# Emergency study of personnel evacuation based on metacellular automata

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**Abstract:** The problem of evacuating people in emergency situations has become particularly important as the flow of people in various cities is rising with economic development, which leads to an increase in the scale of large-scale assembly events. In this paper, we analyze the evacuation effect caused by different key factors in the process of personnel evacuation by building a metacellular automata model. The study can effectively solve the problem of rapid evacuation and escape of people and help reduce casualties. This paper analyzes the effect of key factors on evacuation efficiency comprehensively based on specific conditions, and gives the optimal plan on different conditions. The advantages and disadvantages of the model are evaluated and discussed in this paper, and it is concluded that the model can also be effectively extended to different fields such as biology and defense.

**Keywords:** Metacellular automata; gradient boosting tree regression models; Emergency evacuation; computer simulation.

## 1. Introduction

It is precisely because of the dramatic increase in the number and size of larger collective gatherings in recent years that the issue of emergency evacuation has become more and more important. One of the most notable situations is how to evacuate through doors of limited width or narrow passageways. Researchers have conducted a number of simulation experiments and numerical simulations to better understand and interpret the behavior of people in various emergency situations. The analysis shows that the width of the door[1], the composition of the crowd and the location of the exit are all important factors that affect the effectiveness of emergency evacuation. Researchers often take the approach of organizing real people to conduct experiments for effective simulation, but it is difficult to keep the environment, background, pressure level, crowd density, sample size and other factors exactly the same as the real scenario, so many studies reach controversial or even contradictory conclusions.

To avoid the difficulties encountered in real-life experiments, we adopt a model-based approach to research. The assumptions of the model are crucial, and if the assumptions of the model are not reasonable, the results may be completely different from reality[2]. Therefore, for the sake of rigor, we need to set different parameters for different situations to conduct the study.

The main research elements of this paper are.

An analysis of people's daily experience shows that the level of anxiety, i.e. the degree of urgency of the situation, has a significant impact on the overall process of evacuation. Some experimental results show that an increase in the level of urgency leads to a faster evacuation, while some experimental results show that a high level of urgency leads to a slower evacuation. Let us assume that there are a number of people in a square hall (or room) with an empty interior and no obstacles, and only one of the doors can be used for emergency evacuation. We develop a reasonable mathematical model, identify the key factors involved, investigate the effect of the anxiety level of the crowd (the urgency of the situation) on the evacuation effect, and explain which key parameters have caused the difference in the experimental results.

The interior of the hall (or room) is at the same time as the above question. Obviously, the evacuation process is not uniform, so explore the curve of the evacuation rate over time, and explore how each critical factor will affect the curve.

Suppose there is an exit at a certain distance in a large enough hall (or room), and people's experience shows that when choosing an exit for evacuation in an emergency, they will not necessarily choose only the one relatively closer, but the one with the shortest expected time. Based on the above scenario, please build a reasonable mathematical model for the simulation of the selection process of evacuation routes. And study what dynamic process will be generated when the width of the door is different. If the visibility in the hall (or room) is relatively reduced, what will be the effect on this dynamic process.

# 2. Model assumptions and notation

## 2.1 Assumptions

1. Assume that all relevant personnel are indoors when the emergency occurs
2. It is assumed that the outdoor environment cannot cause any disturbance to the indoor environment, i.e., it does not affect the evacuation of the people inside
3. It is assumed that the room is empty and there are no inherent obstacles to evacuate people
4. It is assumed that there will be no interaction between indoor personnel other than causing crowding among them.

## 2.2 Notations

Important notations used in this paper are listed in Table 1.

