Site Selection Analysis of Urban Emergency Shelter and Path Planning

This is an Interactive Qualifying Project (IQP) completed through WPI's Beijing Project Center.
This project was completed in collaboration with Wuhan University of Technology

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Acknowledgement

We would like to thank:

- Our advisors Jiang Lianyu and Xinming Huang, for providing guidance and feedback on our project.
- Wuhan University of Technology's graduate students for providing us access to and helping us use the ArcGIS software.
- Wuhan University of Technology's freshmen for touring us in the campus for shelter analysis and site selection.
- Firefighters in the fire station for providing us information about city emergencies.

Abstract

We considered 13 potential shelter locations, making use of field research, ase studies, and spatial analysis techniques done with ArcGIS software to select the best options for emergency shelters on Wuhan University of Technology's campus. ArcGIS' vectorization technique was used to produce a simplified version of the campus map, which aided us in demarcating buildings and shelter locations. We then looked at case studies for two types of emergencies: fire and earthquake. Although floods have historically affected Wuhan, evacuation protocols for floods already exist and were not considered in our project. For fire emergencies, we looked at statistical data regarding the most common causes and locations of fires, and estimated population densities of different regions to identify high-risk areas. Daytime and nighttime were considered separately, as the population density of certain locations is dependent on the time of day. We estimated the population of each of these areas and used them to determine the minimum size needed for their corresponding shelters. For earthquakes, which affect a large area, shelters were allocated to either residential or academic buildings (depending on time of day) generally, rather than to a few specific buildings. Finally, we used ArcGIS' shortest path function to plan evacuation routes, which we used to propose a set of protocols for dealing with emergency situations on campus.

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2.1 City of Wuhan	Wenting Li	Elizabeth Hagan
2.2 GIS	Theo Marks	Elizabeth Hagan
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Executive Summary

Background:

In this project, our research and objectives mainly focused on shelter design, city emergencies and GIS. Different types of emergency shelters and the specific criteria for different levels will be explored in order to classify different shelters using GIS software. Researches on city emergencies including fire emergency and earthquake will be conducted. We mainly focus on the historical references, damages it usually cause and where is the most likely place for these emergencies to happen. The purpose of this project is to design emergency shelters in the University for students to evacuate in different emergencies, and to validate these choices throughout a series of simulations.

Methodology:

Our main goals are to design shelter locations and simulate two different natural disasters to validate the shelter locations. For shelter locations, we did field investigation to exam the potential shelters status, because they might look the same on the map, however the condition for that shelters might not meet the criteria for example firebreaks or number of entrances. After the field investigation, we did vectorization on GIS because that allows us to do area calculation and shortest path function on the accident points. Then we did some research on how to do simulation in order to design a more suitable and conclusive simulation and case study of fire emergencies and earthquake. After that, we merged these two parts together, using our choices of shelters to do the simulation we designed to see the suitability of the shelters we chose.

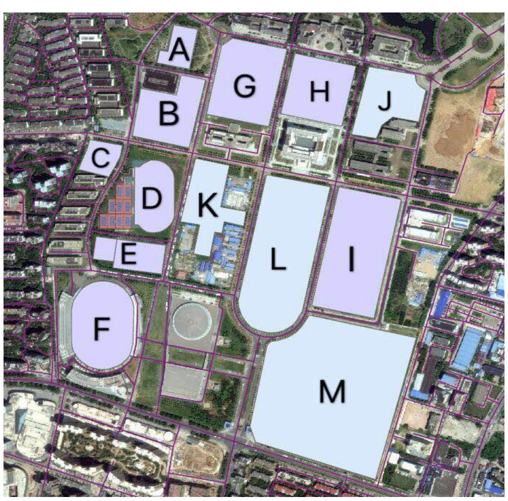


Figure 1: Potential Shelters

Data analysis:

