PLOS ONE

RESEARCH ARTICLE

Fire risk assessment of high-rise buildings under construction based on unascertained measure theory

Wenlong Li[1]*, **Huimin Li**[1], **Yijun Liu**[1], **Sunmeng Wang**[2], **Xingwang Pei**[1], **Qian Li**[1]

1 School of Civil Engineering, Xi'an University of Architecture and Technology, Xi'an, Shaanxi, China,
2 School of Management, Xi'an University of Architecture and Technology, Xi'an, Shaanxi, China

* 1536295967@qq.com

Citation: Li W, Li H, Liu Y, Wang S, Pei X, Li Q (2020) Fire risk assessment of high-rise buildings under construction based on unascertained measure theory. PLoS ONE 15(9): e0239166. https://doi.org/10.1371/journal.pone.0239166

Editor: Baogui Xin, Shandong University of Science and Technology, CHINA

Received: July 11, 2020

Accepted: August 31, 2020

Published: September 14, 2020

Data Availability Statement: All relevant data, calculations and results are presented in the manuscript.

Funding: This study was supported by the National Natural Science Foundation of China, Grant No. 51808424, 51678479, 51478384, 51178386 (http://www.nsfc.gov.cn/). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Competing interests: The authors have declared that no competing interests exist.

Abstract

To prevent fire accidents in high-rise buildings under construction, in this paper, the fire risk assessment of such buildings is studied. First, based on project investigation and a literature review, a fire risk assessment index system suitable for high-rise buildings under construction was established. Second, the unascertained measure theory was applied to establish a fire risk assessment model for high-rise buildings under construction. The index weight was determined by the entropy weight method. Finally, taking a high-rise building project in Xi'an, China, as an example, the feasibility and rationality of the fire risk assessment index system and assessment model were verified. This research provides a new method for objectively assessing the fire risk of high-rise buildings under construction and provides a certain reference for controlling the fire risk of high-rise buildings under construction.

Introduction

The continuous progress of society and the development of the economy have resulted in gradual urbanization and the rapid construction of various types of buildings [1, 2]. At present, the engineering projects under construction can be seen everywhere. Due to the large amount of combustible and flammable materials on the construction site, many fire and heat sources, poor fire fighting conditions, and high fire risk, and once a fire occurs, it is difficult to fight the fire. The frequent fires of engineering projects under construction have caused serious safety accidents, caused serious property losses and casualties, and brought extremely bad social impacts [3]. At the same time, it will also affect the sustainable development of society and the environment [4]. Therefore, the fire risk of engineering projects under construction has attracted the attention of all sectors of society.

The fire risks of high-rise building under construction are relatively large, with many influencing factors and thus high complexity and uncertainty, mainly in the following aspects. On the one hand, high-rise buildings under construction require a large amount of work, a long construction period, and a complex and variable construction environment, and these factors increase fire risk uncertainty. Especially during the peak period of construction, there are many mixed operations, open-fire operations, and fire hazards, which can easily lead to fire accidents. On the other hand, the high-rise buildings under construction are still in the construction state, most of the fire control systems of the buildings have not been installed in place, or are not in use even though they have been installed. Instead, there are only some temporary fire control facilities on the construction site, and the fire water source is limited. Therefore, in the event of a fire, the fire spreads quickly and is difficult to extinguish.

Therefore, it is important to understand the hidden fire hazards present in high-rise buildings under construction, to perform scientific risk assessments and to take effective preventive measures.

Literature review

The literature review and analysis are divided into two parts.

Building fire risk assessment

To reduce the probability of building fires and to prevent and control such fires, much research has been done on building fire risk. In the 1980s, with the continuous progress of science and technology, ultrahigh buildings and super-large buildings began to appear; however, the current design specifications could not meet the fire protection requirements of the new buildings. Therefore, performance-based fire protection design was proposed. In 1985, the UK promulgated the first performance-based fire protection code. Thereafter, some developed countries researched performance-based fire protection design and related fire safety engineering theories and technologies and explored performance-based fire protection design. From 1996 to 2002, four international symposia on performance-based design norms and design methods were held, showing that performance-based fire protection design had become an international trend. Since then, an increasing number of experts and scholars have researched building fire risk. Kang et al. calculated the fire safety assessment level of high-rise buildings by using fuzzy centralization theory, and the developed method was both applicable and practical [5]. Ding et al. developed a smart fire risk estimation model for high-rising buildings by using the back propagation (BP) neural network [6]. Ren designed a model for assessing the fire risks of logistics warehouses by using the analytic hierarchy process (AHP) method [7]. Xin et al. analyzed a large number of fire incidents in China, determined the characteristics and main factors of the fires, and evaluated the risk levels of residential buildings [8]. Wu et al. presented a diagnostic assessment of fire safety by using the extension engineering method, which can be applied for all kinds of buildings [9]. Gao et al. established a fuzzy analytic hierarchy process model that aimed to assess the tunnel fire risk of subways by combining the fuzzy consistent matrix with AHP [10]. Chen et al. established a building fire risk assessment system for factories, hotels, malls, schools and public buildings and applied AHP to evaluate building fire risk [11]. Sun et al. introduced fuzzy mathematics into the analytic hierarchy process; furthermore, the analytic hierarchy process-fuzzy comprehensive evaluation (AHP-FCE) method was used to evaluate risk, and the traditional quantitative evaluation method was integrated with the qualitative evaluation method [12]. Roshan et al. assessed fire risk and economic loss by using event tree analysis [13]. Lau et al. proposed a fire risk scoring system and applied it for determine the fire risk of residential buildings [14]. Wei et al. established a fire risk assessment model based on support vector machine (SVM) theory, and the method was precise even when given a small number of samples [15]. Wei et al. proposed a fast fire risk assessment method based on fuzzy mathematics and the SVM algorithm [16]. Liu et al. proposed a fire risk assessment system for large-scale commercial buildings by using the structure entropy weight method [17]. Li et al. established a mathematical model by using the gray risk degree method, the analytic hierarchy process and the fuzzy evaluation method [18]. Bart et al.

developed a quantitative risk assessment method that can quantify the fire safety level through the failure probability, individual risk and social risk [19]. Sun et al. expounded the procedures and methods of fire risk assessment for super-high-rise buildings and quantified the possibility and consequences of a fire [20]. Qian et al. established an urban fire risk assessment index system according to the possibility and severity of the fire and constructed an evaluation model based on regression with latent variables [21]. Hassanain et al. developed a fire safety evaluation tool that can evaluate existing restaurant facilities to identify and eliminate fire hazards [22]. Omidvari et al. proposed a model based on the analytical hierarchy process and failure mode and effect analysis logic [23]. Li et al. built a fire risk assessment system for coal mines based on the TOPSIS method [24]. Zheng conducted a fire risk assessment of the stadium used for the National Games based on the AHP method to ensure safety [25].

