Security Model of Stadium Evacuation Combined with Multi-agent and Cellular Automata

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Abstract

In order to design a reasonable pedestrian evacuation and exclude the security risks in large stadiums, this thesis proposes the research of security model of evacuation in stadiums combined with multi-agent and cellular automata. The research is based on cellular automata model and the process makes extended analysis to the cell's behavior of autologous, and then it makes simulation experiments of the process of simulating the evacuation in large stadiums. Simulation results finally show that Agent-CA combines the advantages of multi-agent and cellular automata, which fully considers the individual internal factors. Compared to traditional cell cellular automata, it is more close evacuation situation of the realistic major sports stadium, and it shortens the evacuation time and improves the safety.

Keywords: *Node Large Stadium; Multi-agent System; Cellular Automata; Crowd Evacuation; Simulation*

1. Introduction

Crowded public places such as theaters, stadiums, railway stations, docks, business center and supermarkets have characteristics of high t crowds gathering and mobility. In case of when unexpected disasters like fire, explosion and riot occur, serious life and property damage will be caused.

With the development of modern design and technology, the size and capacity of sports stadium continues to develop. The Appearance of great density of crowd in stadium raises the possibility of potential accident casualties. FIFA records that between 1902 and 2000 there are 23 casualties worldwide and the total death is at least 1,380. The accident statistics such as Kristin in Canada and Fruin in New Zealand show that there are 3,000 casualties in the last 10 years in the world sports arena, which is larger that the casualties probability of the frequently occurred accident (such as car crash). Therefore, study on stadiums evacuation has important and practical significance, and it is always the hot point in the research field of public safety.

Stadiums evacuation is an organic whole consisted with many interrelated and interacted elements, which is a complex system with the characteristics of complex, multi-level nature and feedback, and it is with strong spatial and chronological features. For this problem, many domestic and foreign scholars have done a lot in-depth researches and proposed the

stadium evacuation models like cellular automata (CA), multi-agent model (MAS). The museum crowd has strong autonomous and intelligent features, which has become an important direction of current research.

For the researches in this field there are three types of parties, namely the rule-based approach, social force of approach and cellular automata approach. Rule-based approach at a lower population density or moderate cases can simulate the realistic movement of people, but can not handle the contact between people, so it can not simulate the squeezed results. Helbing D et al on the basis of social force method reappear the extrusion pressure when the crowd squeezing through analyzing the repulsion between man and man, the repulsion between man and static obstacles between man and target and the gravity and friction between man and target and establish the simulation model of crowd evacuation under a state of panic. The disadvantage of this model is that when the simulation is with high-density crowd, crowd shaking phenomenon will be appeared. Cellular automata method restricts the movement of people within discrete boxes, and the state of the cellular at some certain moment is according to the state of the last moment and the entire neighbor cellular to locally update, so the performance of the whole cellular space is represented as the changes in discrete time dimension changes. In the study of crowd evacuation simulation on fire scenario, the cellular automaton model is combined with the individual behavior, and this the commonly used methods. Mr Young et al introduce the concept of risk level of location based on cellular automata method to determine the movement of pedestrians and simulate the escaping process of pedestrians when the fire broke. Mr Young et al adopt the method using cellular automata and combined with five different kinds of acting force of individuals under emergency situations. Under the simulating emergency evacuation, Yue Hao er al use two dynamic parameters and combine cellular automata to reflect the pedestrian evacuation. Zhou Jinwang et al consider the effect of side by side pedestrian in pairs, around in pairs and mixed pairs to the process of pedestrian evacuation.

This thesis combines the advantages of agent and cellular automata model; more realistically simulates the process of stadium evacuation behavior and proposes the crowd evacuation model in large stadium combined with multi-agent and cellular automata (Agent-CA). Simulation results show that Agent-CA fully considers the individual internal factors, and it is closer to the crowd evacuation situation in realistic large stadium.

