

Modeling and simulation: social force model modified by Helbing model in fast pass system

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Abstract. This paper introduced Helbing's social force model, modified it with game theory. Then how individuals in the space behave in dynamic non-cooperative games was described, different macro grouping characteristics were obtained. Individual behaviours at the micro level were simulated. Setting different parameters and conditions of the model, the macro effects of individual behaviours were observed. The overall behaviour of the system was studied. It could be used to guide the allocation of public resources.

Keywords: Non-cooperative game, Helbing social force model, Crowd evacuation, Simulation.

1 Introduction

Public resources are always limited, so the allocation of resources is very important. Especially in the multi-agent system, if the individual in the system obtains resources, the optimal strategy depends not only on his own choice, but also on the choice of other individuals. At the same time, individuals can not negotiate with each other and can not reach a binding consensus, that is, individuals are in a dynamic non cooperative game condition of game theory. Using group movement model to study group characteristics can effectively guide the formulation of resource allocation principles.

Resource allocation in public places is a typical application of the above problems. For example, life-saving equipment and escape passage settings, reasonable design can improve efficiency and economy. This paper attempts to solve this economic problem by using game theory and group movement model.

Some scholars have made contributions to the study of individual and group behaviour and put forward a series of models. Such as From Ising Model to Vicsek Model^[1,2] and Couzin Model^[3-5], in which many statistical features of the motion of self-driven particles can be reproduced. Helbing studying cluster movement provides a theoretical basis for the study of human crowd movement, He proposed a social force model which in the research of high density crowd under emergency evacuation problem plays a crucial role^[6,7]. The model uses the concept of social force to simulate human behaviour.

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2 Helbing social force model and its modification

2.1 Helbing social force model

The Social force model is framework of the multiple particles from the self-drive system. Helbing assumes that pedestrians have thinking ability and the ability to respond to the environment, and their walk is not completely affected by external effect, but also is driven by their own subjective initiative. Meanwhile, he sees individuals in a crowd as identical microscopic particles. Each particle receives three forces: its own driving force F_d , and interaction force F_{ij} , and obstruction force F_{iw} , as formula (1).

$$\mathbf{F}_i = \mathbf{F}_d + \sum \mathbf{F}_{ij} + \sum \mathbf{F}_{iw} \quad (1)$$

where $\mathbf{F}_d = \frac{m}{\tau}(\mathbf{v}_i^{exi} - \mathbf{v}_i)$, τ is estimated time spent from \mathbf{v}_i^0 to \mathbf{v}_i^{exi} , \mathbf{v}_i^{exi} is the velocity expectation vector pointing to the exit, \mathbf{v}_i^j is the present velocity of the individual;

$$\mathbf{F}_{ij} = \mathbf{A}e^{[(r_{ij}-d_{ij})/B]} \overline{\mathbf{n}}_{ij} + \mathbf{kg}(r_{ij} - d_{ij}) \overline{\mathbf{n}}_{ij} + \mathbf{kg}(r_{ij} - d_{ij}) \Delta \mathbf{v}_{ij}^t \overline{\mathbf{t}}_{ij},$$

The first term is the repulsive force between two individuals, while the second term is the force of collision between two individuals, and the third one is the force of friction between two individuals when they collide.

r_{ij} is the sum of the radius of two particles. d_{ij} is the distance between the center of mass of two particles, with $g=0$ when $r_{ij} > d_{ij}$, and g is a constant when $r_{ij} < d_{ij}$.

Similarly, $\mathbf{F}_{iw} = \mathbf{A}e^{[(r_i-d_{iw})/B]} \overline{\mathbf{n}}_{iw} + \mathbf{kg}(r_i - d_{iw}) \overline{\mathbf{n}}_{iw} + \mathbf{kg}(r_i - d_{iw}) (\mathbf{v}_{ij}^t \overline{\mathbf{t}}_{ij}) \overline{\mathbf{t}}_{ij}$,

d_{iw} is the distance between the individual center of mass and the obstacle.

The speed of each individual is determined by the formula (2).

$$\overline{\mathbf{v}}_i' = \overline{\mathbf{v}}_i^0 + \frac{\mathbf{F}_i}{m_i} \tau \quad (2)$$

The position is determined by the formula (3).

$$\mathbf{P}_i = \mathbf{P}_i^0 + \mathbf{v}_i \tau \quad (3)$$

2.2 The Modification of Helbing Model

However, Helbing's theoretical model is not perfect enough. Because in a crowded and situation, only a few pedestrians can see the gate through the crowd. So the person who can't see the gate will choose a que which he thinks leads to the direction of the entrance, and choose to follow the que until he sees the entrance and goes straight in. Everybody tends to do that.

