Louvre Efficient Evacuation Plan Based on LSFFM

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Abstract. For large tourist attraction Louvre, it is essential to establish an emergency evacuation plan for personnel in critical situations. We propose an effective graph-based path planning model, which is suitable for limited space with dense visitors flow. This paper analyze individual’s movement pattern with CA model, regional crowd flow, and overall suboptimal path planning. We establish a limited space fast flow model (LSFFM). Then we apply this evacuation model to the Louvre compared with other out of order evacuation condition. It shows a great performance for evacuation efficiency and visitors’ safety.

1. Introduction
Recently, a number of serious incidents have occurred in a number of large-scale public places, resulting in great losses of life and poverty. It is necessary for the Louvre to have a multi-adapted emergency evacuation model.

At present, the scholars have developed more than 20 evacuation models like network model [1] to solve the evacuation problems but most of them ignored the influences of individual subjective consciousness.

We collect some necessary data including some maps of Louvre [2]. Based on these data our model LSFFM is analyzed at three levels. At the individual level, we give an expression of the applicable normalized moving speed. We consider the interaction between people and people in places. Using the cellular automaton model to simulate this process to get the relationship between congestion time and population density and number of exports. At the overall level, to describe the impact of this relationship on the evacuation model, we use network flows to describe the flow of people. And CCRP (Capacity Constrained Route Planner) evacuation path optimization algorithm is used to seek a possible optimal solution for the evacuation path. At the same time we get the time-consuming solution of different path schemes

2. Assumptions and Notations

2.1. Assumptions
1. Regardless of the specific shape of the room, assume that all rooms and roads and exits are rectangular.
2. Visitors can be divided into family visitors, group visitors, individual visitors, and other four categories in all.
3. No longer consider the accidents other than congestion that occurred during the evacuation.
4. The four major exits of Louvre are the most important evacuation routes, and rescue medical personnel will enter from other entrances to avoid convection with the evacuated population.

2.2. Notations

| Symbol | Definition |
|--------|------------|
| $r_i$  | The $i$th room that can not be divided in Louvre |
| $z_i$  | The set of $r_j \in z_i$ |
| $T$    | The time that required to evacuate all the people |
| $t_{ij}$ | The time that required to evacuate the people in $z_i$ and $z_j$ |
| $t_{m}$ | The time that required to move people between two zones $z_i$ and $z_j$ |
| $F$    | $F$ is the fear index of people |
| $D_i$  | The distance between the person and the nearest door in $z_i$ |
| $C_i$  | The distance between the person and the source of danger in $z_i$ |
| $P_i$  | The people in single zone $z$ |
| $V$    | The average speed of crowd |
| $E_{ij}$ | $E_{ij}$ is congestion level evaluation criteria between $z_i$ and $z_j$ |

3. Model of Panic Crowded

In response to the characteristics of the panic population, we have established a model of the panic crowd.

At the time of the emergency evacuation, the flow of the crowd is not a simple traffic flow model, but a flow model with obvious characteristics. The cellular behavioral characteristics required for the constructed cellular automaton model [3] will all be derived from the confusing population evacuation model established here.

3.1. Fear Psychology of Panic Crowd

The specific impact of people’s general fear on the emergency evacuation model is that the closer the source of danger is, the more fear the people will feel. And the more discrete it will be reflected in the population. Let $F$ be defined by $D$ and $C$

$$F = f(D, C) = (\ln 100 - \ln D) \times \ln C$$  \hspace{1cm} (1)

And the Fig.1 shows details.
3.2. Crowd Speed Affecting the Time

The evacuation time for the entire space can be determined by the longest time required for each dispersed population.

\[ T = \max\{t_1, t_2, \ldots, t_{n-1}, t_n\} \]  \hspace{1cm} (2)

And \( T \), the time that required to evacuate all the people in the entire space will be an important factor in measuring the overall evacuation plan.

The speed of the crowd will be an important factor affecting the evacuation of the population [4].

