Influence of exits and evacuees on evacuation efficiency

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Abstract. In order to study the evacuation process of crowd in evacuation space containing four exits (two exits on one side), a simulation environment was built by using multi-agent simulation platform NetLogo, and the evacuation simulation model was constructed. The influence of exit location, exit width and evacuee number on the evacuation efficiency was studied, the results show that: with the exit moving to the middle, the evacuation time first decreases and then increases, and the decreasing rate of evacuation time decreases gradually and the increasing rate increases gradually; when the evacuee number is small, the evacuation time decreases with the increase of exit width, until the evacuation time remains unchanged when the exit width is large enough. However, when the evacuee number is large, the evacuation time in different positions decreases with the increase of exit width, and the overall decrease rate decreases; with the exit moving to the middle, the increasing rate of evacuation time with the increase of evacuee number at different exit widths decreases at first and then increases. The research results can provide some reference value for the evacuation exit design of building and emergency command of crowd evacuation.

1. Introduction
With the acceleration of urbanization, large shopping malls, stations and other densely populated places also increase correspondingly. Due to the large concentration of crowd and complex personnel composition in these crowded places, if the crowd can not be evacuated timely and efficiently in case of emergency, it will cause heavy casualties[1]. Therefore, when an emergency occurs, how to quickly, efficiently and safely evacuate from crowded places is an important technical means to ensure the safety of people's lives and property. However, the exit location, exit width and personnel capacity of densely populated places have a significant impact on the evacuation efficiency. Therefore, it is of great significance to explore the influence of the exit location, exit width and evacuee number on the evacuation efficiency.

Many scholars have done a lot of research on the influence of evacuation exit and evacuee on evacuation efficiency. Cai[2] established a cellular automata evacuation model to study the effects of different internal layout and exit positions on evacuation efficiency. Zhu[3] analyzed the evacuation efficiency under different exit positions and different layouts in the classroom by using the cellular automata evacuation model established before. Li[4] selected the number of exits, exit location, exit width and aisle width to build a simulation model based on steering model to analyze the influence of different factors on evacuation efficiency. Hu[5] studied the influence of the number of people in the hall of metro station, exit conditions on emergency evacuation based on NetLogo. Zhang[6] simulated the evacuation process of students under different exit conditions and different numbers based on Netlogo, and optimized the exit conditions of classroom by using the calculation results. Chen[7] fully verified the rationality of the proposed evacuation attraction region model for double exits through the
simulation analysis of exit width, number of people and exit location. Zhang[8] established the exit selection model, formulated the evolution rules of pedestrian evacuation, formed the pedestrian evacuation model, and simulated the pedestrian evacuation effect of a single exit and two exits in a rectangular room. Although the relevant scholars have done a lot of research, there are not many studies on the evacuation process of the evacuation space containing four exits, and the influence of the exit location, width and evacuee number on the evacuation efficiency needs to be further studied. Therefore, a evacuation space containing four exits is established, and the influence of exits and evacuees on evaluation efficiency is studied by using Netlogo software.

Netlogo software[9] is developed and designed by the Center for Connected Learning and Computer-Based Modeling (CCL) at Northwestern University. It is a modeling and simulation platform based on Java programming, which not only inherits the basic characteristics of Logo language, but also improves the defect that Logo language can only control a single individual[10,11]. Therefore, the software can effectively simulate the macro and micro phenomena in society and nature, especially suitable for the simulation of complex systems changing with time[11]. In addition, NetLogo is free, open source software, which brings great convenience to scientific research.

2. Establishment of evacuation model

2.1. Evacuation environment
The evacuation space is designed as a two-dimensional grid composed of patches. Based on the shoulder width and chest thickness of Chinese people[12], the size of each patch is set as 0.4m * 0.4m, that is, one patch can only be occupied by one agent. The evacuation space is set as 101patches * 101patches and does not circle around the world in both horizontal and vertical directions, as shown in figure1. In figure 1, a total of four exits are set up, with two exits on the left and right sides, which are symmetrically distributed. Y1 is the width of the evacuation exit, Y2 is the distance between the evacuation exit and the boundary of the evacuation space.

