ISSN 2706-655X Vol.4, Issue 10: 1-8, DOI: 10.25236/IJFET.2022.041001

Simulation Study of Crowd Evacuation Based on Metacellular Automata Model

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Abstract: *In this paper, we establish a meta-automata model for crowd evacuation in emergency situations, based on the narrowness of the passage, the noise and visibility of the passage, the psychological and physiological conditions of the passengers themselves and the size of the exit, and make a simulation study on the specific situation of crowd evacuation, and make suggestions on how to improve and enhance the evacuation efficiency. This paper analyzes the influence of relevant factors on crowd evacuation in emergency situations in a more comprehensive manner and gives the best strategy for crowd evacuation under different conditions, and after analysis and verification, the model of this paper is reasonable and of certain practical significance.*

Keywords: *metacellular automata; simulation; location hazard; emergency evacuation; crowd emotion*

1. Introduction

In the past, emergency evacuation issues have become increasingly important due to the increase in the number and size of assembly events. Evacuation through doors of limited width or narrow passageways has become a situation of concern. Many experiments have been conducted to better understand crowd behavior in different situations. Factors such as door width, crowd composition, and location of exits can all affect the effectiveness of evacuation. Although organizing experiments with real people is an effective method, many of the findings are controversial or even contradictory because the realism of the environment and context, stress levels, crowd density, and sample size cannot be kept consistent with the real situation.

The study of the model does not need to face the difficulties encountered in the experiment. However, if the assumptions of the model itself are unreliable, it may produce results that do not match reality. Therefore, we need to study different situations and parameters to understand the dynamics behavior that the crowd may present during evacuation and escape.

To consider the effect of the behavioral patterns of different crowd audiences on the evacuation effect, a meta-cellular automata model is developed and the SIS algorithm is introduced for the study. The model is defined on a metacell space composed of discrete, finite-state metacellular treasures, and time is discretized according to certain local rules, and time is taken as the evolutionary dimension. Each lattice point corresponds to a position hazard, and the pedestrian determines the next moment of motion based on the position hazard of the lattice points in its neighborhood. A tuple automaton model is used to simulate the emergency evacuation movement of the crowd, and the area where the crowd is located is divided into a number of grids, assuming that the area where each person is located can be regarded as the central tuple, and can choose to move to the surrounding neighboring 8 tuples, and can also choose not to move.

Based on the above model, the narrowness (width) and smoothness of the passenger cabin aisle, the size and location of available hatches, the movement speed of different crowd audiences in the passenger aircraft, the choice of exit and evacuation paths, the strength of individual evacuation ability (age, gender, waist circumference, judgment ability), etc. all affect the efficiency of evacuation actions, and the 3-4-3 layout of a two-aisle passenger aircraft cabin using the metacellular automaton model for simulations to study the influence of its key factors on evacuation results.

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2. Assumptions and notations

2.1 Notations

The primary notations used in this paper are listed as Table 1.

Table 1: Notations

Meaning	Symbols
cell side length	Lc
magnitude of repulsive force	lamda1
Relative size of hazards	lamda2
Site width	W
Site length	Le
Disaster spread probability	P
Population coordinates	Ps
Simulation site	Ev
Disaster coordinates	Ds
Sex	Se
Age	Y
Metacell Coordinates	（i，j）
Exit coordinates	Es
Obstacle coordinates	Z
Probability of trampling risk	P1
Evacuation time	Ti
Environment familiarity	Ef
Safety awareness	Sf
Emotion type	p
Passage width	L
Passage width of passenger compartment	H
Passage Visibility	Lt
Noise	Ne
Number of people in the room	N
Average system flow	J
Average speed of pedestrians	v

2.2 Assumptions

We use the following assumptions.

