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Homogeneity and activeness of crowd on aged pedestrian dynamics

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Abstract

An aging population is bringing new challenges to the management of escape routes and facility design in many countries. In this paper the movement properties of middle- and old-aged adults are studied with series of single-file movement experiments under laboratory conditions. The fundamental diagrams for two different groups of pedestrians and time-space diagrams are compared. For the groups with different composition and status, the fundamental diagrams are totally different but maintain the same trend. Active crowd leads to inhomogeneous pedestrian flow but higher flow rate, while inactive pedestrians prefer to keep pace with others or keep larger personal space, which leads to more jams and stop-and-go waves. Density and inhomogeneous of speed do not always play main roles on the appearance of stop-and-go.

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1. Introduction

In recent years, several crowd disasters occur all over the world. For example, the stampede at the 2010 Love Parade electronic dance music festival in Duisburg in Germany caused the death of 21 people and at least 510 more were injured. To avoid such kind of accidents and improve the safety of pedestrians, good understanding on

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pedestrian dynamics, reasonable design of public facilities and effective management of events are of great importance. Even for the basic fundamental diagram, however, large discrepancies are shown in previous studies^{1,2}. It is affected by several factors including pedestrian motivation, facility geometry, culture differences etc. Besides, Aging population, increasing obesity and more people with mobility impairments are bringing new challenges to the management of routine and emergency people movement in many countries. The movement properties of pedestrian crowds with different ages are crucial to be considered in pedestrian dynamics studies. Some models considering the movement characteristics of different age groups are built. Tang et al.³ proposed a cellular automata model for pedestrian flow to investigate the effects of elementary students' individual properties on the evacuation process in a room with two exits. Galiza et al.⁴ employed a micro-simulation approach to investigate the potential effects of increased proportion of older people in pedestrian flow and on the level of service criteria. Koo et al.⁵ studied how seriously residents with disabilities affect the evacuation of other residents in a high-rise building environment through an agent-based model. Kholshchevnikov et al.⁶ investigated the evacuation of children from pre-school educational institutions. Pre-movement time and the relationships between density and speed during upward and downward movement were analyzed for children. Cueta et al.⁷ carried out evacuation experiments in a school building with children from 6 to 16 years old. Regarding to old pedestrians, however, only few studies can be found. Kuligowski et al.⁸ conducted an evacuation experiment with older adults and disabled residents descending the stairwells. Shimura et al.⁹ studied the mobility of the aged pedestrians by experiment and simulation. More detailed movement properties of middle- and old-aged adults are necessary to be considered in pedestrian dynamics studies in the future.

Single-file pedestrian flow involving purely longitudinal interactions among pedestrians could be a good start for studying such problems. The possible influences on the flow in this case have been studied from various aspects with young test persons. Seyfried et al.¹⁰ measured the fundamental diagram of single file flow for densities up to 2 m^{-1} . Similar experiments were also carried out in India by Chattaraj et al.¹¹ and in China by Liu et al.¹² to investigate the culture difference on the fundamental diagram with university students. In France Jelic et al. conducted experiment inside a ring formed by inner and outer round walls to study the properties of pedestrians moving in line¹³. The density in their experiment reaches 3 m^{-1} and the stepping behavior and fundamental diagrams are studied. From the study, three regimes (free regime, weakly constrained regime and strongly constrained regime) are distinguished by analyzing the velocity-spatial headway relationship. Stop-and-go wave¹⁴ as a special phenomenon of congested flow is observed from the experiment with soldiers and pupils in Germany.

In this paper we will study the movement properties of middle- and old aged-adults. The remainder of the paper is organized as follows. In Section 2 we describe the setup of the experiments. Section 3 analyzes the characteristics of pedestrian movement based on trajectories extracted from video recordings and shows the main results. Finally, the conclusions from our investigation will be discussed.

