Fuzzy Risk Assessment for Life Safety Under Building Fires

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Abstract. Many uncertainties are introduced inevitably during estimating fire risk for life safety in buildings. Probabilistic methods, the most widely used method to deal with uncertainties, require a large number of historical data. Due to the uniqueness of building fires, such data are rarely available. In order to address this limitation, a fuzzy risk assessment method for life safety under building fires is presented. Event tree is constructed to analyze potential fire scenarios arisen from the failure of fire protection systems. According to the definition of fire risk for life safety, occurrence likelihoods and expected casualty numbers of fire scenarios are estimated with consideration of some uncertainties. Due to limited statistical data and poor knowledge about fire dynamic and evacuation, fuzzy numbers are employed to describe these uncertainties. Based on calculated occurrence likelihood and expected casualty number for a fire scenario, the risk of life safety for a fire scenario is obtained as a fuzzy number. A practical case study for a hypothetical one storey commercial building is carried out with the assessment method presented in this paper and compared with the conventional probabilistic assessment results.

1. Introduction

Risk assessment for life safety under building fires plays an important role in performance-based fire protection design and fire insurance ratemaking. Reasonable methods should be employed to evaluate the risk for life safety under building fire.

Risk assessment methods for life safety under building fire can be divided into three categories: qualitative, semi-quantitative and quantitative methods [1]. Based on determining the occurrence likelihood and consequence of the fire, quantitative

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methods provide more accurate values of fire risk for life safety and have been employed widely in performance-based fire protection design. As the performance-based fire protection has developed rapidly, many studies have been conducted on quantitative fire risk assessment for life safety under building fires. Considering some stochastic factors in fire dynamics and evacuation, Magnusson et al. [2] employed the limit state equation to determine the failure probability of occupant evacuation from building fires. Frantzich [3] continued his work and introduced standard quantitative risk analysis and extended quantitative risk analysis methods to evaluate the risk for life safety under building fires. He et al. [4] proposed a probabilistic risk assessment method for analyzing the expected risk to life (ERL). Chu et al. [5] later refined the method for analyzing ERL, in which more stochastic factors were included. Based on the refined method, a comprehensive quantitative risk assessment framework for evaluating fire risk to life safety was established, where the probability of each fire scenario is obtained by Markov chain integrated with time-dependent event tree [6]. In addition to above traditional probabilistic methods, Bayesian networks are also widely employed to estimate the risk of human casualties in building fires due to their ability to model probabilistic data with dependencies between events. Considering some uncertainties associated with fire models and occupants, Hasofer and Odigie [7] employed networks to model fire spread and occupant egress under building fire. Based on the networks, the probability of fatalities under building fire can be obtained. Hanea and Ale [8] constructed a Bayesian network which takes into account fire fighters' action, structure of the building and characteristics of the building and the environment in order to analyze low-probability-high-consequence scenarios of human fatality risk in building fires.

Though methods above vary from each other, one objective is in common: uncertainties involved in the fire dynamics and evacuation are considered in order to obtain reasonable risk assessment results. In previous study, probability theory and Bayesian networks are preferred to deal with these uncertainties. Probability-based approach to uncertainty analysis requires a large number of historical data to obtain the precise results. However, due to the uniqueness of fire accidents, such statistical data are sparse. Furthermore, limited or poor knowledge on fire dynamics and occupant evacuation is available. In this case, some subjective assumptions of the statistical characteristics for some parameters have to be made. These assumptions are hard to be proven right or wrong and may introduce additional uncertainties into the result, which makes the decision makers hardly satisfied with assessment results. Due to above reasons, probability-based approach is challenged. For Bayesian Networks, they are indeed powerful approaches to uncertainty analysis since they often produce very convincing results when the historical information is inexact. Furthermore, The Bayesian networks allow updating the insufficient information by engineering and expert knowledge. However, to obtain the probabilities that are required for the conditional probability tables in a Bayesian network can often be daunting [9]. Generally, this problem can be solved by learning the probabilities from large amounts of data [10], which is seldom available in fire safety engineering. In addition, it would be a challenge for the fire safety engineers to construct a Bayesian network and conduct tedious

