Identification of Failure Factors of Self- and Mutual-Rescue in Confined Space Working Accidents

Mengyao Lu[1,a*], Naiwen Li[1,b], Ping Shi[1,c]

531575963@qq.com[a*], 570915380@qq.com[b], shiping@uritest.com.cn[c]

College of Business Administration, Liaoning Technical University, Longwan South Street, Huludao, China[1]

Abstract: In order to prevent the unsafe self- and mutual-rescue behavior in confined space working accidents, the index system of risk factors for emergency rescue was established, including unsafe behavior, unsafe behavior premise, unsafe supervision and organizational impact of the four parts. The factor sets of causes and results were analyzed by integrating decision-making trial and evaluation laboratory (DEMATEL), the interpretative structural model (ISM) was used to analyze the hierarchical structure of influence factors. The study find that, the unsafe self- and mutual-rescue behavior in confined space working accidents is the direct factor, the intermediate factor and the deep factor synthesis function result. Failure factors such as the rescue drills are insufficient and formalized, the leaders' safety awareness and emergency handling ability are low, the operation managers' emergency early warning and risk management ability are insufficient, the self- and mutual-rescue personnel do not wear protective equipment and failure to establish coordination and linkage mechanism with relevant units and social organizations may easily lead to the risk of self- and mutual-rescue, need to focus on.

Keywords: Emergency rescue; Failure factors; Confined space; Decision making trial and evaluation laboratory; Interpretative structural model

1 INTRODUCTION

Confined space of poor natural ventilation, easy to cause toxic and harmful, flammable and explosive material accumulation or insufficient oxygen content. The danger of confined space operation is high, the difficulty of accident rescue is great. The Ministry of National Emergency Management Reports, in recent years, the problem of blind rescue in confined space accidents has become prominent, nearly 80 percent of the accidents resulted in increased casualties due to blind rescue.

The investigation reports of a number of major confined space working accidents, like Huaibei May 25, Fuyang March 28, Shandong May 16, Sanmenxia September 3, Shaoxing September 20, Shanghai September 10 and other places have revealed the failure of the workers in the production and operation units due to the failure of self- and mutual-rescue, directly or indirectly causing the accident to expand, the lesson is profound.

Confined space operators are often in the first time and the first scene of the accident, it is certainly an inescapable duty for them to make decision, carry out safe self- and mutual-rescue, initiate an emergency response quickly, grasp the golden time and correct methods of rescue,

EMIS 2023, February 24-26, Chengdu, People's Republic of China

DOI 10.4108/eai.24-2-2023.2330623

prevent failure of rescue efforts through risk management[1], supervision and management[9], specific training[2], and personal protective equipment [8]. Therefore, it is of great practical significance to study the failure factors of self- and mutual-rescue in confined space working accidents.

Many scholars focus on the factors that affect the safety of confined space working. Adopted social network analysis, explored the interconnectedness of accidents in confined space, it cleared that sewage well, cable well and thermal well ware the core of the accident[6]. Mainly according to the power grid confined space working application scenes, designed a wearable environmental monitoring and alarm system, used it to detect environmental temperature, humidity, gas and vital signs, and to control the wireless data transmission in the background[10]. Took the lead in “He xueqiu’s safety rheology-catastrophe theory” under the guidance of a stronger psychological quality can prevent coal mine staff psychological crisis, concluded that the improvement of psychological quality and the ability of self- and mutual-rescue, and the improvement of emergency plan ware the important supports for work safety and emergency rescue [12]. Calculated the death rate of the intruder versus the rescuer, analyzed that the risk perception ability of rescue in confined space is closely related to the accident rate, clarified the protection level of all types of personnel, divided into “self, non-access, access to the rescue” level structure, created a confined space access rescue five-step security procedures[3-4].

However, there are few researches on the failure factors of self- and mutual-rescue in the field of confined space. This study combines unsafe behavior with rescue strategies, the key failure factors were identified by the DEMATEL method and the ISM method, to provide support for the safety of self- and mutual-rescue in confined space working accidents.

