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2019 Mathematical Contest in Modeling (MCM) Summary Sheet

(Attach a copy of this page to each copy of your solution paper.)

Abstract

In recent years, the frequency of terrorist attacks in France has increased year by year. As one of the largest museums and the most visited museum, the Louvre in France faces the risk of terrorist attacks. Therefore, it is imminent to make a reasonable emergency evacuation plan for the Louvre. Based on the topological network and the modified Floyd-Warshall algorithm, our team presents an optimized evacuation path model. With the presented model, all the occupants could leave the Louvre as quickly and safely as possible, even with the extremum number of visitors.

In the presented model, the Louvre is abstracted into a topological network of points and lines. First, the source nodes, transmission nodes and terminal nodes represent halls, stairs and four main entrances [Pyramid, Passage Richelieu, Carrousel, Portes Des Lions] of the Louvre, respectively. Second, considering that the diversity of visitors leads to the differences of evacuation actions and moving speeds, the limit value of the influx of roads is defined by the weighted average of the visitor's body proportionality parameters, the width of safety channel (stairway) and the length of safety channel (stairway). Finally, with the help of Wireless Sensor Networks (WSNs), the road state can be judged. For example,if the flow of the people monitored by WSNs exceeds the limit value of the influx of roads, the road will be blocked.

Based on the assumptions of the topological network and the help of WSNs mentioned above, the emergency evacuation plan can be implemented as following. To ensure emergency personnel to enter the building as quickly as possible, additional exits can be used by emergency personnel when they enter the building during evacuation. Then, the evacuation route search is performed by the modified Floyd-Warshall algorithm after the emergency personnel entered the Louvre. Due to the fact that the interior layout of the Louvre is complex, it may occur clustering using the conventional Floyd-Warshall algorithm, which will cause channel blockages. Therefore, the dynamical programming is introduced into the Floyd-Warshall algorithm to ensure that the evacuation time is the global optimal solution.

In order to verify the presented model, we select the Louvre's first floor exhibition hall as an example via evacuation simulation software Anylogic with the maximum number of visitors. The results show that the presented model can achieve that goal that all the occupants could leave the Louvre as quickly and safely as possible, even with the extremum number of visitors. Besides, it should be noticeable that the presented model can be applied in large shopping malls after adjustment.

Emergency Evacuation Mode Of Large Buildings

Contents

1 Introduction

1.1 Background

The Louvre is one of the largest and most visited art museum in the world, winging as long as 480 meters. There are five floors in the Louvre, two of them are underground. To enter the museum, we can choose the pyramid entrance which is the main and most used public entrance. Furthermore, the Passage Richelieu entrance, the Carrousel du Louvre entrance, and the Portes Des Lions entrance could also be reserved for individuals and groups with museum memberships.

However, the increasing number of terror attacks in many popular destinations in France force Louvre in Paris to design evacuation plans, in order to have all occupants through optimal exits, leaving the building as quickly and safely as possible.

With more than 8.1 million visitors in 2017, the diversity of visitors in Louvre is nonnegligible, such as speaking a variety of languages, groups traveling together and disabled visitors. Moreover, the number of visitors in the museum varies throughout the day and year. Therefore, working out an appropriate emergency evacuation is urgent.

1.2 Restatement of the Problem

In order to complete the emergency evacuation model, we need to finish these parts below and then propose policy and procedural recommendations for emergency of the Louvre, the first part is the following:

- Allow the museum leaders a range of options to evacuate visitors as quickly as possible.
- Concede emergency personeel to enter the building as quickly as possible.
- Take the number of guests in the museum varies throughout the day and year which provides. challenges in planning for regular movement within the museum into consideration.
- Take the diversity of visitors into consideration.
- Facilitates evacuation plan with the main and most used public entrance: pyramid entrance and three other entrances: the Passage Richelieu entrance, the Carrousel du Louvre entrance, and the Portes Des Lions entrance.
- Consider how technology, such as apps and others could be used.
- Consider when and how any additional exits might be utilized.

After finishing the first part, we still need to conduct a deep discussion. The second part is the following:

- Identify potential bottlenecks that may limit movement towards the exits.
- Address a board set of considerations and various types of potential threats with an adaptable model.

Finally, we need to evaluate our model . The third part is:

- Validate the model and discuss how the Louvre would implement it.
- Implement model for other large, crowded stuctures.

2 Assumptions and Justifications

A variety of variable factors are involved in the process of developing emergency evacuation model. Considering those factors , also making the method more feasible, we make the following basic assumption s to simplify the problem.

- The stairs of the same location are of the same type, with identical width. The stairs of different locations are represented by the variable W.
- All Visitors follow the commands of the emergency personnel.
- All Visitors have the same athletic ability and there is no chance of jumping in the queue.
- All stairs are available and usable during emergency evacuation.
- There is no stamping accident during emergency evacuation.
- Wireless sensor networks (WSNs) are deployed initially.
- The ratio of male to female visitors per year is equal to the ratio of male to female daily visitors.
- The time of the terrorist attack was the opening hours of the Louvre.
- All the halls are open during the opening hours of the Louvre.
- The power-off escalator is used as a stairs during the evacuation process
- The Vertical lift stairs for disabled people in the Louvre are available, but the elevators can not be used because of the unstability during the evacuation process.