2.2. Parameters related to crowd evacuation

2.2.1. Evacuee number
In the simplified evacuation space, the evacuee number is set as 250, 500, 750, 1000, 1250 and 1500 respectively, and the influence of different evacuee numbers on the evacuation efficiency is studied.

2.2.2. Location and width of evacuation exit
Considering the request of Code for Fire Protection Design of Building, the width of evacuation exit (Y1) is set as 3.2m, 4.0m, 4.8m, 5.6m and 6.4m respectively, and the location of evacuation exit (Y2) is set as 0m, 1.2m, 2.4m, 3.6m, 4.8m, 6.0m, 7.2m, 8.4m, 9.6m, 10.8m. The influence of width and location of evacuation exit on evacuation efficiency is studied.

2.2.3. Speed and direction of crowd evacuation
The crowd will move in a certain direction at a certain speed in the evacuation process. According to the principle of proximity, people in the evacuation space are evacuated to the nearest exit. That is to say, taking the midpoint of the evacuation space as the circle center, the evacuation space is divided into four quadrants, and the crowd in each quadrant is evacuated toward the exit of the corresponding quadrant.

In the process of crowd evacuation, people's speed is closely related to the crowd density. When the crowd density is small, the evacuation speed can be higher. When the crowd density is large, they can only travel at a lower speed or queue or change the path. As for the relationship between crowd movement speed and crowd density, scholars at home and abroad have done a lot of research, such as Predtechenskii and Milinskii[13], Fruin[14,15], Hankin and Wright[16], Lu and Fang[17], Zhang[18], Li[19], Tang[20] etc. have proposed the relationship between pedestrian speed and density, In this
paper, Tang's formula of pedestrian speed $v$ and pedestrian density $D$ on the straight channel is selected as shown in formula (1). In addition, in the model, the counter tick represents the simulation time step and each tick is set to 1s.

$$v = -0.589D + 1.687$$  \hfill (1)

2.2.4. Movement rules of crowd evacuation

In the process of evacuation, there will be interaction between individual behavior and group behavior, and Agent-based Flocking model is very suitable for analyzing the dynamic change process of organizations in complex systems, and it can simulate the collective behavior of interactive individuals[10]. According to the three rules of "separate", "align" and "cohere"[21], the Flocking model simulates the anti-collision, alignment and approach behavior of the evacuation crowd in the evacuation space. Therefore, when the evacuation crowd is far away from the exit, the Flocking model is used to set the evacuation interaction. When the crowd is close to the evacuation exit (i.e., the square area with the horizontal and longitudinal distances less than $2Y_1$ from the center of evacuation exit), the evacuation crowd concentrates at the exit, and the crowd lines up to evacuate towards the exit.

![Figure 1. Schematic diagram of evacuation environment](image)

3. Analysis of simulation results

In each simulation process, the location of crowd in the evacuation space is randomly distributed. Therefore, in order to reduce the impact of random distribution on the evacuation results, each time a group of conditions is set, the simulation is conducted 200 times, and the average value of the evacuation time is taken as the evacuation time under the conditions. The curves of evacuation time with $Y_2$ (distance from the boundary) under different $N$ (evacuee number) and $Y_1$ (exit width) is shown in figure 2. The curves of evacuation time with $Y_1$ under different $N$ and $Y_2$ is shown in figure 3. Under different exit width and exit position, the curves of evacuation time with evacuee number are approximately linear, and the slope $K$ represents the increasing rate of evacuation time with the increase of evacuee number under a certain exit width and exit position, the curves of $K$ with $Y_2$ is shown in figure 4.
Figure 2. Curves of evacuation time with Y2

(a) N=250  
(b) N=500  
(c) N=750  
(d) N=1000  
(e) N=1250  
(f) N=1500

Evacuation time/s vs Y2/m for different N values with Y1 = 3.2m, 4.0m, 4.8m, 5.6m, 6.4m, 7.2m, 8.0m, 8.8m, 9.6m, 10.4m, 11.2m, 12.0m.

