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Space-time Simulation Model Based on Particle Swarm Optimization Algorithm for Stadium Evacuation

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***Abstract*—In this paper, a space-time simulation model based on particle swarm optimization algorithm for stadium evacuation is presented. In this new model, the fast evacuation, going with the crowd and the panic behaviors are considered and the corresponding moving rules are defined. The model is applied to a stadium and simulations are carried out to analyze the space-time evacuation efficiency by different behaviors. The simulation results show that the behaviors of going with the crowd and panic will slow down the evacuation process while quickest evacuation psychology can accelerate the process, and panic is helpful to some extent. The setting of parameters is discussed to obtain best performance. The simulation results can offer effective suggestions for evacuees under emergency situation.**

Keywords—stadium evacuation; particle swarm optimization algorithm; simulation component;

I. INTRODUCTION

In recent years, security management for large public places, such as gymnasiums, stations, has been attached great importance for handling emergency situation [1,2]. Once disasters happen in a high-density place, interaction among evacuees may lead to serious aftermath, such as injury or even death. To prevent or reduce such danger in the evacuation process, it is important to study the interaction rules under emergency situation.

In order to simulate evacuation problems, a series of evacuation models were proposed, including cellular automata model [3], lattice gas model [4], social force model [5], fluid-dynamic model [6], agent-based model [7,8], game theoretic model [9,10], optimization-based model [11]. Xie et al. [12] proposed a method to solve a lane-based evacuation network optimization problem. The objective of the approach was to minimize the number of crossing points at the given intersection and an integrated Lagrangian relaxation and tabu search solution method were developed. Fang et al. [13] proposed and demonstrated a space-time use efficiency model on the basis of trajectories in the case of mixed vehicle and pedestrian flows in intersections. A two-tier hybrid multi-objective optimization algorithm was presented to plan vehicle and pedestrian turning movement directions, and three objectives: average evacuation time, the overall length traveled, and space-time use efficiency of network were optimized. These models, however, usually intended to solve evacuation problem macroscopically.

Evacuation modeling is a complicated problem which needs to consider many factors, including behaviors and psychology of evacuees. This is a more challenging issue to study. In this paper, a PSO-based space-time simulation model for stadium evacuation is presented. In this model, the fast evacuation, going with the crowd and the panic behaviors are simulated by defining three moving functions of particles. The simulation experiments are worked out to show the applicability of the model.

This paper is organized as follows. Section II discusses previous work related to simulation and modeling for evacuation. Section III defines three evacuation behaviors and the corresponding moving rules and presents a simulation model based on particle swarm optimization. Section IV analyzes and compares the simulation results by different scenarios. Finally, Section V draws conclusions and discusses directions for future research.

II. RELATED WORKS

Many researchers have focused on evacuation problem by simulation and modeling [14]. For example, Chen et al. [15] presented a force-driving cellular automaton model considering the social forces on cell movement, such as the desire of a pedestrian to exit, the repulsive interaction among or between pedestrians, and the effect of obstacles, to investigate the evacuation behaviors of pedestrians at a T-shaped intersection. The model studied the pedestrian evacuation problem from the microscopic point of view, but neglected attraction forces to simulate the conformity phenomenon. Guo et al. [16] investigated the route choice in pedestrian evacuation under conditions of both good and zero visibility. They presented a microscopic evacuation model with discrete space representation to simulate the behavior of pedestrians. Fang et al. [17] defined evacuation network as a hierarchical directed network and proposed a HMERP algorithm based on ant colony algorithm for evacuation.

Currently, swarm intelligence has been used to simulate evacuation process due to its similar nature to the social behaviors of evacuees, such as the queuing behavior, self-organization, crowd psychology and sub-group phenomena [18]. For example, Izquierdo et al. [19] used particle swarm optimization to simulate and forecast evacuation time. The model took minimizing distance from an exit as the optimization objective. Zheng et al. [20] also presented a PSO-based heterogeneous evacuation model. In the model, the distance from a particle to the nearest exit was taken as the fitness function and the pedestrian's velocity was impacted by the local pedestrian's density. The model simulated the pedestrian's psychology of rapid evacuation and investigated the relationship between velocity and density, but the tendency of going with the crowd was not considered.

