Evaluation of the Disaster Resilience of the Commercial Complex Based on the Cloud Model

Huilin Zhang[1], *Xiaoqun Wang[2], Bin Hu[3]

1113237288@qq.com[1], [2]Corresponding author's email:wxq@sit.edu.cn , 969091611@qq.com[3]

College of Urban Construction and Safety Engineering, Shanghai Institute of Technology, Fengxian, Shanghai, China

Abstract. In order to enhance the accuracy and rationality of disaster-oriented resilience assessment for commercial complexes, we have developed a resilience assessment model based on a combination of the weighted-sum method and cloud model. Firstly, through literature review and on-site investigation, we conducted an analysis of both natural and non-natural disaster risks faced by commercial complexes and established an indicator system. Subsequently, employing a combination of Analytic Hierarchy Process (AHP) and entropy weight method, we allocated weights to resilience indicators. Further, in conjunction with the cloud model, we determined the resilience assessment levels. Finally, we validated the proposed methods based on the specific situation of a particular commercial complex.The results demonstrate that the resilience assessment for the specific commercial complex yielded a classification of "relatively good resilience," which aligns well with the actual conditions. This validation underscores the reliability and effectiveness of the model. The findings provide a theoretical foundation for enhancing the resilience of commercial complexes, particularly from a disaster perspective.

Keywords: commercial complex; disaster; resilience; risk assessment.

1 Introduction

In the process of urbanization, commercial complexes have become the core of urban life, facilitating public activities and commercial transactions. However, the role of commercial complexes is increasingly important, yet they also face challenges from various disaster risks, including natural disasters such as floods, typhoons, earthquakes, as well as non-natural disasters like fires and stampedes.

In resilience research, elasticity refers to the capacity of systems to resist and recover from disasters. Elasticity assessment is one of the forefront studies in disaster risk reduction, aiming to comprehensively evaluate the resilience of buildings, communities, and cities from economic, social, and technological perspectives under disaster conditions. Resilience assessment provides theoretical foundations and scientific guidance for disaster risk reduction strategies[1].Woods D. D[2]analyzed the definition of resilience from four aspects: adaptability, scalability, bounce-back, and robustness. Shen Ningning[3]identified and analyzed the factors influencing the fire vulnerability of commercial complexes. They preliminarily established an indicator system, applied the Likert method for indicator selection, and subsequently constructed an evaluation model combining composite weights and set-pair analysis. The model was applied in practical examples to validate its feasibility. At present, the vast majority of scholars have

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focused on the community and urban areas, and although some have studied the fire resilience of commercial complexes, the systematic assessment of resilience in the event of sudden scarce. In addition, the existing index system construction also has shortcomings, to be further improved and optimized.

2 The resilience evaluation index system of commercial complex

The resilience of commercial complexes is influenced by various factors. Selecting comprehensive and reasonable evaluation indicators and establishing an evaluation system are essential foundations for maintaining their normal operation. Firstly, through relevant analysis and based on literature research, four primary indicators were developed, namely the ability to withstand disasters, the ability to respond to disasters, the ability to adapt to disasters, and the ability to recover after disasters. Secondly, drawing from the principles of scientificity, applicability, comprehensiveness, and hierarchy, evaluation indicators were selected, referencing the "GB/T 40947-2021 Guidelines for Safety Resilience City Assessment" and "XF/T 3019-2023Rules for Fire Safety Management of Large Commercial Complexes." In the end, 16 secondary indicators were determined to construct the resilience evaluation system for commercial complexes, as shown in Table 1.