The speed of movement of the crowd indicates the average speed of the crowd, determined by the individual speed of the same cross section at all times.

\[ v_i = \frac{1}{n} \sum_{j=1}^{n} s_j \]  \hspace{1cm} (3)

Where:
1. \( n \) is the number of \( z_i \)
2. \( s_j \) is the individual in \( z_j \)

The type of visitors are inconsistent. We use the collected data to determine the specific walking speed of different groups [CVPR]. The details are in Tab.2

| Visitor Category | Stride (m) | Frequency (step/s) | Speed (m/s) |
|------------------|------------|-------------------|-------------|
| Family           | 0.65       | 1.58              | 1.10        |
| Single           | 0.68       | 1.99              | 1.35        |
| Group            | 0.54       | 1.38              | 0.74        |
| Other            | 0.58       | 1.85              | 1.07        |

At the same time, the number of four types of visitors will be subject to a normal distribution. The number of family visitors is most, the individual visitors are the second, and the last are the group visitors and the other. The population distribution could be seen in the Fig.2

4. Cellular Automaton Model

We use the cellular automaton model to simulate the evacuation of people in the smallest room.

Based on the established model of the panic crowd, we classify visitors into four groups of people, Family Visitors, Individual Visitors, Group Visitors, and the other. Other visitors that have handicaps or limited mobility are also classified as the other type. People of the same type will have the same behavioral characteristics.
4.1. Single Exit Room
First, we analyse the simplest case, that is, there is only one room and the room has only one exit. We take a square cell with an area of 0.5*0.5 as the smallest unit of the problem. We use a matrix to store the room and simulate the evacuation. One cell corresponds to an element of the matrix. Cells can only be occupied by one person or obstacle. When it is occupied, we record it as its value of 1, otherwise it is 0. People cannot move to a cell with a value of 1.

In this case, we will only consider risk factor caused by the distance from people to the nearest door. We record it as relative risk index \( \Gamma \) and normalize it as follows.

\[
\Gamma = \frac{\sqrt{(x_d - x_i)^2 + (y_d - y_i)^2}}{\sqrt{(x_d - x_{on})^2 + (y_d - y_{on})^2}}
\]  

And rules below will be used to define the transition function
1. Each cell compares the risk of its neighborhood with his own nine cells in all and enters the cell with the minimal risk (or remain motionless).
2. When each cell selects to move to the next cell, if there are multiple cells with the lowest risk in the moving area, the cell randomly selects one of the cells as the next target grid point with the equal probability.
3. Each cell make a choice at the same time. There are multiple cells competing for an idle position at the same time. It will select a cell with equal probability to occupy this idle cell. The selected will move to the idle one. The unselected will stay in the original location.
4. When the cell moves to the door, its state will turn to 0 forever, and free its occupation.

And assuming that each single room is 30 meters by 15 meters in size, and each room has about 50 people, with an average of 0.5 meters by 0.5 meters. And a person corresponds to a cell.

First, simulate the door is 3 meters wide. And help with Matlab We get images of the state of the crowd flowing in a single room over time in Fig.3.

Then we will consider the situation that the door is 6 meters width in Fig.4.
4.2. Multiple Exits Room
For the case where there are multiple doors in a room, in order to study the path selection of the person in this case, it is assumed that the person generally selects a door closer to himself as the path to leave the room.

We also use Matlab to simulate and get the crowd evacuation of the popular multi-door room. And use the average time obtained by the simulation as the basis for future calculations.

Figure 5 shows the room that has two exits simulation.

Through simulation we can get the relationship between the evacuation time and the number of doors the room has in Tab.3 (All simulations are applied 10 times)

| Doors Amount of One Room | Time Consumed (seconds) | Variance |
|--------------------------|-------------------------|----------|
| 1                        | 77.13                   | 4.62     |
| 2                        | 51.33                   | 3.19     |
| 3                        | 39.78                   | 3.11     |
| 4                        | 31.05                   | 2.99     |
4.3. Research on Aisle and Room

After studying the crowd flow model in a separate room, we need to connect the room to the room and observe the flow of people on the channel. The state of the channel is the key to getting through our separate rooms.

Simulations showed the state of crowd flow with Matlab in Fig.6.