Many researchers have introduced and systematically summarized models and methods for quantitatively assessing building fire risk [26]. In addition, there are many fire risk assessment methods [27, 28] (e.g., expert scoring, Delphi, analytic hierarchy process, fuzzy comprehensive evaluation, fault tree analysis, grey comprehensive evaluation, SVM, TOPSIS, artificial neural network, matter element extension). Researchers have applied these methods for fire risk assessment.

In summary, there are many studies on fire risk, and good applications have been developed. Relevant research is mainly focused on the fire risk of existing buildings. There is relatively little research on the fire risk of buildings that are under construction and even less research on the fire risks of high-rise buildings under construction. Therefore, in this paper, high-rise buildings under construction are considered as the research object, the characteristics of fire accidents in the high-rise building under construction are summarized, a fire risk assessment is conducted for high-rise buildings under construction.

However, the fire risks of high-rise buildings under construction are relatively large, with many influencing factors and thus high complexity and uncertainty. In addition, there are many uncertainties associated with the assessment index and the assessment process. Therefore, reasonable mathematical methods are needed for fire risk assessment of high-rise buildings under construction.

Unascertained measure theory

Unascertained information and its mathematical processing theory were first proposed by Wang Guangyuan in 1990 [29]. Unlike fuzzy information, random information and gray information, unascertained information indicates that people do not fully grasp the real quantitative relationships or states being considered, which causes subjective and cognitive uncertainty in the minds of decision makers and evaluators. It can be said that all systems with behavioral factors are unascertained. To develop a method for quantitatively describing the unascertained state or the unascertained size of something, Liu Kaidi et al. [30] established unascertained mathematical theory and proposed an evaluation model for unascertained measure theory to describe an unascertained state or an unascertained nature by using a real number in [0,1].

Thereafter, unascertained measure theory has been rapidly developed and widely applied in many fields, such as mining risk assessment [31, 32], geotechnical risk evaluation [33, 34], pipeline risk assessment [35], geological risk assessment [36], ecological risk assessment [37], chemical safety evaluation [38], and social evaluation [39]. According to the above description, unascertained measure theory can effectively and quantitatively analyze various uncertain factors. Furthermore, it can avoid the incompleteness of risk assessment indexes due to the uncertainty of the influencing factors, and it can avoid the shortcomings of the subjectivity of risk assessment results caused by expert scoring.

This paper applies unascertained measure theory to the fire risk assessment of high-rise buildings under construction to address many uncertainties of fire risk assessment. It is hoped that the model can provide a new idea for fire risk assessment of high-rise buildings under construction.

Model development

The purpose of this study is to conduct a fire risk assessment of high-rise buildings under construction. The algorithm used in this study is illustrated in Fig 1.

Fire risk assessment index system and index grading ranges

Establishment of the fire risk assessment index system. Establishing a scientific and comprehensive assessment index system is the key to risk assessment, as it affects the reliability and accuracy of the assessment results. For high-rise buildings, the chimney effect can occur, which greatly impacts fire risk. Furthermore, for high-rise buildings under construction, the site is complex and changing, and various fire influencing factors are uncertain. Therefore, the establishment of the assessment index system is very difficult.

Based on the above literature review in the "Building fire risk assessment" and relevant standards [40–43], visited and consulted the owner, supervisory unit, design unit, fire brigade and other related units, the index system and index grading standards were determined. A fire risk assessment index system that is suitable for high-rise buildings under construction is established as shown in Table 1.

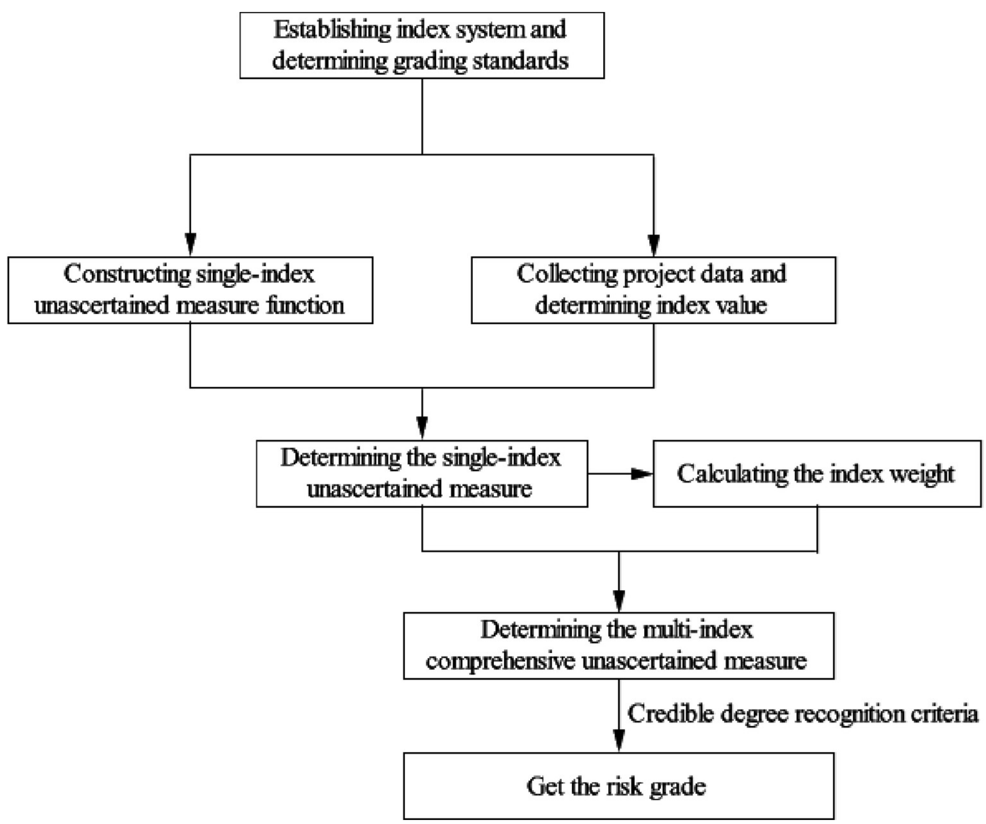

Fig 1. The algorithm for this study.

https://doi.org/10.1371/journal.pone.0239166.g001

Table 1. Fire risk assessment index system for high-rise buildings under construction.