Table 1 The resilience evaluation system of commercial complex

Level 1 indicators	Secondary indicators	Index interpretation
The ability to withstand disasters A1	Effectiveness of the disaster monitoring and early warning system A1	Whether the disaster comes can be effective early warning
	Building Fire Protection Design A12	Whether the design of fire control system, ventilation and smoke exhaust system, fire access, fire prevention partition and smoke control partition is reasonable
	Shopping mall building characteristics A13	1. Whether the building height and area are reasonable; 2, the structural design of the building and the materials used have enough strength and toughness
	Auxiliary system stability A14	Electricity, gas, water supply, network and other infrastructure is stable
	Multifunction using A15	The buildings are designed to be multifunctional so as to flexibly respond to different needs after a disaster
	Environment-friendly and sustainable, A16	Whether buildings are designed to consider environmental friendliness and sustainability
	Elastic design and disaster adaptation A17	Whether elastic design principles are adopted to maintain structural integrity and functionality after impact
Ability to deal with	Rationality of disaster emergency plan A21	Whether the emergency plan initiated by the disaster can deal with different disasters
	Emergency evacuation design A22	Whether the location of safety exit, shelter and evacuation passage is reasonable in disaster occurrence

disasters A2	Mall internal personnel emergency handling capacity A23	Whether the internal personnel of the mall have emergency capabilities
	Emergency facility and equipment reliability A24	Whether the equipment and facilities in the commercial complex are regularly inspected and maintained
Ability to adapt to disasters A3	Emergency evacuation drill situation A31	1.Whether there are guiding documents such as annual disaster prevention and mitigation emergency work plan; 2.Whether to carry out various disaster prevention and reduction work in an orderly manner in accordance with the annual plan
	Staff safety education and training A32	Modern businesses should have good technology and digital capabilities to quickly adapt to change in case of disasters. This could include capabilities such as telecommuting, online sales, and digital marketing
	Maintenance of the equipment and facilities A33	Whether the equipment and facilities in the commercial complex are regularly inspected and maintained
	Implement the rectification and supervision system A34	1. Whether the internal hidden danger inspection is rectified on time;2. Whether to establish a sound supervision system.
Ability to recover from a disaster A4	Construction of the emergency rescue team A41	1.Whether the number of rescue team personnel meets; whether the personnel have emergency experience; 2.Whether the knowledge of emergency rescue is mastered and whether it can be skillfully applied
	Allocation capacity of disaster relief resources A42	Whether the emergency relief supplies are sufficient
	Professional emergency repair capacity A43	The ability to repair the commercial complexes and the corresponding equipment and facilities
	Technology and digital capabilities A44	Modern businesses should have good technology and digital capabilities to quickly adapt to change in case of disasters.
	Supply Chain Management A45	Whether the business body has a sound supply chain management system
	Community engagement and collaboration A46	Whether to establish good relations with the community

3 Mathematical evaluation of the model theory

3.1 Evaluation of disaster resilience level of rail transit system based on extended cloud model

In the comprehensive evaluation of the disaster resilience level of commercial complexes, the weight calculation of the indicators is particularly critical, so the weight of the indicators must be reasonably allocated to ensure the true reflection of the characteristics of the evaluation indicators.We employ the Analytic Hierarchy Process (AHP) for subjective empowerment method and the entropy weight method for objective empowerment method to ascertain subjective and objective weights, respectively. AHP involves the expert scoring method for constructing the judgment matrix,and makes pairwise comparisons in different index layers to calculate the weight coefficient. Finally, it completes the calculation of the index weight of the hierarchical analysis method through the consistency test. The entropy weight rule evaluates the weight of indices using information entropy, which indicates the level of uncertainty associated with the indices. In our study, we utilized the linear weighting method to combine the subjective and objective weights obtained, resulting in the comprehensive weight vector denoted as ω[4][5].

$$\omega = a\omega_i + (1 - a)\omega_j \quad (a=0.5) \tag{1}$$

In the formula: (i, j = 1, 2, 3-n, where i and j represent the number of indicators, w is the subjective weight, and α is the objective weight. α is the bias coefficient, with a value of 0.5 indicating that when subjective and objective weights are equally important, the resulting weight deviation is minimized.)