In this research, a simulation model for evacuation in a large common place has been proposed using particle swarm optimization approach. Different types of evacuees have been defined and different scenarios were simulated and discussed to evaluate different evacuation behaviors.

III. THE SIMULATION MODEL FOR STADIUM EVACUATION

A. The standard PSO algorithm

Particle Swarm Optimization is an evolutionary computation technique that was first developed by Kennedy and Eberhart [21]. The original idea of the PSO algorithm was to simulate the social behavior of a flock of birds trying to find the location of food resources (fitness function) when flying through the field (search space). The movement of every bird is based on the leader (the one with the best performance) and on its own knowledge. In general, it can be said that the model that PSO is inspired, assumes that the behavior of every particle is a compromise between its individual memory and a collective memory.

In the standard PSO method applied for optimization problems, each particle represents a candidate solution. For example, denote X and V as position vector and velocity vector of any particle. X can be defined as $X = (x_1, x_2, ..., x_i, ..., x_N)$, $1 \le i \le N, 1 \le x_i \le N$, and V is represented as $V = (v_1, v_2, ..., v_i, ..., v_N)$, $1 \le i \le N, 1 \le v_i \le N$ with binary value 1 or 0 for each v_i. The position updating rule of particles is defined as

$$V = w \cdot V + c_1 \cdot r_1 (P_{pbest} - X) + c_2 \cdot r_2 (P_{gbest} - X) \qquad (1)$$

$$X = X + V \qquad (2)$$

Where w is called inertia weight, c_1 and c_2 are learning factors, r_1 and r_2 are random numbers between 0 and 1. P_{pbest} is the best position of particle so far, and P_{gbest} is the global best position of all particles.

B. The simulation model based on PSO

During emergency evacuation, the queuing behaviour, self-organization, crowd psychology and sub-group phenomena of evacuees are similar to the social behavior of a swarm in nature. This kind of swarm can simulate physical system and social system. Thus, particle swarm optimization algorithm inspired by swarms in nature is suitable for complicated system simulation and solving evacuation problem.

As for evacuation simulation using PSO algorithm, each evacuee can be referred to as a particle. Initially, a large number of particles are generated and distributed randomly in the study area. Then the particles move according to their own experience and social interactions as well. During the process, they coordinate their movement based on the knowledge acquired towards emergency exits.

For evacuation problems, there are usually multiple emergency exits. Therefore, fitness value of each particle can be defined by Eq.(3), which is the minimum distance from a particle's current position to all exits.

$$fitness(P_i) = \min\{dist^2(P_i, Exit_1), ..., dist^2(P_i, Exit_k)\} \qquad (3)$$

Where P_i represents the position of i^{th} particle, and $dist^2(P_i, Exit_k)$ is square of the distance between P_i and $Exit_k$.

During evacuation process, the movements of evacuees are complex due to the different psychology and behaviors. And the main characteristics of evacuees include going with the crowd, sub-group behaviors and so on. Furthermore, panic behavior is a common phenomenon in emergency situation.

In order to simulate these behaviors, we classify evacuees into three types:

Type 1: the evacuee who always selects the passage nearest from exit.

Type 2: the evacuee who completely moves in accord with the crowd around himself/herself.

Type 3: the evacuee who is under panic.

According to the updating rule of velocity in standard PSO algorithm, the corresponding velocity updating functions for the three types defined above are described as Eqs.(4)-(5):

$$V_{type1} = w \times V_{type1} + f_1 \cdot r(P_{pbest} - X) \qquad (4)$$

$$V_{type2} = w \times V_{type2} + f_2 \cdot r(P_{nbest} - X) \qquad (5)$$

$$V_{type3} = w \times V_{type3} + f_3 \cdot r(P_{rand} - X) \qquad (6)$$

Where V_{type1} , V_{type2} and V_{type3} are the velocities for three types of evacuees. f_1 is the factor for quickest evacuation will,

f_2 is factor for going with the crowd, and f_3 is the panic factor, r is random numbers between 0 and 1. P_{nbest} is the best position of particle in neighborhood of the particle, P_{rand} is the random position selected by a panic evacuee.

