Library fire risk assessment based on variable weight theory-two-dimensional cloud model

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Abstract. The library has the characteristics of large fire load and dense personnel. Once a fire occurs, it will cause immeasurable serious consequences. Therefore, In this study, a method for fire assessment based on a two-dimensional variable-weight cloud model is proposed. Based on the variable weight theory, the variable weight function is introduced to determine the dynamic weight of each index, and the dynamic weight of the index is combined with the two-dimensional cloud model to draw the risk cloud map. Finally, the method is validated using the Yifu Library of Zhengzhou University of Light Industry as an example. This approach enhances the efficiency of evaluation and ensures that the assessment results are more objectively accurate and updated.

Keywords: Library, Fire risk assessment, Two-dimensional cloud model, Variable weight theory.

1 Introduction

The university library is an important place for faculty and students to research, learn, and share knowledge. and it is also a documentary center with a large number of documents and books. Therefore, the fire load in university libraries is very high. When fire breaks out, it may cause fatalities, unpredictable property damage and political impact.

At present, there are a large number of fire risk assessment studies of buildings at home and abroad[1-6].However, in recent years, there has been a lack of research on fire risk assessment for libraries. Therefore, in this study, a new index system for library fire assessment is first developed. Subsequently, a new evaluation method combining the variable weight theory and the two-dimensional cloud model is proposed to evaluate the fire risk of a library.

2 Index system optimization

According to JGJ 38-2015 “Library Building Design Code”, GB 55037-2022 “General Code for Building Fire Protection” and GB50222-2017 “Building Interior Decoration Design Fire Protection Code”, the most comprehensive 5 first-level indicators and 13

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second-level indicators were filtered out, so that the index system for library fire risk assessment was established. As shown in Figure 1

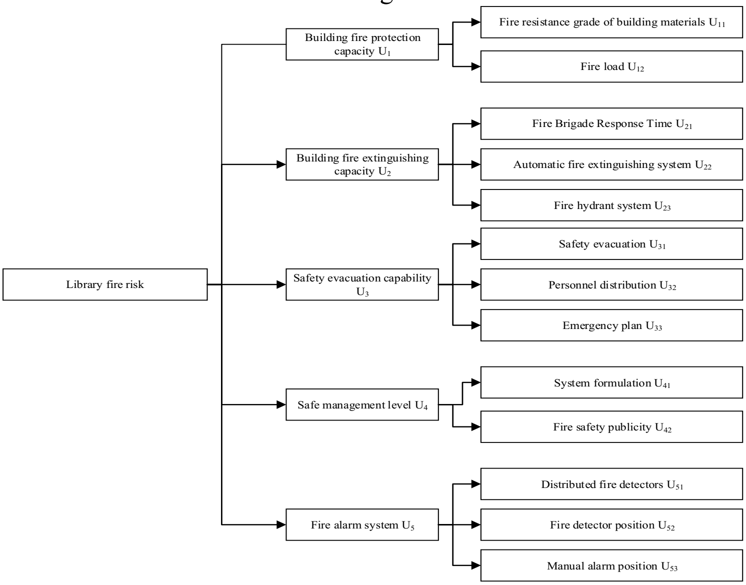


Fig. 1. Key index system

3 Variable weight-two-dimensional cloud model fire assessment method

3.1 Variable weight theory

It is necessary to introduce the variable weight theory to assign weights to the indicators dynamically, so that the obtained weights can better reflect the effects of parameter changes on the security condition of the system. That is, the weight changes dynamically with the change of the state value of the evaluation indicator to achieve an accurate evaluation of the system[7], as shown in equation (1).

$$W_j = \frac{W_j^0 S_i(x)}{\sum_{j=1}^{m} W_j^0 S_i(x)} \tag{1}$$

In the equation, W_j stands for the variable weighting coefficient, W_j^0 for the constant weighting coefficient, $S_i(x)$ is a state variable weight vector.

$$S_i(x)=\begin{cases}\frac{C_2-C_1}{\lambda-\mu}\mu\cdot\ln\frac{\mu}{x_i}+C_2, & 0<x_i\leqslant\mu\\ -\frac{C_2-C_1}{\lambda-\mu}x_i+\frac{C_2\lambda-C_1\mu}{\lambda-\mu}, & \mu<x_i\leqslant\lambda\\ C+\frac{C_2-C_1}{2(\lambda-\mu)(\alpha-\lambda)}(\alpha-x_i)^2, & \lambda<x_i\leqslant\alpha\\ C, & \alpha<x_i\leqslant\beta\\ k(1-\beta)\ln\frac{1-\beta}{1-x_i}+C, & \beta<x_i<1\end{cases} \tag{2}$$

Where $S_i(x)$ is the state variable weight vector of the interval penalty-incentive variable weight function; incentive range (β， 1); intermediate interval (α， β); Initial penalty interval (λ， α); Strong penalty interval (μ， λ); Special penalty interval (0， μ); C、C_1、$C_2$are given constants.k is the adjustment coefficient.

