Two-dimensional evacuation model under the influence of multiple factors

Ke’ao Wang *
North China Electric Power University (Baoding), Hebei, China

*Corresponding author e-mail: 1018891920@qq.com

Abstract. At tourist attractions with large crowds, we have to consider evacuating large Numbers of pedestrians due to an emergency. This paper discusses the evacuation of tourists in emergency, analyzes the possible bottlenecks, and establishes a relatively complete evacuation plan. We considered that although the place is a three-dimensional model, in a certain stage of the evacuation process, each floor is independent of each other, and individuals on different floors do not influence each other. Therefore, according to the fuzzy cellular automata (FCA) model, we adopted the modular processing method to establish the two-dimensional evacuation model initially. First, we established the movement speed and time model of tourists, then introduced obstacle reference factor, direction reference factor and control factor to modify the direction selection of tourists, so as to carry out orderly evacuation.

1. Introduction
There are a large number of tourists in the tourist attractions. If something unexpected happens, how to evacuate the tourists to the safest and most effective place? The problem we need to solve is:

1. Identify potential bottlenecks in the system and model how to address them.
2. Analyze the impact of diversity of tourists on evacuation plan.
3. How do we analyze the use of secret exits known only to first responders and museum staff.
4. How to simulate the evacuation system and evaluate the model.

2. Two-dimensional model

2.1. Basic CA model
The CA model was first proposed by Ulam and Neumann. It is a simplified model describing complex evolutionary phenomena. Originally used for the self-replication phenomenon unique to the life system of "game of live". The cell is the most basic unit that constitutes the cellular automaton. The cell space is a collection of spatial points distributed by the cells. The standard cellular automaton consists of cell, cell state, neighborhood and state update rules.

We choose the moore neighborhood in our model. As the Figure 2-1 shows. And the tourists’ feasible direction of movement is the eight directions shown in Figure 2-2.
2.2. Individual movement speed model
In order to reasonably describe the evacuation time, we use the velocity model. The formula for calculating the speed is as follows:

\[ V = \begin{cases} 
0.37 \\
0.03(3.0 - 0.76D) + 0.2 \\
\frac{V_0}{D} 
\end{cases} \]

\[ D \geq 3 \]

\[ 0.5 \leq D < 3 \]

\[ D < 0.5 \]

In the formula, \( V_0 \) refers to the tourists’ walking speed under normal conditions (We takes 1.25). \( D \) refers to the number of people and obstacles per unit area. While \( D \) is equal to \( \frac{N_p + N_o}{S} \) (\( S \) represents the area corresponding to the field of view, \( N_p \) represents the total number of people in the field of view, and \( N_o \) represents the total number of obstacles in the field of view.)

According to the space of each cell corresponding to 0.5m × 0.5m, the individual’s time consumption is 0.5/V seconds. The evacuation time calculation method in an emergency is as follows:

First, we should calculate the actual speed of each time step of each evacuated individual according to the formula (1).

Secondly, we need to calculate the actual time spent on each step of the evacuated individual, and accumulate it with the previous time step until the individual reaches the exit. The accumulated time-consuming value is the actual evacuation time of the individual.

When the last person evacuated successfully, we comparing the evacuation time of all personnel. And the maximum value was the final evacuation time.

2.3. FCA model

2.3.1. model principle
Considering that tourists who are familiar with the place mainly consider the distance from the location to the safe exit and the density of the obstacle in the direction of choice, the distance and density information obtained is fuzzy, so the direction Select the fuzzy reasoning model used by the model.

The field of view in the target direction is an n × n matrix (n=3 in this paper). When \( k = 1, 3, 5, 7 \), the field of view is the matrix with the target grid as the center of the nearest column (the center of the row). When \( k = 2, 4, 6, \) and 8, the matrix is the vertex of the target mesh.

The field of view when \( k = 1 \) is shown in Figure 2-3.