3 Model Theory

3.1 Determination of the Time to leave the Louvre

The emergency evacuation of the Louvre Museum needs to be considered in many ways, and is also constrained by the behavioral characteristics of visitors and the environment in which the building is located. In order to plan an emergency evacuation mode suitable for the Louvre, we established an optimized evacuation path model based on topological network.

3.1.1 Museum Indoor Topology Network

We abstract the Louvre Museum into a topological network of points and lines.We use formulas $G = (N, A)$ to represent this topological network.N represents the nodes in this network,and A represents the path,Path $A \subset N * N$in network G contains non-negative capacity and non-negative transit time attributes.In practice, network G can represent one floor of a building, while network N can represent the intersection of halls or sections, and path A can represent corridors, corridors or stairs. For a building, we divide the point set into three categories:

For the source node $\mathrm{N}_i^{(1)} \in G$,Its attributes are defined as $\mathrm{N}_i^{(1)}(ID_i, C_i, AID_i)$,$ID_i$represents the sequence number of nodes.C_i represents the capacity of node i, and AID_i stores the node

Table 1: Point set classification

Node type	Place
Source node	Exhibition hall
Transmission node	The intersection of sections of a building (stairs, sections)
Terminal node	Pyramid or Passage Richelieu or Carrousel or the Portes Des Lions

ID number adjacent to node i.For transmission nodes and endpoints $\mathrm{N}_i^{(2,3)} \in G$.We assume that the crowd is waiting for evacuation instructions only at the source node, so these two types of nodes have no capacity attributes, which can be expressed as $\mathrm{N}_i^{(2,3)}(ID_i, AID_i)$.Any road that can connect two or more people can be abstracted as a line in a topological network. For line $A_i \subset N * N$, its attribute is defined as $A_i(fID, nID, W_i, P_i(TN_i, YN_i)L_i, t_i)$.Among them, fID is the front node number of section i, nID is the back node number of section i, W_i is the width of section i, L_i is the absolute length of section i.$P_i(TN_i, YN_i)$ is the blocking degree of section i, TN_i is the actual traffic volume of section i, YN_i is the limit value of the influx of section i, and t_i is the time of section i.

In the figure above, people on the source node arrive at the destination through the transmission node, and Wireless sensor networks (WNSs) are placed on the road connecting each node to monitor the traffic of people in the section.If the flow of people monitored by a sensor node exceeds the thresholdξ, it indicates that the road section is seriously blocked and impassable.

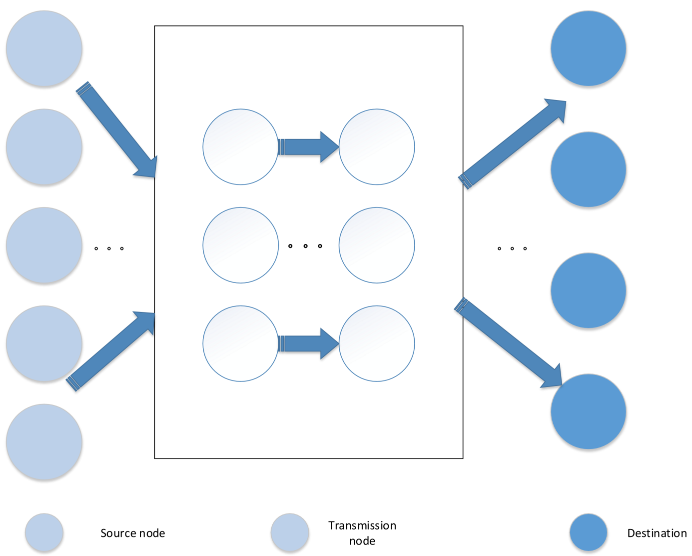

Figure 1: Creat an Energy Profile

3.1.2 Influencing factors of emergency evacuation route

Moving speed V_{L-ave},V_{V-ave}

In evacuation, there are some special individuals who are different from others because of their own physical or psychological constraints in evacuation speed, evacuation behavior and so on. We roughly classify the staff in the library into three categories:

Table 2: Point set classification

Type	Horizontal	Vertical
Familiar with the location and healthy (Personnel)	7.0	3.5
Not familiar with the location and healthy(Tourist)	5.8	2.9
Moving independently(Children, the elderly and the disabled)	4.7	2.4

Our research on the moving speed of the whole human flow is based on the weighted average of their moving speed.

$$V_{L-ave} = \sum_{i=1}^{3} VL_i * W_i \tag{1}$$

$$V_{V-ave} = \sum_{i=1}^{3} VV_i * W_i \tag{2}$$

$V_{L-ave}$is the average moving speed of three types of personnel in the horizontal direction during emergency evacuation.$V_{V-ave}$is the average moving speed of three types of personnel in the stairs during emergency evacuation.VL_i and VV_i represent the level of three types of people in emergency evacuation and the moving speed on the stairs respectively.W_i is the proportion of the number of three types of personnel.