![Figure 6 Crowd Flow State Simulation(Room with Aisle)](image)

Once the width of the aisle is greater than 3 meters, which is greater than the width of the minimum door, we find that the width of the aisle has little to do with the evacuation time of the crowd. Different situations results could be seen in Tab.4

| Aisle's Width (m) | Door's Width (m) | Time Consumed (s) | Variance |
|------------------|------------------|-------------------|----------|
| 3                | 3                | 102.08            | 5.22     |
| 3                | 6                | 76.17             | 4.03     |
| 6                | 3                | 99.03             | 4.15     |
| 9                | 3                | 94.85             | 3.95     |

However, multiple rooms connected by aisles will be congested at critical nodes, which requires good scheduling to minimize congestion. And this discussion will be discussed in detail in the next section, the global suboptimal route planning model.

5. Global Suboptimal Route Model

The CCRP heuristic algorithm [6] is a route planning algorithm that considers capacity first, and finds the suboptimal solution of the evacuation planning problem through heuristic solution.

Use the graph theory and the CCRP optimization algorithm to solve the path planning problem:
1. Rasterized the Louvre and divided it into 60 zones $Z_j$, each containing a number of rooms $\Gamma$.
2. The two zones will be connected only there is an aisle or stair between them
3. Four major entrances and exits are also included in 60 zones

We only consider the people $P_i$ in $z_t$, so the time of total evacuation time(from the zone $z_t$ to one of the 4 main exits) can be calculated by

$$t^A_i = \sum_{j=i}^{n} (t_j + t^m_n)$$

Have to be aware of the following explanations
1. $n$ is the number of zones necessary to pass through when evacuating
2. $N$ is the set of zones necessary to pass through when evacuating

$$\{z_{j1}, z_{j2}, ..., z_{jn}\} \in N$$

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3. \( n \) is the two adjacent necessary zones

Then we promote it to 60 zones, the entire Louvre. We define the total time of evacuation of all the guests \( T \) by the following formula

\[
T = \frac{1}{n-1} \times \sum_{i=1}^{n=60} t_i^A
\]  

According to CCRP algorithm to approach the optimal route planning. The following formulas is the proof procedure.

\[
\min \sum_{(j \in E)} \sum_{t=0}^{T} \lambda_{ij}(t) X_{ij}(t)
\]  

Subject to:

\[
\sum_{(i \in E)} \sum_{t=0}^{T} x_{id}(t) = \sum_{t=0}^{T} s(t)
\]

\[
X_{ij}(t) \leq u_{ij}(t)
\]

\[
IX_{ij}(t) \geq 0
\]

\[\forall (i,j) \in E \ t = 0,1 \ldots T\]  

The purpose of the optimization of the objective equation is to find the minimum cost of the flow of people from the source node \( z_i \) to the refuge point (4 main exits) in the time \([0,T]\). The constraint condition is the flow balance between the source point and the convergence point.

6. **LSFFM Implementation**

This model established by the three above models will provide a perfect and efficient evacuation plan for any large crowded scene. The following Fig.7 shows the procedures when we get the similar problem.
Apply LSFFM to the Louvre emergency evacuation compared with out of order condition (with no external intervention) in 10 times simulation. And assume the evacuation has done successfully when \( P_s > 0.95 \). (\( P_s \) means the people successfully reached the main 4 exits.)

Choosing 3 different normal footfall of Louvre. The average simulation results are in Tab.5

### Table 5 Simulation Results Compared with No External Intervention Condition

| Visitor Amount | LSFFM Evacuation Time (\( / \text{second} \)) | Variance | No External Intervention Condition Evacuation Time (\( / \text{second} \)) | Variance |
|----------------|---------------------------------------------|----------|---------------------------------------------|----------|
| 2500           | 1074.60                                     | 96.28    | 1442.17                                     | 72.21    |
| 9000           | 1891.43                                     | 143.37   | 3291.83                                     | 202.31   |
| 18000          | 3168.97                                     | 282.63   | Over 3600                                   | ——       |

7. Conclusion

As the simulation has demonstrated, LSFFM shows a better performance compared with out of order condition. And the performance gap will grow rapidly with the number of visitors increases.

Then we randomly invalidate some paths and simulate the situation when an accident occurs there. We use the same method to obtain the suboptimal evacuation path. Compared the results of our model with the results of the professional software pathfinder, and the results are in good agreement, indicating that our model has universal applicability and good accuracy for different numbers of visitors and different accident situations.

In addition, our simulation shows that there is a improvement if we could avoid the crowd convection.

References

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