Safety Assessment and Application Model in College Chemical Laboratory

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Abstract. In the new era, the college chemical laboratory(CCL) has developed rapidly. The safety of CCL determines the safety of personnel and facilities in CCL. This paper analyzes various elements of the safety of CCL and builds the theoretical framework for the safety assessment of the CCL based on analytic hierarchy process(AHP). Besides, we use fuzzy comprehensive evaluation(FCE) to apply the assessment model to the M college chemical laboratory(MCCL). According to the results of the safety assessment, we propose improvement strategies for the research on the safety of CCL.

Keywords. college chemical laboratory(CCL); safety assessment; analytic hierarchy process(AHP); fuzzy comprehensive evaluation(FCE)

1 Introduction

In recent years, the number of college chemical laboratory(CCL) has increased, the scale has expanded, and safety incidents have occurred frequently, which makes the safety of CCL face great challenges[1]. According to relevant research[2-3], among the various types of laboratories in colleges and universities, chemical laboratory safety problems are particularly prominent. In terms of safety standards of laboratories, biological laboratories have established international standards for hierarchical management[4], while chemical laboratory hierarchical management standards are still facing a situation of non-uniformity and imperfection. There are also many academic discussions around the safety management of CCL[5-8], while there is a lack of research on how to establish a scientific safety assessment regulation to continuously improve the safety management capability of CCL. This paper applies the analytic hierarchy process(AHP) to the safety assessment of CCL, builds a safety assessment framework for CCL, and applies the assessment model by the fuzzy comprehensive evaluation(FCE), which provides an improvement strategy for the safety work of CCL.

In 1985, Satty *et al.*[9] proposed a classical algorithm called AHP for data analysis. Due to the simplicity, scientific, and hierarchical nature of this method, it has been widely used in applied assessment. AHP constitutes a top-down tree structure by dividing a complex problem into multiple levels. The hierarchical assessment model is obtained by analyzing the relative importance of the elements of each level.

FCE[10] is a comprehensive and quantitative evaluation method based on the theory of fuzzy operation, which is based on the principle of membership degree, and quantitatively evaluates

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complex and difficult problems through membership degree. Since FCE is suitable for the comprehensive assessment of multi-level factors, this paper applies it to the comprehensive assessment of CCL.

2 Analysis of safety elements of CCL

The safety management system of CCL is the standard and basis of safety management. In the management regulations, efficient management is an important force to improve the ability of safety hierarchical management[11]. Besides, safety prevention is the ultimate goal of laboratory safety. Therefore, how to promote the deep integration of safety regulation, safety management, and safety prevention in CCL has become the key to the improvement of the capacity of safety hierarchical management. In this paper, we analyze the laboratory safety elements from the three key elements of safety regulation, safety management, and safety prevention, and establish the safety element structure of CCL. The specific elements are illustrated in Figure 1.

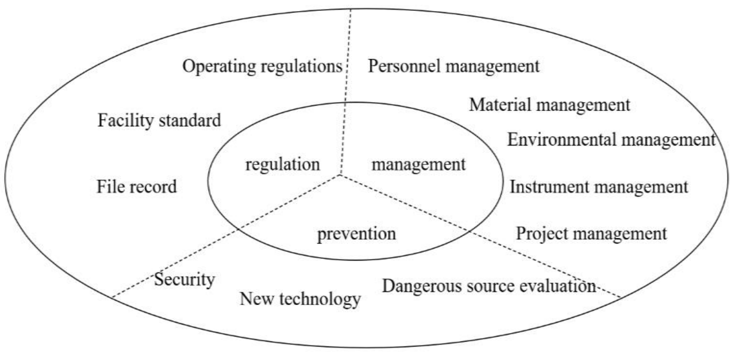

Fig. 1. Safety elements of CCL.

Among the safety elements of CCL, the capability of safety regulation cannot be ignored, which is the basic standard and important guarantee[12]. Improving the capability of safety regulation can be enhanced from the three aspects of operating regulation, facilities standard, and file record, which can strengthen the comprehensive safety of CCL.

The capability of safety management of CCL reflects the comprehensive management capability of laboratories for all kinds of safety factors, including personnel management, material management, environmental management, instrument management, and project management. Safety management is an important basis of the stable operation of CCL[13], which is conducive to the efficient and orderly development of safety work.

Safety prevention of CCL includes four aspects: environmental monitoring, hazardous sources prevention, introduction of new technologies and personnel safety prevention. The improvement of safety prevention can significantly reduce laboratory safety accidents triggered by various types of hazardous sources, which is a crucial support for the safety of CCL[14].

