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Analysis and Management of Laboratory Safety Causes in Universities: A Case Study of J University

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Abstract

The complex and diverse nature of accident causes, as well as the wide spatial distribution, pose a significant challenge in ensuring the safety of laboratories in universities. Therefore, it is imperative to engage in scientific identification and effective management of laboratory safety causes to ensure the overall safety of laboratories in universities. This article presents a case study on the safety management of the laboratory at J University, examining the characteristics and types of accident causes commonly encountered in such environments. Additionally, it provides management recommendations for conducting thorough investigations into these safety causes. The findings of this study provide a foundation for the implementation of effective safety measures in laboratory environments, thereby making a significant contribution to the progression of scientific laboratory safety management. Additionally, this article offers valuable perspectives and inspiration for the enhancement of safety practices in university laboratories.

Keywords

Laboratory Accidents, Safety Causes, Risk Interaction, Universities

1. Introduction

Laboratories are of great importance to universities as they support educational and scientific research activities, as well as play a vital role in nurturing innovative individuals. However, universities have consistently faced difficulties in ensuring the safety of these laboratories. The recent expansion of higher education has resulted in a significant increase in the number and variety of university laboratories. Unfortunately, this growth has also been accompanied by occasional

safety accidents in laboratories, leading to injuries, damages to property, and serious consequences in society. The occurrence of these accidents not only indicates the problems of laboratory safety management, but also affects the operation of teaching and research activities in universities. In recent years, laboratories safety accidents have attracted considerable attention of education administration departments. However, the causes of safety accidents in laboratories are multifaceted, encompassing behavior, material, environmental, and other multidimensional factors. The identification and analysis of accident causes in laboratories are essential for the designing comprehensive safety management mechanisms for reducing the occurrence and consequence of safety accidents in laboratories of university. However, the numerous accident causes are hard to be identified in laboratories. In general, a number of safety causes may cause the accidents in the field of laboratories, including experimental premises category, safety facilities category, the basic safety category, chemical safety, biological safety, mechanical and electrical safety, and special equipment and conventional heating and cooling equipment. Moreover, the accident causes intertwined with another or coexist in this context. That is to say, an accident cause may affect another for increasing its possibility. The management of laboratory safety is faced with the challenge of identifying the interwoven accident causes.

Aiming to prevent safety accidents effectively in laboratories, this research focuses on the identification, analysis, and management of safety causes in laboratory safety management of J University. It provides an innovative method for laboratory safety management. J University has implemented a comprehensive safety management system in laboratories for four years. Accident causes are identified and prevented for preventing accidents effectively in this case. The practice of accident causes identification and management in laboratories in J University are investigated for examining and analyzing the distinctive characteristics safety causes considering the temporal-spatial space for providing recommendations of conducting safety cause prevention. The rest of this paper is organized as following. Section 2 presents the literature review, and the case of laboratory safety scoring system in J University and the research method are introduced. The statistical analysis and network analysis are conducted on the safety causes and their interaction. The analysis results for various types of laboratory safety causes in universities from micro perspectives, and the interaction among safety causes are visualized and analyzed for providing insight of accident prevention in this specific field. A number of recommendations are presented and discussed in Section 5. Finally, Section 6 concludes this research. This research contributes to the development of a comprehensive and profound comprehension of laboratory safety accident causes in universities. It offers innovative perspectives for laboratory safety management in universities for improving the effectiveness.

2. Literature Review

In recent years, as the occurrence of safety accidents in universities, all the socie-

ties have recognized the safety situation in university laboratories is serious increasingly. Scholars both domestically and internationally have conducted numerous research on laboratory safety management from various perspectives.

First, concerning management mechanisms and responsibilities, some scholars advocate for a more scientifically and systematically designed arrangement in aspects such as laboratory layout, ventilation systems, circuits, gases, humidity control, fire safety, emergency facilities, and waste management, viewing them from the standpoint of planning and construction management (Wang et al., 2021). Beyond the planning and management of hardware, collaborative communication mechanisms among different entities, including laboratory core users, designers, and builders, are deemed necessary to ensure project success (Goode & Tucker, 2020). Moreover, issues such as the imperfect laboratory responsibility system (Tian et al., 2021), the lack of responsibility implementation mechanisms (Shi et al., 2020), and the cross-functional nature of administrative management within laboratory safety organizations, characterized by multiple heads and a lack of necessary overall planning and comprehensive governance (He & Huang, 2019), represent prominent challenges in university laboratory safety management.

