World Journal of Educational Studies
Print ISSN: 2959-9989
Online ISSN: 2959-9997
DOI: https://doi.org/10.61784/wjes3076

QUANTITATIVE ANALYSIS METHOD FOR SAFETY ACCIDENT CAUSES IN UNIVERSITY LABORATORIES

Qin Liu[1], ZeMin Qi[1*], Ke Liu[2], HongBing Li[1]
[1]Aba Teachers College, Wenchuan 623002, Sichuan, China.
[2]Sichuan Normal University, Chengdu 610101, Sichuan, China.
Corresponding Author: ZeMin Qi, Email: zmin918@sina.com.cn

Abstract: Recently, safety accident in university laboratories occurs frequently, and it's necessary to dig into its causes which provide scientific basis for precise management of university laboratories. First, the safety accident causes are identified with qualitative method. Then, quantitative analysis of DEMATEL-ISM-MICMAC method is combined with grey number, and hierarchical structure model is constructed to clarify the causal hierarchy and identify its attribute and characteristics. Finally, the grey DEMATEL-ISM-MICMAC method combined with 24 Model is applied to analyze "4.5" Explosion Death Accident of China University of Mining and Technology. The results show: (1) the factors such as the weak supervision of the education administrative department are the deep objective causes; (2) illegal operation, defects in the safety management system, and insufficient attention to laboratory safety rules and regulations are the key subjective causes; (3) the type of safety inspection, inadequate safety protection measures and other factors are secondary causes of the accident. The analysis results are consistent with the report on "4.5" Explosion Death Accident of China University of Mining and Technology, which shows that the 24Model-Grey DEMATEL-ISM-MICMAC method is reliable in the identification, quantitative characterization and attribute feature identification of the cause of safety accidents in university laboratories, and the proposed method is highly practical, providing a decision-making basis for the refined safety management of university laboratories and the scientific formulation of emergency plans.
Keywords: 24 Model; Grey system theory; Decision Making Trail and Evaluation Laboratory (DEMATEL); Interpretive Structural Modeling (ISM); Matrix Impacts Cross-reference Multiplication Applied to Classification (MICMAC) method

1 INTRODUCTION

The laboratory is an important place for colleges and universities to undertake scientific research innovation and talent cultivation[1]. With the high-quality promotion of the strategy of rejuvenating the country through science and education, the construction of university laboratories has developed rapidly. Safety accidents in university laboratories have occurred from time to time, causing huge losses to state-owned property and casualties, which have had a significant negative impact on the reputation of the schools and the image of teachers and students, and therefore have received high attention from society. With the characteristics of complex personnel types, high mobility and uneven safety- quality of personnel participation, and the reality of the increasing scientific research and teaching tasks, the safety management of university laboratories has become cumbersome[2]. Therefore, it is of great significance to accurately identify the causes of safety accidents in university laboratories, accurately depict their internal connections, and identify the characteristics of the cause attributes, so that it can accurately prevent and control the safety risks in university laboratories, scientifically formulate emergency measures for safety accidents in university laboratories, and ensure the safety of the lives and property of teachers and students in colleges and universities.

2 RESEARCH STATUS

The safety mechanism and management of university laboratories have received widespread attention. Using the safety information flow (SIF) accident cause model, Yang et al. analyzed the explosion accident in a university laboratory in 2018[3]. The research results show that laboratory safety information is a key variable in ensuring system security. In Gao's research, the STAMP model was used to analyze the laboratory explosion accidents[4]. And it turns out that identifying control defects in laboratory safety in universities can improve the effectiveness of laboratory safety management in a targeted manner. On account of work experience in the university laboratory, Wu et al. focused on the laboratory safety education system in "double first-class" universities and provided practical basis for the safety management of university laboratories[5]. By summarizing and analyzing the current situation of laboratory safety management in local universities, Lin found out the shortcoming of laboratory safety management in terms of laws and regulations, site planning and informatization level, and put forward corresponding safety measures[6]. By applying HFACS model, Yang et al. found out nineteen types of safety accident causes in university laboratories and dug into the one of human error behavior, which gives enlightenment on the safety management of university laboratories[7]. Later, combing with the actual situation of university laboratories, Yang et al. applied the FDA accident cause mode in their research[8]. They put emphasis on three aspects, the skill level of laboratory personnel, the practice of university laboratory management and the supervision of the education management departments and noticed the importance of each one in preventing the safety accidents in university laboratories. By employing 24 Model, Wang et al. analyzed the whole process of safety accident evolution in university laboratories and proposed a laboratory safety risk control plan[9]. Similarly, given some enlightenment from the 24 Model, Guo et al. divided the safety accident causes in university laboratories into several aspects and then analyzed the evolution mechanism of laboratory safety accident causes[10]. At last, the analysis model of hazardous chemical laboratories in universities and colleges was conducted. In Xu et al.'s research, 46 cases of safety accident in university laboratories were collected and analyzed with the 24 Model[11]. From their research results, the unsafe human behavior and the aging equipment are the main accidents causes. In Fu et al.'s research, the 24-accident model was applied to systematically analyze the direct accidents causes in university laboratories based on 107 accident cases from 2001 to 2016[12]. And the result shows that the process of using experimental reagent materials is prone to be wrong. The above research indicates that accident cause models are effective methods for studying university laboratories safety, and the 24 Model with systematic and modular characteristics is widely favored. Based on this, a series of semi-quantitative methods are proposed. For example, based on cheese model, Moray et al. explored the significance of chemical spillage in the university laboratory safety[13]. The research results indicate that the amount of chemical spillage is not an indicator for summative assessment, and the focus of laboratory safety should be on organizational or site factors. Li et al. applied the Apriori algorithm into the analysis of the influencing factors of laboratory accidents and the relationship among different ones and found out the key to controlling laboratory safety accidents[14]. In lines with association rules, An et al. analyzed safety accident causes in laboratories from four aspects, people, object, environment and management, which provides feasible strategies for improving safety laboratory management[15]. However, the importance and usage of these factors are still unknow, and that may bring difficulties to the precise management and accident prevention of university laboratories.

