# A Simulation Method of Personnel Evacuation Management Based on Mulit-Agent Models

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***Abstract*—To better guide people to evacuate in a given area, this paper proposes a multi-agent emergency evacuation simulation system for the adjustment of people's downward flow in a dynamic disaster environment. The main goal of this paper for managing emergency evacuation is to build a basic model that can simulate the location distribution of people, the speed of personnel, the pedestrian flow, road congestion and other situations. The proposed system mainly combines two multi-agent-based methods, i.e., cellular automata (CA) model and ripple-spreading algorithm (RSA). The CA model simulates the road network and the flow of people, the improved RSA calculates the optimal evacuation path for each people and improves the system calculation efficiency. With the proposed system, we test some specific control measures for high-risk sections in a given area by analyzing evacuation time, road congestion, etc., and the data after the control measures are compared with those before the control measures to verify the effectiveness of the proposed system in the evacuation process. The results can be used to assess the effectiveness of emergency control measures in a given area, such as crowed scenic spot.**

***Keywords—emergency management, cellular automata model, ripple-spreading algorithm, multi-agent***

## I. INTRODUCTION

With the development of economy and society, the number of large and medium-sized public places with dense personnel is increasing. For these crowded places, once a disaster event occurs, if crowd evacuation is not managed properly, stampede accidents are likely to happen, causing mass deaths and injuries. Every year, a considerably large number of disasters occur due to natural events or personnel faults. Actually, most people's gathering places are subject to certain space restrictions (such as the gate of subway, the narrow path of scenic area). These will hinder the activities of pedestrians, and there will be interference between people in the pedestrian flow, which increases the complexity of evacuation during fire and other dynamic disasters. The evacuation of people in crowded places is considered to be the core problem of minimizing the loss of life and property when disasters occur. Evacuating people to designated locations quickly and safely, and reducing congestion are two key issues [1].

Researchers have been working on developing evacuation simulation systems over the past few decades. They model the environment, human physiology, and psychology as realistic as possible to make the analysis more accurate. From the perspective of the evacuation simulation environment, the establishment of a multi-agent evacuation model needs to consider personnel behavior model [2][3]. At present, the evacuation models mainly include the lattice gas model, agent model, and social force model [4-7]. Cellular automata (CA) Model is a classic spatio-temporal dynamic system with homogeneity, spatial discrete and state discrete, etc. It can simulate the real flow of people in dynamic evacuation process. Due to its characteristics, the research results of CA model are basically divided into two types. The first category is mainly for personnel evacuation. Adding the evacuation path algorithm or idea into model, it can simulate in a static or dynamic evacuation environment [8-16]. Another category is mainly for train flow. It's very popular in traffic simulation with a variant of the model because it can simulate a more realistic evacuation environment [17-20].

In reality, when the emergency evacuation starts, each person is in a different position. In other words, personnel evacuation is a many-to-many path optimization problem (POP). To ensure that each person has the shortest path, it is important to calculate the optimal evacuation paths for all people at once. The current path optimization algorithms include breadth-first search method, depth-first search, *A** algorithm and Dijkstra's algorithm, etc., These search methods were originally proposed predominantly for the one-to-one POP and then could be extended to resolve many-to-many POPs in a computational expensive way. No matter which algorithm mentioned above is adopted for many-to-many POP, it can be viewed as a process of repeating searching the optimal path for each one-to-one POP [21-25]. Based on a nature-inspired method, i.e., ripple-spreading algorithm (RSA), we will report a new method for many-to-many POP. The modified RSA can avoid the repetition process and get the optimal paths from all source nodes to all destination nodes by just a single run of algorithm. The calculation efficiency is significantly higher than the other algorithms, which can better serve the requirements of emergence evacuation.

This paper aims to develop a simulation system, i.e., the cellular automata and ripple-spreading system (CRS), to study passenger flow regulation for emergency management under dynamical disaster event scenarios in scenic spots. Compared with other models that simulate pedestrian evacuation, the CRS can not only study on agent's behaviors, but also optimize the evacuation paths efficiently. The focus is put on two key modules of the simulation system, i.e., the simplified CA mode and a modified RSA to calculate the best evacuation paths in a given dynamical disaster event for all passengers by just a single run, in order to improve the computational efficiency of simulation on a large spatial scale.

## II. CRS BASED ON MULTI-AGENT

With the social characteristics of the interaction between people in the evacuation process, the multi-agent system is often used as an important simulation tool. It shows a wide range of excellent characteristics, engineering background and application prospects. The agent can be a man, a vehicle, an aircraft or a living organization, etc. Multi-agent model can describe the system from a micro perspective, comprehensively considering the relationship between the various parts of the system, so as to describe the macro characteristics of the system. Each person in the CRS is an independent agent. The agent's movement mode is used to drive the interaction between agents and environment.

