Research on fire risk assessment model in commercial and residential communities

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ABSTRACT: The causes of fire in commercial and residential communities are complex, rescue is difficult, once a fire occurs, the loss is difficult to estimate, and a reasonable fire risk assessment needs to be made. This paper establishes a complete index system for fire risk assessment in commercial and residential communities, establishes a cloud model by using the ISM-Shapley value method, evaluates the safety level of a commercial and residential community in Jinan, and puts forward corresponding countermeasures, which provides a quantifiable analysis method for fire risk analysis.

1. GENERAL INSTRUCTIONS

With the acceleration of China's urbanization process, ordinary residential communities can no longer meet the new lives of current residents, and residential communities suitable for living and business have become the current development trend in China. However, according to statistics, in the past 10 years of national fire situation, residential places are more prominent. From 2012 to 2021, a total of 1.324 million residential fires occurred nationwide, resulting in 11,634 deaths, 6,738 injuries and direct property losses of 7.77 billion yuan, including 429 large fires, resulting in 1,579 deaths, and 2 major fires, resulting in 26 deaths. As a high-incidence fire accident area, commercial and residential small is bound to cause casualties and property damage, so assessing the risk and safety level of fire occurrence has become an important means to judge whether the building is safe.

Scholars at home and abroad have made the following achievements in building fire risk assessment: A.Bell [1] proposed a multi-mode hybrid neural network for building fire risk prediction, using Shapley value and ablation research to evaluate traditional and novel image features. O. Rachid [2] using artificial neural network models to predict potential fire impacts helps decision-makers strengthen and invest in specific fire safety strategies accordingly. M.D.B [3] developed the BN model to study fire development in ordinary homes down to advanced fire situations. Chen [4] A multi-layered regional model for predicting the development of a single indoor fire was established. The control equations for each layer are established through conservation of energy. Mi [5] conducted a comprehensive assessment of the two-dimensional quantity of building fire risk, and constructed the Fuzzy-DS model, which verified the effectiveness of the model. Zhou [6] used Bayes method and system fault tree analysis to obtain the probability of failure of large and medium-sized commercial buildings in China to control fire spread in the event of fire, which provided a basis for preventing and controlling fire spread. Zhang [7] constructed an assessment system for fire risk correlation factors in urban large-scale public buildings, and explored the mutual influence relationship between key risk factors. Yu [8] constructed a dynamic intelligent fire risk assessment model for old urban communities based on AHP-Bayes, realized the dynamic risk assessment of urban old communities.

In view of the current research status at home and abroad, most scholars have conducted fire risk research on single-function buildings, but there are few studies on fire risk assessment in commercial and residential communities, and there is a lack of fire risk model based on the logical relationship of community factors. In view of this, this paper establishes a complete index system for fire risk assessment in commercial and residential communities, and a cloud model based on the ISM-shapley value method is a fire risk assessment model for commercial and residential communities. It provides a quantifiable means for its fire risk analysis.

1.1. Characteristics of fire in commercial and residential communities

The commercial and residential community in this article refers to a number of commercial and residential buildings with a commercial ground floor or several floors and residential buildings on it, forming a relatively independent area through commercial podiums and other buildings along the street, meeting the needs of residents' residence, entertainment and commerce, and its fire has the following characteristics:(1) The structure is complex, and there are many ways to spread fire. (2) The area is narrow, and the fire protection occupies many roads. (3) The fire load is large. (4) The personnel are complex, the evacuation difficulty is large. (5) Fire safety

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management problems are prominent, and fire safety training has not been implemented.

2. ESTABLISH A FIRE ASSESSMENT SYSTEM FOR COMMERCIAL AND RESIDENTIAL COMMUNITIES

2.1. Indicator system construction

Through the analysis of fire risk factors in commercial and residential communities, reference to research literature and regulations, combined with expert opinions, the fire risk assessment index system of commercial and residential communities was determined. There are 8 level 1 indicators and 34 level 2 indicators. See Table 1:

Table 1. Fire risk assessment index system table for commercial and residential communities.

	Level 1 indicators	Level 2 indicators
Commercial and residential community	Commercial environments1	The size of the mall11
		Independent fire protection zones12
		Fire resistance rating13
		Rationality of the functional zoning of the mall14
		Commodity combustible density distribution15
	Residential environment2	Building structure and height 21
		The age of the building22
		Household fuel density distribution23
	Subsurface environment3	Underground burial depth 31
		Underground structural complexity 32
		Number of parking 33
	Fire fighting equipment4	Automatic sprinkler extinguishing system 41
		Electrical fire protection and circuit layout 42
		Fire water supply system 43
		Automatic fire alarm system 44
		Fire extinguishing and rescue equipment 45
		Anti-smoke extraction system 46
	Safe evacuation5	Number of security exits51
		Evacuation channel width and complexity52
		Emergency lighting and evacuation signs53
	Community personnel6	Personnel fire awareness and self-rescue ability61
		Proficiency in the use of firefighting facilities62
		Personnel activity63
	Common area environment7	The inter-building staggering degree of the community71
		Building fire spacing72
		Outdoor fire protection system73
		Fire lane conditions74
		Fire climbing operation field75
	Fire safety management8	Fire brigade rescue capabilities81
		Daily maintenance inspections82
		Fire department and fire system established83
		Emergency evacuation plan84
		Fire education and training85

