusters with minimal dependency. A tepid response to the stimuli of profound root factors is observed. Collectively, it is deduced that these components maintain a marginal and somewhat isolated impact on the overarching system.

Notably, while the working environment S_{10} and working intensity S_{11} are earmarked as profound factors in Fig. 2, they are positioned within quadrant I and are associated with the autonomous cluster as per Fig. 3. The driving forces underpinning these factors are delineated as being subpar, and their affiliations with mid-tier factors are not deemed robust. Addressing these particular elements with timely, targeted interventions may proffer enhanced outcomes in bolstering coal miners' attention to safety.

Pivotal within the causative factors, the safety atmosphere of the organization S_{15} is discerned to reside at the L_7 echelon. Concurrently, working pressure S_8 , safety information stimulation S_{12} , and safety supervision S_{13} are situated either at the L_5 or L_6 strata, as visualized in Fig. 2. Recognized as the system's profound layers, these factors—due to their pronounced importance are placed within quadrant II in both Figs. 1 and 3. Being constituents of an independent cluster with a formidable driving force, their influence on both mid-tier and superficial elements is profound. Thus, these are perceived as the linchpins modulating coal miners' dedication to safety.

4.3 Exploration of resultant factors

In Table 1, six resultant factors are delineated, possessing a sequence of significance as follows: $S_2 > S_4 > S_5 > S_3 > S_9 > S_1$. Resultant from the cumulative impacts of other determinants, these factors are discerned to directly influence the coal miners' dedication to safety. An elevated level of importance is attributed to them within the system, as visualized in Fig. 1, suggesting a critical role in shaping miners' safety attentiveness.

Upon examination, it was observed that factors such as behavioral habit S_3 , safety self-control S_4 , and risk perception S_5 reside within the L_1 echelon in Fig. 2, typifying the system's initial surface level. Positioned in quadrant IV, these factors are identified as belonging to the dependent cluster in Fig. 3. Characterized by heightened dependency and attenuated driving forces, their manifestation is predominantly influenced by other variables, rendering them contingent on the modulation of external factors.

Conversely, safety cognition S_1 , safety consciousness S_2 , and job burnout S_9 are mapped to the L_2 , L_3 , and L_4 tiers, respectively, in Fig. 2. These mid-tier factors within the ISM serve as conduits, bridging antecedent and subsequent determinants. The driving forces intrinsic to these elements amplify the sway of superficial factors, while their dependencies bolster the imprint of profound determinants. However, an intriguing observation arises from the positioning of safety consciousness S_2 within quadrant IV, aligning it with the dependent cluster. Despite its inherent strong dependency, a subdued driving force has been noted, attenuating its potential reinforcement of surface elements.

Of particular note, safety cognition S_1 and job burnout S_9 are aligned with quadrant III, categorizing them within the connection cluster as illustrated in Fig. 3. Their simultaneous possession of robust driving forces and dependencies suggests that perturbations within these factors could readily ripple through the system, influencing upper and lower echelons. Such dynamism underscores the salience of these factors in determining coal miners' commitment to safety. The analysis infers that mid-level resultant factors, endowed with dominant driving forces and dependencies, significantly modulate coal miners' focus on safety.

4.4 Analysis of practical implications from influencing factors

Hierarchy is often employed as a critical technique in analyzing influencing factors and forms an integral foundation in safety management. Within this hierarchy, surface-level factors have been determined to directly influence safety attentiveness. The direct and targeted intervention of these factors has been acknowledged to yield optimal results in the contemporary domain. Deep-level factors, however, are perceived to be more pivotal, exerting their influence through mid and surface-level determinants. A vast array of deep-level factors has been observed to influence other levels, rendering the nature of their influence intricate. For these deep-level determinants, comprehensive emphasis and preventive measures are generally proposed in current strategies. Mid-level factors, traditionally, are not attributed significant influence over deep-level determinants but are discerned to primarily impact surface-level factors. The prevailing strategy recommends obstructing the connections between mid and surface levels.