Secondly, types and patterns of laboratory accidents are two kind of safety accident analysis. In the context of universities in China, the existing literature indicates that chemical accidents in laboratories are of the highest occurrence (Bai et al., 2022). Safety accidents in laboratories most likely appear during holidays or graduation seasons (Bai et al., 2022). In addition, the past research indicates there exists negative correlation between age and the number of accident victims. The younger persons in laboratories are more susceptible due to weaker safety awareness (Lee & Lee, 2012). In the specific field of accident causes, human factors are identified as the primary aspects (Gopalaswami et al., 2019). Accidents are often attributed to hazardous contact with acidic or alkaline chemicals and improper tool usage (Na et al., 2019). At the organizational level, a lack of appropriate multi-entity collaborative management networks and organizational culture can lead to problems (Olewski & Snakard, 2017). Compared to government and corporate laboratories, academic institutions generally exhibit weaker laboratory safety cultures (Schröder et al., 2016). At the individual level, laboratory safety behavior is influenced by organizational factors, and researchers' characteristics such as gender, age, position, accident experience, and safety training significantly impact organizational safety culture (Wu et al., 2007). In academic institutions, there exists a discrepancy between individual safety awareness and their actual safety behavior. Although many researchers acknowledge the importance of laboratory safety, they often fall short in risk assessment before experiments and the use of personal protective equipment during work (Ayi & Hon, 2018). Particularly in university laboratories, emphasis is placed on experiment progress and outcomes, with mentors prioritizing students' practical experimental skills and sometimes overlooking safety education (Ye et al.,

2022).

Third, in the realm of risk analysis, research on the assessment of laboratory safety risks primarily revolves around three focal points: firstly, the evaluation of risk probability and associated losses. For instance, employing the Monte Carlo method to assess the likelihood and consequences of risk behaviors occurring in university laboratories (Zhang et al., 2021). The utilization of HAZOP and LOPA to ascertain deviations in hazardous behaviors within laboratories, along with their corresponding probabilities and acceptable probability limits, serves as a foundation for devising safety management measures (Shao et al., 2021). Secondly, the assessment of risk transmission relationships. This involves the application of the posterior probability backward inference method to analyze the root causes of unsafe behaviors, often stemming from incomplete regulatory policies (An et al., 2021). Thirdly, the classification and hierarchical evaluation of risks. Notably, some scholars, based on causal analysis and on-site investigation of chemical laboratory accidents in Chinese universities from 2000 to 2021, introduced an IHAC method. This method establishes a quantitative evaluation system with three primary indicators, including materials, equipment, and processes. It categorizes laboratory safety into four levels and proposes corresponding strategies for risk classification management (Liu et al., 2023).

From the perspective of existing literature, the existing literatures can be summarized into two main viewpoints. Firstly, university laboratories are predominantly studied as a holistic research subject, providing a macroscopic analysis of the current status and issues within laboratory safety management mechanisms and responsibility systems. Secondly, based on data analysis related to accidents in university laboratories, scholars derive factors and patterns contributing to accidents, forming a basic understanding of laboratory safety incidents.

3. Case Description and Methods

Aiming to examining the characteristics of safety accidents and hazards, this research takes safety management of laboratories at J University as a case. Case studies involve collecting multiple types of data for and the analysis of complex, diverse, and specific real-world phenomena. According to the selected cases and collected data, the relationships between various elements are examined. Multiple data collection and analysis methods are employed to identify hidden safety accidents causes in university laboratories and explore the underlining characteristics. Safety management in laboratories in J University is taken as a case. In this section, the practice of laboratory safety management in J University in described, including the management systems and processes, effectiveness of management, and the faced challenges in Section 3.1. In addition, the data collection and analysis method are presented in Section 3.2.

