Model Assumptions and Suggestions for the Louvre Crisis Response Measures

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Abstract: To allow visitors to flee the Louvre the first time after a terrorist attack on the Louvre, we have built such a model. We looked up some data about the Louvre, then analyzed the types of terrorist attacks, and developed a more flexible evacuation model. We first put together the closer exits and refer to them as an exit group. Each exit group is accompanied by a region in which visitors must evacuate from that exit group. Each region has a planned escape route, and staff in the region will lead visitors to evacuate. The division of each region is determined by factors such as the traffic capacity of the exit group and the pavilion in which it is located. We calculate the area of each region accordingly. The specific calculation formula is as follows:
$$S_{Xi} = \frac{1}{3} \left(\frac{W_{Xi}}{\sum_{j=1}^{n_j} W_{Xj}} + \frac{N_{Xi}}{\sum_{j=1}^{n_j} N_{X_j}} + \frac{P_{X_i}}{\sum_{j=1}^{3} P_{X_j}} \right) S_X$$
. After each floor block, we get some areas where each region has its own escape route. We come up with an optional path through the ant colony algorithm. Visitors from each region can simply follow the arrangements of the staff on each floor to evacuate quickly. In order to verify the model, we fit the formula of escape speed according to the data of many aspects. Through the formula, we calculated the time of the tourist escape more accurately, which is a better simulation of the real scene of the tourist escape. Also, we have made a lot of recommendations for the Louvre in response to different types of terrorist attacks. We also discussed where terrorist attacks took place and considered them from multiple angles. In order to enable rescue workers to quickly enter the scene, we have also proposed a number of improvement measures.

1. Introduction

1.1 Statement of the Problem

The increasing number of terror attacks in France [1] requires a review of the emergency evacuation plans at many popular destinations. Your ICM team is helping to design evacuation plans at the Louvre in Paris, France. In general, the goal of evacuation is to have all occupants leave the building as quickly and safely as possible. Upon notification of a required evacuation, individuals egress to and through an optimal exit in order to empty the building as quickly as possible.

The Louvre is one of the world's largest and most visited art museum, receiving more than 8.1 million visitors. The number of guests in the museum varies throughout the day and year, which provides challenges in planning for regular movement within the museum. The diversity of visitors speaking a variety of languages, groups traveling together, and disabled visitors makes evacuation in an emergency even more challenging.

The 380,000 exhibits located on these five floors cover approximately 72,735 square meters, with building wings as long as 480 meters or 5 city blocks [3]. The pyramid entrance is the main and most used public entrance to the museum. However, there are also three other entrances usually reserved for groups and individuals with museum memberships: The Passage Richelieu entrance, the Carrousel du Louvre entrance, and the Portes Des Lions entrance. The Louvre has an online application, "Affluences" (https://www.a uences.com/louvre.php), that provides Realtime updates on the estimated waiting time at each of these entrances to help facilitate entry to the museum. Your team might consider how technology, to include apps such as Affluences, or others could be used to facilitate your evacuation plan.

Only emergency personnel and museum officials know the actual number of total available exit points (service doors, employee entrances, VIP entrances, emergency exits, and old secret entrances built by the monarchy, etc.). While public awareness of these exit points could provide additional strength to an evacuation plan, their use would simultaneously cause security concerns due to the lower or limited security postures at these exits compared with level of security at the four main entrances. Thus, when creating your model, your team should consider carefully when and how any additional exits might be utilized.

Your supervisor wants your ICM team to develop an emergency evacuation model that allows the museum leaders to explore a range of options to evacuate visitors from the museum, while also allowing emergency personnel to enter the building as quickly as possible. It is important to identify potential bottlenecks that may limit movement towards the exits. The museum emergency planners are especially interested in an adaptable model that can be designed to address a broad set of considerations and various types of potential threats. Each threat has the potential to alter or remove segments of possible routes to safety that may be essential in a single optimized route. Once developed, validate your model(s) and discuss how the Louvre would implement it. Based on the results of your work, propose policy and procedural recommendations for emergency management of the Louvre. Include any applicable crowd management and control procedures that your team believes are necessary for the safety of the visitors. Additionally, discuss how you could adapt and implement your model(s) for other large, crowded structures. Potential to alter or remove segments of possible routes to safety that may be essential in a single optimized route. Once developed, validate your model(s) and discuss how the Louvre would implement it.