1). Assume that the metacell evacuation grid is the metacell grid of $0.4\mathrm{m} \times 0.4\mathrm{m}$;

2). Assume that the average speed of a pedestrian will reach $1.5\mathrm{m/s}$ in an emergency situation;

3). Assume that the time required for a pedestrian to move one cell $\Delta\mathrm{t} = 0.4s$;

4). Assume that the hall can adequately accommodate all people;

5). Assume that each cell takes only one of the finitely many states at each step;

6). Assume that there are obstacles in the room;

7). Assume that the airliner is at rest and the crowd is evacuated, and each door of the airliner can be opened normally

3. Model building and solving

3.1 Preliminary study of the impact of each key factor on the generation of trampling risk

3.1.1 Study the effect of narrowing of the passage on the risk of trampling

According to the behavior pattern of crowd evacuation in reality, there is a probability that people will stampede during the evacuation process. It is known that the only way for crowd evacuation is a

ISSN 2706-655X Vol.4, Issue 10: 1-8, DOI: 10.25236/IJFET.2022.041001

narrow passage. Now we establish a cellular automaton model to study the impact of "the change of passage width" on the stampede risk. The cellular automaton model is to evenly divide the evacuation map into small grids of $0.4m \times 0.4m$. In this model, everyone is located in the central cell, Move in all directions, as shown in the Figure 1:

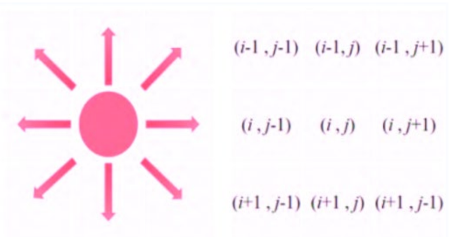

Figure 1: Schematic diagram of metacellular automata[1]

Each of these grid points corresponds to a position hazard, and the pedestrian can decide the direction of movement at the next moment according to the position hazard of its neighboring grid points. The channel is located on the right side of the room, and according to the location of the channel, the room is divided into three areas, A, B and C. The position hazard[1] is determined:

a. When the grid point is at the exit,

$$\eta(i,j) = 0 \tag{1}$$

b. When the grid point is occupied by pedestrians and walls,

$$\eta(i,j) = \infty \tag{2}$$

c. When the grid point is in area A

$$\eta(i,j) = | y_i - y_0 | \tag{3}$$

d. When the grid point is in area B or C

$$\eta(i,j) = \sqrt{(x_i - x_0)^2 - (y_i - y_0)}^2 \tag{4}$$

According to the formula can be calculated according to the location of the danger, the location of the danger of a small grid point will cause the concentration of the crowd, at the location is very easy to trigger a trampling accident, taking into account the more closely related to the actual situation, but also involves different groups of people from the location of the danger of a small grid point of the problem of proximity, the closer to the target grid point of escapees, more advantageous to choose the target grid point, so the more distant escapees to reach the target grid point the smaller the probability.

The more escapees are close to the access point, the more the crowd flow at the access point, if the channel is narrow (L), the average flow rate of the system is used to represent the average escape speed.

$$v = \frac{1}{N}\sum_{i=1}^{N} v_{i(t)} \tag{5}$$

$$J = d_v = \frac{I}{N}\sum_{i=1}^{N} \tag{6}$$

Simulation using a metacellular automaton model written in matlab, changing only the exit width. Changing the width from 2 to 5. Upon comparison, it is clear that a wider passage reduces the risk of trampling while allowing more people to be rescued.

3.1.2 The effect of noise and visibility in the corridor on the risk of trampling

In the process of simulation using metacellular automata model, the noise and visibility in the channel can be transformed into the relative size of disaster hazards. The noise size and visibility will increase the degree of hidden hazards of the original disaster and increase the incidence of trampling risk, and also cause changes in the emotions of the crowd, which can be divided into three categories of people's emotions: calm type, blind type and panic type.

ISSN 2706-655X Vol.4, Issue 10: 1-8, DOI: 10.25236/IJFET.2022.041001

The change of relative size of disaster hazards under the three emotions can be analyzed separately, and the influence of noise and visibility in the channel on the risk of trampling can be more precisely derived.