The combined model of DEMATEL and ISM is a method for quantitatively characterizing the relative importance and roles in influencing factors in complex systems, which is widely applied in industries such as ancient architecture and hazardous chemical transportation. By using the Delphi method, DEMATEL and ISM, Zhang et al. identified and analyzed the 18 certain fire-causing elements in ancient building fire accidents[16]. The results show that the fire accidents in ancient buildings results from neighboring reasons, transitional reasons, and essential reasons. Based on the analysis of 1041 cases of hazardous chemicals tank truck transportation accidents, Zheng et al.'s research, applied with DEMATEL and ISM method, shows that wrong operation, tank and safety accessory faults are the direct key causes of accidents[17]. Using DEMATEL and ISM method, Tu and Wang made an effort to study the blunt effect of anti-riot kinetic energy bomb[18]. They brought forward that impact acceleration and impact displacement are the critical factors affecting the effect. Looking through relevant literature, Zhao et al. analyzed 33 influencing factors of entrepreneurship among university scholars and students with DEMATEL and ISM method[19]. They found out that there are 11 key influencing factors such as academic level and achievements, educational background. Adopting the 24 Model-D-ISM method, Zhou et al. made a quantitative analysis of the impact relationship between the causes of laboratory safety accidents and put forward that the lack of safety management supervision and responsibility system are the root causes of safety accidents[20].

However, one of the limitations of all these methods is that the scores of the mutual influence degree are given by expert which leads to a high degree of subjectivity. At the same time, it is difficult to accurately quantify uncertain scenarios where some information is known and some unknown. Therefore, it is necessary to find an objective method to accurately characterize the degree of mutual influence between factors. And the grey numbers in the Grey System Theory can effectively avoid this problem. For example, using sustainable laboratory evaluation method based on improved Pythagorean fuzzy linguistic set, Zhu et al. conducted case analysis and verified the effectiveness and stability of this method in handling the uncertainty of laboratory evaluation information[21]. And this research provides new technical support for laboratory safety management. Based on the fuzzy comprehensive evaluation with analytic hierarchy process, Ren analyzed the relations among 24 laboratory safety accident causes in a quantitative way[22]. And the objectivity of evaluation results is improved which provides with more objective prevention and control suggestions for laboratory safety management. However, there are still shortcomings in the above research, such as the inability to characterize the attribute characteristics of factors.

To sum up, many scholars have conducted in-depth qualitative analysis of the accident causes of laboratory safety by using different accident cause models and they have achieved significant results. However, none of them have accurately characterized the attribute characteristics of the safety accident causes of university laboratories. Moreover, few scholars have conducted in-depth quantitative analysis on the safety accidents causes in university laboratories, and there is even fewer research on the logical relationship and attribute characteristics of the safety accidents causes in university laboratories. Based on this, this research uses the 24 Model structure and its accident cause identification procedure to identify and select the safety accident causes in university laboratories from three levels: external factors, organizational factors, and personal factors accurately and systematically. Moreover, grey numbers are introduced, and the grey DEMATEL-ISM method is constructed to quantitatively characterize the interaction relationship between the safety accident causes in university laboratories, and the MICMAC method is adopted to identify the attribute characteristics of the safety accident causes in university laboratories. The integrated 24 Model Grey DEMATEL-ISM-MICMAC method is used to deeply analyze the "4.5" Explosion Death Accident of China University of Mining and Technology, and the research results are compared with the investigation report on the causes, which verifies the reliability of the integrated 24 Model Grey DEMATEL-ISM-MICMAC method in the quantitative analysis of the safety accident causes in university laboratories.

The research innovations are as follows: (1) The grey number is introduced to accurately quantify uncertain scenarios in which some information is known and some unknown in university laboratory safety accidents. And that achieves precise and quantitative characterization of the relationship between the safety accident causes in university laboratories. Based on the quantitative relationship among accident causes, an accurate hierarchical structure model of accident causes is constructed to visually describe the complex relationship between the causes. And it intuitively presents the root causes, transition causes, and nearby causes of safety accidents in university laboratories. (2) With the 24 Model, the causal factors of safety accidents in university laboratories are dug out, and the MICMAC method is used to calculate the driving forces and dependence of each factor in university laboratory safety accidents. Based on this, a Cartesian coordinate is established to identify the attribute characteristics of the safety accident causes in university laboratories. And the accident causal factors including autonomous, dependent, associative, and independent elements are identified, providing a theoretical basis for the safety refinement management of university laboratories.

3 RELEVANT METHODS AND PRINCIPLES

3.1 24 Model

Fu et al. launched the first version of the 24 Model in 2005. In it, they introduce a solution to diagnose organizational safety management in a quantitative way. 24 Model is a modern accident cause model[23]. After more than a decade of promotion and development, it has been widely used in various fields such as aviation accident, coal mine gas explosion accidents, traffic safety accidents[24-26]. And its structural framework is shown in Figure 1. This model divides the causes of behavioral outcomes into three aspects: personal factors, organizational factors, and external factors. Personal factors cover two stages: disposable behavior and state of matter, and social convention; Organizational factors cover two stages: operational behavior and guiding behavior; External factors refer to external supervision, natural environment and so on. With the characteristics of modularity and clarity, this model can accurately and systematically identify the safety accident causes. Based on this, putting it into laboratory safety accidents can obtain the identification procedure for the safety accident causes in university laboratories. And the identification procedure for laboratory safety accidents based on 24 Model is shown in Figure 2.