probability calculations to determine the value of fire risk for life safety, because fire safety engineers are usually not proficient in Bayesian networks requiring a solid probability theoretical foundation. With respect to the criteria of flexibility and easy implementation, another major approach for dealing with uncertainties, fuzzy set approaches, are introduced. Fuzzy set approaches are suitable for situations where probabilistic information is not available [11]. Compared with Bayesian networks, fuzzy set approaches are much easier and quicker to be understood and implemented by fire safety engineers. Fuzzy risk assessment method has been widely employed in many fields, such as environmental risk analysis [12], nuclear safety assessment [13], offshore petroleum exploration [14, 15] and civil engineering [16].

This study attempts to propose a framework of fuzzy risk assessment for life safety under building fires. Pursuant to the definition of fire risk, objective of this study is to analyze the occurrence likelihood and consequence of each fire scenario. A fuzzy event tree method is employed to analyze the occurrence likelihood of each fire scenario. When determining the consequence of fire scenarios, uncertainties of fire growth rate and pre-evacuation time are characterized as fuzzy numbers. Based on the fuzzy occurrence likelihood and consequence, fire risk for life safety can be determined as a fuzzy set.

2. Determining the Occurrence Likelihood of Fire Scenarios

Fire risk can be defined as the product of the occurrence likelihood and the expected consequence for each fire scenario [17]. For fire risk for life safety, the expected consequence is the expected number of casualties for each fire scenario. Therefore, the objective of fire risk for life safety is to determine the occurrence likelihood and the expected number of casualties for each fire scenario.

Designing proper fire scenarios is essential for performance-based fire protection design. For the reason that there are many factors influencing fire spread and smoke movement, such as the fuel characteristics, the building geometry and fire protection systems, various fire scenarios may occur. For a specific building, the operational reliability of fire protection systems plays an important role in the occurrence of different fire scenarios [18]. With respect to consider the influence of the operational reliability of fire protection systems on different fire scenarios, event tree method is employed. Since the majority of casualties in fire is caused by inhalation of smoke, four basic events influencing smoke movement are considered [18]: fire sprinklers, automatic smoke detection and alarm, manual smoke detection and mechanical smoke exhausting fans. The event tree is shown as Figure 1.

When using event tree to analyze the occurrence likelihood of each fire scenario, the first step is to determine the occurrence likelihood of basic events. Generally, the occurrence likelihood of basic events can be considered as operational reliability of the fire protection systems. However, due to the limited statistical data, distributions of the operational reliability of the fire protection systems are unknown.

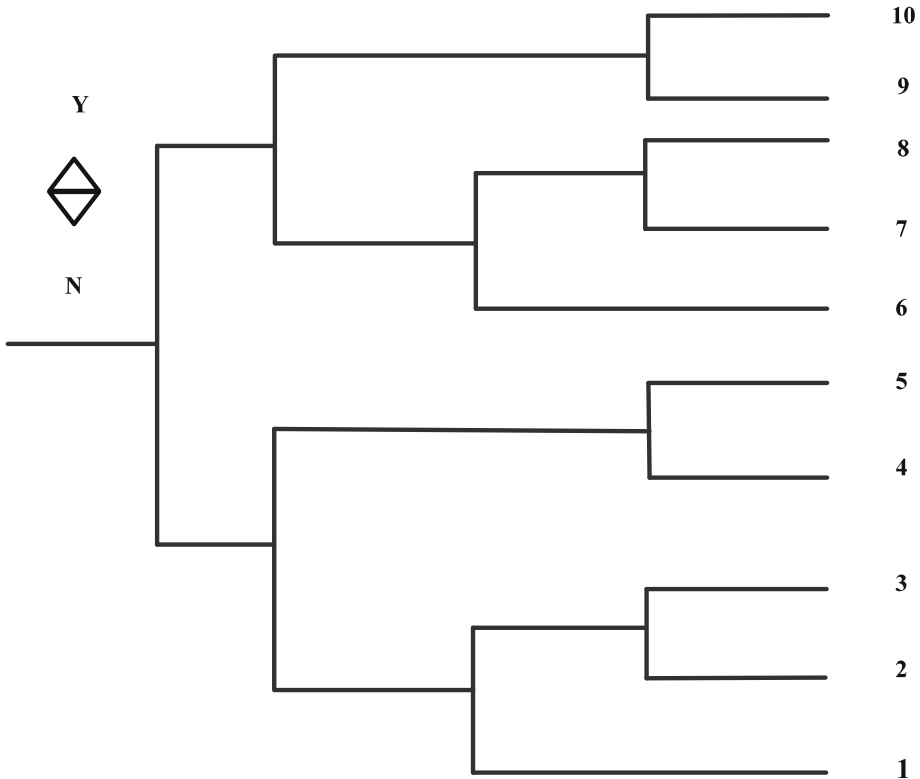| Fire ignition	Sprinkler	Smoke automatic detection and alarm	Manual detection and alarm	Mechanical smoke exhausting fans	Scenario