2. Experiment setup

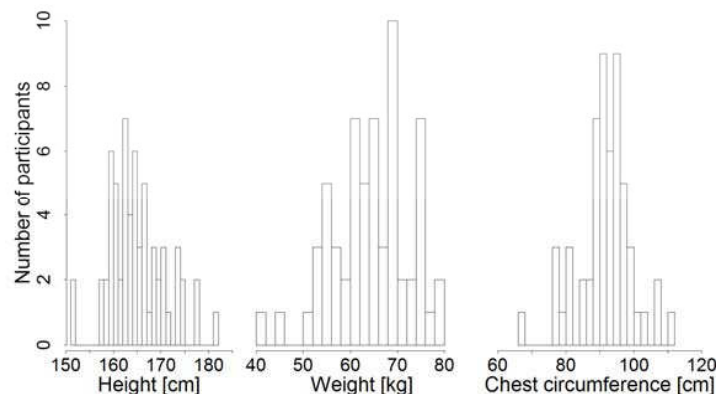


Fig. 1. Distribution of heights, weights as well as chest circumference of test persons.

Table 1 Age and gender distribution of the middle- and old-aged test persons

Age [years]	adult_group_1		adult_group_2	
	Men	Women	Men	Women
36-40	1	1	2	-
41-45	3	4	-	1
46-50	4	7	2	8
51-55	2	6	-	7
56-60	5	4	-	2
61-65	3	2	-	1
66-70	3	-	-	-
71-75	2	-	-	-
Total	23	24	4	19

The experiment was arranged 2015 in Tianshui Health School in Gansu, China. It is a part of the open project from the State Key Laboratory of Fire Science in University of Science and Technology of China. The test pedestrians in the experiment include 80 students (ages 16-19 years, average age of 17) from the school and 47 middle- and old-aged adults (ages 36-73 years, average age of 52) recruited from two residential districts. Their heights (mean 1.65 m), weights (mean 65 kg), chest circumferences (mean 92 cm) and blood pressures were measured before the experiment and their distributions can be seen from Fig. 1. The 47 test persons from the first district (adult_group_1) are all from low-income families, whereas the 23 people from the second district (adult_group_2) have good income condition and common hobbies. The age and gender distribution of these two groups of adults can be found in Table 1. In both groups most test persons are between 45 and 60 years old. In 'adult_group_1' the number of men and women is nearly the same, whereas the number of women participants is about 5 times as the men in 'adult_group_2'.

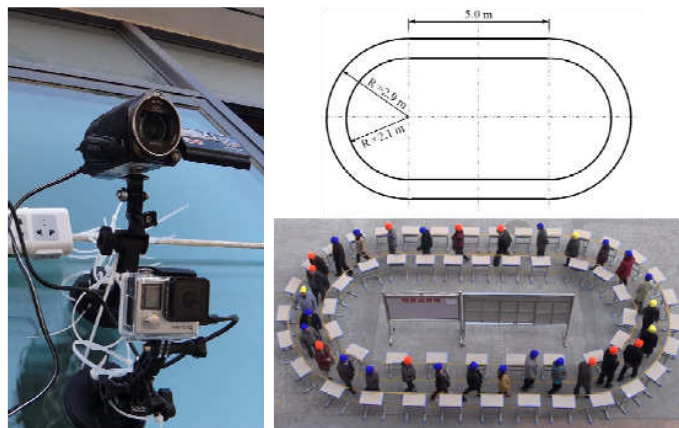


Fig. 2. Mounting of cameras, sketch of the experimental scenario and a snapshot from the experiment. Two cameras were fixed at a glass window with vacuum fixers.

Fig. 2 shows the sketch of the experimental scenario, mounting of cameras and a snapshot from the experiment. The scenario composed of two 5 m long straight corridors and two semicircle corridors with the inner radius 2.1 m and outer radius 2.9 m. The width of the corridor is 0.8 m. Suppose that the test persons move along the middle of the corridor. Then the circumference of walking route is about 25.7 m. Two cameras with a frame rate of 25 fps mounted at a window of a classroom on 4th floor were used to record pedestrian movement in the whole scenario.

Totally 34 runs with different numbers and types of test people (15 runs with pure students, 10 runs with pure adults and 9 runs mixed the students and adults) were performed. The test persons were asked to move at normal speed without overtaking during the experiment. In this paper, we focus on the 10 runs with adults. The global density ρ_g for the runs with adult ranges from 0.23 to 1.17 m^{-1} for experiment with 'adult_group_1' and from 0.19 to 0.89 m^{-1} for runs with 'adult_group_2'. The details for the runs can be seen in Table 2.

Table 2. Information of test persons in each runs with adults.