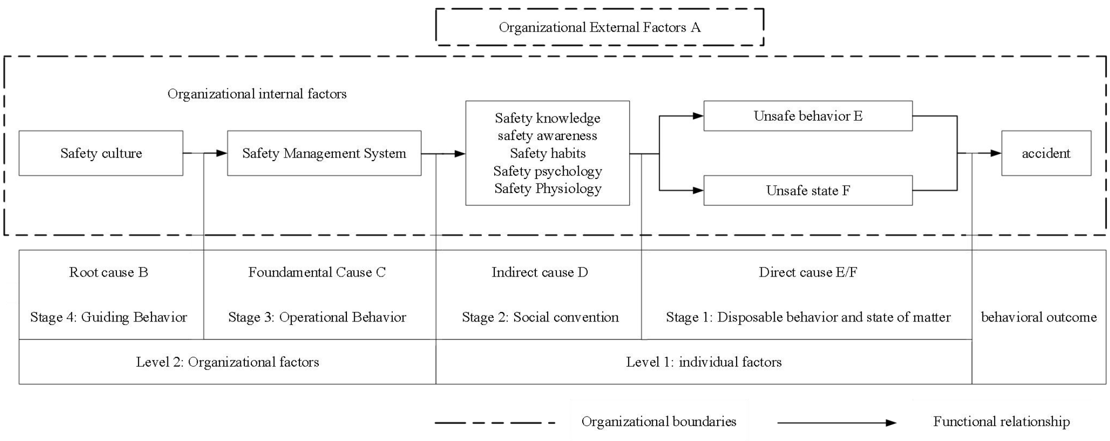

Figure 1 Structural Framework of 24 Model

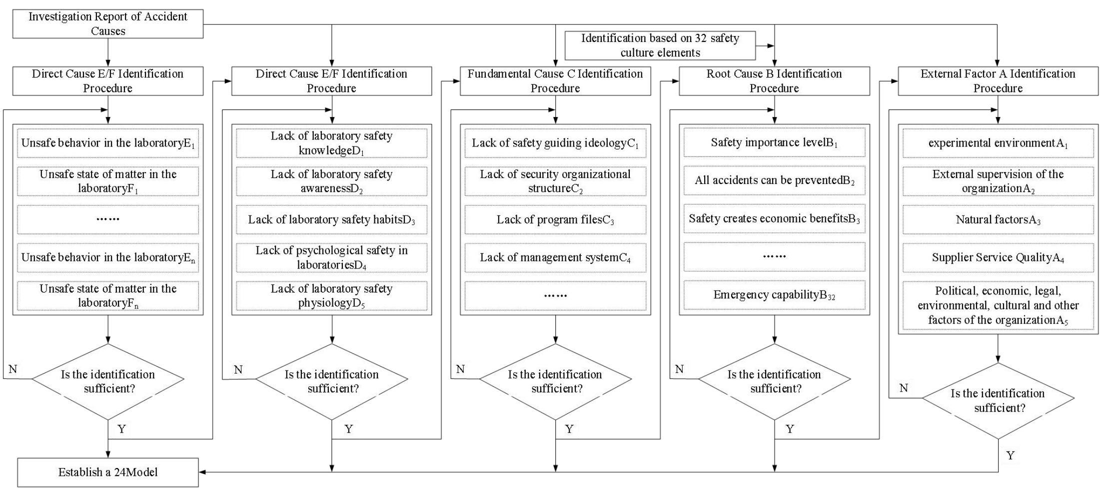

Figure 2 Chart of Accident Cause Identification Procedure Based on 24 Model

3.2 Grey DEMATEL-ISM-MICMAC Method

The traditional ISM method is based on the computer concept of Boolean matrix, and it divides the various elements in the system into two aspects: 1 represents direct relationships and 0 represents no direct relationships. Based on expert judgment, the DEMATEL method is used to describe the relationship between various factors, and its results highly rely on expert opinions. And the DEMATEL-ISM method is constructed integrating the DEMATEL method with the ISM method, which combines the advantages of both methods. However, there are still certain limitations, making it difficult to accurately quantify uncertain scenarios where some information is known and some unknown. Based on the Grey System Theory, grey numbers are introduced, and the Grey DEMATEL-ISM method is integrated to depict the relationship more accurately between factors causing safety accidents in university laboratories. And it, to some extent, reduces the subjectivity of quantitative analysis. Based on this method, the quantitative analysis results are divided into hierarchical structures. Finally, the MICMAC method, which can be used to analyze the attribute characteristics of accident causes, integrates with the Grey DEMATEL-ISM method[27]. And the Grey DEMATEL-ISM-MICMAC method is constructed to deeply explore the attribute characteristics of safety accident causes in university laboratories. The calculation steps of the Grey DEMATEL-ISM-MICMAC method are as follows.

1)Establish accident cause set A, $A = \{A_1, A_2, \cdots, A_i\}$

2)Determine the original impact relationship matrix between two factors B^m

m experts are invited to score the strength of the relationship between each cause according to the five-level grey language scale (see Table 1). And the scorings are converted into grey numbers to construct a grey impact relationship matrix.