Table 1 Notations

| Symbols | Description |
|---|---|
| PD | Location Hazard |
| V | Actual speed of personnel evacuation |
| L | Room length |
| w | Outlet width |
| $\Delta d_i$ | The distance of the ith pedestrian entering this target grid point |
| $P_i$ | The probability that the ith pedestrian enters this target grid point |
| $V_m$ | Average system evacuation speed |
| J | System average evacuation flow |
| $N_m$ | The maximum number of people the room can accommodate |
| $V_{mean}$ | Average walking speed of pedestrians |
| N | Total number of people in room t at the time |
| S | Initial number of people in the space |
| A | The number of people arriving at the exit in the whole space within a certain time |
| Ui(t) | Length of queue at the i-th exit at time t |
| $D_{ij}$ | Distance to each exit |
| $M_t$ | Population flow in room t at the moment |

# 3. Model construction and solution

## 3.1 Modeling of personnel evacuation problems

### 3.1.1 Basic theory of metacellular automata

By metacellular automaton, we mean a dynamical system defined on a metacell space consisting of metacells with discrete, finite states and evolving in discrete time dimensions according to certain local rules[3]. Among its four basic constituent units are the metacell, the metacell space, the neighbors, and the rules. The three most common metacell spaces are mainly triangular, rectangular and hexagonal[4]. Three common types of neighbors are Von Neumann type, Moore type, and extended Moore type. The cellular automaton model is a shallow microscopic model which has the following characteristics[5].

(1) The state transitions of all cells are synchronized and follow the same change rules.

(2) All the cell states are selected in a finite time and are discrete states.

(3) The state changes of all the cells are uniform, which facilitates the computer to perform simulation calculations.

(4) The simulation of personnel evacuation using metacellular automata takes into account more variables and has a richer form than other models, and its simulation achieves better results.

### 3.1.2 Application to metacellular automata models

We divide the space into some equal squares, each of which corresponds to a cell, i.e., a spatial location in the room that can be occupied by evacuees[6]. The evacuation process of the pedestrian flow in the room is simulated on the computer. In order to eliminate the effect of system randomness on the simulation results, 50 samples are taken for the coefficient average[7].

In general, the average speed of pedestrians is 1.0m/s, and in emergency situations, it can reach 1.5m/s or even faster. The time taken by the pedestrian to move one frame, Δt=0.4s, corresponds to the actual speed v=1.0m/s or v= m/s, i.e., the pedestrian has two different speeds of movement. Then there are

① Determination of the degree of position anxiety

$$PD(i,j)=\begin{cases} 0 \\ \dfrac{|y_i-y_0|}{\sqrt{(x_i-x_0)^2+(y_j-y_0)^2}} \end{cases} \tag{1}$$

② Pedestrian movement rule

Compare the position hazard of each grid point in the pedestrian's neighborhood, and the grid point with the smallest position hazard is used as the target grid point for the pedestrian's movement in the next moment. If the position hazard of the target point is less than the position hazard of the point where the pedestrian is located, the pedestrian moves to the point; if the position hazard is equal to the position hazard of the point where the pedestrian is located, the pedestrian moves to the point with 0.5 probability and stays still with 0.5 probability; if the position hazard is greater than the position hazard of the point where the pedestrian is located, the pedestrian moves to the point with 0.2 probability and stays still with 0.8 probability

$$P_i=\frac{1-\dfrac{\Delta d_i}{\sum_{i=1}^{n}\Delta d_i}}{n-1} \tag{2}$$

All pedestrians update their positions synchronously according to the above rules, and when a certain grid point is selected as a motion target grid point by more than one pedestrian at the same time (conflict occurs), all of them are selected randomly with equal probability to enter that target grid point in a certain line. In this paper's model, considering a more reasonable situation, the pedestrian who is closer to the target grid point has an advantage to select the target grid point. Therefore, the probability of a pedestrian entering a target grid point is determined according to its distance to the target grid point. n pedestrians select the same target grid point at the same time, the probability of the ith pedestrian entering that target grid point is.

$$v_{mean}=\frac{1}{N}\sum_{i=1}^{N}v_i(t) \tag{3}$$

$$J=d_{V_{\text{mean}}}=\frac{1}{N_{\text{total}}}\sum_{i=1}^{N}v_i\,(t) \tag{4}$$

Figure 1 Evacuation at 1, 8, 14 seconds

The pedestrian movement to the exit indicates that the pedestrian has achieved the end of the system program, defining the average system pedestrian walking speed as $v_{mean}$, the average system footfall as J, N denotes the total number of people in the room at moment t, d denotes the density of people in the room at moment t, and $N_{total}$ denotes the maximum number of people the room can accommodate. Evacuation at 1, 8, 14 seconds is shown in Figure 1.

