Safety Science 75 (2015) 15–22

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/ssci

Examining influence of merging architectural features on pedestrian crowd movement

Nirajan Shiwakoti [a,*], Yanshan Gong [b], Xiaomeng Shi [b], Zhirui Ye [b]

[a] RMIT University, School of Aerospace, Mechanical and Manufacturing Engineering, Carlton, Victoria 3053, Australia
[b] Southeast University, Jiangsu Key Laboratory of Urban ITS, Jiangsu Province Collaborative Innovation Center of Modern Urban Traffic Technologies, 2 Sipailou, Nanjing, Jiangsu 210096, China

ARTICLE INFO

Article history:
Received 8 August 2014
Received in revised form 8 January 2015
Accepted 22 January 2015

Keywords:
Crowd dynamics
Evacuation
Safety
Empirical analysis
Disaster

ABSTRACT

Architectural features such as merging corridors form an important component in floor plans of any major public infrastructure. Previous studies on documented crowd disasters have highlighted that passage restriction such as merging corridors can have negative impacts on the efficiency of evacuation process. However, limited data exists on merging process in the literature. This study aims to address this issue through empirical data collection and analysis of merging process in a controlled laboratory walking experiments.

A series of experiments were conducted with different merging angles (60°, 90° and 180°) and with different desired speed (normal and slow running). The experiments indicated that pedestrians tend to reduce speeds within merging areas. With higher merging angle, there is greater reduction in speed in the merging area. Speed reduction is statistically significant with merging angles and desired speed. The speed reduction had an effect on the flow rate with reduced flow rate observed for higher merging angle. The empirical results from this study can be used to develop and test pedestrian crowd simulation models.

1. Introduction

Pedestrian's movement forms an important component of a multi-modal transportation system. Besides, promoting walking is an important part of the shift to more sustainable transport. However, it is a great challenge to planners or managers of emergency response to ensure efficient, comfortable and safe walking operations of pedestrian's movements in public places such as multimodal points, shopping malls, stadiums and concert venues. Modelling and empirical study of pedestrian behaviour is imperative to analyse and assess safety precautions for those situations.

One of the important characteristics of pedestrian's movement is merging behaviour as observed in the transit stations, buildings or any other indoor or outdoor public areas. This phenomenon usually occurs when crowd movements from multi directions join to form a single pedestrian stream and hence considered as a combination of turning and weaving movements (Roess et al., 2004). Such complex movement can result in travel delays and comfort reductions, thereby reducing efficiency of passenger transit facilities (Daamen, 2004). Also during an emergency evacuation, merging movement of pedestrian crowd is crucial as they change the direction of their escape route abruptly while merging from different corridors (Chertkoff and Kushigian, 1999; Still, 2000). Previous studies on documented crowd disasters have highlighted that sudden change in the egress direction in a restricted passage due to merging and turning could initiate trampling and stampede as people rush to escape (Chertkoff and Kushigian, 1999). It is very important to identify the use of space and movement pathways in preventing crowd stampede (Fruin, 1993; Shiwakoti et al., 2014). Although merging flows may have an implication on the efficiency and safety during evacuation process or crowd management, limited data exists on merging process in the literature. This study aims to address this issue through empirical data collection and analysis of merging process in a controlled laboratory walking experiments.

The paper starts with a review of relevant literature, followed by a description of the experiments on merging behaviour. Results are described and conclusions are presented including a summary of key findings and a discussion of their implications for future research.

* Corresponding author.
E-mail addresses: nirajan.shiwakoti@rmit.edu.au (N. Shiwakoti), gongyanshan@seu.edu.cn (Y. Gong), shixiaomeng@seu.edu.cn (X. Shi), yezhirui@seu.edu.cn (Z. Ye).

http://dx.doi.org/10.1016/j.ssci.2015.01.009
0925-7535/

2. Literature review

To understand the complex phenomena of crowd movement, investigations have been carried out by researchers using mathematical modelling, simulation and empirical approaches (Daamen, 2004). Mathematical modelling and simulation can be further classified as microscopic, mesoscopic and macroscopic depending on the level of detail. Complementary data are required to test the theoretical models quantitatively for their validity and reliability and also to compare the performance of alternative models. The experimental studies on pedestrian crowds have been carried out mostly with human subjects (Daamen and Hoogendoorn, 2003; Helbing et al., 2005; Ko et al., 2007; Kretz, 2007). Most experiments with human crowd aim to understand the behaviour and characteristics of pedestrian flow under congested and non-emergency conditions. Such experiments are of fundamental importance in understanding the behaviour of people under emergency conditions. Similarly, some studies have focussed on non-human organisms, especially under stressed conditions (Altshuler et al., 2005; Burd et al., 2010; Shiwakoti et al., 2011; Soria et al., 2012; Shiwakoti and Sarvi, 2013) to study collective dynamics. Those studies concluded that animal models may have the potential to provide an alternative means of empirically testing and verifying human pedestrian models, particularly when human subjects cannot easily or ethically be employed. However it is important to further explore the physical and behavioural similarities and dissimilarities among these different biological entities and how they may help to unlock the complexities of collective dynamics that may not be fully captured in existing mathematical models.