First-level index	Second-level index	Third-level index
Passive fire prevention factor (V_1)	Architectural design (V_{11})	Fireproof endurance rating of building material (V_{111})
		Fire and smoke prevention zoning (V_{112})
		Fire separation distance (V_{113})
		Building height (V_{114})
	Fire load (V_{12})	Fire load density (V_{121})
Active fire prevention factor (V_2)	Building fire extinguishing facilities (V_{21})	Allocation situation of temporary fire fighting equipment (V_{211})
		Fire detection and automatic alarm (V_{212})
		Temporary fire water-supply system (V_{213})
	Fire-fighting capacity of fire brigade (V_{22})	Fire lane (V_{221})
		Firefighter business level (V_{222})
Safe evacuation (V_3)	Safe evacuation channel (V_{31})	Evacuation channel condition (V_{311})
		Setup situation of safety export (V_{312})
		Safe evacuation route and distance (V_{313})
	Safe evacuation facilities (V_{32})	Safety evacuation indication sign (V_{321})
		Emergency lighting (V_{322})
	Site personnel situation (V_{33})	Pedestrian flow situation of construction site (V_{331})
		Fire awareness of on-site personnel (V_{332})
	Emergency plan (V_{34})	Emergency relief material (V_{341})
		Preparation of emergency rescue plan (V_{342})
		Drill of emergency rescue plan (V_{343})
Fire safety management (V_4)	Establishment of management system (V_{41})	Establishment and implementation of fire control system (V_{411})
		Division of safety duty (V_{412})
	Daily fire management work (V_{42})	Maintenance of fire fighting facility (V_{421})
		Regular inspection of fire safety (V_{422})
		Education and training of fire safety (V_{423})
		Management of flammable and explosive material (V_{424})
	Managerial personnel factor (V_{43})	Mastery situation of fire control knowledge and skill (V_{431})
		Managerial personnel business level (V_{432})
Fire hazard source control (V_5)	Human factor (V_{51})	Production hot work (V_{511})
		Careless use of electricity (V_{512})
		Careless smoking (V_{512})
	Material factor (V_{52})	Material stacking condition (V_{521})
		Electrical equipment condition (V_{522})

https://doi.org/10.1371/journal.pone.0239166.t001

Determination of the index grading standards. This paper determines the index grading standards through theoretical research and expert experience and converts qualitative indexes into semiquantitative indexes. Based on the above literature review, relevant standards [40–43], project investigation and consulting expert opinions, the fire risk assessment is divided into five grades, i.e., Grade I, Grade II, Grade III, Grade IV and Grade V, which refer to very low, low, moderate, high, very high fire risks, respectively. The specific index grading standards are shown in Table 2.

Unascertained measure theory

Suppose that the assessment object $X = \{X_1, X_2, \cdots, X_n\}$ and the assessment index set $V = \{V_1, V_2, \cdots, V_m\}$. If x_{ij} denotes the measured value of the i-th assessment object X_i with respect to the j-th assessment index V_j, then X_i can be expressed as an m-dimensional vector $\{x_{i1}, x_{i2}, \cdots, x_{im}\}$.

Table 2. Index grading standards.

Index	Grade I (C_1)	Grade II (C_2)	Grade III (C_3)	Grade IV (C_4)	Grade V (C_5)
	(90, 100]	**(80, 90]**	**(70, 80]**	**(60, 70]**	**[0, 60]**
V_{111}	<1%	1%-5%	5%-10%	10%-15%	≥15%
V_{112}	<1%	1%-5%	5%-10%	10%-15%	≥15%
V_{113}	<1%	1%-5%	5%-10%	10%-15%	≥15%
V_{114}	Below 3 floors	4 to 6 floors	7 to 9 floors	10 floors to the top	Capping and Decoration Stage
V_{121}	≤200	200–400	400–600	600–800	>800
V_{211}	<1%	1%-5%	5%-10%	10%-15%	≥15%
V_{212}	Very good usability and very high safety	Good usability and high safety	General usability and general safety	Poor usability and low safety	Not usable and very low safety
V_{213}	<1%	1%-5%	5%-10%	10%-15%	≥15%
V_{221}	<1%	1%-5%	5%-10%	10%-15%	≥15%
V_{222}	Very high level of fire fighting	High level of fire fighting	General level of fire fighting	Poor level of fire fighting	Very poor level of fire fighting
V_{311}	<1%	1%-5%	5%-10%	10%-15%	≥15%
V_{312}	<1%	1%-5%	5%-10%	10%-15%	≥15%
V_{313}	<1%	1%-5%	5%-10%	10%-15%	≥15%
V_{321}	<1%	1%-5%	5%-10%	10%-15%	≥15%
V_{322}	<1%	1%-5%	5%-10%	10%-15%	≥15%
V_{331}	<0.5	0.5–1	1–1.5	1.5–2	2–2.5
V_{332}	Very high fire awareness	High fire awareness	General fire awareness	Low fire awareness	Very low fire awareness
V_{341}	Very adequate	Adequate	General	Inadequate	Very inadequate
V_{342}	Compliant	Basically compliant	Generally compliant	Less compliant	Incompliant
V_{343}	Regular	General	Occasional	Few	Never
V_{411}	Very good	Good	General	Bad	Very bad
V_{412}	Very clear and reasonable	Basically clear and reasonable	Generally clear and reasonable	Less clear and reasonable	Not clear and reasonable
V_{421}	Very good	Good	General	Bad	Very bad
V_{422}	Regular	General	Occasional	Few	Never
V_{423}	Regular	General	Occasional	Few	Never
V_{424}	Very safe and reasonable	Basically safe and reasonable	Generally safe and reasonable	Less safe and reasonable	Not safe and reasonable
V_{431}	Very skilled	Basically skilled	Generally skilled	Less skilled	Very unskilled
V_{432}	Very strong	Strong	General	Weak	Very weak
V_{511}	The operation is strictly in conformity with the specifications and very high safety	The operation is in conformity with the specifications and high safety	The operation is general in conformity with the specifications and general safety	The operation is not in conformity with the specifications and low safety	The operation is strictly not in conformity with the specifications and very low safety
V_{512}	The operation is strictly in conformity with the specifications and very high safety	The operation is in conformity with the specifications and high safety	The operation is general in conformity with the specifications and general safety	The operation is not in conformity with the specifications and low safety	The operation is strictly not in conformity with the specifications and very low safety
V_{512}	Compliant	Basically compliant	Generally compliant	Less compliant	Incompliant
V_{521}	The stacking is strictly in conformity with the specifications and very high safety	The stacking is in conformity with the specifications and high safety	The stacking is general in conformity with the specifications and general safety	The stacking is not in conformity with the specifications and low safety	The stacking is strictly not in conformity with the specifications and very low safety
V_{522}	The erection and utilization are strictly in conformity with the specifications and very high safety	The erection and utilization are in conformity with the specifications and high safety	The erection and utilization are general in conformity with the specifications and general safety	The erection and utilization are not in conformity with the specifications and low safety	The erection and utilization are strictly not in conformity with the specifications and very low safety

The index grading standards of V_{111}, V_{112}, V_{113}, V_{211}, V_{213}, V_{311}, V_{312}, V_{313}, V_{321}, and V_{322} are expressed by the ratio of the number that does not meet the requirements of the specification to the total number, while the index grading standard V_{331} is expressed by the ratio of the number of people in the peak period to the total building area.

https://doi.org/10.1371/journal.pone.0239166.t002

Suppose that the assessment grade space $C = \{C_1,C_2,\cdots,C_p\}$, where $C_k(k = 1,2,\cdots,p)$ is the k-th assessment grade, and suppose that the k-th grade is higher than the k+1-th grade in the risk assessment process, i.e., $C_k > C_{k+1}$. If $C_1 > C_2 > \cdots > C_p$ or $C_1 < C_2 < \cdots < C_p$ is satisfied, then $\{C_1, C_2,\cdots,C_p\}$ is an ordered segmentation class of assessment space C.

