Research on Louvre evacuation based on Dynamic Network Flow model

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Abstract: In this paper, we have improved and applied the dynamic network flow model to identify bottlenecks in the process and recommend improvements. We use the normal distribution to estimate the maximum value of a certain moment for the Louvre visitors, and as the object of study.In order to simulate the evacuation process of people in the building, we adopt the network flow model, and on the basis of it, the dynamic network flow model is studied. The dynamic network flow model has the function of identifying bottlenecks, removing the bottleneck route, re-retrieving the next feasible route, and selecting the shortest path in the remaining routes. In this paper, the theoretical results are verified by an example of the Louvre. By simulating, we get the evacuation time of the Louvre at 418s.

1. Introduction

With the development of economy, the speed of tourism development. The number of tourists is growing rapidly every year, and the attractions have become high-density areas, and their safety risks have become an important issue. Now the problem of the evacuation of personnel in various countries is constantly studied extensively and deeply.

The researchers used different methods to study the problem of emergency evacuation, which is divided into two categories, microscopic model and macroscopic model. The research content of this paper belongs to the macroscopic model, and all evacuees are regarded as a similar group for macroscopic research. At the same time, the mathematical analysis method is mainly based on network flow optimization. Now, although new technologies are constantly being applied to evacuation models, more and more attention has been paid to the use of dynamic network flow to study evacuation problems.

2. Problem Analysis

In this report, we first set up a multi-source multi-outlet network flow evacuation model, the use of two layers for gradual improvement. In the network flow model, the first step, we first set up a single-layer building network flow evacuation model, the second step on the basis of a single layer to establish a multi-storey building network flow evacuation model. After we complete the establishment of this universal network flow model, we use the five-storey building of the Louvre as a verification, and introduce the application of the Louvre in the network flow model in detail.

We use a comprehensive movement rate as the movement speed of the crowd. Because visitors have diversity, it has an impact on the overall speed of movement. Therefore, the sensitivity of the model is tested by synthesizing the movement rate.

3. Assumptions and Justification

(1) assuming that the number of each room or showroom per floor as the source point
(2) assuming that all exits of the high-rise building for the exit point, connecting the source point and the other points of the exit point (such as stairs) as Node
(3) assuming that the connecting node and the node of the curve, become an arc, its length becomes arc length.

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(4) assuming that during the evacuation process, there is no return or circle of tourists
(5) assuming the exit of the evacuation path, to meet the principle of first-in,
(6) assuming that each outlet has a capacity limit of
(7) assuming that each arc has a stable evacuation speed
(8) assuming that the evacuation process, residents can follow the rescue instructions according to the set route to escape
(9) assuming that during the evacuation process, ignore the impact of the residents ' panic psychology on the evacuation plan

4. Models

4.1 Basic Model

The evacuation of high-rise buildings requires first study of the evacuation on each floor, so we use the evacuation route of the single floor as the object of study, and then integrate it into the evacuation route of the high-rise building. In a floor, the safe evacuation of personnel, we use dynamic network flow method, first calculate the route that can be walked, and the bottleneck of the route to remove, update can pass through the collection of routes. In this way, the algorithm has dynamic adjustable, it can be flexible to avoid the use of blocked routes as evacuation routes. On one floor, the adjustable evacuation model is described below:

- Terms, Definitions and Symbols

(1) Set P: A collection of evacuated paths for passage
(2) Set A: For the point where the attack took place, and A={x|x=1, 2, 3 ... X};
(3) Set E: For the export point of the building, and E={e|e=1, 2, 3 ... E};
(4) Set N: Intermediate medium for evacuation source point and public outlet, and N={n|n=1, 2, 3 ... N};
(5) Set Gij: For the distance between node i and Node j, the Arc is a collection,
(6) Set Cij: Capacity for each arc
(7) Set y: number for each path
(8) Set Y: A collection for actual participation in evacuation paths
(9) Set Y ': a collection of feasible paths
(10) Set I: For floor collection
(11) Set m: for layer m
(12) Set F: A collection of dynamic traffic for nodes
(13) Set P_y : As a viable path to article Y, P is a collection of paths
(14) Set μ : A collection of evacuation times for each layer
(15) Set t_{ij} : Time to pass the arc
(16) Set T_y^m : The time required to reach the exit along the path for the M-tier evacuees
(17) Set T^m : Actual evacuation end time for layer m
(18) Set T: Evacuation end time for the entire evacuation network, that is, when the last person leaves the building
(19) Set f_y^m : Indicates the dynamic flow of the path to the exit at T moment
(20) Set r: Exit point for the building
(21) Set x: Total number of people to be evacuated

