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Lattice-gas simulation of escaping pedestrian flow in corridor*

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A lattice-gas model of biased-random walkers is used to simulate the escaping pedestrian flow under the open boundary condition in corridor. Given that the total number of people is unchanging, we have studied the evolution of pedestrian flow by varying parameters of system size. Relationships between parameters of system size and the transition time are discussed in this paper. Scaling behaviour is found as follows: the transition time t_c scales as $t_c \propto W^{-0.85\pm0.04}$, and $t_c \propto D$, where W is the width of corridor, and D is the strength of drift. However, the other parameters are found to have little influence on the transition time.

Keywords: pedestrian flow, scaling, lattice-gas model, biased-random walkers
PACC: 0540, 4630P, 8220M

1. Introduction

Traffic flow is a kind of many-body system of interacting vehicles, and traffic jam is the signature of the complex behaviour of traffic flow. In recent years, various models have been presented for traffic flow simulation, in which the cellular automaton and its upgrades are used most widely.[1−7] For example, a Nagel–Schreckenberg model is presented to simulate the one-dimensional highway traffic;[1] and a Biham–Middleton–Levine model is presented to study the two-dimensional city traffic.[2] Many researches have been done on city traffic by using these models and their upgrades.[3−7] All these studies showed that the dynamical jamming transition from the freely moving state to the stop state would occur at some critical density.

The dynamics of pedestrian flow is similar to that of traffic flow. However, the behaviour of pedestrians is freer, because people are not restricted on lanes like cars. Fukui and Ishibashi[8] have studied the jamming transition of pedestrian counter flow within an underpass by using the cellular automaton. Muramatsu *et al*[9] also presented a lattice-gas model of biased-random walkers to investigate the pedestrian counter flow in a channel. Recently, some updated cellular automaton models have been proposed to simulate the movement of pedestrians on a set of square lattices,[10,11] and the influence of a pedestrian's turning movement on jamming transition has been investigated.

The study of the jamming behaviour of escaping flow is important to our lives, and can guide us to reduce the loss in calamities. Recently, Tajima and Nagatani[12] have studied the crowd flow going outside a hall by using the lattice-gas model of pedestrian flow. They have found that a dynamical phase transition occurs from the choking flow to the decaying flow at a critical time t_c, and the scaling behaviour between the saturated flow rate and the size of door is found in the choking-flow region. Using a cellular automaton, Yang *et al*[13] also simulated the escaping process in a large room.

During the process of escape in a building, a corridor is usually the place at which a jam occurs. In this paper, we investigate the escaping behaviour of pedestrians in a corridor under open boundary con-

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dition. The evolution of escaping flow is studied by varying parameters of system size, given that the total number of people is unchanging. It is shown that the length of corridor, the width of door and the interval of doors have little influence on the transition time. The transition time is only affected by the width of the corridor and the strength of drift. The scaling behaviour is found between the transition time and the width of the corridor as $t_c \propto W^{-0.85\pm0.04}$, and we have found that the transition time is also in proportion to the strength of drift, with its slope increasing with the width of the corridor.

2. Model

The system is defined on square lattices. The corridor is represented by the square of $L \times W$ sites where L and W are the length and the width of the corridor, respectively. Along one of the sides of the corridor, doors are distributed uniformly. The interval of doors is I, the width of each door is d. The exit lies at the end of the corridor on the right-hand side. At the beginning of every time step, people enter the corridor from each door. After that, everybody moves towards the exit without backward step according to the bias-random walker rule.

The bias-random walker rule is described as follows:

(1) At the beginning of each time step, walkers enter the corridor from doors, if there is nobody to hinder him.

(2) All of the walkers are numbered randomly from 1 to N, where N is the number of people existing within the corridor.