2 RISK OF SELF- AND MUTUAL-RESCUE IN CONFINED SPACE WORKING ACCIDENTS

The risk of self- and mutual-rescue in a confined space working accident is similar to the risk of working, but the goal, the object, the request are different. Table 1 differentiates between the two.

Table 1: The difference between the risk of self- and mutual-rescue and the risk of working.

Project	Research on the risk of working accidents	Study on the risk of self-and mutual-rescue space working accidents
Goal	To prevent and reduce the occurrence of accidents in confined space	To avoid increased casualties due to unsafe rescue
Object	Confined space worker	Operational accident rescue personnel
Requirement	Pay attention to safe work, reduce unsafe behavior	Pay attention to safety rescue, effectively prevent the expansion of the accident

Based on the investigation reports on 46 confined space operations accidents issued by the Emergency Management Departments of Anhui, Guangdong, Guizhou, Hebei, Henan, Shandong and Shanghai from 2018 to 2022, of the 43 accidents with increased casualties due to unsafe self-rescue, the major ones were poisoning and asphyxiation (29 in total), accounting for 67% of the total. Since the accident investigation report did not reveal the details of the underlying cause, the root causes of the insecurity need to be dug deeper, to consider the interplay between individual decisions and the dissemination of their actions within the organization[7, 11]. Drawing lessons from the Guide to safety rescue of accidents in confined space operations, integrating the factors affecting the safety management of confined space, introducing expert evaluation, manager experience, systems engineering thinking, and human factor analysis and classification system (HFACS), based on the statistical analysis of the failure factors of self- and mutual-rescue in 43 accident samples, constructing the index system of risk factors of emergency rescue, as shown in Table 2.

Table 2: Index system of risk factors of emergency rescue in confined space working accidents.

Level	Category	Specific failure factors	Frequency	Percentage/ %
A unsafe behavior	A_1 breach of safety procedures during rescue	A_{11} violates the principle of"First ventilation, then detection, then rescue"	16	37.21
		A_{12} not wearing self-help protective equipment	26	60.47
		A_{13} failed to turn off switch and evacuate personnel in time	23	53.49
B the premise of unsafe behavior	B_1 security identification	B_{11} not equipped with safety guidelines and warning signs	22	51.16
	B_2 rescue workers	B_{21} low security awareness and low level of risk perception	19	44.19
	B_3 site ventilation	B_{31} high concentration of toxic and harmful gases, flammable and explosive substances accumulation	18	41.86
	B_4 rescue equipment	B_{41} protection, detection, rescue and other equipment equipped with management is not in place	23	53.49
C unsafe supervision	C_1 personnel communication and attitude	C_{11} guardianship staff failed to detect and stop the rescue violations in a timely manner	19	44.19
		C_{12} the person-in-charge of the operation site did not give a full account of the safety of all personnel	20	46.51
		C_{13} operations managers have inadequate emergency warning and risk management capabilities	23	53.49
	C_2 safety education assessment	C_{21} rescue drill is insufficient and formalized	21	48.84
		C_{22} security training is not in place, the effectiveness of knowledge education is poor	23	53.49
D	D_1	D_{11} not establish a coordination	16	37.21

organizational impact	emergency management and control capability	mechanism with relevant units and social organizations		
		D_{12} leaders have low security awareness and emergency response capability	17	39.54
	D_2 emergency response plan	D_{21} do not have a confined space emergency response plan	23	53.49
		D_{22} the emergency response plan is operability	27	62.79

3 DEMATEL-ISM METHOD

The DEMATEL algorithm helps the bottom-line mind cope with interlaced causality, and by identifying the underlying factors, to fully estimate the problems among the elements of a complex system, strive for the best solution.

The ISM algorithm is a structural modeling technique that simplifies complex systems, and it is widely used in modern systems engineering field, designed to reveal the structural relationships within the system.

Therefore, this paper will introduce ISM analysis based on DEMATEL method, to make the complicated factors hierarchical and coherent.