CRS needs to be established for emergency management of pedestrian flow under dynamic disaster scenarios. There are three main types of input. The first input is road network data, the second input is people location collected by sensors, and the third input comes from the path optimization method, i.e., the modified RSA in this paper. The simulation system is constructed through the following five steps, and the structure of the system is shown in Fig 1.

- Build a basic road network based on the collected data of a given area;
- Establish a people distribution model based on historical distribution data of people, and establish personnel behavior model based on the evacuees' age and gender;
- According to the data provided by the people distribution model, the optimal evacuation path is calculated for each agent by RSA;
- Simulation experiments are conducted based on the road network data, the personnel behavior model and the optimal evacuation paths;
- The evacuation results of the simulation are evaluated, and recommendations are given.

As shown in Fig 1, CRS receives dynamic disaster scenarios and road network data, and RSA receives agent distribution data generated by personnel behavior models and distribution models. RSA is also constrained by CRS. The constraints are related to dynamic disaster scenarios and pedestrian flow control measures. Under the conditions of personnel distribution and constraints, RSA calculates the optimal evacuation path for each agent under the given dynamic disaster scenario. Based on this, CRS can simulate pedestrian evacuation in a given dynamic disaster situation. The risk analysis and decision tools in the simulation system can evaluate the pedestrian flow in the experiment and give CRS some measures to regulate the pedestrian flow. Based on this regulation, RSA receives suggestions to recalculate the optimal evacuation path under new constraints, and then the CRS performs pedestrian flow simulation again. The control measures and pedestrian flow simulation can be repeated until a set of optimal control measures are worked out.

Fig. 1. Framework of the cellular automata and ripple-spreading system (CRS)

## A. *Cellular automata model*

Here we describe the construction of road network, the personnel behavior model and the agent evacuation process in the CRS.

Fig. 2. Traditional (a) and Improved (b) cellular automata model

In this paper, the classic CA model is simplified by considering evacuation path characteristics. The center cell of a classic CA model has 8 neighbors (shown in Fig 2 (a)). In real life, people usually have two directions of the evacuation path, i.e., the front or the back of their location. At this time, the evacuation process can be regarded as agents moving forward or backward on the evacuation path. Therefore, this paper changes the classical CA model to a linear CA model. After simplification, central cell of CA model only has two neighbors which named the predecessor cell and the successor cell (shown in Fig 2 (b)). In addition, different cells are allowed to have different capacities because the actual road widths are different. And different levels of capacity determine the release ability of the cell. Such linear model is consistent with the characteristics of the road in reality. Based on this, the road network is completed. Finally, according to personnel behavior model and personnel position senor, agents are assigned to cells.

In real life, the flow of people will cause different levels of congestion. Congestion should also be considered during the simulation. In CA model, congestion rules exist in the cells at both ends of the path. When CRA simulates the evacuation process, each cell of the both ends of path will calculate its own current cell capacity and margin, and determine whether the next time unit can interact with other cells. If the cell capacity is not saturated, the passenger can continue to move; otherwise, his movement needs to determine the situation which whether he needs to wait according to the congestion model. When more than 1 times, 2 times, 3times the capacity of the current cell itself, the congestion model will give the 1 times, 1/2 times, 1/3 times passing rate to the cell, some of passengers are randomly enter the next cell and the rest are waiting in place.

Next is the agent evacuation process in the simulation. Given a road network $G = (V, E, C)$, $V$, $E$, $C$ are the sets of $N_N$ nodes, $N_L$ links and $Q$ cells, respectively. Road links are represented by a $N_N \times N_N$ matrix $R$. $R (i, j) = m>0$ means that there is a link between 2 nodes and the length is $m$, otherwise $R (i, j) = 0$, and there is no self-link at a node, i.e., $R (i, i) = 0$. $E_M(i, j)$ represents the link number between node $i$ and node $j$. $R (E_M (i, j))$ represents the largest cell number on the $E_M$ link.

For agent $k$ ($1 \leq k \leq T$), $W(k) = 1$ means the agent can pass normally, $W(k) = 0$ means the agent stops passing because of congestion.andrepresent randomly selected and unselected agents who stop passing, respectively. Matrix $M_{PL}$ represents the optimal path set for evacuation, $M_{PL} (k, j)$ represents the $j$th node on the evacuation route of agent $k$, $C_t(E_M, k) = (E_M (M_{PL}(k, i), M_{PL}(k, j)), k)$ represents the cell number of link $E_M (i, j)$ where the agent $k$ is located at time $t$. $C_t (E_M, k)=0$ represents the agent $k$ has reached the destination node. $E_C (E_M, k)>0$ is the capacity of the cell where agent $k$ is located. Then the position of agent $k$ at time $t$ can be expressed as $P_t (k, i, j) = (E_M, C_t (E_M, k))$. If $P_t (k, i, j) = (E_M, 0)$, the agent has reached the destination node.