Table 1 Five-level Grey Language Scale

Grey language	Scoring	Grey number
No impact	0	0
Weak impact	1	(0, 0.25]
Low impact	2	(0.25, 0.5]
High impact	3	(0.5, 0.75]
Extremely high impact	4	(0.75, 1]

3) Whitenization of grey number

① Standardize the upper and lower limits of the grey number through equation (1).

$$\bar{\otimes}\bar{u}_{ij}^m = (\bar{\otimes} u_{ij}^m - \min \bar{\otimes} u_{ij}^m) / \Delta_{\min}^{\max}$$
$$\underline{\otimes}\bar{u}_{ij}^m = (\underline{\otimes} u_{ij}^m - \min \underline{\otimes} u_{ij}^m) / \Delta_{\min}^{\max}$$
$$\Delta_{\min}^{\max} = \max \bar{\otimes} u_{ij}^m - \min \underline{\otimes} u_{ij}^m \tag{1}$$

In the formula: m represents the number of experts; $\bar{\otimes} u_{ij}^m$ and $\underline{\otimes} u_{ij}^m$ are the upper and lower limits of grey numbers; $\bar{\otimes}\bar{u}_{ij}^m$ and $\underline{\otimes}\bar{u}_{ij}^m$ are the standard values for the upper and lower limits of the grey number; $\Delta_{\min}^{\max}$ is the difference between the maximum upper limit and the minimum lower limit of the gray number.

② Calculate the standardized whitening value y_{ij}^m through equation (2).

$$y_{ij}^m = \frac{\underline{\otimes}\bar{u}_{ij}^m(1 - \underline{\otimes}\bar{u}_{ij}^m) + (\bar{\otimes}\bar{u}_{ij}^m \times \bar{\otimes}\bar{u}_{ij}^m)}{(1 - \underline{\otimes}\bar{u}_{ij}^m + \bar{\otimes}\bar{u}_{ij}^m)} \tag{2}$$

③ Calculate the final whitening value b_{ij}^m through equation (3).

$$b_{ij}^m = \min \underline{\otimes} u_{ij}^m + y_{ij}^m \bullet \Delta_{\min}^{\max} \tag{3}$$

4) Calculate the weighted whitening grey influence relationship matrix B through equation (4)

$$b_{ij} = w_1 b_{ij}^1 + w_2 b_{ij}^2 + \cdots + w_m b_{ij}^m \tag{4}$$

In the formula: W_m is the weight and $\sum_{m=1}^{n} w_m = 1$.

5) Normalize the weighted whitening grey impact relationship matrix B through equation (5) to obtain the standardized impact relationship matrix V; Establish comprehensive impact relationship matrix T through equation (6).

$$v_{ij} = \frac{b_{ij}}{\max\limits_{1\le i\le n}\sum\limits_{j=1}^{n} b_{ij}} \tag{5}$$

$$\mathrm{T} = \mathrm{V}\left(E - \mathrm{V}\right)^{-1} \tag{6}$$

In the formula, E and V are identity matrix in the same order.

6) Calculate the overall impact relationship matrix H through equation (7); Then calculate the mean and standard deviation of all elements in the comprehensive impact relationship matrix T, and the threshold value is obtained by summing them; Calculate the reachable matrix $\mathrm{K} = (k_{ij})$ through equation (8).

$$\mathrm{H} = \mathrm{E} + \mathrm{T} \tag{7}$$

$$k_{ij} = \begin{cases} 1 \ \ h_{ij} \ge \lambda(i, j = 1, 2, \cdots, n) \\ 0 \ \ h_{ij} < \lambda(i, j = 1, 2, \cdots, n) \end{cases} \tag{8}$$

7) Calculate the reachable set L_i and antecedent set S_i of each cause through equations (9) and (10).

$$L_i = \{a_j | a_j \in \mathrm{A}, k_{ij} \ne 0\} \ j = 1, 2, \cdots, n \tag{9}$$

$$S_i = \{a_i | a_i \in \mathrm{A}, k_{ij} \ne 0\} \ i = 1, 2, \cdots, n \tag{10}$$

Each cause is verified to see if it meets $L_i = L_i \cap \mathrm{S}_i \ (i = 1, 2, \cdots, n)$. If meets, the cause belongs to the first layer, and then the corresponding row and column are removed from the reachable matrix K; This verification process is repeated until all contributing factors have been assigned and a hierarchical structure model is constructed.

8) Calculate the driving forces DL_i and dependence DS_i of each factor through equations (11) and (12); Then, the causal factors are identified as autonomous, dependent, associative, and independent elements based on numerical values. Among them, the driving force and dependence of autonomous elements are relatively low; the driving force of dependent elements is relatively low, but the dependence is relatively high; the driving force and dependence of associative elements are relatively high; and the driving force of independent elements is relatively high but the dependence is relatively low.

$$DL_i = \sum_{j=1}^{n} k_{ij} \ \ i = 1, 2, \cdots, n \tag{11}$$

$$DS_i = \sum_{i=1}^{n} k_{ij} \ \ j = 1, 2, \cdots, n \tag{12}$$

4 EXAMPLE ANALYSIS

4.1 Accident Overview

An explosion accident occurred about 12:40 on April 5, 2015, at the Laboratory A315 of the School of Chemical Engineering, China University of Mining and Technology, because the person in charge configured and stored 17% methane in violation of regulations and the laboratory personnel improperly operated during the relevant experiments. This accident caused one casualty, four injuries, and a direct economic loss of about 2 million yuan. The "4.5" explosion accident of China University of Mining and Technology ("4.5" accident for short) is a very typical chemical related laboratory explosion accident, and it is also one of the most serious university laboratories methane gas explosion accidents. It fully exposes the loopholes in the safety production and management of education administration departments and schools and colleges, which is highly representative, warning and learning significance to others. In view of this, the "4.5" accident is chosen as an example to conduct a thorough analysis of its safety accident causes.