This paper mainly makes the extensive and innovative work in the following areas:

 (1) The current studies on wireless sensor network resource optimization tend to focus on the MAC or strategies on transport layer to achieve a single optimization goal. In order to improve node energy, storage and computing power, this paper proposes the cross-layer resource optimization algorithm. The algorithm introduces the power control model associated with the probability of link connection and establishes the network collaborative optimization mechanism based on congestion cost and energy cost through combining the power control on physical layer, access control on Mac layer, flow control model on transport layer and using the network utility and life as optimized goal. The vertical decomposition theory is used to realize the decomposition with step-by-step of the optimized goal, and then the updated formula based on the power consumption of nodes and probabilities and rate of link access is deduced to achieve the distributed optimization solutions.

(2) In order to further verify the correctness and effectiveness of the proposed the optimization algorithm with cross-layer resources, the validation experiments cross-layer optimization algorithm in wireless sensor network based on network utility and lifetime are conducted.   Wireless sensor network is consisted with six nodes, and after a brief fluctuation each node is convergent, and the probability of node 5 accessing to aggregation node 6 is 1. After a brief fluctuation the congestion cost is close to zero, which indicates that under the

experimental environment the algorithm can alleviate and eliminate the network congestion status. Energy cost is also convergent varies with the iteration time, in which due to the node 5 bears more data transfer tasks, the energy consumption is higher and its energy cost parameters converge is a nonzero value. The simulation results show that: cross-layer resource optimization algorithm is effective and has fast convergence.

## 2. Cellular Automata and Multi-agent

A. Cellular Automata

Cellular Automata (referred to as CA) is the mathematical model based on the evolution of cell, which is both discrete on time and space. From a historical perspective, cellular automata are first used by mathematician and physicist John Von Neumann and Stanislaw Ulam in 1940. As a mathematical model, cellular automata have a strict scientific definition: cellular automaton is defined in the cellular space consisting of discrete and finite-state cellular composition, and according to some local rules, it is the dynamical system evaluated in discrete time dimensional. Cellular automata system can be expressed by a four-tuple:

$$A = \{d, S, N, f\} \tag{1}$$

Wherein, d is the number of dimension of cellular automata; S represents the discrete and finite set of states of the cellular; N represents the combination of cellular space in the neighborhood; f maps Sn to a partial conversion function on S.

Theoretically, cellular automata can be expressed as any dimension. The current researches are concentrated on one dimension or two-dimension, while a lot of phenomenon are represented by concrete or abstract distributed two-dimensional, so the two-dimensional cellular automata is most widely used. Two-dimensional cellular division dimensional is generally divided as equilateral triangle, regular hexagon or regular square grid (shown in Figure 1).

Diamond grid   Quartet grid   Hexagonal grid
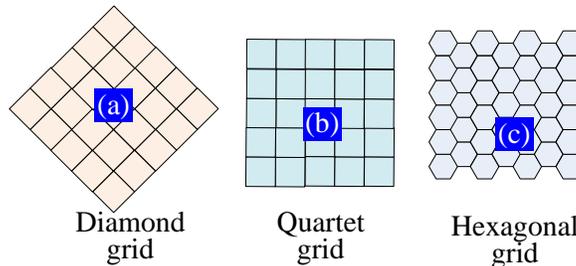
**Figure 1.   Meshing Form of Two-dimensional Cellular Automata**

Cellular automata can be used to study many general phenomena, such as Information transfer, evacuation analysis and urban spatial change. When these studies use CA, there is an obvious common – the model used for large graphical display is based on two-dimensional cellular automaton model. This is because that in the research of searching the change rules of the target, two-dimensional CA can be sufficient to facilitate the expression of computer graphics on the plane.

