

Optimal Location Model and Algorithm of the Emergency Exits

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Abstract

In evacuation, the emergency exits are important. The exit's location is a key which decides the success of evacuation. So how to build the emergency exits is worth to researching. In this paper, the effect of the emergency exit and main door are considered. The emergency exit's ordinate is defined as the independent variable. Then a model of exits is proposed and the golden section algorithm is used to find the most suitable location. At last, it is verified that the method is effective and feasible.

Keywords Evacuation Emergency exits Golden section algorithm Simulation.

1 Introduction

Emergency evacuation is a mass movement of people from areas affected by disasters, such as earthquake, hurricane, and fire, to safer in a timely manner to mitigate disastrous consequences. It involves the choice of routes. If people can quickly find the exit and through the door, then hope of escape is big in the danger. So the location of emergency exit is important. And the right location of the exit can increase the rate of evacuation. In recently, the researchers have found many factors which affect the evacuation [1-5] and provide many evacuation models [6-9]. Although some researches show that the building's structure can affect the evacuation [10-11], the most of the research presupposes the building's layout. They didn't consider the effect of the exit's position. It means the emergency exit, main door and access are designed and don't change in the researches. Obviously, the effect of layout is ignored. If we don't consider the main door in evacuation process, obviously the middle sides is the most suitable exit's location in some symmetrical architect. But if main door can be used well in the evacuation, the new evacuation route is added. So the exits and main door is in some suitable locations, maybe it can shorten the evacuation time. It's useful to evacuation. So it's important to finding the suitable locations.

In this paper, we try to find the suitable location of exit's location. So we only consider the effect of exit's location. And in the research, we also consider the main door in the evacuation. In order to finding the suitable location of exit, we use the golden section algorithm. At last, we discuss and conclude the numerical results by numerical examples.

2 Description

The authors consider a population of N individuals and assumed that each individual $n_k (k = 1, 2, \dots, N)$ moving by the speed V_k in the emergency condition and randomly select the evacuation route. Generally, the evacuation time is that how many times is used between the beginning of escape and all people arriving at the safe place. Because we hope that we can save more people in shortest time, so the evacuation problem can be described by the object function as follows:

$$\min f = \max\{T_i(n_i) \mid i = 1, 2, \dots, N\} \tag{1}$$

where $T_i(n_i)$ is the evacuation time of the i^{th} individual.

In the articles, we consider the situation as follow. All individuals were randomly distributed in space according to the population density, and their initial velocities equal to zero. Everyone has two choose, main door or emergency exits, to escape. We assume that each individual is a particle without quality and each individuals speed is same. We set up a coordinate system as Fig.1 and use the array (x_i, y_i) to show the location of the i^{th} particle.

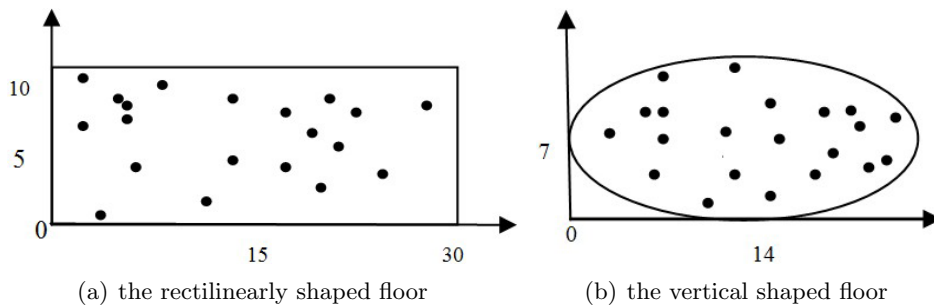


Fig.1 The initial distribution of the people on the floor

We assume the number of main door is l , and the one of exits is w . Then the k th particle's evacuation time by the each door can be as: $(k = 1, 2, \dots, N)$