4.2 Identification of Accident Causes Based on 24 Model

24 causes of the "4.5" mining accident based on the 24 Model is accurately identified with reference to the Report on "4.5" Explosion Death Accident of China University of Mining and Technology and the Notice of Laboratory Safety Inspection in Higher Education Institutions (28) issued by General Office of the Ministry of Education[28-29]. Specifically, it mainly includes: 2 external factors, $\mathrm{A}_1 \sim \mathrm{A}_2$, 7 root causes, $B_1 \sim B_7$, 4 fundamental causes, $C_1 \sim C_4$, 6 indirect causes, $D_1 \sim D_6$, and 5 direct causes, $E_1 \sim E_3$, $F_1 \sim F_2$. And it is as follows in Figure 3.

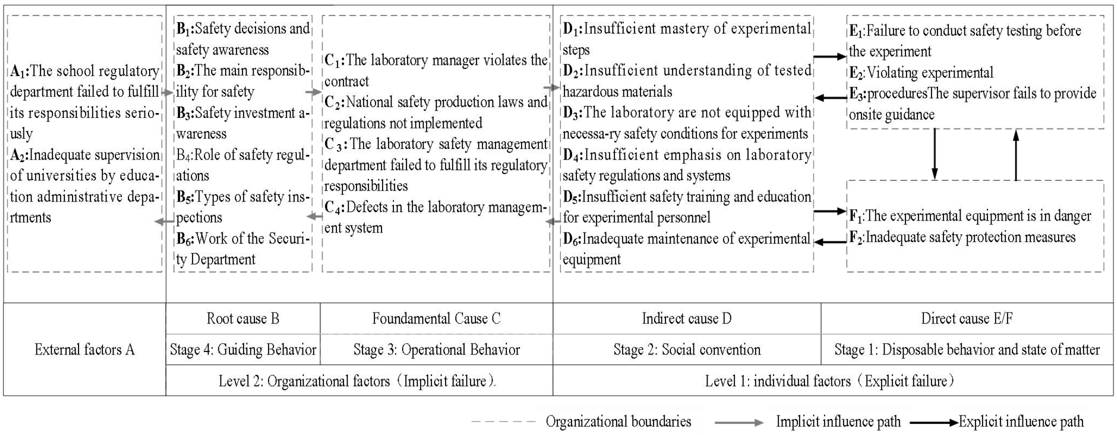

Figure 3 Chart of Cause Identification of "4.5" Accident Based on the 24 Model

3.3 Quantitative Analysis of the Safety Accident Causes in Laboratories Based on the Grey DEMATEL-ISM-MICMAC Method

1)Firstly, experts and scholars engaged in research on the safety management of university laboratories are invited to evaluate the impact degree between various causes, and their opinions afe set as equally important, that is, $w_i = \dfrac{1}{m}\ (i = 1, 2, 3, \cdots, \mathrm{m})$. Then, the evaluation scores of each expert are converted into grey numbers through Table 1, and the weighted whitening grey influence matrix B is calculated according to equations (1) to (4). Finally, the standardized impact relationship matrix V and the comprehensive impact relationship matrix T are calculated according to equations (5) and (6).

2) The mean and standard deviation of the comprehensive impact relationship matrix T are calculated. And the threshold $\lambda = 0.0538$ is obtained by summing them. The reachable matrix K is established based on equations (7) and (8). And a hierarchical structure model is established based on equations (9) and (10). The results are shown in Figure 4.

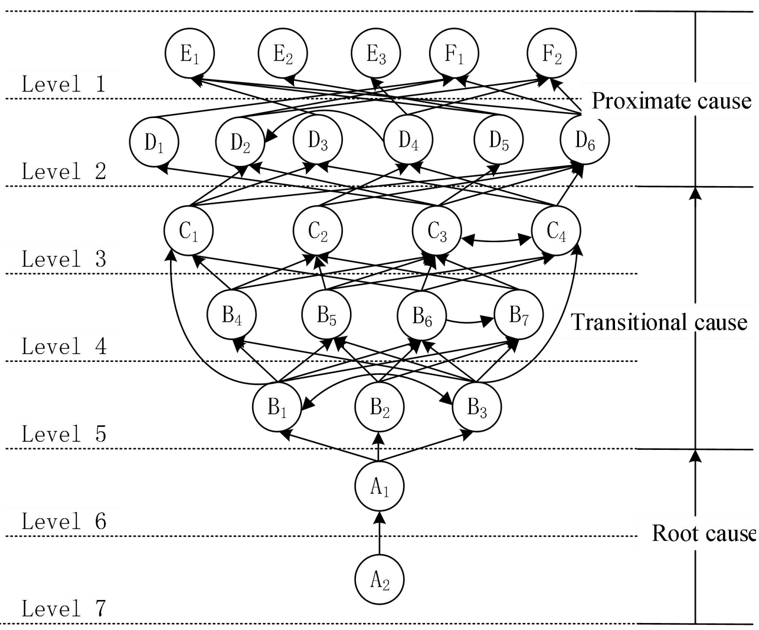

Figure 4 Hierarchical Structure Model of the Cause of "4.5" Accident

3) The driving force and dependence of each cause is calculated according to equations (11) and (12), and Cartesian coordinate is established with the driving force as the horizontal axis, the dependence as the vertical axis, and the mean as the central axis. The results are shown in Figure 5.