3.1. Case Description

Up to 2022, a total of 1290 laboratories distributed across 31 colleges, research

institutes, or campuses in J University, including the School of Life Science and Technology, the School of Chemistry and Materials. The details are outlined in Table 1. The laboratories in these colleges exhibit distinct characteristics. These colleges oversee and manage more than 100 laboratories on average. In particular, there are more than 300 laboratories in the school of life science and technology. Secondly, the experimental activities in the laboratories cover a broad spectrum of disciplines, spanning biology, chemistry, medicine, engineering, pharmacy, and environmental science. There exist pronounced clustering effects in concentration of laboratories, especially in biochemistry laboratories. To prevent the safety accidents in laboratories, the laboratory safety scoring system are implemented in J University. A three-level laboratory safety governance system is established comprising the university, secondary units, and laboratories. At the university level, the laboratory safety management committee consisting of university leaders and the head of functional departments are responsible the safety management. Monthly, all laboratory safety scoring information is consolidated into special reports for the university leaders, who provide supervision of this work. Additionally, university leaders conduct surprise inspections of laboratory safety regularly. Under the unified management of the laboratory safety management committee, various functional departments in university-level take different responsibilities for improving the safety management of laboratories in each college. The detailed responsibilities of functional departments in universities are illustrated in Table 1. Each department is responsible for the oversight of colleges and their laboratories.

At the college level, the heads assume primary responsibility for the safety management of laboratory, signing a safety responsibility agreement with university leaders. Laboratory Safety management forum are formed in each college. It is responsible for the hazard rectification, determination of accident liability,

Table 1. Responsibilities of functional departments for universities in laboratory safety scoring system.

Department	Duty
Laboratory Management Department	Associated with the procurement of controlled chemicals.
Finance and Planning Departments	Tied to budgetary and resource allocations.
Organizational Department	Linked to the performance assessment of the leadership team.
Human Resources Department	Linked to admission quotas, professional titles, and commendations.
Graduate School	Tied to graduate quotas for respective units.
Student Affairs Office	Associated with evaluations and awards.
Discipline Inspection Commission	Conducts inspections during patrols to assess the implementation of laboratory safety management in secondary units.

safety education, safety inspections, programming and deployment of emergency prepared plans, and so on. To implement the laboratory safety management scoring system, vice deans, laboratory directors, or heads of educational departments, are dedicated to take on specific tasks. They receive information, supervise rectification, conduct safety inspections, and manage instruments. They receive information about laboratory safety inspections from the inspection system and conduct preliminary reviews of safety causes rectification statuses submitted by laboratory safety management personnel.

At the laboratory level, the laboratory safety responsible persons take on direct responsibility for laboratory safety management. They sign a safety responsibility agreement with college leadership and oversee tasks related to laboratory management system construction, operating procedures, admission procedures, hazardous material management, project risk assessment, daily management, safety hazard identification, and more.

3.2. Research Method

For collecting and analyzing the accident causes data in safety management scoring system of laboratories, multiple methods are employed as follows:

First, the archival data method is employed to collect the data of accident causes in laboratories. This method involves systematically storing and retrieving archival information about the laboratory management in this case. The study archives electronic files of safety accident causes since the implementation of the safety scoring system of laboratory in J University, thereby creating a database of safety accident causes.

Second, five experts are invited to evaluate the interaction among the safety accident causes according to delphi method. Questionnaires are distributed to multiple experts to get their opinion about the interaction among accident causes. By several rounds of anonymous surveys, the involved experts reach a relatively consistent opinion. Finally, the survey results are obtained for evaluating interactions among laboratory safety causes.

Finally, this research utilizes social network analysis to model, visualize and analyze the interactions between laboratory safety causes. Structural analysis is performed on the laboratory safety hazard network for providing insights of safety management of laboratories.

4. Analysis Results

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4.1. The Characteristics of Different Safety Causes

Up to October 31st 2022, the laboratory safety inspection system has docu-

mented 1919 laboratory safety accident causes in J University. Each identified accident causes are categorized. The distribution of safety causes is illustrated in Figure 1, with 144 accident causes belongs to the experimental premises category, 90 ones in the safety facilities category, 748 ones in the basic safety category, 712 ones in chemical safety, 34 ones in biological safety, 24 ones in mechanical and electrical safety, and 167 ones in special equipment and conventional heating and cooling equipment. Especially, there are 1460 safety causes related to basic safety and chemical safety, constituting 76 percents. The unsafe behaviors of teachers and students are the main safety causes of basic safety category in laboratory safety management. The statistical result indicates that basic safety and chemical safety are the main existing problems in the laboratory safety management.