Assume that the information level of a person on the entrance is determined by the formula (4).

$$\mathbf{S}_i = e^{-\alpha} e^{-di} \quad (4)$$

where α is the number of information transmission, with initial value is 0. After each transmission, α will plus 1. This shows that the more information is lost, the less reliable the information is; d_i is the distance between i and the exit.

Assume that one person \mathbf{P}_i can get gate information from different pedestrians around, and the information of everyone around knows can be shown as $\{\mathbf{S}_j, j=1,2,\dots\}$. Then \mathbf{P}_i will choose the person whose corner mark is \mathbf{j}_c .

$$\mathbf{j}_c = \mathbf{arg}(\mathbf{max}\{\mathbf{S}_j\}) \quad (5)$$

\mathbf{P}_i follows him to the que, because he has the most reliable information leading to the best chance to follow him to the entrance.

Accordingly, the driven force of \mathbf{P}_i can be modified as formula (6).

$$F_{d2} = e^{-\alpha} F_d + (1 - e^{-\alpha}) F_{ijc} \tag{6}$$

where $F_d = \frac{m}{\tau} (\mathbf{v}_i \overline{\mathbf{e}_{exi}} - \overline{\mathbf{v}_i})$, $F_{ijc} = \frac{m}{\tau'} (\mathbf{v}_i \overline{\mathbf{e}_{ijc}} - \overline{\mathbf{v}_i})$, $\overline{\mathbf{e}_{exi}}$ is the vector from P_i to the exit ; $\overline{\mathbf{e}_{ijc}}$ is the vector from P_i to P_{jc} ; τ and τ' are estimated time spent from $\overline{\mathbf{v}_i}$ to $\mathbf{v}_i \overline{\mathbf{e}_{exi}}$ and from $\overline{\mathbf{v}_i}$ to $\mathbf{v}_i \overline{\mathbf{e}_{ijc}}$ respectively.

As moving, the person P_i will always choose the most reliable que around to follow. As the position changes, the selected person will change, and the direction of F_d will also change ^[11].

3 Computer simulation of evaluation model

Suppose there are many individuals in a room, the initial personnel density is evenly distributed and the room has an exit. When an emergency occurs, people close to the exit rush straight to the exit, while people at the side and back of the room need to rely on others to find the direction of the exit. Based on the modified Helbing model, the emergency evacuation model is simulated.

The principle is to calculate the force and acceleration of each person according to the above conditions. Assuming that a person has identified the escape direction (that is, determined the acceleration direction), he can immediately move in this direction, so it can be considered that a person's velocity direction is his acceleration direction. After many times of superposition, guide all people to find the exit to escape.

3.1 Algorithm framework

According to the model established in this paper, computer programming simulation steps are carried out as below:

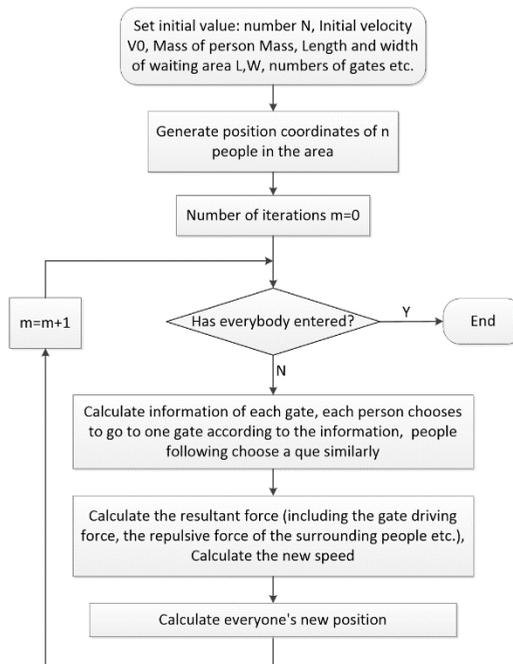


Fig. 1. Algorithm framework.

- Step 1. Initialize various parameters, including individual number, exit position, width, etc.
- Step 2. Determine the position of the individual: if it is in the area, execute the next step; If it's outside the area, end the process.
- Step 3. Calculate the information on entrance or que of each individual.
- Step 4. Calculate the force by individuals, and adjust the position of the individual correspondingly.
- Step 5. Perform step 2, until all the individuals are not in the area.
- Step 6. End all the procedures.