Body proportionality parameters B_{ave}

The space occupied by people of different shapes is also different. We mainly divides the population into three categories: children, women adults and men adults. Since occupancy in space mainly affects the flow of people in horizontal direction, we choose shoulder width as an index to represent the body proportionality parameter (shoulder width corresponds to the width of the passage).

$$B_{ave} = B_c * W_c + B_w * W_w + B_m * W_m \tag{3}$$

B indicate shoulder width of children and women adults and men adults respectively, W are their proportion of populations.

Individual evacuation time t

The population as a whole is composed of several individual individuals, so if we want to study the population as a whole, we must first define the evacuation time of a single individual:

$$L = N_{steps} * L_x + (N_f - 1) * L_turn \tag{4}$$

$$t = L/V_{V-ave} \tag{5}$$

Width of Safety Channel (Stairway) W

The width of the safe passage determines the number of individuals that can be accommodated in the same horizontal direction. The size of the safe passage is inversely proportional to the evacuation time.

Length of Safety Channel (Stairway) L

The combination of the length and width of the safe passage determines the maximum number of people that can be accommodated on the safe passage. The maximum YN_i of this passageway is:

$$YN_i = W/B_ave * L \tag{6}$$

Evacuation Time of i**Channel** $Tstairs_i$

The evacuation time of corridor stairs can be divided into two parts: moving time along the stairs and passing time at the exit of stairs. For the evacuation of a single floor, we calculate the evacuation time according to Togawa's method.
$n$is the number of stories from the end of the current corridor floor, q is the flow of people per unit width pair at the exit of the corridor stairs. When all the people in the building need to evacuate as a group, due to the limited capacity of stairs, when there are enough evacuation individuals on the stairs, people can not enter the stairs and can only wait in line at the entrance, so we have improved the evacuation of the stairs in the corridor:

$$Tstairs_i = \begin{cases} \frac{n \cdot L}{V_{V\_ave}} + \frac{TN_i}{q \cdot W}, & \frac{L}{V_{V\_ave}} > \frac{TN_i}{q \cdot W} \\ \frac{n \cdot L}{V_{V\_ave}} + \frac{\sum_{k=1}^{n} TN_{ik}}{q \cdot W} & \frac{L}{V_{V\_ave}} \leq \frac{TN_i}{q \cdot W} \end{cases} \tag{7}$$

Number of Safe Channels N_{safe}

The more the number of safe passages, the larger the number of people evacuated per unit time, and the higher the efficiency of evacuation.

Congestion index P

We regard the indoor population as a whole, which has the characteristics of density and speed of human flow. According to Predtechenski and Milinski's research, under normal conditions, the relationship between human flow velocity and human flow density in horizontal direction is as follows:

$$V = 112D^4 - 380D^3 + 434D^2 - 217D + 57 \tag{8}$$

V is the speed and D is the ratio of current density N to maximum density N_max. In case of emergency, the moving speed of human in horizontal channel is as follows:

$$V_\varepsilon = V\mu_\varepsilon \tag{9}$$

$$\mu_\varepsilon = 1.49 - 0.36 * D \tag{10}$$

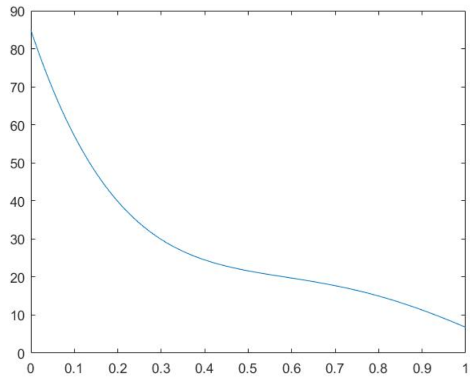

Figure 2: The Relation between the Flow Density and the Moving Speed

From the figure, we can see that when the density of people exceeds a certain threshold, the evacuation speed of the whole crowd will change very slowly, or even stagnate. Therefore, when evacuating the staff in the library, we should take into account the carrying capacity of the section, so as to timely divert the crowd.

$$P_i(TN_i, YN_i) \tag{11}$$

The $P_i(TN_i, YN_i)$ mentioned above is the blocking degree of section i, TN_i is the actual traffic volume of section i, YN_i is the limit value of the influx number of section i. In order to identify the blocking degree of section i, we use function to identify whether the section is feasible or not.

$$P_i(TN_i, YN_i) = \begin{cases} 1, & TN_i/YN_i \leq 1 \\ TN_i/YN_i, & 1 < TN_i/YN_i < \xi \\ \infty, & TN_i/YN_i \geq \xi \end{cases} \tag{12}$$

We digitize the congestion situation. When the number of people in the section is less than or equal to the limit of the influx, the congestion index is 1. When the ratio of the number of people in the section to the limit is less than 4.28, the P value takes their ratio. When the ratio exceeds 4.28, the P value goes infinite, indicating that the section can not be selected.