Single-index unascertained measure. If $\mu_{ijk} = \mu(x_{ij} \in C_k)$ denotes the degree to which the measured value x_{ij} belongs to the k-th assessment grade C_k, then

$$0 \leq \mu(x_{ij} \in C_k) \leq 1 \ (i = 1, 2, \cdots, n; j = 1, 2, \cdots, m; k = 1, 2, \cdots, p) \tag{1}$$

$$\mu(x_{ij} \in C) = 1(i = 1, 2, \cdots, n; j = 1, 2, \cdots, m) \tag{2}$$

$$\mu|x_{ij} \in \bigcup_{l=1}^{k} C_l| = \sum_{l=1}^{k} \mu(x_{ij} \in C_l)(k = 1, 2, \cdots, p) \tag{3}$$

Eq (1) is called nonnegative boundedness, Eq (2) is called normalization, and Eq (3) is called additivity. If μ satisfies Eqs (1)–(3), then μ is called the unascertained measure, which is abbreviated as measure.

For every assessment object $X_i(i = 1,2,\cdots,n)$, the matrix of $(\mu_{ijk})_{m\times p}$ is called the single-index unascertained measure matrix of X_i, as shown in Eq (4).

$$(\mu_{ijk})_{m\times p} = \begin{bmatrix} \mu_{i11} & \mu_{i12} & \cdots & \mu_{i1p} \\ \mu_{i21} & \mu_{i22} & \cdots & \mu_{i2p} \\ \vdots & \vdots & \ddots & \vdots \\ \mu_{im1} & \mu_{im2} & \cdots & \mu_{imp} \end{bmatrix} \tag{4}$$

Before establishing the single-index unascertained measure matrix, it is necessary to establish a single-index unascertained measure function. At present, the construction methods of a single-index unascertained measure function mainly include linear, exponential, parabolic and sinusoidal methods [44]. Regardless of the type of simulation function used, it must satisfy the limiting conditions of Eqs (1)–(3). To operate simply and easily, this paper adopted the linear unascertained measure function, and the calculation expression is as follows [45]:

$$\begin{cases} \mu_i(x) = \begin{cases} \dfrac{-x}{a_{i+1} - a_i} + \dfrac{a_{i+1}}{a_{i+1} - a_i} & a_i < x \leq a_{i+1} \\ 0 & x > a_{i+1} \end{cases} \\ \mu_{i+1}(x) = \begin{cases} 0 & x \leq a_i \\ \dfrac{x}{a_{i+1} - a_i} - \dfrac{a_i}{a_{i+1} - a_i} & a_i < x \leq a_{i+1} \end{cases} \end{cases} \tag{5}$$

Multi-index comprehensive unascertained measure. Given that $\mu_{ik} = \mu(X_i \in C_k)$ denotes the degree to which the assessment object X_i belongs to the k-th assessment grade C_k, as shown in Eq (6), where $0 \leq \mu_{ik} \leq 1$ and $\sum_{k=1}^{p} \mu_{ik} = 1$ are satisfied, the vector $\{\mu_{i1},\mu_{i2},\cdots,\mu_{ip}\}$ is called the multi-index comprehensive unascertained measure vector of X_i.

$$\mu_{ik} = \sum_{j=1}^{m} w_j \cdot \mu_{ijk} (i = 1, 2, \cdots, n; k = 1, 2, \cdots, p) \tag{6}$$

where w_j is the index weight. The specific index weight calculation process is detailed in the following section.

Credible degree recognition. To get the final assessment result, credible degree recognition criteria are introduced. Supposed that λ ($\lambda \geq 0.5$; usually, $\lambda = 0.6$ or 0.7) is the credible degree, if $C_1 > C_2 > \cdots > C_p$ is satisfied and p_0 is satisfied by Eq (7), then the assessment object X_i belongs to the assessment grade C_{p_0}.

$$p_0 = \min \left| p : \sum_{k=1}^{p} \mu_{ik} > \lambda, \ i = 1, 2, \cdots, \ n \right| \tag{7}$$

Determination of the index weight

The entropy weight method [46, 47] is used to determine the weight of each index, and this method can make full use of the values of the single-index unascertained measure matrix.

Suppose w_j denotes the relative degree of importance of an index compared with other indexes. If w_j satisfies $0 \leq w_j \leq 1$ and $\sum_{j=1}^{m} w_j = 1$, then w_j is called the index weight of V_j, and $w = (w_1, w_2, \cdots, w_m)$ is called the vector of the index weight. According to the matrix $(\mu_{ijk})_{m \times p}$, the index weight w_j can be obtained from Eqs (8) and (9).

$$H_j = -t \sum_{k=1}^{p} q_{ijk} \ln q_{ijk} \tag{8}$$

$$w_j = \frac{d_j}{\sum_{j=1}^{m} d_j} = \frac{1 - H_j}{m - \sum_{j=1}^{m} H_j} \tag{9}$$

where $H_j > 0$; $q_{ijk} = \mu_{ijk} / \sum_{k=1}^{p} \mu_{ijk}$; t is a coefficient and $t = 1/\ln p$; and when $\mu_{ijk} = 0$, $\mu_{ijk} \ln \mu_{ijk} = 0$ $(i = 1, 2, \cdots, n)$.

Case study

To verify the effectiveness of the model proposed herein, a high-rise building under construction is taken as an example. The building, which is an inpatient building in a hospital in Xi' an, China, has a shear wall structure with a length of approximately 116 m, a width of approximately 53.7 m and a height of approximately 81.8 m. The building has 21 floors, 2 of which are underground and 19 of which are above ground. The total floor area is 77,260 m^2, the underground floor area is 10,600 m^2, and the ground floor area is 66,660 m^2.

Data collection

This paper used the expert scoring method to determine the actual assessment value of each index. Ten experts in related fields were invited to inspect the construction site, the basic information of these ten experts is shown in Table 3.

Table 3. The basic information of the experts.

Expert code	Professional title	Academic qualification	Working years
E_1	Senior title	Specialty	25
E_2	Intermediate title	Undergraduate	15
E_3	Senior title	Undergraduate	18
E_4	Intermediate title	Master	8
E_5	Intermediate title	Undergraduate	12
E_6	Senior title	Master	21
E_7	Intermediate title	Undergraduate	14
E_8	Intermediate title	Master	9
E_9	Senior title	Master	17
E_{10}	Intermediate title	Undergraduate	15

https://doi.org/10.1371/journal.pone.0239166.t003

And the third-level indexes were scored by these ten experts according to the index grading standards in Table 2. The specific scores are shown in Table 4. To ensure the objectivity and authenticity of the scores, the highest and lowest scores of the indexes are first eliminated, and then the average value of each index was obtained. The fire risk assessment index value of the project is shown in Table 4.