Based on the results of your work, propose policy and procedural recommendations for emergency management of the Louvre. Include any applicable crowd management and control procedures that your team believes are necessary for the safety of the visitors. Additionally, discuss how you could adapt and implement your model(s) for other large, crowded structures.

1.2 Brief Analysis of the Modeling Process

The Louvre is one of the largest and most visited art museums in the world, and its place in France is very important. Yet the recent terrorist attacks in France are on the rise, and it is urgent to have a good evacuation plan for the Louvre. We set up a reasonable mathematical model from three aspects, such as the structural characteristics of the Louvre, the distribution of tourists in the Louvre, and the location of terrorist attacks, so that the problem of rapid evacuation of personnel can be better solved.

In fact, the actual situation will have a very large uncertainty. For example, the diversity of visitors mentioned in the topic, such as multiple languages, group tours, and disabled visitors. However, the factors that affect the evacuation rate of people are much more than that. When the Louvre is hit by a terrorist attack, some of the visitors' present may react violently to disrupt the order of evacuation, thus affecting the rate of evacuation. Second, when people evacuate, there may be crowding, and even stampede events. These can have a big impact on the evacuation of people.

We are building this model to deal with a variety of situations. The process is divided into three main parts.

Part I: according to the location of the Louvre exit, and the main concentration of visitors on each floor to each floor according to the number of exits divided into several areas. The equivalent of each door corresponds to a region, and when an accident occurs, the door can be used as the best evacuation outlet for people in that region. (See 3.1 for detailed procedure)

Part II: In order to know the time required for the full evacuation of personnel, we have to calculate the speed at which the crowd flows. We project people into rectangles and calculate population density according to the projected footprint. Combined with the structure of the Louvre, the rate of population movement is calculated.

Part III: Given the uncertainty of terrorist attacks, we have corresponded the location of terrorist attacks to the previously divided area. If a terrorist attack occurs in another area, the visitor shall immediately abandon the export corresponding to the region. At this point, the group of tourists will have to choose other exits on the same floor. At this point, it is necessary for each region to be the best outlet for the backup. The focus of this model is on how to determine the best alternative exit and direct visitors to retreat quickly.
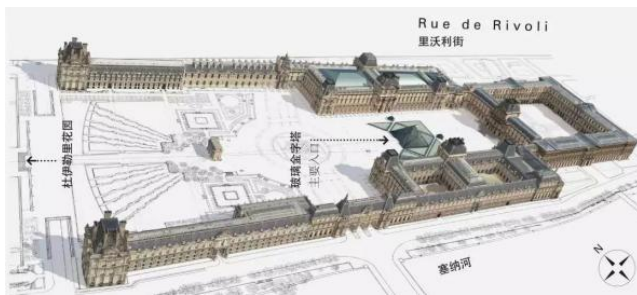

Figure 1. Louvre

Figure 2. Satellites map of the Louvre

2. Symbol Definition and Assumptions

2.1 Symbol Definition

1 L: The stride of a moving stream of people
2 F: Walking frequency
3 ρ: Crowd density
4 V: Visitor flow rate
5 Q: The floor of people
6 SX: Area of the X floor accessible to visitors
7 SXi: The area of region i the X floor
8 WXi: The sum of the staircase widths of an exit group on the x floor
9 NXi: Number of exhibits in area i on the x floor
10 TXi: Time required for the evacuation of people in region Xi

11 MXi: Number of persons in region Xi

12 λXi: The longest distance required for people in region Xi to evacuate

13 PXi: Annual visitor volume for the museum in the region

14 We'll write from 2ND floor to Napoleon Hall in turn as A to E:

A: 2ND Floor B: 1ST Floor C: Ground Floor D: Low Ground E: Napoleon Hall

2.1.1 Basic Assumptions

There will be no multiple accidents at the same time, that is, only one incident can occur at a time.

Sta in the relevant area after the accident were able to quickly notify staff on other floors and raise alerts.

Rescuers can reach the designated entrance within five minutes.

