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*Research Article*

# Research on the Behavior Characteristics of Pedestrian Crowd Weaving Flow in Transport Terminal

**Liya Yao,[1] Lishan Sun,[2] Zhiyong Zhang,[2] Shuwei Wang,[2] and Jian Rong[2]**

[1] *Department of Transport Engineering, Beijing Institute of Technology, 5 South Zhongguancun Street, Haidian District, Beijing 100081, China*
[2] *Key Laboratory of Traffic Engineering, Beijing University of Technology, 100 Pingleyuan, Chaoyang District, Beijing 100124, China*

Correspondence should be addressed to Liya Yao, yaoliya@bit.edu.cn

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Due to the poor transfer organization in urban public transport terminal, pedestrian crowd are often forced to weaving in their transfer flow lines. Frequent weaving behaviors not only decrease passengers' transfer comfort, but may also trigger serious crowd disaster such as trampling. In order to get accurate understanding of the weaving features of pedestrian crowd and analyze the relevant evolution law, researches have been conducted on the basis of field investigation. First, the typical weaving phenomenon were defined and classified, and a microscopic parameters system of pedestrian crowd weaving flow was constructed. The detection and quantification methods of multiple indicator parameters were also given. Then, correlation between different behavioral parameters was analyzed based on the survey data of weaving pedestrian crowd on the stairs of DongZhiMen (DZM) hub. The basic characteristics and evolution law of the weaving behaviors were then discussed, and conclusions were drawn.

## 1. Introduction

Along with the increasing volume of transfer pedestrians, the transferring service level in some existing urban public transport terminals is greatly decreased by the crowding and interweaving pedestrian flow. How to improve the transfer efficiency of transport terminal through optimizing the organization of pedestrian flow has become an interesting thing.

In the past years, scholars at home and abroad have achieved great progress in researches about characteristics and evolution law of the weaving behaviors of pedestrian flow in transport terminals.

In 1971, Henderson analyzed the statistical characteristics of high density pedestrian flow [1]. Helbing and Molnár introduced the principle of fluid dynamics into pedestrian characteristics analysis in 1995 and carried out the numerical simulation research of pedestrian flow [2]. Since then, scholars over all countries started to conduct extensive and thorough research in pedestrian flow characteristics detection and regularity analysis [3–9]. Ukkusuri et al. [10], Laxman et al. [11] and Lam et al. [12] studied the characteristics of pedestrian flow at certain transportation facilities. Siram et al. [13], Zhou et al. [14], and Wang et al. [15] explained the particular phenomenon in elderly pedestrians and paired pedestrians. Hughes [16] gave the maximum speed and density of pedestrian flow. The relationship between pedestrian speed and density was studied by Ando et al. [17], Thompson and Marchant [18], Hughes [19], Hankin and Wright [20], and so on. Cheung and Lam [21] and Tanaboriboon et al. [22] studied the relationship between pedestrian volume and density. On this basis, the 2010 issue of the American Capacity Manual summarized the characteristics of most types of pedestrian flow [23].

With the analysis and brief history above as a backdrop, it is clear that the conventional pedestrian flow studies have made progress. In recent years, scholars began to focus on several special phenomenon analysis of pedestrian flow [24–26]. As an important phenomenon of transfer activities, pedestrian crowd weaving flow generally exists in transport terminals of China [27]. Frequent intertwined behaviors in areas such as entrance, ticket hall, platform, and stairs not only decrease the transfer comfort of pedestrian crowd, but also may trigger serious crowd disaster such as trampling. It is still a problem of how to grasp the characteristics of weaving transfer pedestrian crowds and analysis the relevant evolution law accurately.

This paper describes a survey and analysis method for typical intertwined flow of pedestrian crowd. The remainder of the paper is structured as follow. Section 2 discusses the definition and classification of typical weaving phenomenon. Section 3 constructs a microscopic parameters system of weaving crowd. Section 4 presents the survey method for weaving pedestrian crowd and demonstrates its application to DZM hub in Beijing, China. Analysis results are also presented in Section 4, followed with the conclusions in Section 5.