3.2 Model numerical simulation analysis

Initial input: assume a room which area is $S = L \times W = 10\text{m} \times 10\text{m}$ with m pass gates and which exit door width is $width_Door = 1\text{m}$. $n = 100$ people who randomly distributed in the room.

Simulate the evacuation time also called the number of iterations and personnel density at any time under different exit number m , different total number N and different room area S .

3.2.1 Varying the number of entrances

The following are the cases of one and three pass gates respectively, and the cases of two and four pass gates are similar.

- One pass gate

It can be seen that all pedestrians are randomly distributed in the waiting place. At the beginning of the entering, all pedestrians moved closer to the pass gate. That is, the longer the time, the greater the number of iterations, and the greater the population density at the gate. At 20 iterations, congestion occurred near the pass. It takes more than 60 iterations for everyone to get out of the exit. When the pass area is congested, the speed of movement is very slow, and the population density is very high. It can reach 7 m^2 or more and it is prone to stampede. So a place with 10 m^2 one exit is obviously not enough. The simulation results are shown in Figure 2.

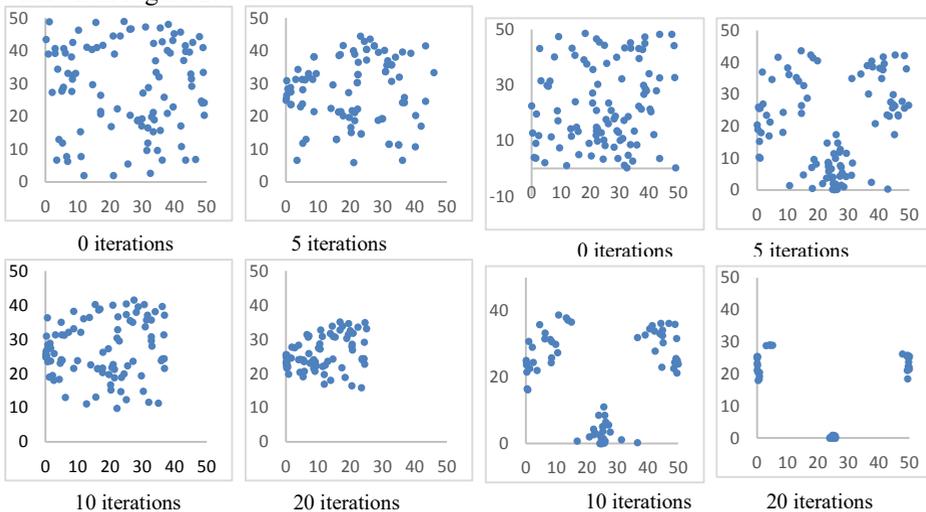


Fig. 2. Different time spots in one pass gate

Fig. 3. Different time spots in 3 pass gates

- Three pass gates

The simulation results with three pass gates are shown in Figure 3.

When the three pass gates were distributed, all the pedestrians were still divided into three groups along the mid-perpendicular line of the exit line and moved to the near-distance gate. At 20 iterations, the gate was more congested and slower, but faster than the two gates case. The whole process is completed 45 iterations. The population density near the gate is 2 to 3 persons per square meter and it is safer for slow movement.

3.2.2 Varying the number of people

In the same area, the different number of people also has an impact on the evacuation speed. The personnel density is defined as the ratio of the number of people and the area of the semicircle with the exit as the center and R as the radius. Figure 4 shows the evolution comparison of personnel density with the increase of iteration times under different exit conditions. Figure 5 ~ 7 show the evolution of the personnel density near the exit under different gates.

It can be seen that when the number of gates is fixed, the evolution trend of personnel density in Figure 5 ~ 7 is basically the same as that in Figure 4. With the increase of the number of people, the maximum density of people near the exit is increasing, and the duration of congestion is getting longer and longer. But the time of congestion peak is basically the same.

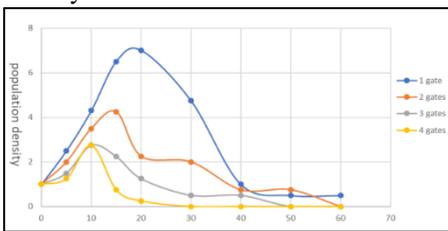


Fig. 4. The evolution of population density at different number of gates.

