Research on Adaptive Emergency Evacuation Model of Large Buildings

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Abstract: Taking the Louvre as an example, this paper studies and analyzes the evacuation plan of large-scale multi-exit large buildings in the event of an emergency. After that, we establishes an adaptive optimization model for different factors and uses Matlab software to finally solve the model by designing the algorithm. First of all, as for the different levels of congestion on different roads during the evacuation, we identify and classify the potential bottlenecks that may limit movement to the exit. The dynamic bottleneck recognition method which based on fuzzy set theory is used to identify and analyze the potential bottle diameter to obtain the membership function of the potential bottle diameter, which is used in our model. Secondly, when establishing a large-scale emergency evacuation model, we grouped the people at each floor to compare the distance between different groups of people and different exits. Last but not the least, during the solution of the model, we first consider the simplest case, that is, the solution algorithm when there is only one floor in the building. Then, based on the algorithm of solving the emergency evacuation model of single-story building, the algorithm for solving the crowd evacuation model in the emergency situation of large buildings such as the Louvre is obtained. Through the established models and algorithms, we built simulation images in the stadium, simulating the scenes of the Louvre in real life, and solving the five-layer evacuation time of the Louvre from low to high are about 7,7,17,9,16 minutes.

1. Notations

Notations	Definition
$\mathbf{E}$	Arc set,Which e_{ij} represents the arc between the connected nodes i,j
$\mathbf{l_{ij}}$	Length of arc e_{ij}
$\mathbf{t_{ij}}$	Travel time through arc e_{ij}
$\mathbf{c_{ij}}$	Maximum capacity allowed for arc e_{ij} per unit time
$\mathbf{q^w}$	Total number of people to be evacuated at floor w
$\mathbf{S^w}$	All path sets from floor w to exit
$\mathbf{K^w}$	All the used path sets from the w floor to the exit
$\mathbf{T_k^w}$	Travel time required for the floor w to be evacuated to the exit along route P_k
$\mathbf{T^w}$	The actual evacuation end time of the floor w
$\mathbf{p_{ij}(k)}$	The proportion of cell i that can receive the ability from the upstream cell j

2. Models

2.1 Model Establishment

The multi-layer building evacuation problem considers how to rationally group each layer of people to be evacuated, and select the appropriate path for evacuation, so that the evacuation time of the evacuation network is minimized. In the model building of this question, we consider the distance between the different layers of the Louvre and the exits of different layers, and take into account the potential bottlenecks. Finally, when making the path selection, we first identify the congested

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sections, i.e. potential After the bottleneck is eliminated, compare the other paths and select the optimal path.

Let $x_k^w(\tau)$ be the total number of people on the floor w to be evacuated from the path P_k at the time τ, according to the dynamic network flow, there is

$$x_k^w(\tau) = \sum_{t=0}^{\tau} f_k^w(t) \tag{1}$$

It can be seen from equation (1) that by the end of the evacuation of the floor w, the number of people evacuated by the trapped person along the path P_k is actually $\sum_{t=0}^{T^w} f_k^w(t)$.

Based on the symbols and variables defined above, the mathematical model for establishing the problem is as follows:

$$(P) \quad min \;\; T = \max_w \{T^w\} \tag{2}$$

$$s.t. \begin{cases} \sum_{w=1}^{W} \sum_{P_k \in K^w} \delta_{ijk}^w f_k^w \le c_{ij}, \; \forall (i,j) \in T, \; t = 1,2,\dots,T & (3) \\ \sum_{P_k \in K^w} \sum_{t=0}^{T^w} f_k^w(t) = q^w, \; w = 1,2,\dots,W & (4) \\ f_k^w(t) \ge 0, \; \forall P_k \in K^w, \; w = 1,2,\dots,W & (5) \end{cases}$$

The objective function (2) indicates that the end time of the entire evacuation network evacuation is minimized; the constraint (3) refers to the constraint that meets the capacity of the road segment at any time; Equation (4) means that all the personnel to be evacuated at each affected point are safe. Evacuation; constraint (5) represents a non-negative condition of the path flow. If the size of the problem is large enough, it is often difficult to enumerate all the paths from each disaster point to the exit. The path can be converted into the following problem:

$$(P') \quad min \;\; T = \max_w \{T^w\} \tag{6}$$

$$\begin{cases} \sum_{w=1}^{W} \sum_{P_k \in K^w} \delta_{ijk}^w f_k^w \le c_{ij}, \; \forall (i,j) \in E, \; t = 1,2,\dots,T & (7) \\ \sum_{P_k \in K^w} \sum_{t=0}^{T^w} f_k^w(t) = q^w, \; w = 1,2,\dots,W & (8) \\ f_k^w(t) \ge 0, \; \forall P_k \in K^w, \; w = 1,2,\dots,W & (9) \end{cases}$$