Stadium crowd evacuation is different from the crowd evacuation in other large-scale venues (such as a large plaza, public entertainment, subway stations, etc.) – the audience stands in stadiums is designed as multi-steps, so when the site map of stadium is mesh divided of cellular automaton, the two-dimensional plane situation can not be simply considered. Because when the emergencies and the audience need to be evacuated, the majority of audience will be eager to find exit due to the panic mentality, the audience stands are the stepped design, so people often will firstly escape to the down side. Therefore, the

elevation factor of the sports stadiums terrain plays an important role in the cellular properties - when the situation of audience choosing escape to the bottom is virtual, for the cellular around the currently occupied cellular automata as long as the current elevation value is high it will not be chosen.

B. Multi-agent crowd evacuation model

In the framework of simulating the crowd movement the crowd evacuation situation is considered, and the framework of crowd evacuation model based on multi-agent can be simplified as in Figure 2; the model components include intelligent body, simulation model, map environment and the observer.
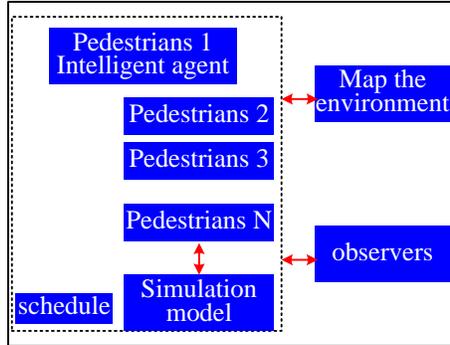
Figure 2.   Crowd Evacuation Model based on Multi-agent

(1) Space Environment Z=Rp-gon, Rp-line, ;B is the test area

The bounded closed set of the inside entire area; planar road collection Rp-gon = Rp1, Rp2, ..., Rpn, which is possible value range of the location of the audience and also is the constraint of the agent audience movement. Linear path collection Rp-line = Rl1, Rl2, ..., Rln, which is the reference direction of the action line of one point when audience is leaving; other environmental collection B = {Build, Block}, which is combined with the collection of buildings and collection of obstacles, and both are polygons.

(2) Audiences agent

$$P - Agent = \begin{Bmatrix} Id, P_o, P_T, P_N, V, P, A, R, D_{Va}, \\ D_a, Rule, Query, SNext, Esti, Act \end{Bmatrix} \quad (2)$$

Wherein, Id is the unique identifier for the audience; PO、PT、PN are the starting position, target position and current position of the agent; V is the mobile speed of the agent; P is the perceived state set; A is the set consisted by all the possible behavioral programs of the agent; R is the set of all the results corresponding to the behavior program; DVa is the rule set corresponding to the sensing status and programs set; Dar is the correspondence between the scheme set and results state set; Rule is the specific decision law; Query defines the process of Agent sensing the surrounding environment; SNext is the latest sensing status, which combines with the corresponding rule of perception state and the program set to determine the progress of the current results set; Esti is the given program set, which according the corresponding rule of perception state and the program set to determine the progress of the possible results state; Act is different decision rule adopted by the set of results state corresponding to one program using state set, which selects a particular program from the set of proposed program.

2.2.3 Population $A^t = \left\{ P_{a1}^t, P_{a2}^t, ... P_{an}^t \right\}$ is the entire set at time t of the simulated audience. In accordance with the different value PN of the current position the elements of A^t can be divided into the set which is reached the destination and not reached the destination A_{in}^t and A_{out}^t; If PNi-POi>ε, Pai∈ A_{in}^t; If PNi-POi<ε, then Pai∈ A_{out}^t. Clearly, $A_{out}^t \cup A_{in}^t = A^t$ and $A_{out}^t \cap A_{in}^t = \cong$. When the simulation starts, $A_{in}^t = A^t$; when the simulation is end, $A_{out}^t = A^t$.

2.2.4. The time when the simulation is complete T={t | $A^t = A_{out}^t$}, thus the evacuation time when evacuating the crowd at emergency can be obtained as T = inf t, that is the minimum of t when t $A^t = A_{out}^t$.

