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Emergency evacuation models based on cellular automata with route changes and group fields

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HIGHLIGHTS

- A new model based on non-deterministic cellular automata is proposed for pedestrian evacuation simulation.
- In environments with more than one exit route, route change probabilities and group fields are important extensions.
- Computational simulations show that the extensions effectively modify the evacuation times and allow for better estimates.

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ABSTRACT

In this paper, we propose an extension of cellular automata models applied to emergency evacuation pedestrian dynamics. The new extensions are the route change probabilities and group fields. The first extension allows for pedestrians to change direction when necessary to access an alternate exit route. The second extension adds a field that makes groups of pedestrians always walk close to each other and exit together. Several experiments were conducted to study the effects of these new extensions, first to verify the associated collective phenomena and to verify the effect with the security performance measures, more precisely, in the evacuation time, as well as to perform comparisons with other previous models. The main conclusions are that the effects of these new extensions effectively modify the security performance measures and can therefore be important for improving the models and providing better estimates.

1. Introduction

Pedestrian dynamics studies have become an attractive research area for physicists and engineers, mainly due to their high applicability and complex nature. The literature contains some models for describing the main characteristics of pedestrian flows. Among these models, the most known are the models of social forces [1–3], models based on queueing theory [4–8], and cellular automata (CA)-based and multiagent-based models [9–12].

Although it is a complex system [13], in pedestrian dynamics, the perception of individual pedestrians or a particular subgroup must exist about direction, obstacle avoidance, and others, which does not occur in other types of complex systems. Therefore, CA-based models are considered to be excellent tools for this purpose because such models enable adding group

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effects or individual effects without losing the emerging collective pattern. Due to its simplicity, the CA model allows for very high simulation speeds and is very well suited for the optimization of evacuation procedures, even in complex situations [14].

This work is based on the CA theory [15–18] for emergency evacuation pedestrian dynamics. Studies of this type are important for several reasons. Many real events, such as disasters from fires or concentrated crowds, are of great importance for developing research on this topic and the great contributions that these studies can offer. Until recently, safety studies against such phenomena, although considered essential in the performance of building designs, were rarely contemplated due to the complexity and lack of research, in part due to the computational limitations of the past. Recently, this has become a vast research field.

The CA models for dynamic pedestrians initially described by Schadschneider [19] are considered to be efficient and simple models. In these models, pedestrians are represented by cells moving stochastically in a reticulated fashion, *i.e.*, the movement is performed by discrete steps.

The CA models for pedestrian dynamics are a recent theory. The main contributions were recently published. The first work to present this theory, in the format that will be presented in this work, was developed in 2001 by Schadschneider [19]. This work was fundamental in showing a dynamic pedestrian model in a format that includes the most obvious collective phenomena: the pedestrian interaction and the environment interaction via the 'transition probability'.

Over the past decades, there has been progress in these models, in part due to computational advances. Over time, several extensions have been incorporated to make the simulations closer to the real collective behavior. Various important characteristics are studied, such as walking toward the destination [14], effects of walls [20], forces between pedestrians [21], collisions among pedestrians [22,23], suitable position of an exit [24], density around an exit [25], turning at an exit [24], velocity changes according to density [12], anticipation floor field [26] and so on.

As an example, some of the work in this topic has proposed models in which there is more than one exit route, with the emergent properties of this behavior. In cases of emergency simulations, this type of model is very important because evacuations can occur through more than one exit. However, there are some behaviors that have not been modeled in previous models. One is the initial choice of the exit route. How will a pedestrian choose the best route? The other is the possibility of a route change. A pedestrian may initially choose a route and then realize that this was not a good alternative due to factors such as congestion, for example, deciding to return and follow a new route. It is believed that not adding this behavior may create a deviation in the security parameters. In real evacuation events, although most people search for the exit alone, the formation of groups can occur, in which people exit together. Rather than a single person in the group selecting an alternative route, everyone in the group will have the same behavior. These affinity groups can be family, friends or people who, even not knowing each other, decide to join during emergency situations. It is believed that the considerable presence of these groups can affect the security parameters, and thus, this behavior is added to the simulations. In this work, these effects are the main behaviors to be reproduced through a new set of rules and equations that define the transition probability in CA models.

Indeed, ideas about multiple SFs were presented in other studies. However, models that allow pedestrians to change routes whenever necessary during emergency situations are still limited in the literature. The currently available literature does not offer this important mechanism that allows pedestrians to identify problems in their preferred path and to proceed to an alternate exit if there is any other way to vacate. We believe that this new component is required in models with multiple SFs to represent the pedestrian intelligence component to perform more realistic simulations. Moreover, close groups of people generally exist in real events; however, no model thus far has presented simulations that include these groups, which may influence the security metrics.

The remainder of this paper is organized as follows. Section 2 presents a brief review of stochastic CA models for pedestrian dynamics. This section also presents the components of this model, which are the preference matrix and the dynamic, static and anticipation floor fields. Next, the new CA model for dynamic pedestrians with changing routes and group floor fields is presented. Moreover, we show the transition probability to group cells. In Section 3, we present the simulation procedure, initial conditions, simulation results and previous conclusions. Section 4 presents the main conclusions, comments and suggestions for future works.

2. Cellular automata models for pedestrian dynamics

In CA models, pedestrians are viewed as cells or particles that move in two-dimensional lattices. Each lattice can be occupied by only one pedestrian at a step. Each pedestrian can move to one of the neighboring lattices according to the transition probabilities p_{ij} in each discrete step. The direction options are represented by arrows. In this case, we have a system in which the reference neighborhood is called a *Moore* neighborhood. In cases where the movement can only be performed for the vertical and horizontal lattices, we have the so-called *von Neumann* neighborhood. This can also be called a one-movement neighborhood because only one movement is allowed in each step. When two movements are allowed in a step, we call it a two-movement neighborhood, which can be used as an alternative to increase pedestrian speed [12].