(1) Calm type (as shown in Figure 2):

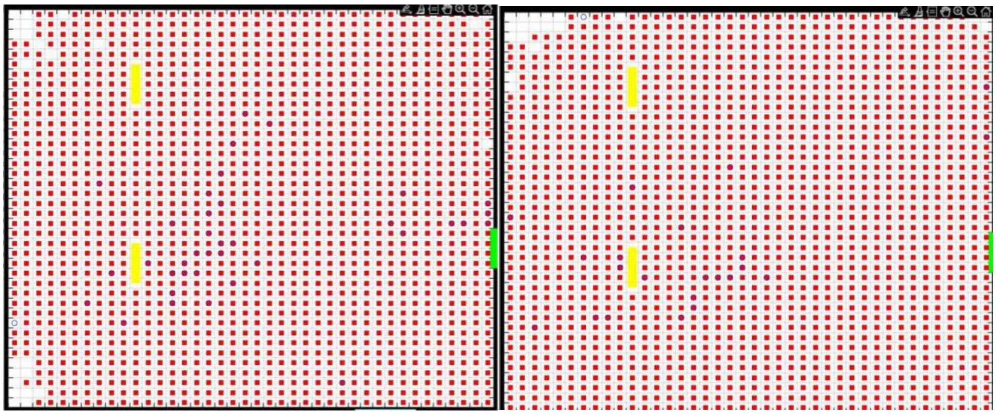

Figure 2: Relative size of disasters 3 and 4

(2) Blind type(as shown in Figure 3):

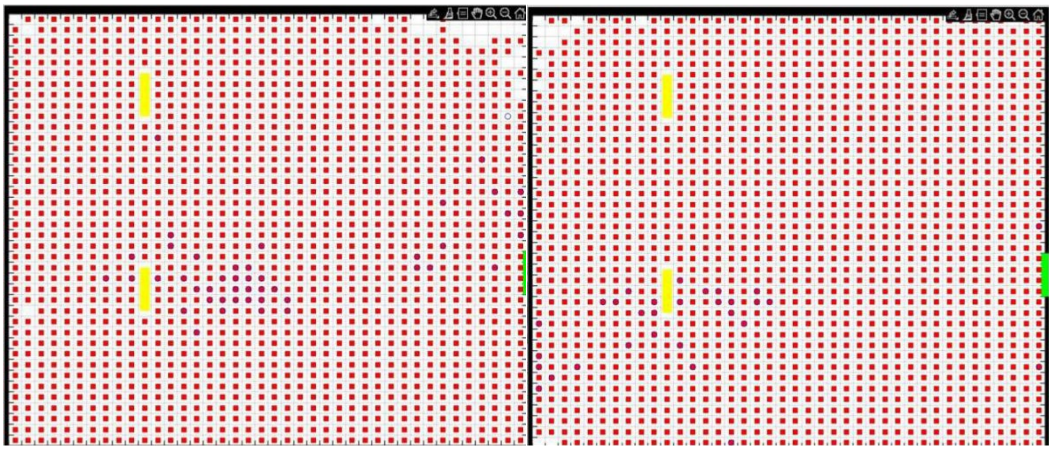

Figure 3: Relative size of disasters 3 and 6

(3) Panic type(as shown in Figure 4):