- An algorithm for evacuation model of single-storey buildings

(1) Initialize network flow values: Enter A (number of points of attack), E (number of exits), N (number of stairs), G_{ij} (length of Arc), C_{ij} (capacity per arc)
(2) the use of graph theory, the generation of graphics, the calculation of the disaster point to the export of the shortest path P_y , and increase it to the P set, then P=P$\cup P_y$, the shortest path required time is T_p , then $T_p = T_p \cup T_{p_m}$

(3) Calculate the maximum allowed capacity C_{p_m} for the shortest path P_y, then =min{ C_{ij} }

(4) set up $f_y = C_{p_m}$ =, F=F∪{ f_y };

(5) the dynamic update of the maximum capacity C_{ij} of each arc , then $C_{ij} = C_{ij}$ - f_y, when C_{ij} =0, indicating that the path is a bottleneck, then from the original path network to remove the arc C_{ij}, dynamically update the network, this part makes the algorithm has self-regulation ability, can adapt to a variety of dangerous situations.

(6) when the updated path is not connected, then make the 7th, otherwise m=m+1, and then the 2nd, start the loop execution.

(7) output feasible shortest path set P, evacuation time set Tp, route of human flow set F

- Solution and Result

According to $\begin{cases} x \geq \sum_{y=1}^{m_1} (T_{P_{m1}} - (T_{P_y} - 1)) f_y \\ x \leq \sum_{y=1}^{m_1+1} (T_{P_{m1+1}} - (T_{P_y} - 1)) f_y \end{cases}$, when the formula is satisfied, it is the path of actual participation in the evacuation, apparently $P_y \in$ P={ P_1, $P_2 \ldots\ldots P_{m1}$ }

- Set the evacuation end time to T, the evacuation time should depend on the last person to reach the end of the time to get the formula $T = \frac{x + \sum_{y=1}^{m_1} T_{P_y} f_y - \sum_{y=1}^{m_1} f_k}{\sum_{y=1}^{m_1} f_k}$

- Based on the $x_y(T) = (T - (T_{P_y} - 1)) f_y$, calculation of the number of people that each selected path should actually need to allocate, the excess traffic needs to be allocated near other non-public entrances at this time

- Analysis of the Result

In one floor, we designed an algorithm based on the above equation to determine the actual participation of the evacuation path, you can determine the maximum evacuation end time, and then according to the formula (1) Distribution of the number of people, to determine the optimal evacuation path.

4.2 Improved Model

The evacuation algorithm of single-layer architectural design, when converting into high-rise buildings, should consider the following factors:

1) When you reach the lower level from the top, the low-rise channel is used by the upper level, so that the channel will be affected

2) The outlet flow f_y of a node is constant in a single-storey building, but it is a variable in a high-rise building and needs to be constantly adjusted.

Therefore, the evacuation route of high-rise buildings is more complex than the single layer, we in the algorithm for the long evacuation of the floor priority evacuation, priority saturation of the shortest evacuation route, so that the overall evacuation time will be reduced. It is also necessary to consider the human flow of interconnected channels between floors, which needs to be constantly updated to identify the moment when the path is in a bottleneck and to optimize it to determine the optimal evacuation plan.

