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Investigation and Analysis on Evacuation Behavior of Large Scale Population in Campus

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Abstract

The field investigation on the crowd evacuation behavior of young people is carried out in Northeastern University of Shenyang under time pressure, such as the class break at 9:55-10:05am and the lunchtime at 11:55-12:15am.The database of pedestrian walking velocity of different behavior characteristics is established and the large scale crowd evacuation behavior characteristics are analyzed. Based on the application of the Self-adaptive Ant Colony Optimization Algorithm, the large scale evacuation path is optimized to the whole scale. Based on the academic pedestrian flow investigation and the route optimization analysis, the large scale evacuation behavior in campus is simulated and compared by FDS+Evac. The analysis results show that the personnel flow coefficient will be increasing under time pressure, and the crowding will be produced easier as the same reason. Large scale evacuation plan can be optimized based on the Self-adaptive Ant Colony Optimization Algorithm, which can not only reduce the Real Safety Evacuation Time (RSET) on the whole scale, it can also effectively alleviate the congestion of the crowd in the main exit of evacuation route.

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Keywords: large scale population; crowd flow coefficient; self-adaptive ant colony optimization algorithm; evacuation path

1. Introduction

As a typical public arena with the dense crowd in various types of middle and primary school in China, the problems of potential safety hazard on crowd flow are outstanding. The trample accidents occur frequently here and there in emergent situations such as fire and earthquake because of the confused emergency evacuation sequence which is lead by the weakness of safety consciousness of students and the lack of emergency evacuation management measures in campus, etc. For example, the trample accident which made 47 persons hurt was occurred in Aksu city in Xinjiang in Nov, 2010. In December of 2009, another serious accident which took away 8 children's lives happened in Xiangxiang city in Hunan. The investigation and analysis on evacuation behavior of large scale population in campus will provide scientific basis for the plan making and drilling of the emergency evacuation, and provide guiding significance to large-scale population emergency evacuation in city in unconventional emergency.

Many scholars at home and abroad carry out a lot of research work of human evacuation behavior from the beginning of last century. Some of them paid attention to the study on human behavior in building fires. The others paid attention to do some simulation about evacuation behavior or analyze the emergent resources distribution and evacuation plan optimization in a wide filed including natural disaster areas such as typhoon and torrent, production accident such as fire and the leakage of toxic gas, as well as terrorist attack, etc.

The database of pedestrian walk velocity of different behavior characteristics is established based on the investigation at high density in academic building, canteen and dormitory in rush time period such as class break and lunchtime. The large scale crowd evacuation behavior characteristics are analyzed at the same time. According to the data-collection of different behavior, the large scale evacuation behavior in campus is simulated by FDS+Evac. The large scale evacuation plan is optimized by the Self-adaptive Ant Colony Optimization Algorithm(SACOA). The large scale evacuation plan in campus is

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evaluated with performance-based simulation of the large scale evacuation behavior in FDS+Evac based on the optimal evacuation route choice of personnel evacuation path by SACOA.

2. Investigation and statistical analysis of crowd evacuation behavior

In order to analyze the pedestrian behavior characteristics of crowds in campus and set up the foundation of parameters which will be used in the FDS+Evac evacuation simulation, the datum of the characteristics of pedestrian flow behavior are investigated and statistically analyzed in some key exits of academic buildings.

2.1. Investigation in Campus

As is known, there are always large crowds and sometimes congestion on the main exits or corridors in academic building when needle points to 10 o'clock in the morning and students rush to and from the classroom under time stress. Similarly, congestion can also be observed at the exits of canteen at lunch time almost every day under the strong motion for food. Based on the aforesaid reasons, the major observation time is selected when the maximum density of crowds appears, saying 9:55am-10:05am, as well as the lunchtime at 11:55-12:15am. The observation sites include the north and south gate of the 1# academic building, and the north gate of the NO.1 canteen which is connected with NO.1 dormitory (see Fig.1 and Fig. 2).

