Agent-Based Simulation on Pedestrian Flow Capacity of Narrow Space

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Abstract. The narrow space in the urban pedestrian traffic system is the area which is liable to be congested. Recently, researches on the maximum pedestrian flow of space mainly focus on the width of exit, but there are not sufficient researches on the walking space with a certain length. The aim of this paper is to analyze the change of pedestrian flow capacity of the narrow space with a certain length under the influence of width. The simulation model of walking behavior is established by NetLogo software. By changing the space width and the number of pedestrians entering into the space per unit time, the quantitative relationship between the width of space and the space pedestrian flow capacity is simulated. In the simulation, the pedestrians’ walking behavior is influenced by the target area, the space boundary and the visible surrounding pedestrian density. The results show that when the length of the walking space is 30 m and the space width is less than 10.33 m, the increase of the width will significantly improve the pedestrian flow capacity of the space. When the space width is larger than 10.33 m, the increase of the width will enhance the pedestrian flow capacity less significantly. The research results can be applied to the design of the width of urban long and narrow walking space.

1. Introduction
In recent years, with the sustained and stable economic development, the number of urban public places fulfilling material and cultural needs experienced a rapid development. The scale of gathering crowd grew in various public places. The design of urban walking areas suffering from pedestrian congestion had attracted great attention. Crowd congestion occurs mainly in pedestrian bottleneck areas with poor maximum pedestrian flow capacity, and therefore the importance of the study of pedestrian traffic bottleneck area is increasing [1]-[3]. Helbing et al. thought that every pedestrian felt the application of both "social" and "physical" forces. Social forces had no physical source, instead they reflected the pedestrian’s intentions and did not collide with other people or walls in the room and moved in a particular direction at a specific speed [4]-[6]. Weng et al. divided pedestrian walking behavior into "move", "dodge" and "turn" 3 kinds of basic behaviors. The direction of walking was determined by walking weights, which were the sum of the basic behavior of each vector multiplied by the weights in the respective directions. The model could be used for path analysis and congestion simulation [7]. Based on the NetLogo platform, Lee et al. proposed a multi-agent path selection model based on field of view. With the consideration of the view angle, visual distance, visual disturbance, moving speed, attractiveness factors and other pedestrian factors, the problem of pedestrian path selection under the influence of building entity was analyzed [8]. Wang et al. proposed a new congestion evacuation model based on multi-agent to simulate the process of pedestrian evacuation in...
an obstructed or unobstructed stadium. The state of each agent was divided into normal condition, catching up and death. In this model, all pedestrians were divided into 4 types, each with 6 different competencies. The individual's course of action was influenced by its competencies, distance to exit, number of agents in field of vision, and crowd density. The simulation analyzed congestion and death phenomena [9]. Harada et al. studied that when evacuation numbers exceeded the capacity of the evacuation zone, those who could not enter the evacuation zone changed their destination to other zones. In order to simulate the change of destination, a switch action model was developed. The behavior of destination change during evacuation was considered as an important factor and the switch-effect algorithm was introduced into the traditional multi-agent model in order to be able to reproduce the destination change during the evacuation process [10]. Li et al. used the population dynamics theory to study the clogging of evacuation spaces during emergency evacuation, the consequent accidents and stampeded. Research showed that the amount of the population flow was related to population and spatial factors. Based on the distribution model of population movement along evacuation routes, the influence of initial population density on congestion was analyzed in detail. The results showed that when the population density reached 2.17 persons·m\(^{-2}\), the crowd would be hard to move [11]. Shi et al. conducted a series of controlled laboratory tests to examine the safety constraints that affected the mobility of people in the merger perspective and the direction of flow under slow operation and obstruction visual conditions. Studies showed that the direction of flow had a significant effect on the outflow of pedestrians, while visual disturbances had an impact on the interactions and mergers of pedestrian populations [12]. The previous studies provided a scientific basis for the establishment of walking behavior model and the setting of relevant parameters, but few researches have studied the pedestrian flow capacity of spaces with a certain length.

In this paper, aiming at the long and narrow walking space prone to traffic jam in walking environment, the simulation models with different widths are established and the traffic efficiency is analyzed, which provides reference for the design of walking space width in urban design.