Calculation process

(1) Constructing the single-index unascertained measure function

The unascertained measure function studied in this paper is linear. The single-index unascertained measure function is constructed as follows:

$$\mu_{x\in C_1} = \begin{cases} 0 & x \leq 85 \\ \dfrac{x-85}{5} & 85 < x \leq 90 \\ 1 & x > 90 \end{cases} \tag{10}$$

$$\mu_{x\in C_2} = \begin{cases} 0 & x \leq 75 \text{ or } x > 90 \\ \dfrac{x-75}{10} & 75 < x \leq 85 \\ \dfrac{90-x}{5} & 85 < x \leq 90 \end{cases} \tag{11}$$

$$\mu_{x\in C_3} = \begin{cases} 0 & x \leq 65 \text{ or } x > 85 \\ \dfrac{x-65}{10} & 65 < x \leq 75 \\ \dfrac{85-x}{10} & 75 < x \leq 85 \end{cases} \tag{12}$$

$$\mu_{x\in C_4} = \begin{cases} 0 & x \leq 60 \text{ or } x > 75 \\ \dfrac{x-60}{5} & 60 < x \leq 65 \\ \dfrac{75-x}{10} & 65 < x \leq 75 \end{cases} \tag{13}$$

Table 4. The fire risk assessment index value of the project.

Index	Scoring by ten experts										Final index value
	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	
V_{111}	85	83	87	84	87	83	84	82	84	83	84.13
V_{112}	86	88	83	84	85	86	84	84	85	87	85.13
V_{113}	87	89	92	90	88	90	88	89	87	89	88.75
V_{114}	65	63	64	68	63	64	65	64	66	63	64.25
V_{121}	63	65	67	66	68	65	67	66	63	66	65.63
V_{211}	92	85	87	90	88	86	91	87	89	86	88.00
V_{212}	56	60	58	61	63	58	59	58	61	56	58.88
V_{213}	88	83	86	85	87	88	85	87	85	84	85.88
V_{221}	89	91	88	85	86	87	90	86	90	87	87.88
V_{222}	88	90	93	87	92	87	91	92	91	88	89.88
V_{311}	84	87	86	83	82	83	85	84	85	82	84.00
V_{312}	85	88	87	84	83	89	83	87	86	83	85.38
V_{313}	88	83	85	84	89	83	88	85	88	84	85.63
V_{321}	90	88	85	91	89	89	90	89	87	85	88.38
V_{322}	87	83	84	86	87	85	84	86	83	87	85.25
V_{331}	83	85	79	80	83	82	84	81	85	84	82.75
V_{332}	88	90	86	87	83	87	88	85	89	86	87.00
V_{341}	89	92	94	90	91	91	90	90	93	91	91.00
V_{342}	83	85	86	83	82	86	86	86	82	86	84.63
V_{343}	87	89	84	86	87	88	87	86	84	87	86.50
V_{411}	84	80	83	81	85	82	84	82	83	81	82.50
V_{412}	81	81	79	82	80	81	79	82	82	81	80.88
V_{421}	83	81	84	81	82	81	80	84	80	81	81.63
V_{422}	83	81	85	81	84	83	81	84	83	83	82.75
V_{423}	85	83	87	83	85	85	87	86	84	86	85.13
V_{424}	85	86	84	88	84	87	85	84	87	85	85.38
V_{431}	87	85	89	85	86	85	85	85	88	85	85.75
V_{432}	89	87	88	84	82	86	87	86	85	85	86.00
V_{511}	84	88	87	83	82	87	85	82	86	84	84.75
V_{512}	85	82	81	83	80	82	81	80	82	84	81.88
V_{512}	85	87	84	83	88	83	86	83	84	85	84.63
V_{521}	86	87	85	88	83	84	87	87	87	85	86.00
V_{522}	80	81	80	84	85	82	80	80	84	80	81.38

https://doi.org/10.1371/journal.pone.0239166.t004

$$\mu_{x\in C_5} = \begin{cases} 1 & x \leq 60 \\ \dfrac{65-x}{5} & 60 < x \leq 65 \\ 0 & x > 65 \end{cases} \quad (14)$$

In this paper, the single-index unascertained measure function is represented by a graph, as shown in Fig 2.

(2) Calculating the single-index unascertained measure matrix

According to the index value in Table 4 and based on the single-index unascertained measure function established by Eq (10)–Eq (14), the three-level index unascertained measure

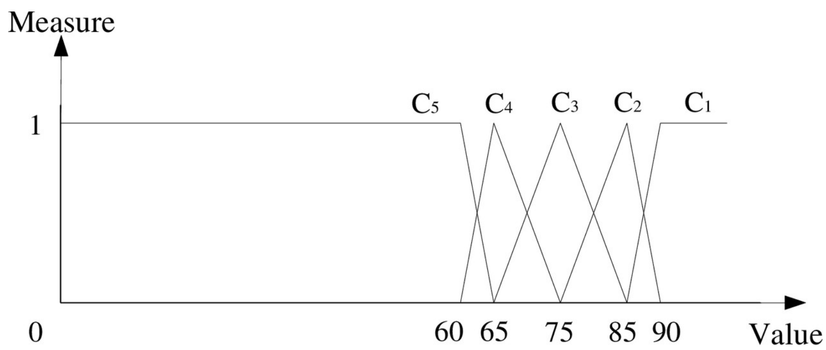

Fig 2. The single-index unascertained measure function.

https://doi.org/10.1371/journal.pone.0239166.g002

matrix can be obtained.

$$\mu_{11} = \begin{bmatrix} 0.000 & 0.913 & 0.088 & 0.000 & 0.000 \\ 0.025 & 0.975 & 0.000 & 0.000 & 0.000 \\ 0.750 & 0.250 & 0.000 & 0.000 & 0.000 \\ 0.000 & 0.000 & 0.000 & 0.850 & 0.150 \end{bmatrix} \mu_{12} = \begin{bmatrix} 0.000 & 0.000 & 0.063 & 0.938 & 0.000 \end{bmatrix}$$

$$\mu_{21} = \begin{bmatrix} 0.600 & 0.400 & 0.000 & 0.000 & 0.000 \\ 0.000 & 0.000 & 0.000 & 0.000 & 1.000 \\ 0.175 & 0.825 & 0.000 & 0.000 & 0.000 \end{bmatrix} \mu_{22} = \begin{bmatrix} 0.575 & 0.425 & 0.000 & 0.000 & 0.000 \\ 0.975 & 0.025 & 0.000 & 0.000 & 0.000 \end{bmatrix}$$