In the aspect of basic safety, 274 safety causes were documented, encompassing unsafe electrical behaviors such as the unauthorized use of power strips and high-power equipment. In addition, 396 safety causes are relevant to personal protective equipments. The two aforementioned categories, when combined, accounted for approximately 90% of the overall basic safety concerns. A significant disparity became evident between the safety consciousness and behaviors of laboratory teachers and students. Despite the importance of laboratory safety are recognized, the teachers and students in laboratories rarely adhere to the use of

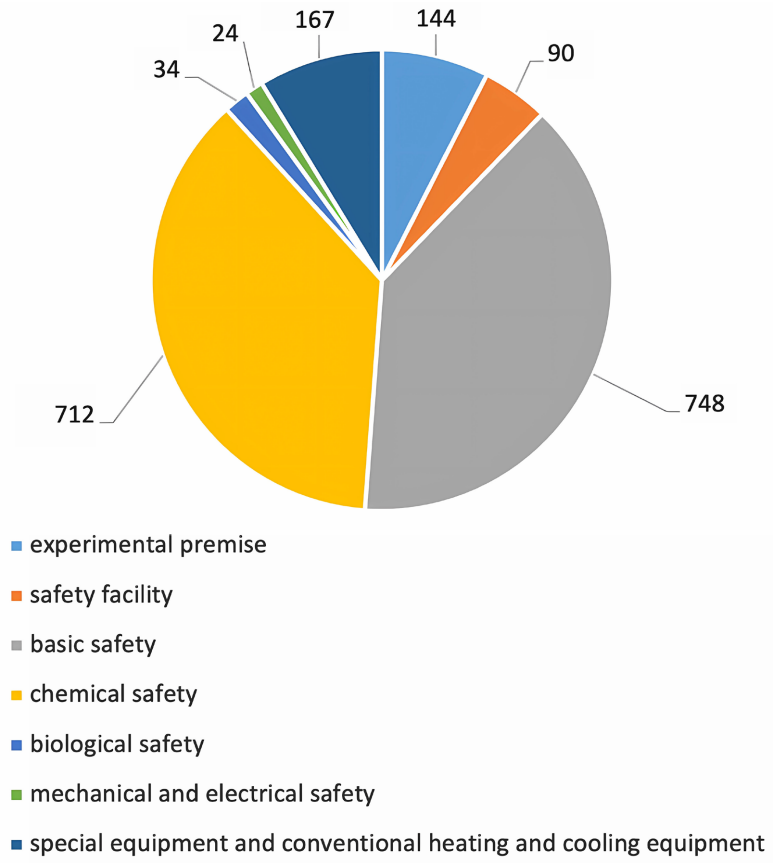

Figure 1. Distribution of types of risk hazards in laboratories at the J University.

personal protective equipment or conduct risk assessments before the experiments are conducted. During the interviews, several students in laboratories says that lab coats are not wear in compliance with requirements, and the phenomenon of eating food in laboratories are prevalent. That highlights the pervasive presence of fundamental safety management issues within university laboratories.

In terms of chemical safety, a total of 170 safety causes were attributed to the lack of labeling during reagent preparation, while 118 causes were associated with the improper storage and use of gases. Additionally, 83 causes were related to the improper storage of chemicals, 72 causes were linked to the improper storage of explosive chemicals, and 72 causes were connected to the non-standard collection of chemical waste. These four categories collectively accounted for 72% of all chemical safety issues, suggesting that inadequate chemical usage frequently leads to risks in laboratory chemical safety.

In regards to both specialized equipment and conventional heating and cooling equipment, a total of 44 safety causes were found to have violated spatial and temporal requirements in the utilization of refrigerators, ovens, and resistance furnaces. Furthermore, 34 ones were attributed to the use of open flame electric stoves or hair dryers without proper safety precautions, while 31 ones were linked to the absence of safety operating procedures for heating equipment such as ovens and resistance furnaces. Additionally, 22 ones occurred due to the absence of specialized management systems, operating procedures, and the implementation of usage registration for pressure vessels. The combination of these four categories accounted for 72% of the overall safety causes within the special equipment and conventional heating and cooling equipment classification. The combination of these four categories accounted for 72% of the overall concerns within the special equipment and conventional heating and cooling equipment classification.

