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An Empirical Investigation into Laboratory Safety Management Behaviors and Their Relative Importance

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Abstract: Utilizing the fuzzy decision-making laboratory method, empirical research is conducted to explore the mutual influence relationship and relative importance of laboratory safety management behaviors through defining and refining their connotations. The study demonstrates variations in the mutual influences of various safety management behaviors. Among these elements, the development of safety objectives and work plans holds greater significance. Process control primarily serves as a bridge and link in various safety management practices. The safety atmosphere is predominantly influenced by other safety management practices, whereas the safety environment has a lesser influence on shaping other safety management behaviors. Laboratory managers are advised to select and apply various safety management practices in a methodical and rational manner.

Keywords: laboratory safety; safety management behavior; influence relationship; relative importance

I. Introduction

While there has been significant improvement in the quality of laboratories built by universities and enterprises in recent years, leading to a significant decrease in the number of deaths from laboratory accidents, the foundation of laboratory safety operations in China remains weak compared to many developed nations. Furthermore, the incidence of non-fatal safety accidents remains high. Therefore, there is still significant progress needed in the realm of laboratory safety management.

Laboratory accident investigations and research indicate that while the unsafe behavior of laboratory personnel is the immediate cause of laboratory operational accidents, the root cause of frequent laboratory operational accidents is often attributed to management errors. Petersen et al. (Petersen 1997) highlighted that while accidents are primarily attributed to human unsafe behaviors, the underlying causes of accidents are linked to management policies, procedures, supervision, and training. Heinrich et al[1]. (Heinrich et al. 2019) concluded that the primary root causes of accidents encompass inadequate management systems and decision-making processes, personal factors, and environmental factors. They highlighted that personal and environmental factors are shaped by management practices, emphasizing that poor management systems and decision-making are the principal underlying causes of accidents[2].

Laboratory safety management entails various tasks that influence laboratory personnel and operations differently. The role of different safety management practices varies depending on the specific context. The effectiveness of laboratory safety management work can be significantly enhanced by comprehensively utilizing various safety management tools that align with the specific influence characteristics of safety management. This can be achieved through the establishment of a scientific and efficient laboratory safety management system. In the past, there was a predominant focus on examining the influences of various safety management behaviors on personnel's unsafe behavior in research. However, there was a lack of attention given to investigating the reciprocal influence among different safety management behaviors (Moreira 2019)[3]. This study focuses on laboratory safety management behavior as its research subject. Data is gathered through on-site interviews and questionnaires to empirically examine the characteristics of the influence relationship among various laboratory safety management behaviors using the fuzzy decision-making laboratory method. The results aim to offer valuable theoretical insights for guiding laboratory safety management practices[4].

II. Identification of System Elements

According to the nature of work, there are two main types of behaviors involved in laboratory safety management; one is work behavior, and the other is management behavior. Correspondingly, the behavior-based

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laboratory safety management system mainly includes two elements: managerial behavior and personnel behavior. The two elements are analyzed below.

(1) Personnel behavior

In laboratory operations, personnel may engage in various behaviors, such as walking, casting an eye on an object, reaching for something, using labor tools and so on. However, from a safety perspective, these personnel behaviors can be divided into safe and unsafe. Any behavior that may cause an accident and violate safety procedures is unsafe, and all other behaviors are considered safe (Ramos 2012)[5].

Most scholars have examined whether personnel behavior is safe from both structural and interactive aspects (Tkachenko et al. 2021). Structural mainly examines the extent to which personnel are involved in organizational safety activities. In contrast, interactional mainly examines the extent to which personnel interact and influence each other with their managers and their colleagues in their daily work. Specifically, the amount of compliance and participation behavior can be used to express the security of personnel behavior (Strielkowski et al. 2019). Among them, compliance behavior refers to the behavior of personnel strictly observing rules and regulations and working by safety processes or regulations, and participation behavior refers to the behavior of personnel helping their workmates, increasing their initiative to work safely, and striving to improve the level of safety at the workplace[6].

