Short Research Article

Experimental study on pedestrian speed - buffer space

ABSTRACT

Buffer space is an essential condition for pedestrian micro-behavioral decision-making. To obtain the data relationship between pedestrian speed and buffer space, the pedestrian single-file walking experiment and field observation experiment is designed, the buffer space data of pedestrians at different rates is obtained, the speed-buffer space mathematical model is established, and the influence of buffer space on pedestrian deceleration behavior is analyzed. The model will provide data support and parameter calibration for pedestrian flow simulations.

Keywords: Pedestrian traffic; Deceleration mechanism; Behavioral decision making; Buffer space

1. INTRODUCTION

The micro pedestrian flow model is essential for studying pedestrian flow. In recent years, it has become more and more the primary way to establish the pedestrian flow model by simulating the micro decision-making behavior of pedestrians and combining it with the surrounding environment and other factors to explain the macro pedestrian flow movement mode. Therefore, obtaining the influencing factors and relevant data of pedestrians' micro behavior decisions is crucial. However, pedestrians' behaviors are pretty complex and easily influenced by environmental, personality, physiological, psychological, and cultural factors [1]. Many scholars' studies on the decision-making factors of pedestrian micro-behavior mainly focus on pedestrian speed, spatial distance, and other factors. For example, Seyfried[2] obtained the essential pedestrian speed and distance diagram through a single-file pedestrian flow experiment. Since then, the single-file pedestrian flow has been widely studied [3-8]. In addition, some scholars have obtained the relationship between pedestrian turning distance and speed [9]. The relationship between step length and space [10], step frequency and speed [11] and pedestrian trajectory diagram [12-14], etc.

In line flow modeling, pedestrians when and how to change their speed is a significant problem because of a lack of quantitative relationship between rate and its influencing factors and specific mechanism; the behavior of pedestrians slows down most of the existing line flow model by introducing common-sense assumptions and parameter is set to solve these two problems, therefore, cannot provide a reasonable basis for line flow simulation. To solve these problems, this paper introduces the concept of buffer space and uses experimental and statistical methods to obtain empirical data on single-line pedestrian movement under emergency conditions. It is expected to establish the mathematical model between pedestrian speed and buffer space, and provide future data support for the pedestrian flow simulation model.

2. EXPERIMENTAL DESIGN

2.1 Data Acquisition Method

Pedestrian traffic data collection is the basis of pedestrian flow research. A credible pedestrian flow traffic model can be established through a large sample size and high-quality original data. This paper will collect pedestrian buffer space data through two experiments:

Firstly, the field observation method is used to obtain the relevant data on buffer space and speed under the normal motion state of pedestrians. Standard field observation methods include manual observation, camera recording, and other methods. Video recording observation is a widely used technique at present, which can observe the basic parameters of a variety of pedestrian flow and record the flow process of the crowd, and can be used for repeated observation.

Then, the controlled experiment is used to obtain the relevant data on buffer space and speed under the running state of pedestrians. The controlled experiment can reproduce the situation of pedestrian flow under the emergency scene more truthfully by controlling the variables unrelated to the experimental research, with solid repeatability and high reliability.

2.2 Definition of buffer space

By observing the group's walking behavior, it is found that pedestrians always control their speed to keep a distance from the surrounding pedestrians or obstacles to maintain the space needed for their movement. Therefore, the distance between pedestrians and other pedestrians is an important factor affecting the individual speed of pedestrians. In this paper, the buffer space is defined as the motion space when the pedestrian starts to slow down, that is, the minimum motion space when the pedestrian maintains the expected speed.

In this paper, pedestrian buffer space is divided into two parts, longitudinal buffer space, and transverse buffer space:

(1) Longitudinal buffer space refers to the product of the pedestrian buffer distance (the distance between the pedestrian and the pedestrian in front of him when he starts to slow down) and his shoulder width. It is important to note that the buffer distance between pedestrians here provisions refers to the pedestrian overlooking the linear distance between the center of the projection and not the actual distance between before and after the pedestrians (rear pedestrians) distance between the chest and pedestrians ahead back, follow-up experiments under the different state is to get the purpose of the pedestrian buffer, the relationship between distance and speed. The specific data of buffer distance will be obtained in the later experiment. Pedestrian shoulder width is set at 0.5m[15].