Empirical approaches for understanding complex pedestrian crowd behaviours such as turning (Dias et al., 2014), crossing (Helbing et al., 2005; Asano et al., 2009; Dias et al., 2013) and weaving (Wu and Lu, 2013) have been conducted in the past to study collective pedestrian dynamics. However, regarding merging crowd flows, experimental studies (and also modelling) is limited in literature.

Tajima and Nagatani (2002) applied a lattice-gas model of biased random walkers to simulate the pedestrian merging flows in a T-shaped channel. They found that clogging can occur at either channel or both channels. In another study, by using a cellular automata procedure with multi-floor fields, Peng and Chou (2011) state the formation of congestion at a merging "T" intersection. Likewise computer simulations have been used to demonstrate the importance of merging process in floor-stairs interface in multi-floor buildings (Galea et al., 2008). In terms of empirical analysis, Zhang et al. (2012) performed a series of controlled experiments with human participants in straight corridors and T-junctions. Based on the experiments, they established fundamental diagrams of the two geometrical layouts and studied their performance. With respect to non-human organism approach, a series of experiments with panicking ants to investigate the impact of complex configurations like turning, crossing and merging on the collective egress have been performed (Shiwakoti et al., 2012; Dias et al., 2013). These studies on non-human biological entities concluded that the complex architectural configurations can potentially lead to inefficient egress. However, there have been no empirical studies on human crowds that have examined the impact of merging angle to the pedestrian crowd flow in a merging area. Therefore, this paper investigates the influence of merging angle on the performance of pedestrian flows at merging corridors. In the next section, the experimental setup is described.

3. Experiments

A series of experiments were conducted with different merging angles (60°, 90° and 180°) and with different desired speed (normal and slow running) with 22 participants (6 female and 16 male) in total. The experiments were carried out inside a building at the Southeast University, Suzhou, China in May 2014. All the participants were students selected from the Southeast University and were aged between 22 and 26 years. These merging angles (60°/90°/180°) were chosen as these angles were more frequently noticed in the merging section of several buildings and train stations in China. While normal walking would be relevant to the congested situation in day to day pedestrian activities or special events, slow running or faster walking may be more representative when people are in hurry (as observed in train stations) or in normal evacuation process (Daamen, 2004). Due to ethical and safety concerns, it is not possible to conduct experiments with running participants which could be relevant to highly competitive behaviour and emergency situation. The number of participants considered in this experimental setup was enough to create Level of Service E (>0.7–1.4 m^2/pedestrian, HCM, 2000) in the merging corridor. It thus represented a congested but stable flow suitable for the intended study. Three repetitions were conducted for each angle and desired speed resulting in total 18 experimental trials. Although higher number of repetitions may be desirable for statistical analysis; considering resource and cost constraints, three to five repetitions have been sufficient to conduct relevant analysis for laboratory walking experiments (Asano et al., 2009, 2007; Kretz 2007).

The experimental layout consisted of two corridors (7 m) merging to a one common corridor (6 m). All the corridors had width of 1.2 m as shown in Fig. 1. The corridors were created using chairs and ropes, a similar logistics used by Helbing et al. (2005), where they used classroom desks to create a corridor to study crossing behaviours of pedestrians. Also researches on pedestrian walking behaviour have shown that pedestrian usually keep some safe distance (also referred as shy distance) from the wall or boundary while walking (HCM, 2000). Hence, unless pedestrian behaviour is very competitive and pushing each other, use of chairs and ropes for laboratory walking experiments as presented in this study is a stable configuration (i.e. risk of pedestrian pushing through the ropes/chair is low). To reduce the degrees of freedom, the effect of blocked vision (due to walls) was excluded by setting out the corridors only with chairs and tapes. Such logistic arrangements for reducing the degree of freedom have been used for several experimental studies on pedestrian walking behaviour (Helbing et al., 2005; Asano et al., 2009; Dias et al., 2014). By reducing the degree of freedom, it is easier first to explore the global behaviour resulting from pedestrian's local interactions rather than the overlapping complexity introduced by the external interactions (such as blocked vision). The effect of blocked vision can be studied later once the fundamental understanding of pedestrian's interactions is clear.

Participants were divided into two similar groups considering gender and body size. To avoid a perfect symmetry (in terms of number of participants), one group consisted of 12 participants while the other group had 10 participants. This setup replicates more realistic situation (in real world) as rarely there would be a situation where there are equal number of pedestrians in each of the merging corridors.

Before the start of the experiments, participants were instructed where to gather, when to start walking and where to walk. However, no information was provided to the participants regarding the research aims of the study. Few warm up walking trials were conducted to ensure that participants were comfortable in walking through the corridor and follow the instruction. A lunch meal voucher was offered to the participants after the experiments as a token of appreciation for participating in the experiments.

Two groups of participants were held separately behind a waiting line that was 0.5 m away from the entrance of the each