Personnel behavior is a choice of action based on their cognition after complex internal psychological activities, which is ultimately determined by the cognitive psychological factors of personnel. Based on the cognitive psychological processes of laboratory personnel, these cognitive psychological factors can be categorized into three types (Nijsse et al. 2017). Laboratory personnel in action know what they should do and how to do it, that is, the laboratory personnel's "knowledge" factor; laboratory personnel in action can make safe behavior do not make mistakes, that is, the laboratory personnel's "ability" factor; laboratory personnel in action whether they can make safe behavior, do not make mistakes, that is, the laboratory personnel's "ability" factor. Laboratory personnel's ability to act safely without making mistakes, i.e., laboratory personnel's "competence" factor; laboratory personnel's willingness to make behavioral choices to act safely, i.e., laboratory personnel's "attitude" factor. Personnel behavior is personnel in their work in the field environment, according to their own "knowledge," "ability," "attitude," and other individual cognitive psychological factors to make the choice of action, compliance, Behavior, and participation in the behavior of personnel are the result of this choice of action[7].

(2) Managerial behavior

In laboratory safety management, in order to prevent the laboratory operation process personnel from doing unsafe behavior, the manager must take various methods or measures to personnel's "knowledge," "ability," "attitude," and other cognitive psychological factors. "and other cognitive psychological factors to exert influence and control, prompting them to make safe behavioral choices. To this end, managers can implement a variety of management behaviors. For example, managers can be selected through the selection of suitable personnel from the source to ensure that personnel can meet the needs of laboratory safety production; managers can be through education and training to influence the personnel's "knowledge," "ability," "Attitude" and so on, so that it makes a safer choice of action; of course, managers can also use assessment, rewards and punishments and other means to influence the personnel's "knowledge," "ability," managers can also use evaluation, rewards and punishments and other means to influence the personnel's "knowledge", "ability," "attitude" and so on, prompting them to make a more conscious choice of safe behavior[8-9].

Many scholars summarize the various safety management behaviors that managers may implement from two aspects: design behavior and management behavior (Boudreau 2004). Design behavior refers to the manager's experience, knowledge, and course of action for personnel through prior thinking and design to develop various safety behavioral norms, protocols, plans, programs, and systems. Management behavior refers to the managers through education and training, safety supervision, communication, rewards, and punishments incentives, etc., with their practical actions to directly affect the personnel's "knowledge," "ability," "attitude," and other cognitive psychological factors. "And other cognitive psychological factors, which in turn affect their behavioral choices. In addition, to make their own behavioral choices more effective, managers also need to communicate with other managers to carry out the necessary information exchange or communication to understand and grasp the information of personnel behavior management through others in a timely manner. These activities that managers engage in can be expressed in communicative behaviors. In this way, a laboratory manager may engage in three main types of behaviors: design behaviors, management behaviors, and communication behaviors[10-13].

Similar to personnel, managerial behavior is a choice of action made by a manager based on his or her cognition and after a complex internal mental activity, which is ultimately determined by the cognitive psychological factors of the manager. According to the cognitive psychological process of laboratory managers, they can also be categorized into "knowledge," "ability," and "attitude" of the three types. Managerial behavior is the manager in the specific management environment, according to their own "knowledge," "ability," "attitude," and other individual cognitive psychological factors to choose action[14].

III. COMPOSITION OF LABORATORY SAFETY MANAGEMENT BEHAVIORS

To enhance the identification of laboratory safety management behaviors, the expert survey method is employed. This method involves screening various laboratory safety management behaviors through a systematic analysis of relevant research literature by scholars both domestically and internationally. Additionally, it considers the specific characteristics of laboratory safety management work[15-17].

Firstly, conduct interviews with individuals involved in laboratory safety management to gather insights on common safety management practices in laboratory settings. Secondly, categorize and summarize these identified safety management behaviors. Secondly, the research literature concerning safety management behaviors both domestically and internationally has been reviewed and systematized. Each study's safety management behaviors have been refined and compiled into a table illustrating the composition of safety management behaviors (Kontogiannis et al. 2017). Thirdly, the aforementioned two sections were presented to 5 experts specializing in laboratory safety management research. They were tasked with suggesting the precise structure of laboratory safety management behaviors drawing from their individual experiences. After multiple iterations, the experts' comprehension essentially aligned, resulting in the refinement of a total of 25 laboratory safety management behaviors. Each of these safety management behaviors was defined based on their connotations[18-19].

