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Evacuate the Crowd in the Louvre

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Abstract: Taking the Louvre museum, this paper studies a model based on Ant Colony Algorithm, which can adapt to the emergency evacuation of large public places. Further, we improved the model by analyzing potential bottleneck factors and enriching path pheromone and heuristic function of ant colony model. We try to change the model parameters to adjust the model. The result of the analysis model show agreement with the actual result.

Keywords: Louvre museum; Ant colony algorithm; Adaptive; Evacuation path

1. Introduction

1.1. Background

As a sensitive issue, the issue of security has aroused wide concern among people all over the world. The Louvre is one of the world's largest and most visited art museum..It's difficult to plan for emergency evacuation plans within the museum. This paper aims to take the Louvre museum as an example to study a model that can adapt to the evacuation of large public places.

1.2. Restatement of the problem

The problems that we are required to solve in this paper are:
Develop an emergency evacuation model according to the floor plan of Louvre and other information. The model should allow the museum leaders to evacuate visitors from the museum and emergency personnel to enter the building as quickly as possible.
Next, we are required to identify potential bottlenecks that may limit movement towards the exits. Also, we should improve our model including a wide range of consideration and various kinds of potential threats in order to satisfy the need of the museum emergency planners.

2. Notation

Table 1. Notation

Parameter	Meaning
$F_i^{(1)}$	Zone i of floor l
T_{ij}	Maximum evacuation time from area I to exit j
$t_{ij}^{(1)}(t)$	The entire path from the stream of people in zone I of floor l to exit j at time t
$d_{is}(t)$	heuristic function
$N_i(t)$	Number of visitors to division I at time t

3. The Improved Ant Colony Model

3.1. Data processing

3.1.1. Evacuation exits and the division of evacuation zones

We only considered five exits：Carrousel exit (D1), pyramid exit (D2), lion gate exit (D3), riche lieu exit (D4) and riwori street exit (D5)[5].
We converted the three-dimensional diagram of the Louvre into a two-dimensional plan。 According to the plan of the Louvre, we can simulate the size of the Louvre as follows: The pavilion is a square with 170m sides. The riche lieu pavilion and the den on pavilion are rectangular, each 50m long on the short side and 480m long on the long side.

3.1.2. Determination of evacuation distance and evacuation speed

From the main entrance is napoleon hall, about 9 meters. The height of the Louvre is 4.5m, and there are 50 steps. The height and width of each step can be calculated as 180 mm and 270 mm respectively. The first flight of stairs is 13.5 metres. Channel size can be measured.
The walking speed of the stairwell satisfies the formula：

$s = k \times (1 - 0.226D)$,

Where, k is related to the height and width of the step, which can be referred to the table, and D is the personnel density.
When the density of personnel is less than 0.92, the moving speed of flat land meets the formula：

$v = (112p^4 - 380p^3 + 434p^2 - 217p + 56)/60$

Considering the age and disability groups, the average stair speed can be estimated to be 1.2 m/s for different regions [6].

3.1.3. Determination of average evacuation time

Calculate the maximum evacuation time according to the maximum flow of people. Based on the normal distribution, we can determine that the maximum number of simultaneous visitors is 21,000. The calculated average evacuation time is 1286.5s, which is the maximum evacuation time. According to the maximum evacuation time and the ideal evacuation time, the evacuation time is 806.64s.

3.2. Improved ant colony algorithm

3.2.1. Model assumption

Assume that the staircase is a one-way staircase. The evacuation time of one-way evacuation is shorter than that of two-way evacuation.
Assume the pheromone concentration of each path is the same at the beginning. The initial state is the same environment.
We will not discuss the influence of heuristic functions for the time being
Assume the visitors are evenly distributed.