3 Construction of the safety assessment model

3.1 Calculation of indicator weights

Based on the framework of safety elements in CCL, the indicator weights are calculated by AHP. Besides, the questionnaire on the importance of the indicators is completed by six experts in related fields. The data from the questionnaire are integrated, and the judgment matrix is constructed, which is based on the importance scores of two indicators by the 1–9 scale method. The output of the judgment matrix is shown in Table 1, Table 2, Table 3, Table 4.

Table 1. Safety assessment.

Safety assessment	Safety regulation	Safety management	Safety prevention
Safety regulation	1	0.4	1.4
Safety management	2.5	1	2.4
Safety prevention	0.714	0.417	1

Table 2. Safety regulation.

Safety regulation	Operating regulation	Facilities standard	File record
Operating regulation	1	3.2	4
Facilities standard	0.312	1	2.4
File record	0.25	0.417	1

Table 3. Safety management.

Safety management	Material management	Personnel management	Instrument management	Environmental management	Project management
Material management	1	1.2	1.5	1.143	1.125
Personnel management	0.833	1	1.333	1.667	1.25
Instrument management	0.667	0.75	1	1.4	1.351
Environmental management	0.875	0.6	0.714	1	1.316
Project management	0.889	0.8	0.74	0.76	1

Table 4. Safety prevention.

Safety prevention	Environmental monitoring	Hazardous source prevention	Introduction of new technology	Personnel safety prevention
Environmental monitoring	1	4	1.6	2.4
Hazardous source prevention	0.25	1	0.7	0.9
Introduction of new technology	0.625	1.429	1	2
Personnel safety prevention	0.417	1.111	0.5	1

After completing the judgment matrix of the safety assessment indicators of CCL, it is necessary to check all judgment matrices for consistency. If there is an inadequacy, we need to adjust the judgment matrix accordingly[15]. We use equation (1)–(3) to check the consistency of each judgment matrix. If there is no problem, the subsequent calculation of the indicator weight can be carried out.

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{1}$$

$$RI = \frac{CI_1 + CI_2 + \cdots + CI_n}{n} \tag{2}$$

$$CR = \frac{CI}{RI} < 0.1 \tag{3}$$

By calculating the eigenvector of the largest eigenvalue of each judgment matrix and applying equation (4) to set the weights of each element, the weight vectors of each indicator are shown in Table 5.

$$\rho_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \tag{4}$$

Table 5. Weight vectors of assessment indicator.

Name of indicator	Weight vector
Safety assessment	（0.250，0.547，0.203）
Safety regulation	（0.625，0.247，0.128）
Safety management	（0.234，0.233，0.195，0.173，0.165）
Safety prevention	（0.442，0.142，0.26，0.156）

After figuring out the hierarchical single sorting weights within each indicator group, we need to calculate the comprehensive evaluation weights of each hierarchical indicator. By calculating the comprehensive weights of each element from the top to the bottom of the hierarchy, the final assessment model is shown in Table 6.

Table 6. Safety assessment model of CCL.

First level indicator	Weight	Second level indicator	Weight
Safety regulation A	0.250	Operating regulation A1	0.156
		Facilities standard A2	0.061
		File record A3	0.032
Safety management B	0.547	Material management B1	0.128
		Personnel management B2	0.127
		Instrument management B3	0.106
		Environmental management B4	0.09
		Project management B5	0.09
Safety prevention C	0.203	Environmental monitoring C1	0.09
		Hazardous source prevention C2	0.029
		Introduction of new technology C3	0.053
		Personnel safety prevention C4	0.032

We establish a safety assessment system by AHP from three dimensions of safety regulation, safety management, and safety prevention according to the safety elements of CCL, which lays the foundation for the application of the model.

3.2 Application of assessment model

According to the index weights of safety assessment standards and FCE to evaluate the safety management capability of M college chemical laboratory(MCCL) comprehensively. In this paper, five chemical laboratory administrators, five chemical laboratory safety officers, ten teachers, and twenty-five laboratory students are invited to assess the safety indicators of CCL by questionnaire survey. As is shown in Table 7, we get safety assessment results by the fuzzy comprehensive assessment matrix.

Table 7. Statistics of safety assessment results of CCLM.