Fig. 3. The process of cellular automata (CA) model

The current capacity $E_{CD}$ of cell $q$ in link $E_M$ is expressed as:

When $C_t (E_M, k)>0$,

. (1)

. (2)

At time $t$, the total number of agents in the road network is:

. (3)

Due to multi-agent systems has the characteristics of social, autonomous and cooperative, it means that agents have cooperation, negotiation, competition and other behaviors. Considering these behaviors in emergency evacuation, in the congestion rules, some people wait in situ because they are courteous to others or weak, and some people go first because they are commissariat or strong. The specific rules as:

When $C_t$ ($E_M$, $k$) satisfies the following conditions, the pass rate of the congestion rules takes work:

or . (4)

The formula (5) is used to determine whether agent needs to wait:

. (5)

Where and are:

. (6)

. (7)

The evolution process of CA model is shown in Fig 3.

## B. *Ripple-spreading Algorithm (RSA)*

In emergency management, proper planning of people evacuation plays a vital role, and the key is to resolve a many-to-many path optimization problem (POP), as people in different locations needs to be evacuated to different exits or assembling points. In this section, we give a method to address the many-to-many POP, in order to provide the optimal evacuation path for each person.

There are currently two popular types of practices for path planning. One practice is to publish the best static paths from each location to its closest exit or assembly station. Unfortunately, such static paths are often not feasible in a dynamical disaster event. For example, a fire could occur just on such a static path, which means the published path is not accessible at all. The other practice is to online re-plan evacuation paths for each person according to the current disaster situation. However, such dynamically planned paths could often lead to turning back and going around behaviors, which implies a waste of time [26]. To find out the theoretical optimal path, here we adopt a relatively new nature-inspired method, i.e., ripple-spreading algorithm (RSA), which is actually a decentralized, multi-agent-based simulation model [26].

The principle of RSA comes from the natural ripple-spreading phenomenon. A ripple spreads on the liquid surface in all directions at the same speed. Therefore, the ripple always reaches the closest spatial point first. By mimicking the ripple-spreading phenomenon in nature, RSA can find the shortest path of one-to-one path optimization problem. This paper modifies the RSA developed in reference [26]. Assuming that each agent's location is regarded as a source node, and each safe evacuation location as a destination node. Then finding all people optimal evacuation paths can be viewed as solving a many-to-many POP. After modification, the RSA can solve many-to-many POP, and it only needs to calculate once in a given dynamic disaster environment to find the optimal evacuation paths for all people. Here, we complete the third step of constructing CRS.

Because RSA does not use the route network of CA model to calculate the shortest path, road network of RSA is different from CA model. Assuming that the road network $G_0 = (V_0, E_0)$, $V_0$, $E_0$ are the sets of $N_R$ nodes and $L_R$ links, and represent the set of the source nodes and destination nodes, . The $N_R \times N_R$ matrix $A$ represents the road links. $A$ ($i$, $j$) = n > 0 indicates that there is a link between node $i$ and node $j$, and n is the link length. $A$ ($i$, $j$) = 0 means there is no link between node $i$ and node $j$, $A$ ($i$, $i$) = 0 means node $i$ is not connected to itself. $R(i)$ records node information in a path, $i$ =1, ⋯, $N_{RL}$, $N_{RL} \geq 2$ indicates how many nodes in this path. $R(1)$ is the source node, $R(N_{RL})$ is the destination node. The cost of route $R$ is:

. (8)

represents the set of all feasible routes connecting the source node and destination node. The many-to-many shortest path is:

. (9)

Suppose $F(i)=j>0$ indicates that ripple $i$ has been activated by ripple $j$. $r_R(i)$ is the radius of the current ripple $i$, and letanddenote the sets of inactive and active ripples, respectively. Then, the modified RSA includes the following steps.

The evolution process of RSA is shown in Fig 4.

Fig. 4. The process of ripple-spreading algorithm (RSA)

# III. The Case Study

This section simulates the personnel evacuation in a part of the Summer Palace, Beijing, China, in order to verify the effect of passenger flow regulation which is provided by CRS.