3. BUILD A FIRE RISK ASSESSMENT MODEL FOR COMMERCIAL AND RESIDENTIAL COMMUNITIES

3.1. Introduction to ISM model

The ISM GAO [9] model decomposes complex problems into several subsystem elements, analyzes the mutual influence relationship of constituent elements, clarifies the level and structure of problems, and forms a multi-level ladder model for the system. The steps are as follows:

(1) Determine the adjacency matrix

Use 0 and 1 to represent the relationship between the two elements and establish the adjacency matrix. If V_i has a direct effect on V_j, A_{ij} is 1; If V_i has no direct effect on V_j , A_{ij} is 0. When $i = j, A_{ij} = 1$ each element is autocorrelated. The result is expressed as an adjacency matrix A=(A_{ij}).

(2) Calculate the reachability matrix

The reachability matrix represents the indirect effects between factors. A matrix can be obtained by adding A to the identity matrix I. The formula is as follow:

$$M = (A + I)^{n+1} = (A + I)^n \neq (A + I)^{n-1} \neq \cdots \neq (A + I)^2 \neq (A + I) \quad (1)$$

(3) Hierarchical division

The intersection of the reachability set $M(S_i)$ of a constraint and the antecedent set $N(S_i)$ is compared with the reachability set, and if $M(S_i) \cup N(S_i) = M(S_i)$, the influencing factor is deleted at the top level, and the above steps are repeated to obtain an explanatory structural model.

3.2. Introduction to Shapley value

Some index factors are interrelated due to some interaction between fire risk indicators in commercial and residential communities. The Shapley method, based on the ISM explanatory structural model, was chosen to express the degree to which multiple factors influence the overall goal [10].

(1) Normalize the mean of the original data and calculate the risk value of the index

$$v_i = \frac{a_i}{\sum_{i=1}^{n} a_i} \quad (2)$$

(2) Calculate the impact value of each indicator combination

$$v(1,2, \ldots, n) = \begin{cases} 0.8 \sum_{i=1}^{n} v(i), v(i) \in [0,1] \\ 1.2 \sum_{i=1}^{n} v(i), v(i) \in [0,1] \end{cases} \quad (3)$$

(3) Calculate the weights of each indicator

$$Sh_i(N, V) = \sum_{S \subset N, i \in S}^{n} \frac{(s-1)!(n-s)!}{n!} \left[v(S) - v\left(\frac{S}{i}\right) \right] \quad (4)$$

3.3. Introduction to cloud models

The basic idea of the cloud model is: assuming that U is a quantitative domain and C is a qualitative expression on U, if $x \in u$, and x is still a random implementation on C, and satisfies the membership degree of x to C $\mu(x) \in [0,1]$ is a random number with a stable tendency. Then the distribution of $\mu(x)$ satisfies $\mu: U \to [0,1], \forall x \in U, x \to \mu(x)$ is called a single x droplet, and the distribution state of all x on U is called a cloud [11]:

(1) Determine the collection of comments

The evaluation index set U and comment set V are established, and the value range corresponding to the comment set V is [0,100].

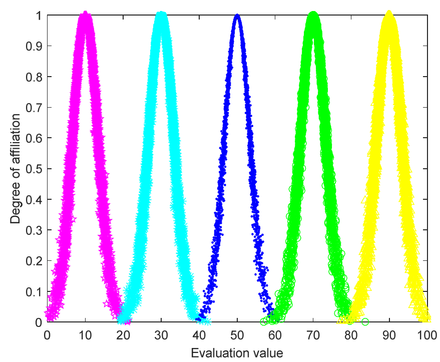
(2) Build a cloud map of evaluation ratings

The comment set is reduced to the standard cloud parameter (E_x, E_n, H_e), and the transformation process is as follows. As shown in Table 2.

$$\begin{cases} E_x = \frac{V_{max} + V_{min}}{2} \\ E_n = \frac{V_{max} - V_{min}}{6} \\ H_e = k \end{cases} \quad (5)$$

Table 2. Evaluation parameters and standard cloud map.

