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Students' Evacuation Dynamic Characteristics in Canteen with a Modified Cellular Automata Model

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Abstract: The students' emergency process from a canteen is simulated by a modified cellular automata model through considering students' emergency behavior characteristics and the restricted sight. The different movement rules in dead zone and visible zone are adopted. The simulation results show that under the normal evacuation, it is beneficial if the side doors are relatively far away from the main entrance. The evacuation time decrease with the decrease of the total number of students. In addition, under restricted sight, evacuation signs can significantly improve evacuation efficiency.

Key words: Students' emergency evacuation, cellular automata model, canteen, dead zone, evacuation time

INTRODUCTION

Canteen, as one of the most crowded places and the fire, explosion and other safety accident-prone place in school, how to reduce casualties in emergency evacuation has been an important research topic. The prime models to simulate pedestrian evacuation are social force model (Helbing and Molna, 1995), hydrodynamic model (Jiang *et al*., 2010), lattice gas model (Tajima and Nagatani, 2001; Kuang *et al*., 2008) and cellular automata model (Kirchner and Schadschneider, 2002; Varas *et al*., 2007). As a microscopic model, the cellular automata model can better characterize the different behaviors of pedestrian. Tajima and Nagatani, 2001) simulated an evacuation process from a room and found that scaling relations between pedestrian flow, phase transition time and exit width. Li and Sun (2013) investigated the effect of strong movement ability on students' emergency evacuation in a classroom with obstacles. Moreover, some researches were conducted considering the case where pedestrian sight is restricted. Nagai *et al*. (2004) simulated the effect of exit configuration on evacuation of a room without visibility. Isobe *et al*. (2004) studied the evacuation process in a dark or smoky room using the experiment.

However, in most above models, the object of study was mainly focused on the general pedestrian. It is well known that student have their own special behaviors. How these typical factors influence the evacuation process is still an open problem. In this study, a case study is presented for students' evacuation from No.1 student canteen in Taiyuan University of Science and Technology with an improved cellular automaton model, in which such typical behavior factors as intelligent choice, panic phenomenon, etc. and other building structures such as the position of side doors, evacuation sign have been considered.

MODEL

As is shown in Fig. 1, the canteen is composed of dining selling area and dining area, where ▬ denotes desktop. Considering the dining table seats, we set the whole table occupy 4 lines cell in actual simulation, i.e., the table seats become an obstacle when students leave seats or seats are empty. The plane change diagram of

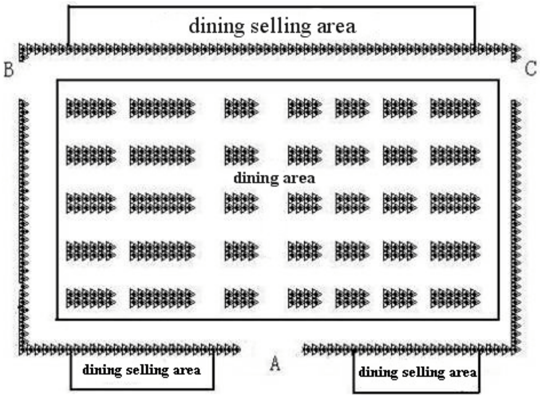

Fig. 1: Plane diagram of canteen

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Fig. 2: Change plane diagram of dining table when students leave seats