Figure 1. Event tree of fire scenarios.

Though the distributions are rarely known, the maximum, minimum and mean are available based on the limited statistical data. Therefore, it is flexible to present the operational reliability of fire protection systems, i.e., the occurrence likelihood of basic events, as a special kind of fuzzy sets, triangular fuzzy numbers (TFNs), i.e., $\tilde{L} = (a, b, c)$. The membership function is:

$$\mu_{\tilde{L}}(x) = \begin{cases} 0 & x < a \\ \frac{x-a}{b-a} & a \leq x < b \\ \frac{c-x}{c-b} & b \leq x \leq c \\ 0 & x > c \end{cases} \tag{1}$$

where, a and c are lower and upper bounds of the reliability of fire protection systems, respectively. b is the most possible value. Based on the statistical data available, the minimum, mean and maximum can be considered as a, b and c.

Having determined the occurrence likelihood of each basic event, occurrence likelihoods of fire scenarios can be obtained by the built event tree and the arithmetic operations of fuzzy numbers [19, 20].

Take scenario 1 as an example, the reliability of sprinkler, smoke detection system, manual detection and mechanical smoke exhaust system are denoted as $\tilde{L}_{sp}, \tilde{L}_{de}, \tilde{L}_{man}, \tilde{L}_{ex}$, respectively. The occurrence likelihood of scenario 1, $\tilde{L}_{sp}$, can be calculated according to the event tree:

$$\tilde{L}_1 = \left(1 - \tilde{L}_{sp}\right) \times \left(1 - \tilde{L}_{de}\right) \times \left(1 - \tilde{L}_{man}\right) \tag{2}$$

Fuzzy numbers can also be presented as intervals, which are called α-level sets [16]. For a fuzzy number, $\tilde{A}$, the α-cuts or α-level sets of $\tilde{A}, A_\alpha$ are defined as follows:

$$A_\alpha = \left\{x \middle| x \in R, \mu_{\tilde{A}}(x) \geq \alpha\right\} = \left[a_L^\alpha, a_U^\alpha\right] \tag{3}$$

where $\alpha \in [0, 1]$. It means that for all x belonging to R, their degree membership in $\tilde{A}$ is at least equal to α.

According to the definition of α-level sets, the occurrence likelihood of scenario 1 at α level can be described in the following expression:

$$\begin{aligned} L_{1L}^\alpha &= \left(1 - L_{spU}^\alpha\right)\left(1 - L_{deU}^\alpha\right)\left(1 - L_{manU}^\alpha\right) \\ L_{1U}^\alpha &= \left(1 - L_{spL}^\alpha\right)\left(1 - L_{deL}^\alpha\right)\left(1 - L_{manL}^\alpha\right) \\ L_1^\alpha &= \left[L_{1L}^\alpha, L_{1U}^\alpha\right] \end{aligned} \tag{4}$$

Similarly, occurrence likelihoods of other fire scenarios can also be obtained.