Within the domain of safety facilities, a total of 67 occurrences were observed to exhibit an unclean and disorderly laboratory environment. 27 ones were identified to involve the obstruction of laboratory fire exits and the improper placement of instruments and objects in public areas. 22 ones were found to be associated with the absence of safety information signage within experimental zones, while 13 ones transpired in hazardous laboratories that lacked essential first aid provisions. Collectively, these four classifications accounted for 90% of the overall concerns within the safety facilities category.

Concerning safety facilities, 38 safety causes involved unreasonable configuration, abnormal use, and improper operation of fume hoods, 17 ones featured the lack of regular maintenance for emergency showers and eye wash devices, 12 ones occurred due to obstructed emergency evacuation routes, and 10 ones happened in laboratories lacking appropriate fire extinguishing equipment and not conducting regular usage training. These four categories collectively constituted 86% of the total issues in the safety facilities category.

In field of biological safety, there were 15 safety causes characterized by inadequate segregation, insufficient protective measures, and inadequate disinfection protocols for biological waste. 7 safety causes were attributed to non-compliance with pertinent regulations regarding the acquisition, breeding, and dissection of experimental animals. 2 ones were linked to non-adherence to safety precautions during the procurement of pathogenic microorganisms, the absence of operational guidelines for experiments involving such microorganisms, and the improper transfer and disposal of biological waste. In total, six categories safety causes constituted 88% of the biological safety causes.

The analysis of mechanical and electrical safety reveals the identification of 20 distinct safety causes, primarily attributed to the absence of essential safety protection measures in specialized equipment. Furthermore, an additional four ones were reported, highlighting the improper utilization of large and specialized equipment, which were found to be in violation of pertinent regulations..

4.2. The Interaction between Safety Causes

According to the laboratory safety inspections conducted at J University, it has been observed that safety causes frequently coexist rather than existing in isolation. This research introduces the concept of "interaction relationships" to elucidate the phenomenon wherein multiple safety causes concurrently manifest within a given laboratory space. Essentially, the presence of one safety cause tends to augment the presence of another. In this research, a comprehensive analysis of 46 categories of laboratory safety causes have undertaken for identifying the potential interaction relationships. Four experts were invited to identify and evaluate the impact relationships among the identified safety causes in laboratories. Finally, the potential interaction among the identified safety causes is list in Table 2. All the interaction relationships are encoded in a matrix. Each row or column represents a safety cause. If an element in the matrix is encoded to be 1, then the occurrence of safety cause in row impact that of safety cause in column. In order to visualizing all identified causes of laboratory safety and their interaction relationships, this research utilized the Social Network Analysis (SNA) tool UCINET. A network model of safety causes interaction are presented in Figure 2.

According to the developed the network model of laboratory safety causes, network model, this research integrates network analysis metrics to evaluate the network structure of interacted laboratory safety problem. Specifically, the betweenness centrality is employed to measure the relative frequency with which a node appears on the connecting paths between two other nodes. In this research, when a safety cause node is of higher betweenness centrality value, it is position at the crossroads of several other nodes. In other words, it assumes a pivotal and influential role, possessing the ability to regulate the dissemination of effects among other safety causes. Consequently, nodes with higher centrality should be prioritized for control and mitigation efforts to simplify hazard governance resulting from the interaction of laboratory safety causes. In the network depicting

Table 2. Secondary identification of laboratory safety hazards at J University.