Given the accessibility of research data and the importance of the research for practical management, a secondary screening of the aforementioned laboratory safety management behaviors was carried out utilizing Nominal Group Technique (NGT) (Varga-Atkins et al. 2017). This study involved the selection of 10 experts, comprising 7 middle and senior managers in laboratories and 3 research scholars specializing in laboratory safety management. Each expert was tasked with identifying the most crucial safety management behaviors from a pool of 25 options and recommending a maximum of 15 behaviors. Following a comprehensive analysis, it was observed that nearly all experts nominated 13 laboratory safety management behaviors. These 13 behaviors related to laboratory safety management include: safety goal and policy development (B1), creating a safe atmosphere (B2), managing safety facilities (B3), modifying safety operating procedures (B4), evaluation and incentive/penalty (B5), task safety analysis (B6), safety education and training (B7), improving safety work environment (B8), on-site command and supervision (B9), safety information communication (B10), accident investigation and accountability (B11), safety investment (B12), and summary of safety work experience (B13). The forthcoming study will focus on the 13 laboratory safety management behaviors outlined.

Inevitably, there exists an interactive relationship among various behaviors related to laboratory safety management. Which safety management behaviors have a more significant influence? Which safety management behaviors have a lower influence? What safety management behavior holds the highest and lowest roles and statuses? The recognition of these issues is crucial for the development of a laboratory safety management system. The implementation of more effective safety management practices holds significant importance. Decision-Making Trial and Evaluation Laboratory (DEMATEL) method is a technique introduced by international researchers for the analysis of system factors through the application of graph theory and matrix tools (Lee et al. 2011). The visualization of the relationship among complex system factors using directed graphs and deterministic algorithms has emerged as a significant method for examining the interdependencies among system variables in recent years (Giang et al. 2022). This paper aims to investigate the interaction among the aforementioned laboratory safety management behaviors[20-21]

IV. RELATIVE IMPORTANCE OF 3 DIFFERENT SECURITY MANAGEMENT BEHAVIORS

Firstly, it is essential to compute the direct influence matrix A (Dette and Reuther 2010) that represents the relationships between various laboratory safety management behaviors. To derive the direct influence matrix among the 13 safety management behaviors, a scale was developed to assess the reciprocal influence of these behaviors, drawing on prior research. The relationship between any two factors is categorized into five levels, denoted by numbers 0 through 4. In this matrix, 0 signifies no influence, while 4 signifies an exceptionally significant influence.

A questionnaire survey was carried out involving 12 experts, and all questionnaires were collected, yielding valid data. Given the challenge faced by experts in quantifying the significance of laboratory safety management behaviors with specific numerical values, resorting to vague terms like "important", "relatively important", or "not important", it is more appropriate to employ fuzzy set theory for analysis (Mockor 2020). Therefore, the triangular fuzzy number method (Sadi-Nezhad et al. 2013) was employed to convert the experts' judgments into fuzzy values. Subsequently, Converting Fuzzy numbers into Crisp Scores (CFCS) method (Wu and Lee 2007) was utilized to transform the fuzzy numbers into crisp scores, facilitating the derivation of the direct influence matrix A for various laboratory safety management behaviors. Subsequently, Equation (1) was used to derive the normalized direct influence matrix D.

$$D=\frac{A}{s} \quad \text{(where } s=\max\left(\max_{1\le i\le n}\sum_{j=1}^{n}a_{ij},\max_{1\le j\le n}\sum_{i=1}^{n}a_{ij}\right)\text{)} \qquad (1)$$

Utilizing Equation (2), the comprehensive influence matrix T was derived to assess various laboratory safety management behaviors. The specific values are presented in Table 1.