- Extra Symbols

Set S: A collection of floors for high-rise buildings, S_y representing layer y

Set m: Disaster Point

- Evacuation model algorithm for multilayer buildings

1)Initialize, enter the floor set S, initialize the maximum capacity C_{ij}, initialize the actual evacuation path set to Y=$\varnothing$, the feasible path is Y'=$\varnothing$, the floor set is I=$\varnothing$, the dynamic flow is F=$\varnothing$, the evacuation time set of each layer μ =$\varnothing$, make r=1;

2)Find the acceptable collection of evacuation paths P_m for each layer S_m to reach the exit, the time required for the channel is $T_{p^m}=\sum_{g_{ij}\in p^m} t_{ij}$, and the time required is sorted in size.

3)And according to the single-layer network flow model to determine the actual evacuation route P_{m_r}, $P_m=P_{mr}\cup P_m$, evacuation end time $\mu=\mu\cup T^{m_r}$, flow set $\mu=\mu\cup T^{m_r}$;

4) When the disaster point is r=m, do the following, $I=I\cup\{m_r\}$ $Y'=Y'\cup Y_0^{m_r}$,go to step 7, or go to step 5;

5)If $T^{m_r}<T_{p_{m_r+1}}$, go to step 6, or do the following: $I=I\cup\{m_r\}$, $Y'=Y'\cup Y_0^{m_r}$, $Y'=Y'\cup Y_0^{m_r}$, r=r+1; then go to step 3;

6)Order $T^{mr}=T^{mr}$, $\left\langle\begin{array}{l}\{Y^{m_r}=Y^{m_r}\cup\{P_y^{m_r}|P_y^{m_r}\le T^{m_r}\text{ and }P_y^{m_r}\in Y_0^{m_r}\}\\ \mu=\mu\text{-}\{T^{m_r}\}\\ F=F\text{-}\{f_y^{m_r}\}\end{array}\right.$, and then go to step 11;

7)Sort the factors T^{m_r} in the floor collection I by from large to small, taking $T^{m_r}=\max\{T^{m_r}\mid m_r\in I\}$

8)Take the shortest path $P_y^{m_r}\in Y'$, for any path $P_l^{m_\eta}\in Y'\cup Y$ $(\eta\ne r)$, if the collection $\{g_{ij}\mid g_{ij}\in P_y^{m_r}\cap P_y^{m_\eta}\}=\varnothing$, then define $f_y^{mr}(t)=\begin{cases}\min\{c_{ij}(t)\mid g_{ij}\in P_y^{mr}\} & t\ge T_{p_y^{mr}}\\ 0 & else\end{cases}$, go to step 10, or go to step 9;

9)Starting from the source point along the path $P_y^{m_r}$ to encounter the first intersection, find the path $P_l^{m_\eta}\in Y'\cup Y$ $(\eta\ne r)$ to meet with $P_l^{m_\eta}$ and $P_y^{m_r}$ only that intersection, the path through time is $T_{P_y^{m_r}}$ $T_{P_l^{m_\eta}}$, for the floor $m_r\in I$, because $T^{m_r}\ge T^{m_\eta}$, in order to balance the evacuation time, should give priority to saturation and evacuation of the r layer of passengers; The following definitions $P_l^{m_\eta}$ and $P_k^{m_r}$ the dynamic traffic that arrives at the exit at t time are:

a) when $t<\min\{T_{P_y^{m_r}},T_{P_l^{m_\eta}}\}$, $f_y^{m_r}(t)=0$, $f_l^{m_\eta}(t)=0$;

b) when $T_{P_y^{Mr}}\le t<T_{P_l^{M\eta}}$, $f_l^{M\eta}(t)=0$, $f_y^{Mr}(t)=\min\{c_{ij}(t)|g_{ij}\in P_y^{Mr}\}$; or when $T_{P_l^{M\eta}}\le t<T_{P_y^{Mr}}$ $f_l^{M\eta}(t)=\min\{c_{ij}(t)|g_{ij}\in P_y^{Mr}\}$, $f_y^{Mr}(t)=0$;

c) when $\max\{T_{P_y^{Mr}},T_{P_l^{M\eta}}\}\le t\le T^{M_\eta}$, $f_y^{Mr}(t)=\min\{c_{ij}(t)|g_{ij}\in P_y^{Mr}\}$; $c_{ij}(t)=\begin{cases}c_{ij}(t), e_{ij}\notin P_k^{Mr}\\ c_{ij}(t)-f_y^{Mr}(t), e_{ij}\in P_y^{Wr}\end{cases}$, $f_l^{M\eta}(t)=\min\{c_{ij}(t)|g_{ij}\in P_l^{M\eta}\}$;