3.2 Two-dimensional cloud model

(1)Secondary risk cloud

The security level and consequences of risk can reflect the risk level of fire[8]. Therefore, in this study, the security level and consequence level of the index are selected as the two basic variables of the secondary risk cloud. Relevant experts are asked to evaluate the security level and consequence level of each secondary indicator. A ten-point system is used, and the precision is 0.1. The calculation formula for the digital characteristics of the secondary risk cloud is as follows:

$$\begin{cases}E_x=\frac{1}{q}\sum_{k=1}^{q}x_i\\ E_n=\sqrt{\frac{\pi}{2}}\times\frac{1}{q}\sum_{k=1}^{q}|x_k-E_x|\\ H_e=\sqrt{|S^2-E_n^2|}\\ S^2=\frac{1}{q-1}\sum_{k=1}^{q}(x_k-E_x)^2\end{cases} \tag{3}$$

In the formula :E_x is the expected value; q is the number of samples; x_k is the score of the k-th expert; E_n is entropy; H_e is super entropy;S^2 is the sample variance.

(2)Comprehensive risk cloud

Therefore, a new construction method is proposed in this study, that is, the stage variable weight function is used to construct the risk cloud. By analyzing the influence of a single index change on $S_i(x)$, the stage variable weighting function selects the parameters of the state variable weighting vector $S_i(x)$ as shown in equation (4).

$$S_i(x)=\begin{cases}0.8\ln\frac{0.4}{x_i}+0.7, & 0<x_i\leqslant 0.4\\ -2x_i+1.5, & 0.4<x_i\leqslant 0.5\\ 0.2+\frac{10}{3}(0.8-x_i)^2, & 0.5<x_i\leqslant 0.8\\ 0.2, & 0.8<x_i\leqslant 0.9\\ 0.15\ln\frac{0.1}{1-x_i}+0.2, & 0.9<x_i<1\end{cases} \tag{4}$$

By combining the eigenvalue matrix of the secondary security level risk cloud and the secondary consequence level risk cloud with the corresponding variable weight vector by equation (5), the eigenvalues of the security level risk cloud of level 1 and the consequence level risk cloud of level 1 are obtained. Two level 1 risk clouds can be combined into one comprehensive risk cloud by a two-dimensional cloud generator.

$$C = (w_1, w_2, \dots\dots, w_n)\begin{pmatrix} E_{x_1} & E_{n_1} & H_{e_1} \\ \cdots & \cdots & \cdots \\ E_{x_n} & E_{n_n} & H_{e_n} \end{pmatrix} = (Ex', En', He') \tag{5}$$

In the formula :Ex'， En'， He' are the expected value, entropy and super entropy of the first-level cloud respectively.$(w_1, w_2, \dots\dots, w_n)$ is the variable weight.

(3)Standard Cloud

In this study, the risk probability and consequences of the evaluation index are divided into five levels, from I to V, and the score [0,1] is divided into five intervals. The j-th subinterval is expressed as $[S_j^{min}, S_j^{max}]$.The formula for calculating the digital characteristics of the standard cloud is as follows :

$$\begin{cases} \overline{E_x} = \frac{S_j^{min}+S_j^{max}}{2} \\ \overline{E_n} = \frac{S_j^{max}-S_j^{min}}{2} \\ \overline{H_e} \in [\frac{E_x}{100}, \frac{E_n}{10}] \end{cases} \tag{6}$$

In the formula : $\overline{E_x}$ is the expectation of Standard Cloud;$\overline{E_n}$ is the entropy of Standard Cloud;S_j^{min} is the minimum value of the j-th interval;$S_j^{max}$is the maximum value of the j-th interval;$\overline{H_e}$ is the super entropy of Standard Cloud. The value range, grade description and digital characteristics of I to V are shown in Table 1.