Evacuation time of this floor T_{toalt}

The total evacuation time of this floor is the maximum evacuation time of staircase entrance of each passage.

$$T_{total} = \max_{N_{safe}} Tstairs_{N_{safe}} \tag{13}$$

3.2 Design of emergency evacuation algorithm

3.2.1 Path search algorithm

In the above, we modeled the environment of Louvre Layer X as a topological network $G(N, A)$ composed of points and lines. The initialization number of nodes at each starting point was determined by the location results. Emergency personnel evacuated the crowd according to the evacuation path. Therefore, it is necessary to search the path of each starting point, find the path between the point and the end point, and finally send the path to emergency personnel to complete the emergency evacuation work. There are many path search algorithms, such as $Dijkstra$ algorithm (D algorithm), $Floyd$ algorithm, ant colony algorithm and so on. Although D algorithm is the most widely used, but the efficiency of dense graph with a large number of search vertices is very low. After extensive consideration, we choose a more effective algorithm - $Floyd-Warshall$ algorithm, referred to as F algorithm. In our work, we adapt the modified Floyd-Warshall algorithm by introducing the dynamical programming into the Floyd-Warshall algorithm.

(1) Floyd-Warshall algorithm

When the F algorithm is running once, it can compare all possible segments between two points in the graph to find the shortest path between any two points. The F algorithm has two important matrices: a weight matrix and a routing matrix.

The weight matrix initialization method is as shown in the matrix $Ad_(N)$:

$$Adj_{(N\in G)} = \begin{array}{c} v_1 \\ v_2 \\ \vdots \\ v_n \end{array} \begin{bmatrix} 0 & a_{12} & \cdots & a_{12} \\ a_{12} & 0 & \cdots & a_{12} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & 0 \end{bmatrix} \tag{14}$$

On the diagonal line of matrix $Ad_(N)$, the value is 0. On the non-diagonal line, if there is a path connection between point i and point j, then a_ij is the path length, and if G is undirected graph, then $a_ij = a_ji$, otherwise it may not be equal.

The routing matrix is initialized as follows:

$$r_{ij} = \begin{cases} j & a_{ij} < \infty \\ 0 & a_{ij} = \infty \text{ or} i = j \end{cases} \tag{15}$$

For graphs with n vertices, the calculation besgins with the initial weight matrix $W^{(0)}$ and the routing matrix $R^{(0)}$, updating the values of the two matrices according to the following formula:

$$W_{ij}^{(k)} = \min(W_{ij}^{(k-1)}, W_{iq}^{(k-1)} + W_{qj}^{(k-1)}) \tag{16}$$

$$r_{ij}^{(k)} = \begin{cases} r_{ij}^{(k-1)} & if(W_{ij}^{(k-1)} = W_{ij}^{(k)}) \\ r_{ik}^{(k-1)} & if\,(W_{ij}^{(k)} = W_{ij}^{(k-1)}) \end{cases} \tag{17}$$

After calculation, the shortest distance between points i and j and the conversion nodes passed by the shortest paths of i and j are continuously updated and recorded through the routing matrix R. The algorithm stops when $W^{(n)}$ and $R^{(n)}$ are calculated, where $W^{(n)}$ holds the value of the shortest path between every two points, and $R^{(n)}$ holds each The vertices through which the shortest path passes.

3.2.2 Dynamic programming

The interior layout of the Louvre is complex, and the space of each evacuation channel varies. In an emergency, clustering will occur, which will cause channel blockage. Therefore, for any starting point, there may be multiple evacuation paths, as shown in Figure 3:

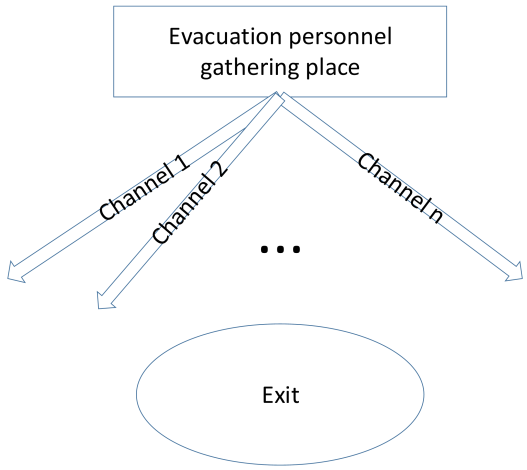

Figure 3: Selection of multiple evacuation paths

In order to plan the evacuation plan of the Louvre emergency, we need to dynamically plan the evacuation channel to ensure that the evacuation time is the global optimal solution. In the dynamic programming algorithm, if the problem involves multiple inputs, in order to find the optimal solution of the problem, the problem is usually solved in stages, and the decision of the next stage is also affected by the previous stage, as shown in Figure 4:

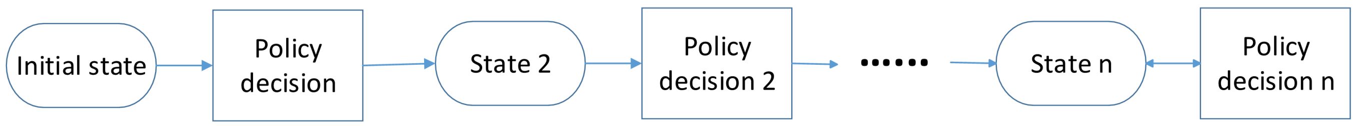

Figure 4: Decision-making process of dynamic programming

In the initial state, we make decision 1, get state 1, and then make a decision change in the state change, so that after a series of decision processes and state changes, we finally reach the optimal state n. The decision $i+1$ generated by the state i in this process is only related to i, so we divide the problem into sub-problems to make decisions, and each sub-question has multiple decision-making schemes, in which the optimal solution is inevitably generated.