First level indicator	Second level indicator	L1	L2	L3	L4	L5
Safety regulation A	Operating regulation A1	0.08	0.22	0.68	0.02	0
	Facilities standard A2	0.06	0.26	0.54	0.12	0.02
	File record A3	0.12	0.32	0.44	0.12	0
Safety management B	Material management B1	0.14	0.28	0.54	0.04	0
	Personnel management B2	0.24	0.46	0.22	0.08	0
	Instrument management B3	0.18	0.36	0.32	0.12	0.02
	Environmental management B4	0.22	0.32	0.36	0.08	0.02
	Project management B5	0.16	0.34	0.38	0.12	0
Safety prevention C	Environmental monitoring C1	0.14	0.32	0.42	0.12	0
	Hazardous source prevention C2	0.24	0.46	0.28	0.02	0
	Introduction of new technology C3	0.18	0.38	0.32	0.12	0
	Personnel safety prevention C4	0.22	0.42	0.24	0.10	0.02

*L1, L2, L3, L4, L5 represent high, relatively high, normal, relatively low, low.

As is shown in equation (5), we establish a comprehensive assessment matrix based on the assessment results. The specific steps are as follows.

$$R_A = \begin{bmatrix} 0.08 & 0.22 & 0.68 & 0.02 & 0 \\ 0.06 & 0.26 & 0.54 & 0.12 & 0.02 \\ 0.12 & 0.32 & 0.44 & 0.12 & 0 \end{bmatrix}, R_B = \begin{bmatrix} 0.14 & 0.28 & 0.54 & 0.04 & 0 \\ 0.24 & 0.46 & 0.22 & 0.08 & 0 \\ 0.18 & 0.36 & 0.32 & 0.12 & 0.02 \\ 0.22 & 0.32 & 0.36 & 0.08 & 0.02 \\ 0.16 & 0.34 & 0.38 & 0.12 & 0 \end{bmatrix}, \dots$$

$$R_C = \begin{bmatrix} 0.14 & 0.32 & 0.42 & 0.12 & 0 \\ 0.24 & 0.46 & 0.28 & 0.02 & 0 \\ 0.18 & 0.38 & 0.32 & 0.12 & 0 \\ 0.22 & 0.42 & 0.24 & 0.10 & 0.02 \end{bmatrix} \tag{5}$$

The comprehensive assessment vector U is calculated based on the weight vector W, the fuzzy comprehensive assessment matrix R, and the scoring coefficients $X = (5, 4, 3, 2, 1)^T$. As is shown in equation (6)–(8). The results of the second level assessment of MCCL are shown below.

$$U_A = W_A * R_A * X = (0.625,0.247,0.128)\begin{bmatrix} 0.08 & 0.22 & 0.68 & 0.02 & 0 \\ 0.06 & 0.26 & 0.54 & 0.12 & 0.02 \\ 0.12 & 0.32 & 0.44 & 0.12 & 0 \end{bmatrix} * X$$
$$= 3.33566 \quad (6)$$

$$U_B = W_B * R_B * X = (0.234,0.233,0.195,0.173,0.165)\begin{bmatrix} 0.14 & 0.28 & 0.54 & 0.04 & 0 \\ 0.24 & 0.46 & 0.22 & 0.08 & 0 \\ 0.18 & 0.36 & 0.32 & 0.12 & 0.02 \\ 0.22 & 0.32 & 0.36 & 0.08 & 0.02 \\ 0.16 & 0.34 & 0.38 & 0.12 & 0 \end{bmatrix}$$
$$* X = 3.63108 \quad (7)$$

$$U_C = W_C * R_C * X = (0.442,0.142,0.26,0.156)\begin{bmatrix} 0.14 & 0.32 & 0.42 & 0.12 & 0 \\ 0.24 & 0.46 & 0.28 & 0.02 & 0 \\ 0.18 & 0.38 & 0.32 & 0.12 & 0 \\ 0.22 & 0.42 & 0.24 & 0.10 & 0.02 \end{bmatrix} * X$$
$$= 3.61632 \quad (8)$$

As is shown in equation (9), comprehensive assessment of MCCL was obtained based on the scores of second indicators of safety elements and the weights of each second indicator:

$$U = (0.250, 0.547, 0.203) * (U_A, U_B, U_C) = 3.55422872 \quad (9)$$

This paper divides the safety assessment indicators into five levels as shown in Table 8. According to the assessment indexes, the safety of MCCL is in good level. In terms of safety regulation, MCCL is rated low. Therefore, the safety regulation can be improved through the improvement of emergency facilities standards and file record.

Table 8. Assessment indicators of safety elements.

Membership grade	Poor	Fair	Average	Good	Excellent
Numerical range	（0,1）	[1,2）	[2,3）	[3,4）	[4,5）

4 Conclusions

This paper establishes a three-layer safety element model by analyzing the safety elements of CCL. We employ AHP to set the weight of each safety element layer by layer and structure the safety assessment model. Besides, we utilize FCE to assess the safety of MCCL. Based on the assessment results, improvement strategies are proposed for the application of MCCL.

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