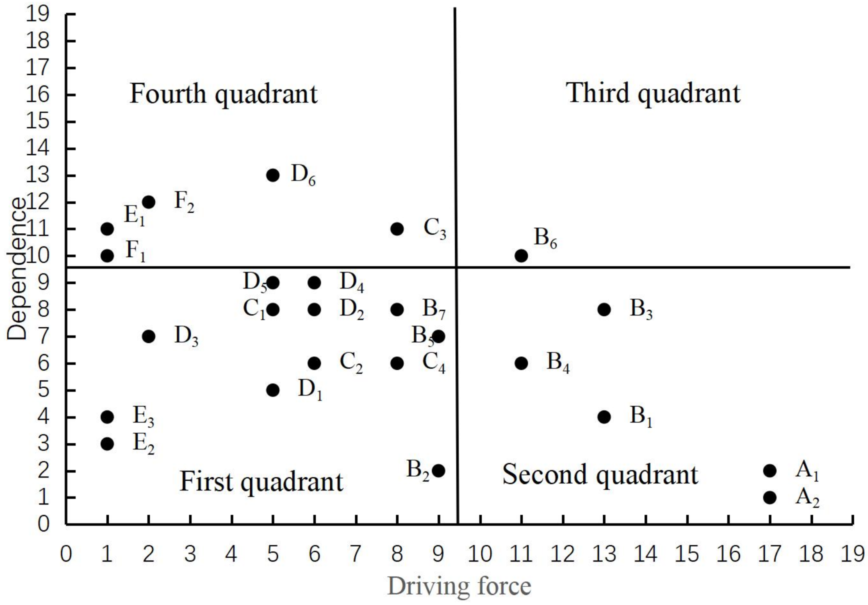

Figure 5 Diagram of MICMAC Identification Results of “4.5” Accident Cause

3.4 Result Analysis

3.4.1 Cause identification analysis of “4.5” accident based on 24 model

The 24 Model is used to identify the causes of laboratory safety accidents accurately and comprehensively in universities, and it clearly identifies the different safety accident causes of university laboratories at different stages. From the analysis in Figure 3, it can be seen that the relationship between the causes of safety accidents in university laboratories is extremely complex. This complex relationship is not only manifested in the interaction between external causes and organizational causes, but also in the interaction between organizational causes and individual causes, as well as the interaction between internal factors of organizational causes and individual causes. Among them, there are implicit influence paths of interaction between external cause A and guiding behavior cause B, between guiding behavior cause B and operational behavior cause C, and between operational behavior cause C and social conventional cause D. And there is an explicit influence path of interaction among social conventional cause D, unsafe behavior cause E, and unsafe state cause F. This indicates that among the causes of laboratory safety accidents in universities, regardless of which stage of the cause has a negative impact, it will directly or indirectly affect others. This lays a solid theoretical analysis foundation for further research, with quantitative analysis, on the interrelationships between the various causes of safety accidents in university laboratories.

3.4.2 Analysis of hierarchical structure model

From the analysis in Figure 4, it can be seen that the 24 causes of the “4.5” accident is divided into 7 levels. Among them, the nearby causes of the “4.5” accident are in the 1st to 2nd layers, including 11 factors including E_1, E_2, E_3, F_1, F_2, D_1, D_2, D_3, D_4, D_5, and D_6. These causal factors are the direct causes and explicit macroscopic manifestations of the “4.5” accident. The transition causes of the “4.5” accident is located on the 3rd to 5th layers, including 11 factors, B_1, B_2, B_3, B_4, B_5, B_6, B_7, C_1, C_2, C_3, and C_4. These factors affect each other and serve as a bridge between the root causes and the nearby causes. They are the indirect causes of the “4.5” accident in the entire laboratory safety accident. The root causes of the “4.5” accident is in the 6th to 7th layers, including two factors, A_1 and A_2. And these two factors can directly affect the transition causes, which in turn has an indirect impact on the nearby causes and are the fundamental causes of the “4.5” accident. Through in-depth analysis of the hierarchical structure model, the complex interaction between the causes of laboratory safety accidents is discovered. This relationship is manifested not only between the same levels and adjacent levels, but also between cross level interactions. Accurately controlling the root causes and transition causes of laboratory safety accidents is the key to preventing their coupling effect and causing accidents.

3.4.3 MICMAC analysis of accident causes

As shown in Figure 5, the 24 causes of the “4.5” accident are identified as autonomous, independent, associative and dependent elements, located in the first, second, third, and fourth quadrants of the Cartesian coordinate respectively.

The autonomous elements located in the first quadrant include a total of 13 items, including B_2, B_5, B_7, C_1, C_2, C_4, D_1, D_2, D_3, D_4, D_5, E_2, and E_3. The driving force and dependence of these elements are relatively low, but in laboratory safety accidents, they serve as a key point and are regarded as the focus of accident prevention. At present, with the continuous development of the market economy, it is very common to see the phenomenon of cooperation between university laboratories and enterprises. However, in pursuit of maximizing profits, cooperative enterprises are likely to reduce safety investment and even engage in illegal operations. Therefore, there are deficiencies and inadequate supervision in the laboratory management system, which may lead to risks such as contract violations. So, the autonomous element in the accident causes should be given special attention. Colleges and universities should make an effort. For example, they should establish a comprehensive laboratory management system and strengthen their supervision. National laws and regulations, and operating procedures should be strictly implemented. It is recommended to include the leaders' safety training effectiveness and lesson plan quality of the laboratory management in the year-end performance evaluation and use the training lesson plan and activities of the laboratory as the basis for professional title evaluation. The treatment of laboratory leaders should be properly improved to promote their implementation of safety training. Safety knowledge training and regulatory education for laboratory personnel should be strengthened, which aims to enhance safety awareness. Students who have received safety training and passed the assessment will be granted the right to enter and exit the laboratory. Students who have failed will not be eligible to provide opening reports, thesis defense, or regular graduation. A laboratory safety knowledge competition could be held and students for outstanding performance are rewarded[30]. Relevant laboratory safety emergency plans should be improved, and regular drills conducted. Cooperative enterprises and universities should establish a strong awareness of the safety production red line, strengthen the investment on the awareness of safety for teachers, students, and employees, which could improve their safety emergency skills and awareness.