Assuming that the initial state is S_0, the decision made by S_0 is represented by the set $D_1 = \{d_{11}, d_{12}, \cdots, d_{1k}\}$ and the state produced by the decision in the same D_1 is S_1, and the state of the decision substate under S_1 is $S_1 = \{s_{11}, s_{12}, \cdots, s_{1k}\}$ means that when the decision is made to the state $S_(n-1)$, its substate is:

$$S_{n-1} = \{s_{n-1,1}, s_{n-1,2}, \cdots, s_{n-1,k_{n-1}}\} \tag{18}$$

In the decision set D_n, for $S_(n-1, i)$, there are corresponding series of decisions:

$$D_{n,j} = \{d_{n,i1}, d_{n,i2}, \cdots, d_{n,ik}\} \tag{19}$$

$$D_n = \{D_{n,1}, D_{n,2}, \cdots, D_{n,k}\} \tag{20}$$

If $D_{n,j}$ under the decision set D_n produces the optimal decision $S_{n,i}$,it can be seen that this decision is generated by $S_{n-1,i}$,and this backtracking can be continued until the first decision D_1.And then we get an optimal decision sequence.

When introducing dynamic programming into the flow distribution of the Louvre emergency evacuation strategy, we can take the transit time of each channel at different personnel densities as input, and make the final evacuation time optimal through decision-making strategies.

3.2.3 Dynamic programming algorithm for evacuation paths

(1) The Principle of Algorithmic Design

The Louvre is large in scale and has a large number of visitors. The sudden situation in the process of emergency evacuation is difficult to avoid. We have considered the following issues:

- How to evacuate to ensure that the evacuation time is the shortest.
- How to avoid clogging during evacuation (involving personnel diversion).
- How to respond to the emergency signal in time to adjust the evacuation path.

For the first problem, we dynamically plan all evacuation paths. For the second problem, we use the positioning technology to count the location of the tourists and divert the tourists according to the maximum capacity of the evacuation channel. For the third problem, we plan to A plurality of wireless sensor networks are arranged in the exhibition hall for detecting environmental information, thereby establishing a model relationship with the path weights. For the analysis of the problem, we propose a dynamic orogramming algorithm for the sluice path based on the wireless sensing system. The flow chart is as follows:

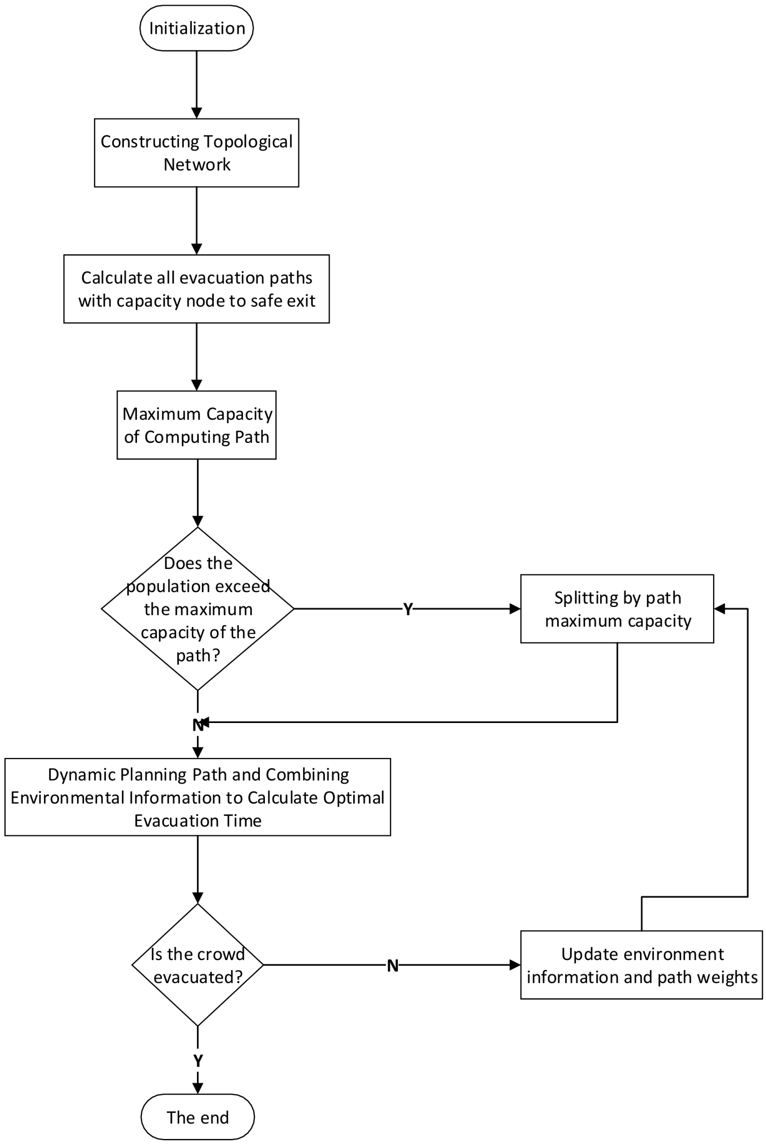

Figure 5: Decision-making process of dynamic programming

(2) Specific implementation steps of the algorithm

According to the above flow chart, the input of the algorithm is: Louvre spatial topology $G(N, A)$; all feasible evacuation paths of a node are calculated by F algorithm. The weight matrix W and the routing matrix R calculated by the F algorithm can calculate all feasible paths. In the weight matrix, if the weight of the starting point i to the ending point k is ∞, there is no feasible path between the two points. If not, the adjacent node j of the point i is found; if $d_{ij} + w_{ij} < \infty$, Recorded as a feasible path, and through the routing matrix R can get j to k transit node, similarly continue to search for the adjacent node q of node j, repeat the above process until all adjacent nodes are excluded, get all feasible Evacuation path.

After obtaining the feasible path of all points, the weight model, the flow density-motion velocity model are used to calculate the maximum number of evacuation personnel that can be tolerated by these paths, and the maximum bearing capacity in the topology network is determined. If the number of people to be evacuated exceeds the maximum capacity, Personnel grouping is divided into two parts: evacuation and evacuation. For the evacuation part, the personnel are assigned to multiple evacuation channels through dynamic global planning to obtain the shortest evacuation time. In the calculation process, the weight of the path also changes with the change of environmental information, so that the number of personnel in each channel can be quickly adjusted to avoid accidents and reduce casualties.

3.2.4 Algorithm specific implementation steps

The basic principle of the algorithm can be understood through the flow chart of the dynamic planning of the evacuation path, and the specific implementation steps of the algorithm are as follows:

- Step1: According to the Louvre space abstract network graph G, the path matrix $R^{(ij)}$ is initialized, and each element in the matrix is the path length and width (L_ij, W_ij) of the points v_i to v_j, if there is no direct between v_i and v_j The connected segments are initialized with $L_ij = \infty$.

- Step2: Firstly, the shortest path from the source point S to the exit set D is calculated by the F algorithm as a heuristic function, and then all m feasible paths are calculated by the A^* algorithm, and the path is marked as:

$$P_k = \{S, \cdots, v_i^{(k)}, \cdots, D\}, 1 \leq k \leq m \tag{21}$$

  $v_i^{(k)}$ said the other transfer point by article K in the path.

- Step3: For the road segment $SN_{ij}^{(k)}$ included in the feasible path P_k, calculate the maximum capacity $C_{ij}^{(k)}$ of the road segment according to the maximum human flow density that can be tolerated per unit area, and take the smallest of all the road segments of P_k. Capacity as the maximum capacity of the path P_k, expressed as $C_{\max}^{(k)}$ as follows:

$$C_{\max}^{(k)} = \max(C_{\max}^{(1)}, \cdots, C_{\max}^{(k)}, \cdots, C_{\max}^{(m)}) \tag{22}$$

  And the maximum capacity n of the topology network graph G is expressed as:

$$n = \max(C_{\max}^{(1)}, \cdots, C_{\max}^{(k)}, \cdots, C_{\max}^{(m)}) \tag{23}$$

- Step4: Construct a $m \times n$ weight matrix $W^{(m,n)}$ according to the path number m and the maximum capacity n calculated in steps 1-3, and use the environment factor-weight model of the road segment environment information returned by the WSN. Calculate the weight coefficient $a_{ij}^{(k)}$ of the road segment $SN_{ij}^{(k)}$, and use the population density-moving speed model to calculate the traffic speed $v_{ij}^{(k)}$ when the number of people is u and assign an initial value to the weight matrix:

$$W(k, u) = a_{ij}^{(k)} \times a_{ij}^{(k)} L \div v_{ij}^{(u)} \tag{24}$$

- Step5: Let $f_i(x)$ be the minimum evacuation time obtained when the evacuation group is assigned to the first i evacuation path, and $d_i(x)$ denote the number of people assigned to the i-th evacuation path when $f_i(x)$ is the largest. In the first phase, only x individuals are assigned to the first evacuation path, as follows:

$$\begin{cases} f_1(x) = W(1, x) \\ d_1(x) = x \end{cases} \quad 0 \leq x \leq n \tag{25}$$

In phase i, only x individuals are assigned to the first i paths, as follows:

$$\begin{cases} f_i(x) = \min(\max(W(i,z), f_{i-1}(x-z))) \\ d_i(x) = z(\min(f_i(x))) \end{cases} \tag{26}$$

of which $0 \leq x \leq n$,$0 \leq z \leq n$. Assuming that the minimum travel time of stage i is t_i, then:

$$t_i = \min(f_1(x), \cdots, f_i(n)) \tag{27}$$

Let p_i be the number of people assigned to the first i path at the minimum time of t_i, so $f_i(x)$, $d_i(x)$, t_i, p_i are saved at each stage, and the global minimum travel time t_min is calculated at the m stage, and the evacuation number $x_i(i \in m)$ allocated by each path is calculated by backtracking.