(2) Transverse buffer space refers to the

product of the left and right swing of the pedestrian's body and the distance of the pedestrian in front when the pedestrian starts to slow down. In walking, the pedestrian will not walk along a straight line but slightly swing from side to side. The size of the swing decreases with the increase of speed, and the smaller the swing, the more conducive to improving the evacuation efficiency. According to the experimental data, Liu et al. [11] obtained that the relationship between swing and pedestrian speed was A=-0.16V+0.292. However, Liu found that when the rate was more significant than 1.16m/s, the swing was fixed at 0.055m. When the linear fitting rate is less than 1.16m/s, the relation is A=-0.074V+0.146, and the magnitude of the swing in this paper is still in the same link:

$$A = -0.074V + 0.146 \qquad (1)$$

Where，A is pedestrian swing; For pedestrians whose speed is more significant than 1.16m/s, the swing is 0.055m. Therefore, the size of the buffer space can be expressed as follows.

$$\begin{cases} S_a = (2A + 0.5) \cdot h_{ab} & v \leq 1.16 m/s \\ S_a = 0.61 h_{ab} & v > 1.16 m/s \end{cases} \qquad (2)$$

Where, S_a is the buffer space of pedestrian A; H_{ab} is the buffer distance between pedestrian A and pedestrian B in front;

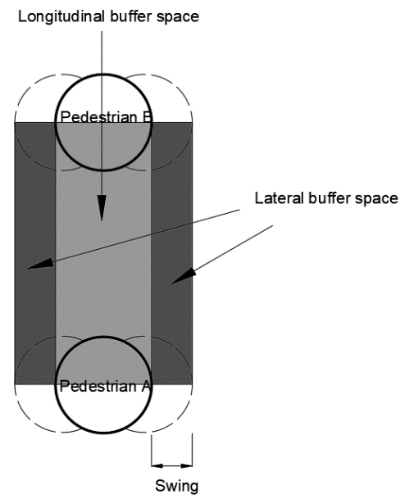


Fig. 1 . Schematic diagram of buffer space

2.3 Field observation experiment

This experiment takes the teaching building of a university as the experimental site. It uses the camera to record the flow of students from the second floor of the teaching building hall.

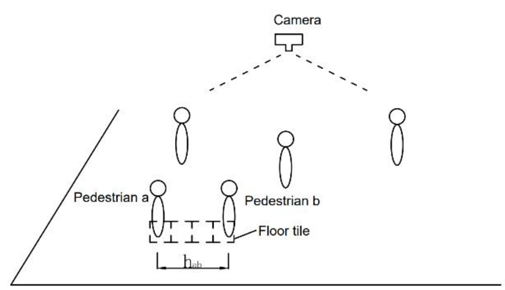
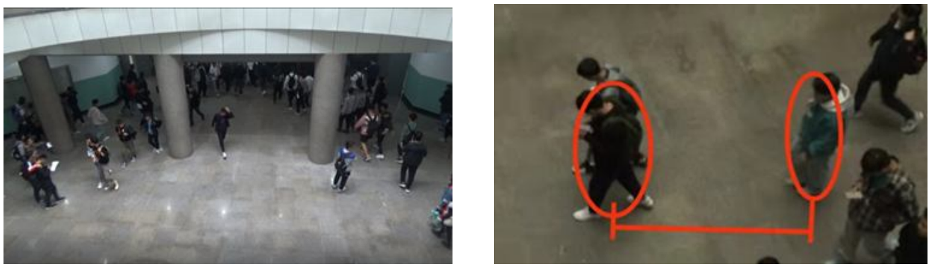


Fig .2 .Field observation experiment

The camera frame rate is 25 frames per second, and the time for starting and finishing classes is 9:40 to 10:00, 11:40 to 12:00, and 18:10 to 18:30. The measurement size of floor tiles under students' feet is 600mm×600mm, and the distance measurement is estimated according to the number of floor tiles under both feet.



(a) (b)

Fig.3.(a) The experimental scene,(b) Pedestrian buffer distance measurement

Adopt the method of artificial statistics statistical pedestrian speed and buffer distance, first broadcast video footage at normal speed, when found that pedestrians have apparent deceleration, before and after taking the pedestrian four frame passes through the length of the divided by the corresponding time calculation of the instantaneous velocity at the moment, and then statistical different times pedestrian speed, pedestrian speed is slow, at this point and pedestrians in front of the distance is the buffer distance.

2.4 Single-file pedestrian motion experiment

Since the video observation method can only observe the daily walking behavior of pedestrians, the expected speed of pedestrians and the buffer space size are relatively concentrated. A single-line pedestrian motion experiment is designed to obtain further relevant data on the buffer space of pedestrians at a higher rate. The buffer space experiment scene is shown in the figure below. The site has a passage 15 meters long and 1 meter wide. Every 0.5 meters of the course is marked, and pedestrians stand at the end of the path to simulate obstacles.