The independent elements located in the second quadrant include 5 items: A_1, A_2, B_1, B_3, and B_4. This type of factor has a high driving force and a low dependence, and it mainly causes accident by influencing other causes. The education administrative department should learn from the lesson of the "4.5" accident to strengthen the supervision of university laboratories. Measures to establish a university laboratory big data supervision platform could be established, which includes but is not limited to VR images, experimental equipment, main uses, main principals, management methods, maintenance measures and other information of each laboratory. And on-site assessment and inspection should be carried out periodically. VR images, assessment results and other information should be updates and uploaded on the platform, which are the measures to stop and rectify university laboratories with high security risks. Safety laws and regulations should be vigorously promoted, and their role should be implemented in the management system of university laboratories. Safety summary meetings for university laboratories could be regularly held and new hidden dangers should be discussed in a timely manner to figure out the rectification measures, which is a way to strengthen safety awareness. Spot checks on the safety knowledge reserves and emergency skills could be regularly conducted within university teachers and students to verify the implementation and effectiveness of laboratory safety training. The above measures can enhance the influence of education administrative departments on other causes and in the end reduce laboratory safety risks.

The associative elements locate in the third quadrant is B_6 with both high driving force and dependence. The type of safety inspection has a significant influence and control over other causes, and the effective implementation of relevant laws and regulations is the main driving force for reducing hazards and preventing and controlling accidents.

Therefore, relevant departments should improve their own regulatory and inspection systems, pay timely attention to laboratory accidents both at home and abroad, study and assess new safety issues in university laboratories in the new era, and revise and improve relevant safety inspection laws and regulations. And the reason is that strict implementation is an effective way to curb accidents at the root.

The dependent elements located in the fourth quadrant include C_3, D_6, E_1, F_1 and F_2. These elements have a low driving force and a high degree of dependence. They are subordinate to operational behavior, one-off behavior, physical state and social convention, which need to be solved by other factors.

5 CONCLUSION

(1) 24 causes of the "4.5" accident analyzed with the 24Model were accurately identified. The Grey DEMATEL-ISM method was used to quantitatively analyze the impact between the causes of the "4.5" accident, which clarifies the logical relationships in the accident causes, and a 7-level hierarchical structure model of the causes of the "4.5" accident was constructed. The MICMAC method was used to identify the attribute characteristics of the cause of the "4.5", and specific causal factors of the four categories, autonomous, independent, associative, and dependent factors of the "4.5" accident were excavated. All those methods have fully verified the practicality of the 24 Model Grey DEMATEL-ISM-MICMAC method in analyzing the causes of safety accidents in university laboratories.

(2) The joint efforts from cooperative education administrative departments, universities, cooperative enterprises, and other aspects are required to prevent and control the safety accidents in university laboratories. The education administrative department should establish the concept of safety working, strengthen the supervision and inspection of university laboratories, as well as actively improve laws and regulations on safety inspection, which curbs accidents from an external perspective. Cooperative enterprises should strengthen their own safety management and investment and improve personnel's safety awareness and ability. Universities should carefully study and actively implement laws and regulations on safety working, strengthen the safety inspection and management of hazardous materials in university laboratories, establish and improve a system for identifying safety hazards, as well as strengthen safety education and training for laboratory personnel, which could reduce risk levels from an organizational level.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

FUNDING

It is the authors' sincere gratitude to anonymous for their helpful and constructive comments on this paper. The relevant works were supported by the Open Fund of Sichuan Oil and Gas Development Research Center (No. 2025SY011); Project funded by the Tuojiang River Basin High Quality Development Research Center of Sichuan Provincial Key Research Base for Social Sciences (No. TJGZL2025-12); Project of Emergency Management Knowledge Popularization Base for Social Science Popularization in Sichuan Province (No. YJ25-13); Supported by the Key Laboratory of Intelligent Emergency Management of the Key Laboratory of Philosophy and Social Sciences of Sichuan Province (No. 2025ZHYJGL-18); Supported by the Key Laboratory of Intelligent Emergency Management of Philosophy and Social Sciences in Sichuan Province (No. 2025ZHYJGL-19); The 2025 Qinglan Project (Second Installment) of Aba Teachers College (No. 20250202063).

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Qin Liu: Conceptualization, Method, Writing – original draft. Ke Liu and Zemin Qi: Data curation, Formal analysis, Writing – review & editing. Hongbing Li: Visualization, Investigation, Validation.

REFERENCES

[1] Wang Shi. On Characteristics of Creative-type Scientific Research Group in College——Take State Key Laboratory of Life Science Department as Case Study. Operations Research and Management Science, 2013, 22(6): 243-248.

[2] Tian Zhigang, Guo Zimeng, Tong Ruipeng. Analysis of laboratory safety accidents and exploration of crisis management in colleges and universities based on causative mechanism. Experimental Technology and Management, 2021, 38(6): 265-268+286.

[3] Yang Fuqiang, Hu Tao, Yu Longxing. Construction and application of double-loop mechanism for laboratory safety management information in universities. Experimental Technology and Management, 2023, 40(4): 205-211.

[4] Gao Wenhong. Analysis of causes of explosion accidents in university laboratories based on STAMP model. Experimental Technology and Management, 2021, 38(8): 265-268.

