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Modeling, simulation and analysis of group trampling risks during escalator transfers

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HIGHLIGHTS

- A state shifting model for group trampling was proposed.
- Several scenarios were simulated to study the impacts of 6 key factors.
- The factors were ordered by their impacts quantitatively.
- The propagation rate is faster than the recovery rate.
- Early emergency measures are helpful to reduce the severity of a group trampling.

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ABSTRACT

The risks of *group trampling* during escalator transfers were studied in this paper. A state shifting model was proposed to describe the behaviors of a pedestrian during a *group trampling* accident. Based on the model, a *group trample* during escalator transfers was simulated from the beginning of the accident to the transfer recovery using the social force model. The impacts of 6 key factors were studied including the initial location of the accident, the time taken to invoke emergency measures, pedestrian velocity, escalator velocity, time taken for a fallen pedestrian to stand up, and pedestrian traffic. The results show that (1) when an accident happens in the transfer aisle, the peak number of pinned pedestrians is higher, while when it occurs near an escalator exit, the pressure exerted on the pinned pedestrians is more serious; (2) the speed of propagation of the accident is always faster than the recovery rate, and the earlier the emergency measures are taken, the less serious the accident is; (3) overall, except for the initial location of a trampling accident, which cannot be controlled, the other five factors have positive correlations with the severity of a *group trampling* accident, and can be descending ordered by their impacts using a regression analysis: early measures, pedestrian traffic, short standing-up delay, pedestrian velocity, and escalator velocity. These results can be referenced in the development of countermeasures to reduce *group trampling* risks.

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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 segments proceeds as follows: "escalator" → "transfer aisle" → "escalator". Chaotic transfers can cause trampling accidents. In America, the United States Consumer Product Safety Commission (USCPSC) estimates that there are approximately 7300 escalator-related injuries each year (USCPSC, 2003), and during the period 1991–2005, the rate of escalator-related injuries among older adults doubled [1]. In Australia, a crush occurred in an Esplanade train station when pedestrians were taking a downward escalator on February 9, 2014. The incident was caused by passengers pausing at the bottom of the escalator rather than moving down the platform; this stop caused the people following them to fall and pile on top of each other, injuring more than a dozen.[1,2,3] In China, there were 33 reported accidents during escalator transfers in 2007 and 38 in 2008, increasing to 44 in 2010.[4] A recent trampling accident occurred on April 18, 2013 when a group of students were taking an escalator during their visit to a children's playground at Shenzhen, Guangdong. The trigger was that a student stopped suddenly to bend down to tie his shoes after stepping off the escalator. Ten students were injured in the accident.[5] Therefore, it is important to study the trampling risks during escalator transfers for pedestrian safety and for the normal operation of large buildings.

2. Related work

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

(1) Statistical epidemiology studies. Accident causes, frequently injured body parts, and correlations with factors such as gender and age are the main concerns of these studies. O'Neil et al. [1] studied the epidemiology of escalator-related injuries among adults age 65 and older in the US between 1991 and 2005. The authors found that the most frequent cause of injury was a slip, trip or fall. Howland et al. [2] studied falls at a metropolitan airport. They found that 44% occurred on escalators; escalator fall risks included carrying bags, using cell phones, and compromised strength and balance. Chi et al. [3] studied escalator-related injury patterns occurring at Taipei Metro Rapid Transit stations. Their study reported that most escalator injuries were caused by passengers trying to perform other tasks while riding, losing their balance, not holding the handrail, or riders who were struck by other passengers.

(2) Empirical mechanism studies. In these studies, researchers analyze the data recorded in real trampling accidents and attempt to identify the triggers and the patterns of their evolution. Krausz and Bauckhage [4] analyzed the video data recorded in a trampling accident at Love Parade in Germany. They proposed an automatic, video-based method based on histograms of the flow vector magnitude and direction. Motion patterns, such as congestion and crowd turbulence, could be detected automatically to allow early warnings. Helbing and Mukerji [5] analyzed videos recorded in the Love Parade stampede accidents from a systems perspective. Geo-coded videos and a detailed timeline of the crowd's motions were employed to identify the key factors that caused the accidents. Wang, Liu, and Zhao [6] analyzed a trampling disaster that occurred at the Mihong Bridge in China. A poor estimate of the tourist numbers, dereliction of duties, deficient communication, and a design fault in the bridge were believed to be the key factors that led to the disaster.

(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 [7] proposed a strategy based on 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 [8] modified the social force model by adding a factor that reflects the strong interactions between pedestrians in extremely crowded areas; they were able to reproduce stop-and-go and crowd turbulence. Li et al. [9] proposed a five-stage model to describe the trampling process of an individual pedestrian caused by picking-up behaviors; based on this model, the individual trampling risks during escalator transfers were simulated, and the impacts of key factors, namely, pedestrian traffic, escalator velocity, picking-up duration and pedestrian velocity, on trampling risks were studied.

Among the 3 approaches, the main causes and general statistical rules of trampling accidents can be found by epidemiological studies, however, the detailed processes are always neglected in those studies; as for empirical studies, it is difficult to collect complete data for every trampling accident. Thus, many researchers tend to study the detailed trampling

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