Runs	Test persons				
	Source	Total number	Men	Women	$\rho_g [\text{m}^{-1}]$
ring-adults-01-30	adult_group_1	30	14	16	1.17
ring-adults-02-26	adult_group_1	26	13	13	1.01
ring-adults-03-21	adult_group_1	21	11	10	0.82
ring-adults-04-16	adult_group_1	16	8	8	0.62
ring-adults-05-11	adult_group_1	11	7	4	0.43
ring-adults-06-06	adult_group_1	6	2	4	0.23
ring-adults-07-05	adult_group_2	5	-	5	0.19
ring-adults-08-10	adult_group_2	10	1	9	0.39
ring-adults-09-15	adult_group_2	15	3	12	0.58
ring-adults-10-23	adult_group_2	23	4	19	0.89

3. Trajectory extraction and calibration

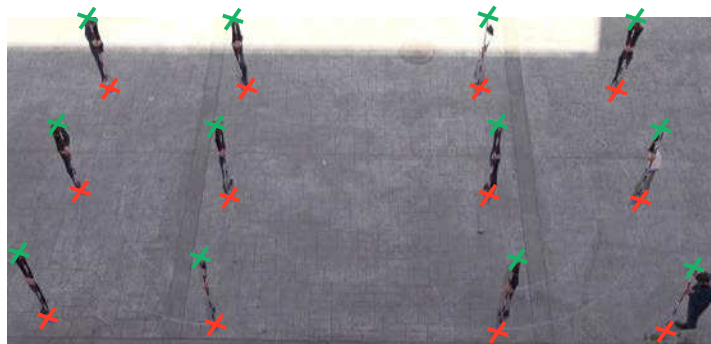


Fig. 3. Extrinsic calibrations with 3D coordinate system. The 3D coordinates of the points marked on the floor and the corresponding points of height 2 m are recorded before experiment.

The trajectories of pedestrians were extracted from video recordings automatically afterward with the software *PeTrack*¹⁵. Since 3D coordinate system is now available in *PeTrack* for measuring positions and distance between pedestrians based on image data, videos recorded with a view not perpendicular but slanted to the floor can be used. For easier recognition and detection uniform hats with different colors were used in the experiment. To extract precise trajectories, a few calibration steps are needed. Firstly we transfer the captured images from the camera to undistort ones. Because of lenses inside the camera system the resulting image is usually distorted especially at the border of the image. The distortion correction coefficients are obtained by capturing an absolutely flat and squared arranged chessboard and comparing the resulting image with the original. Next we calibrate the image to the extrinsic 3D space. As shown in Figure 3, some feature points were marked on the floor and 2.0 m height with a leveling pole before the experiment. With the 3D coordinates $(x, y, 0)$, $(x, y, 2.0)$ and their corresponding 2D pixel coordinates in the image and some information about the camera system like the focal length, the rotation and the translation between the camera and the 3D coordinate system is calculated. Then a linear system is gotten to

calculate 3D coordinates out of 2D pixel coordinates. To solve the linear system and get the 3D position the height of the person is needed and we use three colors of hats to mark it in the experiment. The persons who are shorter than 1.6 m wear yellow hat, between 1.6 and 1.65 m wear blue hat, and red hats are for people taller than 1.65 m. Lastly pedestrians in image were recognized tracked by detecting the used colors of the caps.

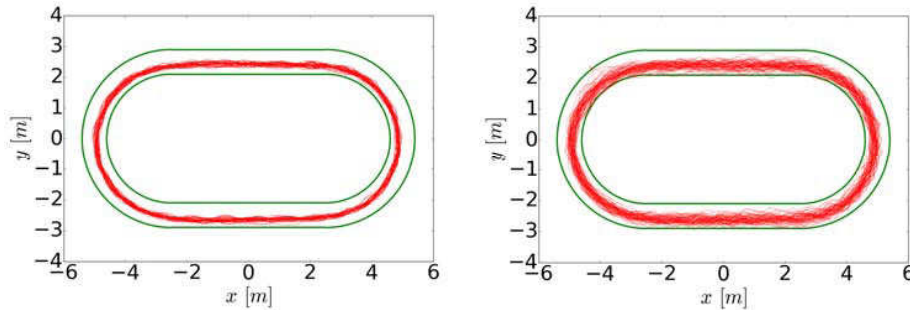


Fig. 4. Trajectories extracted from the runs 'ring-adults-07-05' and 'ring-adults-02-26'.