3. Determining the Expected Number of Casualties

In performance-based fire protection design, casualties are usually determined by comparing available safety egress time (ASET) and required safety egress time (RSET) [1]. If ASET is smaller than RSET, it reveals that some occupants still remain in the building when untenable condition reaches. Casualties will occur at this moment. Hence, it is essential to estimate ASET and RSET accurately. Calculation of ASET and RSET is associated with fire dynamics and occupant evacuation, both of which are highly complex and involved many uncertainties. Therefore, uncertainties in these two aspects should be considered in order to obtain the accurate ASET and RSET.

3.1. Uncertainty Involved in ASET

From a life safety point of view, the first 10 min or 15 min in a building fire, i.e., fire's early stage is the most important period for occupant evacuating to safety

place [21]. For the fire's early stage, it can be assumed as a time squared t^2 fire and the heat release rate can be written as following [22],

$$\dot{Q} = \gamma t^2 \tag{5}$$

where, $\dot{Q}$ is the heat release rate of fire (kW); t is the time after fire ignition (s); γ is fire growth rate (kW/s^2).

Based on the t^2 fire assumption, the main factor influencing heat release rate is fire growth rate. The fire growth rate is often rated as slow, medium, fast and ultra-fast (see Table 1). However, due to the variation of fuel characteristics and location of the ignition, real fires cannot be described using a single growth curve. Holborn et al. [23] suggested log-normal distribution can fit the observed data of fire growth rate well. However, he also highlighted that due to limited sample of data for analysis, the result obtained may be best regarded as being indicative of the possible magnitude of fire growth rate rather than providing a definitive value. Since four fire growth rates are available as shown in Table 1, trapezoid fuzzy number (TrFN), i.e., $\tilde{A} = (a, b, c, d)$ is assumed to represent uncertainty associated with the fire growth rate. The membership function is:

$$\mu_{\tilde{A}}(\gamma) = \begin{cases} 0 & \gamma < a \\ \frac{\gamma - a}{b - a} & a \leq \gamma < b \\ 1 & b \leq \gamma < c \\ \frac{d - \gamma}{d - c} & c \leq \gamma \leq d \\ 0 & \gamma > d \end{cases} \tag{6}$$

According to Equation (6), the fire growth rate at α level is

$$\gamma^\alpha = \left[\gamma_L^\alpha, \gamma_U^\alpha\right] = [\alpha(b - a) + a, d - \alpha(d - c)] \quad \alpha \in [0, 1] \tag{7}$$

Taking time when the smoke height descends to within 2.1 m from the floor or the smoke temperature exceeds 100°C as the criterion of ASET, ASET at α level can be determined by CFAST model to the degree of fire growth rate at α level and the fire scenario:

$$ASET_i^\alpha = \left[ASET_{iL}^\alpha, ASET_{iU}^\alpha\right] \tag{8}$$

Table 1
Values of Fire Growth Rate

Fire	Fire growth rate (kW/s^2)	Time when $\dot{Q}$ reaches 1055 kW (s)
Slow	0.0029	600
Medium	0.0117	300
Fast	0.0469	150
Ultra fast	0.1846	75

3.2. Uncertainty Involved in RSET

RSET is consisted of three components: fire detection time, occupant pre-movement time and occupant evacuation time. When determining the detection time, smoke detection is assumed to be activated as the smoke height descends below the ceiling by 5% of the compartment height [21]. For manual detection succeeds, detection time is assumed as the time when smoke height is below the ceiling by 10% of the compartment height. For the scenario that manual detection fails, the time when smoke height descends to below the ceiling of 15% of the compartment height is assumed as detection time [24]. Due to the influence of fire growth rate on smoke height, detection time at α level can be described as following:

$$t_{dei}^{\alpha} = \left[t_{deiL}^{\alpha}, t_{deiU}^{\alpha} \right] \tag{9}$$