Evacuation personnel follow staff arrangements during evacuation.

2.2 Problem Analysis

2.2.1 Analysis of the Structure of the Louvre

The Louvre covers an area of about 45 hectares (including lawns) and covers an area of 4.8 hectares. The total length is 680 meters. Its overall building is "U" shape, divided into new and old parts, the old built in Louis 14 period, and the new built in the Napoleon era.

According to statistics, the Louvre Museum, which covers 19 hectares, including the courtyard, is lying from east to west on the right bank of the Seine River, with a length of 690 meters on both sides, and the entire building is magnificent and majestic. The hundreds of spacious halls used to showcase the treasures are magnificent, with fine frescoes and fine reliefs at the four walls and top of the hall, all of which are breathtaking artistic crystallization everywhere. A visit to this Hall of art is also an unforgettable treat.

Now we begin to analyze the structure of the Louvre. Let's analyze the location of the stairwell on each floor of the Louvre (ABCDE instead of each floor):
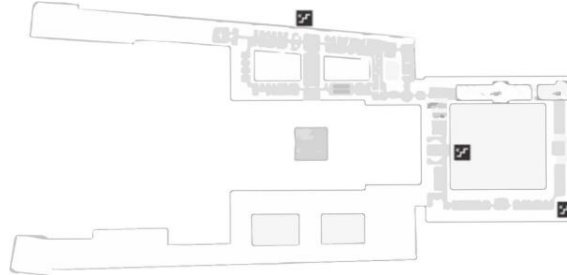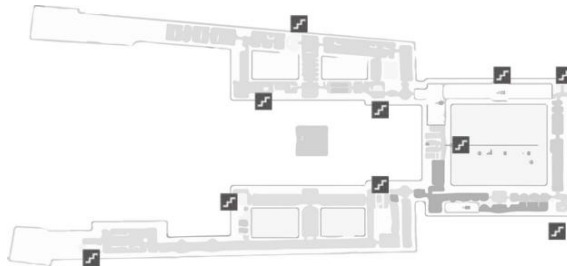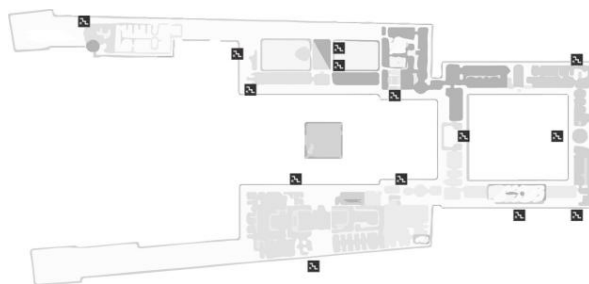

Figure 3. A

Figure 4. B

Figure 5. C

2.3 Analysis of the Number of Tourists

From January 2017 to December, there was a significant increase in the number of visitors to the Louvre, reaching 8.1 million (an increase of 14% over 2016). The number of visitors to the Louvre rose again in the year of the opening of the Louvre in Abu Dhabi, the revival of tourism in Paris and the renovation of the permanent collection of the Louvre, and the exhibition "Masters of Vermeer and genre paintings" attracted many visitors from home and abroad. In the 2017, a total of 8.5 million visitors enjoyed the Louvre's collection and footage in Paris. The number of foreign tourists rose to nearly 5.7 million in 2017, or 70% of the museum's total visitors, in 2016, following a sharp decline in tourism caused by terrorist attacks and June floods in the Seine (Seine). The most iconic country is the United States, where the number of visitors has increased by 23% (1 million tourists accounted for 13% of total visitors), China (626,000 tourists accounted for 8%), Brazil (289,000 tourists accounted for 3.5%), the United Kingdom (280,000 visitors), Germany (259,000 tourists) and Spain (224,000 visitors). The largest in- creases were in Russia (up 92% from 2016), Brazil (+82% per cent) and Japan (+52% per cent).

