On influencing of a space geometry on dynamics of some CA pedestrian movement model

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Abstract. In this paper we show an effect that a shape of way contributes to dynamics of one Cellular Automata pedestrian movement model. The fundamental diagrams for a closed and strait pathes are presented and discussed.
Key words: pedestrian dynamics; transition probabilities; fundamental diagram.

1 Intoduction

Here we present some investigation of dynamics of our model. The model is stochastic discrete CA model and supposes short-term decisions made by the pedestrians [1]. A possibility to move according the shortest path and the shortest time strategies are implemented to the model. From the comprehensive theory of pedestrian dynamics [2] such model may be refereed to tactical level.

It is obvious that a shape of a way influences on dynamics of people flow in real life. Here we focus on the influence of turns. The fact is that the pedestrian flow velocity goes down on turns; and model should be able to reproduce it. We investigated the realization of the same effect in our pedestrian movement model. The people flows were simulated under approximately constant densities on a straight path and a closed path. Differences between two cases were investigated comparing fundamental diagram.

In the next section the model is presented. Section 3 contains description of the case study and results obtained.

2 Description of the model

2.1 Space and initial conditions

The space (plane) is known and sampled into cells $40cm \times 40cm$ which can either be empty or occupied by one pedestrian (particle) only (index $f_{ij} = \{0, 1\}$). Cells may be occupied by walls (index $w_{ij} = \{0, 1\}$) and other nonmovable obstacles.

The model imports idea of a map (static floor field S) from floor field (FF) CA model [3] that provides pedestrians with information about ways to exits.

Our field S increases radially from exit cells. It doesn't evolve with time and isn't changed by the presence of the particles.

A target point for each pedestrian is the nearest exit. Each particle can move to one of four its next-neighbor cells or to stay in present cell (the von Neumann neighborhood) at each discrete time step $t \to t+1$; i.e., $v_{max} = 1[step]$.

A direction of the movement of each particle at each time step is random and determined in accordance with the distribution of transition probabilities and transition rules.

2.2 Update rules and transition probability

A scheme typical of the stochastic CA models is used. At the first stage, some preliminary calculations are made. Then, at each time step the transition probabilities are calculated, and the directions are selected. In the case, when there are more than one candidate to occupy a cell, a conflict resolution procedure is applied. Finally, a simultaneous transition of all the particles is made.

In our case, the *preliminary step* includes the calculation of FF S. Each cell $S_{i,j}$ stores the information on the shortest discreet distance to the nearest exit.

The probabilities of movement from cell (i,j) to, e.g., up neighbor is[4]

$$p_{i-1,j} = N_{i,j}^{-1} \exp\big[k_S \triangle S_{i-1,j} - k_P F_{i-1,j}(r^*_{i-1,j}) - \\ - k_W(1 - \frac{r^*_{i-1,j}}{r})\tilde{1}(\triangle S_{i-1,j} - \max \triangle S_{i,j})\big](1 - w_{i-1,j}); \quad (1)$$

where
– $N_{i,j} = \tilde{p}_{i-1,j} + \tilde{p}_{i,j+1} + \tilde{p}_{i+1,j} + \tilde{p}_{i,j-1}$;
– $\triangle S_{i-1,j} = S_{i,j} - S_{i-1,j}$, $k_S \geq 0$ is the (model) field S sensitive parameter (the higher k_S, the better directed the movement);
– $r > 0$ is the visibility radius (model parameter) representing the maximum distance (number of cells) at which the people density and obstacles influence on the probability in the given direction;
– $r^\star_{i-1,j}$ is the distance to the nearest obstacle in the given direction ($r^\star_{i-1,j} \leq r$); the people density lies within $0 \leq F_{i-1,j}(r^*_{i-1,j}) \leq 1$;
– k_P is the (model) people sensitivity parameter which determines the effect of the people density, the higher parameter k_P, the more pronounced the shortest time strategy;
– $k_W \geq k_S$ is the (model) wall sensitivity parameter which determines the effect of walls and obstacles.

The decisions rules are the following:

1. If $N_{i,j} = 0$, motion is forbidden.
2. If $N_{i,j} \neq 0$, target cell $(l,m)^*$, $(l,m)^* \in I = \{(i-1,j), (i,j+1), (i+1,j), (i,j-1), (i,j)\}$ is chosen randomly using the transition probabilities.