2. Methods

2.1. Simulation environment settings

In this paper, the model space length is 30 m, the grid size is 0.33 m, and the space width is increased gradually by 4 times grid width (1.33 m). The model space width is 3.67 m, 5.00 m, 6.33 m, 7.67 m, 9.00 m, 10.33 m, 11.67 m, 13.00 m and 14.33 m respectively. 9 different widths are simulated in total, as shown in Fig. 1.

Environment settings in space include target space, walls and pedestrians. The target space is located in the black region at the far right side of the space. All the pedestrians walk towards the target space gradually. The walls are the light grey regions located at the upper and lower edges of the space as the boundary of the simulation space. The pedestrians start from the dark grey region on the left side of the space, and leave on the dark grey region on the right. Taking Asian body size into account, the pedestrian diameter is set 0.33 m, and walking speed is set 1.3 m·s\(^{-1}\). In the simulation, the number of pedestrians entering space per unit of time is gradually increased until the number of pedestrians entering space per unit time reaches the maximum flow rate in that space.

![Figure 1. 30 m long and 7.67 m wide model simulation results.](image)

2.2. Walking behavior setting
The walking behavior of the population is mainly affected by the spatial environment and other pedestrians within the visible range. In this paper, aiming at the walking behavior of high-density crowd, the visible area is set to the area within 120° of the pedestrian’s walking direction and within 2 m from the pedestrians’ current location. Pedestrians’ response to the environment within the visible range is divided into 4 basic behaviors: moving forward, turning, bypassing and waiting. When there are no obstructions in front of pedestrians, the pedestrians move toward the target. When pedestrians are less than 2 steps away from the wall, pedestrians randomly rotate within 30° to the opposite direction of the wall in order to avoid getting out the current region. When there are other pedestrians in the visible range of pedestrians, the degree of congestion in the visible area is evaluated by the number of pedestrians in different distance ranges of the target space. Pedestrians will bypass other pedestrians and select the routes with lower congestion when they go to the target area. According to the research of Li et al., when the pedestrian density is larger than 2.17 persons·m⁻², pedestrians stop walking [8]. According to the visible area condition set in this article, pedestrians will stop walking and wait for other pedestrians if the number of pedestrians exceeds 8 in the visible range. Then, pedestrians continue to walk after others’ passing, as shown in Figure 2.

3. Results
If the flow of people entering the space within a unit time does not reach the maximum flow rate of space, the number of people entering the space and the number of people leaving the space will reach a balance after a period of operation of the model, and the number of pedestrians in the space will no longer increase. When the number of passengers exceeds the maximum capacity of the space, congestion will occur, resulting in a continuous increase in the number of pedestrians in the space. When the space width is 6.33m, the maximum capacity of the space is 5 persons·s⁻¹. If the number of pedestrians entering the space exceeds the capacity, the number of pedestrians will continuously increase, as shown in Table 1.

Table 1. Simulation results of the change of population under the width of 6.33 m.
3.1. The maximum flow rate
For the walking space of 30 m in length, the maximum flow has positive correlation with the space width. The maximum flow rate of the space is 3 persons·s$^{-1}$ when the space width is 3.67 m, 4 persons·s$^{-1}$ when the space width is 5.00 m, 5 persons·s$^{-1}$ when the space width is 6.33 m, 6 persons·s$^{-1}$ when the space width is 7.67 m, 7 persons·s$^{-1}$ when the space width is 9.00 m, 8 persons·s$^{-1}$ when the space width is 10.33 m, 9 persons·s$^{-1}$ when the space width is 11.67 m, 9 persons·s$^{-1}$ when the space width is 13.00 m, and 9 persons·s$^{-1}$ when the space width is 14.33 m, as shown in Table 2.