2.2.5. The set of the entire audience agent at t moment all audience location is as follows:

$$P \; A^t = \left\{ PN_1^t, PN_2^t, ... PN_n^t \right\} \quad （3）$$

Vector $P A^T$ Describes the position information of all the simulation objects at time t; the rule of $P A^T$ changing with the time describes the dynamic process of the crowd movement, which becomes the core state variables of the simulation model, and it is the s fundamental object observed by the observer in process of model simulation. The ultimate goal of simulation is to find out the change rule of the state variables.

3. Crowd Evacuation Model

A. Model assumption

(1) When the crow is evacuating in stadium they are always toward the exit, and adjust the next behaviors and decisions based on the environmental risk and their own circumstances.

(2) When the crow is evacuating in stadium, there are some complex phenomena like together, herd, hinder, "haste makes waste" and so on.

(3) Evacuation speed of the crowd in stadium is influenced by their own psychological factors, physiological factors and population density, and different types of people have different speeds.

(4) Crowd in stadium can be divided into agent, and there are three types of agents: elderly, adults and children. The elderly and adults occupy 16 cellular and children occupy nine cellular, which are respectively represented with yellow, blue, purple, and each agent identifies the respective numbers.

B. Model Construction

Based on multi-agent technology, stadium crowd is regarded as autonomous agent, which has complex decision making ability, their knowledge and experience. They can adjust their behavior according to the outside information and internal factors, and the general structure of its models is shown in Figure 3.
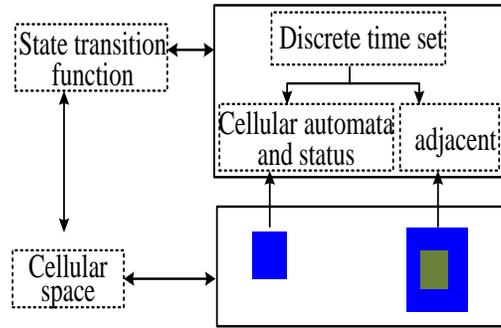
Figure 3.   Agent Structure

C. Perception of crowd

Information in virtual environment can be mainly obtained through perceptual model, so the key of perceptual model is how to simulate the functional limitations of human senses. Through the perception filter to get the information can be sensed by the sense organ and filter the can the information can not be sensed. Yhis article only make modeling for the crowd visual perception, because it can simplify the model, but also 80% of information is the obtained from the outside world. The principle of vision filter is based on the relative positions of the objects of the environment and the human eye to determine if the object is sensed. Wherein the object need to determined that if it is in the sensing range and if the line of the object and human eyes is obscured by other objects.

(1) Vision sensing range. As shown in Figure 4, wherein R_{v1} is the best viewing distance; R_{v2} is the maximum line of sight; φ_{v1} is the best viewing angle; φ_{v2} is the maximum angle of view. The perception radius of agent is

$$\frac{R_{v2}}{D} = (1 - C_{panic})k_v \tag{4}$$

Wherein, C_{panic} is the degree of panic; the value of C_{panic} is between $[0,1]$; k_v is the sight unit; D indicates the size of the object.
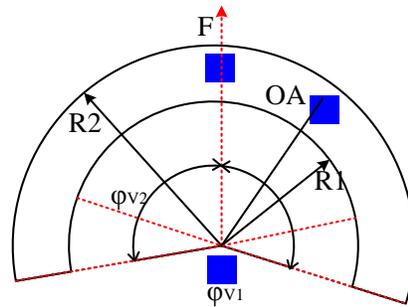
Figure 4.   Vision Sensing Range of Agent

(2) Obstacle relationship of space. By calculating if there is any intersection of the line of eight vertices of the agent to the bounding box with other bounding rectangle of objects to determine whether there is occlusion between spaces.

(3) Attention mechanisms. Focus Factor is used to reflect the degree of concern of agent on an object, and the focus factor of the object A is expressed as:

$$f_A = a \frac{\overset{?}{OA} * F}{\left|\overset{?}{OA}\right| * |F|} + \frac{b}{\left|\overset{?}{OA}\right|} + \frac{c}{|V_a - V_o|} \qquad (5)$$

Wherein, $\overset{®}{OA}$ is the vector of the agent to object A; V_a is the velocity of the object A; a, b and c is the scale factor, and scaling factor of different agents reflects the individual differences of intelligence bodies.

