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Extended route choice model based on available evacuation route set and its application in crowd evacuation simulation

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ABSTRACT

In this study, we propose an extended route choice model based on an available evacuation route set to simulate the selection of pedestrians in selecting an appropriate route during evacuation in emergency situations. In this model, four parameters (i.e., distance to available route, length of available route, level of congestion in available route, and capacity of available exit) affect the route choice of the pedestrian and the evacuation route set. In this study, the evacuation route set is created and optimized by a modified social force model and a route learning method. Experimental results show that the extended model can effectively reproduce crowd behavior in an emergency situation, which can assist in analyzing emergency evacuation scenarios. Moreover, two important conclusions regarding increasing evacuation efficiency show that the proposed model is in line with real-world situations.

1. Introduction

The study on crowd dynamics and related complex pedestrian behavior in emergency situations, which emphasizes that individuals must exit a public building or space in an emergency situation, has gained significant interest. Research shows that the behavior of a crowd is highly complex, which leads to squeezing, trampling, and even death, especially in emergency situations. The goal of such research lies in modeling crowd evacuation to provide a basis upon which the design of public buildings and spaces may be improved and minimize the incidence of fatalities and injuries [1–4]. Several discrete and continuous models, which focus on demonstrating pedestrian behaviors in crowd evacuation, have been proposed in the literature, such as cellular automata model [5], lattice model [6], social force model (SFM) [7], and reciprocal velocity obstacle (RVO) model [8]. Most studies have generally viewed crowd dynamics and pedestrian behavior on three levels (i.e., operational level, tactical level, and strategic level); the levels represent basic walking behavior, evacuation route selection, and general planning, respectively [9]. However, the models may not fully reflect the complex behaviors of pedestrians in evacuation scenarios [2].

The behaviors and related actions of pedestrians in emergency evacuation situations are extremely complex and often driven by crowd dynamics. Such behaviors depend on pedestrians' perception of their environment and the purpose of a visit to a large degree [10]. Thus, modeling the relationships between these factors is key in reproducing crowd dynamics in emergency situations. These relationships may be properly represented by the choice of an appropriate route in such

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scenarios. Intrinsically, the selection of an evacuation route is on a tactical level. Although a crowd exhibits complex and variable patterns of behavior during evacuation, the principal concern is using the minimum time for efficient and safe evacuation in emergency scenarios and enabling pedestrians in selecting an appropriate route to minimize the “evacuation cost” [11]. This study addresses the aforementioned concerns.

In this work, we propose a route choice model (RCM) based on available evacuation route set (AERS) to simulate the route choice behavior of pedestrians during evacuation in emergency situations. In this model, the factors affecting the route choice of pedestrians (i.e., the distance between pedestrian and route, length of route, traffic congestion of route, and density of exit) are used to calculate the selection probability of every route in AERS. These factors assist pedestrians to identify an appropriate evacuation route in emergency situations. An inertia factor is introduced into the RCM to avoid frequent change of routes. Moreover, a modified SFM (MSFM) for avoiding obstacles is used to initialize the AERS, which is optimized by a route learning (RL) method.

The remainder of this paper is structured as follows. In Section 2, we review the related works. In Section 3, we define the AERS. In Section 4, the MSFM, which is used to initialize the AERS, is introduced. In Section 5, we discuss the AERS optimization and adjustment algorithm (i.e., RL). In Section 6, we describe the RCM based on the AERS. Experimental results based on a simulation are discussed in Section 7. In Section 8, the paper concludes with closing observations and an outline of proposed future research.

2. Related works

Many factors can influence an individual’s choice of routes during evacuation, and these factors have received extensive analysis in the literature. For example, Hoogendoorn and Bovey presented a summary of factors that influence an individual’s decision on the appropriate route selection and presented a number of schemes by optimizing some predicated pedestrian-specific utility function [12]. Hartmann designed navigation fields with the shortest distances to a pedestrian’s targets with respect to arbitrary metrics and proposed a method to ensure that the pedestrians along the steepest descent of the navigation field can evacuate the scenario [13]; this method is extended to other evacuation models. Guo analyzed the pedestrian route choice behavior and constructed a plausible framework that can predict physical congestion [14].

Kneidl and Borrmann in [15] designed a series of experiments and simulations to explore the manner in which pedestrians choose a route in the evacuation process. Guo et al. studied the features of route selection under conditions of both good and zero visibilities and proposed a microscopic pedestrian model to simulate pedestrian behaviors [9]. Xi and Son analyzed the psychological preferences of pedestrians with respect to different route choice options based on decision field theory, and proposed a two-level modeling framework for pedestrian route choice and walking behaviors [16]. Guo and Huang applied route capacity intolerance in their model and reproduced the pedestrian route choice behavior in selecting different routes toward the same and different exits [17]. Kirik et al. introduced the shortest path and time strategy into a floor field (FF) model for simulation; the strategy is based on transition probability calculated by congestion and route length [18]. Fu et al. analyzed the effects of different environmental elements (i.e., distance and local density) on the evacuation time and presented an exit-choosing mechanism [19].

Guo and Loo proposed an assessment method based on pedestrian route choices; in this model, the utility of the pedestrian environment is quantified [20]. Canca et al. introduced an approach based on length perception of subjective links and k-paths to the destination in their model to simulate route selection [21]. Stubenschrott et al. utilized a dynamic approach for pedestrian route selection with validation based on a high-density subway station [22]. Wang et al. incorporated a random Markov model to simulate the route options of evacuees in emergency evacuation scenarios; in this model, the impact of the physiological and psychological factors in crowd has been quantified in large-scale evacuations [23]. Ma et al. presented a route selection model that incorporates hyperpath and generalized extreme values of network based on link choice models [24]. Hoogendoorn et al. proposed a novel specification for a local RCM based on the assumption that people will locally minimize their “travel cost” [25]. Tan et al. developed a semantic model that considered route changes, which are caused by the change in connectivity structure of activated fire safety facilities during emergency situations [26]; this study is used to predict a reliable building evacuation performance and thus provides a rational basis for evacuation management. Wagoum et al. presented an event-driven approach to redirect pedestrians in leaving a facility efficiently; the redirection strategy includes congestion situation and route evaluation [27]. Xu et al. introduced the density along possible evacuation routes into an FF model to simulate the exit-choosing behavior of pedestrian and significantly reduce evacuation time [28].

In general, pedestrians’ behavior during evacuation is complex and is influenced not only by their purpose and special environment but also by individual property. Hua et al. quantitatively described complex human subconscious behaviors; this research helps to understand the nature of a phenomenon during evacuation [29]. The authors also presented the complex behaviors of pedestrians using a new optimal velocity function [30]. Wong et al. simulated the complex behavior of pedestrians with poor visibility by analyzing the individual desire and interaction among pedestrians [31]. Pedestrians in an evacuation situation always have a strong sense of purpose; thus, their behavior always varies from different evacuation scenarios, desire, and relationship with other pedestrians [32–34]. Moreover, individual property is considered as an important factor affecting the behavior of pedestrians during evacuation, which has been analyzed by speed, density, and flow extracted from a recorded video [35]. Tang et al. discussed evacuation efficiency considering different individual properties and evacuation efficiency in two special scenarios (i.e., aircraft and classroom) [33,36]. Guo et al. analyzed some elements that influence the behavior of pedestrians, which involved the individual property mentioned in [37–39].