$$\mu_{31} = \begin{bmatrix} 0.000 & 0.900 & 0.100 & 0.000 & 0.000 \\ 0.075 & 0.925 & 0.000 & 0.000 & 0.000 \\ 0.125 & 0.875 & 0.000 & 0.000 & 0.000 \end{bmatrix} \mu_{32} = \begin{bmatrix} 0.675 & 0.325 & 0.000 & 0.000 & 0.000 \\ 0.050 & 0.950 & 0.000 & 0.000 & 0.000 \end{bmatrix}$$

$$\mu_{33} = \begin{bmatrix} 0.000 & 0.775 & 0.225 & 0.000 & 0.000 \\ 0.400 & 0.600 & 0.000 & 0.000 & 0.000 \end{bmatrix} \mu_{34} = \begin{bmatrix} 1.000 & 0.000 & 0.000 & 0.000 & 0.000 \\ 0.000 & 0.963 & 0.038 & 0.000 & 0.000 \\ 0.300 & 0.700 & 0.000 & 0.000 & 0.000 \end{bmatrix}$$

$$\mu_{41} = \begin{bmatrix} 0.000 & 0.750 & 0.250 & 0.000 & 0.000 \\ 0.000 & 0.588 & 0.413 & 0.000 & 0.000 \end{bmatrix} \mu_{42} = \begin{bmatrix} 0.000 & 0.663 & 0.338 & 0.000 & 0.000 \\ 0.000 & 0.775 & 0.225 & 0.000 & 0.000 \\ 0.025 & 0.975 & 0.000 & 0.000 & 0.000 \\ 0.075 & 0.925 & 0.000 & 0.000 & 0.000 \end{bmatrix}$$

$$\mu_{43} = \begin{bmatrix} 0.150 & 0.850 & 0.000 & 0.000 & 0.000 \\ 0.200 & 0.800 & 0.000 & 0.000 & 0.000 \end{bmatrix} \mu_{51} = \begin{bmatrix} 0.000 & 0.975 & 0.025 & 0.000 & 0.000 \\ 0.000 & 0.688 & 0.313 & 0.000 & 0.000 \\ 0.000 & 0.963 & 0.038 & 0.000 & 0.000 \end{bmatrix}$$

$$\mu_{52} = \begin{bmatrix} 0.200 & 0.800 & 0.000 & 0.000 & 0.000 \\ 0.000 & 0.638 & 0.363 & 0.000 & 0.000 \end{bmatrix}$$

(3) Determining the index weight

According to the previous content, the index weight is calculated, as shown in Table 5.

(4) Calculating the comprehensive unascertained measure matrix

1) Calculating the second-level index comprehensive measure matrix

According to the third-level index unascertained measure matrix and the third-level index weight, the second-level index comprehensive measure matrix can be obtained.

$$\mu_1 = \begin{bmatrix} 0.163 & 0.578 & 0.023 & 0.200 & 0.035 \\ 0.000 & 0.000 & 0.063 & 0.938 & 0.000 \end{bmatrix} \mu_2 = \begin{bmatrix} 0.207 & 0.358 & 0.000 & 0.000 & 0.436 \\ 0.822 & 0.178 & 0.000 & 0.000 & 0.000 \end{bmatrix}$$

$$\mu_3 = \begin{bmatrix} 0.066 & 0.901 & 0.033 & 0.000 & 0.000 \\ 0.306 & 0.694 & 0.000 & 0.000 & 0.000 \\ 0.186 & 0.694 & 0.120 & 0.000 & 0.000 \\ 0.470 & 0.516 & 0.013 & 0.000 & 0.000 \end{bmatrix} \mu_4 = \begin{bmatrix} 0.000 & 0.673 & 0.327 & 0.000 & 0.000 \\ 0.028 & 0.855 & 0.117 & 0.000 & 0.000 \\ 0.174 & 0.826 & 0.000 & 0.000 & 0.000 \end{bmatrix}$$

$$\mu_5 = \begin{bmatrix} 0.000 & 0.898 & 0.102 & 0.000 & 0.000 \\ 0.107 & 0.725 & 0.168 & 0.000 & 0.000 \end{bmatrix}$$

2) Calculating the first-level index comprehensive measure matrix

According to the second-level index unascertained measure matrix and the second-level index weight, the first-level index comprehensive measure matrix can be obtained.

$$\mu = \begin{bmatrix} 0.042 & 0.147 & 0.052 & 0.750 & 0.009 \\ 0.621 & 0.237 & 0.000 & 0.000 & 0.143 \\ 0.242 & 0.720 & 0.038 & 0.000 & 0.000 \\ 0.071 & 0.790 & 0.139 & 0.000 & 0.000 \\ 0.042 & 0.830 & 0.128 & 0.000 & 0.000 \end{bmatrix}$$

3) Calculating the total target comprehensive measure matrix

According to the first-level index unascertained measure matrix and the first-level index weight, the total target comprehensive measure matrix can be obtained

$$\mu_{total} = [0.181 \;\; 0.584 \;\; 0.078 \;\; 0.133 \;\; 0.024]$$

(5) Credible degree recognition

The total target comprehensive measure matrix of fire risk of high-rise buildings under construction is μ_{total} = [0.181 0.584 0.078 0.133 0.024].

According to the obtained measure matrix, the credible degree recognition criterion is used for fire risk assessment. λ, which is generally 0.6 or 0.7, is set to 0.6 in this paper. As 0.181+-0.584 = 0.765>0.7, p_0 = 2; that is, the fire risk assessment grade of the high-rise building under construction is Grade II and the risk is low, and this assessment result is consistent with the result determined by the fire department. Similarly, the fire risk assessment grades of all indexes can be obtained are shown in Table 6.

Table 5. Index weights.

First-level index	First-level index weight	Second-level index	Second-level index weight	Third-level index	Third-level index weight
V_1	0.178	V_{11}	0.255	V_{111}	0.261
				V_{112}	0.296
				V_{113}	0.208
				V_{114}	0.236
		V_{12}	0.745	V_{121}	1.000
V_2	0.158	V_{21}	0.327	V_{211}	0.254
				V_{212}	0.436
				V_{213}	0.310
		V_{22}	0.673	V_{221}	0.383
				V_{222}	0.617
V_3	0.206	V_{31}	0.317	V_{311}	0.333
				V_{312}	0.348
				V_{313}	0.319
		V_{32}	0.257	V_{321}	0.410
				V_{322}	0.590
		V_{33}	0.204	V_{331}	0.535
				V_{332}	0.465
		V_{34}	0.222	V_{341}	0.397
				V_{342}	0.357
				V_{343}	0.246
V_4	0.218	V_{41}	0.301	V_{411}	0.529
				V_{412}	0.471
		V_{42}	0.346	V_{421}	0.199
				V_{422}	0.220
				V_{423}	0.306
				V_{424}	0.275
		V_{43}	0.353	V_{431}	0.517
				V_{432}	0.483
V_5	0.240	V_{51}	0.605	V_{511}	0.380
				V_{512}	0.251
				V_{512}	0.369
		V_{52}	0.395	V_{521}	0.537
				V_{522}	0.463

https://doi.org/10.1371/journal.pone.0239166.t005

Results and discussion

Through the analysis of the above assessment results, it is concluded that the actual fire risk level of the case is Grade II, which represents a low fire risk and an acceptable state. From Table 6, we can see the assessment results of each index level. Among them, the risk level of the "passive fire prevention factor" is Grade IV, while the risk levels of the "active fire prevention factor, the safe evacuation factor, fire safety management and fire hazard control" are Grade II.