Figure 4 shows the trajectories extracted from the runs 'ring-adults-07-05' and 'ring-adults-02-26' by *PeTrack* automatically. The 3D coordinates of the center of each head is obtained and only (x, y) information is plotted in the figure. Since we only use three colors of hat to mark the height information of pedestrian, the coordinates are not really based on the exact height of each pedestrian. The mean values 1.575 m, 1.625 m and 1.675 m are used as the height of people to transfer the data from 2D image coordinates to real world coordinates here.

4. Results and analysis

In this study, we focus on the longitudinal interactions among pedestrians and their one dimensional characteristics. Thus in the following analysis 1D movement information is approximated by projecting the 2D coordinates to the central line of the ring. We transfer the trajectory data to the new coordinate system from the position $x = -2.5$ ($y < 0$) in 2D system and each pedestrian is regarded as a new one when he/she passes this position. In the new system the maximum of one's coordinate is $C = 25.7$ m. With this kind of transformation the lateral oscillations of pedestrian movement are totally neglected.

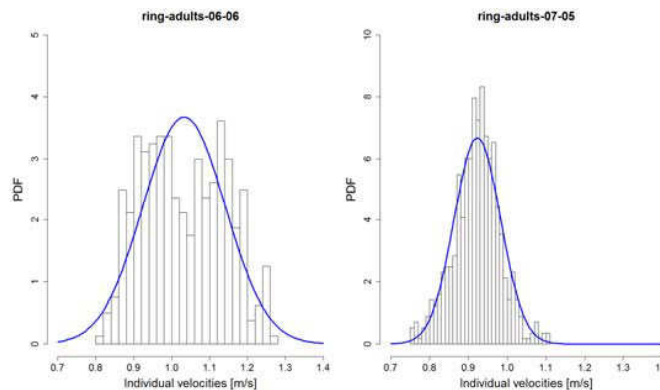


Fig. 5. Distributions of individual velocity at free flow state from runs 'ring-adults-06-06' and 'ring-adults-07-05'. They are fitted with Gaussian distribution ($\mu_1 = 1.03$, $\sigma_1 = 0.10$, $\mu_2 = 0.92$, $\sigma_2 = 0.06$).

Firstly, we check the status of these two groups of pedestrians during the experiment by studying their free speeds. Fig. 5 shows the individual velocity distribution from the runs 'ring-adults-06-06' and 'ring-adults-07-05'.

In these two runs only 6 persons from ‘adult_group_1’ and 5 persons from ‘adult_group_2’ were in the corridor, which corresponds to ρ_g of 0.23 and 0.19 m^{-1} . With such low density the pedestrians move under free flow state and their speed can be assumed as free speed. We calculate the individual velocity $v_i(t)$ at time t over 10 frames (0.4 second) from the trajectories under new coordinate system. For simplicity we use Gaussian distribution to fit the data. Their mean values and standard deviations are $\mu_1 = 1.03$, $\sigma_1 = 0.10$ and $\mu_2 = 0.92$, $\sigma_2 = 0.06$ respectively. In the histograms the velocities range from 0.8 to 1.3 m/s for ‘adult_group_1’ and 0.8 to 1.1 m/s for ‘adult_group_2’. It seems that the pedestrians from ‘adult_group_1’ are more active than that from the other group. Meanwhile, the statuses of pedestrians in ‘adult_group_2’ are closer each other. From the point of composition of crowd, the ‘adult_group_2’ is more homogeneous. This is true not only from the age distribution but also the gender ratio.