4) If $t\le T^{Mr}$, at that time, the M_η first floor had not yet been evacuated, the $f_l^{M\eta}(t)=\min\{f_y^{Mr}(T^{Mr})+f_l^{M\eta},c_{ij}(t)|g_{ij}\in P_l^{M\eta}-P_y^{Mr}\}$, $f_y^{Mr}(t)=0$

10) Order $Y'=Y'-\{P_y^{Mr}\}$, $Y^{Mr}=Y^{Mr}\cup\{P_y^{Mr}\}$, $F_0=F_0-\{f_y^{Mr}\}$, if $Y'\cap(\cup P_y^{Mr})=\emptyset$, ; order $T^{Mr}=T^{Mr}$, go to step 11, or go to step 8;

11) Order $Y=Y\cup Y^{Mr}$, $F=F\cup\{f_y^{Mr}(t)\}$, $\mu=\mu\cup\{T^{Mr}\}$, $I=I-\{m_r\}$;

12. If so $I=\emptyset$, go to step 13, or, depending on the dynamic flow of step 9, use theorem 1 and formulas $\sum_{P_l^{M\eta}}\sum_{t=0}^{T}f_y^{M\eta}(t)=q^{M\eta}$ to determine the evacuation time $T^{M\eta}$ of the layer M_η under new traffic, update $T^{M\eta}$, go to step 7;

13) Output path collection Y, path dynamic flow set F, evacuation time collection η for each layer.

- Solution and Result

According to the above method, the actual evacuation scheme of the floor can be obtained, and step 9 solves the problem of redistributing human flow at the intersection of the evacuation path of the high-rise building. At the same time, the model can identify the bottleneck route and delete the route for retrieval of other routes. The model has dynamic adjustable nature and can be adapted to many disaster scenarios. Therefore, the above algorithm can effectively solve the problem of evacuation of high-rise building personnel.

5. Example validation of the Louvre

5.1 Review

The above algorithm can be applied flexibly in multi-storey buildings, which is very suitable for solving the problem of evacuation of multiple sources and exits. As a practical example, the Louvre will verify the multi-validity and accuracy of the dynamic network flow model.

5.2 Evacuation personnel assigned according to normal distribution

By studying the daily number of visitors to the Louvre, it was found that there were significant differences in the number of visitors to the Louvre at different times. By fitting the data, the phenomenon conforms to the normal distribution law. The total number of visitors to the Louvre in 2018 was 10.2 million, compared with a 25% increase in 2017. The greater the number of visitors, the higher the requirements for the network flow evacuation model, so we chose the number of visitors for 2018 as the subject of the study, the specific data are as follows:

Table 1. Summary of Visitors ' data from the Louvre

	Total annual visitors	**Total number of visitor days**	**The maximum number of visitors at a certain time**	**Average number of visitors on a certain floor at a certain time**
Quantity (person)	10,200,000	24,000	16,368	3,274

From the table, according to 2018 data, the maximum number of visitors per floor at a certain time in the Louvre is 3,274, and this data will be the subject of our study。

5.3 Louvre network flow Figure

Figure 1 is to map the Louvre building structure as a network flow map, the showroom or the crowd in the room as a whole, called the source point. Use the export of the building as a destination for evacuation and become an outlet point. The staircase between the source point and the exit point is the node of the network flow model. Table II expounds the significance of figure two symbols.