$$T=D\left(I-D\right)^{-1} \qquad (2)$$

Table 1: Comprehensive Influence Matrix

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13
B1	0.12	0.30	0.22	0.20	0.25	0.21	0.27	0.24	0.29	0.28	0.19	0.20	0.22
B2	0.13	0.16	0.18	0.12	0.14	0.13	0.18	0.16	0.21	0.22	0.13	0.11	0.18
B3	0.12	0.24	0.11	0.13	0.20	0.13	0.16	0.14	0.24	0.23	0.15	0.10	0.17
B4	0.15	0.26	0.18	0.11	0.20	0.20	0.24	0.14	0.26	0.22	0.17	0.13	0.19
B5	0.12	0.24	0.14	0.12	0.11	0.13	0.18	0.12	0.20	0.21	0.14	0.10	0.14
B6	0.13	0.24	0.15	0.14	0.19	0.11	0.23	0.14	0.24	0.22	0.17	0.12	0.19
B7	0.12	0.23	0.14	0.12	0.16	0.12	0.12	0.13	0.18	0.19	0.13	0.09	0.15
B8	0.08	0.18	0.10	0.08	0.10	0.13	0.11	0.07	0.12	0.11	0.08	0.07	0.09
B9	0.10	0.24	0.16	0.12	0.16	0.12	0.15	0.12	0.13	0.21	0.12	0.11	0.14
B10	0.12	0.26	0.15	0.16	0.15	0.14	0.21	0.17	0.23	0.14	0.14	0.10	0.20
B11	0.16	0.26	0.15	0.14	0.21	0.17	0.21	0.15	0.19	0.19	0.10	0.10	0.20
B12	0.11	0.21	0.16	0.11	0.14	0.12	0.17	0.18	0.18	0.16	0.11	0.07	0.12
B13	0.19	0.27	0.18	0.19	0.21	0.20	0.23	0.19	0.26	0.22	0.16	0.16	0.14

Further analysis involves quantifying the influence and interdependence among various laboratory safety management practices through the application of Equations (3) and (4) (Zhang and Gong 2022).

$$r=\left[r_i\right]_{n\times 1}=\left(\sum_{j=1}^{n}t_{ij}\right)_{n\times 1} \qquad (3)$$

$$c=\left[c_j\right]'_{1\times n}=\left(\sum_{i=1}^{n}t_{ij}\right)_{1\times n} \qquad (4)$$

Where ri represents the influence of factor i on other factors through direct or indirect influences and ci represents the affectedness of factor i by other factors through direct or indirect influences. Therefore, (ri+ci) represents the overall influence and affectedness of factor i (Liou et al. 2008); whereas (ri-ci) represents the net influence of factor i (Meloni and Rocchi 2022). The degree of influence, affectedness, total influence, and correlation of different safety management behaviors, as calculated from the comprehensive influence matrix T (Table 2) (Hsu et al. 2010).

Table 2: Influence of Different Laboratory Safety Management Behaviors

Safety Management Behavior	Influence Degree	Affectedness Degree	Total Influence (ri+ci)	Net Influence
Safety Goal and Policy Development (B1)	2.87	1.52	4.39	1.35
Creating a Safety Atmosphere (B2)	1.91	2.96	4.87	-1.05

Managing Safety Facilities (B3)	2.00	1.89	3.89	0.11
Modifying Safety Operating Procedures (B4)	2.32	1.60	3.92	0.72
Evaluation and Incentive/Penalty (B5)	1.82	2.09	3.91	-0.27
Task Safety Analysis (B6)	2.14	1.78	3.92	0.36
Safety Education and Training (B7)	1.74	2.34	4.08	-0.60
Improving Safety Work Environment (B8)	1.18	1.83	3.01	-0.65
On-Site Command and Supervision (B9)	1.74	2.61	4.35	-0.87
Safety Information Communication (B10)	2.03	2.46	4.49	-0.43
Accident Investigation and Accountability (B11)	2.11	1.67	3.78	0.44
Safety Investment (B12)	1.72	1.33	3.05	0.39
Summary of Safety Work Experience (B13)	2.47	1.99	4.46	0.48

The analysis above suggests that the reciprocal influence of various laboratory safety management behaviors fluctuates. For instance, the cumulative influence of actions like fostering a safety culture, sharing safety-related information, and consolidating safety-related work experiences is significant, indicating a robust association with other safety management practices. On the contrary, safety objectives and the formulation of policies, adaptation of safety protocols, and consolidation of safety-related work background demonstrate a substantial net influence, suggesting a noteworthy influence on other safety management practices. Figure 1 illustrates the interconnections among various laboratory safety management behaviors.

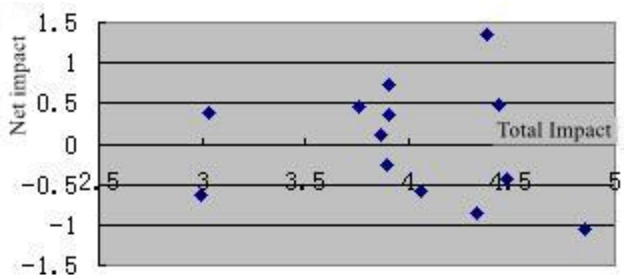

Figure 1: Interrelationships between Different Safety Management Behaviors.