Number	Name of the Safety hazard
R1	Lack of safety information signs in the laboratory premises.
R2	Absence of a reasonable layout for safety space in the laboratory.
R3	Accumulation of a large number of instruments and items in public spaces.
R4	Laboratory construction and decoration do not comply with fire safety requirements.
R5	Unreasonable layout of water, electricity, and gas pipelines with non-standardized installation.
R6	Unreasonable zoning and layout within the laboratory premises.
R7	Dirty and messy laboratory environment.
R8	Lack of or inadequate implementation of hygiene safety regulations.
R9	Lack of suitable firefighting equipment and infrequent training.
R10	Unclear emergency evacuation routes.
R11	Improper installation of emergency sprinklers and eye-washing devices, hindering normal usage.
R12	Lack of regular maintenance for emergency sprinklers and eye-washing devices.
R13	Absence of a ventilation system meeting design specifications.
R14	Unreasonable fume hood configuration, with non-compliance in operator behavior.
R15	Non-compliance with national standards and industry standards for laboratory electrical safety.
R16	The water supply and drainage system is arranged unreasonably and operates abnormally.
R17	Laboratory personnel not equipped with suitable personal protective equipment.
R18	Lack of two-person presence during hazardous experiments.
R19	Dirty laboratory benches and non-standardized experimental records.
R20	Lack of a dynamic ledger for hazardous chemicals.
R21	Absence of a designated space for exclusive chemical storage, leading to disorganized storage.
R22	Total quantity of hazardous chemicals stored not meeting regulatory requirements.
R23	Chemical labels not prominently displayed, complete, or clear.
R24	Highly toxic chemicals did not implement the requirements of "double acceptance, double storage, double delivery, double locks, double accounts", and the technical defense measures did not meet the control requirements.
R25	Improper storage of explosive chemicals without double-person double-lock storage.

Continued

R26	The storage of easily manufactured toxic chemicals is not standardized and the ledgers are not clear.
R27	Improper procurement of experimental gases, lacking a gas cylinder ledger.
R28	Non-compliance in gas storage and usage.
R29	Oxygen content monitoring and gas alarm devices are not installed in relatively small sealed experimental spaces.
R30	Gas pipelines are incorrectly connected to cylinders, lacking clear identification.
R31	The laboratory has not established a temporary storage area for chemical waste.
R32	Non-standard collection of chemical waste is observed in the laboratory.
R33	Non-compliance with regulations for the transport of chemical waste.
R34	Reagents are prepared without affixing labels.
R35	Damaged glassware, such as graduated cylinders, test tubes, pipettes, etc., is used.
R36	Biological waste is not separated adequately and lacks proper protection and disinfection.
R37	Special equipment is not equipped with corresponding safety protection measures.
R38	Pressure vessels are used without obtaining the "Special Equipment Usage Registration Certificate".
R39	Both the operators and inspection units for pressure vessels lack the necessary qualifications.
R40	The storage area for pressure vessels is poorly arranged, lacking proper safety warning signs.
R41	Pressure vessels operate without a dedicated management system and operating procedures, and usage registration is not enforced.
R42	Refrigerators used for storing hazardous chemicals do not meet explosion-proof requirements.
R43	Items stored inside the refrigerator lack clear labels, and reagents are not properly sealed.
R44	The usage of refrigerators, ovens, and resistance furnaces does not adhere to specified usage periods and spatial requirements.
R45	Safety operating procedures are not established for ovens, resistance furnaces, and other heating equipment.
R46	Open flame electric stoves or hair dryers are used without implementing adequate safety precautions.

the interaction of laboratory safety causes, nodes with higher betweenness centrality value rankings are depicted in Table 3. These laboratory safety causes merit focused attention in the management of laboratory safety from the system perspectives.

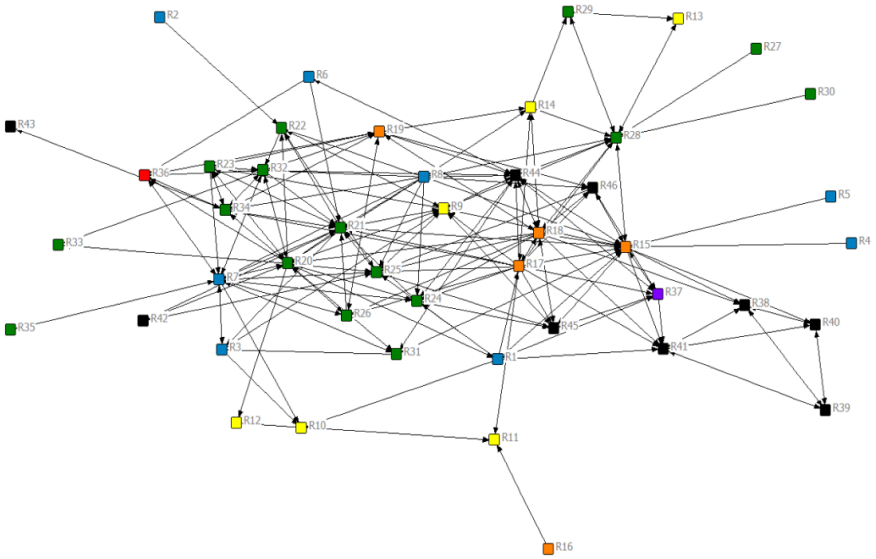

Figure 2. The interaction among safety causes.