## 2. Passenger Weaving Flow Categorization

Due to the limited space in transport terminal, there are often many conflict points among the pedestrian flow lines. Pedestrian crowd are forced to weaving at the conflict points frequently during their transfer process. Summarizing the weaving law of pedestrian crowd is the foundation to carry out analysis of various types of weaving phenomenon. In this study, weaving pedestrian crowd can be defined as a traffic phenomenon that more than two pedestrian crowd flows with transfer purpose confluence or shunt continuously in a short distance.

According to the definition and characteristics analysis of weaving pedestrian crowd, combined with field investigation, weaving phenomenon of pedestrian crowd can be classified from three aspects as follows.

(1) According to the weaving angle, weaving phenomenon can be divided into forward weaving behavior, cross weaving behavior, and lateral weaving behavior, as shown in Figure 1.

(2) According to the law of weaving occurrence, weaving phenomenon can be divided into regular interweave and sudden interweave.

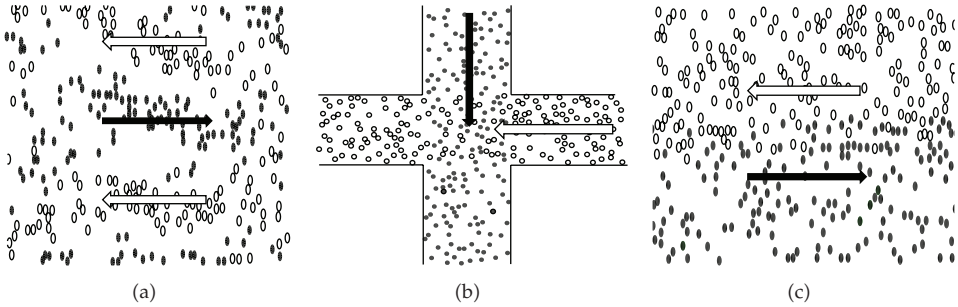


**Figure 1:** Schematic diagram of weaving pedestrian crowd—forward weaving flow (a), cross weaving flow (b), and lateral weaving flow (c).

(3) According to the boundary condition, weaving phenomenon can be divided into boundary interweave and no boundary interweave.

## 3. Characteristics of Weaving Pedestrian Crowd

Different with the conventional of pedestrian crowd, the weaving pedestrian crowd show special characteristics as follows.

(1) Spatial constraint. In a transport terminal with good guidance system, pedestrian crowd usually have relatively fixed directions. But due to the limited internal space, most of the pedestrians are forced to move laterally.

(2) Time constraint. Due to the impact of subway departure time, passengers arrive periodically, with high walking speed, which leading to a more frequent acceleration, deceleration, and way finding phenomenon in the weaving process.

Due to the spatial-time constraints above, pedestrian flow show more frequent crowding and collision, leading to a fluctuation of traffic density and speed.

Trajectory tracing and interaction analysis are required in the pedestrian crowd's numerical simulation. For pedestrian crowd tracks and interaction, behavior indicators which can accurately describe the pedestrian behavior are needed to explain the weaving process. Considering the spatial-time restriction of pedestrian crowd interweaving phenomenon, speed variation and lateral movement were selected together with conventional indicators such as passenger flow, average speed, average density, stride length, and frequency [28]. Definition and quantify method for indicators are as follows.

(1) Pedestrian crowd volume (person/meter/second): the quantity of pedestrian crowd that going through the weaving section within a unit time period as (3.1)

$$Q = D \times V, \tag{3.1}$$

where $Q$ represents the pedestrian crowd flow, $D$ represents the average density of weaving area, and $V$ represents the average speed of pedestrian crowd in weaving area.

(2) Average walking speed (meter/second): the average time that pedestrian crowd walk through a certain distance within the weaving area as follows:

$$V = \frac{L}{\sum_{i=1}^{N} t_i / N}, \tag{3.2}$$

where $L$ represents walking distance, $N$ represent the number of pedestrian crowd observed, and $t_i$ represents the walking time of pedestrian $i$.