(3) Pedestrians in the corridor are updated in sequence according to their numbers. Each site contains only a single person. The pedestrians are inhibited from overlapping on a site, and a person can move no more than one lattice distance in a time step. Figure 1 shows all the possible configurations of a pedestrian. The solid circle represents a pedestrian random walker. Cross points indicate sites occupied by other people. A pedestrian can move only to unoccupied sites. $P_{t,x}$, $P_{t,y}$ and $P_{t,-y}$ are the transition probabilities. In configuration (a), $P_{t,x} = D + (1-D)/3$, $P_{t,y} = P_{t,-y} = (1-D)/3$; in configuration (b), $P_{t,x} = D + (1-D)/2$, $P_{t,-y} = (1-D)/2$; and in configuration (c), $P_{t,x} = D + (1-D)/2$, $P_{t,y} = (1-D)/2$, where D indicates the strength of drift. For configuration (d), $P_{t,y} = P_{t,-y} = 1/2$; and $P_{t,x} = 1$ for configuration (e); $P_{t,y} = 1$ for configuration (f); and $P_{t,-y} = 1$ for configuration (g). In configuration (h), the pedestrian is unable to move.

(4) After all of the pedestrians have updated, people at the exit are removed from the corridor, and the evolution of this time step finishes.

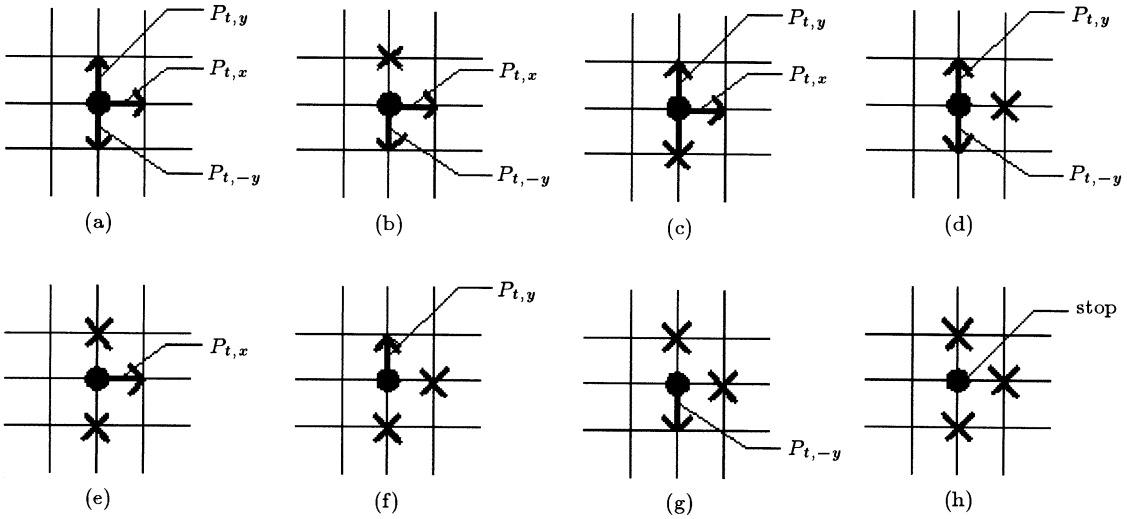


Fig.1. All the possible configurations of a pedestrian on the square lattice.

The density of the system is defined as $\rho = N/(LW)$, which indicates the occupation of the corridor. The velocity of the system is defined as $v = N_m/N$, where N_m represents the number of movable people in the corridor at the moment. The flow rate is defined as $J = v\rho = N_m/(LW)$.

3. Computer simulation and results

We have carried out a computer simulation. Initially, the corridor is empty. At the beginning of every time step, the people at the doors go into the corridor, if there is nobody to hold up him. Given that L=100, W=5, I=20, d=4, D=1, the total number of escaping people is 1000, and the number of pedestrians entering from each door is the same. At each time step, people update their sites according to the bias-random walker rule. We put down the density, velocity and mean flow rate at each time step.