2.4 Division of Exhibit Location

Visitor Distribution: We know that the Louvre is divided into five floors, each with a corresponding exhibition area. Most of the works at the Louvre are located at the 1ST floors and ground floors. Of course, there are generally more tourists here than there are tourists on other floors. The Louvre's lower ground floor, ground floor, 1ST floor, 2ND floor, with a permanent exhibition. And lower ground floor, napoleon hall has a temporary exhibition.
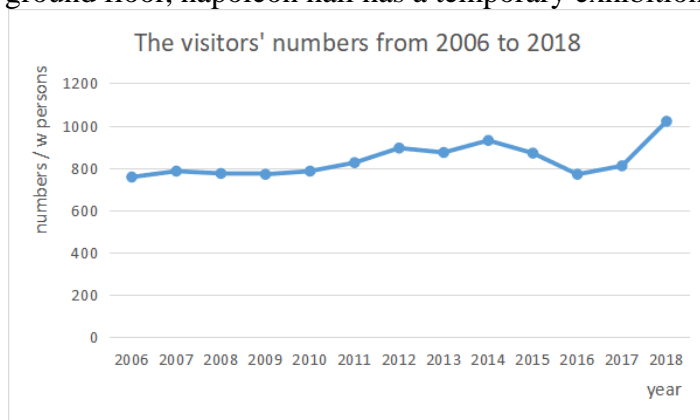

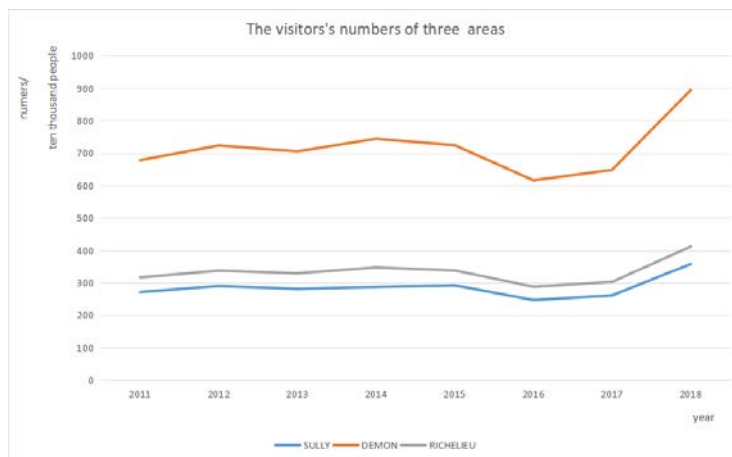*Figure 6. The visitors 'numbers from 2006 to 2018*

Figure 7. The visitors of every year since 2014 to 2018

Since there are so many works in the Louvre that we can't study them all, we're just talking about some of the works that appeal to visitors on each floor more than relatively.

2 ND Floor: There are 8 selected works on this floor, such as portrait of the marquise de pompadour, portrait of the artist holding a thistle, the virgin of chancellor rosin...

1 ST Floor: There are 15 selected works on this floor, such as winged victory of Samothrace, the seated scribe, berberine ivory: the emperor triumphant...

Ground floor: There are 9 selected works on this floor, such as Aphrodite known as the Venus de milo, the sarcophagus of the spouses, frieze of archers...

Low ground: There are 10 selected works on this floor, such as floor gilded parade helmet of Charles vi, the Marely horses, starry Magdalene.

Napoleon hall: There are no selected work on this floor.

2.5 Analysis of Terrorist Attacks

February 3, 2017 an attacker tries to attack soldiers near the Louvre. The attacker carried a machete and 2 backpacks, but there were no explosives in the bag, the Paris police chief said. The attacked soldier red 5 shots, including one that hit the attacker in the stomach, causing him serious injuries. And the soldiers suffered minor injuries in the attack. The case of terrorist attacks, large and small, in France in the last two years has largely not stopped since the January 7, 2015 terrorist attack in the editorial board of the Charlie Weekly in Paris, which killed 12 people and injured 11 others. It has caused great losses to the main local museums.

Paris, France the Louvre administration announced 5th that the world-renowned museum received 7.3 million visitors in 2016, down 15% from 2015, and that the attack was the main cause of the situation.

The Louvre management analysis noted that a series of terrorist attacks in France in 2015 and 2016 were the main reasons for the decline in the number of visitors to the museum. In addition, the temporary closure measures taken by the Louvre at the beginning of June last year as a result of rising water levels on the Seine also affected the number of visitors.