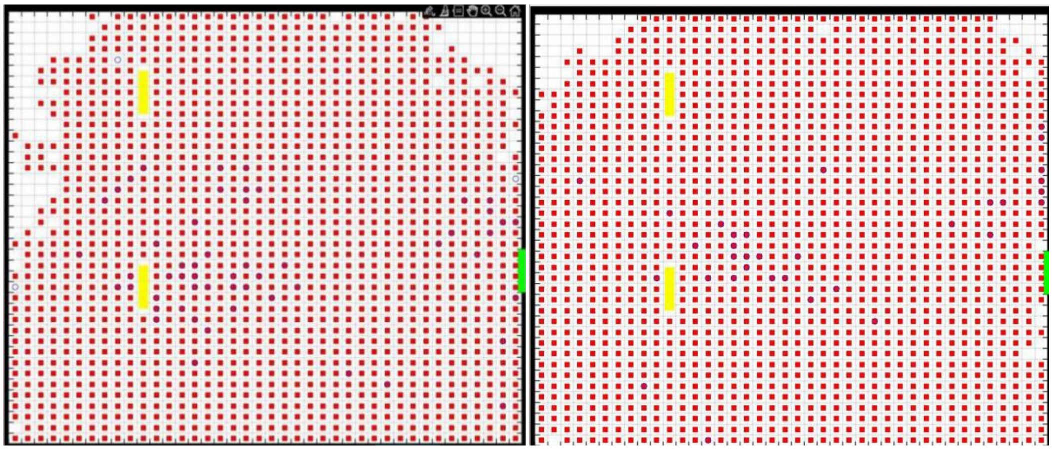

Figure 4: Relative size of disasters 3 and 8

Conclusion: According to the comparison of three groups of simulations, it can be seen that the relative size of disaster hazards is directly proportional to the noise level in the channel and inversely proportional to the visibility size. Through the comparison, the smaller the relative size of disaster hazards, the greater the noise in the channel, the lower the visibility, the greater the degree of people's

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emotional fluctuation, the more crowded the crowd in the evacuation process, the lower the judgment ability, the risk of trampling will rise; the larger the relative size of disaster hazards, the lower the noise in the channel, the higher the visibility, the smaller the degree of people's emotional fluctuation, the more calm the crowd in the evacuation process, the risk of trampling will be reduced.

3.2 Cabin environment model based on ultra-fine network segmentation

For the passenger aircraft evacuation problem, it may be assumed that each passenger is well aware of the evacuation situation of the entire cabin, including the status of each exit, the number of obstacles near the exit, the queuing situation at the exit, the evacuation signs near the exit and the distance from the passengers to each exit, and the evacuation simulation is conducted on this premise. That is, passengers evacuate without relying on the command of the flight attendants and move completely spontaneously for evacuation. Through the analysis of the passenger cabin found that

The aisle in the cabin of a civil airliner is narrower, and only one person is generally allowed in the lateral direction; the aisle in the first class cabin is wider, and generally a person evacuating in the forward direction and a person evacuating in the lateral direction can be evacuated in parallel. Accordingly, a finely divided grid model is adopted and a side-to-side overtaking between occupants with different attributes is allowed by acceleration in the wider passenger cabin aisle, so that an emergency evacuation metacellular automaton model for passenger cabin occupants can also be established.

The main factors affecting aircraft cabin evacuation are.

(1) Cabin occupants move at different speeds in aisles of different widths. We can try to simulate the moving speed of several groups of passengers in aisles of different widths so as to improve the evacuation efficiency. To address this problem, this paper proposes a mesh discretization method to represent the cabin environment in order to improve the description accuracy of the cabin environment.

In order to simplify the design of the simulation model and program processing, the cabin space is often discretized into a grid of the same size. A square grid of 0.4m×0.4m is also used. Taking the cabin layout of a Boeing 747-8 (shown in Figure 5) as an example, it is obvious to see that the aisle in front of the seat is smaller than both the seat size and the main aisle size. In fact, the seat pitch (the distance between two adjacent seatbacks) in economy class is about 0.8 m, with the space in front of the seat being about 0.3 m. As you can see, the width of the aisle affects the movement of passengers to some extent, with narrow aisles usually causing difficulties for passengers to move, and spacious aisles helping them to move. It follows that it is necessary to consider how the differences in width dimensions of different aisles will affect the evacuation outcome.