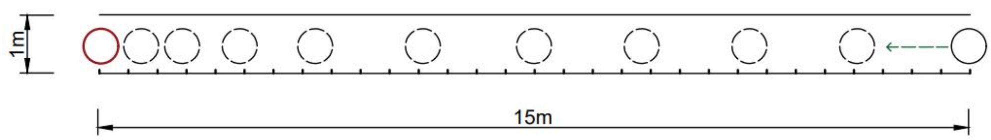


Fig. 4 . Schematic diagram of the experiment

A total of 16 participants participated in the experiment, each repeated three times. To prevent the participants from being disturbed by the objective of the investigation, the purpose of the experiment was not explained to the participants before the study, and only the following requirements were put forward: first, the experimenter should not exceed the scope of the channel; Second, the experimenter needs to dash from one side of the track to the other side and stop without touching or surpassing the obstacles. A camera was set up in the open space beside the passageway to record the experiment.

Fig.5. A frame from the experiment

Data statistical method is similar to the above experiments, watching the movement of pedestrians from video footage, by recording the experimenter sideways center through the distance between two markers used time, to calculate the pedestrians in a particular position, the speed of the speed when found the researchers began to decrease, the work and the distance between the end at the moment, is the size of the buffer distance.

3. ANALYSIS OF PEDESTRIAN BUFFER SPACE

The relevant data on pedestrian buffer distance and speed are obtained by analyzing the two groups of experimental video data. Then, the mathematical model of pedestrian expected rate and buffer space is obtained according to the formula's calculation and statistics.

3.1 Buffer space analysis under normal motion state

Through the observation and analysis of the students' walking video in the teaching building, the expected speed of pedestrians and the relevant data of the corresponding buffer space are obtained.

Table. 1 Data distribution under the normal walking condition

	Mean value	Range	Main distribution interval
Expect speed（m/s）	1.18	0.8~2.0	1~1.3
Buffer space（m^2）	0.524	0.2~0.854	0.5~0.8

After screening the collected data and eliminating the abnormal data, 120 data between the expected speed of pedestrians and the buffer space were obtained, and the speed-buffer space model was established:

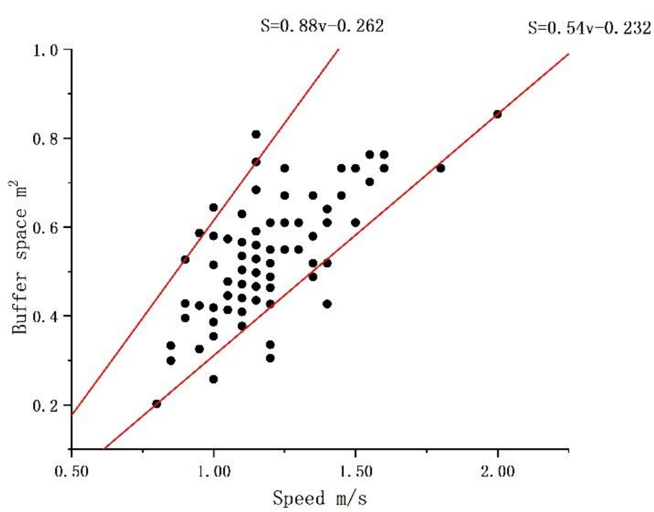


Fig. 6. Speed-buffer space model under normal motion

FIG. 6 shows the relationship data between pedestrians' expected speed and buffer space under normal movement. The distribution regularity of these data is not apparent, and the fitting index is low (R^2=0.45), indicating that a relationship function cannot determine pedestrians' expected speed and buffer space. It can also be understood from people's cognition of distance that individuals' different physical and psychological qualities will determine varying buffer distances. Therefore, data can be concentrated between two upper and lower limits of functions. At different speeds, the buffer distance of pedestrians is taken as the value between the two parts.

After analysis, it is found that almost all data are concentrated between S= 0.88v-0.262 and S= 0.54v-0.232. According to the statistical data, it can be seen that in the normal walking state, the expected speed of pedestrians is mainly concentrated between 1m/s and 1.3m/s, and the corresponding buffer space size is 0.2m^2 to 0.854m^2. The minimum desired rate is 0.8 m/s; in the actual observation, it is challenging to observe pedestrian speed under the condition of low to slow behavior, or before this behavior has been slowing down, the rate can't be expected on behalf of the people at the moment, in the range of the observed pedestrian desired speed and size of the buffer space were positively correlated.