Occupant pre-movement time is influenced by occupant characteristics, such as gender, emergency training level, occupant location and initial feeling [25, 26]. It makes the occupant pre-movement time varying from individual to individual. Previous study indicates that pre-movement time follows a probabilistic distribution, but the specific distribution form is unknown [27–31]. Moreover, most data in previous study are obtained from evacuation drills. Since human behavior in real fires is distinct from that in evacuation drills, the pre-movement time in fire situation varies from that in evacuation drills. An effective way to obtain the pre-movement time in real fires is post-fire survey. However, on grounds of the uncertainty of human behavior, the pre-movement time obtained by post-fire survey is usually an imprecise or linguistic value rather than a precise one. Therefore, employing a fuzzy set to describe the pre-evacuation time is more appreciate. In this paper, the Gaussian membership function is assumed to characterize pre-evacuation time:

$$\mu_{\tilde{t}_{pre}}(t_{pre}) = \exp\left(-\frac{(t_{pre} - c)}{2\sigma^2} \right) \tag{10}$$

where, c and σ are the center and width of fuzzy set $\tilde{t}_{pre}$, respectively.

For calculating occupant evacuation time, Building EXDOUS [32], which is based on a fine grid evacuation model, is employed. It considers the impact of pre-movement time on evacuation time and the result is relatively reasonable. Similar to ASET and detection time, pre-movement time at α level can be obtained according to Equation (10) and presented in the following expression:

$$t_{prei}^{\alpha} = \left[c - \sqrt{-2\sigma^2 \ln \alpha}, c + \sqrt{-2\sigma^2 \ln \alpha} \right], \quad \alpha \in [0, 1] \tag{11}$$

Taking pre-movement time at α level as the input, the evacuation time at α level can be obtained with the aid of Building EXDOUS

$$t_{evaci}^{\alpha} = \left[t_{evaciL}^{\alpha}, t_{evaciU}^{\alpha} \right] \tag{12}$$

According to Equations (8)–(11), RSET for scenario i at α level can be determined

$$RSET_i^\alpha = \left[RSET_{iL}^\alpha, RSET_{iU}^\alpha \right] \tag{13}$$

3.3. *Determining the Expected Number of Casualties Considering Uncertainties*

As mentioned above, if ASET is smaller than RSET, it indicates that there are still some occupants remaining in the building when untenable condition reaches. In real fires, the number of people still remaining in the building is influenced by the development of fire growth and smoke spread. However, ASET is little dependent on the number of people remaining in the building. In this case, ASET and RSET can be considered as two independent events. Based on this assumption, the number of casualties when ASET and RSET follow probabilistic distributions can be determined as follows [5]:

$$C_i = \int_0^{RSET_i} \left[F_{Ni}(t) \cdot f_{ASETi}(t) \right] dt \tag{14}$$

where, C_i is number of casualties for scenario i; $F_{Ni}(t)$ is number of occupants still remaining in the building at time t; $f_{ASETi}(t)$ is the probability density function of ASET.

According to the definition of α cut, ASET at each α level can be described as an interval. Therefore, ASET at each α level can be considered to follow uniform distribution. Therefore, the probability density function of ASET can be determined as following:

$$f_{ASET_i^\alpha} = \frac{1}{ASET_{iU}^\alpha - ASET_{iL}^\alpha} \tag{15}$$

Substituting Equations (12) and (14) into Equation (13), then we can obtain the lower and upper bounds of number of casualties for scenario i as following:

$$
\begin{aligned}
C_{iU}^\alpha &= \frac{1}{ASET_{iU}^\alpha - ASET_{iU}^\alpha} \int_{ASET_{iL}^\alpha}^{RSET_{iU}^\alpha} F_{Ni}(t) dt \\
C_{iL}^\alpha &= \frac{1}{ASET_{iU}^\alpha - ASET_{iU}^\alpha} \int_{ASET_{iL}^\alpha}^{RSET_{iL}^\alpha} F_{Ni}(t) dt
\end{aligned}
\tag{16}
$$