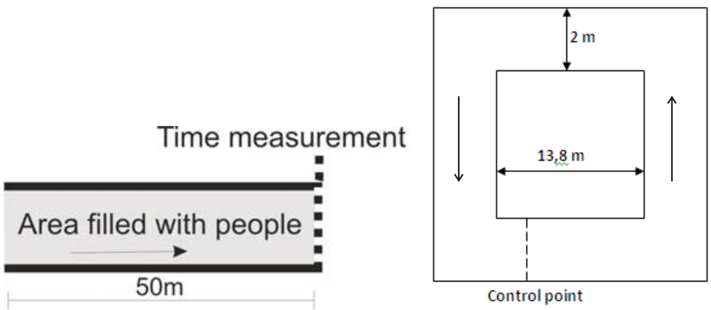
[4] Probabilities $p_{i,j+1}, p_{i+1,j}, p_{i,j-1}$ are calculated similarly. $p_{i,j} = 0$: the probability of retaining the current position is not calculated directly. Nevertheless, the decision rules are organized so that such opportunity could be taken.

3. (a) If $N_{i,j} \neq 0$ and $(1 - f^*_{l,m}) = 1$, then target cell $(l,m)^*$ is fixed.
   (b) If $N_{i,j} \neq 0$ and $(1 - f^*_{l,m}) = 0$, then the cell $(l,m)^*$ is not available as it is occupied by a particle. In such case $p_{i,j} = \sum_{(y,z)\in I:(1-f_{y,z})=0} p_{y,z}$ and $p_{y,z} = 0 \forall (y,z) \in I : (1 - f_{y,z}) = 0$. Again, the target cell is chosen randomly using the transformed probability distribution.
4. Whenever two or more pedestrians have the same target cell, movement of all the involved pedestrians is denied with probability μ. One of the candidates moves to the desired cell with the probability $1 - \mu$. The pedestrian allowed to move is chosen randomly.
5. The pedestrians that are allowed to move perform motion to the target cell.
6. The pedestrians that appear in the exit cells leave the room.

The above rules are applied to all the particles at the same time; i.e., parallel update is used.

3 Case study

To investigate the contribution of turnes to model dynamics we use two case studies, see fig. 1. The first path is strait; the other one is closed path. A set of densities was considered. During each experiment the initial density was kept approximately constant.



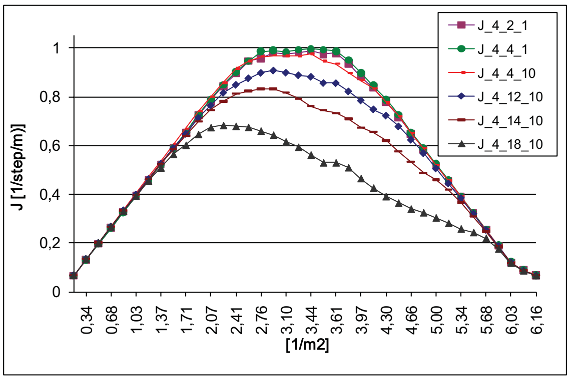
a) Strait path. b) Closed path.

Fig. 1.

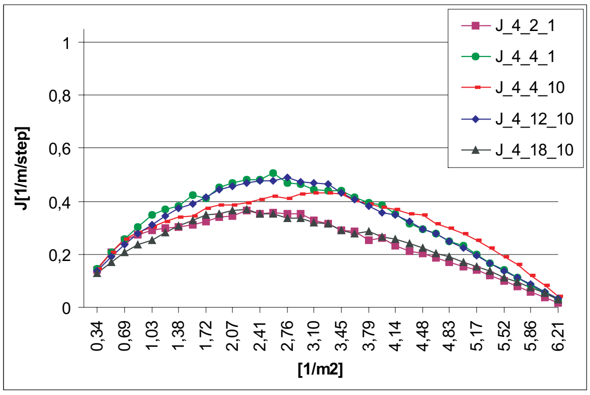
In all experiments we investigate the directed movement $k_S = 4$; the attitude to walls is "loyal" ($k_W = k_S$).