### 3.2 Gradient boosting regression algorithm model

#### 3.2.1 Modeling

The gradient boosting regression algorithm GBDT (Gradient Boosting Decision Trees) is a Boosting iterative decision tree algorithm proposed by Friedman in 2002. By sequentially accumulating each of the addable base classifier functions and training an equivalent optimization objective function in the gradient direction and an exponential loss function based on the class spacing distribution. In each base classifier model fitted in Gradient Boosting, a regression tree in a decision tree is generally taken, and thus Gradient Boostin turn is treated as a Gradient Boost Decision Trees (GBDT) algorithm by a wide range of researchers. Moreover, GBDT has a strong generalization ability (generalization), and like SVM (Support Vector Machine), it is often used to do classification and regression analysis, and achieves good results on most of the data sets. In recent years, researchers have started to experiment with applications in areas such as machine learning models for search sorting[8].

Through simulation tests, the actual number of people passing per minute within the maximum number of people accommodated Nm, varying the walking speed, door width, total number of people and tension level, using gradient boosting regression algorithm, regression to produce prediction results, fitting the line chart table can present the results more clearly.

Table 2 Predicted evacuation number results using GBDT

| Serial number | Predicted results Y | Passengers per minute | Crowd Density | Walking speed | Door width | Number of people | Tension |
|---|---|---|---|---|---|---|---|
| 1 | 199.8874284 | 200 | 25.8 | 3 | 3 | 2020 | 86 |
| 2 | 201.4409383 | 202 | 26.7 | 2 | 2 | 2910 | 89 |
| 3 | 196.9716381 | 197 | 28.2 | 3.5 | 3.5 | 2500 | 94 |
| 4 | 196.965543 | 197 | 24 | 3.5 | 3.5 | 2100 | 80 |
| 5 | 200.2641074 | 200 | 24.6 | 3 | 3 | 1950 | 82 |
| 6 | 193.2523474 | 193 | 24.6 | 4 | 4 | 2560 | 82 |
| 7 | 196.281236 | 196 | 25.2 | 1.5 | 1.5 | 2400 | 84 |
| 8 | 202.025909 | 202 | 28.2 | 2 | 2 | 1900 | 94 |
| 9 | 187.9469455 | 188 | 27.6 | 5 | 5 | 2650 | 92 |
| 10 | 206.1002435 | 206 | 25.2 | 2.5 | 2.5 | 2240 | 84 |
| 11 | 190.9484665 | 191 | 26.4 | 4.5 | 4.5 | 2500 | 88 |
| 12 | 196.1573593 | 196 | 24 | 1.5 | 1.5 | 2250 | 80 |
| 13 | 206.0447552 | 206 | 24 | 2.5 | 2.5 | 2400 | 80 |

### 3.2.2 Solving the model

The prediction of the number of evacuees was performed using the model in this paper, and for the input variables of the model, the factors of number density, walking speed, anxiety level, door width, and anxiety level were considered as the outputs. The model is tuned to find the best combination of parameters with the best prediction accuracy for each of the four variables. As can be seen from Figure 2 below, the predicted end is in good agreement with the actual number of evacuees.

Figure 2 shows the situation considering the factors of number of people density, walking speed, anxiety level, width of the door and anxiety level, the relative importance of each input variable in the model, the profile influenced on the predicted value, which also has the largest share. Among the factors, when the number of people in the room is too much, fluctuates the anxiety level increases, making the evacuation speed, that is, the actual number of evacuees, decreases; on the contrary, when the number of people decreases, the anxiety level of the room decreases and the walking speed of people in the room increases, thus greatly increasing the number of evacuees.