Nonetheless, challenges are evident in these hierarchical solutions to influencing factors. An overwhelming number of factors demand attention, resulting in significant workload. Given the dynamic nature of safety information, implementing these controls becomes challenging, thereby potentially overlooking certain mid-level factors over time. Strikingly, analyses from improved methodologies suggest that specific mid-level factors play a pivotal role in modulating coal miners' safety attention, raising concerns over safety management, especially in minor injury incidents. It has been inferred that the nuanced interrelations among various factors cannot be aptly captured solely via hierarchical structures. Instead, the implementation of refined methodologies is advocated to establish a hierarchical structure. Within this, both driving forces and dependencies of influencing factors should be meticulously analyzed, unearthing the intricate interplay among them. Such a comprehensive approach promises to yield insights of paramount practical relevance.

Upon scrutiny of the enhanced DEMATEL-ISM method and the intricate interplay among all influencing factors, two focal points emerge for mining entities. Firstly, the deep-level causative factors manifesting pronounced driving forces demand attention. Secondly,

mid-level resultant factors characterized by robust driving forces and dependencies necessitate scrutiny. Salient among these are safety atmosphere of the organization S_{15} , work pressure S_8 , safety information stimulation S_{12} , safety supervision S_{13} , safety cognition S_1 , and job burnout S_9 . Addressing these six pivotal determinants in isolation poses challenges, given their intertwined nature and hierarchical interactions. Yet, devising unified, systematic countermeasures tailored to their characteristics appears promising for mining entities, potentially alleviating concerns over minor injury incidents by enhancing miners' safety vigilance.

The aforementioned six influential factors and their main associated personnel can be systematically approached in two dimensions. The initial dimension targets the triad of safety information stimulation S_{12} , safety supervision S_{13} , and safety atmosphere of the organization S_{15} . Integration of safety information stimulation S_{12} and safety supervision S_{13} into the overarching framework of organizational safety atmosphere S_{15} is recommended, elevating the significance of the former two within the latter. This amalgamation predominantly concerns the safety managers within mining firms, underscoring the pivotal role of establishing a scientifically rigorous safety organizational atmosphere to elevate the safety management caliber. The secondary dimension focuses on safety cognition S_1 , work pressure S_8 , and job burnout S_9 . Primarily pertinent to coal miners, these factors, however, necessitate vigilant oversight from safety managers. Proactive measures, both in terms of rewards and penalties, are suggested to foster miners' intrinsic motivation to hone their safety cognition and maintain optimal working conditions, thereby enhancing safety awareness. Concurrently, vigilant monitoring is essential to promptly identify concerns related to miners' work pressure and burnout. Decisive interventions should be swiftly deployed upon the identification of any detrimental behaviors jeopardizing miners' safety attention. The systematic management of these dimensions, centered on the highlighted six determinants, is postulated to hold profound practical and strategic implications in mitigating minor injury incidents within coal mining entities.

5. CONCLUSIONS

In the presented research, factors influencing coal miners' attention to safety were meticulously examined through an enhanced DEMATEL-ISM method. From this comprehensive analysis, critical determinants closely interlinked were extracted from the broader factor group. Such extraction is postulated to diminish the substantial workload inherent in managing minor injury accidents and to counteract the potential oversight of pivotal factors.

The findings elucidated that the coal miners' safety attention emanates from a composite interplay of factors, including their degree of importance, system level grade, driving force, and dependency characteristics. Notably, two salient dimensions emerged as particularly significant for mining entities. The first dimension underscored that deep-level causative factors, characterized by an intense driving force, profoundly influence both middle and surface-level determinants, thus serving as pivotal elements modulating miners' safety focus. The second dimension accentuated the importance of mid-level resultant factors. Endowed with a robust driving force and dependency, these factors are discerned to potentially sway deep and surface-level determinants, thereby critically affecting coal miners' safety attention.

It is surmised that devising systematic response measures addressing the influencing factors from both dimensions holds potential for mining companies, offering strategic solutions to challenges posed by minor injury incidents and fostering enhanced safety attentiveness among miners. Anticipated avenues for future research encompass the exploration of barriers and conflicts inherent in the formulation of such systematic response measures, as these issues hold significant implications. Furthermore, a limitation identified pertains to the sample size and scope; subsequent investigations would benefit from expanded sample sizes and diverse organizational and cross-national contexts to bolster the generalizability and robustness of the findings.

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