3.2Evaluation standard: the determination of the cloud

In the cloud model, the mapping relationship between qualitative concepts and quantitative features is represented by three numerical characteristic values: expectation (Ex), entropy (En), and hyper-entropy (He)[6].Construction evaluation standard level, where the evaluation range for the m-th level is $[x^{min}, x^{max}]$, the formula for calculating the numerical characteristic values (E_x, E_n, H_e) of the standard cloud corresponding to this range is as follows:

$$\begin{cases} E_x = \frac{x^{max}+x^{min}}{2} \\ E_n = \frac{x^{max}-x^{min}}{6} \\ H_e = k \end{cases} \tag{2}$$

In the equation, x^{max} and x^{min} represent the maximum and minimum boundaries of the comment set, respectively; k is a constant, and in this context, it is set to 0.5.

3.3Determine the index evaluation cloud and the comprehensive evaluation cloud[7][8][9]

Based on the evaluation level of the construction, conduct n evaluations of the designated indicators. Convert the qualitative assessment values of the indicators into numerical features represented by a cloud model. The specific formula is as follows.

$$\begin{cases} E_{x_j} = \bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \\ E_{n_j} = \sqrt{\frac{\pi}{2}} \times \frac{1}{n}\sum_{i=1}^{n} \left| x_i - E_{x_j} \right| \\ H_{e_j} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n} \left(x_i - E_{x_j}\right)^2 - \left(E_{n_j}\right)^2} \end{cases} \tag{3}$$

The cloud numerical features of each evaluation indicator at the indicator level are multiplied by their respective weights, yielding the comprehensive result of the higher-level evaluation indicator. Consequently, the comprehensive cloud numerical features of various indicators at the target level in the indicator system are calculated. The specific formula for calculating the comprehensive cloud numerical features is as follows.

$$\begin{cases} E_x = \frac{E_{x_1}E_{n_1}\omega_1+E_{x_2}E_{n_2}\omega_2+\ldots+E_{x_n}E_{n_n}\omega_n}{E_{n_1}\omega_1+E_{n_2}\omega_2+\ldots E_{n_n}\omega_n} \\ E_n = E_{n_1}\omega_1 + E_{n_2}\omega_2 + \ldots + E_{n_n}\omega_n \\ H_e = \frac{H_{e_1}E_{n_1}\omega_1+H_{e_2}E_{n_2}\omega_2+\ldots+H_{e_n}E_{n_n}\omega_n}{E_{n_1}\omega_1+E_{n_2}\omega_2+\ldots+E_{n_n}\omega_n} \end{cases} \quad (4)$$

4 Application instances

Take the actual situation of Huaihai Parkson as an example.

4.1Determine the evaluation criteria

The evaluation results of the resilience of the commercial complex are divided into five grades, which indicate the advantages and disadvantages of the modified evaluation system, and the evaluation grades are divided into (poor, range, commonly,preferably, good). Quantitative description was made according to the interval [0,100] scored by experts, and the corresponding quantification interval for each evaluation grade was [0,40), [40,60), [60,75), [75,90), [90,100]. Equation (2) transforms it into the digital features of the cloud model, and the results are shown in Table 2.

Table 2 Standard cloud digital characteristic indicators

order of evaluation	descriptive grade	section	(Ex,En,He)
V	poor	[0,40)	(20,6.67,0.5)
IV	range	[40, 60)	(50,3.33,0.5)
III	commonly	[60,75)	(67.5,2.5,0.5)
II	preferably	[75,90)	(82.5,2.5,0.5)
I	good	[90,100]	(95,1.67,0.5)

4.2 Calculate the index weights and the cloud feature values

Establish the judgment matrix, and use AHP (Analytic Hierarchy Process) and entropy weighting method to obtain the combined weights of indicators at all levels, and calculate the cloud parameters of each indicator, as shown in Table 3.

