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Study on the Failure Probability of Occupant Evacuation with the Method of Monte Carlo Sampling

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Abstract

Occupant safety evacuation in fires is a critical issue in public safety field. The evacuation process is divided into several stages and each stage can be influenced by various uncertain factors. Some factors were studied in this paper based on the Monte Carlo approach. The safety level affected by different factors and the sensitivity of sampling size were analysed according to the failure probability model of occupant evacuation. The results show that safety level of occupant evacuation in buildings can be evaluated by the failure probability model. When the population density is more than 0.8 pers/m^2, the failure probability goes up rapidly with the fire growth rate increasing. Whether the fire is large or not, the population density have a great impact on the evacuation. Then the influencing degree on failure probability of different parameters are changeable in various conditions. In addition, when the sample capacity is large enough, the Monte Carlo simulation can be deemed accurate.

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Keywords: occupant evacuation, failure probability, Monte Carlo method, fire growth rate, population density

Nomenclature

A	room area (m^2)
$ASET$	available safety egress time (s)
F	flow capacity of doors (pers/(m·s))
G	escape time margin (s)
H	room height (m)
N	population density (pers/m^2)
$RSET$	required safety egress time (s)
t_d	detection time (s)
t_p	pre-movement time (s)
t_m	movement time (s)
W	door width (m)
Greek symbols	
α	fire growth rate (kW/s^2)
Subscripts	
f	failure

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1. Introduction

In recent years, different kinds of accidents in public places have occurred frequently. Whether an accident is serious or not, huge panic will spread rapidly through the crowd. Furthermore, if there are some extra factors such as fire, dangerous goods, enormous loss in people's lives and belongings will be caused definitely. Especially for assembly occupancies, when a fire occurs, people's life safety and property would be threatened seriously. How to evacuate people as fast as possible in fires is of crucial importance in fire protection field. Available Safety Egress Time (*ASET*) and Required Safety Egress Time (*RSET*) are two critical indexes to evaluate safety evacuation level in buildings. The duration time from the start of fire to the construction limitation is defined as *ASET*. That is affected by fire load density, fire resistance of buildings, conditions of fire protection equipment and so on. The duration time from the start of fire to the accomplishment of evacuation is defined as *RSET*. That is composed of detection time t_d, pre-movement time t_p and movement time t_m. As can be seen in Fig.1, the criterion for occupant safety evacuation is that the value of *RSET* is less than *ASET*.

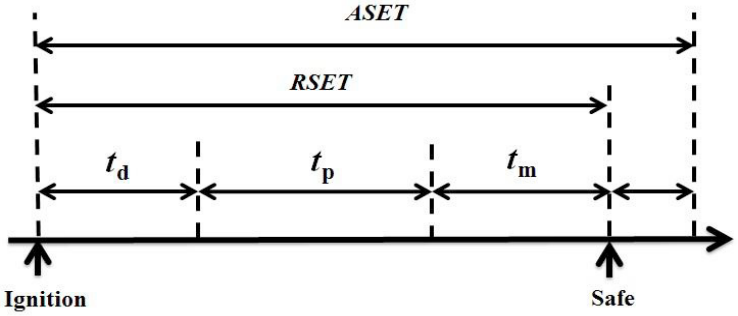

Fig. 1. Time criterion for occupant safety evacuation.

The occupant evacuation process in a building fire is influenced by various factors. The majority of deterministic factors have been studied by many previous researches. As we all know, deterministic factors are easy to quantify. The consequences only affected by those factors can be predicted and avoided early. However, the occurrence and developing process of an accident is generally full of uncertainty according to many researches. Some mathematic methods are used to describe the value of uncertain parameters in the calculating process of *RSET* and *ASET*. Fuzzy analysis method uses membership function to deal with those problems, but it's difficult to determine the membership degree. Interval analysis is a rather rough method that uses a numerical interval including the upper and lower limits to describe uncertainty. While the probabilistic method is the commonest [1]. Because a probabilistic function is totally based on the original data and the consequences that the function speculates will be the closest to the real conditions. According to the survey on occupant escaping behaviour in the World Trade Center, a series of data analysis was carried on by Chu et al [2]. Although the building structure, fire protection facilities and other conditions were the same in both towers, the pre-evacuation time of occupants in these two buildings were significantly different. They also concluded that pre-movement time can be expressed by the probabilistic distribution instead of constant value. What's more, a risk assessment method for evacuees in building fires was established to obtain the evacuation results influenced by the variables. Many kinds of calculation models have been established currently and they are proved effective in some conditions. However, two major elements that play a decisive role in the evacuation process, pre-evacuation time and movement time, are quite difficult to be described and calculated [3]. Through lots of investigations and analysis of people evacuation in building fires, Purse et al concluded that pre-movement time in evacuation can be described by Gaussian distribution, lognormal distribution and Weibull distribution. Also the movement time can be predicted reasonably by the flow calculation approach. In the process of fire engineering design, the default value of pre-evacuation time and movement time can be provided according to the study. But more parameters must be considered in the models because of the complex building structure. As an important criterion in occupant safety evacuation, *ASET* also depends on many kinds of variables related to fire growth. With the development of fire, some condition factors such as heat release rate, smoke concentration and fire detection reliability will play a decisive role in *ASET* calculation. What's more, such factors have apparent uncertainty and cannot be defined as invariant constants. Therefore, the simulation approach was employed widely to study the uncertain impact of some parameters on the calculation results. And that has been proved effective. A method based on Latin hypercube sampling was adopted to analyse the uncertainty in the calculating process of *ASET* by Kong et al and the most influential factors were concluded as fire growth rate and the position of fire detectors [4-5]. Lv studied tunnel fires and expressed uncertain factors that have an

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