Among the visitors hosted by the Louvre last year, the number of foreign tourists fell significantly, falling to 70% per cent, according to the announcement. The number of local tourists in France remained stable, with the number of visitors at the same level as in 2015, up to 2 million.

It is worth mentioning that the July 2016 Louvre Pyramid entrance renovation project was fully completed and put into use, significantly improving the visitor experience, with a satisfaction of 70%

visitors in 2016, well above the 2015 53%.

The Louvre is a world-renowned museum and one of the most visited attractions in Paris. The Louvre received 8.7 million visitors in 2015, including 820,000 Chinese tourists and second only to the United States among foreign tourists.

In recent years, the regionalization of international terrorism has become more

And more obvious. On the one hand, the terrorist forces spread to all parts of the world with the help of interregional geopolitical, economic, religious and cultural factors, on the other hand, there are great differences in the distribution of terrorism between regions and national quality inspection. International Strategy against terrorism:

(1) Double standards must be abandoned in the fight against radicalism.

(2) The fight against terrorism must be both a specimen and a cure.

(3) Counter-terrorism must strengthen international cooperation.

(4) Give full play to the leading role of the United Nations in the fight against terrorism.

(5) The means of counter-terrorism must be multi-pronged.

A series of terrorist attacks, let us pray for the death of our compatriots in silence, but also understand that the implementation of counter-terrorism is imminent. Therefore, it is an urgent problem for all countries to raise the awareness of counter-terrorism, fully understand this worldwide problem, and how to make the best response to sudden terrorist incidents, so as to avoid the devastating consequences as far as possible. This also highlights the necessity of our analysis of the current situation of terrorist attacks and the study of control countermeasures.

3. Mathematical Modelling

3.1 Block Area of Each Floor

We put together a portion of each layer of exports that are closer to each other as an exit group. Each exit group corresponds to an area where people in the area can flee from this exit group. The area formula for this area is Formula

$$S_{Xi} = \frac{1}{3} \left(\frac{W_{Xi}}{\sum_{j=1}^{n_j} W_{Xj}} + \frac{N_{Xi}}{\sum_{j=1}^{n_j} N_{X_j}} + \frac{P_{X_i}}{\sum_{j=1}^{3} P_{X_j}} \right) S_X \tag{1}$$

Based on the calculation results, we use the computer to get the following block method:
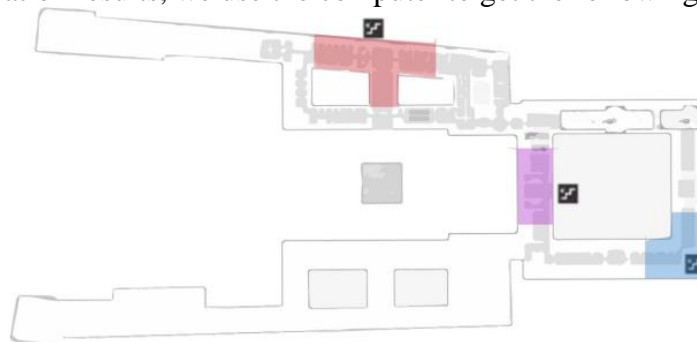

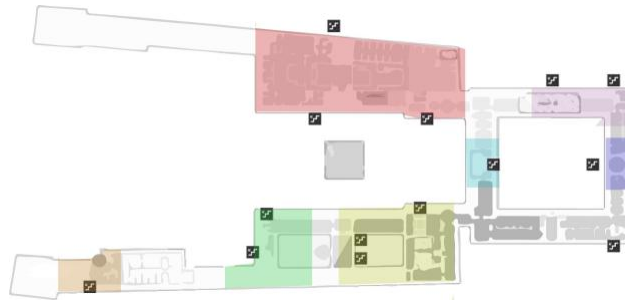*Figure 8. The result of the chunking A*

Figure 9. The result of the chunking B

Figure 10. The result of the chunking C

Figure 11. The result of the chunking D

The Chunking result we get is A1A2A3 B1B2B3B4B5B6B7 C1C2C3C4C5C6C7 D1D2D3D4
One of the paths we get through the ant colony algorithm is

$A_1 \Longrightarrow B_1 \Longrightarrow C_1$

$A_2 \Longrightarrow B_4 \Longrightarrow C_4 \ A_3 \Longrightarrow B_2 \Longrightarrow C_2$

etc.