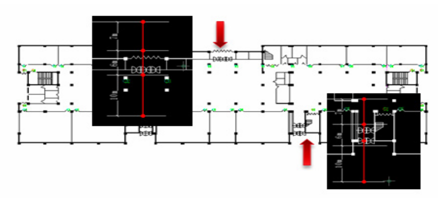


Fig. 1 Observation figure of teaching building exits

Fig.2 Observation of human movement behavior outside the school canteen

2.2. Statistical Analysis of Investigation Datum

According to the analysis of investigation datum (Fig.3 and Fig.4) and the comparison with other researchers, when the density of crowding is smaller under time stress, the analysis of different researchers is similar. That is to say, the pedestrian walk velocity is decreased with the increase of crowd density, while the crowd flow coefficient is increased when the crowd density increased and is below 3 p (person)/ m2. When the crowd density reaches to 3 p (person)/ m2 under time pressure, the value of crowd flow coefficient reached the maximum at 1.65p/m.s. When the value of crowd density stays between 4-5p / m2, the value of personnel flow coefficient is 1.4p/m.s. If the crowd density continued to increase, the crowd flow velocity will be slow down until stagnation appears. It will lead to the decline of crowd flow coefficient.

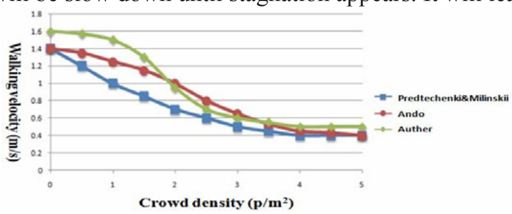


Fig. 3 Comparative analysis between human density and velocity

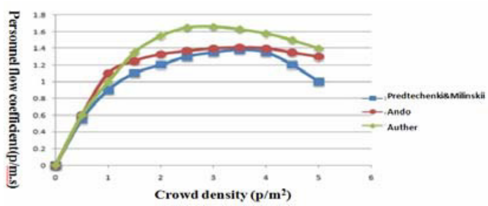
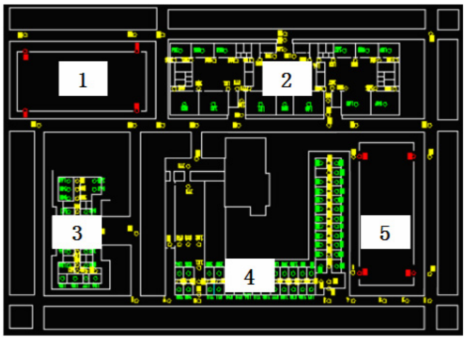


Fig.4 Comparative analysis of coefficient of human mobility

The comparative analysis results show that the crowd flow coefficient of younger students will be increasing under time pressure, and the probability of trample accident will be increased because of the flustered and unassisted crowd, confused evacuation and easer trip at the exits where the gathered high density is easy to conjecture in emergency.

3. The initial input parameter of FDS+Evac Simulation Model

The simulated evacuation area includes five major parts, saying, teaching building, dormitory and canteen, hospital and two refugee squares(Fig.5), and the total evacuation area in campus is about 21,108 square meters, saying, 239m length, 172m width and 11m height. The number of the large scale population in campus is 4500p, including 2000 person in teaching building, 2200 person in the connected building of dormitory and canteen, and 240 person in the school hospital. In order to disperse the flowing of the evacuation area in the process of evacuation reasonably, two evacuation squares are distributed in the diagonally opposite position of the area combining with the actual situation. The area of each refugee square is 2100 square meters.



1. Evacuation square A (2100m^2) 2. Teaching building (4403m^2) 3. Hospital (2520m^2)
4. Dormitory and canteen (7400 m^2) 5. Evacuation square B (2100m^2)

Fig. 5 Plan of the campus evacuation area

FDS+Evac use the laws of mechanics to follow the trajectories of the agents during the calculation. Each agent follows its own equation of motion:

$$m_i \frac{d^2 x_i(t)}{dt^2} = f_i(t) + \delta_i(t) \tag{1}$$

Where $x_i(t)$ is the position of the agent i at time t, mi is the mass, and the last term, $\delta_i(t)$, is a small random fluctuation force. The velocity of the agent, vi(t), is given by dxi/dt, fi(t)is the force exerted on the agent by the surroundings that is defined as follows:

$$fi = \frac{mi}{\tau i}(v_i^0 - v_i) + \sum_{j \neq i}(f_{ij}^{soc} + f_{ij}^{att} + f_{ij}^{c}) + \sum_{\omega}(f_{jw}^{soc} + f_{jw}^{c}) + \sum_{k} f_{ik}^{att} \tag{2}$$

Where the first sum describes agent-agent interactions, the second sum describes agent-wall interactions, and the third sum describes agent-environment interactions.