In fact, the movement of an evacuee may rely on the synthetic affection of the three behaviours. In this case, the velocity updating function can be defined as Eq. (7).

$$V_{syn} = wV_{syn} + f_1 r(P_{pbest} - X) + f_2 r(P_{nbest} - X) + f_3 r(P_{rand} - X) \quad (7)$$

Eqs. (4)-(7) above are moving rules of different types of evacuees (particles). Eq. (4) shows that a particle of Type 1 will always search for the nearest exit. Eq. (5) indicates that a particle of Type 2 prefers to follow the particles nearby. Eq. (6) is the updating velocity of a particle who belongs to Type 3 under panic, so that there is no regulation for the movement of evacuee of this type. Eq. (7) simulates the movement of a particle who is affected by the psychology of fast evacuation, going with the crowd and panic simultaneously, which is prevalent in real evacuation process.

C. *Simulation procedure*

The evacuation model is implemented using a modified PSO algorithm to simulate the different effects with these types of behavior. And the simulation procedure for evacuation can be described in Table I.

TABLE I. SIMULATION PROCEDURE

Step 1. Initialization
  Set parameters, including total number of evacuees M, the type of each evacuee, and parameters f_1, f_2, f_3
  Randomly generate velocity and position for each particle
Step 2. Evacuation simulation
  Do Until all particles reach exit
    for $i = 1 : M$
      Calculate the fitness value of particle i according to Eq. (3)
      Update the velocity of particle i by Eqs.(4)-(7) according to its type
      Update the position of particle i by Eq. (2)
      if particle i has reached any one of the exit nodes
      Mark the status of particle i as successful
      end
    end
  end

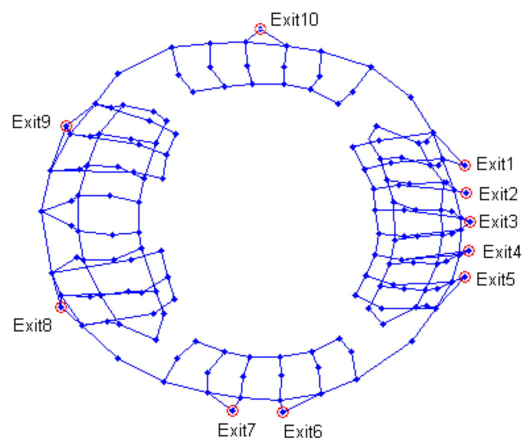
Output: Evacuation time
  Evacuation routes

IV. SIMULATION RESULTS

The simulation model was applied to the stadium of Wuhan Sports Center (China). This stadium has 157 nodes in total including bleachers, stairs, exits and passages distributed in all three floors, as shown in Fig. 1(a). The simplified graph of the stadium is shown in Fig. 1(b).

Experiments were carried out to simulate the influence on evacuation efficiency by different behavior. The model was implemented and run on a PC with i5-2430M CPU and 4 GB of RAM. In this paper, 10000 particles particles were used as test data to simulate pedestrians. At the beginning of the simulation, 10,000 evacuees were randomly placed in the 42 stands.

(a) The stadium



(b) Network of the stadium

Fig. 1. The study area

In order to analyze the impact on evacuation efficiency of different behaviors, four cases were designed as follows:

Case 1: All evacuees belong to Type1;

Case 2: All evacuees belong to Type2;

Case 3: All evacuees belong to Type3;

Case 4: The type of each evacuee is set randomly.

In each case, the speed function of evacuees under emergency situation is defined as Eq.(8), which indicates that the speed is decreasing with the increase number of evacuees.

$$v_i(t) = v_{\max} \cdot e^{-\frac{num_i(t)}{C_i}} \quad (8)$$

Where $v_i(t)$ is the passing speed through i at time t, $v_{\max}$ is the maximum speed of evacuees, $num_i(t)$ is the number of evacuees in node i at time t, C_i is the capacity of node i.

Table II lists the parameters that are used in this model. The maximum value of speed for pedestrians was given by [22].