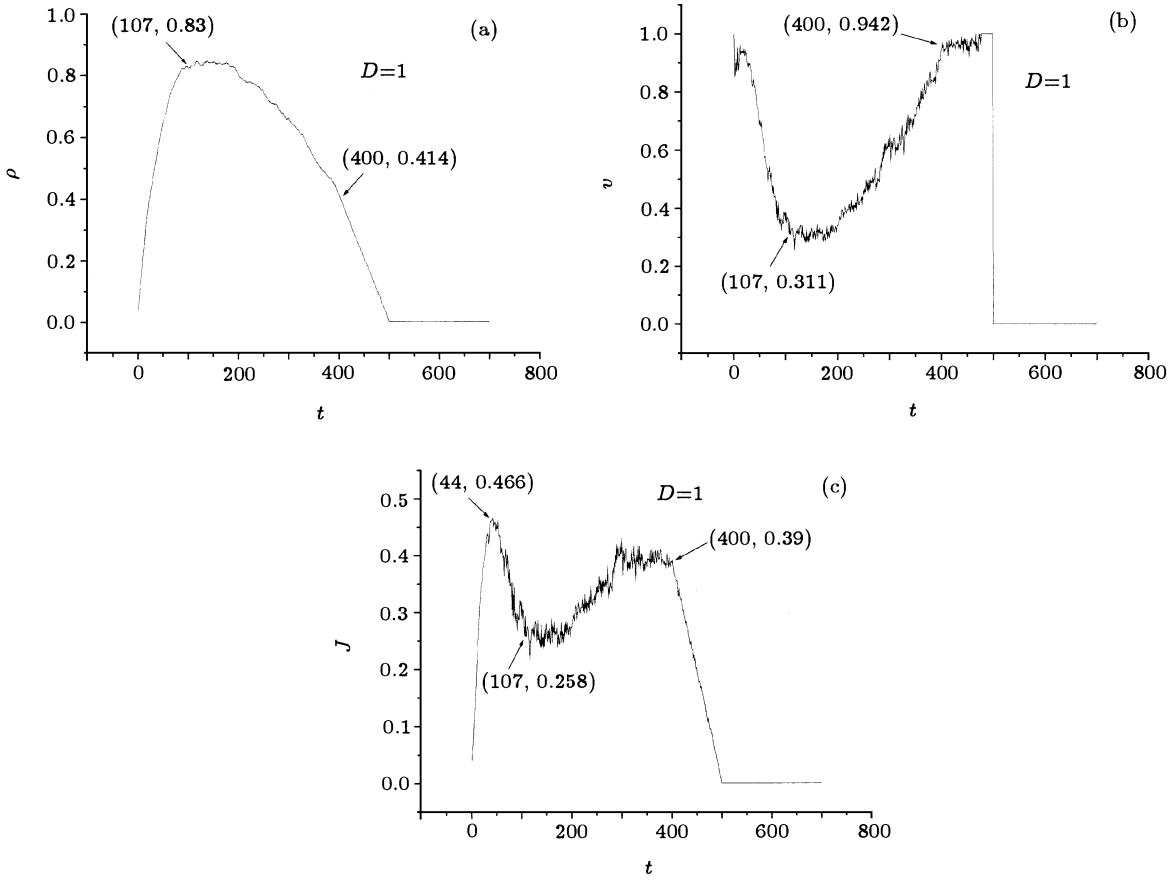


Fig.2. Plots of density ρ (a), velocity v (b) and mean flow rate J (c) against time step t.