[5] Wu Jian, Wu Yong, Shi Dong, et al. Exploring the Construction of Laboratory Safety Education System in Double-Class Universities. Frontiers in Educational Research, 2023, 6(9).

[6] Lin Zhengzheng. Exploring the Path of Laboratory Security Management in Local Universities. Higher Education Research, 2023, 8(2).

[7] Yang Fuqiang, Xie Chengyu, Lin Xiaohang. Application of HFACS model in safety management of university laboratories. Experimental Technology and Management, 2020, 37(10): 278-283.

[8] Yang Fuqiang, Mao Yajun, Tao Jing. Safety management of university laboratory based on FDA accident cause model. Experimental Technology and Management, 2021, 38(4): 307-311.

[9] Wang Li, Yu Yanmei, Liu Linqiang, et al. Prevention and Control Strategy of Security Risks of Scientific Research Laboratories in University. Research and Exploration in Laboratory, 2020, 39(6): 278-284.

[10] Guo Haijun, Tang Hanlu, Wang Kai, et al. Accident analysis and countermeasures of university hazardous chemical laboratory based on 24Model. China Safety Science Journal, 2022, 32(11): 168-174.

[11] Xu Chao, Guo Lin, Zhao Chunyu, et al. Causes and countermeasures of inflammable and explosive laboratory accidents in colleges and universities based on “2-4” model. Experimental Technology and Management, 2021, 38(5): 248-254.

[12] Fu Jing, Liu Hong, Liu Hui, et al. Application of “2-4 Model” in Accidents Analysis of University Laboratories. Research and Exploration in Laboratory, 2019, 38(4): 277-281.

[13] Moray S Stark, Aimilia M Tsokou, Alix Howells. Chemical Spillage as a Model for Accident Causation. Journal of Chemical Education, 2021, 98(1).

[14] Li Xiangong, Wu Zhuwu, Zhang Chunlei, et al. Laboratory accident analysis based on association rules, 2022, 39(10): 218-221.

[15] An Yu, Guo Zimeng, Wang Biao, et al. Accident Cause Analysis And Safety Management Research of Laboratory Collegesand Universities. Safety & Security, 2022, 43(8): 34-39+6.

[16] Zhang Yanni,Yang Dan, Huang Luoxin, et al. A DEMATEL-ISM -integrated cause factors system for fire accidents inancient buildings. Fire Safety Science, 2023, 32(1): 59-66.

[17] Zheng Shiqiu, Zhou Rongyi, Yang Bifan, et al. Research on key causes and transmission paths of hazardous chemicals tank truck transportation accidents. China Safety Science Journal, 2023, 33(04): 172-178.

[18] Tu Mingcong, Wang Song. Analysis of the Influence Factors of Anti-riot Kinetic Energy Bomb Based on ODI Method. Fire Control & Command Control, 2019, 44(11): 78-83.

[19] Zhao Jinlong, Cui Huaying, Wang Guru, et al. Risk assessment of safety level in university laboratories using questionnaire and Bayesian network. Journal of Loss Prevention in the Process Industries, 2023, 83.

[20] Zhou Yingxin, Wu Liyun, Zhang Yadong. Research on influencing factors of safety management in university laboratories based on 24Model-D-ISM. Experimental Technology and Management, 2023: 1-10.

[21] Zhu Yuting, Han Ying, Yuan Anfu. Sustainable Laboratory Evaluation Method Based on Improved Pythagorean Fuzzy Linguistic Set. Operations Research and Management Science, 2019, 28(11): 149-155.

[22] Ren Ying. Application of fuzzy comprehensive evaluation in assessment of laboratory safety management. Journal of Safety Science and Technology, 2015, 11(1): 186-190.
[23] Fu Gui, Lu Bai, Chen Xiuzhen. Behavior Based Model for Organizational Safety Management. China Safety Science Journal, 2005, 15(9): 21-27.
[24] Suo Xiao, Fu Gui, Wang Chunxue, et al. An Application of 24 Model to Analyses Capsizing of the Eastern Star Ferry. Polish Maritime Research, 2017, 24(s1): 116-122.
[25] Fu Gui, Zhao Ziqi, Hao Chuanbo, et al. The Accident Path of Coal Mine Gas Explosion Based on 24Model: A Case Study of the Ruizhiyuan Gas Explosion Accident. Processes, 2019, 7(2): 7020073.
[26] Yan Mingwei, Chen Wentao, Wang Jianhao, et al. Characteristics and Causes of Particularly Major Road Traffic Accidents Involving Commercial Vehicles in China. International Journal of Environmental Research and Public Health, 2021, 18(8): 1803878.
[27] Sun Yilin, Zheng Xiaoqiang, Liu Xianfeng, et al. Research on quantitative analysis approach for deep organizational causes of serious leakage and explosion accident of gas pipeline. Journal of Safety and Environment, 2022, 22(5): 2677-2684.
[28] Safety Management Network. Investigation Report on "4.5" Explosion Death Accident of China University of Mining and Technology. 2015. http://www.safehoo. com/Item/1533355.aspx.
[29] Notice of the Ministry of Education of the Ministry of Education of the People's Republic of China and the General Office of the Ministry of Education on Organizing the Laboratory Safety Inspection of Colleges and Universities in 2022. 2022. http://www.moe.gov.cn/srcsite/A03/s7050/20 2204/t20220406_614080.html.
[30] Lu Zisheng, Wang Ruzhu, Luo Weili, et al. Analysis of the safety - stressed education regulations for the research - focused university laboratories from the point of view of game theory. Journal of Safety and Environment, 2018, 18(6): 2273-2278.