TABLE II. PARAMETERS SETTING

M	w	f_1	f_2	f_3	v_{max}
10000	1	2	2	2	1.44 m/s

TABLE III. SIMULATION RESULTS

Exit No.	Case 1	Case 2	Case 3	Case 4
Exit 1	912	1066	774	890
Exit 2	451	417	589	556
Exit 3	938	893	1125	1018
Exit 4	529	601	560	558
Exit 5	979	841	761	787
Exit 6	812	714	717	810
Exit 7	598	714	700	602
Exit 8	1724	1673	1723	1674
Exit 9	1627	1660	1621	1675
Exit 10	1430	1421	1430	1430
Evacuation time (s)	720	7960	1200	5200

The simulation results are shown in Table III, including the number of evacuees at each exit and the total evacuation time. Comparing the three types of behaviors, those evacuees who always want to evacuate from the nearest exit spend the least time while those ones who completely go with the crowd need the longest time. This indicates that going with the crowd behavior can lead to lower efficiency and should be avoided during evacuation process. It is shown that most of people evacuate from Exits. 8-10 in all cases because the stands near these exits are rather intensive so that some measures should be taken especially in these exits.

Fig. 2 depicts the curves of varying number of evacuated individuals with time. It is shown that all evacuees have been evacuated in 800 s for Case 1 and Case 3. But during this process, only 70% pedestrians of Case 2 completed evacuation. It is demonstrated that after 1600 s, the curve of Case 2 varies little, which means that this behavior can not help pedestrians flee quickly when most of pedestrians have reached to the exits of the stadium. The evacuation efficiency of fully panic behavior (Type 3) is longer than Type 1 but shorter than Type 2 due to the random selection of path finding. But it is also avoided because it may cause congestion, tramping or serious injury. Case 4 was implemented for more realistic simulate. In this case, each evacuee was set to one type randomly (Type1: 3289 pedestrians, Type 2: 3352 pedestrians, Type 3:3359 pedestrians).