Table 3. List of point median centrality of laboratory safety causes.

Ranking	Risk number	Betweenness centrality
1	R15	256.851
2	R20	229.839
3	R28	205.945
4	R9	152.085
5	R7	150.028
6	R18	144.239
7	R44	142.855
8	R21	99.990
9	R34	87.778
10	R32	75.018

5. Discussion

Laboratory safety accidents present significant challenge to campus safety management in universities. The identifying and analysis of safety causes in J University laboratories as a case study provides deep understanding of the characteristics and patterns of laboratory safety causes. That guides the scientific and effective design of laboratory safety management plans.

First, the laboratory safety causes are of diversity, covering a wide range of factors pertaining to individuals, machines, materials, management method, and the surrounding environment. These safety causes are decentralized, secretive, and dynamically strong, distributed within various substances, equipment, or behaviors of laboratory personnel. Moreover, all the safety causes are during in a state of constant change. That makes it difficult for routine safety inspections to fully cover all safety causes. Therefore, the laboratory safety causes management

should focus on the identification and analysis of laboratory safety risks. Emphasis should be placed on analyzing laboratory safety risks to prioritize and promptly address the key safety causes during routine safety inspections.

Second, data analysis of safety causes indicates that unsafe behaviors of teachers and students are the main safety causes of basic safety category in laboratory safety management. Improving the risk awareness of students and teachers in laboratories is the main method to eliminate unsafe behaviors. Therefore, the accident cases caused by unsafe behaviors for students during experiments should be publicized for educational purposes. The students and teachers should understand that those behaviors which do not conform the experimental regulations are of high risk levels and would lead to potential accidents.

Third, safety causes in university laboratories do not exist in isolation. Multiple safety causes often occur simultaneously in the same laboratory space. The characteristic of risk interaction among laboratory safety causes challenges traditional strategies that focus on individual hazards. Consequently, an innovative method is needed to analyze the interacted laboratory safety causes from the system perspectives. According to system analysis of the interaction relationships among laboratory safety causes, holistic strategies for managing laboratory safety causes can be designed and deployed for better performance.

Fourth, the diverse range of laboratory safety issues and their interactive nature within university settings require the need of interdepartmental collaboration in laboratory safety management. The occurrence of different types of safety causes in university laboratories indicates that the implementation of responsibilities by different units is incomplete, highlighting deficiencies in both laboratory self-management and the supervision responsibilities of colleges and other functional units within the universities.

Finally, the occurrence and elimination of laboratory safety causes are not independent. The work of eliminating safety causes may affects other types of safety causes. Therefore, the identification and management of laboratory safety causes require the collaborative involvement of various functional departments, colleges, and laboratories within the university to achieve a coordinated and collective governance of safety causes. The cross-sectoral collaboration mechanism for laboratory safety management should be designed and implemented for identifying and managing safety causes. One involved sector should identify the safety causes and analyze how they affect safety risk within other sectors.

6. Conclusion

Laboratory safety accidents pose a significant challenge to campus safety within universities, endangering the well-being of students. Consequently, it is imperative to implement scientific and efficient approaches to identify and mitigate the causes of laboratory safety incidents. Taking the innovative practices in laboratory safety management at J University as a case, this research systematically identifies and analyzes laboratory safety causes from the system perspectives aiming to

achieve better safety causes elimination effectiveness.

This research reveals the characteristics and patterns of laboratory safety causes at J University, presents an innovative method for scientifically formulating strategies to identify and manage laboratory safety causes. Several key types of laboratory safety causes are identified, providing a rationale for strategically allocating attentions for laboratory safety inspections. In addition, this research recognized the interactive nature of laboratory safety causes, underscoring the necessity for a systematic analysis of the relationships between them to achieve comprehensive safety management. Finally, this research proposes precision prevention strategies for laboratory safety accidents, offering valuable insights for the management of laboratory safety causes in universities.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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