3.2.2. The establishment and solution of the model

There is no horizontal evacuation in the evacuation of the first, second and first floors, and the one-way direction of stairs determines that the -2 and -1 floors cannot move upward. Therefore, path planning only needs 0 and -2 layers.
We use the idea of ant colony algorithm to build an improved ant colony model. Observe the calculation results of the model, that is, the change of the optimal path planning and analyze the result.
Step1 Define path pheromone and pheromone update formula
We take the ideal path as the initial path of the model, Sets the pheromone concentration of each route to the longest path according to the planning in evacuation time countdown.
In our Louvre evacuation model

$$t_{ij}^{(l)} = \frac{1}{W_j}(t) + 1/Base_{ij}^{(l)}$$

$Base_{ij}^{(l)}$ is the base movement time from zone i of floor l to zone j,
The solution formula is： $Base_{ij}^{(l)} = R_{ij}^{(l)} / V_{stairs}$
On the type, $R_{ij}^{(l)}$ from the stream of people in zone i of layer l to exit j at time t.

$W_j(t)$ is the estimated waiting time for passing through gate j at time t.
As follows:

$$W_1 = (N_2 / 2 - V_{door} * t) / V_{door}$$
$$W_2 = (N_2 / 2 - V_{door} * t) / V_{door}$$
$$W_1 = (N_5 / 2 - V_{door} * t) / V_{door}$$
$$W_4 = (N_3 / 2 - V_{door} * t) / V_{door}$$
$$W_5 = (N_3 / 2 - V_{door} * t) / V_{door}$$

N_2 is the number of $F_d^{(0)}$, N_3 is the number of $F_b^{(0)}$.
Step2: Determine the threshold
The average evacuation time $\overline{T}$ calculated by the ideal model was used as the threshold r of accumulation of pheromone concentration.
When the heromone concentration on path R_{ij} fits the following $t_{ij}^{(l)}(t) > r$, the flow of people will change under certain probability.
Step3 Determine the mobile function
The total number of people waiting to be evacuated from the Louvre is: $\sum_{i=1}^{14} \mathrm{N}i(t)$, in that I is the number of partitions. We divided the fifth floor into 14 evacuation zones according to different evacuation exits.
In the process, depending on the pheromone concentration $t_{ij}^{(l)}(t)$ and heuristic functions $d_{is}(t)$ of each pathway, using adaptive pseudo-random proportional rules to determine the path.
Doesn's change the path, else

$$j = \begin{cases} \max\{t_{is}(t) + d_{is}(t)\}, & s \in Door(D_1 \dots D_s) \text{g} t_{ij}^{(l)}(t) > r \\ \text{Doesn's change the path}, & \text{else} \end{cases}$$

Step4 Determine the maximum number of iterations
In case of emergency evacuation, repeated changes to evacuation plans can add to the tension, leading to an increase in site uncertainty. Therefore, we believe that the iterative function of the model is related to the number of people in the museum. It should conform to the following formula:

$$C = \frac{1}{14} \sum_{i=1}^{14} Ni(t) / V_{stairs} \tag{1}$$

$$n = \overline{T} / C \tag{2}$$

C is average wait time for evacuees in each zone on the stairs, V_{stairs} is the flow rate of people in the stairwell, $\overline{T}$ is evacuation time, n is the number of iterations.

3.2.3. Analysis of the results

By analyzing the results, we get the following information:
Some regional planning paths remain unchanged.
Some regions update paths that appeared some time ago.
The path of the lower region is updated, and the vertical upper layer is generally updated as well.
Analyzing the above information, we can draw the following conclusions：
The planning of the path is vertical, vertically related regions generally update the planning path at the same time.
There are only a few of the most efficient paths in different regions, cycling over time.

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More efforts should be made to evacuate the $F_a^{(0)}$ and $F_c^{(0)}$. Sending more rescue and guidance personnel.

The optimal evacuation route does change over time.

The predicted results of our model are quite different from those in the ideal case. In the simulated case, it is impossible for all people to evacuate in the path with the shortest evacuation time. Our model is more in line with the actual situation.

4. The Model including potential Bottlenecks

4.1. The structure of the model

Further analysis of the problem shows that there are many factors influencing the evacuation time. Language will lead to communication barriers and affect the efficiency of evacuation. People's choice of entrance will affect people's choice of exit. There will be emergencies that will affect the speed of population movement.

The bottleneck factors affecting evacuation and their influences on evacuation are shown in Figure 1.