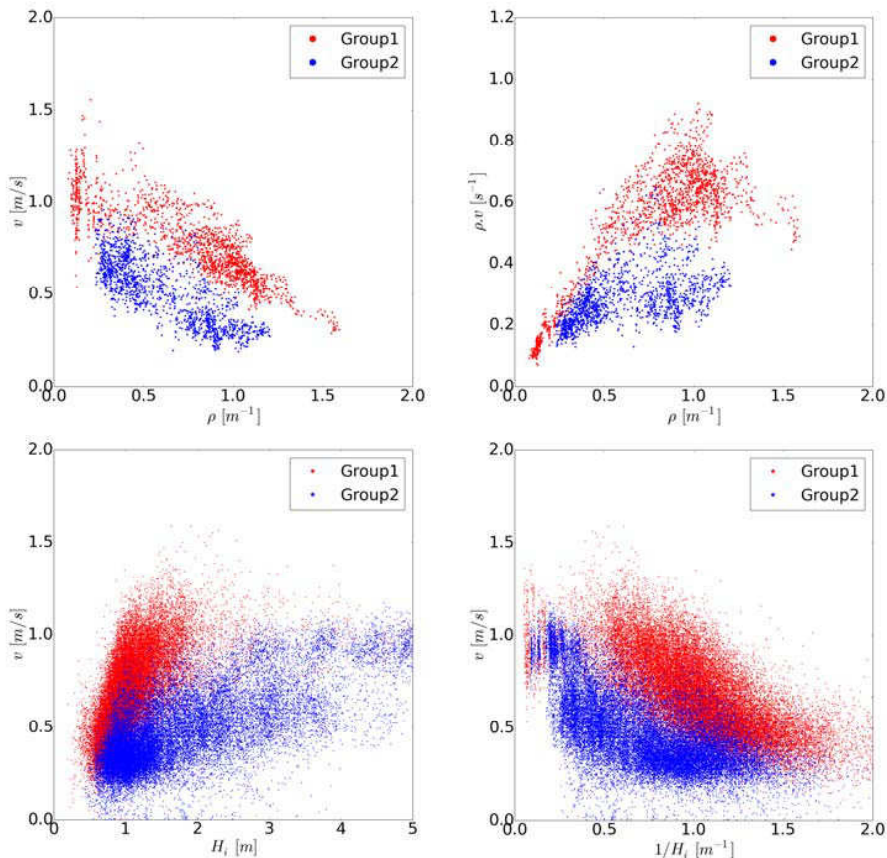


Fig. 6. Comparison of fundamental diagrams for the two groups with two measurement methods. The two figures above are measured with Voronoi method as in [16], while the two below are calculated from individual level via headway H_i and instantaneous velocity.

Fig. 6 we compare the fundamental diagram for the two groups in two ways. Due to the insufficient number of participants, we can only compare the movement properties for the situations of global density $\rho_g < 1.17 \text{ m}^{-1}$. On one hand, mean density and velocity over a 6 m long area were calculated with Voronoi method¹⁶. At the density level, the movement speed of ‘adult_group_1’ is always higher than the other group, which correspondingly leads to higher flow rate. If we use $J_s = \rho v$ to calculate specific flow, the observed flows for ‘adult_group_1’ are also higher than that of ‘adult_group_2’. The highest flow reaches about 0.8 s^{-1} for the former and 0.4 s^{-1} for the latter. On the other hand, we compare the fundamental diagram in microscopic level via the relationship between individual speed $v_i(t)$ and headway $H_i(t)$ for each pedestrian i at time t . Here the individual headway $H_i(t)$ is defined as the distance between the head center of i and his predecessor. The individual speeds for people in the two groups tend to be

converge when $H_i < 1$ m, whereas obvious difference can be observed when $H_i > 1$ m. The speeds for people in 'adult_group_1' are higher and have stronger dependency on the free space in front when $H_i > 1$ m. This agrees with the results above. People in 'adult_group_1' are more active and inhomogeneous. They tend to maintain their self-awareness during movement, whereas people from 'adult_group_2' prefer to keep pace with others in the group.