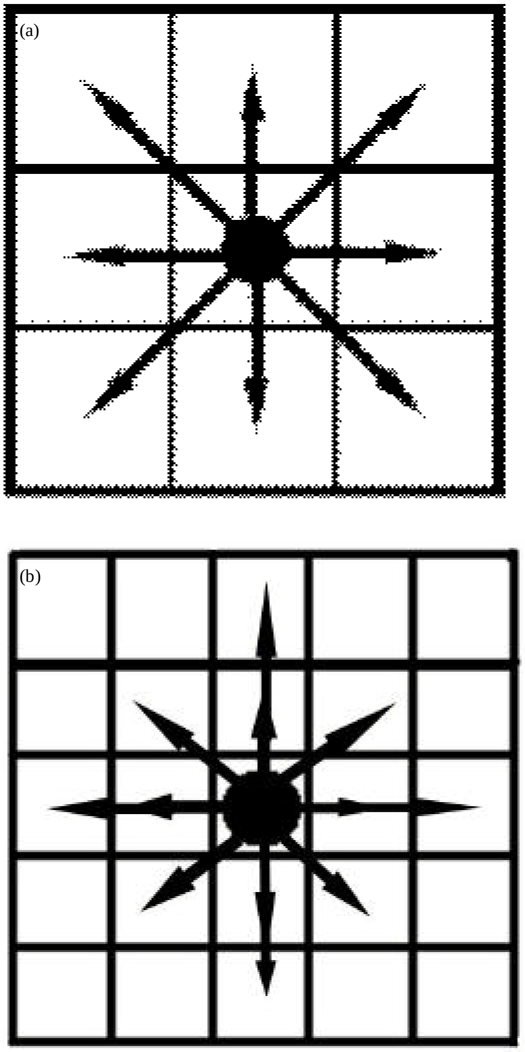

Fig. 3(a-b): (a) Moore two fields and (b) Extended Moore two fields

dining table when students leave tables is shown in Fig. 2, where ◆ respects student. Canteen has 3 exits. The length of canteen is 31 m and the width is 19 m, the width of front door is 4 m and the side door is 2.5 m. The cellular automata model is defined on a square lattice of 63×39, where front door and side door occupy 8 and 5 cells, respectively. The canteen plane is uniform meshed and each grid can be empty or occupied by a pedestrian or obstruction.

According to the conventional Moore two fields (Fig. 3a), the individuals can move toward 8 directions and arrive to an adjacent empty cell in one time step and the size of the arrow indicates the speed magnitude is 1 m s^{-1} (move up or down or left or right), 1.5 m s^{-1} (move to diagonal), respectively. Here, we increase the maximum speed of individual to simulate the students with different abilities in the process of evacuation, i.e., extended Moore two fields, as is shown in Fig. 3b. The individual can go toward the adjacent 12 empty grids of his location, the maximum speed is 2 m s^{-1} and can exceed the others.

We define the average density ρ and average velocity v as follows:

$$\rho=\frac{1}{T}\sum_{j=1}^{T}\frac{N_n}{N_c} \tag{1}$$

$$v=\frac{1}{T}\sum_{j=1}^{T}\frac{\sum_{i=1}^{N_n}v_i(t)}{N_n} \tag{2}$$

where, N_n and N_c denote the number of students in canteen at one moment and that canteen can contain, respectively; $v_i(t)$ is the velocity of ith student at time t; T is the time of simulation.

Then we introduce the concept of location risk of each grid point as follows:

$$PD(i,j)=\begin{cases}0 & \text{(the cell at the exit)}\\ \text{inf} & \text{(the cell is occupied)}\\ \min(\sqrt{(x_i-x_1)^2+(y_i-y_1)^2},\sqrt{(x_i-x_2)^2+(y_i-y_2)^2}, & \\ \sqrt{(x_i-x_3)^2+(y_i-y_3)^2}) & \text{(the cell is empty)}\end{cases} \tag{3}$$

where, (i, j) and (x_i, y_i) denote the cell's location and coordinates, respectively; (x_1, y_1), (x_2, y_2) and (x_3, y_3) are three exits' coordinates, respectively.

Generally, students have following behavior and psychological characteristics in emergency evacuation (Li and Sun, 2013): panic, going first for the students in the front row, exceeding others, conformity and intelligent choice. Therefore, we expand Eq. 3 to make location risk can comprehensively reflect the distance, psychological and objective factors. The specific rules are as follows: (1) Firstly, according to Eq. 3, PD(i,j) of all cells is determined;

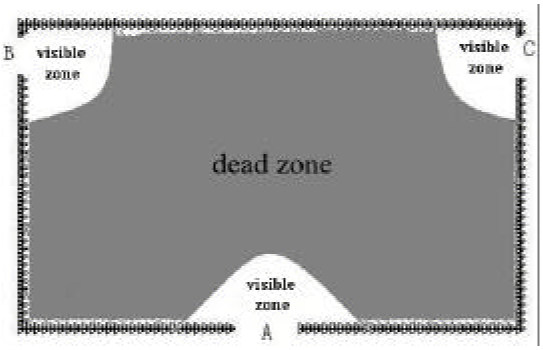

Fig. 4: Schematic diagram of dead zone and visible zone

(2) When the student is in a panic state, PD(i,j) = 0 at that time, (3) When one student follows the leaders, he only selects the adjacent cell as the next step moving target and PD(i,j) of other directions are infinity, (4) When one student intelligently chooses the left exit as the ultimate goal, PD(i,j) of student's right area is infinity and vice versa.