Consequently, the number of casualties of scenario i at α level can be written as following:

$$C_i^\alpha = \left[C_{iL}^\alpha, C_{iU}^\alpha \right] \tag{17}$$

4. Determining the Fire Risk for Life Safety

As the occurrence likelihood and the number of casualties for each fire scenario are described as α cuts, fire risk for life safety in building at α level can be determined by the following equation:

$$R^\alpha = \sum_{i=1}^n C_i^\alpha \cdot L_i^\alpha = \left(\sum_{i=1}^n C_{iL}^\alpha \cdot L_{iL}^\alpha, \sum_{i=1}^n C_{iU}^\alpha \cdot L_{iU}^\alpha \right) = \left(R_L^\alpha, R_U^\alpha \right) \tag{18}$$

where, R^α is the fire risk for life safety at α level, n is the number of fire scenarios.

Having obtained the fuzzy risk value at each α level, the next step is defuzzification of the fuzzy risk for life safety. Defuzzification is interpreting the membership degrees of the fuzzy sets into a specific decision or crisp value. By employing defuzzification, the representative value of a fuzzy number can be obtained. It is a very important procedure for decision making in a fuzzy environment. Various methods are proposed for the defuzzification of fuzzy numbers, such as maxima method, the distribution methods and the area methods [33]. Since the fuzzy risk for life safety in this paper is described as α cuts, the defuzzification method with total integral value [34] is adopted:

$$D^\beta(\tilde{R}) = (1 - \beta)I_U(\tilde{R}) + \beta I_L(\tilde{R}) \tag{19}$$

where,

$$I_i(\tilde{R}) = 0.5 * \left[U_i(\tilde{R}) + L_i(\tilde{R}) \right] \tag{20}$$

$$U_i(\tilde{R}) = \sum_{\alpha=0.1}^1 \alpha_i(\tilde{R})\Delta\alpha \tag{21}$$

$$L_i(\tilde{R}) = \sum_{\alpha=0}^{0.9} \alpha_i(\tilde{R})\Delta\alpha \quad i = L, U; \ \Delta\alpha = 0.1. \tag{22}$$

When $\beta = 0$, $D^\beta(\tilde{R}) = I_U(\tilde{R})$, which can be regarded as the upper bound of $\tilde{R}$. Similarly, when $\beta = 1$, $D^\beta(\tilde{R})$ is the lower bound of $\tilde{R}$.

If fire ignition frequency is known, the lower and upper bounds of expected risk to life (ERL) can be determined as following:

$$ERL = \frac{f \cdot D^\beta(\tilde{R}) \cdot A}{N} \tag{23}$$

where, f is the fire ignition frequency. A is building area (m²); N is occupant number in the building.

The fuzzy risk assessment method for life safety proposed in the present paper can be concluded as the flowchart, shown as Figure 2.

5. Case Study and Analysis

In order to illustrate the method in details, an evaluation of the fire risk for life safety in a hypothetic one-story commercial building is presented. Details about the commercial building are shown in Table 2.

When calculating the occurrence likelihood of each fire scenario, the fuzzy occurrence likelihood of each basic event is determined according to Table 3 [35]. For fire growth rate, based on statistical data collected by Holborn et al. and the categories of fire growth rate, a, b, c and d in membership function of fire growth rate are 0.0117 kW/s^2, 0.027 kW/s^2, 0.04689 kW/s^2 and 0.1846 kW/s^2, respectively. c and σ in membership function of pre-movement time are 210 and 70, respectively. Based on the proposed method in this paper, fuzzy fire risk for life safety in this building can be determined, as shown in Table 4.

In order to demonstrate the effectiveness of this method, probabilistic method proposed in reference [5] is also employed to calculate the fire risk for life safety in this building. The occurrence probability of each basic event, i.e., p, equals to b. The distribution of ASET is assumed to follow trapezoid distribution, whose probabilistic density function is

$$f(t) = \begin{cases} \frac{2(t-a)}{(b-a)(c+d-a-b)} & a \leq t \leq b \\ \frac{2}{c+d-a-b} & b \leq t \leq c \\ \frac{2(d-t)}{(d-c)(c+d-a-b)} & c \leq t \leq d \end{cases} \tag{24}$$

where, a, b, c and d are the values of ASET when the fire growth rate equals to 0.1846 kW/s^2, 0.04689 kW/s^2, 0.027 kW/s^2 and 0.0117 kW/s^2, respectively.