3.2 Calculate The ow Rate of The Crowd

By projecting a person int an ellipse, we conclude that the area of the ellipse is $S_p = \frac{1}{4}\pi B_p D_p$

Some assumption

Table 1 Shoulder width and body thickness of people in different countries

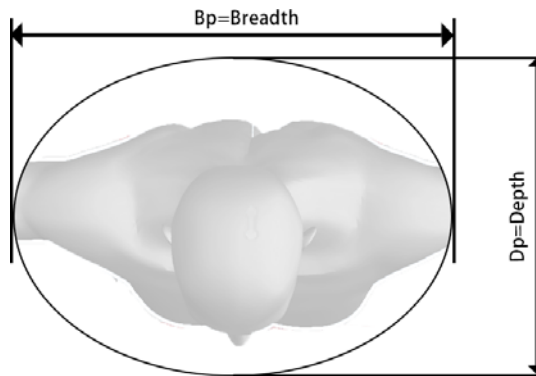| Country		Shoulder width B_p (m)	Body thickness D_p (m)	Ellipse area S_E (m²)
British	M	0.5100	0.2850	0.1142
	F	0.4350	0.2950	0.1008
Japanese	M	0.4750	0.2300	0.0858
	F	0.4250	0.2350	0.0785
USA	M	0.5150	0.2800	0.1133
	F	0.4700	0.2950	0.1089
Indian	M	0.4550	0.2350	0.0840
	F	0.3900	0.2550	0.0781
Average		0.4850	0.2310	0.0887

Figure 12. Human oval Model

Flow rate is limited to the one-way axed width innate long channel forward, and relatively full, that is, the speed is not greater than a certain limit speed $V_{max} = 3m/\sec$

Any individual follows the universal principle: Do not attempt to surpass the individual in front of you, nor do you leave too much spacing.

Population density ρ（$human/m^{2)}$ is equal throughout the channel and de-creases with the increment of Speed V（$m/\sec$）, with a range of values （ρ_{Min}, ρ_{Max}）

Define the person flow Q （$person = m*\sec$） for the unit time, unit channel cross-sectional area through the number of people, there is $Q = \rho v$

Using the speed, stride and other data given by [6] and [7], it is possible to determine the relationship between population density rho and walking frequency F:

$F = K\rho^n$

And can further verify the k=1.36 in the upper formula, $n \approx 0.5$

A function that represents the speed of a population as a density:

$$V = LF = (\frac{1}{（B_p + 0.1）\ \rho} - D_p)\ K\rho^n$$

Calculate Q

$$Q = \rho V = \left(\frac{1}{(B_p + 0.1) \, \rho} - D_p \right) K\rho^{n+1}$$

Using the above mathematical model and related parameters, and considering the boundary conditions, the V- curve and Q- curve are drawn as follows:
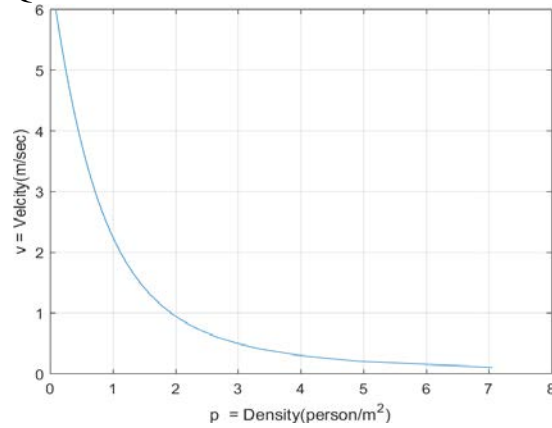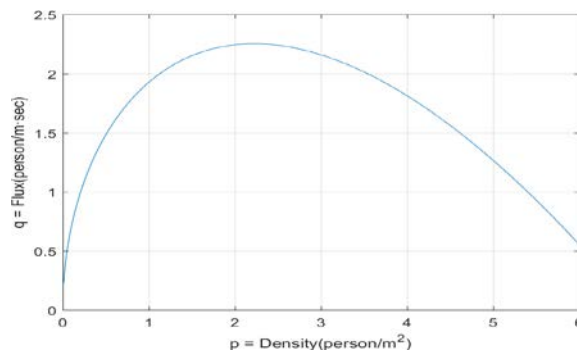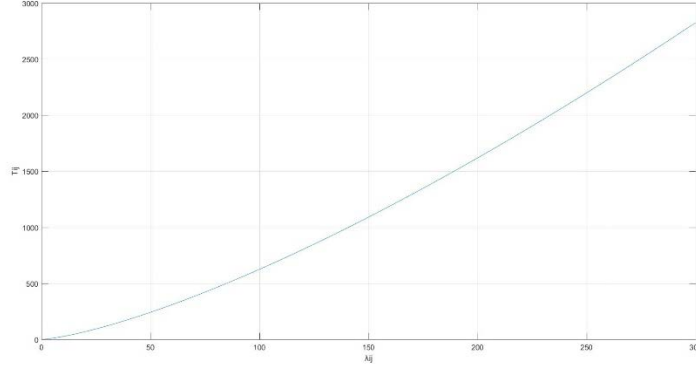