Figure 2 shows the plots of density ρ, velocity v and mean flow rate J against time t for one process of evolution. Figure 3 shows the patterns formed by escaping pedestrians at different time steps. At the beginning, the corridor is empty, $\rho = 0$, $J = 0$, and the people at doors can enter the corridor without any hindrance, so $v = 1$. When people go into the corridor from every door one by one, the density ρ increases sharply, and the flow rate J increases accordingly; however velocity v decreases, for the people in the corridor begin to interfere with each other. This phase can be defined as 'entering'. The entering phase would last until $t \approx 44$. At the end of the entering phase, the flow rate J reaches its maximum value 0.466 (an approximation). At this moment, the number of movable people reaches its maximum level. In Fig.3 we can also see that the distribution of pedestrians now is comparatively even, and there is space everywhere for people to move. The maximum J here is a little lower than that of the traffic flow (0.5). When the entering phase finishes, the flow rate J begins to decrease. This is because with the density ρ increasing continuously, the interference between pedestrians becomes stronger and stronger, thus the velocity decreases continuously. Therefore, the number of movable people decreases though the total number of people in the corridor increases. This phase can be defined as 'jamming'. At the moment of $t \approx 107$, the density reaches its maximum 0.83, indicating that the jam is in the most serious condition. Hardly anybody can move ex-

cept those near to the exit. At the same time, the velocity v and flow rate J reach their minima. This state would saturate until $t \approx 150$, and during this state the density ρ keeps steady, i.e. the number of people entering is the same as that of those outgoing. After that, the density tends to decrease, for the people at some doors have all gone into the corridor, and there is nobody there to enter the corridor. With people continuing to leave the corridor through the exit, the corridor becomes sparse, and the jamming condition is released. Then the velocity v and flow rate J increase again. This phase can be defined as 'release'. When $t \approx 400$, there is nobody at any doors. In Fig.3 we can see the distribution of pedestrians at this moment. Figure 2 shows that the velocity has approached to 1, and the flow rate reaches another maximum again. The last phase can be defined as 'evacuating'. In this phase people evacuate by the exit without being hindered, so the density and flow rate decrease rapidly until all of the people get out of the corridor.

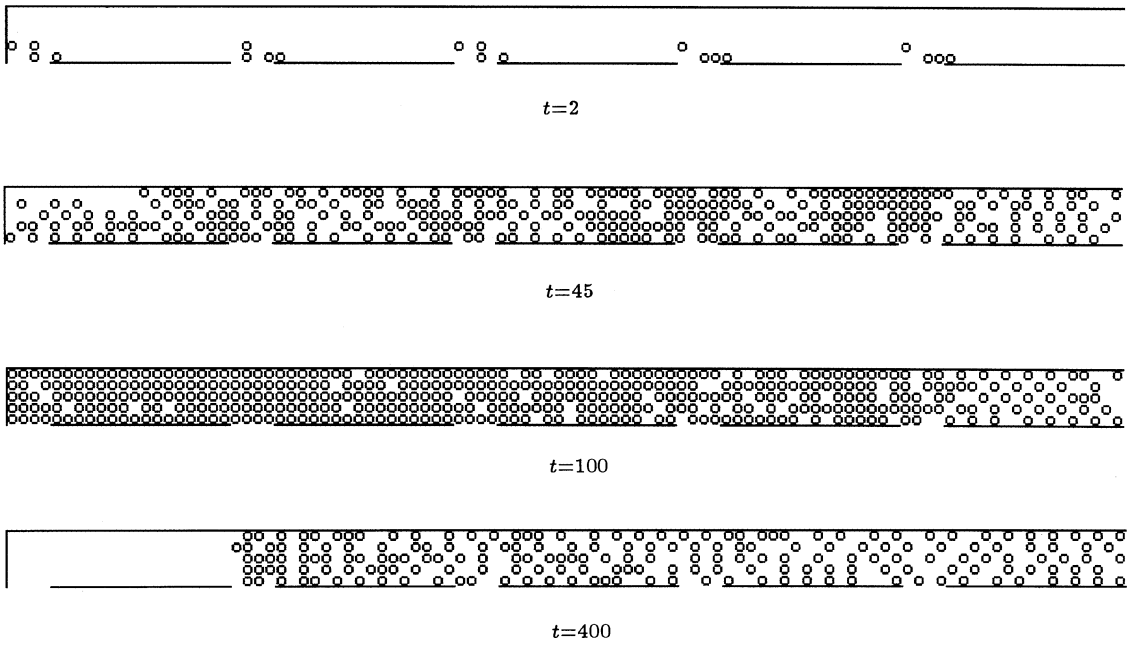


Fig.3. Patterns formed by escaping pedestrians at different time steps.