Formally, these two problems are mainly different in the path set. For small-scale networks, you can simply enumerate all the paths, which usually do not have much impact on the running time. For a slightly larger network, it is difficult to enumerate a huge number of paths. This means that the set of paths in question (P) may be approximately infinite, and the set of paths in question (P') must be finite, with a relationship between them, i.e. $K^w \subseteq S^w$. In addition, although the path flow of the problem (P') is written as a non-negative condition, $f_k^w(t) \ge 0$, the solution process actually retains only the path information satisfying $f_k^w(t) \ge 0$ at least one time. Obviously the problem (P) and the problem (P') are equivalent , so we use the solution problem (P') to directly replace the solution problem (P).

2.2 Model Solving

2.2.1 for Single-layer Buildings

In the model solving process, we first discuss the single-layer algorithm, based on the single source point evacuation model with no path capacity limitation, and on this basis, consider the single-layer multi-exit building evacuation problem with path capacity limitation. Then draw the following conclusions.

Theorem 1 [2] : set $P_1, P_2, \dots, P_\gamma$ to be the path selected to evacuate the person, then the evacuation time required for all evacuation groups in the optimal evacuation scheme is equal, is $T_1 = T_2 = \dots = T_\gamma = T$.

The basic idea of the path capacity limited single source point evacuation model algorithm is to determine the feasible path set $\{P_1, P_2, \dots, P_m\}$ by continuously updating the network according to the greedy principle of the saturated evacuation shortest path.

2.2.2 for Multi-layer Buildings

We noticed the fact that in multi-story buildings, because the time of each floor reaching the bottom exit is different, the total number of people to be evacuated is different, and some floors are already evacuated, but the trapped people on other floors On the road, theorem 1 is usually not true, so the single-layer evacuation model algorithm cannot be directly used for multi-layer evacuation models.

On the other hand, the high-level source points need to share some low-level road segments with the low-level source points. The actual traffic of these shared road segments is generally affected by the convergence of people on different floors. Therefore, f_k^w is usually not a constant, but is constantly adjusted over time.

Therefore, the multi-layer evacuation model is far more complicated than the single-layer model. How to determine the actual set of evacuation paths K^w and the dynamic flow of each person to evacuate the trapped people $f_k^w(t)$ is the key to solving the multi-layer evacuation problem.

Since the objective function is the minimization of the evacuation end time, it is necessary to balance the evacuation time as much as possible in order to achieve a better evacuation effect. The basic idea of the algorithm is to first determine whether there is an influence on the evacuation flow between the floors. If there is no influence on each other, it is only necessary to treat each floor as a single-layer model and evacuate independently according to Algorithm 1.

In this case, we determine the feasible path set according to Algorithm 1, and then preferentially evacuate the floors with long evacuation time, preferentially saturate the evacuation short paths to achieve the equilibrium evacuation time, find the intersection of the road sections between different floors, and update the intersecting road sections in real time. Dynamic traffic is applied to determine the evacuation plan. Since multi-source evacuation does not have a polynomial time algorithm, we expect to give an efficient algorithm to determine a feasible solution:Algorithm 2: Multi-layer Building Evacuation Model Algorithm[3]

3. Conclusions

By collecting data we know that the Louvre received a total of 8.1 million visitors in 2018. Among them, 52 of the 365 days are not open every Tuesday, so the actual opening is 313 days, so the theoretical number is 26,000 per day. Combined with the data of the dry season, it is concluded that the peak venue is 30,000 people per day. The Louvre has a 12-hour daily opening hours, so the peaks hold 2,500 people per hour and the single hall accommodates 833 people per hour.

Through the above established model, the simulation image in the venue is established, in which the number of danger sources and the number of visitors located in the building are randomly determined, which better simulates the scene of the Louvre visit in real life. Provide a safer approach to the evacuation of visitors.

The evacuation model takes the zeroth floor as an example. There are a total of 2 exits, of which yellow is the obstacle, red is the danger source, and the blue point is the visitor in the building. The simulation image is:

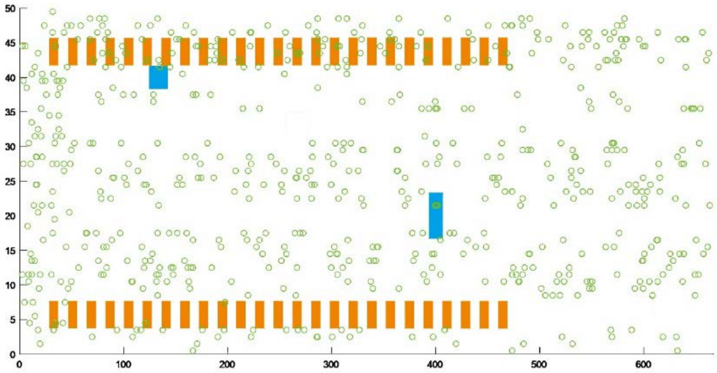

Figure 1 0 layer evacuation simulation image of the Louvre

By looking at the Louvre design, the approximate data for the interior is: the width of the stairs is 2 meters, there are 4 stairs on each floor, and there are 20 steps on each floor, considering the average number of elevators is 6.