(3) Average density (person/square meter): the quantity of pedestrian crowd within a unit area of the weaving area as (3.3)

$$D = \frac{Q}{S}, \tag{3.3}$$

where $D$ represents average density, $Q$ represents the number of pedestrian crowd within the weaving area, and $S$ represents the measure of the weaving area.

(4) Stride length ($m$): the distance that pedestrian go through by one step in weaving situation. Stride length is influenced mainly by the flow density, psychological status of pedestrian crowd, and other factors. The stride length can be estimated through the length of the floor tiles or a grid drawn on the weaving area.

(5) Stride frequency (number/second): the numbers of steps pedestrian walk during a unit time period in weaving situation. Stride frequency is influenced mainly by the flow density, transfer facility status, and other factors.

(6) Speed variation (meter/second): the maximum increase or decrease value of pedestrian crowd's walking speed within weaving area.

(7) Lateral movement probability: the percentage of pedestrian that are forced to deviated from their original path due to the weaving behavior.

## 4. Investigation Method of Weaving Phenomenon

Forward-boundary-regular weaving phenomenon appears very frequently in a transport terminal, which is also the main factor reducing the hub's operation efficiency. Choose DZM station of Beijing subway as investigation object, illustrate the acquire method of weaving behavior indicators, and then analyze the characteristics of pedestrian crowd weaving flow.

*(1) Investigation Time*

Weaving phenomenon in a transport terminal occurs most frequently during peak hours, which has the maximum interference to terminal operation. So the investigation time was selected as working day 8:00-9:00 (A.M) and 17:00-18:00 (P.M).

*(2) Investigation Area*

Weaving phenomenon of pedestrian crowd tends to occur in areas with high density and complex streamlines, such as stairs and platform areas and so forth. The connecting area

**Table 1:** Investigate methods for behavior indicators of weaving pedestrian crowd.

| Investigation method | | Observing point number | Indicator | | |
|---|---|---|---|---|---|
| Manual | Fixed point observation | 1, 2 | Pedestrian crowd volume | Stride length | — |
| | Following investigation | — | Average volume | Stride frequency | — |
| Video | Vertical recording | 3 | Average density | Speed variation | Lateral movement probability |
| | Parallel recording | 4 | Stride length | — | — |

**Table 2:** Behavior indicator data of weaving pedestrian crowd flow.

| | Average stride length (m) | Average stride frequency (n/s) | Maximum acceleration ($m/s^2$) | Speed variation (m/s) | Lateral movement probability (%) |
|---|---|---|---|---|---|
| Without weaving behavior | 0.6 | 1.262854 | −0.31 | 0.17 | 0.089 |
| With weaving behavior | 0.2 | 1.213844 | −5.81 | 2 | 0.55 |

between stairs and platform of DZM hub was chosen as the investigation area. Weaving behaviors within this area can be regarded as a forward-boundary-regular one.

*(3) Data Collection and Analysis Method*

Aiming at the characteristics of short weaving duration, high walking speed, and so forth, manual recording and video recording were combined in the investigation. Manual recording method was used to get pedestrian volume, average speed, stride length, and frequency; video recording method was used to get average density, speed variation, and lateral movement probability, as shown in Table 1. Figure 2 shows the distribution of data collection points.

A statistical analysis of the walking speed and pedestrian crowd density were conducted, results show that the weaving phenomenon takes 140 seconds for a periodic regularity of occurrence and dissipation, as shown in Figures 3 and 4. This meets the actual arrival and departure regularity of metro vehicle.

On these basis, record the related parameters of interweave phenomena by the cycle of 140 seconds according to weaving phenomenon occurrence regularity, get the relationship between pedestrian crowd volume, speed, and density of interweaving phenomenon, as shown in Figures 5, 6 and 7, the value of other related indicators are shown in Table 2.