The distribution of pre-evacuation time is assumed as normal distribution, i.e. $N(210, 70^2)$.

Fire risk value for life safety for each fire scenario is shown as Table 5. Then the fire risk for life safety in this building is $R = \sum_{i=1}^{5} P_i C_i = 2.2442$.

When $\alpha = 1$, it indicates the most possible value. Therefore, the mean of α-cut interval with $\alpha = 1$, denote as d^{MOM}, is used to compare with the probabilistic results. In Table 4, $d^{MOM} = 1.8392$, which is close to the probabilistic result. Furthermore, the probabilistic result is a little larger than d^{MOM}, which may be due to: (1) the probability of each basic event in probabilistic method is considered as a precise value; (2) uncertainty factors in determining the number of casualties are considered as a precise probabilistic distribution. These two reasons make the probabilistic result a little conservative.

According to Equations (18)–(21), after defuzzification, the lower and upper bounds of risk for life safety can be determined. Since fire ignition frequency is 4.12×10^{-6}/(year m^2) [36], according to Equation (22), the lower and upper bounds of ERL can be determined. The result is shown as Table 6.
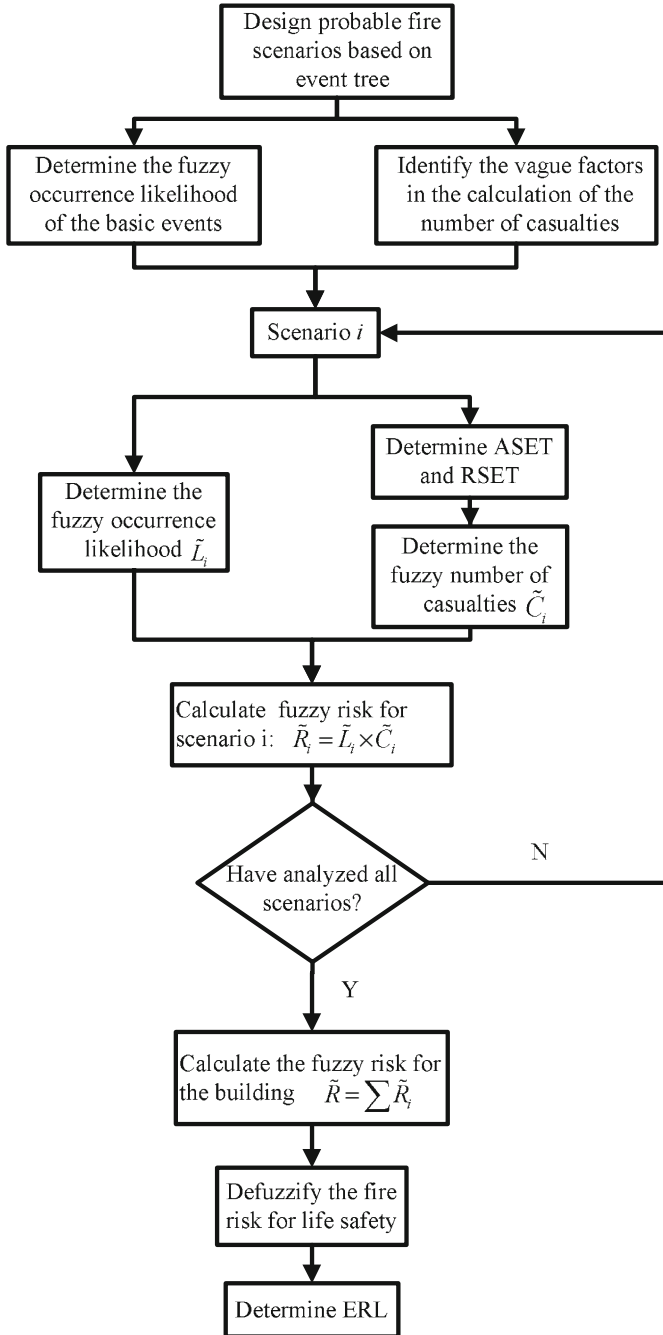
Figure 2. Flowchart of fuzzy risk assessment method for life safety under building fires.