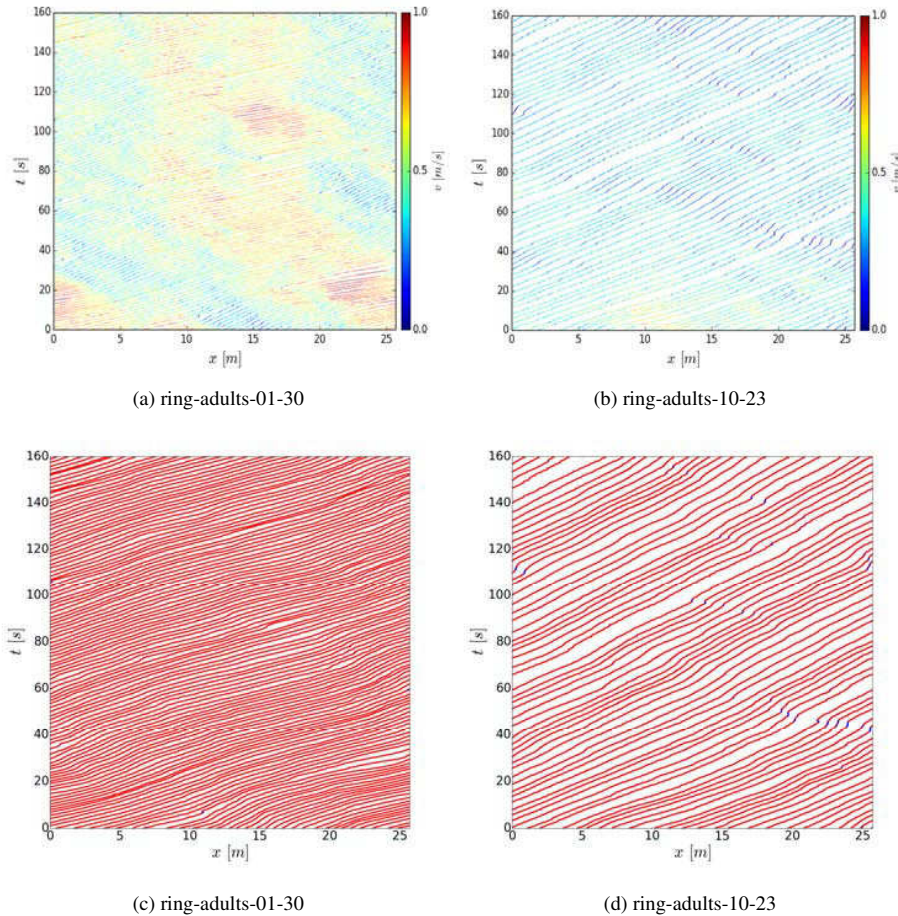


Fig. 7. Comparison of time-space diagram from two runs of the experiment. The global densities for the runs are about 1.17 and 0.89 m^{-1} . The corresponding individual speeds are 0.52 ± 0.13 and 0.33 ± 0.09 m/s respectively.

Fig.7 shows time-space diagram from the runs 'ring-adults-01-30' and 'ring-adults-10-23', whose global densities ρ_g are about 1.17 and 0.89 m^{-1} respectively. Here we use two different ways to show speed information in the diagrams. Firstly, we show the instantaneous velocities $v_i(t)$ directly in the graph like Fig. 7(a) and (b). The mean individual velocity for 'ring-adults-01-30' is 0.52 m/s (STD: 0.13 m/s), while it is 0.33 m/s (STD: 0.09 m/s) for 'ring-adults-10-23'. At the density ranges, the speeds are not homogeneous anymore over space and time in both cases but the inhomogeneity is more obvious for 'adult_group_1'. Besides, jams can be also observed from the diagrams. To visualize the jams or the potential stop-and-go, we show the diagram in another way. The individual speed is shown in red for $v_i(t) > 0.1$ m/s and blue for other values. When $v_i(t) < 0.1$ m/s the people can be regarded as in stop phase. Oppositely, we observe more stop status from the run 'ring-adults-10-23' although the global density of it is lower and the individual speeds are more homogenous. From this point, it seems that density is not the only factors leading to stop-and-go waves in mass crowd. The homogeneity of the crowd and activeness of each individual in the group also play an important role on the appearance of stop-and-go wave.

5. Summary

In this paper, the properties of single-file pedestrian movement in oval corridor are studied by means of an experiment performed under laboratory conditions. Totally 34 runs were performed and the experiment were recorded by two cameras from slanted view. We focus on the study of the movement of middle- and old-aged adults from two different groups. The activeness of people in the groups is checked by analyzing their free speed. The fundamental diagrams are calculated in two different ways and time-space diagrams are compared especially at high density conditions. It is shown that the speed of pedestrian depends not only on the crowd density but also the composition and status of people in the crowd. When pedestrians are more active, they will try to maintain their self-awareness, which lead to inhomogeneous pedestrian flow but higher flow rate. On the contrary, pedestrians prefer to keep pace with others in the crowd or keep larger personal space if they are inactive, which leads to more jams and stop-and-go waves. Density does not always play main roles on the appearance of stop-and-go.

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