Multi-floor Emergency Evacuation Model of the Museum

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Abstract: In order to research the problem of evacuation management at large, crowded museums when an emergency occurred and finding out the best evacuation program, this paper analyzed the particularity of the Louvre, established an information notification model and a water flow model (multi-floor evacuation model) to discussion the shortest time of the objective function. The model provides theoretical guidance for emergency evacuation and emergency drills of such high-density buildings and provides recommendations and expectations for construction organizations.

1. Introduction

1.1 Background

The Louvre is a long-established French royal palace that carries the history of France for 800 years. Since its founding in 1793, 50 thousand priceless and world-famous collections have been collected. With a growing number of visitors each year, it has long been the world's most visited museum. [1, 2]

Given that the huge scale of precious collection, the big number of daily visitors and the upgrading threat of terrorism in recent years, several effective evacuation plans are urgently demanded when an emergency (terrorist attacks, fires, etc.) occurs. However, passengers of different languages and physical states and the changing number of guests in the museum do bring the challenge.

When an emergency happens, all the public entrances must be used as evacuation exits. Thus, there will be three exits: the pyramid entrance, the Carrousel du Louvre entrance and the Portes Des Lions entrance.

1.2 Map simplification

We collected much data to clarify the preference of visitors for different collections, which can reflect the real-time visits to different collection. Furthermore, we carry out an estimate of the flow density distribution of each floor and draw a heat map [3].

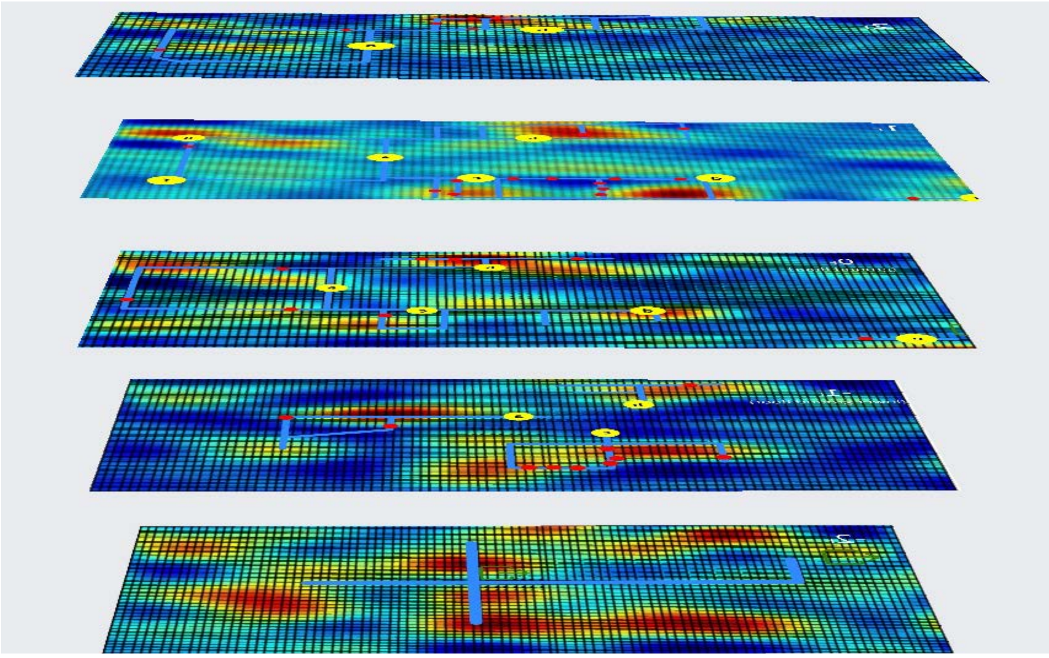

Figure 1. Flow density heat map of the Louvre

2. The Basic model of emergency evacuation model

To better clarify the whole evacuation process, a procedure sequence diagram is given below:

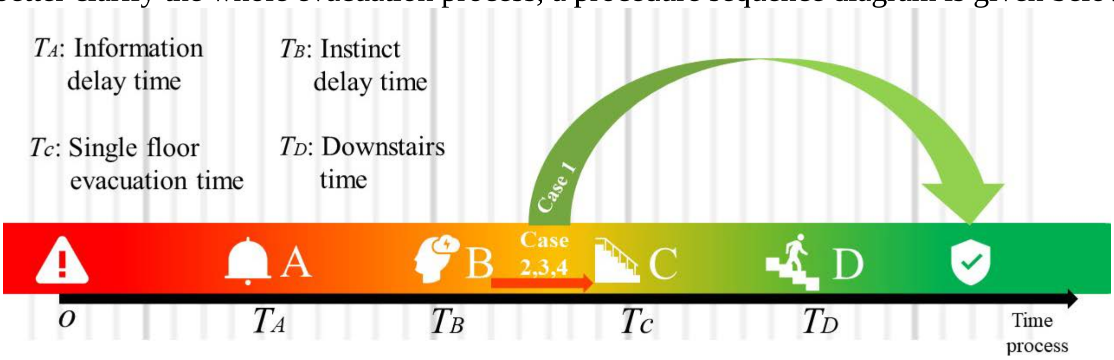

Figure 2. Procedure sequence diagram

Case 1: Visitors at the -2 Floor (connected with E_M and E_S) rush to the optimal exit strictly.
Case 2: Visitors near stair-e (connected with E_S) rush to the optimal exit strictly.
Case 3: Visitors near stair-a, b, c, d, go downstairs and join in Case 1.
Case 4: Visitors near stair-g, f go downstairs and join in Case 3.

Since the -2 Floor and stair ***e*** connect to the outside directly and the three exits are wide enough, we consider visitors entering Case 1 and 2 are evacuated successfully.

The Necessary Safe Evacuation Time (NSET) can be calculated by the equation:

$$\text{NSET}=T_A+T_B+T_C+T_D \quad (1)$$

Thus, we will discuss the time spent on each part and the ratio of total time to find the bottleneck of the problem in the paper below. Our model focuses on finding the time to evacuate the **last person** in the museum.

2.1 Information notification model

(1) The design of INM in a single floor

This model simulates the diffusion of information sources on a certain floor. Since the information's diffusion rate depends on its spatial state and the corridors in the Louvre are approximately linear. Therefore, the information can only be spread along the linear path.

We assume that the parameter v_i and V_i denote the information **spread-speed** and informed **location** respectively. And the number of people R_i can be estimated according to the density heat map.

So the information delay time t_{id} from V_i to V_j can be calculated.

$$t_{id} = \frac{\boldsymbol{R}}{v_i} \tag{2}$$

where $\boldsymbol{R}$ denotes a matrix. $\boldsymbol{R} = \begin{bmatrix} R_{11} & \cdots & R_{1j} \\ \cdots & \cdots & \cdots \\ R_{i1} & \cdots & R_{ij} \end{bmatrix}$ and $R_{ij} = \int_{V_i}^{V_j} f(i)\, di$.

(2) The result of INF in the whole Louvre

Since each floor is constructed similarly, we think v_i is equal but R_{ij} varies with different flow density distribution of each floor. Therefore, we get a graph about the changing number of informed visitors in the museum N_i when an emergency occurs and finally get the information delay time T_A.