3.1 Build the DEMATEL impact matrix

1) Construct the direct influence matrix L.

By investigating the opinions of 12 subjects (including field workers, operation managers, rescue workers and experts in the field of human factors engineering and emergency safety) on the strength of the interaction between factors, adopting the five-grade scale method of 0,1,2,3,4, which is used in the world, reflect the relationship of no influence, weak influence, medium influence, strong influence and extremely strong influence among different factors in turn.

From the formation of the initial direct impact matrix, to indicate the significant direct influence relationship between systemic risk factors. To eliminate individual differences, by rounding off the average score, form the direct influence matrix L (16-order square matrix, constituent elementsl_{ij}, representing the influence of *i* factor on *j* factor, matrix diagonall_{ii}, representing the influence of factors on their own, all take 0) .

2) Determine the normalized direct influence matrix M and the synthetic influence matrix T.

$$M = \frac{1}{\max\left(\sum_{j=1}^{16} l_{ij}\right)} L \tag{1}$$

$$T = M(I - M)^{-1} \tag{2}$$

Form: I is the unit matrix; l_{ij} is the element of the matrix L.

3) Calculate the influence degree (h_i), the affected degree (z_j), the center degree($h_i + z_j$), and the cause degree ($h_i - z_j$) of each factor, and draw the cause and effect diagram accordingly.

$$h_i = \sum_{j=1}^{16} t_{ij} (i = 1,2,\cdots,16) \tag{3}$$

$$z_j = \sum_{i=1}^{23} t_{ij} (j = 1,2,\cdots,16) \tag{4}$$

Table3: Centrality and causality of emergency rescue risk factors for confined space working accidents.

Variable	influence degree (h_i)	affected degree (z_j)	center degree($h_i + z_j$)	cause degree($h_i - z_j$)
A11	8.82	9.77	18.59	-0.94
A12	10.04	10.54	20.58	-0.50
A13	8.12	8.05	16.18	0.07
B11	9.48	8.35	17.84	1.13
B21	9.46	9.85	19.30	-0.39
B31	8.60	7.67	16.27	0.93
B41	8.97	9.48	18.44	-0.51
C11	7.51	8.41	15.92	-0.90
C12	7.80	8.97	16.77	-1.17
C13	9.81	10.41	20.22	-0.60
C21	9.81	8.39	18.21	1.42
C22	9.74	8.54	18.29	1.20
D11	9.13	10.63	19.75	-1.50
D12	9.199	9.41	18.60	-0.23
D21	9.45	8.23	17.68	1.22
D22	9.25	8.48	17.73	0.77

3.2 Construct the ISM

1) The reachablility matrix R is obtained from the property of the moving law.

Determining the global influence matrix Y, introducing the threshold λ, $\lambda=\alpha+\beta$, where α and β are the mean and standard deviation of the aggregate influence matrix T based on the statistical distribution, $\lambda\in[0,1]$, emphasize objectivity, obtain the reachability matrix R.

$$\mathrm{Y} = \mathrm{I} + \mathrm{T} \tag{5}$$

$$\mathrm{R} = (r_{ij})_{n\times n}, r_{ij} = \begin{cases} 1 & y_{ij} \geq \lambda \\ 0 & y_{ij} < \lambda \end{cases} \tag{6}$$

2) Divide the hierarchy.

Find the reachability set $S(Z_i)$ and the antecedent set $Q(Z_i)$ of the influencing factors, if satisfied $S(Z_i) \cap Q(Z_i) = S(Z_i)$, row and column are deleted from the reachability matrix, and the process is repeated repeatedly, with all row and column deleted, hierarchical structure appears, explain the construction of structural model.