The simplest type of the way, the strait path, supposes that strategy of the shortest path coincides with the shortest time strategy for the whole way. Geometry of the way does not influence on the movement, and the shape of the flow and velocity are only determined by the density. To realize only the shortest path strategy the model density sensitive parameter k_P has to be low ($k_P < k_S$).

If there are turns on the way, congestions appear before turns (depending on density), and some people start to use detours facilities (that means to follow the shortest time strategy) and not to wait when the shortest path will free. As a result the average velocity and flow go down. In the model the shortest time strategy is pronounced under $k_P > k_S$. The mechanism is the following. If the shortest path direction has a high density, $F(r^\star) \approx 1$, the probability of this direction goes down. At the same time, the probability of direction(s) that are more favorable to movement ($F(r^\star) \ll 1$) rises, and the detours around high-density regions are made. One can say that the model is density adjustable.



a) Strait path.



b) Closed path.

Fig. 2. Fundamental diagram for different sets of parameters k_S, k_P, r ($J\_k_S\_k_P\_r$).

In figures 2a, 2b the fundamental diagrams presented for strait and for closed pathes correspondingly. Comparing figures one can see that the flow [5] goes down (approximately in half) from the strait path case to the closed one. Shapes of the fundamental diagrams change. Maximum of the flow shifts to lower densities. Thus, general expectations are realized.

We tested different sets of parameters. These sets reproduce the different people movement: from using only one strategy (the shortest path) when $k_P < k_S$ to combining both strategies if $k_P > k_S$.

In fig. 2a one can see that the flows are the highest and approximately coincide for 3 sets of parameters ($k_S = 4, k_P = 2, r = 1$; $k_S = 4, k_P = 4, r = 1$; $k_S = 4, k_P = 4, r = 10$). In all of this cases the shortest path strategy is mainly reproduced by the model; the influence of the people density sensitive term is reduced to minimum by low parameter k_P.

The other curves in fig. 2a give flows for cases when the the shortest time strategy is already reproduced by the model. But the type of the path does not suppose using of this strategy. And realizing of the shortest time strategy delivers some disturbance to the directed movement, average velocity of the flow slows down, and this results in the lower flow.

Note that for wide range of low densities and for high densities all sets of model parameters give the same flow. This says that for such type of way the model is sensitive to model parameters only under middle flow density.

At the same time a comparison of figures 2a and 2b shows that for the closed path starting with the lowest densities the model is sensitive to the parameters. Curves in figure 2b diverge for the whole range of densities and approximately coincide only for extreme density values. But value of maximal divergence is considerably less then in fig. 2a.

Moreover dynamics of the model, on the whole, is very sensitive to the shape of way. Only for $\rho < 0,75[1/m^2]$ flows for parameters considered in figure 2a and figure 2b approximately coincide. Starting with $\rho > 0,75[1/m^2]$ presence of turns results in a slowing down of the velocities and flows (approximately in half).

Interesting facts are: the most divergent curves from fig. 2a ($J\_4\_2\_1$ and $J\_4\_18\_10$) approximately coincide in the closed path case; the most coincident curves from fig. 2a ($J\_4\_2\_1$ and $J\_4\_4\_1$) are the most divergent in fig. 2b.

The first fact may be explained in the following way. Parameters $k_S = 4, k_P = 2, r = 1$ and $k_S = 4, k_P = 18, r = 10$ deliver opposite extreme strategies of movement (see above); and for the straight path this gives expected very divergent curves. For the closed path these opposite properties gives coincident the lowest flows because the type of the way implies the combining of the strategies.

[5] We use specific flow $J = 1000/T_{st}/2$ $[1/step/m]$, where T_{st} – number of steps that 1000 particles need to cross the control line under given density.

4 Conclusion

At the moment we have no appropriate real data for the similar closed path to compare with. But simulation results obtained show the expected decreasing of the flow comparing the straight and the closed pathes. We believe that specific feature of CA model, i.e., discreteness of the space and the von Neumann neighborhood, gives some contribution to the decreasing. But nevertheless the proper model "senses" the shape of the way.

At the same time simulation results show that model parameters play important role. Of course the fundamental diagram could not depict the all variety of the difference in model dynamics for different parameters and type of ways, and more criterions should be investigated for thorough identifying the all features of the model dynamics. But time and spatial adaptation of model parameters becomes clear to make the model geometry adjustable.

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