Table 3 Weights and the cloud model feature values

Level 1 indicators	Secondary indicators	Subjective weight		Objective weight		combination weight		Digital features of the cloud model	
		Secondary indicators	Level 1 indicators	Secondary indicators	Level 1 indicators	Secondary indicators	Level 1 indicators	Secondary indicators	Secondary indicators
A_1	A_{11}	0.19	0.47	0.16	0.31	0.17	0.39	(89.68,1.91,0.65)	(92,2,0.22)
	A_{12}	0.18		0.17		0.17			(92,2,0.22)
	A_{13}	0.30		0.17		0.23			(90.4,2.1,0.4)
	A_{14}	0.09		0.14		0.12			(91.2,2.3,1.1)

	A_{15}	0.06		0.13		0.10			(82.6,1.6,1.1)
	A_{16}	0.04		0.11		0.08			(87,1.5,1.4)
	A_{17}	0.15		0.13		0.14			(85,1.5,1.4)
A_2	A_{21}	0.11	0.28	0.27	0.27	0.19	0.27	(88.18,1.97,0.53)	(88,2,0.22)
	A_{22}	0.50		0.27		0.39			(89.2,1.8,0.9)
	A_{23}	0.31		0.22		0.26			(87.4,2.1,0.4)
	A_{24}	0.07		0.25		0.16			(87.6,2.1,0.4)
A_3	A_{31}	0.38	0.16	0.25	0.24	0.31	0.20	(87.08,2.01,0.70)	(89.2,1.8,0.9)
	A_{32}	0.30		0.18		0.24			(85.4,2.1,0.4)
	A_{33}	0.17		0.28		0.23			(86.8,2.3,0.5)
	A_{34}	0.16		0.28		0.22			(86.6,1.9,1.1)
A_4	A_{41}	0.23	0.10	0.20	0.18	0.21	0.14	(82.24,2.03,0.74)	(90.2,2.3,0.5)
	A_{42}	0.30		0.18		0.24			(79.2,1.8,0.9)
	A_{43}	0.25		0.17		0.21			(79.6,2.1,0.4)
	A_{44}	0.13		0.16		0.14			(83.2,1.8,1.2)
	A_{45}	0.03		0.15		0.09			(78.4,1.9,1.1)
	A_{46}	0.07		0.13		0.10			(77.8,2.3,0.9)

4.3 Comprehensive Evaluation Results

By calculating the standard characteristic values and the computed comprehensive cloud numerical characteristic values using the Python software through the forward cloud algorithm, standard cloud charts and comprehensive evaluation cloud charts are drawn for comparison. As shown in Figure 1.

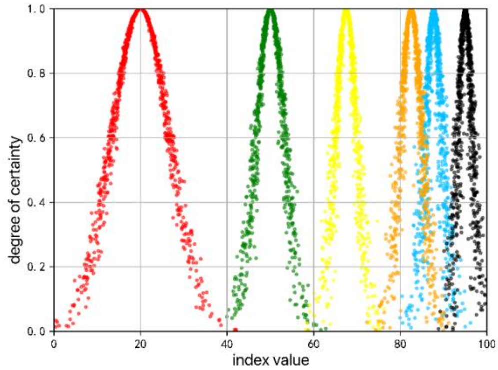

Figure 1.Standard cloud and evaluation comprehensive cloud map.

5 Conclusion

1) Entropy weight method and hierarchical analysis method are selected to determine the index weight, which weakens the influence of subjectivity and extreme value; reuse cloud model to determine the risk level, effectively avoiding the ambiguity and randomness of evaluation index, thus improving the accuracy of resilience evaluation of commercial complex.

2) The digital characteristics of the comprehensive cloud model of a commercial complex are (87.69,1.96,0.64), and the evaluation level is the highest at 87.69, and the cloud drop is the

most concentrated, at a good level. The evaluation grade is good, which is basically consistent with the actual situation in the field, and verifies the effectiveness of the model.

3) The index system and evaluation model established in the paper have good applicability, which can provide reference for the future research on the resilience of commercial complex and improve the level of safety management.

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