Figure 13. V-ρ

Figure 14. Q-ρ

4. Test And Expend The Model

4.1 Test the Model

After our comparison of multiple groups of evacuation models, we t the following formula for escape time:

$$T_{Xi} = \frac{\lambda_{ij}^{2.371}\left(\dfrac{\varepsilon^2 \lambda_{ij}^2 M_{Xi} S_E}{S_{Xi}^2} - \dfrac{\lambda_{ij}^2 M_{Xi} S_E}{S_{Xi}^2}\right)}{\displaystyle\int_{\frac{\lambda_{ij}^2 M_{Xi} S_E}{S_{Xi}^2}}^{\frac{\varepsilon^2 \lambda_{ij}^2 M_{Xi} S_E}{S_{Xi}^2}} V d\rho}$$

Figure 15. $T_{ij} - \lambda_{ij}$

By calculation, we get the corresponding calculation of the relationship between the time spent by the visitor in full evacuation and the location where it is located. From then on, we found that visitors at 2ND floor were able to evacuate all 13 minutes at the fastest. In 1ST Flood visitors can take up to 7 minutes to evacuate altogether.

4.2 Model Extension

Once we have mastered this modeling method, we can apply this method to more places. We only need to find out the distribution of the export location of a building, personnel concentration point, ow density, and so on, we can build the model.

We need to get those places that could be hit by terrorist attacks to step up security measures to protect the lives of people. Divide the area into buildings and design escape routes for each area. Depending on where the terrorist attack took place, a reasonable change of course.

5. Some Suggestions for The Louvre

1. To enhance the safety awareness of Louvre passengers, familiar with the emergency exit location of the Louvre, passengers must follow the instructions of the rescuers in the event of an emergency.

2. Unified leadership, hierarchical responsibility, self-help and social rescue combination, clear responsibilities, implementation of responsibility, rely on science, timely response, decisive measures, emergency relief, to adhere to the forefathers,

First and then slow, first weight and then light principle, first personnel, after the goods, first important items, post-secondary items; all staff of the museum have the responsibility and obligation to participate in or cooperate with emergency relief e orts and to obey unity of command.

3. Security incidents of terrorist attacks: (1) In the event of a terrorist attack or the discovery of dangerous items such as suspicious explosives, the person found should immediately report to the leading team of emergency rescue work and call the police. (2) The emergency rescue work leading group organizes the relevant personnel to protect the scene and prohibits anyone from being

exposed to suspicious objects. (3) Emergency rescue work leading group to evacuate the nearby area, set up a temporary cordon, prohibit personnel into the inside. (4) Emergency rescue work leading group to organize personnel on the nearby area of a comprehensive search, eliminate hidden dangers. (5) The leading group of emergency rescue work assists the police in removing dangerous hazards and investigations such as explosions. (6) If the danger has occurred, the emergency rescue work leading group organizes the rescue and transfer of the wounded, while organizing the safe evacuation of personnel, to protect the scene.

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