## A. *Introduction to the study area*

Here we will test the proposed CRS by simulating personnel evacuation in a scenic spot, i.e., the Summer Palace, which is a famous scenic spot in China. The paths in the Summer Palace are relatively narrow. In 2019, the annual passenger flow of the Summer Palace has reached 6.12 million. As a large annual passenger flow in China, it is important to have a proper plan for personnel evacuation. In this paper, the area near the Hall of Jade Ripples in the Summer Palace is selected as the simulation research area. The narrow path sections have been the bottleneck of passenger flow on the tour route for a long time, such as from East Palace Gate to Hall of Jade Ripples, Yiyun House, and Yaoyue Gate tour route. In the event of a fire in this area, it is crucial to evacuate tourists in a timely and safe manner.

## B. *Parameters*

According to the three inputs of CRS, we need to obtain three categories of data, namely road network data (Fig 3), tourist data and evacuation path data (Fig 4).

Fig. 5. Topographic map before(a) and after(b) the opening of the emergency route

In the Fig 5, red lines are the wheelchair emergency channel and blue lines are the square emergency channel. When the emergency channel is not opened, the Summer Palace road network has 832 nodes, 933 links, a total of 31509 cells; when the emergency channel is opened, the wheelchair and square access of the research area is opened, the Summer Palace road network has 832 nodes, 937 links, 31617 cells. The length of each cell is 1m.

By analyzing and organizing the passenger's data for the Summer Palace in the "October 1st" week in 2019, we set 610 people at the Hall of Jade Ripples randomly, and the 390 people in other areas randomly. We set the maximum speed of passengers is 1.25 cells per second (1.25m/s), and the minimum speed of passengers is 1 cell per second (1m/s). We randomly assign these speeds to passengers, to get closer to the real situation.

Fig. 6. Optimal evacuation path before(a) and after(b) emergency passage opening

This paper makes a comparative simulation experiment, i.e., when the emergency channel is opened, and when the emergency channel is closed. According to the distribution of tourists and the dynamic disaster model, the optimal evacuation paths calculated by many-to-many RSA is shown in Fig 6 before and after the emergency channel is opened. The red solid circle in the Fig 6 represents the evacuation endpoint, and the blue solid square represents the evacuation starting point, i.e., where tourists are located at the beginning of evacuation.

### C. Results

Fig. 7. The experimental simulation diagram at time $t$ = 20

Fig 7 shows the experimental comparison results at $t$ = 20s. It can be seen from the Fig 7 that the congestion of cells after the regulation is reduced when compared with that before the regulation. After regulation, the congestion of passengers at nodes 246 and 234 is significantly reduced; the number of passengers at the Hall of Jade Ripples area has also reduced (the blue frame area in Fig 7).

Fig. 8. Statistics on congestion time of each node in the study area

Fig 8 reflects the congestion time of each node in the study area in the experiment. By comparing the congestion time regulation of each node, the congestion time of most nodes is greatly reduced after regulation, and the congestion time of a few nodes increases slightly. Only a few nodes (such as 232 and 235) become more congested. The reason is that the total number of passengers remains unchanged, but passengers moved from one road to another. Due to the evacuation time of the part and the whole area is reduced, it is acceptable that the congestion time of a few nodes become longer. From the overall analysis, the proportion of the gray part in the Fig 8 is significantly lower than that of the orange part, that means, the congestion time of the node in the experiment is significantly reduced.

TABLE 1. Case simulation results

| Evacuation time (unit: s) | Before regulation | After regulation | Whether the time decreases |
|---|---|---|---|
| Hall of Jade Ripples | 75 | 37 | Yes |
| Difference value of part | 38 | | Yes |
| The whole area | 204 | 183 | Yes |
| Difference value in total | 21 | | Yes |

TABLE 1 records the complete simulation data. The comparison of simulation results shows: After regulation, the evacuation time of Hall of Jade Ripples was shortened by 38 seconds, and the evacuation time near Hall of Jade Ripples was shortened by 21 seconds. Through the comparison of the data obtained after CRS simulation, it can be found that the evacuation time of study area is greatly reduced after regulation. Through CRS simulation, we can clearly observe the evacuation status and congestion level of each spots at any moment, which provides data support for the regulation of passenger flow and scientific advice for emergency management. The experiment proves that the simulation base on the reported CRS can be useful to study the regulation of emergency evacuation.

## IV. CONCLUSION AND ANALYSIS

In this paper, we built CRS on the basis of the simplified CA model and the improved RSA, combining the characteristics of multi-agents, we develop an effective simulation system which aims to provide reasonable regulation of passenger flow suggestions for emergency management through simulation. By improving one-to-one RSA to many-to-many RSA and simplifying the traditional to a linear CA model, we enhance the calculation efficiency. It is successfully proved the goal of CRS through the case study of Summer Palace. In the future work, in order to make the system simulate more realistic evacuation conditions, the personnel behavior model in the simulation system can be improved, and more regulation measures can be introduced.


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