After obtaining the fire risk grade of the project, the project leader, management personnel, technical personnel and relevant experts conducted a field investigation, discussed and analyzed the actual situation of the project. For the "passive fire prevention factor", the project is in the sealing stage of the main body structure, and the building is very tall. Once a fire occurs, the chimney effect and fire load will be very large. In addition, the construction site of the project occupies a relatively small area and piles a lot of materials. There are a large number of people on the site, food and accommodation are all on the construction site, and most of the building materials and workers' daily necessities are flammable, which greatly increases the fire load on the construction site. For the "active fire prevention factor", the fire protection of the project is relatively in place, but the fire detection and automatic alarm equipment is just like being idle and cannot be used. For the "safe evacuation factor", the overall situation is good. For the "fire safety management", the on-site fire fighting facilities are well equipped, a sufficient number of fire extinguishers are installed, and the fire fighting facilities are reasonably distributed, but most of these facilities are idle and unusable. For the "fire hazard control", there are illegal operations of electrical equipment and unlawful pulling of wires on site.

Although the overall fire risk level of this project is Grade II, as the height of the building increases, it is very important to pay attention to fire prevention in the subsequent construction process. For those indexes with risk level of Grade V and Grade IV, measures must be

Table 6. Fire risk assessment grade of each index.

First-level index	Risk grade	Second-level index	Risk grade	Third-level index	Risk grade
V_1	IV	V_{11}	II	V_{111}	II
				V_{112}	II
				V_{113}	I
				V_{114}	IV
		V_{12}	IV	V_{121}	IV
V_2	II	V_{21}	V	V_{211}	II
				V_{212}	V
				V_{213}	II
		V_{22}	I	V_{221}	II
				V_{222}	I
V_3	II	V_{31}	II	V_{311}	II
				V_{312}	II
				V_{313}	II
		V_{32}	II	V_{321}	II
				V_{322}	II
		V_{33}	II	V_{331}	II
				V_{332}	II
		V_{34}	II	V_{341}	I
				V_{342}	II
				V_{343}	II
V_4	II	V_{41}	III	V_{411}	II
				V_{412}	III
		V_{42}	II	V_{421}	III
				V_{422}	II
				V_{423}	II
				V_{424}	II
		V_{43}	II	V_{431}	II
				V_{432}	II
V_5	II	V_{51}	II	V_{511}	II
				V_{512}	III
				V_{512}	II
		V_{52}	II	V_{521}	II
				V_{522}	III

https://doi.org/10.1371/journal.pone.0239166.t006

taken immediately to deal with them, and they must be carefully supervised and inspected.; for those indexes with risk level of Grade III and Grade II, measures should be taken to deal with them according to the specific circumstances; for those indexes with risk level of Grade I, it is not necessary to deal with them.

By analyzing the basic situation of the project and comparing the assessment results of the model with the on-site situation, it is confirmed that the assessment results are scientific, reasonable, and consistent with the on-site situation. Based on the results, the project managers should strengthen the configuration and supervision of the fire extinguishing facilities of the building itself, as well as the fire control management, and adopt reward and punishment measures. In addition, the project managers should strengthen the fire safety investigation at the construction site, monitor the potential fire hazards at all times, and rectify them immediately to minimize the possibility of a fire.

According to the above analysis, the assessment model established in this paper is feasible. It shows that in view of the various uncertainties in the fire risk assessment of high-rise buildings under construction, this method can obtain reasonable assessment results. In addition, the calculation process of the model is simple. In summary, the assessment model can handle the uncertainty of fire risk assessment, and it is very suitable for the fire risk assessment of high-rise buildings under construction.

Limitations

The unascertained measure theory can be used for the fire risk assessment of high-rise buildings under construction, but the study has several limitations. Due to the project is under construction and the fire hazards are in a state of change in each stage. The index system established in this paper is a static index system. More research is needed to establish a dynamic assessment index system and to determine the fire hazards in each stage from time to time.

Conclusions

To discover hidden fire hazards and to reduce the occurrence of fire accidents in high-rise building under construction, this paper studied the fire risk assessment of high-rise buildings under construction. First, a fire risk assessment index system for high-rise buildings under construction was established, including 5 first-level indexes, 13 second-level indexes and 33 third-level indexes. Second, according to the uncertainty of the fire influence factors of high-rise buildings under construction and the uncertainty of the assessment process, a fire risk assessment model for high-rise buildings under construction based on unascertained measure theory was proposed. Finally, the feasibility and rationality of the proposed fire risk assessment index system and assessment model were verified by taking an inpatient building project of a hospital in Xi'an as an example. This study can solve the problem of fire risk assessment and provide new ideas and methods for the fire risk assessment and control of high-rise buildings under construction in the future.

Author Contributions

Conceptualization: Wenlong Li, Huimin Li.

Data curation: Wenlong Li, Yijun Liu.

Investigation: Wenlong Li, Sunmeng Wang, Xingwang Pei.

Methodology: Wenlong Li, Qian Li.

Writing – original draft: Wenlong Li, Huimin Li.

Writing – review & editing: Wenlong Li.

