Crowd infection and its prevention strategy in a subway station based on social force model

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Abstract. With the development of society, crowds in public buildings are dense, and the subsequent spread of diseases in places with high population density has attracted widespread attention. In the real situation, the spread of the disease has its complexity, such as the influence of factors such as the movement of people and the intervention of external measures, so it is necessary to further refine the description of the process of infection transmission. Based on the social force model, this article focuses on the impact of microscopic crowd movement in public places on the dynamics of infection. Taking a typical pedestrian exit process in a subway station as an example, we numerically simulated the infection problem among small-scale people in public places, observed the impact of pedestrian movement characteristics on infection transmission, put forward corresponding prevention and control measures, and verified the effectiveness of the measures.

1 Introduction

There is a strong link between the movement of people and the spread of diseases, from the global spread of infectious diseases to the cross-infection in a subway station. By tracing the movement of infected people, the scope of the disease can be roughly predicted, and effective prevention and control measures can be taken. Li et al. Combined SEIR model and urban traffic network model, proposed a simulation system suitable for urban epidemic transmission in China[1]. Based on the warehouse model, Chen Renxia[2] and Zhao Jing[3] introduced indirect infection rate and non-uniform transmission respectively. Yu Hong[4] studied the effects of different susceptibility, infectivity, individual movement and infection cycle based on the complex network theory. Based on the social force model, Namilae[5] simulated the impact of contact between passengers during boarding and disembarkation on the transmission of infection, and evaluated the impact of different boarding and disembarkation methods on the number of contacts.

Based on the social force model that can describe the individual movement of pedestrians, this paper studies the infection transmission process of micro people by introducing factors such as infection status, contact duration and infection probability, and studies the impact of crowd movement on infection by taking subway station, one of the typical public buildings, as an example.

2 Numerical model

2.1 Social force model considering individual infection

The social force model[6] is based on Newton’s second law of motion, takes each pedestrian as the research object, analyzes its force, and studies the movement of the crowd.
The relationship between the force and acceleration of pedestrian $i$ is shown in formula (1):

$$m\frac{dv_i}{dt} = f_i^D + \sum_{j\neq i} f_{ij} + \sum_w f_{iw} \quad (1)$$

The resultant force received by pedestrians includes three parts. The first part $f_i^D$ is the driving force of pedestrians. The second part $f_{ij}$ refers to the force of other pedestrians acting on pedestrian $i$. The third part $f_{iw}$ is the force of obstacles such as walls on pedestrians. Specific calculation references [6].

Therefore, this paper determines the direction of pedestrian expected speed by calculating the flow field velocity vector by lattice Boltzmann method. D2Q9 model is adopted, and the boundary condition is set as rebound boundary. In order to prevent the emergence of vortex, a small Reynolds number is used to determine the rebound boundary. In order to prevent the emergence of vortex, a small Reynolds number is used to determine the initial state parameters.

The judgment method of pedestrian infection is as follows: in the process of crowd movement, when the distance between the susceptible person and the infected person is less than or equal to the infection radius $R_{inf}$ and remains within this range for a certain time, it is considered to have come into contact with the infected person. Next, the system will generate $N_{random}$ random numbers $0 < N_{random} < 1$ and then judge the generated random number. If the random number is less than or equal to the infection probability $P_{inf}$, the susceptible person will be infected and become a latent person. Finally, susceptible people who become latent become infected after a period of time. The different values of $f_i$ are as follows: 0 represents susceptible, 1 represents latent, and 2 represents infected. The existence of the remover (rehabilitator) is not considered in this paper.

$$f_i = \begin{cases} 
0, & \text{if } d_{ls} \leq R_{inf} \cup N_{random} \leq P_{inf} \cup (t_t \geq t_{cl}) \\
1, & \text{if } d_{ls} > R_{inf} \cup N_{random} > P_{inf} \cup (t_t < t_{cl}) \\
2, & \text{otherwise}
\end{cases} \quad (2)$$

Where $d_{ls} = \| r_i - r_s \|$. The transmission route mainly considers droplet transmission, $r_i$ is the location of the infected person, and $r_s$ is the location of the susceptible person. The transmission route mainly considers droplet transmission, and the infection radius $R_{inf}$ indicates the maximum distance that the virus can spread. $t_t$ is the contact duration, $t_{cl}$ is the limit value of contact duration. Here, 2.5 seconds is taken according to the literature [5]. Delyt is the total time after infection ($f_i = 1$ then start timing), $t_{cl}$ is the incubation period. Infection probability $P_{inf}$ refers to the probability of infection between infected persons and susceptible persons in one contact. Statistically, it is the ratio of the number of infected persons to the number of exposed persons.