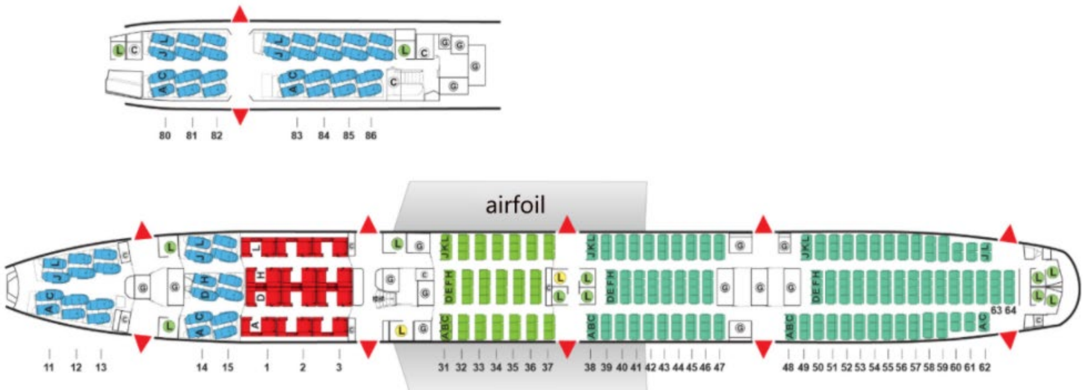

Figure 5: Cabin interior of the Boeing 747-8

For a clearer study, an ultra-fine grid is used to discretize and represent the cabin, resulting in a more accurate model of the cabin environment (as shown in Figure 6). Using multiple grids to represent a seat and its corresponding aisle, this grid discretization enables the cabin environment to be closer to the real situation[2].

ISSN 2706-655X Vol.4, Issue 10: 1-8, DOI: 10.25236/IJFET.2022.041001

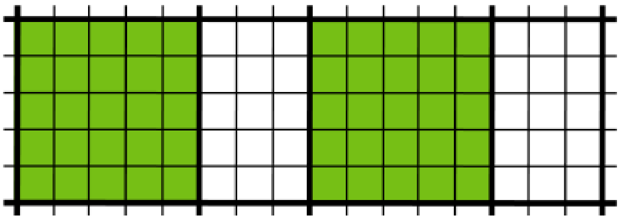

Figure 6: Ultra-fine network division[2]

A study of economy class was conducted. Boeing's product statistics show that the seat rows in economy class are between 0.787m and 0.863m apart[3], while the seat widths are between 0.45m and 0.53m as shown in Figure 7.

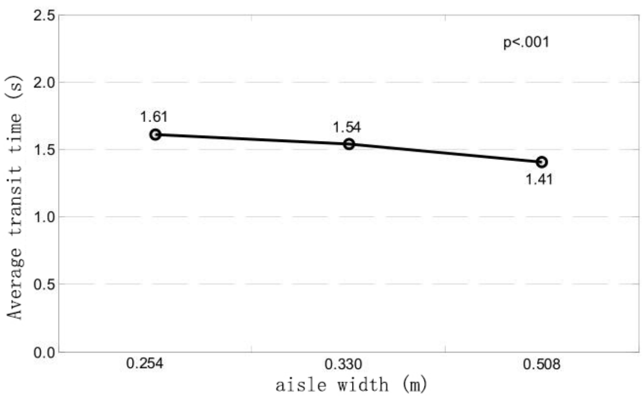

Figure 7: Effect of aisle width on passenger movement

(2) Cabin exit size will have an impact on the outcome of passenger evacuation, the Federal Aviation Guidelines for passenger aircraft exit types make seven cabin exit definitions as follows[4,5].

(a) Class I exits. Rectangular exits with dimensions not less than 24inch x 48inch (about 0.61m x 1.22m) and a radius of rounded corners not greater than 8inch (about 0.2m).

(b) Class II outlet. Size not less than 20inch × 44inch (about 0.51m × 1.12m), the radius of the rounded corners is not greater than 7inch (about 0.18m) of the rectangular outlet.

(c) Class III outlet. Size not less than 20inch × 36inch (about 0.51m × 0.91m), the radius of the rounded corners is not greater than 7inch (about 0.18m) of the rectangular outlet.

(d) Class IV outlet. Size not less than 19inch × 26inch (about 0.48m × 0.66m), the radius of the rounded corners is not greater than 6.3inch (about 0.16m) rectangular outlet.

(e) Class A outlet. Size not less than 42inch × 72inch (about 1.07m × 1.83m), the radius of the rounded corners is not more than 7inch (about 0.18m) rectangular outlet.

(f) Class B outlet. Rectangular outlet with dimensions not less than 32inch × 72inch (about 0.81m × 1.83m) and a radius of rounded corners not greater than 6inch (about 0.15m).

(g) Class C outlet. Size not less than 30inch × 48inch (about 0.76m × 1.22m), the radius of the rounded corners is not more than 10inch (about 0.25m) of the rectangular exit.

Obviously, the type of hatch chosen for the airliner will have a crucial impact on the evacuation of passengers. A smaller size exit will cause difficulties for the evacuation movement of passengers, thus making the entire emergency evacuation time of the airliner longer and the evacuation success rate will be greatly reduced.