The updating rules of the model are as follows: (1) Determine each cell's PD(i,j), (2) Students choose the cell with the minimum PD(i,j) as the goal grid at the next moment. If the students reach the exit, they are removed from the system, (3) After every person has updated in each time step, location risk is recounted, (4) Cycle calculation until all the students have walked out of the canteen.

The above rules are for those students whose views are not restricted. If students' views are restricted when a power failure happens or full of smoke, they often have a big psychological reaction and evacuation become 'crossing a river by feeling the stones'. At this situation, we divide the canteen into dead zone and visible zone (Fig. 4).

- **Visible zone:** students evacuate normally according to the above rules
- **Dead zone:** Students evacuate according to the understanding to their surroundings before emergency event occurs and the direction of next step has a probability. The maximum speed becomes 1 m sec^{-1} and students can only move toward up or down or left or right, where Ps, Px, Pz, Py, Pj denote the probability of upward, downward, left, right and immobility, respectively

We take the students located in the top left of front door to explain the behavior rule of students in the dead zone. The movement configuration and probability is shown in Fig. 5

Table 1: Different initial No. of students

R	R1	R2	R3	R4	R5	R6
Number	700	600	500	400	300	200

- Ps = 0, Pz = Pj = 0.1, Py = 0.3, Px = 0.5
- Can't move toward left. Ps = 0, Pj = 0.1, Py = 0.3, Px = 0.6
- Can't move toward right. Ps = 0, Pz = 0.1, Pj = 0.2, Px = 0.7
- Can't move toward down. Ps = 0, Pz = 0.1, Pj = 0.3, Py = 0.6
- Can't move toward left and down. Ps = 0, Pj = 0.3, Py = 0.7
- Can't move toward left and right. Ps = 0, Pj = 0.2, Px = 0.8
- Can't move toward right and down. Ps = 0, Pj = 0.7, Pz = 0.3
- Can't move toward left, right and down. Ps = 0, Pj = 1

Similar, the movement configurations of students located in the top right of front door A, near to side door B and C are same to Fig. 5 and can also be obtained.

SIMULATION RESULTS

We assume 360 students (canteen has 360 seats) are distributed in canteen. Firstly, we analyze the influence of side doors position on evacuation time under the normal evacuation. The different side doors locations K1, K2, K3 are shown in Fig. 6.

The relationship between evacuation time and side doors position is shown in Fig. 7. When side doors are close to front door A gradually, the evacuation time also increases gradually and the increase amplitude also becomes large. The evacuation efficiency of K3 is far lower than that of K1, K2. The free space around K1 side doors is larger than that of K3, which will be beneficial for the evacuation. In the case of K3, on the one hand, the time for the students to reach the side doors is longer; on the other hand, because the side doors are much closer to front door, the evacuation function of the side doors has not been fully achieved. So, we should try to design side doors far away from front door.

Secondly, we investigate the influence of personnel density on evacuation time. Here we set side doors location as K1. Initial numbers of students are shown in Table 1. The students are mainly distributed in the region of the dining table and the rest are randomly distributed in the free area.

The curve between evacuation time and personnel density is shown in Fig. 8. It can be seen that with the increase of the number of students, the evacuation time

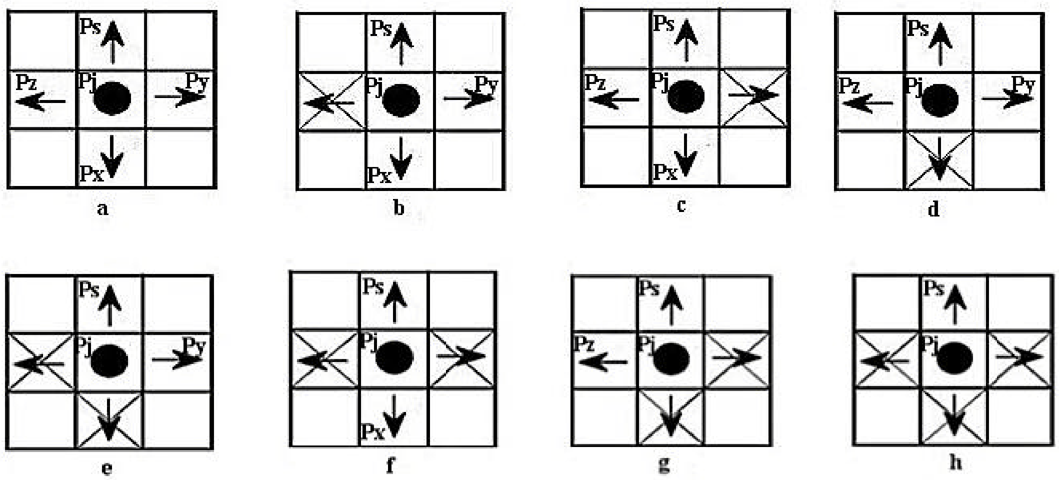

Fig. 5(a-h): Students' movement configuration and the corresponding choosing probability for each movement direction