The field of view when \( k = 2 \) is shown in Figure 2-4.
After the scope of the visitor’s field of vision, the density of the obstacle is determined by the total number of people and obstacles in the field of view. Divide it into three fuzzy sets $T=\{\text{low, middle, high}\} = \{\text{Low quantity, middle quantity, high quantity}\}$. The membership function is a ladder type.

The distances from the 8 directions that the visitor may select to the nearest exit are subjected to the range normalization processing as the distance input, and the distance is divided into three fuzzy sets $D=\{\text{near, middle, far}\}=\{\text{near distance, middle distance, far distance}\}$, and the membership functions are trapezoidal and triangular (as shown in Figure 2-5).

Moving to the Kth ($k=1,2,...,8$) direction, the possibility of move-probability (as output) is divided into 5 fuzzy sets, respectively, $P=\{\text{NB, NM, ZO, PM, PB}\} = \{\text{negative big, negative middle, zero, positive middle, positive big}\}$ (as shown in Figure 2-6).
Considering the basic principles of tourists' choice of evacuation routes: If the distance from an exit is close and the density of the target direction is small, the possibility of choosing the exit is great. If the distance from an exit is long and the density of the target direction is high, the possibility of choosing the exit is very small. The fuzzy inference rules established in this paper are as shown in Table 1.

|   | low | middle | high |
|---|-----|--------|------|
| near | PB  | PM     | ZO   |
| middle | PM  | ZO     | NM   |
| far   | ZO  | NM     | NB   |

### 2.3.2. Direction selection

Based on the FCA model, the direction selection model of the visitors during the emergency evacuation was established.

**Obstacles-factor**

In the emergency evacuation of tourists, pavilions, elevators, toilets and other buildings are regarded as obstacles. Considering human obstacle avoidance behavior, we set up the obstacle reference factor obstacles_factor.

If there is obstacles in the direction, obstacles_factor = 0; If there is no obstacle in the direction on you choose now, but you will encounter obstacles in the next time, then obstacles_factor = α (this article takes α = 0.7); if there is no obstacle, and will not encounter obstacles the next time, then obstacles_factor = 1.

**Direction reference factor**

In order to consider the consistency of the direction of the tourists, we set as the angle between the direction of travel of the next time and the direction of travel of this time. That is 90°.

If crowded, pedestrians will choose to wait in the same place instead of going backwards. The article introduces direction_factor. If the waiting time is less than the number of waiting (this article takes 5) or the waiting time step is greater than the waiting time, direction_factor = 1; otherwise the direction_factor = 0.

**Control-factor**

This paper sets the emergency personnel to adjust the direction of the tourists, and consider which channel to choose according to the distance from the location to the channel and the personnel density on the channel. Therefore, this paper introduces the cognitive reference factor (recognition-factor) to correct the direction selection possibility (choice_vector[i, j](k)).

The adjustment factor control_factor[i,j](k) corresponding to the Kth direction of the visitor{i,j} is calculated according to the following principle: the distance channel is close, and the channel is relatively wide, and the personnel density is small, the possibility of selection is large. To this end, the model is constructed from both the channel intrinsic characteristics and the channel personnel density.

Take the distance from the nearest channel in the kth direction to ld, and the channel width is cw, then the intrinsic feature of the Kth direction channel is pa-feature(k) = ld/cw, and the corresponding characteristics of the 8 directions are normalized.

For pa-feature(k)(k = 1, 2, ..., 8), the channel feature reference factor f-factor(k) is calculated as follows:

\[
    f_{-factor}(k) = (-0.5) \times pa_{-feature}(k) + 1.5
\]

In the Kth direction of the visitor, the nearest channel is taken with the row (column) of the visitor as the axis of symmetry, the length is 7 cells, and the width is the ch_w area of the dredging width, and the channel density is calculated.
\[ \text{pa - density}(k) = \frac{N_p}{7 \times 8 \times k}(k = 1, 2, ..., 8) \]