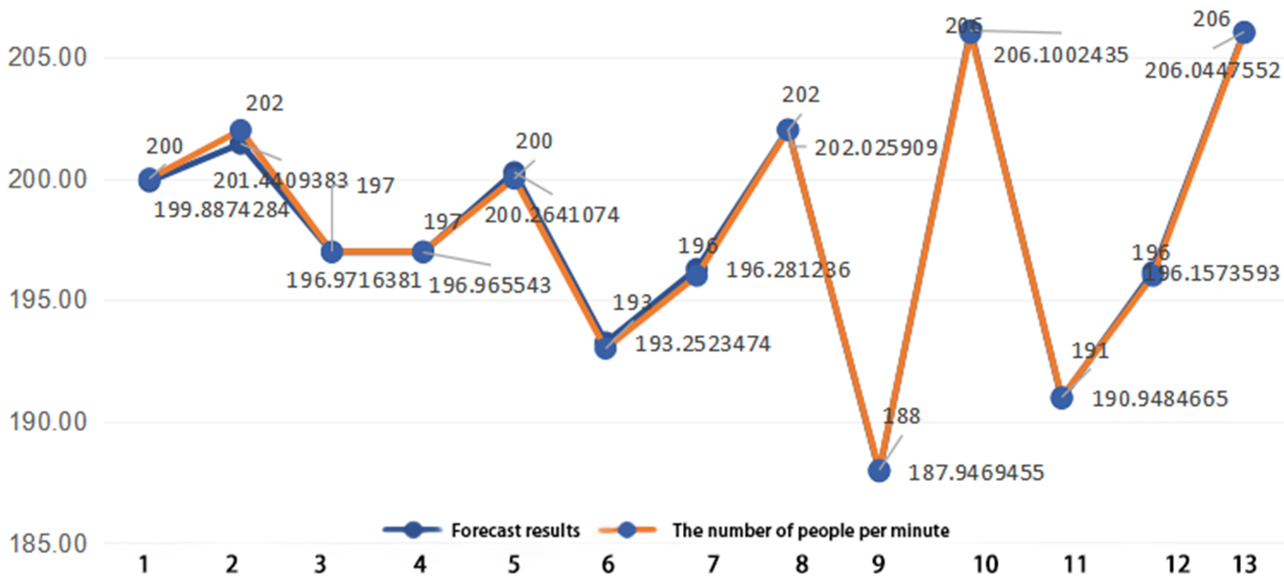


Figure 2 Folding line fitting of predicted evacuation number and actual evacuation number

## 3.3 Multi-Export Metacellular Automata Model

### 3.3.1 Modeling

Simulation of moving process: For each cell in a process, that is, the process of moving people can be divided into the process of staying, moving, assigning and moving. If the "neighbor" position is selected by more than one cell, then the system randomly assigns it to one of the cells and selects a new moving cell at Ti+1 according to the updated situation at Ti+1. The system randomly assigns a new mobile cell to one of the cells, and selects a new mobile cell for everyone at Ti+2 based on the update at Ti+1. We assume the experimental site as a square matrix, double-door accessible scene, the room size is set to 30m×50m, the width of both double doors is 3m, as shown in the figure below, the number of people in the room is set to 100, and when there is an unexpected event to escape, everyone moves with the exit as the target[9].

The simulation results of the cellular automaton show that at the very beginning, most of the people will evacuate towards the exit which is shorter distance from them[10]. As the distance to the exit and the density of people at the exit and the safety factor jointly determine the path with the shortest escape time, the density of people at the exit increases over time, slowing down the evacuation speed and reducing the safety factor of the exit, so some people choose to turn back during this escape process, both even though the person is heading to the exit closer to Evacuation of their own closer to the exit, but because of the density of people at the exit is too large, escapees will choose to abandon the path of movement, and choose another to the door to move, thus reducing their own escape time, to enhance self-safety. Evacuation space for two doors is shown in Figure 3.


Figure 3 Evacuation space for two doors

If the density of people in the closer range of exits is low, you do not need to choose to abandon the escape path and continue to move forward, when the density of people at all the exits of the currently selected path is higher than the preset value, the meta-automaton will change the direction of evacuation by calculating the speed weights of people toward the 180 ° range, which is a simple idealized evacuation path.

### 3.3.2 Solving the model

Based on the above analysis and the chosen model it is easy to know that the number of people lined up at the door is related to each person's own choice. Therefore, in order to be able to objectively and accurately describe the real-time dynamic choice of each person for different evacuation routes in the whole evacuation space, we need to clarify several states first.