4 MODEL BUILDING

C_{21}, D_{21}, C_{22}, B_{11}, B_{31}, D_{22}, A_{13} are the cause factors, the cause degree of C_{21}, D_{21}, C_{22}, B_1 are more than 1. It shows that they are more likely to affect other factors and lead to rescue accidents. It mainly involves insufficient and formalized rescue drills, lack of special emergency plans for confined space, lack of safety training, poor effectiveness of knowledge popularization education, and lack of rescue guidelines and warning signs. D_{11}, C_{12}, A_{11}, C_{11}, C_{13}, B_{41}, A_{12}, B_{21}, D_{12} are all the outcome factors, the lower degree of cause, the more susceptible to other factors. The cause degree of D_{11}、C_{12}、A_{11}、C_{11}、C_{13} are less than -0.6, it is the key proximal cause of the failure of self- and mutual-rescue in accidents. To analyze the overall influence degree and hierarchical structure among the failure factors of self- and mutual-rescue, take $\alpha = 0.5671$, $\beta = 0.0759$, set the λ to 0.6430, obtain the reachability matrix R.

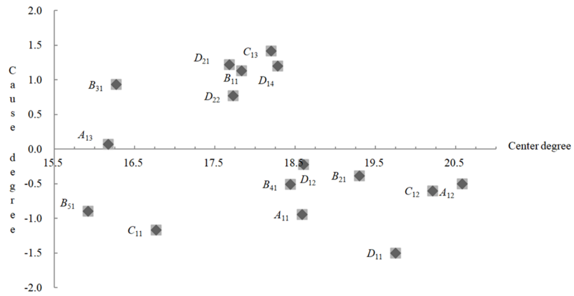

Figure 1: Cause and effect diagram of failure factors of self- and mutual-rescue.

According to the four-level model in Figure 2, self- and mutual-rescue, unsafe behavior is at the top, the premise of unsafe behavior lies in the middle with organizational factors, “the rescue drill is insufficient and formalization” is at the bottom. The risk of self rescue in a confined space working comes directly from the top influencing factors: A_{11}、A_{12}、A_{13}、B_{31}、C_{11}、C_{12}、D_{11}.When the situation at the scene is not clear and no protective measures are taken, the red line “at the expense of safety” has been crossed; if the toxic gas exceeds the exposure limit, personnel may be poisoned or even killed by not wearing self-protective equipment; failing to establish a coordinated and coordinated rescue mechanism with relevant units and social organizations, affect the integration and optimization of emergency resources and rescue efficiency; if the guardian and the person in charge of the operation site do not know the situation on the scene and the status of the trapped persons, they would unable to report the accident accurately and timely; units carried out in-depth emergency rescue drills, dynamic evaluation of employees’ ability to save themselves and each other, is the key to avoiding rescue accidents.

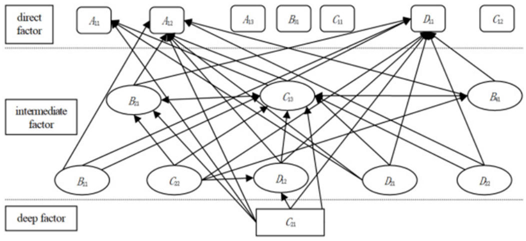

Figure 2: The interpretative structural model of the failure factor of self- and mutual-rescue.

5 CONCLUSIONS

1) The risk index system of emergency rescue in confined space working is constructed. From the unsafe behavior, the unsafe behavior premise, the unsafe supervision, the organization influence 4 levels start, sixteen risk factors are identified.

2) By using the DEMATEL-ISM method, this paper probes into the failure factors of self- and mutual-rescue. The degree of cause and the degree of centrality of each factor are calculated. The factors with more than one degree of cause: the rescue drill is insufficient and formalized(1.42)>no special emergency plan for confined space has been formulated(1.22)>the safety training is not in place, and the effect of knowledge popularization education is poor(1.20)>no rescue guide and warning sign(1.1). It shows that the above factors are more likely to affect other factors and lead to rescue accidents in the confined space operation emergency system.

3) Identify that "insufficient and formalized of the rescue drill→ insufficient emergency warning and risk control ability of operation manager→ self-rescue personnel not wearing protective equipment" is the strong risk cause chain. The risk mechanism of self- and mutual rescue in confined space working accidents is analyzed, the mutual influence and logical relationship among the deep, middle and direct factors are clearly defined, provides the basis and reference for the risk management of self- and mutual-rescue in the confined space working accidents.