A collection of comments	Interval	Eigenvalue
U_1Slightly risky	[0,20]	(10.00,3.33,0.33)
U_2General risks	(20,40]	(30.00,3.33,0.33)
U_3Minor risk	(40,60]	(50.00,3.33,0.33)
U_4Higher risk	(60,80]	(70.00,3.33,0.33)
U_5High risk	[80,100]	(90.00,3.33,0.33)



(3) Calculate the cloud assembly of a single indicator

The reverse cloud generator is used to convert the score of each indicator x_i into the characteristics of the cloud model (E_x, E_n, H_e).Scoring data is based on the design of questionnaires that invite experts to assign scores to each risk indicator.

Expert evaluation matrix for each indicator: $R =$

$$X_{ij} = \begin{bmatrix} X_{11} & \cdots & X_{1m} \\ \vdots & \ddots & \vdots \\ X_{n1} & \cdots & X_{nm} \end{bmatrix} \quad (6)$$

The cloud vector is calculated using the following equation $C(E_X, E_n, H_e)$:

$$E_x = \bar{X} = \frac{1}{n} \sum_{i=1}^{n} (x_i) \quad (7)$$

$$S^2 = \frac{1}{n-1} \sum_{i=1}^{n} (x_i - \bar{X}) \quad (8)$$

$$E_n = \sqrt{\frac{\pi}{2}} \times \frac{1}{n}\sum_{i=1}^{n}|x_i - E_x| \tag{9}$$

$$H_e = \sqrt{|S^2 - E_n^2|} \tag{10}$$

(4) Integrate evaluation cloud parameters

Combined with the weight result Z, the fire cloud parameters of commercial and residential communities are calculated as follows:

$$\begin{cases} E_x = Z_1 E_{x_2} + Z_2 E_{x_2} + \cdots + Z_n E_{x_n} \\ E_n = \sqrt{{Z_1}^2 {E^2}_{n_1} + {Z_2}^2 {E^2}_{n_2} + \cdots + {Z_n}^2 {E^2}_{n_n}} \\ H_e = \sqrt{{Z_1}^2 {H^2}_{e_1} + {Z_2}^2 {H^2}_{e_2} + \cdots + {Z_n}^2 {H^2}_{e_n}} \end{cases} \tag{11}$$

(5) Determine the level of risk

MATLAB is used to generate risk cloud maps, and compare them with standard cloud maps to determine the fire risk level of commercial and residential communities.

4. EXAMPLE SIMULATION

4.1. Project overview

The project is located in Longshan Street, Jinan. The community has a planned land area of 11,214 square meters, a total construction area of 46,800 square meters, a total of 3 16-storey residential buildings, a total of 226 sets, the community is equipped with small four-storey commercial buildings along the street, and various supporting public facilities.

4.2. The ISM-Shapley method finds the weight

4.2.1. Build the ISM model diagram

(1) Using a matrix of 34×34, the adjacency matrix A is obtained as shown in Figure 1:

(3) (2) Entering the adjacency matrix into the MATLAB program, and the resulting matrix M is:

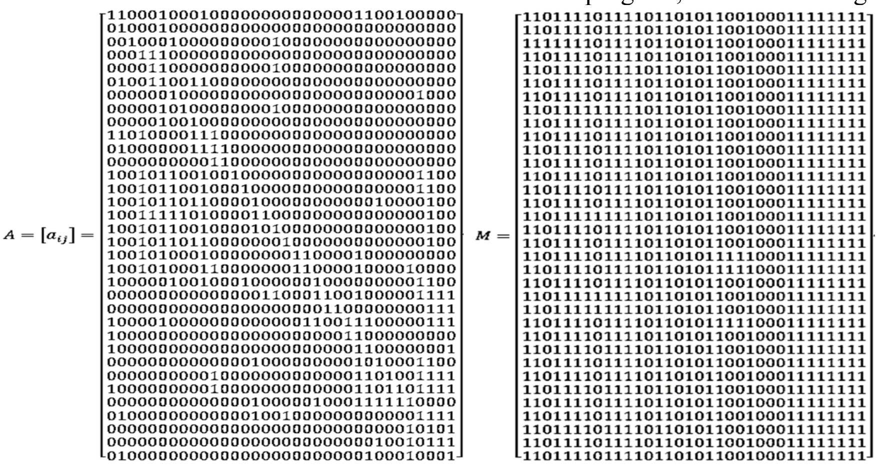


Figure1. Matrix diagram.

(4) The reachability matrix is divided into five levels through MATLAB software as shown in Table 3. The hierarchical diagram of the ISM model is shown in Figure 2.

Table 3. Classification table.