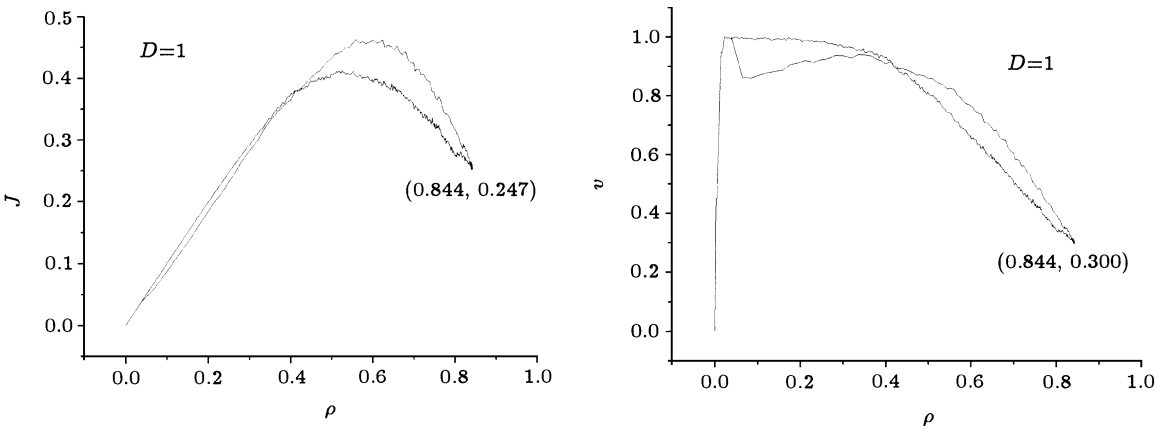


Fig.4. Plots of J and v against ρ.

We have averaged the flow rate and the velocity over 20 samples. Figure 4 shows the plots of J and v against ρ. When ρ is less than 0.5, J increases with ρ; and when ρ is higher than 0.5, J begins to reduce. This property is similar to that of traffic flow. The tendency of velocity to reduce with the increase of

density is also similar to that of traffic flow. However, the J–ρ and v–ρ plots here are all closed, for the processes of entering and of leaving are all contained in the evolution process. From Fig.4, we can find that when the density reaches its maximum 0.844, the velocity and flow rate all reach their minima at the same time.

In the problem of escaping, what we care about most is the transition time, which is the time from the first person entering the corridor to the last person leaving the corridor. To investigate the influence of different factors on the transition time, we change the values of system parameters, such as W, I, d, L and D, and average the evolutions over 20 samples. Figure 5 is the plot of J against t, where $D = 1$, $W = 4, 5, 6, 7$. It shows that transition time t_c decreases with the increase of W. Figure 6 shows the log–log plots of t_c and W for different D. The scale behaviour can be found to be

$$t_c \propto W^{-0.85\pm0.04}.$$

This is similar to Tajima and Nagatani's research.[12]

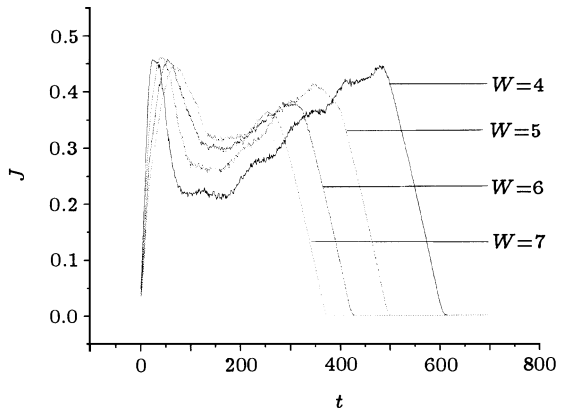


Fig.5. Plots of J against t under different W.