- Step6: If the total number of evacuation x is larger than n, in order to prevent overcrowding, x should be divided into parts with k less than n, and step 5 should be repeated to calculate the total evacuation time of each part:

$$t_{total} = \sum_{i=1}^{k} t_{\min}^{(i)} \tag{28}$$

- Step7: For the case where x is less than n, if x is greater than n, after each evacuation group, go back to step 4, update the values in the weight matrix according to the environmental information and calculate the evacuation personnel assigned to each section again until all evacuations are completed, and the algorithm is finished.

The key points of the above steps are the calculation of feasible paths in step 2 and the assignment of evacuees in step 5. The algorithm used in step 2 is F algorithm and A^* algorithm, and the time complexity is $O(m * N^3)$. When calculating personnel allocation, it needs m cycles to keep the personnel allocation table of the first i sections, and M evacuation personnel should be allocated in each cycle. This process requires m^2 comparisons, so the time complexity of step 5 is $O(m * N^3)$. Among them,N is the number of nodes in network G, n is the maximum number that network G can accommodate calculated in step 3, so the time of the algorithm is Inter-complexity is magnitude N^3, which can be realized by computer.

4 Model Implementation and Results

4.1 Simulation and result analysis of the algorithm

For the calculation and allocation of evacuation route in emergency evacuation process, firstly, the indoor structure of the Louvre Museum should be analyzed, and the safety exit, the intersection point of each section, the personnel gathering place and each passage section should be modeled. Fig. x is the actual internal structure of the X floor of the Louvre Museum and the topological network $G(N, A)$:

After modeling, the source point S, a secure exit D (simulation only considers the single source point to the single exit) and a topological network composed of X transmission nodes:X and an evacuation channel are obtained. Using step 2 of the dynamic planning algorithm of evacuation path mentioned above, all evacuation paths (excluding loops) from the source point to the safe exit can be obtained. There are X evacuation paths:

4.2 Model adaption for other large, crowded structures

In order to discuss how to adapt and adjust our model to other large buildings, we selected a large shopping mall in Beijing, which integrates clothing, cosmetics, electronic products and other stores.Weekends or holidays tend to lead to large-scale crowds gathering in shopping malls. At this time, if there is a crisis, due to the complex structure of shopping malls (large building area, stairway location is not obvious) and the dynamic distribution of people, it is very necessary to study their emergency evacuation.

4.2.1 Model adjustment

Flowrate

In order to better adapt our model to the emergency evacuation of the shopping mall, we selected the number of holidays in the shopping mall on weekends as our statistic, and the flow of people was as high as 1075.

Personnel distribution

We mentioned earlier that for different categories of people, their speed of movement during evacuation is also different. So we analyzed the distribution ratio of different kinds of people in one storey of a shopping mall,as follow:

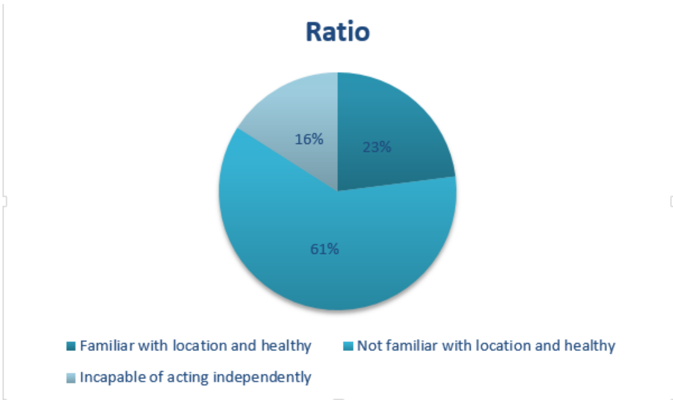

Figure 6: Proportion of three categories of people in V

so the Average moving speed is $V_{V-ave} = \sum_{i=1}^{3} VV_i * W_i = 1.2$.

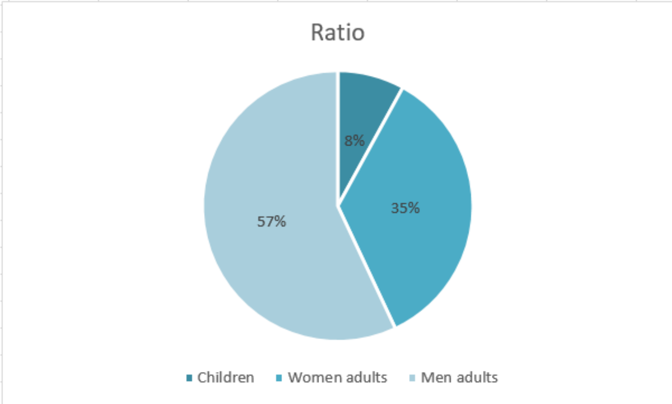

Figure 7: Proportion of three categories of people in B

so the Average Shoulder width is $B_{ave} = B_c * W_c + B_w * W_w + B_m * W_m = 0.37$.