Figure 3. Curves of evacuation time with Y1

(a) N=250  
(b) N=500  
(c) N=750  
(d) N=1000  
(e) N=1250  
(f) N=1500

Evacuation time/s vs Y1/m for different N values with Y2 = 0m, 1.2m, 2.4m, 3.6m, 4.8m, 6.0m, 7.2m, 8.4m, 9.6m, 10.8m, 12.0m.
It can be seen from figure 2 that under different $Y_1$, i.e. different exit widths, with the exit moving towards the middle, the evacuation time was gradually reduced and then increased. This is mainly because when the exit is close to the boundary, evacuees in the middle walk to the exit on the boundary will spend a long time. However, when the exit position is too close to the middle, it takes too long for the evacuees on the boundary to walk to the middle exit. On the whole, the decreasing rate of evacuation time is decreasing, and the increasing rate of evacuation time is increasing. Therefore, when designing the location of evacuation exit, it should not be arranged at the boundary position, and the specific location needs to be determined by simulation experiments according to the actual situation.

As can be seen from figure 3, under different $Y_2$, i.e. different exit positions, with the gradual increase of exit width, the change rules of evacuation time under different evacuee numbers are slightly different. From figure 3 (a), we can see that when the evacuee number is small, the evacuation time gradually decreases with the increase of exit width, until the evacuation time remains basically unchanged when the exit width is enough large. However, compared with figure 3 (b) to (f), when the evacuee number is large, the evacuation time gradually decreases with the increase of exit width, and the reduction rate shows a decreasing trend as a whole. Therefore, when designing the width of evacuation exit, the evacuee number in the evacuation space should be considered comprehensively. When the evacuee number is small, it is not that the larger the evacuation exit width, the better the evacuation efficiency. When the evacuee number is large, the evacuation efficiency can be improved by increasing the exit width. In addition, the growth rate of evacuation time varies with the increase of evacuee number at different exit locations. These conclusions can provide

4. Discussion
A simple evacuation space containing four exits (two exits are set symmetrically on the left or right sides) is set up, and the influence of different exit location, exit width and evacuee number on evacuation efficiency is discussed. Through the study, it is found that the location of evacuation exit should not be arranged at the boundary of the evacuation space, and the specific optimal evacuation location should be determined comprehensively according to the exit width and the evacuee number. It is not that the larger the evacuation exit width, the better the evacuation efficiency. When the evacuee number is small and the width of the exit reaches a certain value, increasing the width of the exit has little effect on the evacuation efficiency. When the evacuee number is large, the evacuation efficiency can be improved by increasing the exit width. In addition, the growth rate of evacuation time varies with the increase of evacuee number at different exit locations. These conclusions can provide
reference for evacuation design and emergency command of buildings. However, the response time, panic psychology and return behavior of the evacuees are ignored in the study, which needs to be further studied in the future.

5. Conclusion
(1) With the exit moving to the middle, the evacuation time first decreases and then increases, and the decreasing rate of the evacuation time decreases as a whole, and then the increasing rate of the evacuation time presents an increasing trend.

(2) When the evacuee number is small, the evacuation time decreases with the increase of exit width, until the evacuation time remains approximately unchanged when the exit width is large enough. However, when the evacuee number is large, the evacuation time in different positions decreases with the increase of exit width, and the overall decrease rate decreases.

(3) With the exit moving to the middle, the increasing rate of evacuation time with the increase of evacuee number under different exit widths decreases at first and then increases.

Acknowledgments
This work was supported by the National Key R&D Program of China (Grant No. 2019YFF0301300). The support is gratefully acknowledged.

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