Which indicates the total number of people in the corresponding area as \( N_p \), and the channel density reference factor (d-factor(k)) is calculated as follows:

\[ d \_ \text{factor}(k) = 0.5 \times \text{pa - density}(k) + 1 \]

Based on the above work, the emergency personnel guide the visitors \( \text{visitor}(i,j) \) in the \( k \)th direction:

\[ \text{contra}\_\text{factor}\{i,j\}(k) = f\_\text{factor}\(k\) \times d\_\text{factor}\(k\) \]

Final formula

Based on the above work, we can conclude that the possibility of the visitor() selecting the \( k \)th direction:

\[ \text{choice}\_\text{vector}\{i,j\}(k) = \text{move}\_\text{propobility}\(k\) \times \text{obstacles}\_\text{factor}\(k\) \times \text{direction}\_\text{factor}\(k\) \times \text{contra}\_\text{factor}(k) \]

3. Summary
We introduce the variable export impact factor exit_factor in the end. In order to show when tourists move to the vicinity of the right exit, they will not choose to move further in the direction from the position to the exit. If the \( K \)th direction is not far from the current position to the exit, then exit_factor\(k\) = 1; otherwise exit_factor\(k\) = 0 (\( k = 1, 2, ..., 8 \)).

Based on the above analysis, the model of the emergency evacuation problem we established in this paper is as follows:

step1: Calculating the possibility of choosing the position of the visitor (\( i, j \)). That is choice_vector\{i,j\}(k)(k=1,2,...,8). If the visitor reaches a certain range near the doorway (this article sets the distance to the doorway within 6m), and then use the export factor exit-factor to correct the direction selection possibility.

\[ \text{choice}\_\text{vector}\{i,j\}(k) = \text{choice}\_\text{vector}\{i,j\}(k) \times \text{exit}\_\text{factor}(k) \]

step2: Selecting the moving position. If the maximum probability of selection is 0, the visitor does not move. Otherwise, visitors move as follows: The next time step for the visitor moves to the maximum likelihood corresponding grid. When multiple tourists select the same location grid as the moving target, then one of the tourists is randomly selected to move to the target location. And other tourists select the sub-optimal grid in their neighbors as the moving target according to the above rules. If all the selectable directions are not the target position, the tourists wait.

step3: Follow the target location selected by each visitor in Step2. All visitors move at the same time. Meanwhile, recording the evacuation process data of all tourists. Such as evacuation time and evacuation speed according to the time model of Individual movement speed model.

step4: Repeating the above process until all visitors have been evacuated.

References
[1] NEUMANNJVBA. Theory of self-reproducing automata [M]. Urbana: University of Illinois Press, 1966: 745.
[2] Zhao Yibin, Liu Yanyan, Zhang Meidong, et al. A multi-exit occupant evacuation model based on fuzzy cellular automaton.[J]. Journal of Natural Disasters, 2013, 22(2): 13-20.
[3] Jiang Chuansheng. Study on Evacuation Ability of Disabled People and Its Influence on Evacuation Ability of Healthy People [R], 2009.1

[4] Li Shiyong et al. Ant colony algorithm principle and its application [M]. Harbin: Harbin Institute of Technology Press, 2004

[5] Yin Yujie. Research on cellular automata evacuation model based on ant colony algorithm and potential energy field [D]. Hubei University of Technology, 2015

[6] Li Nan, Wang Jinhuan, Wang Yang, Zhang Lei. Study on the Behavior Evacuation of Small Groups in Multi-Exit Venues in Accidents [J]. Computer Simulation, 2017, 34 (06): 402-406.

[7] Liu Mengting, Jiang Meiying. Study and Modeling of Evacuation Exit Selection Behavior Considering Crowd Congestion [J]. Science and Technology of Production Safety in China, 2016, 12 (09): 157-163.

[8] Xu Guang, Qu Jun, Xia Changjun, Wang Tianhui. Study on evacuation exit scheme based on queuing theory [J]. Security Technology, 2010 (12): 35-38.