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Simulation and analysis of individual trampling risk during escalator transfers

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HIGHLIGHTS

- A five-stage trampling model for individual pedestrians was proposed.
- Several scenarios were simulated to study the impacts of 4 key factors.
- The pedestrian traffic is the main factor that influences the trampling risks.
- A decrease in the picking-up duration decreases the trampling risks.
- The trampling risk is higher than the average risk if the pedestrian velocity is low.

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ABSTRACT

A type of trampling process that is caused by picking-up activities during escalator transfers was studied in this paper. A five-stage trampling model for individual pedestrians was proposed, and the social force model was modified considering the transfer features. Several scenarios were simulated to study the impacts of 4 factors, namely, pedestrian traffic, escalator velocity, picking-up duration and pedestrian velocity, on trampling probability. The results show that pedestrian traffic strongly affects the trampling probability, with a positive correlation throughout all scenarios; the picking-up duration affects the trampling probability, with a negative correlation throughout all scenarios; lower pedestrian velocities can result in higher trampling probabilities if the picking-up duration is short; and the escalator velocity may also affect the trampling probability, but there are no general rules for all scenarios. Thus, the impacts of these 4 factors can be queued in descending order as follows: pedestrian traffic > picking-up duration > pedestrian velocity > escalator velocity. Countermeasures can be employed according to the results to reduce trampling risks.

1. Introduction

Escalators are common in large buildings, where they facilitate the transfer of pedestrians from one floor to another. Escalators are composed of several individual segments, each of which links two floors. A typical transfer between escalator

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segments proceeds as follows: "escalator" → "transfer aisle" → "escalator". Chaotic transfers can cause trampling accidents. In China, there were 33 accidents during escalator transfers in 2007, 38 accidents in 2008, and 44 accidents in 2010.[1] A recent trampling accident occurred on April 18, 2013, when a group of students were taking an escalator during their visit at a children's playground in Shenzhen, Guangdong. The trigger was that a student stopped suddenly to bend down to tie his shoes after his stepping down from the escalator. Ten students were injured in the accident.[2] Therefore, it is important to study trampling risks during escalator transfers for the safety of pedestrians and for the normal operation of large buildings.

2. Related studies

Previous studies on trampling accidents can be generally classified into 3 types:

(1) Empirical studies. In these studies, researchers analyzed the data recorded in real trampling accidents and attempted to find the triggers as well as the patterns of their evolution. Krausz and Bauckhage [1] analyzed the video data recorded in a trampling accident at Loveparade in Germany. They proposed an automatic, video-based method that was based on histograms of the flow vector magnitude and direction. Motion patterns, such as congestion and crowd turbulence, could be detected automatically to allow for early warnings. Helbing and Mukerji [2] analyzed videos that were recorded in the LoveParade stampede accidents from a systemic perspective. Geo-coded videos and a detailed timeline of the crowd's motions were employed to identify the key factors that caused the accident. The analysts argued that the accident was a systemic failure that included a failure of flow control and a lack of overview from the participants. They also proposed proactive measures that assess the criticality levels of crowd situations to avoid or mitigate such accidents. Wang, Liu, and Zhao [3] analyzed a trampling disaster that occurred at the Mihong Bridge in China. A poor estimation of the tourist population, a dereliction of duties, deficient communication, and a design fault in the bridge were believed to be the key factors that led to the disaster.

(2) Experimental studies. Because of ethical issues and the danger of trampling accidents, non-human organisms have always been employed as a proxy to discover the rules of group behavior in panic situations. Altshuler et al. [4] conducted experiments on Cuban leaf-cutting ants. Their results agreed with symmetry breaking (the ineffective use of exits) by panicked crowds. Shiwakoti et al. [5] performed experiments with panicking ants to study the effect of with and without a partial obstruction near the exit. The "partial obstruction effect" was reproduced. Soria et al. [6] found experimental evidence of the "faster is slower effect" in a system of escaping ants that were stressed with increasing levels of citronella. Lemercier et al. [7] designed an experimental study on human group-following behaviors. A total of 28 participants were employed to observe how humans adapt their motion to follow someone. Based on the results of that experiment, they designed a microscopic model to simulate the emergence of stop-and-go waves at both macroscopic and microscopic levels.

(3) Simulation studies. In simulation studies, trampling processes are simulated and studied in a virtual world by modeling the interactive behaviors among pedestrians. Lee and Hughes [8] proposed a strategy that was based on a continuum theory to minimize the risk of trampling in a very dense crowd. The study demonstrated that effective crowd control can be achieved by adjusting either the size of the crowd or the complexity of the environment, which effectively influences the crowd speed. Yu and Johansson [9] modified the social force model by adding a factor that reflects the strong interactions between pedestrians in extremely crowded areas based on which stop-and-go and crowd turbulence could be reproduced. Kuang et al. [10] proposed an extended optimal velocity model to simulate single-file pedestrian movement at a high density by considering the differences in the interaction forces between pedestrians. Their numerical simulations showed that the model could reproduce the space–time evolution of headway during pedestrian movement.

Among the above 3 approaches, one obstacle for empirical studies is that it is difficult to collect all the data for every trampling accident; the problem posed by experimental studies using non-human organisms is that different species have different sizes, behaviors, and cognitive abilities compared with humans. Thus, a simulation approach was employed in this paper. Moreover, most previous studies focused mainly on panicking crowd assembly. However, some escalator accidents happen in normal conditions (rather than in panic conditions) [11], and the most frequent causes of escalator injury include slips, trips, or falls [12]. Activities that someone stops suddenly to pick up something (see Section 1) or to tie their shoes [11] are typical triggers of some stampede accidents during escalator transfers. Such situations differ from previously studied scenarios. Moreover, the movement of pedestrians in escalator transfers is unique. As shown in Table 1, when transferring in escalators, pedestrians must shift their motion states during a transfer on and off the escalators: they typically stand still and are carried along by the escalator; however, at some point, they must step off the escalator and walk by themselves.

The Helbing social force model [13–17] is regarded as one of the bases for microscopic crowd simulation and has been successfully employed for many applications [18–23]. Rational crowd patterns, such as "faster-is-slower" and "stop-and-go", can be reproduced [18]. Therefore, in this paper, the social force model is employed to model trampling accidents caused

[1] The trample accident in Xi'an and it is urgent to guarantee the safety in escalator transfer activities. Available from: http://news.21csp.com.cn/c34/201303/56641.html (Accessed 2 November 2013).

[2] A trample accident happened in the escalator. Available from: http://news.163.com/13/0418/08/8SNTC9RR00014AED.html (Accessed 2 November 2013).