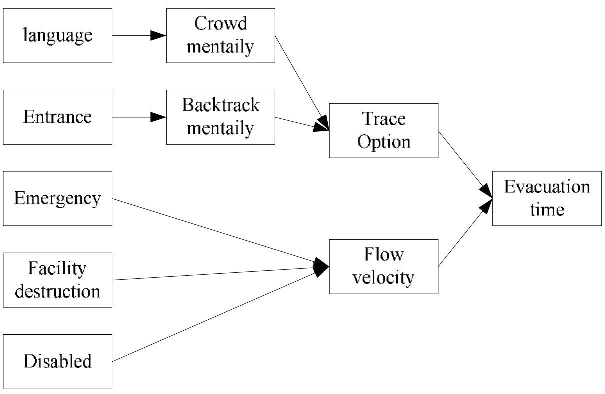

Figure 1. Potential bottlenecks

We will mainly consider the following two aspects:

Considering the influence of path selection on evacuation time.

Consider the effect of crowd speed on evacuation time.

In both cases, we improve our model.

4.2. The establishment and solution of the model

4.2.1. In the first case our model enriched the pheromone

In the face of the same pheromone path, choose the number of people who tend to influence a given region to influence the pheromone, Pheromone = (basic movement time + passing through waiting time) * selection bias, The formula can be expressed as:

A_j is the selection bias matrix. The waiting time of each entry can be estimated by observing the Affluence APP's real-time update. About A_j the following two constraints are satisfied:

$$s.t = \begin{cases} 0 \le A_j \le 1 (1) \\ \sum_{j=0}^{5} A_j = 1 (2) \end{cases}$$

4.2.2. In the second case, we improve the model by heuristic function prime

In the improved model, the heuristic function is expressed as follows:

Activity factor matrix: $f = \{f_1 f_2 f_3 \mathbf{L} \mathbf{L} f_n\}$

Probability random number matrix: $0 < P_i < 1$, represents the random occurrence of n active factors. If $P_i = 0$, this activity factor does not affect evacuation time.

$d_i = p * f$

We input the above heuristic function into the model

$$V_{stairs} = (1 - \sum_{i=0}^{n} d_i) * V_{staris}$$

Then input N=21000 into the model to obtain the path change result, as shown in Table 2:

Table 2. Improved Model for Predicted Evacuation

N=21000	Ant Colony Algorithm	Improved Ant Colony Algorithm
Estimated evacuation time	≈1250s	≈1800

For the model with added revelatory function, the optimal path planning does not change much.

The change of the path is mainly due to the different tendency of the crowd to export. For D_4, D_5, people will initially gravitate towards D_5. Because group ticket visitors enter through this door. When the path fluctuates for a period of time, the crowd's tendency to the two gates becomes no difference.

Our long expected time may be due to insufficient analysis of the impact of activity factors on velocity. But our model takes everything into account. It still has reference value.

5. Sensitivity Analysis

5.1. Change the number of stairs and doors of the model

First, we observe the change of evacuation time by changing the number of stairs and doors in the input model.

From the diagram, we find that with the increase of the number of stairs and doors, the evacuation time decreases at first but finally approaches to the shortest evacuation time.

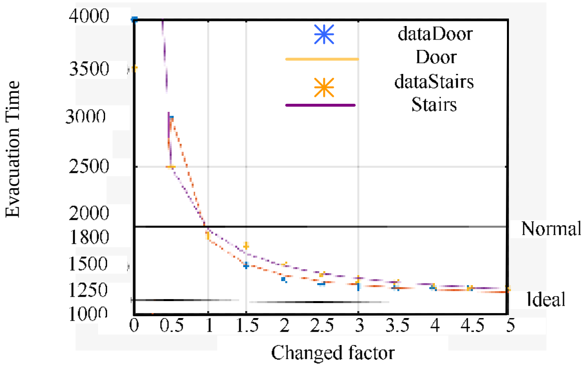

Figure 2. Scatter diagram

6. Conclusion

Our model has good sensitivity. It can plan evacuation paths in different physical and geographical environments and adapt to a wide range of factors and various types of potential threats. Our model can plan the evacuation route of the crowd in the Louvre, and it can adapt to a variety of situations, which has certain practical significance

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