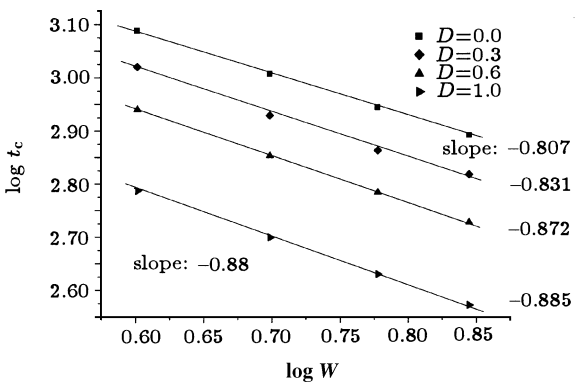


Fig.6. Log–log plots of t_c and W under different D.

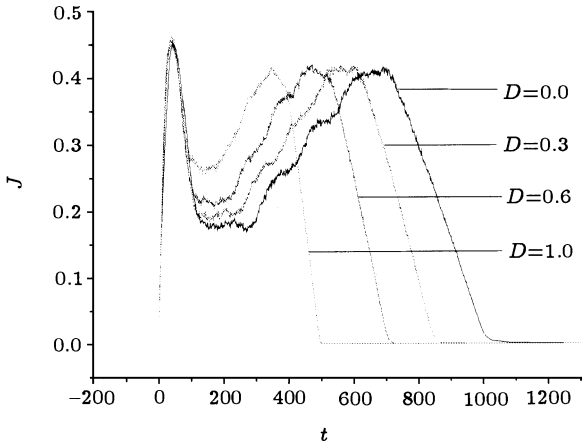


Fig.7. Plots of J against t under different D.

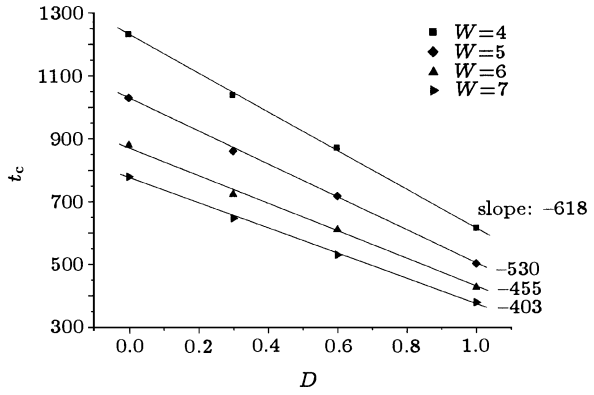


Fig.8. Plots of t_c against D under different W.

Figure 7 is the plot of J against t for different D, where $W = 5$, $D = 0, 0.3, 0.6, 1$. It shows that transition time t_c decreases with the increase of D. Figure 8 is the plot of t_c against D for different W. It shows that the transition time is in proportion to the strength of drift, that is

$$t_c \propto D.$$

But the slopes of the lines increase with the width of the corridor.

Moreover, we have also found that altering of the other parameters has little influence on transition time.

4. Conclusion

Using the lattice-gas model with biased random walkers, we have simulated the evolution of pedestrian escaping flow in the corridor. We found that the evolution of escaping flow includes the following phases: entering, jamming, release and evacuating. Given an unchanging total number of pedestrians, we have found

that the width of the corridor and the drift are the main factors that affect the transition time. The transition time t_c scales as $t_c \propto W^{-0.85\pm0.04}$. The transition time is also in proportion to the drift, with its slope increasing with the width of the corridor. We have also found that the transition time is very little affected by the length of corridor, the width of doors or the intervals of doors. Therefore, these factors can be ignored in the design of buildings.

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