Table 1. Risk level partition quantization criterion

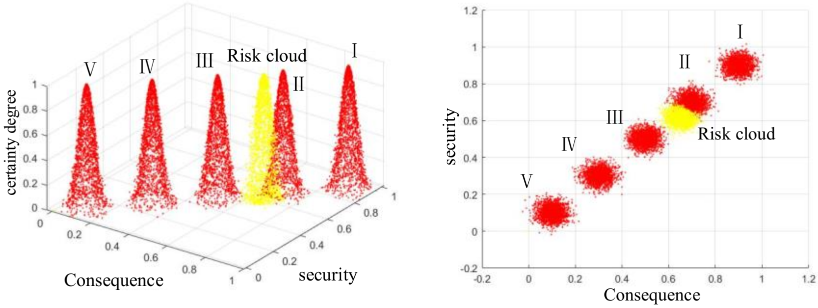
Risk level	Grade standard	Value interval	Consequence level description	Security level description	Digital characteristic
I	Very low	[0.8,1.0]	Minor	Very safe	(0.9,0.033,0.005)
II	Low	[0.6,0.8)	Greater	Safer	(0.7,0.033,0.005)
III	Moderate	[0.4,0.6)	Grave	General security	(0.5,0.033,0.005)
IV	High	[0.2,0.4)	Very serious	Insecurity	(0.3,0.033,0.005)
V	Very high	[0,0.2]	Disastrous	Very unsafe	(0.1,0.033,0.005)

4 Case analysis

The Yifu Library of Zhengzhou University of Light Industry Science Campus has a total area of 25,800 square metres, 7 above-ground floors and 1 underground floor. The height of the main body is 32.20 metres, and the design collection includes 900,000 books. It was opened in September 2014.

4.1 Analysis

As shown in Figure 2, the yellow color represents the risk cloud, while the red color represents the standard cloud. Based on the similarity calculation, it can be concluded that the degree of closeness between the risk cloud and the secondary standard cloud is the largest, which is 21.78. Therefore, the risk level of the library is rated as three levels, and the risk is partially accepted. It is acceptable to take certain control measures.

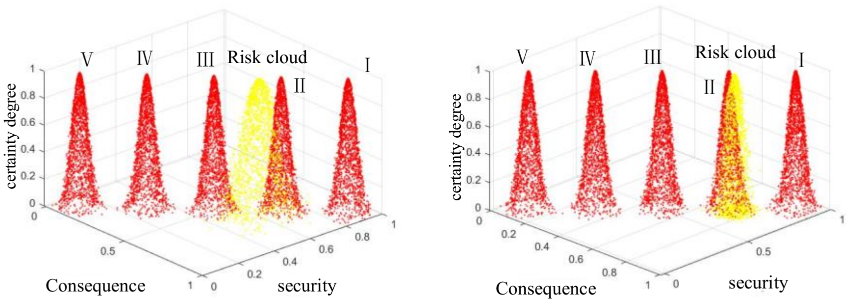


a. Main view b. Vertical view

Fig. 2. Comprehensive risk cloud

4.2 Variable weight-two-dimensional cloud model accuracy verification

In this study, the most commonly used combination weighting method [9], the dynamic weighting method [10] (the weighting multiplier in the method is 1) are used for experimental comparison. The risk cloud diagram of the three evaluation models is shown in Fig.3. From the figure, we can see that the evaluation results of both models indicate a second-level risk, consistent with the assessment results of the proposed variable weight-two-dimensional cloud model in this paper. This validates the accuracy of the model proposed in this paper, and confirms that the fire risk level of the Yifu Library is at a second-level risk.



(a)Combination weight method (b) Dynamic weight method

Fig. 3. Risk cloud of two assessment models

5 Conclusion

This paper presents a comprehensive fire risk assessment system based on existing national design models. It establishes a library fire risk assessment model using variable weight theory and the two-dimensional cloud model. The Yifu Library of Zhengzhou University of Light Industry is used for risk assessment, demonstrating the reliability and comprehensiveness of the indicator system. The two-dimensional cloud model evaluates fire risk considering building safety levels and consequence impacts, enhancing assessment comprehensiveness and reliability. The proposed method, combining variable weight theory with the two-dimensional cloud model, is deemed reliable and accurate. It better balances the influence among various indicators compared to existing methods, resulting in more accurate and objective evaluation outcomes.

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