(1) Initial state

There are S people in the whole space, the spatial location coordinates of two exits are $X_1$, $X_2$, the maximum peer flow is S1m, S2m, the spatial location of each person is marked as $w_i$ (i=1, 2, 3, 4, 5, ..., S), the anxiety level of each person for the same emergency is Ji, and the respective walking speed of people is $v_i$=f(Ji), and the two exit queue lengths are denoted as U1(t)=0, U2(t)=0.

(2) Calculate the length of the straight line from the exit for all the people in the field

S individuals respectively from the ith exit of the straight line length for $D_{ij}$

(3) Update the set of evacuees

The set of all the people located in the entire evacuation space to the exit is recorded as A (t), the set of people who arrived at the exit in a certain time period is recorded as B1, B2, then the set of the remaining evacuees to be evacuated is recorded as.

$$C(t)=C_{A(t)}\left(B_1 \bigcup B_2\right) \tag{5}$$

(4) Selection of exit

1. when the queuing length of two exits U1(t) is not equal to U2(t), take the exit with the smallest queuing length

2. When the queue length of two exits U1(t) = U2(t)

a. Calculate the distance $D_{ij}$ from each exit, take the exit with the smallest distance

b. If the distances are equal, the order of the doorway is assigned in turn.

(5) The speed of human flow at the exit

$$M_i(t)=\begin{cases} U_i(t) & U_i(t)<S_{i\max} \\ S_{i\max} & U_i(t)\geqslant S_{i\max} \end{cases} \tag{6}$$

Therefore, in order to reflect the real-time dynamics of each outlet, based on the above push-to-analysis, we design the simulation algorithm as follows.

Step1: The initial data at output t=0

Step2: Find those who satisfy the following equation in the set A

$$t<\frac{\min\left(d_{1j},d_{2j}\right)}{V_i}\leqslant t+1 \tag{7}$$

Step3: Calculate the actual time taken by the personnel to select the exit from their own spatial location at t-t+1 time

Step4: Update the actual number of people arriving at each exit at time t-t+1 P(t)

Step5: Calculate the population flow Mi(t)

Step6: Calculate the number of people in line at time t+1

$$U_i(t+1)=U_i(t)+P_i(t)+M_i(t) \tag{8}$$

Step7: Determine whether C(t) is the empty set

a. If C(t) is empty, the evacuation process is complete

b. If C(t) is not empty, then continue the loop

## 4. Conclusion

A metacellular automaton is a lattice dynamics model in which time, space and state are discrete and both spatial interactions and temporal causality are localized, and thus has the ability to simulate the spatio-temporal evolution process of complex systems. In crowd evacuation, each person is an independent individual cell, and these primitives can then be regarded as the most fundamental part of the automaton. Just as its founder, John von Neumann, focused the problem on the nature of life, where simple cells can self-replicate and thus make life so amazing, the metacellular automaton model uses simple usage rules and discrete methods to describe complex global continuous systems, making the model an efficient tool for exploring complex systems.

The basic starting point of the meta-cellular automata approach is threefold.

(1) Complex systems are composed of many elementary units

(2) Each elementary unit has a finite number of states

(3) The evolution of the state of each elementary cell over time depends only on the states of neighboring cells.

Because of the specificity of its starting point, its direction of thinking from simple to complex modeling, and the way of thinking adopted by most studies of complex systems, metacellular automata are used in a wide range of applications, including but not limited to.

(1) Sociology: mass human evacuation simulations, rumor propagation, etc.

(2) Biology: exploration of human brain mechanisms, new coronavirus transmission processes, research on cloning technology, etc.

(3) Computer science: research on parallel computing

(4) physics: simulation of fields such as magnetic and electric fields, heat diffusion, heat conduction and mechanical waves

(5) Military science: simulation of military operations and understanding of war processes.

Although the basic unit cell in the cellular automaton has various shapes, but in the same cell space is the same shape and regular discharge, there are various external disturbances in real life basically do not have such a regular state

The wide range of metacellular automata has led to their development in various fields. This has led to the introduction of other neighborhood specialization methods into the meta-cellular automata model. For example, if a genetic algorithm is combined with a cellular automaton, the state update rule must be hereditary and the model is improved as a genetic automaton.

With the continuous in-depth research and expanding lateral development of meta-cellular automata research, the standard meta-cellular automata will also continue to expand, making the meta-cellular automata closer to the simulation of the real world.

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