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Fire risk analysis of residential buildings based on scenario clusters and its application in fire risk management ☆

Jing Xin [a,b,*], Chongfu Huang [a]

[a] Academy of Disaster Reduction and Emergency Management, Beijing Normal University, Beijing 100029, PR China
[b] Department of fire command, Chinese People's Armed Police Force Academy, Langfang 065000, PR China

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ABSTRACT

This article presents building fire risk analysis model based on scenario clusters and its application in fire risk management of buildings. Building fire risk analysis is a process of understanding and characterizing the fire hazards, the unwanted outcomes that may result from the fire, and the probabilities of fire and unwanted outcomes occurring. The purpose is to evaluate and make a decision about the level of fire risk to determine whether to take appropriate risk management measures or not. Therefore, building fire risk analysis serves as a basis for fire risk management. In the paper, scenario clusters are constructed in the process of building fire risk analysis, and the number of deaths and directive property loss are selected as building fire risk indexes. Finally, the average fire risk of residential buildings is quantified in detail. With the types of detailed fire risk models developed here, fire risk management measures could be taken to improve the building fire safety grading and reduce fire risk levels and subsequent damage.

1. Introduction

Fire is crucial for the development of human society, and it has become an important part of human civilization. Among different types of disasters, fire constitutes a significant threat to life and property in urban and rural areas. According to the data offered by Fire Service Bureau, Ministry of Public Security, in 2011, a total of 125,417 fires were reported in mainland China, 1108 civilian deaths, 571 civilian injuries, and 2057 million Yuan (RMB) direct property losses [1]. Building fires, especially residential fires, remain a critical concern as 52,661 fires or 39.7% of all fires occurred in residential buildings, resulting in direct property damage of approximately 309 million Yuan (RMB), 853 civilian deaths and 347 civilian injuries [2–5]. Society has responded to the threat of fire in buildings in many ways, including fire department intervention, insurance, building regulations, education on fire hazards, controls on the use of materials and products in buildings, and the design of buildings to resist the effects of fire. A growing concern in China is how to take appropriate fire risk management measures in buildings, prevent and control potential fire accidents, reduce the casualties and losses of accidents, and ensure building fire safety.

This definition of risk management used in the paper has been adopted from ISO 31000:2009 [6,7]. According to the definition, risk management includes risk assessment and risk treatment, and the different stages in fire risk management procedures are illustrated in Fig. 1. The risk assessment of a system consists of the use of all available information to estimate the risk to individuals or populations, property or the environment, from identified hazards, the comparison with targets, and the search for optimal solutions [8]. Fire risk assessment in buildings comprises three steps of fire risk identification, fire risk analysis, and fire risk evaluation. Fire risk identification is the systematic process to understand how, when, and why fire could happen. Fire risk analysis is the process of estimating magnitudes of consequence and probabilities of the adverse effects resulting from fire in a building [9]. The end result of fire risk analysis is expressed either in qualitative, mixed or quantitative terms depending on the type of risk, the purpose of risk analysis, how detailed the analysis is to be and the information resources available. Fire risk evaluation then involves applying the developed risk criteria and making a decision about the level of fire risk. Fire risk treatment is the process of improving existing risk controlling measures, developing new risk controlling measures and implementing these measures to reduce fire risk. Therefore, fire risk analysis is only one part of fire risk management process, and it serves as the foundation of regulatory decision-making on whether to take actions to reduce risk or choose appropriate risk treatment

* Corresponding author at: Academy of Disaster Reduction and Emergency Management, Beijing Normal University, Beijing 100029, PR China.
Tel.: +86 18942673501.
E-mail address: xin_jing@126.com (J. Xin).

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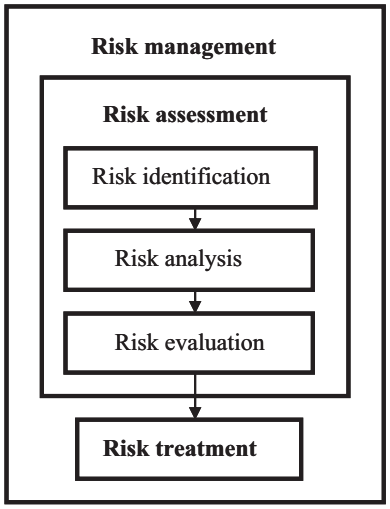

Fig. 1. Different stages in fire risk management procedures.

measures or not [10]. Research related to fire risk analysis is, therefore, critical and essential.