$$t_i(n_k) = \frac{S_{ki}}{V_k} \quad i = 1, 2, \dots, l \tag{2}$$

$$t_j(n_k) = \frac{S_{kj}}{V_k} \quad j = l + 1, l + 2, \dots, l + w \tag{3}$$

which the S_{ki} is the shortest distance between the i^{th} main door and the k^{th} particle, the S_{kj} is the shortest distance between the j^{th} exit and the k^{th} particle. So the k th particle's evacuation time T_k is satisfied the equation:

$$T_k(n_k) \leq \max\{t_i(n_k) \mid i = 1, 2, \dots, l, l + 1, l + 2, \dots, l + w\} \tag{4}$$

Summary, the evacuation problem can be as:

$$\begin{aligned} \min f &= \max\{T_k(n_k) \mid k = 1, 2, \dots, N\} \\ &\leq \min \max_{1 \leq k \leq N} \{t_i(n_k) \mid i = 1, 2, \dots, l, l+1, l+2, \dots, l+w\} \end{aligned} \quad (5)$$

Obviously, when the each people choose the shortest path, the equation is established.

The people's location is fixed. Perhaps, the each evacuation time maybe change, if the emergency exit's location is changed. Because the distances between the exits and the k^{th} particle are changed. So the location of emergency exit effects the evacuation. As follow, we consider the exit's location. We assume (x, y) is the coordinate of emergency exit and $f(x)$ is the max evacuation time. In articles, we only consider the situation that there are two emergency exits which are distributed on the right and left sides of building respectively. In the situation, the coordinate y is 0 and the x is the independent variable. So we only consider the coordinate of emergency exit x . Absolutely, the $f(x)$ is decided by x . Because we hope to find the most suitable location of emergency exit, which the evacuation time is the shortest, so we can setup the function as follows:

$$\begin{aligned} \min f(x) &= \max\{T_k(n_k, x) \mid k = 1, 2, \dots, N\} \\ \text{s.t. } &a \leq x \leq b \end{aligned} \quad (6)$$

where a is the index of wall-width, b is the superscript of wall-width, and x is the coordinate of emergency exit's center point.

3 Algorithm

According to the shortest path theory, when everyone selects the shortest path, the each individual's evacuation time and total time are the shortest. We select the shortest path as the each individual's escaping path. Let each individuals distance function as: $(k = 1, 2, \dots, N)$

$$S_k(x) = \min\{S_{ki}(n_k, x) \mid i = 1, 2, \dots, l, l+1, l+2, \dots, l+w\} \quad (7)$$

Absolutely, the function $S_k(x)$ is the linear and the $f(x) = \max\{T_k(n_k, x) \mid k = 1, 2, \dots, N\}$ is the linear, too. We can solve the problem by the optimization algorithm. We hope that we can exclude the unsuitable position in the process of searching. So we select the golden section algorithm to solving the problem. The golden section algorithm is a kind of optimization algorithms for solving one-dimensional problem as follow:

$$\begin{aligned} \min f(x) \\ \text{s.t. } &a \leq x \leq b \end{aligned} \quad (8)$$

where $f(x)$ is a uni-modal descent function. The method is a iteration algorithm and find the best solution by shorting the independent variables interval in each iteration, which reduced probability is the 0.618.

The algorithms step is as follows:

Step1:define the a, b, ε and (x_i, y_i) , $i = 1, 2, \dots, N$;

Step2:define:

$$x_2 = a + 0.618 * (b - a) \quad (9)$$

$$S_k(x_2) = \min\{S_{ki}(n_k, x_2) | i = 1, 2, \dots, l, l + 1, l + 2, \dots, l + w\} \quad (10)$$

$$f_2 = \max\{T_k(x_2) = \frac{S_k(x_2)}{V_k} | k = 1, 2, \dots, N\} \quad (11)$$

go to step3;

step3:define

$$x_1 = a + 0.382 * (b - a) \quad (12)$$

$$S_k(x_1) = \min\{S_{ki}(n_k, x_1) | i = 1, 2, \dots, l, l + 1, l + 2, \dots, l + w\} \quad (13)$$

$$f_1 = \max\{T_k(x_1) = \frac{S_k(x_1)}{V_k} | k = 1, 2, \dots, N\} \quad (14)$$

go to step4;

