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Randomness in the evacuation route selection of large-scale crowds under emergencies

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ABSTRACT

To date, considerable research has been conducted into micro and macro evacuation models, fuelling the development of the field of emergency evacuation. However, the uncertainties of large-scale evacuation under emergencies have not yet been fully elucidated. In this paper, the impact of the crowd physiological and psychological factors on large-scale evacuation is presented and quantified, then incorporated into a random Markov route selection model of evacuees, to obtain a probabilistic description of crowd route selection. Against a background of instantaneous leakage and diffusion of CO poison gas, a detailed analysis of the uncertainties inherent in the evacuation process and results (specifically, the sensitivity of clearance time to a variety of factors) is conducted using the Markov process, integrating the initial distribution of crowds, route travelling capability, and so on. The variation rule of clearance time under the influence of relevant parameters is revealed and also the significance of considering the psychological and physiological risks in large-scale emergency evacuation is proved.

1. Introduction

When natural disasters such as earthquakes, tsunamis and hurricanes are imminent or have recently occurred, often a large number of people in the affected regions require evacuation. When man-made disasters occur, such as terrorist attacks in a metro station or riots in a major demonstration, emergency evacuation of the large crowd present is usually also required. Industrial accidents, such as hazardous material leakage and explosions, also tend to cause a large number of surrounding residents to be evacuated. Such emergency evacuations, which involve a large number of people and differ from the escape actions of small or medium-sized crowds in ordinary building evacuations, are described as large-scale evacuations.

For such an evacuation, although existing micro and macro evacuation models have achieved effective analysis of personnel movement or the overall traffic situation during evacuation [1–4], and thus played an important role in predicting evacuation time and evaluating evacuation plans, in emergencies, people are affected by abnormal pressure, thus individual and group psychological and behavioral reactions are quite different from those in normal situations [5] and can cause many uncertainties.

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A great many factors, such as the disaster environment, guidance information, risk perception of the individual and individual psychology, can influence individual behavioral decisions in the evacuation process, and the impact of these factors changes with time. Hoogendoorn and Bovy [6,7] stated that individual behavior is affected by external factors, such as environmental stimuli and obstructions, internal factors, such as pedestrian intention and time constraints, and traffic conditions, such as average speed and congestion. Therefore, pedestrian behavior is uncertain. Given this uncertainty, they proposed a route selection model able to determine the continuous movement path of pedestrians and make optimal dynamic decisions as to resource allocation in continuous space and time. In this model they considered the behavioral cost of physical space restrictions and pedestrian dynamics. Sime [8] presented a pedestrian evacuation time analytical model, in which the impact of multiple factors, such as pedestrian psychology, building structures and evacuation facilities, on pedestrian route choice behavior was considered. In large-scale evacuation under emergencies, the individual is more significantly affected by the disaster environment, population density and emotional state than in conventional cases. Thus, the behavioral uncertainty is greater. Escape speed and path selection are real-time varying, and depend on the perception of the surrounding environment, and physiological and psychological state of the individual [9,10]. Therefore, in addition to objective factors, such as disaster environment, time cost and congestion, we should also consider subjective factors relating to the crowd's physiology and psychology while studying the uncertainties in large-scale evacuation, so as to reflect more realistically the stochastic characteristics of crowd route selection behavior under emergencies.

According to their different principles of route selection, regional evacuation models may be divided into three categories.

(1) Evacuation models which employ pre-established evacuation routes. These models usually determine routes before simulation according to an existing evacuation plan or principles determined by the model users, such as the nearest destination [11].
(2) Evacuation models which employ route optimization. At the core of these models is the optimization objective of the evacuation route. Different optimization objectives will result in selection of different routes [12]. Most models design and simulate the evacuation process according to the principles of least evacuation time or shortest distance.
(3) Evacuation models which dynamically select evacuation routes according to certain principles, which usually include:
  - Evacuation in the direction with lowest disaster risk, in which disaster spread direction, spread speed, etc., should be considered.
  - Evacuation towards the destination with least transit cost (time or distance).
  - Evacuation along paths where congestion is less, in which real-time traffic information should be integrated.
  - Evacuation according to final destination or vehicle type.

Depending on the guiding principle(s), the evacuation route selection may be either deterministic [13,14] or probabilistic [15].

To describe uncertainties, stochastic models based on the Markov approach have been widely applied in the field of traffic flow [16,17], but these models ignore subjective characteristics and only focus on objective information related to traffic network, such as distance and the congestion. In this work, the primary concern is large-scale crowd evacuation in which the physiological and psychological factors of the crowd itself are significant, affecting not only the objective parameters, e.g. moving speed or crowd density, but also other subjective aspects, such as whether people can withstand movement through a dangerous environment (such as a toxic gas cloud), whether panic will arise and influence movement, etc. In consideration of these problems, the stochastic Markov model of large-scale crowd evacuation presented in this work will not only contain the key features of prior work, but also some original macro elements related to crowd physiology and psychology.

2. Probabilistic description of route selection

2.1. The basic stochastic Markov model

Markov process-based random evacuation is essentially a process of crowd density changing with time. In order to calculate the changes in population distribution in the evacuation space, a dynamic model based on the Markov random process is used to simulate the movement of the population. First a schematic diagram of the evacuation area is established, following the approach used in prior literature [17]. The key elements are as follows:

(1) The area to be evacuated is divided into N sub-areas. Each sub-area is known as a grid node.
(2) Each node represents an artificially delineated space region, whose size and shape may be changed as required. In other words, a node does not necessarily need to correspond to a single building or functional area in the real world. It may represent one building or a region consisting of multiple buildings.
(3) The nodes are connected by line segments. If there are two nodes representing two buildings, the connection between them can represent a road between the buildings. If the two nodes represent multiple buildings, the connection can represent the link capability between them. By assigning the parameters of travelling capacity and length to links, the link capability of the connections may be characterized. For a $n \times n$ grid network, the corresponding number of links is $(1 + 2 + \cdots + n) \times 4 = 2n \cdot (n + 1)$.