The initial walk velocity in straight road and downstairs is shown in Table1.

Table 1 walking velocity of different kinds of people in simulation

Types of people	Walking velocity in straight road（m/s）			Walking velocity in incline surface（m/s）		
	Max	AVG	Min	Max	AVG	Min
Male students	1.6	1.4	1.2	1.1	0.9	0.7
Female students	1.5	1.3	1.1	1.0	0.8	0.6
Male staffs	1.4	1.2	1.0	0.9	0.7	0.5
Female staffs	1.3	1.1	0.9	0.8	0.6	0.4

4. Optimized evacuation management in campus

4.1. Self-adaptive Ant Colony Optimization Algorithm

As one kind of ancient social insects, ants owned the ability of communication and information transfer with each other. Ants can leave the pheromone which product the track of pheromone on the route to the nest from the food source and the return. The final path emerges as the one that the more ants walked, the more pheromone they leave, and the greater probability others choose. A new optimization algorithm, Ant Colony Optimization(ACO), firstly proposed by M.Dorigo and V Maniezzo, depended on the inspire by the foraging behavior of real ants in nature. ACO can be used to solve a series of combinatorial optimization problems.

There are some problems of traditional ACO, such as the longtime search, early-maturing and easier to stagnate. The Self-adaptive Ant Colony Optimization Algorithm(SACOA) of human evacuation is built combining with the characteristics of evacuation behavior in emergency, and get the good balance between accelerating convergence and prevention of early-maturing and stagnate based on the update of dynamic pheromone. The rules of Self-adaptive Ant Colony Optimization Algorithm of human evacuation are as follow.

4.1.1 Route choice rules by Adaptive Ant Colony Algorithm

According to the dispersion of node w_i, next evacuation route w_iw_j is selected among the global collection of $W = \{w_i w_j\}$ based on the following rules:

$$W = \{w_i w_j\} = \begin{cases} A, A \subset W, and \max\limits_{w_j \in A_k} \{[\tau_{w_i w_j}(t)]^{\alpha} [\eta_{w_i w_j}(t)]^{\beta}\} \cdots\cdots\cdots q \le q_0 \\ C_W A = \{x, x \in W, x \notin A\}, P(w_i, w_j) \cdots\cdots\cdots\cdots\cdots\cdots q > q_0 \end{cases} \tag{3}$$

Among that, q is a uniformly distributed random variable. if $q \leqslant q_0$, evacuees focus on a relatively concentrated searching domain, the route with the maximum pheromone and the maximum inspiration stimulator factor will be selected in next iteration in child collection A. Among that, $\tau_{w_i w_j}(t)$ is the pheromone of route w_iw_j at time moment t, $\eta_{w_i w_j}(t)$ is the inspiration function, α and β are adjustable parameters to weight the significance of pheromone and length in the selection of next node. If $q > q0$, evacuees on node w_i search for the next optimal node w_j in the left collection of A, which is defined as $C_W A = \{x, x \in W, x \notin A\}$. The search process is random, the route selection probability $P(w_i,w_j)$ in the left collection $C_W A$ is:

$$P(w_i, w_j) = \frac{[\tau_{w_i w_j}(t)]^{\alpha} [\eta_{w_i w_j}(t)]^{\beta}}{\sum\limits_{s \in N_i^{k_s}} [\tau_{w_i w_s}(t)]^{\alpha} [\eta_{w_i w_s}(t)]^{\beta}} \quad , \qquad \tau_{w_i w_j}(t) < \Gamma_{w_i w_j;} \quad w_j \in A_k, \tag{4}$$

$\eta_{w_i w_j}(t)$ is named as inspiration function, it is defined as follows:

$$\eta_{w_i w_j}(t) = \frac{1}{d_{w_i w_j}(t)} \tag{5}$$

Where there, $d_{w_i w_j}(t)$ is the equivalent length of route w_iw_j at any moment in time t. For any member of evacuee person k, with the decrease of the equivalent length of route w_iw_j, the inspiration function $\eta_{w_i w_j}(t)$ increases, it means that evacuee k has a higher expectation degree on the evacuation action from w_i to w_j.

