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Research on evacuation in the subway station in China based on the Combined Social Force Model

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HIGHLIGHTS

- A modified Combined Social Force Model is built which integrates the SFM with the Gaussian Puff Model.
- We model the process of emergency evacuation in a subway station when there is a sudden toxic gas attack.
- The influence on passengers varies according to the position and numbers of gas sources.
- More casualties will occur if people do not detect the danger.
- The wind speed will also influence the casualties.

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ABSTRACT

With the increasing number of subway stations, more and more attention has been paid to their emergency evacuation, as it plays an important part in urban emergency management. The present paper puts forward a method of crowd evacuation simulation for bioterrorism in subway station environment using the basic theory of the Social Force Model combined with the Gaussian Puff Model. A Combined Social Force Model is developed which is suitable for a real situation where there is a sudden toxic gas event. The model can also be used to demonstrate some individual behaviors in evacuation, such as competitive, grouping and herding. At last a series of experiments are conducted and the results are as follows. (1) When there is a toxic gas terroristic attack in subway stations, the influence on passengers varies according to the position that the gas source lies in and the numbers of gas sources. (2) More casualties will occur if managers do not detect the toxic gas danger and inform passengers about it. (3) The larger the wind speed is, the smaller the number of injured passengers will be. With the experiments, the number of people affected and other parameters like gas concentration can be estimated, which could support rapid and efficient emergency decisions.

1. Introduction

In recent years, with the sharp increase of population in large cities such as Beijing and Shanghai in China, subways have been playing a more and more important role in transportation. During the operating time, especially traffic peaks and holidays, the number of people usually reaches durative summits. Hence, subways become prone to terrorist attacks. Biological and chemical terrorist attacks have been widely used due to their devastating power and huge infection. According to A Global Chronology of Incidents of Chemical, Biological, Radioactive and Nuclear Attacks: 1950–2005 published on July 7, 2006, and supported by US Department of Homeland Security, during the 1950–2005 period, there were 423 terrorist

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attacks in the world, leading to 318 people losing their lives. Besides, the number of terrorist attacks is increasing and chemical attacks have been occurring more frequently.

It is important to detect the incident position, the affected area and the number of infected people after sudden terrorist attacks. There exist several famous models in the domain of evacuation: Cellular Automaton model [1,2], Social Force Model, Agent-based Model [3–5], etc. Among them the Social Force Model is the best one to simulate pedestrians' behaviors. The Primary Social Force Model (PSFM) is usually used to emulate people's actions in daily life. There are some recent papers which improve the PSFM by introducing features or variables to emulate people's action in emergency evacuation [5–9]. Besides, many researchers have combined different models to study evacuation. Xia et al. [10] propose a probabilistic occupant evacuation model for fire emergencies using Monte Carlo methods and then integrate the model into a fire risk analysis model CUrisk. The model produces a similar result to other simulation software and the percentages of remaining occupants are in good agreement with the real fire consequences. Joo and Jaekoo et al. [11] present a simulation model which is agent-based and perception-based. It allows a human agent to make decisions based on the perceived affordance given by the environment. Son et al. [12] introduce a framework of evacuation simulation and the necessary technologies needed to implement the framework, like grid-based data environment, agent-based individual model and the method of associated individual behavior with spatial environment. The paper [13] uses a lattice model to simulate an evacuation under the context of a no visibility room due to thick smoke. It could be seen as a preliminary research on the complex behaviors of people in a dark situation. The paper [14] develops a model consisting of two sub-models, while the Environmental Model manages the spatial real-time environment using CA and the Pedestrian Model bases on behavior agents to respond to the real-time environment. The model can simulate a set of individuals with heterogeneous behaviors. Guo et al. [15] have modified the heterogeneous lattice gas model by introducing an altitude factor which is for describing the position height of lattice sites. First the author verified the importance of the added altitude factor. Then propose an agent-based fire and a pedestrian interaction model to simulate evacuations in a classroom.

So far, almost all of these researches are based on a hypothesis that there are no casualties, and only a few insert real emergency situations into evacuation models. It turns out that the existing models lacked veracity and vitality. Besides, it must go with casualties when a terroristic attack happens, which will also affect evacuation velocity.

In the present work, we put a scene into the social force evacuation model that a terrorist attack about toxic gas happens in a subway station. Then we build a modified evacuation model containing the special scene. The modified model goes by the name of Combined Social Force Model (CSFM). It can simulate the influence that toxic gas has on velocity and casualties. It can also describe the whole process of an incident. We will conduct two series of experiments to validate the rationality of the CSFM.

The remainder of this paper is organized in the following structure: in Section 2 we introduce two basic models used in this paper. In Section 3 we give our modified models and the general parameters. The series of simulation experiments and result explanations will be presented in Section 4. And we close with the conclusion and future work in Section 5.

2. Basic model

The following parts introduce two basic models used in the present paper: Social Force Model and Gaussian Puff Model, which are used for modeling individual movement and attack incidence in bioterrorism respectively.

2.1. Social Force model

The conception of Social Force was put forward in 1951. In 1995, based on the Fluid dynamics equation, Helbing and his colleagues proposed the Social Force Model in their papers [6–8], which contains several forces with different properties. They are Desire force, Repulsive force and Attractive force. The SFM dynamics equation is

$$m_\alpha \frac{d\overrightarrow{\omega_\alpha}}{dt} = \overrightarrow{F_\alpha(t)} + \xi, \tag{1}$$

$$\overrightarrow{F_\alpha(t)} = \overrightarrow{F^0_\alpha}(\overrightarrow{v_\alpha}, v^0_\alpha \overrightarrow{e_\alpha}) + \sum_\beta \overrightarrow{F_{\alpha\beta}}(\overrightarrow{e_\alpha}, \overrightarrow{r_\alpha} - \overrightarrow{r_\beta}) + \sum_B \overrightarrow{F_{\alpha B}}(\overrightarrow{e_\alpha}, \overrightarrow{r_\alpha} - \overrightarrow{r_B}) + \sum_i \overrightarrow{F_{\alpha i}}(\overrightarrow{e_\alpha}, \overrightarrow{r_\alpha} - \overrightarrow{r_i}, t). \tag{2}$$

m_α is the particle mass, $\overrightarrow{\omega_\alpha}$ is the desired velocity and $\overrightarrow{F_\alpha(t)}$ is the magnitude force. Terms on the right of Eq. (2) contain the desired force, repulsive force and attractive force. ξ means a fluctuation term that represents random variations of the behavior.

Desire force determines the force that drives people to their destinations. The equation is

$$\overrightarrow{F^0_\alpha}(\overrightarrow{v_\alpha}, v^0_\alpha \overrightarrow{e_\alpha}) = m_\alpha \frac{1}{\tau_\alpha}(v^0_\alpha \overrightarrow{e_\alpha} - \overrightarrow{v_\alpha}). \tag{3}$$

If not disturbed, a pedestrian will walk into the desired direction $\overrightarrow{e_\alpha}$ with certainly desired speed v^0_α. A deviation between the actual velocity $\overrightarrow{v_\alpha}$ and the desired speed $v^0_\alpha \overrightarrow{e_\alpha}$ due to fluctuation can be modified by relaxation time τ_α.