Hierarchical	Factor indicators
r=1	S11 S12 S14 S21 S22 S31 S32 S34 S42 S43 S45 S46 S53 S71 S72 S73 S74 S75 S81 S82 S83 S84 S85
r=2	S13 S23 S41 S51 S52
r=3	S44 S63
r=4	S61
r=5	S62

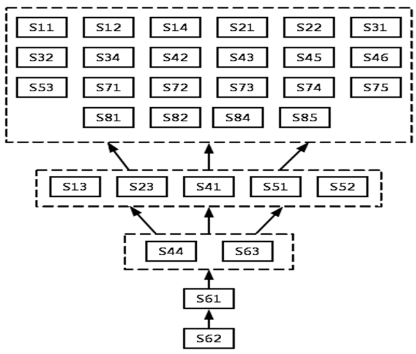


Figure 2. ISM model diagram

4.2.2. Shapley value method weight determination

Based on the index portfolio association impact degree of the ISM explanatory structure model, the combined risk value is obtained by formula, as shown in the Table 4.

Table 4. Risk portfolio value.

(N,V)	$V(S)$	(N,V)	$V(S)$	(N,V)	$V(S)$
V_1	0.165	V_6	0.182	…	…
V_2	0.125	$V_{(1,2)}$	0.232	$V_{(1,2,4,5,6)}$	0.718
V_3	0.102	$V_{(1,3)}$	0.214	$V_{(1,3,4,5,6)}$	0.700

V_4	0.250	$V_{(1,4)}$	0.332	$V_{(2,3,4,5,6)}$	0.668
V_5	0.176	$V_{(1,5)}$	0.273	$V_{(1,2,3,4,5,6)}$	1

Factor layer weights: $w_0 = (0.371,0.137,0.095,0.210,0.031,0.066,0.023,0.067)$

4.3. Model fire risk clouds

Experts in the field of fire protection are invited to score the risk level of the indicators of the D community.

According to Equation (2-10), the feature values of the cloud model can be calculated, this is shown in Table 5. Using the mathematical software MATLAB, and the fire risk was observed by comparing with the standard cloud map, this is shown in Figure 3.

Table 5. Cloud parameters.

indicators	cloud parameters	indicators	cloud parameters
C_1	(16.685,0.634,0.083)	C_6	(33.216,0.594,0.713)
C_2	(24.446,1.090,0.524)	C_7	(22.172,0.567,0.440)
C_3	(32.517,0.786,0.427)	C_8	(26.040,0.922,0.198)
C_4	(13.684,0.665,0.248)	C_0	(20.756,0.634,0.404)
C_5	(26.112,0.613,0.249)		

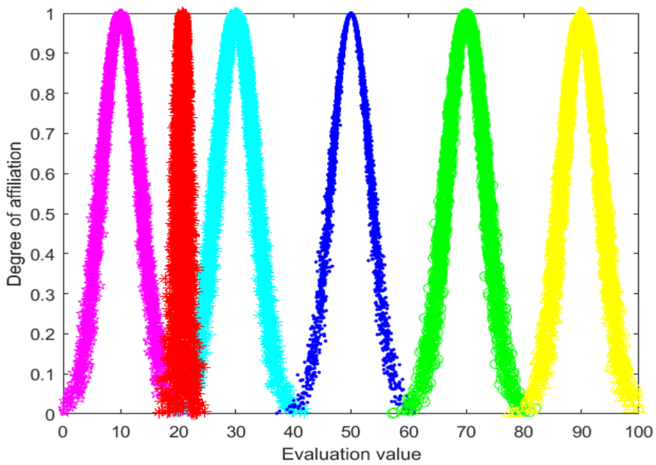


Figure 3. Evaluate the cloud map.

5. CONCLUSION

(1) Establish an evaluation system for commercial and residential communities through the investigation of the overall situation of fire accidents and reference to relevant literature. A cloud model of fire risk assessment based on ISM-Shapley value commercial and residential communities was established, and the conclusion that the fire risk level of residential area D was close to the level of "general risk" was concluded.

(2) According to the evaluation results of the fire risk assessment model of commercial and residential communities, fire control countermeasures are proposed, such as: improving the safety and fire management level of community properties, improving the planning and layout, and enhancing residents' fire awareness.

REFERENCES

1. A. Bell, et al. Remote Sens. Appl. Soc. Environ. **21** (2021)
2. O. Rachid, et al. J. Build. Eng.**42** (2021)
3. M.D.B, et al. Reliab. Eng. Syst. Saf. **114** (2013)
4. Chen. Combust. Sci. Technol. (2004)
5. Mi. China, Saf. Sci. Technol.**14** (2018)
6. Zhou. J. Build. Sci. (2008)
7. Zhang. J. Saf. Environ. **21** (2021)
8. Yu, et al. Saf. Environ. Eng.**28** (2021)
9. Gao. Math. Eng. (2021)
10. Ning. J. Eng. Manage. **30** (2016)
11. Song. Water Res. Prot. (2022)