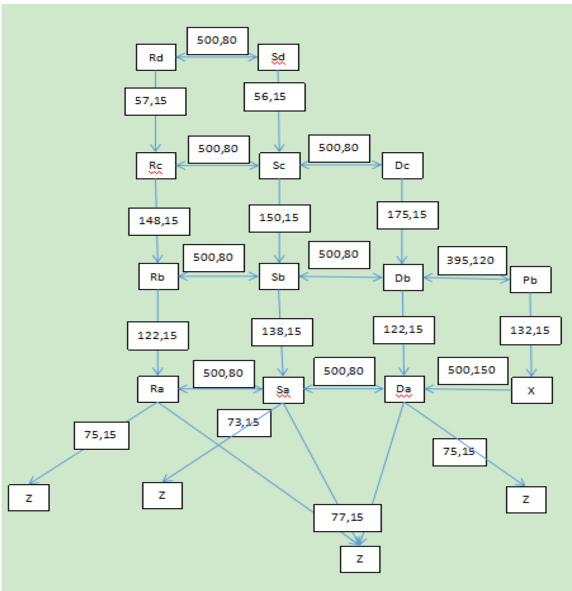

Figure 1: Network flow diagram of the Louvre

Table 2. Symbolic Meaning of the Louvre network flow chart

symbol	meaning
X	The intersection of the route
Z	Four public exits of the Louvre building
Ra	1/F, Richelieu Pavilion
Rb	0/F, Richelieu Pavilion
Rc	1/F, Richelieu Pavilion
Rd	2/F, Richelieu Pavilion
Sa	The 1 floor of the Montessori Pavilion
Sb	0 floors of the Montessori Pavilion
Sc	1 floors of the Montessori Pavilion
Sd	2 floors of the Montessori Pavilion
Da	1/F, Tak Nong Pavilion
Db	1/F, Tak Nong Pavilion
Dc	1/F, Tak Nong Pavilion
Dd	1/F, Tak Nong Pavilion
(a,b)	a is path capacity and b is path time

5.4 Advantages and disadvantages of non-public entrance to analytic hierarchy process

Table 3. Judgment matrix of the criterion layer

A	B_1	B_2	B_3	B_4	B_5	B_6
B_1	1	5	0	0	0	0
B_2	1/5	1	0	0	0	0
B_3	0	0	0	0	0	0
B_4	0	0	0	0	0	0
B_5	0	0	0	0	0	0
B_6	0	0	0	0	0	0

The above forms C5, C4, C3, C2 and C1 represent old secrets, emergency exits, employee exports, VIP entrances, service doors, respectively. Get their pros and cons through hierarchical analysis. The above table is divided into c1,c2,c3 and C3,C4,C5, through programming analysis, C4>C1>C3>C2>C5,0.64>0.4995>0.32>0.1669>0.0388, can be seen C4 emergency export security performance is better, followed by service door, employee export, VIP entrances, old secrets, so when using non-public entrances, priority can be given to the use of emergency entrances.

5.5 Results

According to table, we determine the end time of each floor evacuation, T^{-1}=418s, T^{0}=330s, T^{1}=195s, T^{2}=180s (T^{-1}, T^{0}, T^{1}, T^{2} representing the evacuation time of each floor, respectively), based on the actual route of the evacuation on each floor, as shown in table III, and the evacuation time of the last Louvre is t=max{T^{m}}=418s

In table III, we determine the actual flow on each path at all times, in accordance with the principle of giving priority to the long floor of saturated evacuation, and conclude that the total number of evacuees on the 1 floor is 4464, the total number of 0-storey evacuations is 4464, the total number of 1-storey evacuations is 4464, and the total number of 2-storey evacuations is 2976.

Table 4. Path Evacuation collection Km and evacuation end time of actual participation t^m

floor	The initial number	The path P_k^m	The road is long T_k^m	T^m
2	2976	P_1^2: Rd---Rc---Rb---Ra---Z	60	418
		P_2^2: Sd---Sc---Sb---Sa---Z	60	
		P_3^2: Sd---Sc---Dc---Db---Da---Z	140	
		P_4^2: Sd---Sc---Dc---Db---Pb---X---Da---Z	410	
1	4464	P_1^1: Rc---Rb---Ra---Z	45	330
		P_2^1: Sc---Sb---Sa---Z	45	
		P_3^1: Dc---Db---Da---Z	45	
		P_4^1: Dc---Db---Pb---X---Da---Z	315	
0	4464	P_1^0: Rb---Ra---Z	30	195
		P_2^0: Sb---Sa---Z	30	
		P_3^0: Db---Da---Z	30	
		P_4^0: Pb---X---Da---Z	180	
-1	4464	P_1^{-1}: Ra---Z	15	180
		P_2^{-1}: Sa---Z	15	
		P_3^{-1}: Da---Z	15	
		P_4^{-1}: X---Da---Z	165	