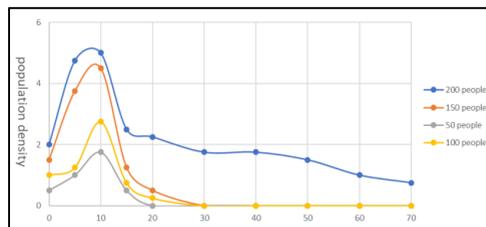


Fig. 5. The evolution of population density in different populations in 4 gates.

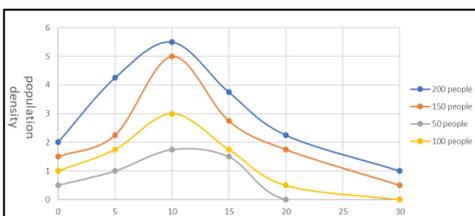


Fig. 6. The evolution of population density in different populations in 3 gates.

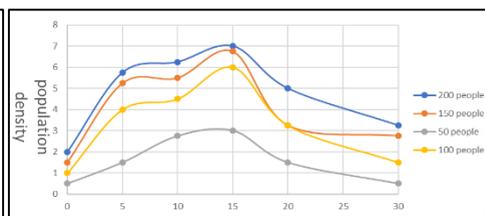


Fig. 7. The evolution of population density in different populations in 2 gates.

While the number of people fixed, change the number of gates, change the time of congestion peak, peak density and evacuation time; while the number of gates fixed, change the number of people, congestion peak time does not change, only change the peak density and evacuation duration.

3.2.3 Varying the area of the waiting place

When the exit and the number of people are the same, the room size also has an impact on the evacuation speed. Figure 8 shows the room with $50 \times 50m^2$, $60 \times 60m^2$, $70 \times 70m^2$ iterates 0, 5, 10 and 20 times respectively. With the increase of the room, the speed of

evacuation is obviously slower, and more people stay in the room at the same time. With the evacuation, the larger the room area, the smaller the density of people at the exit.

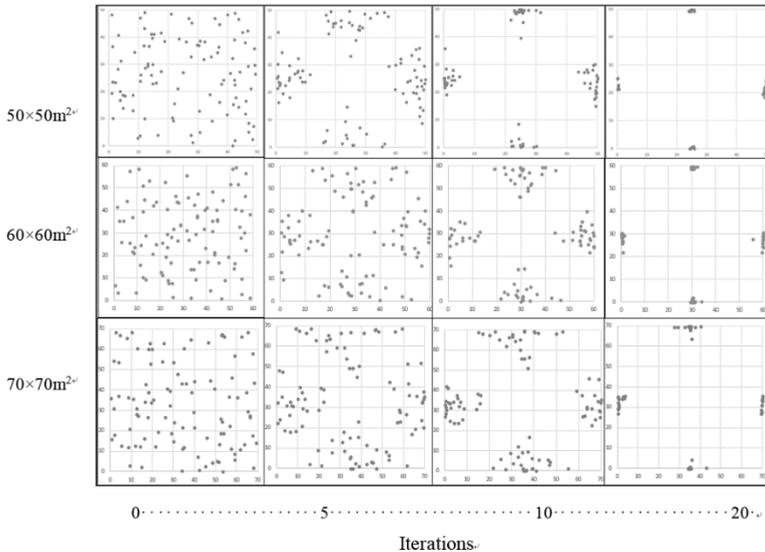


Fig. 8. The evolution of population density in different area.

3.2.4 Conclusion of evacuation model simulation

We can conclude that the more exits, fewer people and larger rooms in crowded places, the higher the evacuation efficiency. In the process of evacuation, there will be congestion near the exit. The time of congestion is only related to the number of exits, and the more exits, the earlier the congestion occurs, but the shorter the duration. The maximum density of people in congestion is related to the number of exits and the number of people in the room.

The relationship between evacuation time and the number of exits is inverse proportional and nonlinear; the relationship between evacuation time and the number of people in the area is also similar and inverse proportional, and it is nonlinear. Therefore, the simulation data can provide a reference for setting reasonable escape routes, and the method used in this paper has a certain value.

4 Conclusion

The method of calculating group behaviour from individual decision-making and individual behaviour model is consistent with the empirical results. This shows that it is a scientific and feasible method to study the overall behaviour of the system through modelling and simulation to observe the macro effect of individual behaviour through action or interaction. It can be used to guide the allocation and intervention of public resources. Economically, this method can also be used to study similar economic behaviours.

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