(3) The physiological factors of the passengers will also have an impact on the evacuation results. For example: waist size, age and gender, reaction time and movement speed. In addition, disabled evacuees can have a significant impact on the evacuation process. Passenger physiological characteristics data will be generated based on sample data of realistic aircraft passengers to improve the realism of the evacuation model[4].

①It is worth noting that the waist size of passengers is one of the main factors affecting their evacuation during the evacuation of passenger aircraft. Human waist size has a strong statistical correlation with age, gender and race, and in most cases, men and older people have a larger waist size than women and young people as shown in Figure 8.

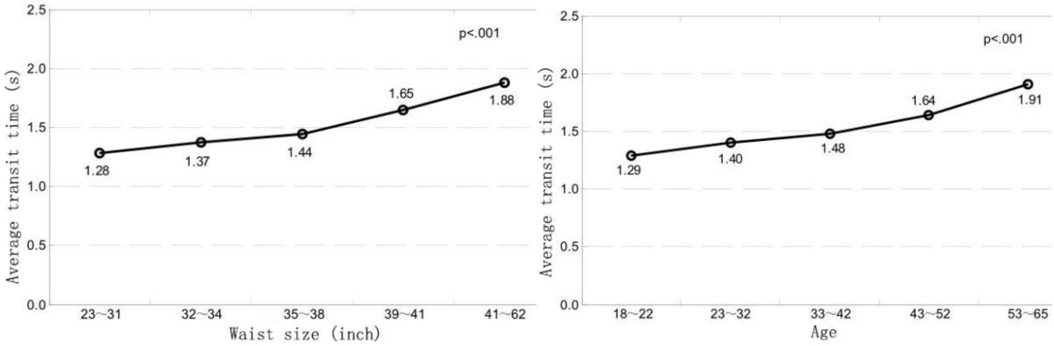

Figure 8: Effect of passenger waist size and age on average speed through the exit

②In order to avoid the influence of uncertainties on the experiment, we assume that the age of passengers in the cabin is limited to the range of 18 to 65 years old, and the ratio of men to women should be changed appropriately as shown in Figure 8.

③Men have some advantages over women in strength, endurance, reaction time and movement speed, so male and female passengers perform differently in emergency evacuation. Young adults also respond to emergencies with faster reaction time and movement speed than older adults.

The discrete modeling of the evacuation space uses a finely divided grid model with a uniform grid division of the cabin plane with a minimum grid size of 10cm×10cm, and each cell can have three states: occupied by obstacles, occupied by people, and temporarily blank. The finely divided grid is not only more descriptive of the obstacles in the evacuation scene, but also more descriptive of the linear obstacles and narrow passages as well as the human body. Since each human body can occupy 15 cells (50cm × 30cm), its central cell is used as its location identifier. Within each update time step, the change in the position of a person is represented by the change in the position of the central cell in which it is located[5].

When evacuation starts, each passenger in the cabin will choose an exit to leave. According to the statistics of actual aviation accidents, more than 70% of the passengers tend to choose the closest exit to escape from the cabin, so we use the shortest path principle as the path selection criterion for virtual passengers.

4. Conclusion

The meta-automata model established in this paper based on simulation does a more realistic simulation of the movement of meta-automata, which can intuitively represent the movement state of individuals through the combination of numbers and shapes, and can truly reflect the process of emergency evacuation of personnel in emergency situations. Thus, it is more relevant, realistic and typical. This paper simplifies the complex problem by establishing a meta-automata model, which facilitates the measurement calculation and can make the expression more simple and intuitive. This paper considers the influence of personnel mental activities on evacuation efficiency during emergency evacuation, and also considers the influence of movable obstacles on emergency evacuation.

This paper ignores a certain tendency and randomness in a complex environment. In a meta-automaton, the simulation process is often deterministic, and the individual cells are regularly arranged in a given space. But in complex realistic environments there are rarely such regular states, and the behavior of the metacells is often random. In order to get more realistic data, we need to collect a large amount of systematic and authoritative actual measurement data and recorded data of real accidents to make some parameters in the model more accurate and minimize the error as much as possible.

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