Table 2
Details About the Commercial Building

Parameter	Value
Area (m^2)	3750
Height (m)	6
Number of exits	2
Total width of exits (m)	6
Occupant number (person)	1913

Table 3
Statistical Data About Fire Protection Systems

Fire protection systems	Minimum	Average	Maximum
Sprinkler	0.88	0.93	0.98
Automatic smoke detection	0.70	0.72	0.74
Manual detection	0.60	0.70	0.80
Mechanical smoke exhaust fan	0.90	0.95	0.97

Table 4
Calculated Risks for Life Safety at Each α Level

α	R_L	R_U
0.0	0.00	0.021
0.1	0.00	0.017
0.2	0.00	0.007
0.3	0.01	0.065
0.4	0.08	0.175
0.5	0.10	0.161
0.6	0.21	0.295
0.7	0.42	0.782
0.8	0.53	1.022
0.9	0.74	1.241
1.0	1.49	2.202

Table 5
Results Calculated by Probabilistic Method

Scenario	ASET				RSET (s)	C	p
	a (s)	b (s)	c (s)	d (s)			
1	554	576	589	617	685	289.429	0.00588
2	554	576	589	617	651	146.477	0.000686
3	604	626	637	656	651	26.051	0.013034
4	554	576	589	617	612	40.357	0.00252
5	604	626	637	656	612	0.014	0.04788

Table 6
Lower and Upper Bounds of Risk for Life Safety and ERL

	Lower	Upper
R	0.05	0.2047
ERL	4.04e−7	1.65e−6

Due to the limited data, the fuzzy method and probabilistic method made subjective assumptions of the membership function and probabilistic density function. In Table 6, the defuzzified fire risk for life safety is an interval while the result obtained by probabilistic method is a precise value. To some extent, the interval can reflect the influence of risk analysts' subjective assumptions on the result, which is more reasonable and easier to be accepted by the decision makers.

6. Conclusions

A framework of fuzzy assessment of fire risk for life safety is presented in this paper. When determining the number of casualties, fuzzy information involved in ASET and RSET is considered. Due to limited data and poor knowledge about fire growth rate, trapezoid fuzzy number is employed to describe the fire growth rate. In this way, the effect of uncertainty associated with fire growth rate on ASET is considered. When calculating RSET, pre-movement time is described as a Gaussian fuzzy number with the consideration of the vagueness of pre-evacuation time. In order to obtain the occurrence likelihood of each fire scenario, reliabilities of fire protection systems are characterized as triangular fuzzy numbers. Based on event tree analysis, the fuzzy occurrence likelihood of each fire scenario is obtained. Having obtained the occurrence likelihood and casualty number for each fire scenario, fire risk to life safety can be evaluated as a fuzzy set.

In order to verify the effectiveness of the proposed method, the risk for life safety under building fire in a hypothetic one-storey commercial building is evaluated by the fuzzy assessment method proposed in this paper and the probabilistic assessment method. It indicates that both results are much close, the result obtained by the method proposed in this paper is a little smaller than that obtained by the probabilistic method.

The current work only considers the influence of fire protection systems on fire scenarios. Other influencing factors, such as the response time and the capacity of extinguishing fire for the fire brigade, should also be incorporated. Moreover, due to high complexity of fire and evacuation, large amount of fuzzy factors are associated with these two processes. Only a few uncertain factors in calculations of ASET and RSET are considered in this paper. Further research should incorporate more uncertain factors involved in these two processes to obtain more reasonable results.

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