## 5. Conclusions

Aiming at the pedestrian weaving behavior in transport terminal, this paper defined and classified the pedestrian crowd weaving flow and constructed a characteristic indicator system. The investigation and quantization methods for indicators were also given. Then summarize the basic regularity of pedestrian crowd interweaving phenomenon through field

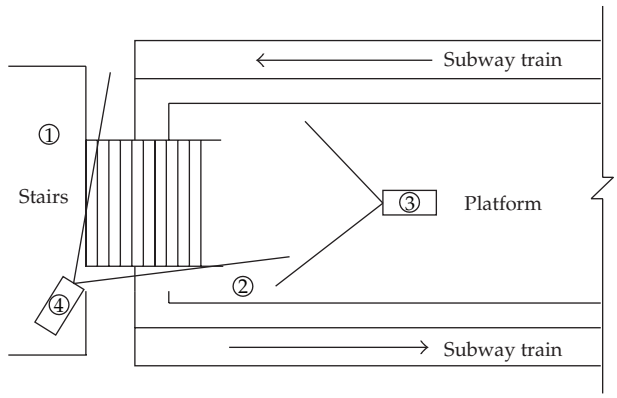


**Figure 2:** Investigate scheme for behavior indicators of weaving pedestrian flow.

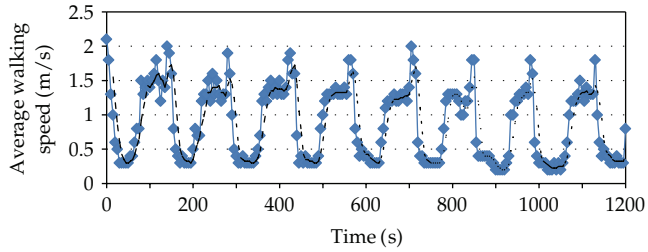


**Figure 3:** Walking speed change of weaving pedestrian crowd.

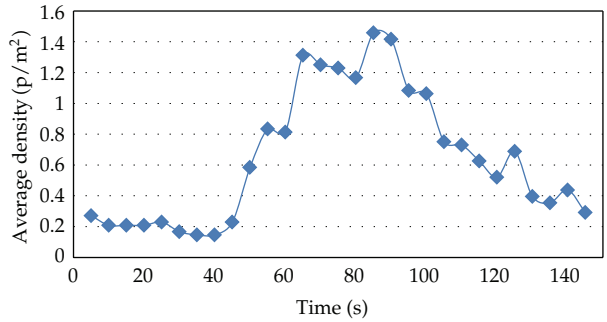


**Figure 4:** Average density change of weaving pedestrian crowd.

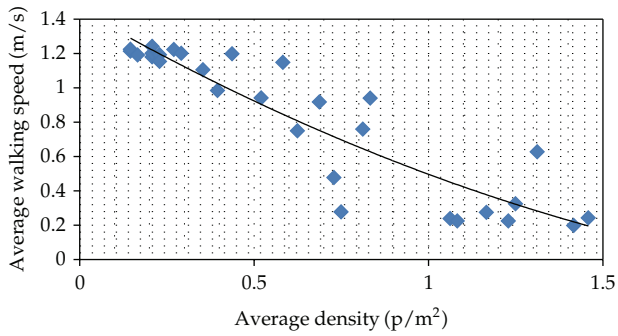


**Figure 5:** Correlation between the walking speed and density of weaving pedestrian crowd flow.

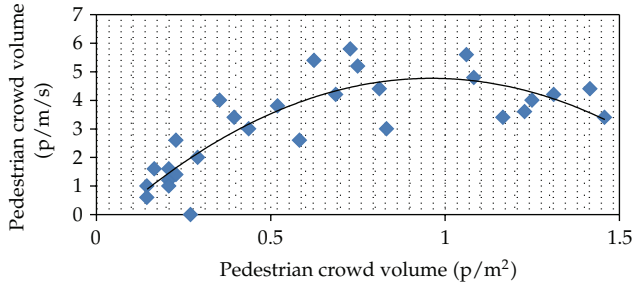


**Figure 6:** Correlation between the pedestrian crowd volume and average density of pedestrian crowd.

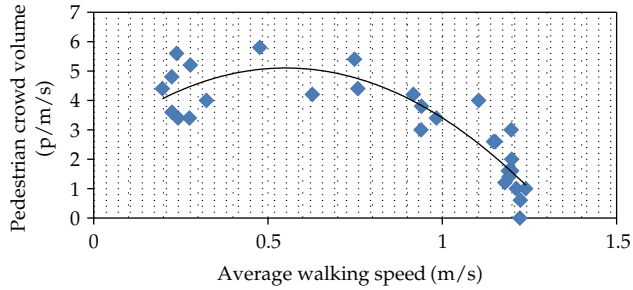


**Figure 7:** Correlativity between the pedestrian crowd volume and average walking speed.

investigation of Beijing DZM transport terminal, which provides a reference for the practical work of high density pedestrian crowd control and transfer facility design. Compared with the conventional pedestrian crowd, pedestrian crowd weaving behaviors show different regularities as follows.

(1) Pedestrian crowd weaving phenomenon appears relatively apparent periodic with three basic states: begin, spread, and dissipated. And the cycle length is closely related to the arrive and departure time of mass transit way.

(2) Due to the limitation of space and time, pedestrian of different flow line need to share space and are forced to adjust their behavior frequently. This is the reason why collisions among weaving pedestrians occurred more frequently.