D. Behavioral Decision

Decision-making is a fundamental problem of artificial intelligence, and the purpose is to study how to reach the goal state from the existing state, which can be achieved through the decision to give a goal every step of the action sequences or behavioral strategies.

In the stadium crowd evacuation process, evacuation behavior can be summarized as the target behavior, herd behavior, obstacle avoidance behavior, escape behavior, helping behavior and queuing behavior. Selection mechanism of inclusive type behavior proposed by Brooks is adopted to select the mode of various behavior patterns, and the priority order of the behavior of each patterns from high to low are: escape behavior, obstacle avoidance behavior, herd behavior, helping behavior, queuing behavior, target behavior.

(1) Escape behavior. When the agent perceived that risk reaches a certain degree of value it will automatically select the escape behavior and the speed is got by Equation (4).

$$v_{prefer} = (1 + C_{panic})e^{-\varepsilon r/l} . v_{max} \qquad (6)$$

Wherein, ρ is the density of perception; λ is the physical value, and the maximum value of a physical adults is 1; the elderly is 0.8 and the children is 0.5. When the agent is conducting in, each step of the physical value decreased power, waiting for power recovery; ε is coefficient of determination; vmax is the maximum speed of evacuation; Cpanic is the degree of panic.

(2) Collision avoidance behavior. By perceived the information, the relative speed of the obstacle avoidance method is used to implement the collision of the agent to the dynamic and static objects. To reflect differences of agent and make the model more realistic, there are different settings for the agent when choosing the collision avoidance behavior, such as different setting values of detection distance of bold type and carefully agent to avoid collision obstacle.

(3) Herd behavior. When the fear reaches a certain value, the crowd tends to herd behavior; when the panic drops to a certain value the agent tend to at leave the group a certain probability and the individual select the target to leave. According to behavior principle of separate, alignment and cohesion, the speed can be expressed as:

$$\vec{v}_{prefer} = l(a\vec{v}_{separate} + b\vec{v}_{align} + g\vec{v}_{cohesion}) \qquad (7)$$

Wherein, $\vec{v}_{separate}, \vec{v}_{align}, \vec{v}_{cohesion}$ are respectively the speed generated with the rule separate, alignment and cohesion.

(4) Helping behavior. When the agent within the scope perception perceives that there are callers, and their physical values and the degree of panic are in the allowable range, they will choose to helping behavior; when simultaneously multiple agents has perceived callers, the nearest one will select to provide assistance; when lack of conditions, the second closest will take execution.

(5) Queuing behavior. When the agent perceives that their environment is nearby the exit and at present there is not too dangerous and can not move forward, they will select the

queuing behavior. The rules is that if there is a agent moving forward, the agent occupy a grid, or continue to wait.

(6) Target behavior. The ultimate target of the population is move forward to the exit. Under the circumstance of people's physical and mental conditions meeting the requirements and people are familiar with the environment, the agent will choose to move forward to appreciate direction, and the path is obtained by the A^* algorithm; the traveling speed is determined by the formula (6).

Behavior execution

The speed obtained by the decision of other agents will update the location of each agent, the specific implementation process is shown in equation (8) as follows:

$$\vec{P}_{t+1}(x, y) = \vec{P}_t(x, y) + \vec{v}_{prefer}.\mathrm{D}t \qquad (8)$$

Wherein, $\vec{P}_t(x, y)$ is the current agent position; $\vec{P}_{t+1}(x, y)$ is the position for the next time step; $\vec{v}_{prefer}$ is the speed of agent after decision according to the environmental information and self status; $\mathrm{D}t$ is the time step. Flow chart of the specific algorithm is shown in Figure 5.