References

1. He B J. Towards the next generation of green building for urban heat island mitigation: Zero UHI impact building. Sustainable Cities and Society. 2019; 50: 101647.
2. Zhang G, He B J, Dewancker B J. The maintenance of prefabricated green roofs for preserving cooling performance: A field measurement in the subtropical city of Hangzhou, China. Sustainable Cities and Society. 2020; 61: 102314.
3. Shao B, Hu Z G, Liu Q, Chen S, He W Q. Fatal accident patterns of building construction activities in China. Safety Science. 2019; 111: 253–263.
4. Qin G J, Zhang P, Hou X, Wu S, Wang Y. Risk assessment for oil leakage under the common threat of multiple natural hazards. Environmental Science and Pollution Research, 2020; 27: 16507–16520.
5. Kang Q, Ma B. Research on fire-safety assessment of high-rise building based on the fuzzy centralization theory. International Conference on Fuzzy Systems & Knowledge Discovery. IEEE. 2010.
6. Ding Y, Weng F, Yu J. Applying BP neural network in high-rising buildings fire risk assessment. 2011 3rd International Conference on Advanced Computer Control. IEEE. 2011.
7. Ren S. Assessment on logistics warehouse fire risk based on analytic hierarchy process. Procedia Engineering. 2012; 45: 59–63.
8. Xin J, Huang C F. Fire Risk Assessment of Residential Buildings Based on Fire Statistics from China. Fire Technology. 2014; 50(5): 1147–1161.
9. Wu P C, Wang M H, Lin T C. Risk Assessment of Building Fire Safety Based on the Extension Theory. International Symposium on Computer. IEEE. 2014.
10. Gao J P, Xu Z S, Liu D L, Cao H H. Application of the model based on fuzzy consistent matrix and AHP in the assessment of fire risk of subway tunnel. Procedia Engineering. 2014; 71: 591–596.
11. Chen J J, Fang Z, Wang J H, Guo X J. Research on Building Fire Risk Assessment Based on Analytic Hierarchy Process (AHP). International Conference on Intelligent Computation Technology & Automation. IEEE. 2015.
12. Sun B, Xiao R. Bridge fire risk assessment system based on analytic hierarchy process-fuzzy comprehensive evaluation method. Journal of Tongji University (Natural Science). 2015.
13. Roshan S A, Daneshvar S. Fire Risk Assessment and Its Economic Loss Estimation in Tehran Subway, Applying Event Tree Analysis. Iranian Journal of Health. 2015.
14. Lau C K, Lai K K, Yan P L, Du J. Fire risk assessment with scoring system, using the support vector machine approach. Fire Safety Journal. 2015; 78:188–195.
15. Wei Y, Jia W. Research on public building fire risk assessment control model. Control & Decision Conference. IEEE. 2016.
16. Wei Y Y, Zhang J Y, Wang J. Research on building fire risk fast assessment method based on fuzzy comprehensive evaluation and svm. Procedia Engineering. 2018; 211: 1141–1150.
17. Liu F, Zhao S Z, Weng M C, Liu Y Q. Fire risk assessment for large-scale commercial buildings based on structure entropy weight method. Safety Science. 2017; 94:26–40.
18. Li S Y, Tao G, Zhang L J. Fire risk assessment of high-rise buildings based on gray-fahp mathematical model. Procedia Engineering. 2018; 211: 395–402.
19. Bart V W, Xavier D, Robby C, Bart M. Development of an Integrated Risk Assessment Method to Quantify the Life Safety Risk in Buildings in Case of Fire. Fire Technology. 2018.
20. Sun X Q, Luo M C. Fire Risk Assessment for Super High-rise Buildings. Procedia Engineering. 2014; 71: 492–501.
21. Qian D. Risk evaluation of urban fire by regression model with latent variables. China Safety Science Journal. 2012; 7 (22): 159–163.
22. Hassanain M A, Abdul Hafeez M. Fire safety evaluation of restaurant facilities[J]. Structural Survey. 2005; 23(4): 298–309.
23. Omidvari M, Mansouri N, Nouri J. A pattern of fire risk assessment and emergency management in educational center laboratories. Safety Science. 2015; 73: 34–42.
24. Li X X, Wang K S, Liu L W, Xin J, Yang H R, Gao C Y. Application of the entropy weight and topsis method in safety evaluation of coal mines. Procedia Engineering. 2011; 26: 2085–2091.

25. Zheng W. Fire Safety Assessment of China\"s Twelfth National Games Stadiums[J]. Procedia Engineering. 2014; 71: 95–100.

26. Yuan J, Xia C H. Research on method of quantitative evaluation of building fire hazard. Silicon Valley. 2009; 15: 107+104.

27. Song X S, Chen C, Liu Y X. Study on probabilistic fire safety analysis procedures. China Safety Science Journal. 2012; 22(1): 39–45.

28. Fan W C, Sun J H, Lu S X. The Methodology of Evaluation of Fire Hazard. Beijing: Sciencen Press. 2004.

29. Wang G Y. Uncertainty Information and its Mathematical Treatment. Journal of Harbin Architecture and Engineering Institute. 1990; 23(4): 1–8.

30. Liu K D, Pang Y J, Sun G Y, Yao L G. The Unascertained Measurement Evaluation on a City's Environmental Quality. Systems Engineering Theory and Practice. 1999; 12: 52–58.

31. Zeng J L, Huang R, Guan Y H, Cheng J, Song G C. Research on application of entropy-unascertained measure theory in tailing pond safety standardization. Journal of Safety Science and Technology. 2014; 2: 160–166.

32. Yang F Q, Wu C. Risk Assessment on spontaneous combustion of sulfide ore dump in stope based on uncertainty measurement theory. Journal of Central South University: Science and Technology. 2010; 41(6): 2373–2380.

33. Li S C, Wu J, Xu Z H, Li L P. Unascertained measure model of water and mud inrush risk evaluation in karst tunnels and its engineering application. Ksce Journal of Civil Engineering. 2017; 21(4): 1170–1182.

34. Gong F Q, Li X B, Dong L J, Liu X L. Underground goaf risk evaluation based on uncertainty measurement theory. Chinese Journal of Rock Mechanics & Engineering. 2008; 27(2): 323–330.

35. Wang X M. Risk assessment on blocking of filling pipeline based on uncertainty measurement theory. China Safety Science Journal.2012; 22(4): 151–156.

36. Wu Q, Zhao D, Wang Y, Shen J, Mu W, Liu H. Method for assessing coal-floor water-inrush risk based on the variable-weight model and unascertained measure theory. Hydrogeology Journa. 2017; 25(10): 1–15.

37. Peng X L, Guo S H. Research on Ecological Risk Assessment and Prevention Mechanism in Mining Areas Based on Unascertained Measures Theory. Forestry Economics. 2018; 40(08): 92–97.

38. Wei D, Jiang J C, Ni L, Shen S L, Fu G. Uncertainty measurement theory based evaluation of inherent safety of chemical process. China Safety Science Journal. 2018; 28(05): 117–122.

39. Li Y C, Yang J, Shi H W, Li Y J. Assessment of sustainable urban transport development based on entropy and unascertained measure. PLOS ONE. 2017; 12(10): e0186893–.

40. MOHURD. Technical code for fire safety of construction site. 2011.

41. MOHURD. Standard of construction safety inspection. 2011.

42. MOHURD. Code for fire protection design of buildings. 2014.

43. MOHURD. Code for disign of extinguisher distribution in buildings. 2005.

44. Li H M, Qin K, Li P. Selection of project delivery approach with unascertained model. Kybernetes. 2015; 44 (2): 238–252.

45. Li S C, Wu J, Xu Z H, Li L P. Unascertained measure model of water and mud inrush risk evaluation in karst tunnels and its engineering application. Ksce Journal of Civil Engineering. 2017; 21(4): 1170–1182.

46. Sahoo M M, Patra K C, Swain J B, Khatua K K. Evaluation of water quality with application of bayes' rule and entropy weight method. European Journal of Environmental and Civil Engineering. 2016; 21 (6): 1–23.

47. Hamid T, Al-Jumeily D, Mustafina J. Evaluation of the dynamic cybersecurity risk using the entropy weight method. Technology for Smart Futures. 2018.