(3) Although the indicators of pedestrian weaving behavior showed strong complexity and variability, but indicators such as pedestrian crowd volume, speed, and density still has a strong correlation in accordance with the basic characteristics of fluid mechanics.

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## References


[1] L. F. Henderson, "The statistics of crowd fluids," *Nature*, vol. 229, no. 5284, pp. 381–383, 1971.

[2] D. Helbing and P. Molnár, "Social force model for pedestrian dynamics," *Physical Review E*, vol. 51, no. 5, pp. 4282–4286, 1995.

[3] W. Wang, W. Zhang, H. Guo, H. Bubb, and K. Ikeuchi, "A safety-based approaching behavioural model with various driving characteristics," *Transportation Research Part C*, vol. 50, no. 8, pp. 1704–1714, 2011.

[4] J. K. K. Yuen and E. W. M. Lee, "The effect of overtaking behavior on unidirectional pedestrian flow," *Safety Science*, vol. 50, no. 8, pp. 1704–1714, 2012.

[5] H. Gotoh, E. Harada, and E. Andoh, "Simulation of pedestrian contra-flow by multi-agent DEM model with self-evasive action model," *Safety Science*, vol. 50, no. 2, pp. 326–332, 2012.

[6] B. Piccoli and A. Tosin, "Time-evolving measures and macroscopic modeling of pedestrian flow," *Archive for Rational Mechanics and Analysis*, vol. 199, no. 3, pp. 707–738, 2011.

[7] M. Di Francesco, P. A. Markowich, J. F. Pietschmann, and M. T. Wolfram, "On the Hughes' model for pedestrian flow: the one-dimensional case," *Journal of Differential Equations*, vol. 250, no. 3, pp. 1334–1362, 2011.

[8] C. Dogbe, "On the Cauchy problem for macroscopic model of pedestrian flows," *Journal of Mathematical Analysis and Applications*, vol. 372, no. 1, pp. 77–85, 2010.

[9] B. Steffen and A. Seyfried, "Methods for measuring pedestrian density, flow, speed and direction with minimal scatter," *Physica A*, vol. 389, no. 9, pp. 1902–1910, 2010.

[10] S. Ukkusuri, S. Hasan, and H. M. A. Aziz, "Random parameter model used to explain effects of built-environment characteristics on pedestrian crash frequency," *Transportation Research Record*, no. 2237, pp. 98–106, 2011.