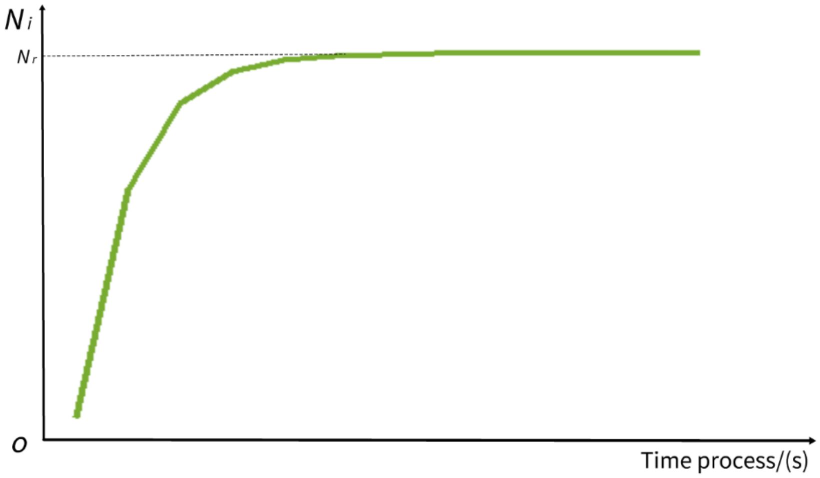

Figure 3. The curve of growing $\mathrm{N_i}$ when an emergency occurs

2.2 Water flow model

(1) The design of WFM

In the case of high density of visitors in the museum, the flow of people can be seen as a continuous flow of water [4]. We regard the flow velocity of water v_{flow} as the moving speed of the human. It is apparent that in the place where flow density D_f is too large (confluence and the entrance of the stairs), congestion will occur. So the D_f is the resistance to v_{flow}, and the congestion is converted to a small. The maximum v_{flow} also corresponds to the maximum flow density.

We can deduce the below equation from **P & M empirical equation** [5]:

$$v_{flow} = 1.867{D_f}^4 - 6.333{D_f}^3 + 7.2333{D_f}^2 - 3.617D_f + 0.95 \tag{3}$$

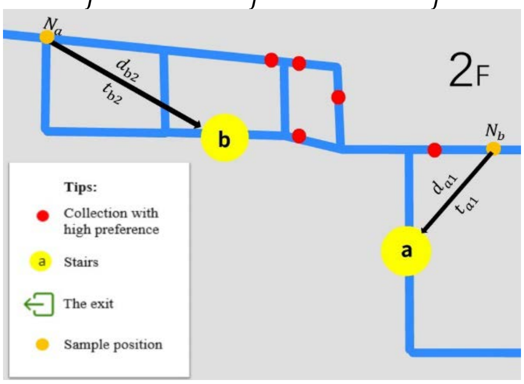

Figure 4. Notions for t_{oj}, d_{aj} and N_o

Taking the second floor as an example, when people receive an emergency evacuation notice, they rush to the nearest stairway a or b after a short biologically delay. Therefore, there are some one-way flows (with good guidance) and these one-way flows will choose the nearest stair entrance object stair-***a*** or ***c***. Here we define three notations $t_{oj},\ d_{aj}\ and\ N_o$ about time, distance and number of visitors with parameters stair entrance object *o* and number of channels j.

$$t_{bj} = \frac{d_{bj}}{v_{flow}};\ t_{aj} = \frac{d_{aj}}{v_{flow}} \tag{4}$$

Furthermore, the maximum time for all visitors reaching the stair entrance $T_C = max\{t_{oj}\} = max\{\sum_{j=1}^{j=n} t_{aj}, \sum_{j=1}^{j=n} t_{bj}\}$ can be calculated.

(2) The result of WFM

We next discuss the evacuation between floors.

$$T_D = \frac{(N_o - 1)d_{indi} + d_{stairs}}{v_{down}} \tag{5}$$

$$v_{down} = kv_{flow} \tag{6}$$

$$k = \frac{cw_s}{N_r} \tag{7}$$

Where k is the downward correction factor.

C is natural passing coefficient.

w_s is the distance between two certain floors when going downstairs.

d_{indi} is the distance between two certain floors when going downstairs.

d_{stairs} is the distance between individuals.

(From the **P & M empirical equation**)

Table.1. Evacuation Time on Different Floors

The Floor	Total Evacuation Time/ (min)	Single Floor Evacuation Time / (min)
2F	35.81	9.79
1F	26.02	11.57
0F	16.15	7.24
-1F	7.72	4.57

2.3 Spot the bottlenecks

According to the above two models, we can get TA, TC, TD, and TB is the instinct delay caused by people's panic in an emergency. It can be directly obtained by scientific investigation and its value is about 0.3s. Therefore, we have been able to calculate NSET.

We can find that in the absence of any evacuation plan, the higher the floor of visitors, the more time it is consumed for downstairs. The time they spend downstairs is even **half** of the total time for high floor!