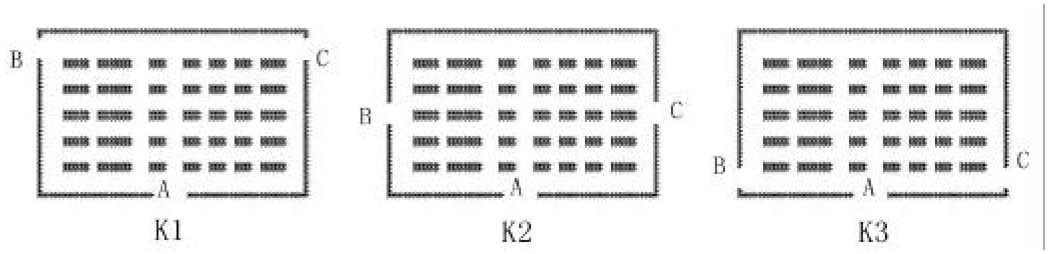

Fig. 6(a-c): Schematic diagram of side doors position

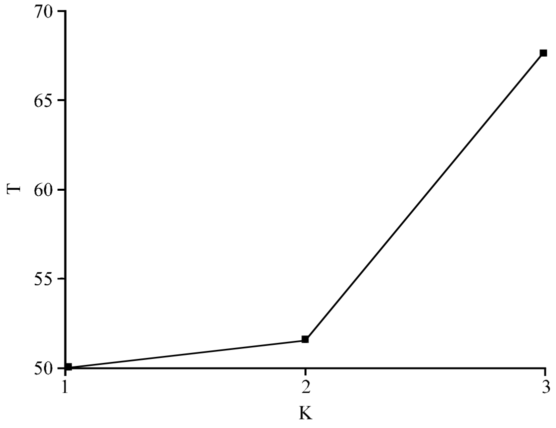

Fig. 7: Relationship between evacuation time and side doors position

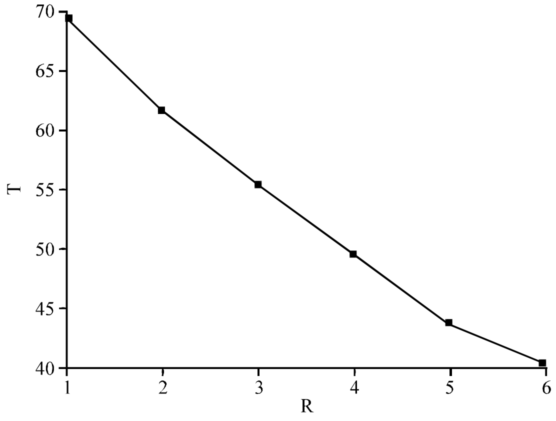

Fig. 8: Relationship between evacuation time and personnel density

also increases gradually. The change curves of average speed for R2, R4, R6 are shown in Fig. 9. We can find: (1) Average speed of R6 is higher than R2, R4 within 8-15 sec and higher than 1 m sec^{-1}, which means in the case of R6, much free area can be chosen for evacuated students. Average speed of R4 is higher than that of R2 and both