4.1.2Pheromone Function

On the initial moment time t=0, the information amount of every route is supposed to be constant, that is to say, $\tau_{w_i w_j}(0) = \text{const}$. In case of group characterization and the resulted crowd stagnation in the evacuation process, the pheromone of route should be updated timely.

a) Local pheromone update

The significant reduction of pheromone is mainly aimed to reach the average amount of pheromone of every possible route so that evacuees increase stronger search ability for other currently less interested routes. Local pheromone update is based on following equations

$$\tau_{ij}(t+1) = (1-\xi)\tau_{ij}(t) + \xi \bullet \tau_0 \tag{6}$$

Where there, ξ is the volatile coefficient of local pheromone update, 0< ξ <1, τ_0 is the initial value of pheromone function

b) Global pheromone update

Global pheromone update is based on following equations:

$$\tau_{ij}(t+1) = (1-\rho)\tau_{ij}(t) + \rho \Delta \tau_{ij}^{gb} \tag{7}$$

$$\Delta\tau_{ij}^{gb} = \begin{cases} \dfrac{1}{L^{gb}} \cdots\cdots\cdots if\ \ route\ w_i w_j\ included\ is\ an\ optimal\ route \\ 0 \cdots\cdots\cdots\cdots others \end{cases} \tag{8}$$

Among that, Lgb is the equivalent length of the currently optimal route; ρ∈（0，1） is the volatile coefficient of the overall pheromone, (1- ρ) is the residual coefficient of the pheromone. The Human Evacuation Route Optimization Model established here changes the assignment value of ρ adaptively according to the following rules:

$$\rho(t+1) = \begin{cases} 0.95\rho(t) & if \quad 0.95\rho(t) \geq \rho_{\min} \\ \rho_{\min} & otherwise \end{cases} \tag{9}$$

Among that, ρ min is the minimum of ρ in case that the convergence rate becomes too low． In the initial stage of solving, a bigger ρ is necessary to increase the searching efficiency of the Ant Colony Algorithm. With the increased cycles, if there is no much difference in two optimal solution processes, it indicates that the optimization process goes into an extreme point and is not necessarily a global optimal solution. As a result, ρ should be decreased to enhance the search ability of algorithm.

4.2. Path optimization of large scale population in campus

The entire evacuation area in simulation was separated as space mesh by the Self-adaptive Ant Colony Optimization Algorithm. The nodes of evacuation area were divided into three kinds, such as the originating nodes, transmission nodes and the root nodes which represent the safety exits. Outflow cluster can be passed by the originating nodes but into cluster. The unidirectional flow cluster from originating nodes and transmission nodes can be passed by the root nodes. Transmission nodes are the necessary nodes which connected from originating nodes to root nodes in the evacuation process.

8 root nodes which instead of exits of evacuation squares, 85 origination nodes which instead of middle of every room in each buildings, and 113 transmission nodes were set in the entire campus.

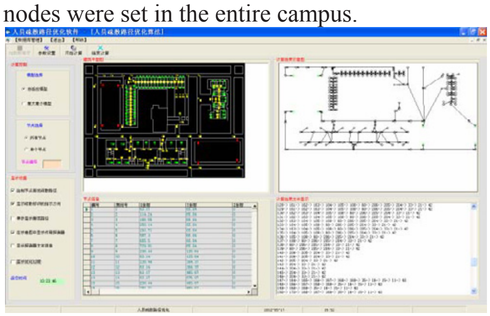


Fig.6 path optimization of the campus evacuation area

The database of parameter about detailed information such as properties, and coordinates and the number of adjacent nodes of all nodes in evacuation area were built based on the characteristic of personnel distribution and evacuation paths after separating the entire evacuation area as space mesh. In order to optimize the evacuation path, the database was used by self-adaptive ant colony optimization algorithm. The number of calculation iterations was set as 1000.

According to the result of optimization calculation, the optimal path of each person in different places in campus was calculated and realized clearly by self-adaptive ant colony optimization algorithm(Fig.6). The basic parameters which depended on the optimal results of selected paths and utilization rate of evacuation exits were set on the large scale population in campus.