A conclusion can be drawn that the **main bottleneck** is the downstairs process. Though the single floor evacuation time in high floor is almost equal to the downstairs time, it is not the main bottleneck. Because evacuation distance in a single floor is much bigger than that between floors. Also, the information delay time cannot be ignored.

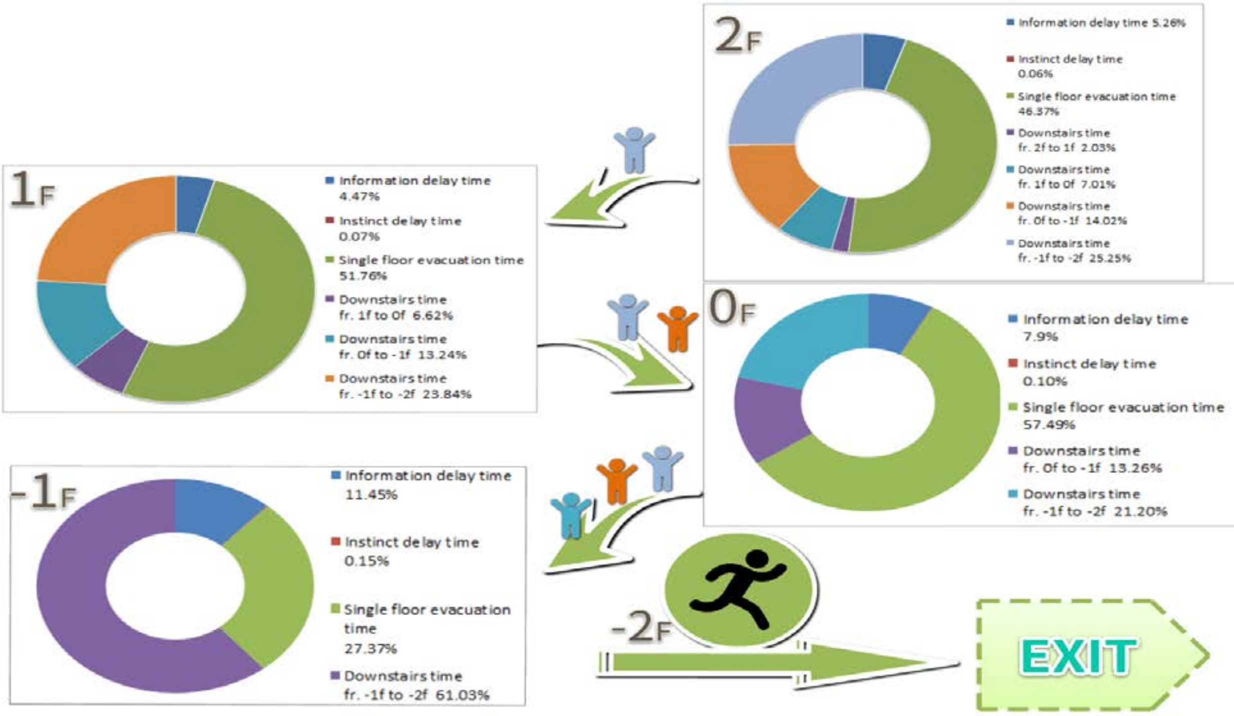

Figure 5. The Percentage of Evacuation Time in Different Floor

3. Conclusion

By adjusting the internal structure of the Louvre and the location where collection placed, the distribution density of people will be homogenized. This helps to alleviate the congestion of evacuation channels. According to the analysis with our model, in the event of an emergency, there is such a situation where the channel load near Mona Lisa is overwhelming, while some other channels have just little load. Therefore, it is also valuable to relieve the evacuation pressure by adjusting the position of some collection, if possible.

The above investigation shows that the ground floor and lower ground floor is the hub floor. Once an emergency occurs on these two floors, the evacuation plan is prone to embarrassment because the high-floor pedestrians are difficult to evacuate to the two main exits on the bottom floor. Therefore, if museum officials do not adjust the location of the three evacuation exits, the emergency measures for the hub layer must be more stringent.

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