Step4: if $|b - a| \leq \varepsilon$, define

$$x^* = \frac{a + b}{2} \quad (15)$$

and stop; else go to step5;

Step5: if $f_1 < f_2$, define $b = x_2$, $x_2 = x_1$, $f_2 = f_1$ then go to step3;

if $f_1 = f_2$, define $b = x_2$, $x_2 = x_1$, $f_2 = f_1$, then go to step3;

if $f_1 > f_2$, define $a = x_1$, $x_1 = x_2$, $f_1 = f_2$, then go to step6;

Step6: define

$$x_2 = a + 0.618 * (b - a) \quad (16)$$

$$S_k(x_2) = \min\{S_{ki}(n_k, x_2) | i = 1, 2, \dots, l, l + 1, l + 2, \dots, l + w\} \quad (17)$$

$$f_2 = \max\{T_k(x_2) = \frac{S_k(x_2)}{V_k} | k = 1, 2, \dots, N\} \quad (18)$$

then go to step4.

4 Simulation results

4.1 Architectural attributes

To design the suitable position of exit, the authors have designed the building layout to be two shaped. One is the rectilinearly shaped building, which each floor is a 10×30 units orthogonal area. The another is the vertical shaped building, which major semi-axis of floor is 14units, and the minor semi-axis is the 7units. In the two layouts, we consider the one kind of scenario that main entrance is placed on the bottom middle-south side of the floor. Because the exits are usually placed on the right and left sides in most buildings, we consider the exits on the right and left sides, and they are opposite. The space occupancy levels vary in square meter per person ranging within the limits of space and occupancy density standards. In the two scenarios, the authors used occupancy densities of 0.15, 0.25, 0.5, 0.7, and 1.2 person/units

4.2 Simulation and numerical tests

To verify the feasible and effective of the way, it's run each scenario for six hundred times, take the average of the evacuation time, and analyze the all results. In the all tables, where x , is the center point's coordinate of emergency exit, P is occupancy densities, and p is the percentage of people selecting the emergency exit. In order to clearly verify our conclusion, we compare the number results to the evacuation time of building with emergency exits in center sides.

Simulation numerical results reveal the following:

Table 1.1 The results of rectilinearly shaped with one main entrance

P (person/m ²)	situation of emergency exit					
	Number of $0 < x < 1$	Number of $1 \leq x < 2$	Number of $2 \leq x < 3$	Number of $3 \leq x < 4$	Number of $4 \leq x < 4.9$	Number of $4.9 \leq x < 5.1$
0.15	1	7	4	176	44	3
0.25	0	1	5	98	55	14
0.5	0	0	0	128	39	8
0.7	0	0	0	100	49	12
1.2	0	0	0	87	34	12

Table 1.2 The results of rectilinearly shaped with one main entrance.

P (person/m ²)	situation of emergency exit				
	Number of $5.1 \leq x < 6$	Number of $6 \leq x < 7$	Number of $7 \leq x < 8$	Number of $8 \leq x < 9$	Number of $9 \leq x < 10$
0.15	40	171	50	81	53
0.25	0.45	191	63	70	32
0.5	82	208	50	50	35
0.7	103	201	53	44	38
1.2	128	200	66	40	33

Table 2 The results of vertical shaped with one main entrance.

occupancy densities	Building with emergency exits in center sides		Results of simulations	
P (<i>person/m²</i>)	Average-time (unit)	the percentage of people selecting the emergency exit P	Average-time (unit)	the percentage of people selecting the emergency exit P
0.15	6.51	0.51966	6.43	0.51049
0.25	6.66	0.51896	6.56	0.51319
0.5	6.78	0.52090	6.67	0.51368
0.7	6.82	0.51860	6.71	0.51167
1.2	6.89	0.51890	6.77	0.51450

Table 3.1 The results of vertical shaped with one main entrance.