### Table 2. Simulation results of maximum flow in walking space of different width.

| Width (m) | Area (m$^2$) | Maximum flow (persons·s$^{-1}$) | Capacity (persons·m$^{-1}·$s$^{-1}$) | Density (persons·m$^{-2}$) |
|----------|--------------|---------------------------------|-------------------------------------|--------------------------|
| 3.67     | 110          | 3                               | 0.82                                | 0.42                     |
| 5.00     | 150          | 4                               | 0.80                                | 0.44                     |
| 6.33     | 190          | 5                               | 0.79                                | 0.43                     |
| 7.67     | 230          | 6                               | 0.78                                | 0.43                     |
| 9.00     | 270          | 7                               | 0.78                                | 0.43                     |

3.2. Pedestrian flow condition
For simulation of the walking space of 30 m in length, the area of space, the maximum pedestrian flow, the maximum pedestrian flow per meter and pedestrian density according to the space width are shown in Table 3.

### Table 3. The statistics when walking space reaches the maximum number of people.

| Width (m) | Area (m$^2$) | Maximum flow (persons·s$^{-1}$) | Capacity (persons·m$^{-1}·$s$^{-1}$) | Density (persons·m$^{-2}$) |
|----------|--------------|---------------------------------|-------------------------------------|--------------------------|
| 3.67     | 110          | 3                               | 0.82                                | 0.42                     |
| 5.00     | 150          | 4                               | 0.80                                | 0.44                     |
| 6.33     | 190          | 5                               | 0.79                                | 0.43                     |
| 7.67     | 230          | 6                               | 0.78                                | 0.43                     |
| 9.00     | 270          | 7                               | 0.78                                | 0.43                     |
| Width (m) | Capacity (persons/s) | Density (persons/m²) |
|----------|----------------------|---------------------|
| 10.33    | 310                  | 0.77                |
| 11.67    | 350                  | 0.69                |
| 13.00    | 390                  | 0.69                |
| 14.33    | 430                  | 0.63                |

4. Discussion

With the increase of walking space width, the maximum flow rate is on the rise. When the space width is between 3.67 m and 10.33 m, the maximum flow rate increases significantly with the increase of space width. When the space width increases by 1.33 m, the maximum space flow increases by about 1 person·s⁻¹. When the space width is between 10.33 m and 14.33 m, with the increase of width, the maximum flow rate in space has a decreasing tendency of increase. When the space width increases by 1.33 m, the maximum flow rate in space increases by about 0.5 persons·s⁻¹, as shown in Figure 3. Then, it is a more meaningful method to enlarge the space width when it is less than 10.33 m.

![Figure 3. The trend of maximum flow rate of space with width.](image)

With the increase of walking space width, the maximum pedestrian flow rate per meter of walking space shows a downward trend. When the space width is between 3.67 m and 10.33 m, the maximum flow rate per meter of walking space shows a slow downward trend when the walking space reaches the maximum and maximum flow rate. When the walking space reaches the maximum pedestrian flow rate, and the space width is between 10.33 m and 14.33 m, the drop of the maximum flow rate per meter with the increase of walking space width is significant. When the space width is between 3.67 m and 10.33 m, the pedestrian density keeps at about 0.43 persons·m⁻² when the pedestrian space reaches the maximum pedestrian flow rate. When the space width is between 10.33 m and 14.33 m, and the pedestrian space reaches the maximum pedestrian flow rate, the pedestrian density shows a downward trend.

With the analysis of the simulation results, it can be seen that when the width of the space is increased by 1.33 m and the number of pedestrians is increased by 1 person·s⁻¹, the pedestrian density in the spatial range almost remains stable. But when the space width is more than 10.33 m, the pedestrian density will reduce. The reason may be the increase of the complexity of mutual interference between pedestrians and the uneven distribution of pedestrians in space.

5. Conclusion
It can be seen from the simulation results that the width of walking space is directly related to the maximum traffic in space. When the width is between 3.67 m and 10.33 m, the effect of the increase of space width on the maximum flow rate is remarkable, and the maximum flow per unit width shows a slowly decreasing trend. The pedestrian density maintains 0.43 persons·m⁻². When the width is between 10.33 m and 14.33 m, the effect of the increase of space width on the maximum flow rate is subtle, and the maximum flow per unit width shows a significantly decreasing trend. The pedestrian density decreases. For the space with a certain length, if the space width is increased, the increasing trend of maximum flow will decrease when the space with reaches a certain threshold. In future, the space types can be more abundant, and different kinds of pedestrians, such as different genders and ages, can be taken into consideration to make the simulation applicable in some typical environments.

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