REFERENCES

[1] Feng, Y. J.& He, T.(2022).Safety Risk Evaluation of Municipal Engineering Based on Poset+ SNA. J. Safety and Environmental Engineering,29(02):1-8.

[2] Hu, Z., Hu, H.& Xu, F., et al.(2022).Research on personalized safety manage for construction workers considering personality traits. J/OL. Journal of Safety and Environment:1-10.

[3] Jason, S., et al.(2018).An investigation into the rate and mechanism of incident of work-related confined space fatalities. J. Safety Science,109 : 333-343.

[4] Jason, S., et al.(2019).Confined space rescue: A proposed procedure to reduce the risks. J. Safety Science, 113 : 78-90.

[5] Li, M. H.& Su, J. Z.(2021).Study on influence of group dynamics on miners' unsafe behavior intention. J. China Safety Science Journal,31(07):48-55.

[6] Liu, Y.& Qin, Y.(2017).Analysis of confined space working accidents in Beijing based on social network analysis. J. Industrial Safety and Environment Protection. 43(04):18-22.

[7] Shi, J., Zheng, P.& Chang, D. Y., et al.(2021).On the propagation manner of the miners' reckless behaviors based on the so-called SEIMR model. J. Journal of Safety and Environment, 21(03):1203-1211.
[8] Simms, A., Fear, N. T.& Greenberg, N.(2020).The impact of having inadequate safety equipment on mental health. J. Occupational medicine,70(4) : 278-281.
[9] Wang, Q., Peng, X.& Li, Z.(2020).Determining Strategies for Constructing the Safety Supervision System by Considering Both Internal and External Safety Environments: A Case Study of X Group Corporation, China. J. International Journal of Environmental Research and Public Health, 17(24):9486.
[10] Yang, H. Z., Wang, Y.Y. & Wu, J. W., et al.(2022).Design of wearable environment monitoring and alarm system for limited space operation in power grid. J. Chinese Journal of Electron Devices. 45(03):760-766.
[11] Yang, Z. H., Ding, G. C.& Zhang, T., et al.(2018) Investigation and analysis of the influential factors on the spreading reckless behaviors of the building workers based on the SEM.J. Journal of Safety and Environment,18(03):987-992.
[12] Zhao, P. F., He, A. H.& Yao, Y., et al. (2019). Psychological Changes of Trapped Persons in Coal Mines Based on Rheology-Mutation Theory. J. Safety in Coal Mines, 50(08): 253-256.

Appendix

Table : Reachability Matrix R of emergency rescue risk factors for confined space working accidents.

Variable	A_{11}	A_{12}	A_{13}	B_{11}	B_{12}	B_{13}	B_{14}	C_{11}	C_{12}	C_{13}	C_{21}	C_{22}	D_{11}	D_{12}	D_{21}	D_{22}
A_{11}	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A_{12}	1	1	0	0	1	0	1	0	0	1	0	0	1	1	0	0
A_{13}	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
B_{11}	0	1	0	1	0	0	0	0	0	1	0	0	1	0	0	0
B_{21}	0	1	0	0	1	0	0	0	0	1	0	0	1	0	0	0
B_{31}	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
B_{41}	0	1	0	0	0	0	1	0	0	1	0	0	1	0	0	0
C_{11}	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
C_{12}	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
C_{13}	1	1	0	0	1	0	1	0	0	1	0	0	1	0	0	0
C_{21}	1	1	0	0	1	0	0	0	0	1	1	0	1	1	0	0
C_{22}	0	1	0	0	1	0	1	0	0	1	0	1	1	0	0	0
D_{11}	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0
D_{12}	0	1	0	0	0	0	0	0	0	1	0	0	1	1	0	0
D_{21}	1	1	0	0	0	0	0	0	0	1	0	0	1	0	1	0