V. Relative importance of different safety management dimensions

A meticulous examination of Figure 1 indicates that the 13 laboratory safety management behaviors outlined can be classified into five management dimensions. At the apex of Figure 1, the safety goal and policy development are situated, constituting a different dimension referred to as safety objectives. These elements represent the initial managerial tasks and serve as the standards or foundation for directing other safety management practices. Situated in the central-left section of Figure 1 are predominantly the safety operating procedures, task safety analysis, compilation of safety work experience, accident investigation, and accountability, all of which constitute managerial tasks associated with task execution. Therefore, they fall under the second dimension, namely the work plan. Situated centrally in Figure 1 are primarily safety education and training, evaluation, incentive/penalty systems, safety information communication, and the establishment of safety supervision teams. These elements predominantly pertain to controlling or providing feedback on the safety work processes, thus falling under the third dimension, namely process control. Located on the left side of Figure 1 are primarily safety investments and efforts to enhance the safe working environment. These initiatives focus on enhancing equipment or the physical environment at the operational site, thus falling under the fourth dimension, namely the safe environment. Situated at the base of Figure 1 are primarily the establishment of a secure atmosphere and on-site command and supervision tasks, with their principal objective being the establishment of a safe working environment. Therefore, they can be classified as the fifth dimension, specifically the safety atmosphere.

By employing a weighted average processing method on the safety management behavior data across various dimensions, it is possible to derive data on the levels of mutual influence, being influenced, total influence, and net influence among the five safety management dimensions. These results are presented in Table 3, while the interrelationships of mutual influence are illustrated in Figure 2.

Table 3: Influence of Different Safety Management Dimensions

Safety Management Dimension	Influence Degree	Affectedness Degree	Total Influence	Net Influence
Safety Goals (D1)	2.86	1.51	4.38	1.35
Work Plans (D2)	1.90	2.95	4.00	0.50
Process Control (D3)	1.99	1.88	4.07	-0.30
Safety Environment (D4)	2.31	1.59	3.01	-0.13
Safety Atmosphere (D5)	1.81	2.08	4.59	-0.95

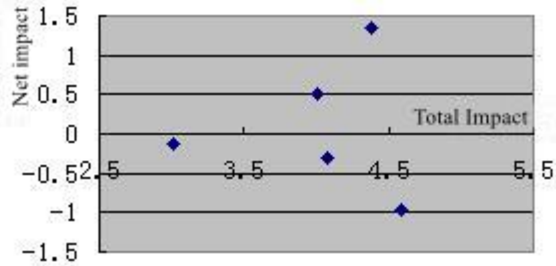

Figure 2: Diagram of Interrelationships between Different Safety Management Dimensions

The analysis indicates that both safety climate shaping and safety goal setting have a significant combined influence on the laboratory safety management system. This suggests that these safety management behaviors play a crucial role in the overall management system. Safety goals have the most significant net influence, suggesting that establishing safety goals serves as the foundation and assurance for other safety management practices. The safety climate exhibits the least significant influence, suggesting that efforts to shape the safety climate are heavily influenced by other safety management practices. The safety environment exhibits the lowest total influence degree, indicating that it exerts minimal influence on other safety management behaviors. Additionally, it is influenced by safety objectives and work plans. The work plan demonstrates a positive influence (Cheng et al. 2020) and aligns with the safety objective, suggesting that the work plan is not only guided by the safety objective but also has the potential to significantly influence other management behaviors. The process control occupies a central position with a significant degree of overall influence, suggesting a strong correlation between process control activities and other management practices. The safety culture is influenced not only by safety goals, work plans, and other managerial practices but also by the safety climate. It serves as a link between different safety management tasks and can facilitate top-down management effectiveness..

VI. Conclusion

Firstly, within the realm of laboratory safety management, it is imperative for managers to prioritize safety objectives and the development of work plans, as these tasks are not only crucial but also significantly influence other safety management practices.

Secondly, effective process control must be prioritized as it serves as the bridge and link among various safety management behaviors. It not only ensures the achievement of safety objectives and the implementation of work plans but also plays a crucial role in establishing a conducive safety atmosphere.

Thirdly, it is unnecessary to overly emphasize the shaping of a safety atmosphere, as it primarily emerges organically through the effective execution of other management behaviors. Given that the safety environment has the least correlation with other laboratory safety management activities, focusing excessively on this aspect does not significantly influence other safety management behaviors.

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