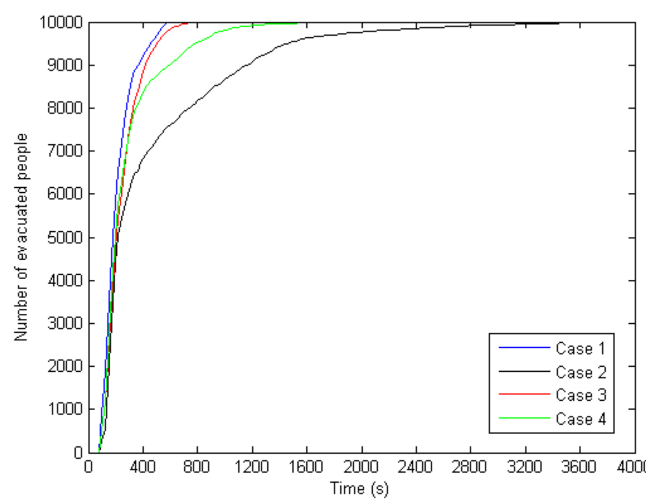


Fig. 2. Varying number of evacuated individuals versus time

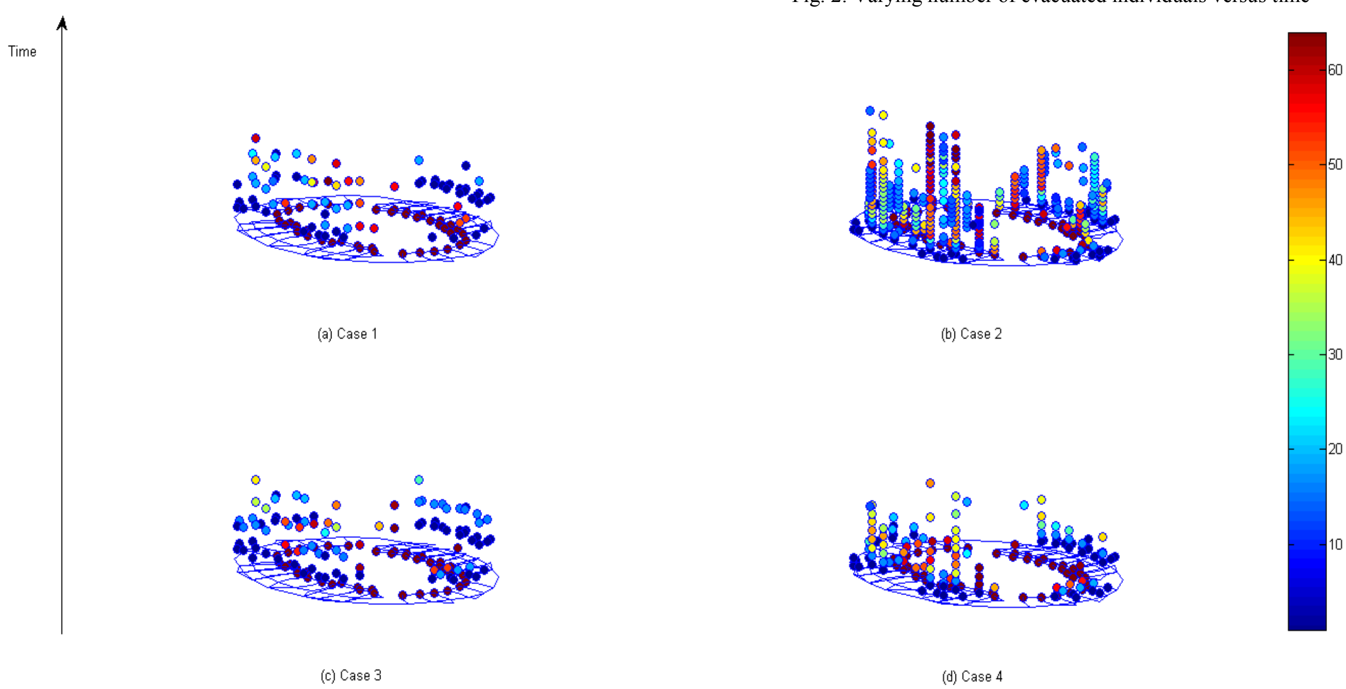


Fig. 3. The space-time distribution of evacuees

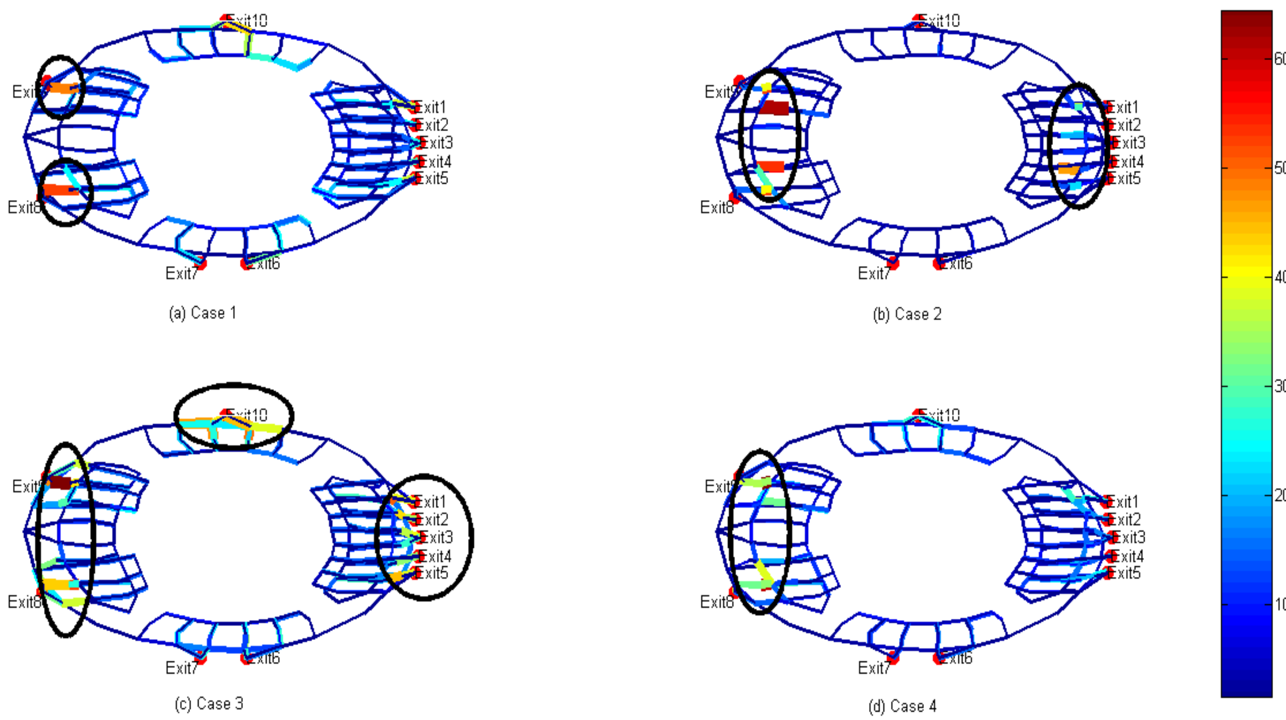


Fig. 4. Passing frequency of passages

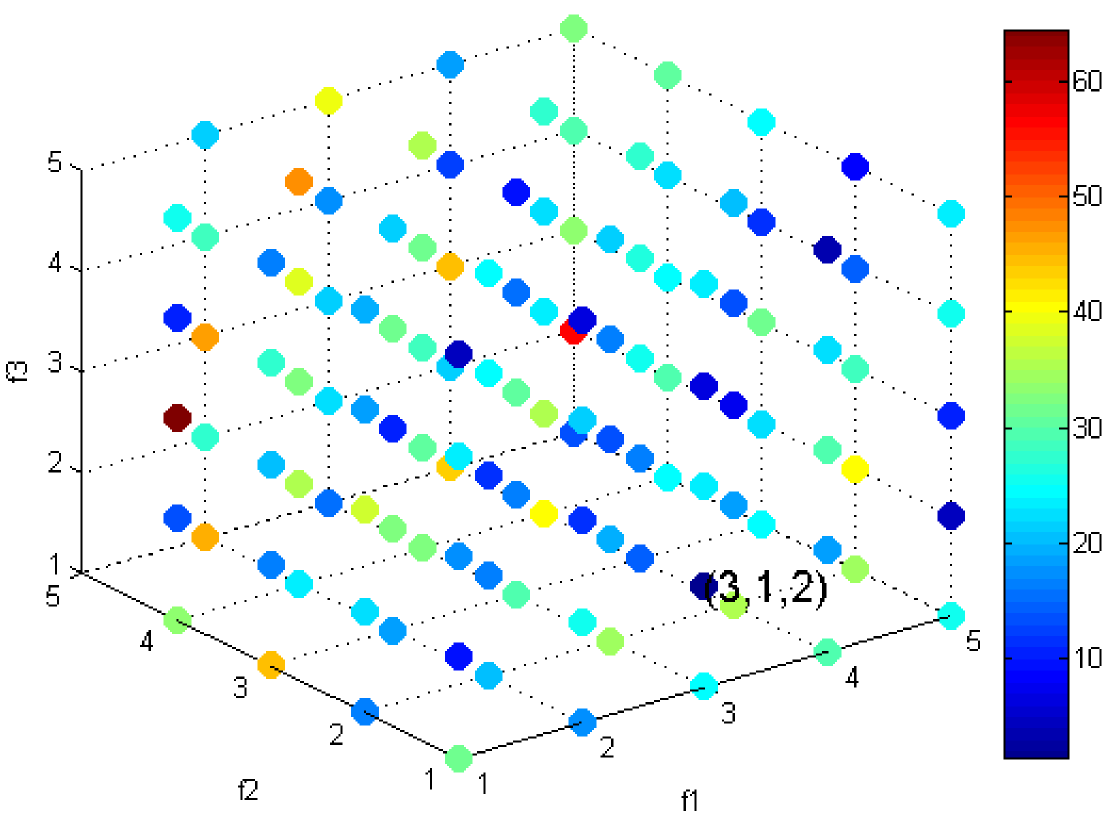


Fig. 5. Evacuation time with different f_1, f_2 and f_3

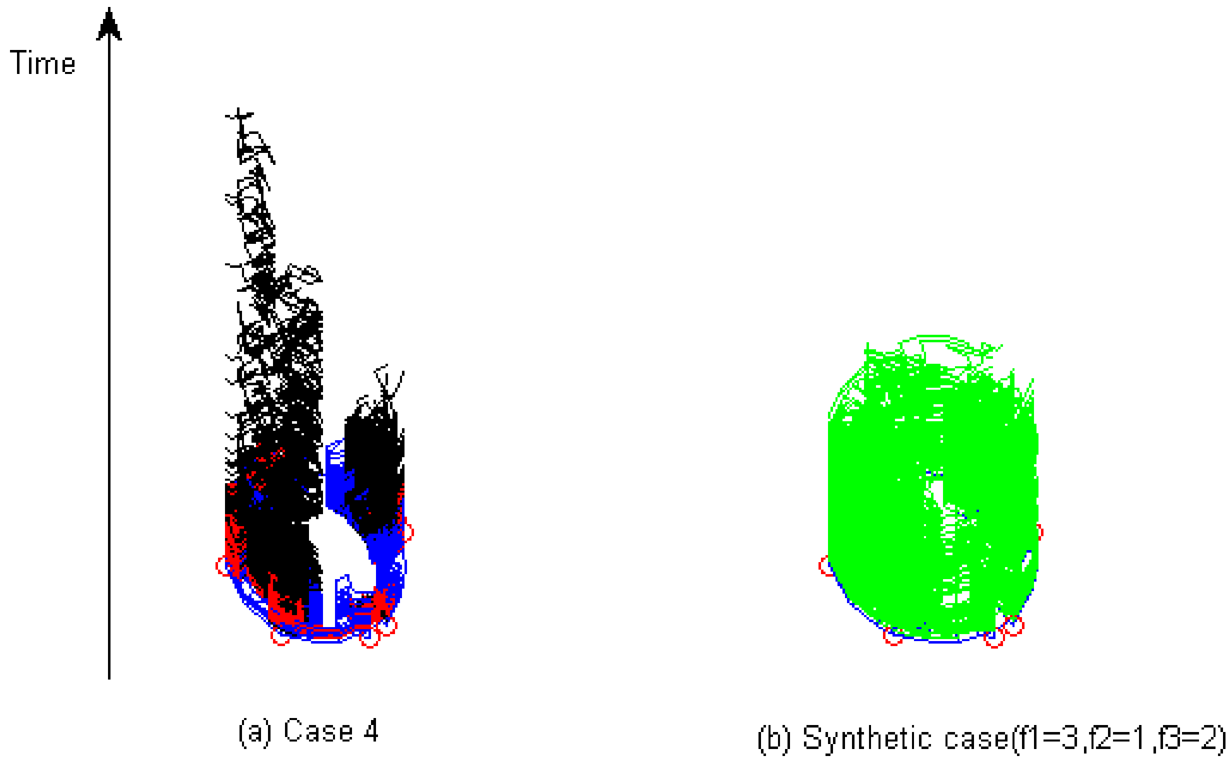


Fig. 6. The space-time evacuation routes

Fig. 3 shows space-time distribution of evacuees by different colors changing from blue to red in the legend, representing the number of different evacuees changing from small to large. It can be seen that many evacuees crowded in bleachers at beginning in Case 1 due to the will of quickest evacuation, as well in Case 3 owing to the congestion caused by panic. For Case 1, the congestion is serious at exits at the end of evacuation. In Case 2, congestion lasts from the beginning to the end as a result of group psychology. The space-time distribution keep the moderate level comparing with Cases 1,2,3.

Fig. 4 draws the passing frequency of each passage inside the stadium in four cases. Each passage is depicted in different colors varies from blue to red and width varies from fine to thick to indicate the different frequency through the passage from low to high. The higher passing frequency indicates the higher crowding level as marked areas in Fig.4. It is demonstrated that the congestion may happen in the passages close to exits in Case 1 because the psychology of quickest evacuation. Many passages in Case 2 are crowded as marked and most of pedestrians evacuate from Exits No. 1-5 and Exits No. 8-9 due to the group psychology. Most of passages from the stands to exits are rather crowded in Case 3 as the result of panic. Therefore, these passages marked in Fig.4 need to be considered carefully when making evacuation plans.