### 2.2 Parameter setting

Referring to the CAD drawings of existing typical subway stations, the simulation scene set in this paper is shown in Figure 1. -1F is the platform layer and 1F is the station hall layer. The expected speed of pedestrians meets the uniform distribution [7], and the individual size is taken to relevant standards [8].

### 3 Results

As shown in Figure 2, assuming that the value of $R_0$ is 50, the infection probability is 0.083. Use this infection probability to simulate the movement and infection process and count the number of infected people (i.e. the value reflected as $R_0$). It can be seen that after the number of repetitions of the example reaches 600, the simulation results are consistent with the assumed $R_0$ and remain unchanged. Therefore, it is proved that the accuracy of the model meets the requirements, and the example can be repeated 600 times to obtain stable results.

![Fig. 1. Simulation scene](https://doi.org/10.1051/e3sconf/202235602020)

![Fig. 2. The relationship between $R_0$ and the number of running samples](image)

Then, we simulated the changes of contact times and the number of infected people under the condition of different total number of outbound people. Among them, the infection radius is 1.5m and the infection probability is 0.083. As can be seen from Figure 3 (a), with the increase of the total number of people leaving the station, the contact times and the number of infected people among pedestrians increase, and the fluctuation range of
the contact times results is larger. This may be because pedestrians have the following effect\(^9\). Due to the following effect, most of the infected people are pedestrians around the initial infected people. Therefore, the location of the initial infected people will have an important impact on the number of infected people. We simulated the infection situation under different infection radius and basic infection number, and the results are shown in Figure 3 (b-c). It can be seen that in any case, the number of infected people increases with the increase of the total number of outbound people.

3.1 Analysis of pedestrian aggregation in subway station

As shown in Figure 4 (a). The aggregation phenomenon mainly occurs at the narrow exit where individuals pass through, such as subway entrance, elevator entrance, etc, so the staircase is the main location where pedestrians gather. As shown in Figure 4 (b), the infection density diagram is shown. The size of Rho value represents the number of infected persons per unit area. It can be seen that there are a large number of infected people at the entrance of the elevator.

3.2 Increase pedestrian spacing and expected speed

The parameter Bi in the social force model represents the characteristic length of individual social repulsion force to other pedestrians. The larger the value is, the greater the repulsion force between pedestrians is. The larger the corresponding distance between pedestrians is. Therefore, to increase the distance between pedestrians, only increase the value of \( B_i \), and the results are shown in Figure 5. Figure 5 (a) shows that the number of infected people decreases when the pedestrian spacing increases; The simulation results in Figure 5 (b-c) show that when the number of people exiting the station is 300, increasing the distance between pedestrians reduces the degree of aggregation and infection probability density.

We simulated the effect of expected speed change on the number of infected people, and the results are shown in Figure 6 (a-b). With the increase of expected speed, the number of infected people decreases, especially when the total number of outbound people is large.
3.3 Guide pedestrians to take stairs

It can be seen from Figure 7 (a) that when walking from stairs, the space range is larger, and the distance between crowds increases correspondingly, and the contact between crowds decreases. The comparison chart of infection probability density in Fig.7(b-c) also illustrates this situation. The infection situation at the elevator entrance has decreased. Therefore, pedestrians should be guided to use stairs to reduce the possibility of infection during an epidemic.

4 Conclusion

Taking a typical subway station in public places as an example, this paper studies the impact of individual movement on infection transmission in micro population, and analyzes the effectiveness of various prevention and control measures. The results show that:

1) Guiding pedestrians to enter the station hall floor from the elevator can effectively reduce the number of infected people. The existence of elevator plays a role in dispersing the flow of people and reducing the number of pedestrian contact.

2) Increasing pedestrian spacing can reduce the number of susceptible people within the infection radius, increase the expected speed and reduce the contact time between pedestrians. Both can significantly reduce the number of infected people. Therefore, pedestrians can be guided to keep a distance and leave the station as soon as possible by means of subway station broadcasting, drawing sign lines and staff supervision.

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References