4.3. comparative analysis of evacuation management in campus

Two different situations about evacuation of large scale population in campus were designed depended on the same condition of number and the walking velocity of population. The situation one was defined as the blank one without any evacuation management measure in campus. In the same way, the situation two was defined as the contrast one with evacuation management measure of path optimization. The same degree of familiar (population in campus to every building exit, every entrance of squares and every evacuation path) was designed by FDS+Evac in situation one. It meant there was no difference among the probability of choice when the building exits, entrances of squares and evacuation paths had to be selected. On the contrary, the different degree of familiar was designed depended on the results of self-adaptive ant colony optimization algorithm in situation two. The value of probability of choice was set as 1 when the optimal path was selected, the value of probability of choice was set as 0 for the other paths.

According to the results of the simulation, the comparison of the Real Safety Evacuation Time (RSET) in different situations is indicated in Fig.7, and screenshots of evacuation simulation in different situations about 200s after the beginning of the evacuation are shown in Fig 8.

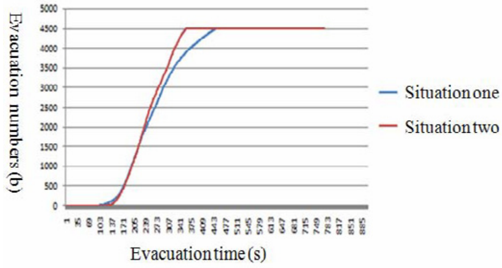
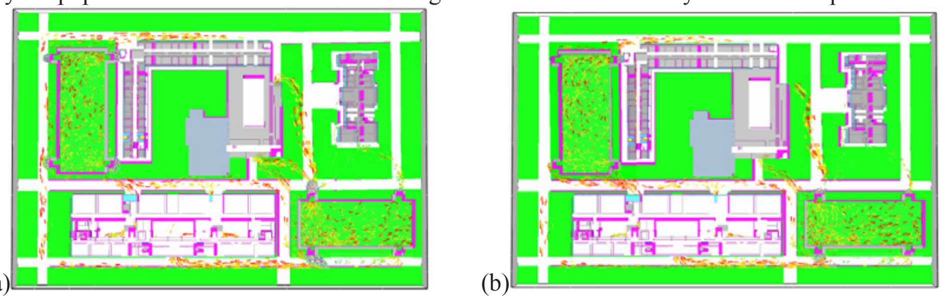


Fig.7 Comparative curve of RSET in different situations

Compare with situation one, the REST was shorten to 372s from 450s if evacuation management measure of path optimization was required. Furthermore, as shown in Fig.8, the slope of curve of situation two is not changing obviously. It is clear to see that the retention phenomenon was not produced in the whole evacuation process of large scale population in campus when evacuation management measure of path optimization was required. The state of crowd congestion was not grown obviously for population at the exits of each building and the entrance of every evacuation square.

(a) (b)



Situation one Situation two

Fig.8 Screenshots of evacuation simulation in different situations

Based on the screenshots of evacuation simulation, population who had been escaped to outside from buildings almost was swarming into the evacuation squares on a large scale at the evacuation time moment of 200s. The state of crowd congestion was grown obviously if evacuation management measure of path optimization was not required. The probability of congestion accident will be increasing because of frightened and precipitance of population in emergency. The evacuation will be shown faster, more unhindered, more safety and more planned after evacuation management measure of path optimization was executed as population started to move at different time in different sites of evacuation area. Therefore, the congestion of the crowd in the main exit of evacuation route can be alleviated effectively and the probability of congestion accident can be reduced largely by the evacuation management measure of path optimization which was executed by Self-adaptive Ant Colony Optimization Algorithm as foundation setting parameters.

5. Conclusions

According to the results of analysis, conclusions are obtained as follows:

a) When the value of crowd density is 3 p (person)/ m2 under time pressure, the value of personnel flow coefficient reached the maximum of 1.65p/m.s. The pedestrian walking velocity will be slow down as the crowding when the density of crowd is continued to increase. It will lead to the decline of the value of personnel flow coefficient;

b) The optimal path of large scale population in campus can be optimized based on the Self-adaptive Ant Colony Optimization Algorithm, which can not only reduce the Real Safety Evacuation Time(RSET), it can also effectively alleviate the congestion of the crowd in the main exit of evacuation route in order to reduce the probability oftrample accident. It will be helpful to evacuate to a sage area for crowd in time.

Acknowledgements

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