[11] K. K. Laxman, R. Rastogi, and S. Chandra, "Pedestrian flow characteristics in mixed traffic conditions," *Journal of Urban Planning and Development*, vol. 136, no. 1, pp. 23–33, 2010.

[12] W. H. K. Lam, J. Y. S. Lee, and C. Y. Cheung, "A study of the bi-directional pedestrian flow characteristics at Hong Kong signalized crosswalk facilities," *Transportation*, vol. 29, no. 2, pp. 169–192, 2002.

[13] S. M. Siram, V. Sonaike, O. B. Bolorunduro et al., "Does the pattern of injury in elderly pedestrian trauma mirror that of the younger pedestrian?" *Journal of Surgical Research*, vol. 167, no. 1, pp. 14–18, 2011.

[14] J. W. Zhou, H. Kuang, M. R. Liu, and L. J. Kong, "Paired behavior effect on pedestrian evacuation dynamics," *Acta Physica Sinica*, vol. 58, no. 5, pp. 3001–3007, 2009.

[15] W. H. Wang, Q. Cao, K. Ikeuchi, and H. Bubb, "Reliability and safety analysis methodology for identification of drivers' erroneous actions," *International Journal of Automotive Technology*, vol. 11, no. 6, pp. 873–881, 2010.

[16] R. L. Hughes, "A continuum theory for the flow of pedestrians," *Transportation Research Part B*, vol. 36, no. 6, pp. 507–535, 2002.

[17] K. Ando, H. Ota, and T. Oki, "Forecasting the flow of people," *Railway Research Review*, vol. 45, no. 8, pp. 8–14, 1998.

[18] P. A. Thompson and E. W. Marchant, "A computer model for the evacuation of large building populations," *Fire Safety Journal*, vol. 24, no. 2, pp. 131–148, 1995.

[19] R. L. Hughes, "The flow of large crowds of pedestrians," *Mathematics and Computers in Simulation*, vol. 53, no. 4–6, pp. 367–370, 2000.

[20] B. D. Hankin and R. A. Wright, "Passenger flow in subways," *Operational Research Quarterly*, vol. 9, no. 2, pp. 81–88, 1958.

[21] C. Y. Cheung and W. H. K. Lam, "Pedestrian route choices between escalator and stairway in MTR stations," *Journal of Transportation Engineering*, vol. 124, no. 3, pp. 277–285, 1998.

[22] Y. Tanaboriboon, Sim Siang Hwa, and Chin Hoong Chor, "Pedestrian characteristics study in Singapore," *Journal of Transportation Engineering, ASCE*, vol. 112, no. 3, pp. 229–235, 1986.

[23] National Research Council (NRC), *Highway Capacity Manual*, National Research Council (NRC), Washington, DC, USA, 2010.

[24] X. H. Cui, Q. Li, J. Chen, and C. X. Chen, "Study on MA-based model of occupant evacuation in public facility," *Journal of System Simulation*, vol. 20, no. 4, pp. 1006–1023, 2008.

[25] J. Wu, J. Feng, and J. Ye, "Capacity analysis of magnetic card and contactless IC card automatic fare gate in railway stations," *Journal of Tongji University*, vol. 38, no. 1, pp. 85–91, 2010.

[26] A. El Kacimi and O. Laghrouche, "Numerical analysis of two plane wave finite element schemes based on the partition of unity method for elastic wave scattering," *Computers and Structures*, vol. 88, no. 23-24, pp. 1492–1497, 2010.

[27] L. Sun, J. Rong, and L. Yao, "Measuring transfer efficiency of urban public transportation terminals by data envelopment analysis," *Journal of Urban Planning and Development*, vol. 136, no. 4, pp. 314–319, 2010.

[28] H. F. Jia, L. L. Yang, and M. Tang, "Pedestrian flow characteristics analysis and model parameter calibration in comprehensive transport terminal," *Journal of Transportation Systems Engineering and Information Technology*, vol. 9, no. 5, pp. 117–123, 2009.