However, it can also be found that even if the expected speed of different pedestrians is the same, the buffer space size is not the same. The buffer space corresponding to each rate has a wide distribution range. When the speed is 1.15m/s, the buffer space distribution range is the widest, ranging from 0.43m^2 to 0.81m^2. Therefore, pedestrian buffer space is not the only factor that makes pedestrians slow down for different pedestrians. It may also be related to the psychology, behavior habits, physical state of pedestrians, etc., which needs more experiments to determine.

3.3 Analysis of buffer space in running state

After observation and analysis of the experimental video of single-line pedestrian movement, two groups of abnormal data are eliminated, and 46 groups of data of pedestrian expected speed and buffer space are obtained.

Table. 2 Pedestrian data distribution in running state

	Mean value	Range	Main distribution interval
Expect speed（m/s）	3.53	2.2~5.4	3.4~4
Buffer space（m^2）	1.31	0.73~2.23	1.43~1.73

Based on this, the mathematical model between the expected speed and buffer space under the running condition of pedestrians is established:

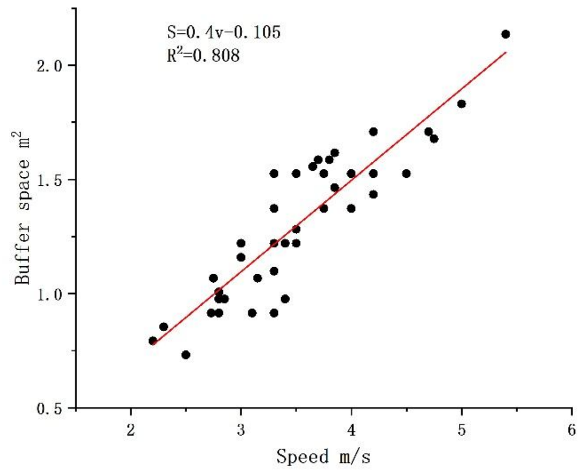


Fig. 7 . Speed-buffer space model in running state

The linear fitting of the relationship between the expected speed and the buffer space data was carried out in the pedestrian running state, and the equation was obtained: S= 0.4V-0.105, R^2=0.808. In the running form, the buffer space distribution was not dispersed in the normal state, and the fitting effect was better. The expected pedestrian speed ranges from 2.2m/s to 5.4m/s, and the maximum observed buffer space is 2.23m^2. Since it is more difficult to measure the rate in the running state than in the normal state, the error is more significant, and the buffer space distribution will also be affected. To obtain more accurate data, we can use other instruments to measure. It can be found that whether in the normal walking or running state, the impact of buffer space on pedestrians' deceleration behavior decision is similar, and the buffer space increases monotonically with the increase of pedestrians' expected speed.

Although this model is similar to the speed-buffer space fitting curve in the normal state, there are still many differences. For example, the buffer space corresponding to the speed in the normal walking state is more widely distributed, and the linear fitting effect is poor. After analysis, it is believed that there may be the following reasons: in the single-line pedestrian movement experiment, the pedestrian moves in a one-dimensional environment with constraints on both the left and right sides, while in the field observation experiment, the pedestrian walks in a two-dimensional environment, and the conditions on the left and right sides change according to the changes of the environment, which has a particular impact on the pedestrian deceleration behavior. In addition, it is necessary to measure further the swing under the running state of the pedestrian, and the resulting error affects the result of the buffer space.

4. CONCLUSION

In this paper, the concept of buffer space is introduced, and the relevant data of buffer space under different expected speeds are obtained through the field observation method and single-line pedestrian movement experiment. The mathematical model of speed-buffer space is established, and the following conclusions are found:

（1）Under normal pedestrian movement, the buffer distance range is 0.3m~1.4m, and the corresponding buffer space range is $0.2m^2$~$0.854m^2$. The faster the pedestrian moves, the larger the buffer space will be occupied.

(2) The relationship between the speed and buffer space of pedestrians in normal walking and running states is obtained between S= 0.88V-0.262 and S= 0.54V-0.232 in the normal walking state; Under the running condition, S= 0.4V-0.105. The expected speed of pedestrians is positively correlated with the size of buffer space, and the influence degree of regular walking and running is similar.

(3) The expected speed of pedestrians and the buffer space are not corresponding. Even if the predicted rate of pedestrians is the same, the buffer space size is not the same. The buffer space corresponding to each speed has a wide distribution; some differences can even reach more than double under normal walking conditions.

In addition, there are various factors for pedestrians to make deceleration decisions, and the decision-making process is also very complex. Therefore, the deceleration mechanism of pedestrians cannot be summarized only by the buffer space, and more experiments are needed to study the deceleration behavior of pedestrians.

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