4. Simulations

A. Simulation environment

To test the usefulness of Agent-CA model, it is applied to evacuation plan of Changsha Stadium as shown in Figure 6. There are 240 nodes and 8 exports. Simulation experiments are implemented in the computer with PIV 3.0GHZ CPU, 2GB RAM, Windows XP. The algorithm programming language is as VC6.0 + +, and single CA model and MAS model are used for comparative experiment.

B. Results and Analysis

Under the circumstance of the different physical decline value power, the curve changes of the evacuation crowd and evacuation time are shown in Figure 7. As can be seen from Figure 7, the physical value decreased value power of has a greater impact on evacuation time.

Considering when the not panic value Cpanic, the curve changes of the evacuation crowd and evacuation time is shown in Figure 8. As can be seen from Figure 8, when considering the panic value Cpanic, the crowd evacuate faster at the beginning stage, but when the number of people is large, there are a large crowd, which causes the panic herd behavior, and then the phenomenon of the long evacuation time and the "haste makes waste" will be appeared.
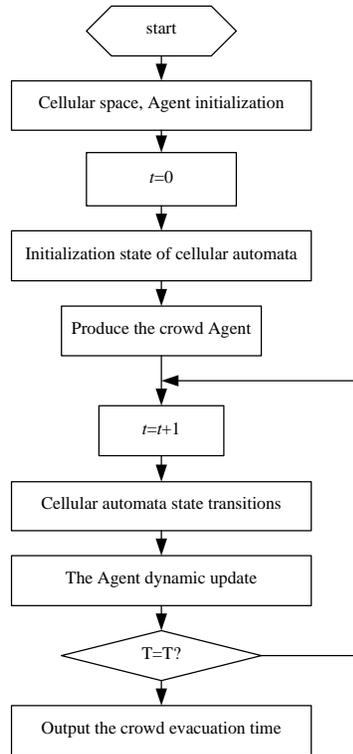
Figure 5.   Flow Chart of Agent-CA Algorithm
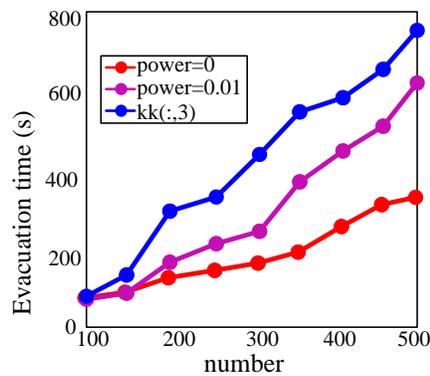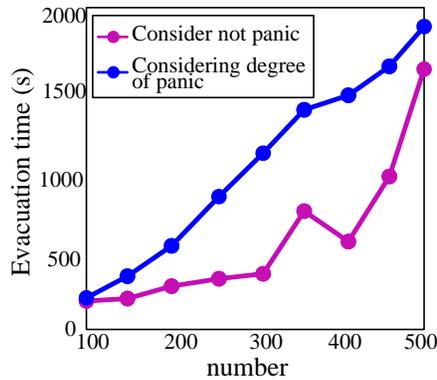
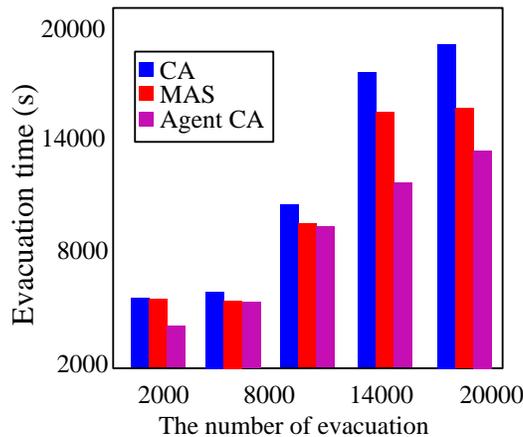