The influence of the parameters f_1, f_2, f_3 on evacuation time is shown in Fig. 5. f_1, f_2 and f_3 vary from 1 to 5 respectively, and the corresponding point, whose color changes from blue to red, represents the value of evacuation time, changing from small to large. It can be seen that the evacuation time is shortest when f_1=3 , f_2=1 , f_3=2 . This indicates that during evacuation process, each evacuee should judge rationally and flee away from the path closest to exits. The group psychology is dangerous though it is common. The bigger value of f_2, the longer time it costs.. Furthermore, it is not best with the smallest value of panic factor f_3, a little panic can accelerate evacuation process.

Evacuation routes of all pedestrians in Case 4 and synthetic case (f_1=3 , f_2=1 , f_3=2) are drawn in Fig. 6. In Fig. 6(a), the blue, black and red lines represent the paths of evacuees belong to Types 1, 2, and 3, respectively. It is shown that the clearance time of all pedestrians completing evacuation is shorter with the best parameter setting. And the distribution of routes in space is more reasonable.

The potential congestion level of the stadium during evacuation process is shown in Fig. 7. The node colour varies from blue to red, which indicates that the congestion level of the node varies from low to high. It is demonstrated that most of the roads were not very crowded except the area marked.

This indicates that some effective measures should be taken in this area with more attention.

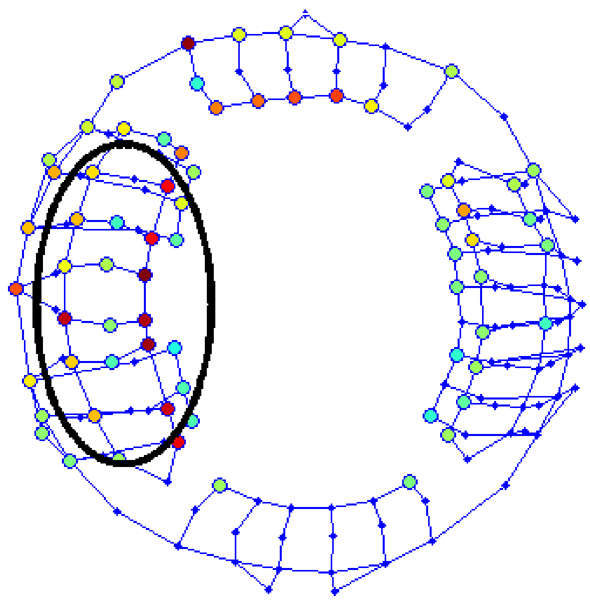


Fig. 7. The potential congestion points (f_1=3 , f_2=1 , f_3=2)

The simulation results compared with the model based on HMERP [17] algorithm are listed in Table IV. It shows that pedestrians belong to Type 1 have the shortest evacuation time for both HMERP and PSO method. And the pedestrians who always want to go with the crowd spend the longest time to reach the exits. Comparing with the HMERP algorithm, the proposed model based on PSO algorithm can achieve better results in the four cases, which demonstrates that the self-learning and social-learning mechanism of particle swarm optimization is more suitable for evacuation simulation.

TABLE IV. SIMULATION RESULTS OF TWO MODELS

Model	Number of pedestrians	Case No.	Evacuation time(s)
HMERP	5000	Case 1	840
		Case 2	8180
		Case 3	2320
		Case 4	2860
PSO	5000	Case 1	360
		Case 2	7620
		Case 3	820
		Case 4	2080

V. CONCLUSION

In this paper, an evacuation simulation model based on particle swarm optimization algorithm is presented. In this model, the fast evacuation, going with the crowd and the panic behaviors are simulated by defining different moving functions of particles. The model is applied to a stadium and simulations are designed to compare the space-time influences by different evacuation behaviors. The simulation results show that during evacuation process, the behavior of the quickest evacuation and modest panic can improve efficiency, while the behavior of going with the crowd should be avoided. Furthermore, the synthetic case which integrated three psychologies is analyzed and the best parameter setting is discussed to obtain best evacuation efficiency.

Since the pedestrians' behaviors are much more complex in emergency situation. Future study involves the simulation of more factors, such as age, gender, habits, etc and the application of the model to different emergency situations.

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