With development of performance-based design, some studies have been conducted on fire risk analysis in buildings from different perspectives and levels. Models such as FiRECAM [11,12] and FiERAsystem [13] were used to calculate the expected life risk. In other studies probabilistic methods have been used to assess levels of people safety in buildings [14]. Quantitative risk analysis approaches have also been used to quantify the risk to occupants using stochastic factors [15]. However, studies to date have largely been concerned with various aspects of fire risk analysis and there has been little in the way of development of systematic theoretical methods for analyzing fire risk in buildings in terms of fire risk management. Existing fire risk management involves the identification of alternative fire safety design options [16,17], the ongoing inspection, maintenance of fire protection systems [18] and evacuation training and drills [19]. In this study, basic process of fire risk analysis in building is described, and a fire risk analysis model based on scenario clusters is established with consideration of the characteristics of fire dynamics and occupants' behavior. The number of deaths and directive property loss are selected as fire risk indices and the average fire risk of residential buildings is quantitatively analyzed, so that appropriate fire risk management measures can be adopted.

2. Fire risk analysis process of buildings

Fire risk is defined as the product of the probability of fire occurrence and the consequence or extent of damage to be expected on the occurrence of fire [20]. It is a function of three factors: loss of or harm to something that is valued (e.g., life, property, business continuity, heritage, the environment, or some combination of these), the scenario that may induce the loss or harm, and a judgment about the probability that the loss or harm will occur. Fire risk is a weighted average of the risk values of each scenario, and it can be presented with the following formula:

$$FR = \sum_{i=1}^{n} P_{f_i} C_{f_i} \quad (1)$$

where, FR is the fire risk (fatalities per year or money per year), P_i is the probability of occurrence of fire scenario i (year^{-1}), C_{f_i} is consequences of scenario i (fatalities or money), n represents the total number of scenarios.

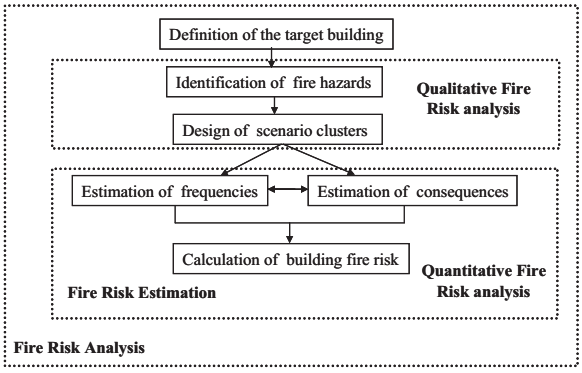

Fig. 2. Flow chart of fire risk analysis of buildings.

There are many quantitative measures for building fire risk, such as fire death rate per 100,000 population, annual mortality rate, loss of life expectancy, and so on. In this paper, the risk of occupant deaths (FR_O) and risk of the directive property loss (FR_P) are selected as fire risk indexes to quantify building fire risk [21].

$$FR_O = P_f C_{O/f} \quad (2)$$

$$FR_P = P_f C_{P/f} \quad (3)$$

where, P_f is the frequency of occurrence of a developed accidental fire in buildings, $C_{O/f}$ is the number of deaths due to the occurrence of fire accidents, $C_{P/f}$ is the directive property loss due to the occurrence of fire accidents.

The different stages involved in analyzing building fire risk are shown in Fig. 2. Each of these steps is now considered in turn.

2.1. Definition of the target building

The first step is to obtain relevant information about the target building. Required information related to the building includes the size, location, construction, the processes carried out in the building, fire safety prevention systems, the nature and likely state of occupants and the information on fire department such as the distance to the target building should be acknowledged.

2.2. Identification of fire hazards

Identification of fire hazards is a process of recognizing that fire hazards exist and defining their characteristics. The location of the design fire and the occupation of the building at all hours, in addition to initial conditions of fire detection and alarm equipment, and fire sprinklers must be acknowledged.

2.3. Design of fire scenario clusters

A 'fire scenario cluster' is a subset of fire scenarios that resembles each other. It could group the universe of possible fires into a manageable number of scenario subsets so that all the elements are present [22]. A fire scenario is a sequential set of fire events that are linked together by the success or failure of certain fire protection systems or actions [23]. A fire event is an occurrence that is related to fire initiation, or fire growth, or smoke spread, or occupant behavior, or fire department response [24]. In the process of understanding fire risk analysis, three fire scenario clusters can be considered important to support calculations of frequency and consequence; namely a fire scenario cluster, a fire automatic suppression scenario cluster, and a behavior cluster.

The fire scenario cluster must specify all the elements including design fire curve and as well many other surrounding circumstances of the fire, such as compartment geometry and properties,