P (<i>person/m²</i>)	situation of emergency exit						
	Number of $0 < x \leq 1$	Number of $1 < x \leq 2$	Number of $2 < x \leq 3$	Number of $3 < x \leq 4$	Number of $4 < x \leq 5$	Number of $5 < x \leq 6$	Number of $6 < x \leq 6.9$
0.15	13	9	20	8	10	15	2
0.25	11	5	10	13	4	7	1
0.5	2	0	7	6	2	3	0
0.7	0	2	8	3	9	4	1
1.2	0	0	1	2	0	2	0

Table 3.2 The results of vertical shaped with one main entrance.

P (<i>person/m²</i>)	situation of emergency exit						
	Number of $6.9 < x \leq 7.1$	Number of $7.1 \leq x < 9$	Number of $9 \leq x < 10$	Number of $10 \leq x < 11$	Number of $11 \leq x < 12$	Number of $12 \leq x < 13$	Number of $13 \leq x < 14$
0.15	7	19	22	115	99	209	52
0.25	6	11	11	103	115	256	47
0.5	1	2	8	101	65	341	62
0.7	0	2	3	87	52	378	60
1.2	0	2	4	79	22	411	77

Table 4 The compare of vertical shaped with one main entrance.

occupancy densities	Building with emergency exits in center sides		Results of simulations	
P (<i>person/m²</i>)	Average-time (unit)	the percentage of people selecting the emergency exit P	Average-time (unit)	the percentage of people selecting the emergency exit P
0.15	7.78	0.64214	5.62	0.68798
0.25	8.22	0.64292	5.94	0.67642
0.5	8.62	0.65034	6.18	0.68156
0.7	8.81	0.64968	6.26	0.68131
1.2	9.01	0.64573	6.37	0.68303

5 Discussions and Conclusion

From the table 1.1, table 1.2, table 3.1, and table 3.2, it can be known that the x are not distributed randomly, but most in some areas. The occupancy density is more, the number of x 's appearance is larger in these areas. In the rectilinearly shaped building, there are about 50% x in the area from 5.1 to 7. In the vertical shaped building, the x is the most in the areas from 12 to 13. And both of these numbers are rising with the occupancy density's raising. In the centre area, the percentage of x 's appearance is less than 2.5% in each simulation, both of two shapes. Obviously, the more the occupancy density is, the smaller the individual's distributive space is. So the regularity is clearer as the density raising. These show that the effect of emergency exit is existent and the center point is not the suitable place for buildings of this size and shape. Because that if the effect isn't existent, the distribution of x is random and no regular.

From the table 2 and table 4, the evacuation times of simulations are shorter than the one of situations which emergency exit is in the center of right and left sides, although the p are close in each comparison. It shows the location of emergency exits is effect the evacuation, and the center point is not necessarily the most suitable position. The suitable location of emergency exit can shorten the evacuation time.

So the authors conclude the conclusions as follow:

1. The location of emergency exit effects the evacuation in some way.
2. The suitable place of emergency exit is related to the shape of building, occupancy density, and the layout and people distribution. The center point of left and right sides is not necessarily the most suitable position in different situation.
3. Golden section algorithm about searching the emergency exit is effective. Because the distribution of people is random and irregular in each simulation, so the results are not clustering some point. But when a building is designed and built, the building's shape, the buildings layout and the distribution of people can be estimated. So for buildings, we can use the golden section algorithm to search the emergency exit in base of some constraint, such as the shape of building, the width of exit, the pass-rate per unit of exit and the estimable distribution of person.

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