6. Sensitivity analysis

In this section, we simulate the diversity of the population as a reference factor. Dynamic network flow model is a macroscopic analysis method. The diversity of population has different language, different age composition, panic psychology when running away, etc. The diversity of the population is a microscopic analysis of the evacuation process. After considering the total composition of the population, we introduce a comprehensive movement speed, which can take good care of the elderly, children, disabled people walking slow, can reflect the Louvre Hall Group is closer to the actual rate of movement.According to the number of tourist numbers, calculated the overall speed of visitors to the original 0.874, obviously, the overall movement speed slows down, repeat the above steps, calculated the floor movement time T^{-1} =373.7s, T^0 =295s, T^1 =174.3s, T^2 =161s, the overall movement time is T=373.7s, for the original 0.894. Therefore, the dynamic network model has good sensitivity.

7. Strengths and Weaknesses

7.1 Strengths

- The dynamic network flow method, aiming at the minimization of evacuation end time, can obtain the shortest evacuation time and the optimal evacuation path through the mathematical model.
- This model has good self-regulation ability. It uses the dynamic network flow model, according to the node outflow and the inflow speed comparison, can be sensitive to the bottleneck point occurrence moment, and quickly deletes the path in the network flow diagram, no longer

consider, and automatically selects the next route for judgment and planning.

- The dynamic network model has good portability and can adapt to a variety of high-rise buildings. We only need the specific value of a given variable to arrive at the optimal planning path.
- The model can be adapted to the scenarios in which multiple disasters occur. Earthquakes, fires, explosions and other attacks occur, will cause damage to different evacuation routes, or even blockage, difficult to access. The model identifies bottleneck points and automatically plans for the most routes.
- The model has a small amount of computation, giving priority to the path of actual participation in the evacuation. The model does not look for all paths from each floor to the exit, it first records the optimal path of actual participation, so that the traversal time is reduced. Such an algorithm is a good way to improve the performance of the model.

7.2 Weaknesses

- In the hypothetical conditions of dynamic network model, we ignore the influence of people's behavior caused by panic psychology on the evacuation process when disaster occurs. In practice, we should seriously consider and solve this problem.
- The model does not consider the evacuation process, people in the exit queuing clearance, when the time is more adequate, we have the ability to solve this problem, and constantly improve the integrity of the model.
- The model ignores a more important concept, that is, the shortest path to the distance exit, not necessarily the optimal path. When the population is close to the outlet and the export is selected, there is a queuing situation, which requires the inclusion of queuing time, so that the shortest path is not necessarily the optimal path.

References

[1] YUAN Yuan, WANG Ding-wei. Route Selection Model in Emergency Evacuation under Real Time Effect of Disaster Extension [J]. Journal of System .Simulation (S1004-731X), 2008, 20(6): 1563-1566

[2] Sangho Kim, Shashi Shekhar. Contraflow network reconfiguration for evacuation planning: a summary of results [C]// Proceedings of the 13th annual ACM international workshop on Geographic information systems, New York, USA, 2005. USA: ACM, 2005: 250-259

[3] Zheng Xiaoping, Liu Mengting. Forecasting model for pedestrian distribution under emergency evacuation [J]. Reliability Engineering and System Safety (S0951-8320), 2010, 95(11): 1186-1192.

[4] Xie C, Turnquist M A. Lane-based evacuation network optimization: An integrated Lagrangian relaxation and tabu search approach [J]. Transportation Research Part C (S0968-090x), 2011, 19(1): 40-63.