4.2.2 Simulation

The building area of the shopping mall is about 5790 square meters. Here we take the shopping area of the first floor of the shopping mall as the main research object. There are six stairways as the exit. We divide this floor into eight areas. The floor plan of the shopping mall is as follows:

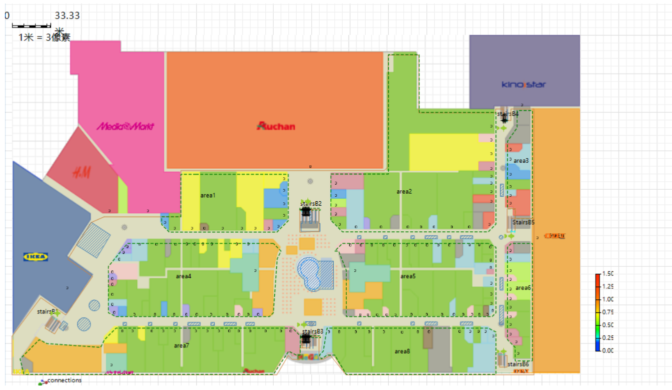

Figure 8: Plane Structural Diagram of Large Mall

For the convenience of viewing the evacuation path of the shopping mall, we abstract the plan of the shopping mall into the evacuation logic diagram,and set the value of the parameter.The simulation process is as follows:

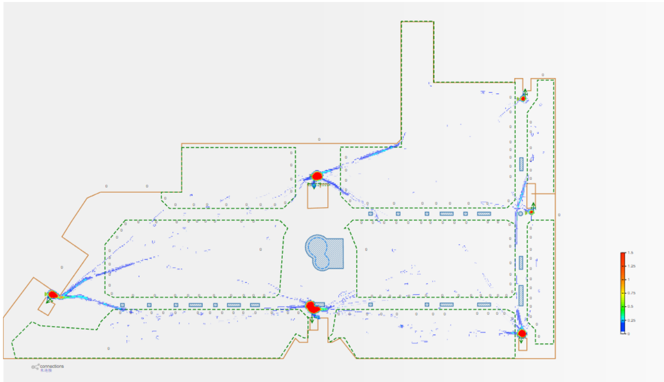

Figure 9: Initial

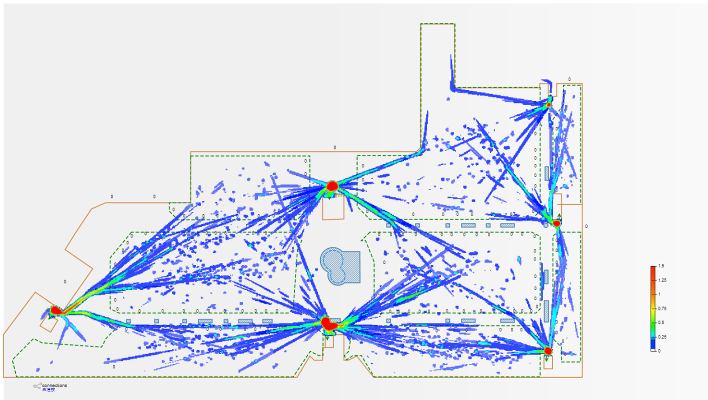

Figure 10: In the beginning

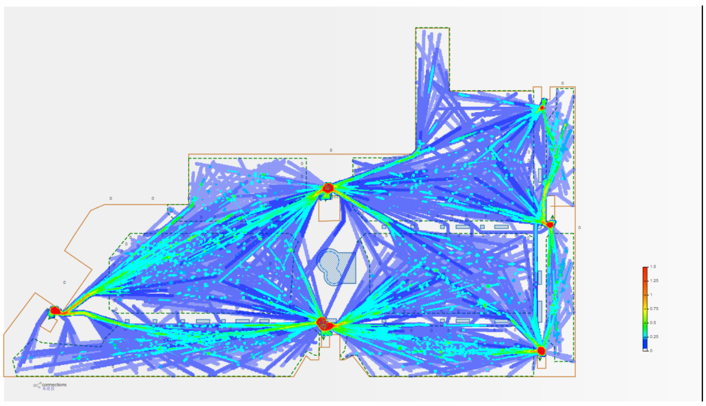

Figure 11: In the middle

The red nodes in the figure indicate the location of the highest density of people in the shopping mall, that is, the flow of people in the stairway during evacuation.

4.2.3 Conclusion

We use Anylogic to simulate the emergency evacuation of people in shopping malls. The simulated evacuation time was 423 seconds.

5 Conclusion

We put the model into the software "Anylogic" to simulate the emergency evacuation. The final evacuation time is 4096 seconds and 423 seconds, respectively.According to the calculation formula in "Guidelines for Building Disaster Prevention Planning" of Japanese building center hairstyle, the available evacuation time of the Louvre and our selected shopping mall are 4393s and 504s respectively, so our emergency evacuation model is feasible.

5.1 Strengths

- This model abstracts the key passageway intersections and exhibition areas in large buildings into a network topology map, which facilitates the acquisition of global information about escape routes.
- This model takes into account the diversity of indoor personnel, such as children, adult males and adult females, and adopts weighted average method to calculate the characteristics of evacuees according to the typicality.
- In the path search algorithm, this model creates a dynamic programming based on Freud's path exploration. Real-time update of road congestion information in order to guide the rapid and effective evacuation of people in the building.

5.2 Weaknesses

This model is for emergencies that can be perceived by the public in a short time, but not for emergencies with latency. For example, when a fire occurs, there is a certain latent spread period, and when the smoke concentration is higher than a certain value, it will be perceived. At this time, the reaction time of the personnel in the building is longer and can not be ignored.

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