If only the ground floor 0 is considered, the underground evacuation situation is not considered, that is, the first floor and the second floor of the ground are evacuated to the 0th floor, and the number of people on the floor 0, 1 and 2 are 300, 280, 350, respectively. The other parameters are the same.

The evacuation time is calculated by the model: 6.6010 minutes, 16.662 minutes.

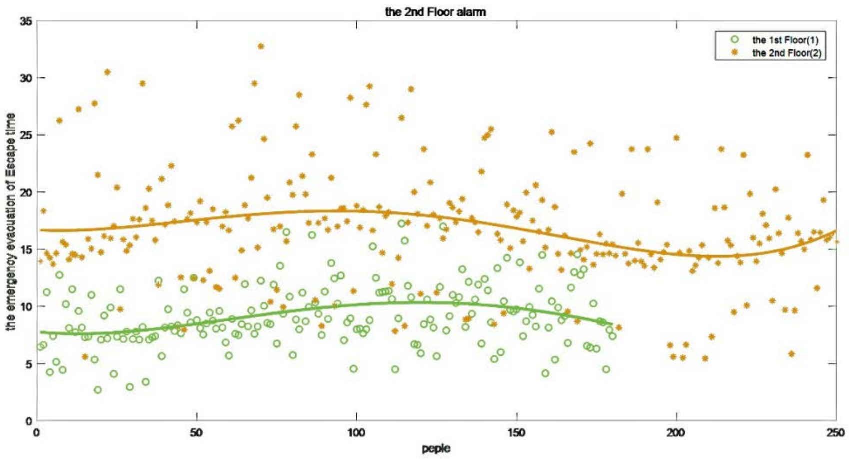

Figure 2 only consider the relationship between ground 0 evacuation time and number of people

From the time curve of the fitting, there is no junction between the first layer and the second layer of the ground. Compared with Fig. 1, it can be seen that the evacuation of the ground 0 layer can reduce the evacuation time.

Considering the evacuation situation, the bottleneck model is used to judge the congestion degree of each channel at that time, so as to judge the forward direction of the people on different floors. The number of people on the -2, -1, 0, 1, and 2 floors are: 200, 200, 300, 380, 350, respectively. The evacuation time of the first and third floors on the ground was 9.1225 minutes and 15.5361 minutes, respectively, and the evacuation time of the underground-1 layer was 7.2758.

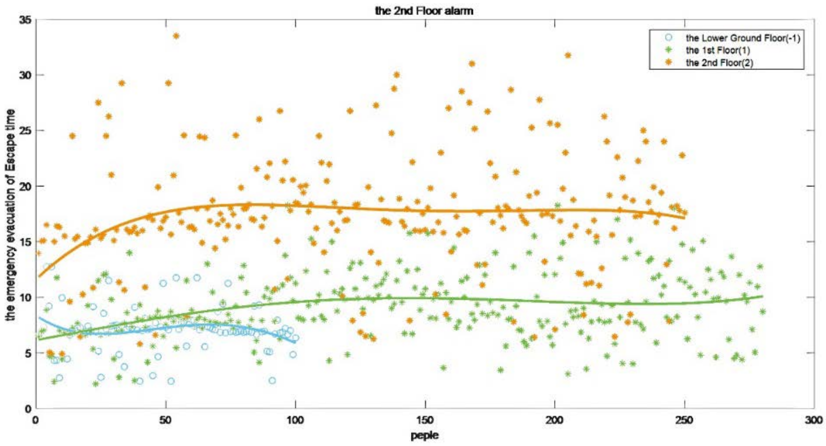

Figure 3 consider the relationship between multi-layer evacuation time and number of people

It can be seen from the evacuation process of the emergency state based on the cellular automaton model:

1) Because the zero layer is the main evacuation port, we can evacuate the person passing the ground to the main evacuation port, and at the same time play the role of the ground layer, so that the evacuation time can be reduced more quickly and the danger can be reduced more quickly;

2) When the emergency evacuation commander leads the people to transfer, the speed of the crowd can be appropriately reduced to avoid the occurrence of stamping and crowding, and the evacuation effect can be improved.

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