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Experimental study of pedestrian inflow in a room with a separate entrance and exit

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HIGHLIGHTS

- We conduct pedestrian experiments to study the inflow process in a room.
- We analyze the features of the normal pedestrian inflow process.
- We discuss the influence of inactive persons.
- The proxemics and attraction to exit are both considered as influencing factors.

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ABSTRACT

Pedestrian inflow process frequently occurs in various pedestrian facilities in our daily life. Great importance should be attached to the study of this process. In this paper, we explore the pedestrian inflow process in a room with a separate entrance and exit. Two kinds of experiments are conducted: experiment 1 has no inactive persons and primarily focuses on analyzing the features of the normal pedestrian inflow process and analyzing the representative spatial parameters in the steady state, while experiment 2 involves the influence of the inactive persons. In order to quantitatively discuss the distribution of pedestrians in the steady state, we adopt several analytical methods, such as the Voronoi diagram method, proxemics, and point pattern analysis. Some features of the inflow process are captured. The distribution of pedestrians in the steady state is not uniform. The proxemics and attraction to the exit are both considered to affect pedestrians' distribution in the inflow process. The presence of inactive persons may have an impact on both the inflow and outflow processes. Practical suggestions are provided for the managers of pedestrian facilities.
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1. Introduction

Pedestrian flow can be seen frequently in our daily life, and pedestrian dynamics has gained growing interest in recent years [1–8]. Many kinds of approaches including experiments, field surveys and modeling have been proposed to study pedestrian behaviors under different situations, such as unidirectional and intersecting flow [1–3] in channels, evacuation of buildings [4–6], and crowd disasters in public places [7,8].

Pedestrian evacuation is a kind of outflow process in which pedestrians move out of some certain areas, and its contrastive process is the inflow process [9]. The inflow process is the situation where pedestrians enter a limited area and stop after they acquire comfortable positions [10]. This process can be commonly observed in various facilities everyday, e.g., elevators

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and public transport vehicles. Though the damage caused by the inflow process may be less than the evacuation process, the inflow process occurs more frequently. Furthermore, no clear destination during the inflow process may cause confusion among pedestrians [9]. Thus, it is significantly essential and meaningful to study the inflow process in our daily life.

In recent decades, a countless number of people have preferred to live in big cities and their demand for transportation has become extremely huge. In order to reduce the traffic congestion and air pollution, traveling with public transport, e.g., subway, bus and train, is widely encouraged in the whole world [11]. Therefore, high performance and good service quality of these public transport facilities are of great importance for passengers. Cantwell et al. [12] examined the factors that impacted public transport commuting satisfaction, and satisfaction levels were found to decrease for those who traveled on crowded or unreliable services and those who had long wait-times. Tirachini et al. [13] suggested that crowding exerted a significant influence on passengers' modal choice, together with travel time, cost, trip time reliability and service frequency. Fernandez et al. [14] performed laboratory experiments to study the effect of the density of passengers in a vehicle on the boarding and alighting times. Dwell time of public transport is a critical factor affecting passengers' traffic modal choice, and it depends on the number and speed of boarding and alighting passengers [15]. A number of studies [16–22] have been conducted to investigate dwell time. Boarding and alighting of public transport facilities are actually the typical inflow and outflow processes. There is an urgent need to understand these processes.

Various studies have focused on pedestrian counter flow existing in the boarding and alighting process. Guo [23] proposed a revised social force model to simulate the pedestrian counter flow through a bottleneck, which was similar to a subway door. It was found that the efficiency of passing through a bottleneck could be improved when adopting proper spatial and temporal separation rules. Seriani et al. [15] showed that pedestrian traffic management measures had significant impacts on the passenger service time, passenger density in cars and on platforms as well as passengers' dissatisfaction in metro stations. According to experimental data or field data, some researchers [24–26] developed computer models to identify the boarding and alighting process in public transport facilities. Plenty of results, such as the position, density, time interval and alighting/boarding time, were given and discussed.

Although much research into the pedestrian inflow process has been performed, more studies are needed to determine the characteristics and intrinsic mechanism of the inflow process. With the help of proxemics theory, Was et al. [27–29] developed cellular automata models to simulate passenger dynamics in trams and stadiums. The interaction between pedestrians was described by "social distance force" derived from the proxemics introduced by Hall [30,31]. In the proxemics, human spatial behavior depends on the four interaction zones, namely intimate distance, personal distance, social distance, and public distance. It is assumed that persons' repulsion force will increase with the decrease of the distance between pedestrians. Ezaki et al. [10] proposed a discrete model and analyzed the inflow process that pedestrian enters a certain area. It indicated that the inflow dynamics were more complicated than the evacuation process. The effect of proxemic force was considered in this model, and was set as a predominant factor. Some fundamental phenomena, including pedestrians' preference for boundaries of an area, were also reported in this study. The authors [9] then conducted an experiment of the inflow process and compared it with the evacuation process. Several features of the inflow process were identified in this experiment: pedestrians tend to be attracted by boundaries; the distribution of pedestrians is inhomogeneous. To the best of our knowledge, few studies focused on the pedestrian distribution in pedestrian facilities, for instance, passengers in the public transport. It is of vital importance to study pedestrian distribution in the inflow process since it can not only affect the crowding in facilities, but also impact the traffic efficiency. The presence of passengers standing in the aisle of the bus was considered as a crowding effect, and slowed down both the boarding and alighting processes [20].

In this paper, we have presented a series of pedestrian experiments in a rectangular room. The aim is to describe the features of the inflow process in this kind of pedestrian facility with a separate entrance and exit. No counter flow exists in the facility, but more factors need to be involved with respect to the pedestrian distribution. Pedestrians may not distribute uniformly in the room. Proxemics may have an impact on the inflow process, whilst the desire to remain away from the entrance and the attraction to the exit may also exert an influence. In reality, due to laziness, fatigue or other reasons, some persons may stop at a place obstructing others. This may affect normal persons' movement and ultimately reduce the traffic efficiency. Therefore, we analyze the influence of this kind of persons on both the inflow and outflow processes.

The rest of this paper is organized as follows. In Section 2, the experimental setup and several analytical methods are introduced. Section 3 presents the detailed results and discussions, including the features of the normal pedestrian inflow process and the influence of inactive persons. Finally, we summarize results and provide practical suggestions in Section 4.

2. Experimental setup and method

The experiment was conducted in a rectangular room. The room has one entrance in the front and one exit near the middle. The length of the room is 10 m and its width is 2 m, while the width of the entrance and exit is 1 m, 1.5 m respectively. The layout of the room is similar to the standing areas in a typical bus in China, as depicted in Fig. 1(a). Two HD cameras were installed to record the whole experiment process. Snapshots of the video scene are shown in Fig. 1(b) and (c).

2.1. Experiment arrangement

40 college students in total participated in the experiment, and the ratio of males to females was 1:1. In order to avoid the bias induced by the familiarity between participants during the experiment, the participants were divided into several

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