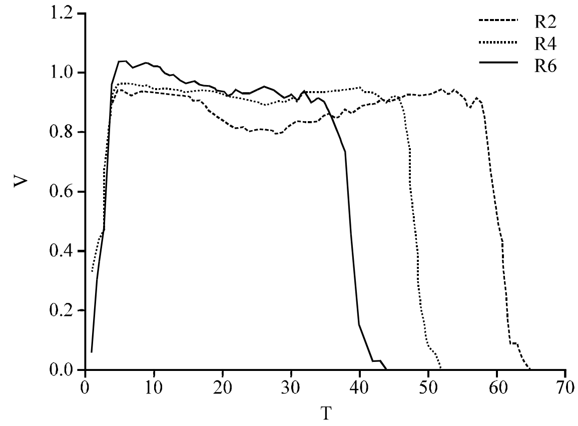

Fig. 9: Change curves of average pedestrian speed for R2, R4, R6

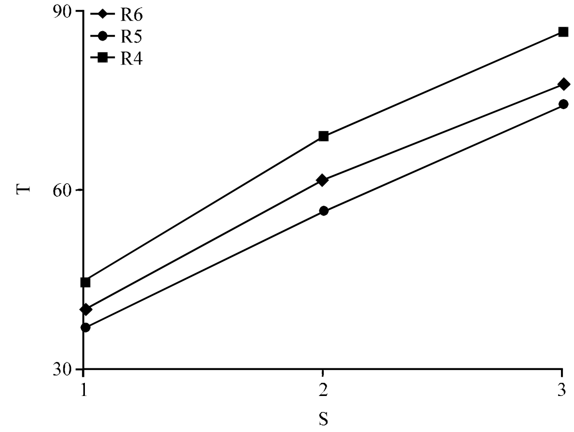

Fig. 10: Relationship between evacuation time and different view conditions for R4, R5, R6

R2 and R4 are almost 1 m sec^{-1}, in this case relatively small free area can be chosen for evacuation but students still can normally evacuate, (2) Average speed of R4 is almost same to that of R6 within 18-35 sec but is much higher than that of R2 and average speed of R2 is less than 1 m sec^{-1}, which shows in the case of R2, crowd phenomenon occurs easily. Average speed of R4 is almost 1 m sec^{-1} in all process. Therefore, the number of students in this canteen should be kept under 500.

Finally, we investigate the influence of evacuation sign on evacuation time. Here we set the numbers of students are R6, R5, R4, side doors location is K1. We consider three different cases: S1 denotes the evacuation situation that pedestrian' view is not restricted, i.e., without dead zone; S2 denotes that pedestrian' view is restricted but with evacuation sign; S3 denotes that pedestrian' view is completely restricted, the probability is chosen as that in Fig. 5. Note that with evacuation sign, i.e., S2, during the evacuation, students reduce blindness, randomness and uncertainty greatly and movement probabilities of each direction in Fig. 5 are also adjusted as follows:

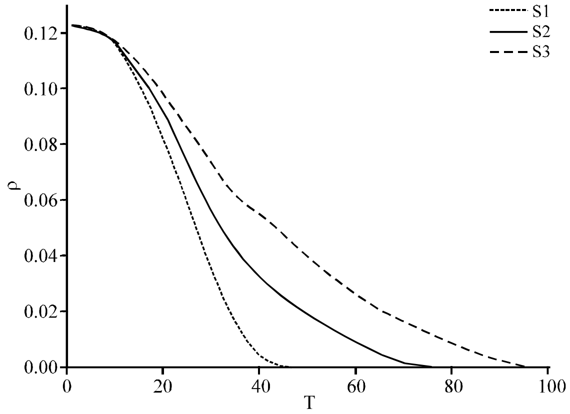

Fig. 11: Relationship between personnel density and evacuation time for S1, S2, S3

- Ps = Pz = 0, Pj = 0.1, Py = 0.2, Px = 0.7
- Ps = Pj = 0, Py = 0.2, Px = 0.8
- Ps = Pz = 0, Pj = 0.1, Px = 0.9
- Ps = Pz = 0, Pj = 0.2, Py = 0.8
- Ps = 0, Pj = 0.2, Py = 0.8
- Ps = 0, Pj = 0.1, Px = 0.9
- Ps = 0, Pj = 0.9, Pz = 0.1
- Ps = 0, Pj = 1

Similar, the movement configurations and probabilities in other locations are also changed according to the above rules.

The relationship between evacuation time and different view conditions are shown in Fig. 10. The change trend of R6, R5, R4 is almost same but the evacuation time of S3 is much higher than that of S2, S1 for three curves. The relationship between personnel density and evacuation time under the given initial numbers of students R5 is presented in Fig. 11. The personnel density of S3 is highest, followed by S2, which means that under the influence of restricted view, the evacuation efficiency without evacuation signs is slowest. Therefore, in practice, to install evacuation sign is very important for evacuation.

CONCLUSIONS

Present aim in this study is to deliver a better exploration of students' evacuation characteristic from a canteen. To do so, we have proposed an extended cellular automata model, in which the typical students' behavior and building structures are considered. Through numerical simulation, it can be concluded that: (1) To increase the distance of the side doors to the front door will improve the evacuation speed; (2) The evacuation time increase gradually with the increase of the total number of students, which should be controlled to a certain range in order to have a higher and safe evacuation efficiency; (3) During the evacuation under restricted view, to design appropriate evacuation signs is highly necessary to reduce evacuation time.

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