Figure 6.   Stadium

**Figure 7.   Impact of the Physical Value on Evacuation Behavior**

Figure 8.   Impact of the Level of Panic on Evacuation Behavior

Under the circumstance of different Evacuation crowd, the stadium crowd evacuation time of single CA model, MAS model and Agent-CA model are shown in Figure 9. Figure 9 shows that compared with the single CA model and MAS model, the total time of Agent-CA model is relatively stable, and the crowd evacuation time is relatively small, which greatly save the total time of pedestrian evacuation. Comparative results show that Agent-CA model is good to overcome the shortage of personality differences caused by simple using the cellular automata, and at the same time avoid the computational complexity generated by simply use the multi-agent model and the macro problem of can not sufficiently presenting the crowd movement.

Figure 9.   Performance Comparisons of Different Stadium Crowd Evacuation Models

The relationship between the number of evacuated crowd and time is shown in Figure 10; when considering the individual response time, the average response time is set as 60 s, the proposed model is adopted to re-simulate; the relationship between the number of evacuation with double outlet and time is shown as curve a in Figure 10. When considering the multi-agent movement, the relationship between the number evacuation and time is shown as curve a3 in Figure 7. Figure 10 shows that the curve a1 and curve a2 are approximate linear; a3 is nonlinear; the number of evacuation and time curve is nonlinear and they are comparatively real. Thus, by adding multi-agent and cellular automata in simulation, the phenomenon of crowd evacuation can be better simulated.
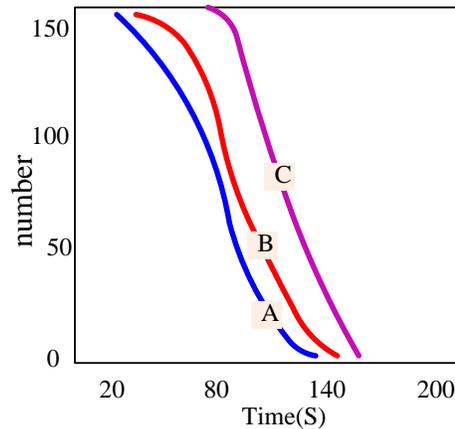
Figure 10. Relation Curve between the Number of Exit s and Evacuation Time

Assume that the emergency occurs, one road (or several rode) of crowd evacuating is closed for some reason, and the evacuation movement is simulated. At the beginning, the basic shape remains the same as when the roads are not closed, and the crowd inside the stadium began to take shape of the annular flow patterns, which are not significantly different displays, and it is the same with the actual situation consistent with audience in place; when in the progress of stimulating the crowd to spread and there are two outlet adjacent to the closed exit, the flow of people obviously increased, and the population around the closed exit is substantially gather at the nearest exit adjacent to these two exits (shown in Figure 11). In the subsequent diffusion process, in several second nearest exits the flow of people also have significant increase, which show that when the road is closed, the multi-agents in order to reach the original goal they have to take the bypass road, which will increase the flow of people in neighboring exits and roads. The duration of the entire simulation process is significantly longer, the complexity of the temporal and spatial variation is greatly increased, and also the complexity and difficulty of the treatment of emergency are significantly increased.

Figure 11. Progress of Dynamic Simulation of Crowd Evacuation with Emergency Event

5. Conclusion

In order to eliminate the security risks in large stadiums, this paper proposes the crowd evacuation safety model based on multi-agent and cellular automata in large stadiums. The model is based on the characteristics and laws of crowd evacuation in large stadiums and combined with multi-agent and cellular automata. This model is closer to crowd evacuation situation in real large stadiums, which shortens the evacuation time and provides some reference for the scientific and rational analysis of crowd evacuation behavior in large stadiums.

Acknowledgements

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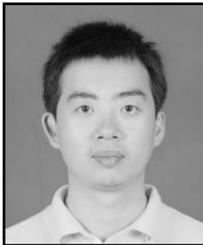
Bai Xuesong, he was born in Heilongjiang province of China in 1983. He has received his bachelor degree and master degree respectively. Currently, he is a lecturer. His research interests include Pattern Recognition and Image Processing.