The potential shelter are Listed in the graph above. There are 13 in total, after our filtering with the criteria for shelters, the shelters colored in purple are the qualified shelters, and the shelters colored in light blue are not qualified to use. Then GIS calculate the area for each shelter, which that allows us to calculate the maximum capacity of each shelter. Our final design for the simulation is fire emergency in the dorm and library, earthquake on the whole campus during daytime and nighttime. Here is the quick conclusion on our simulation:

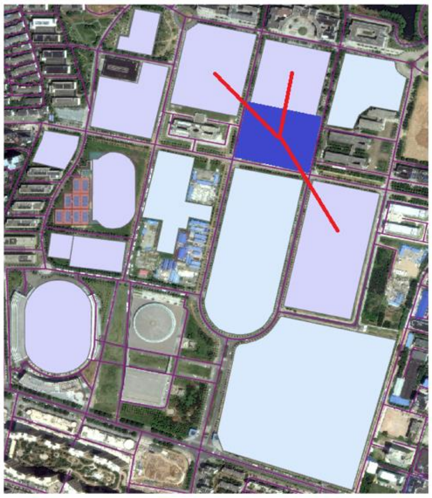


Figure 2: Result Evacuation Graph

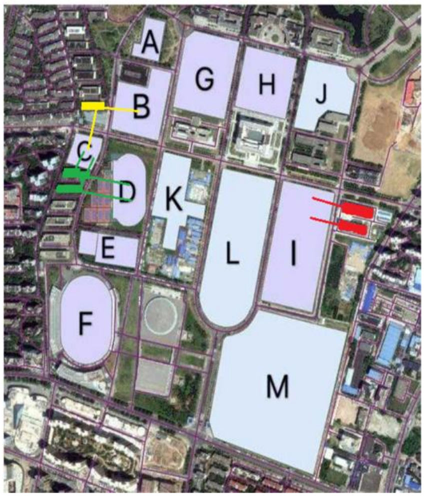


Figure 3: Result Evacuation Graph

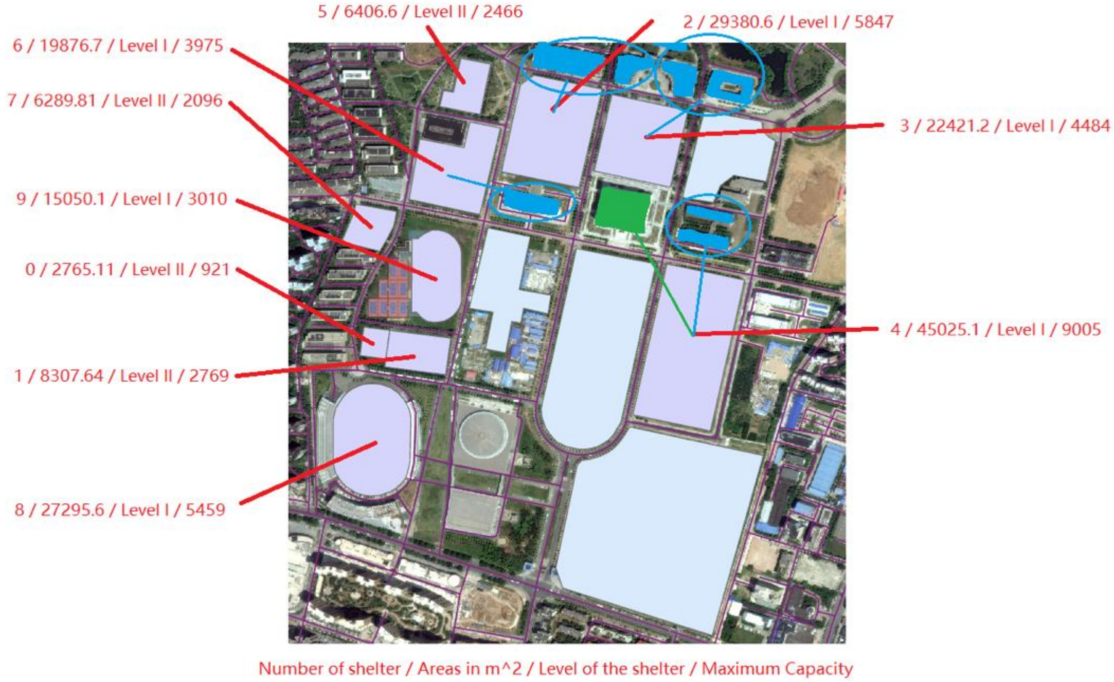


Figure 4: Shelter Allocation for Main Academic Building

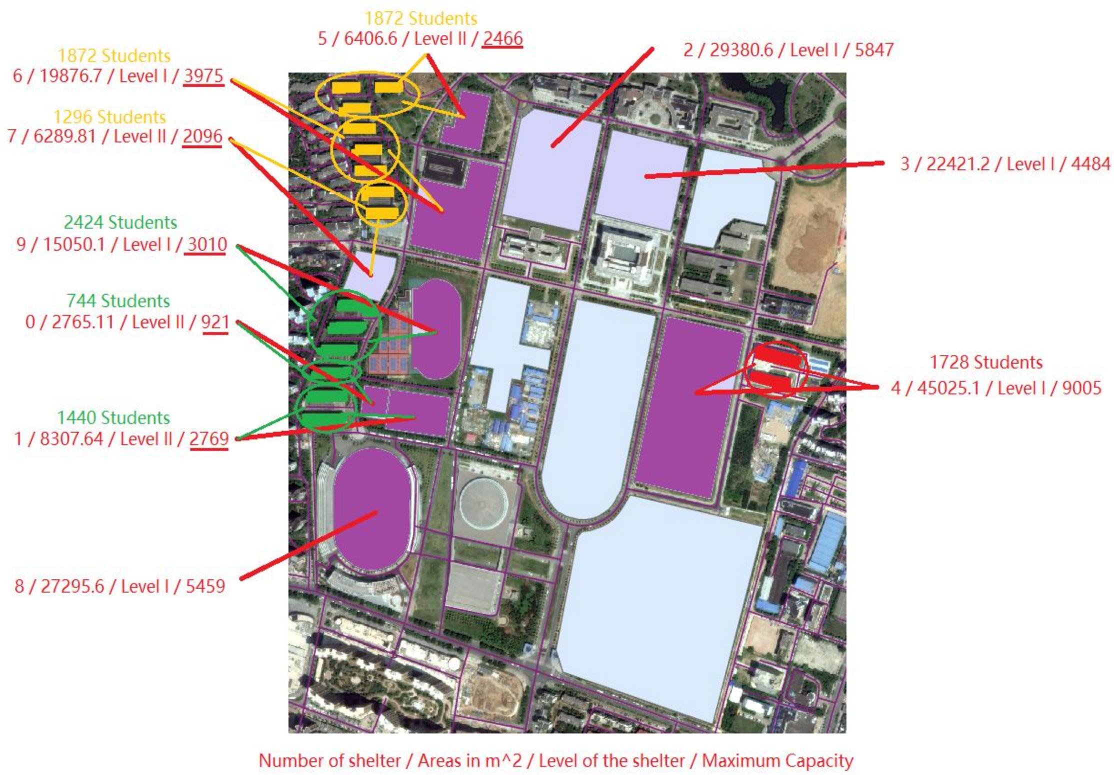


Figure 5: Shelters Used in This Simulation

Conclusion and Recommendations:

We have developed a versatile protocol for emergency evacuation which accounts for two types of emergencies, fire emergency and earthquake, with separate cases for daytime and nighttime. After determining which residential and academic buildings on the WUT campus were most at risk for loss of life in a fire or earthquake, we selected shelter locations providing coverage to each. Our protocol is validated by case studies, which set a precedent for the criteria used, and computational methods which let us find optimal evacuation routes. However, the protocol we have developed is only a virtual simulation; to work in real life, people must be trained to implement it in response to an emergency. We have decided to leave the details of this protocol's implementation open-ended to allow for flexibility in future implementations; consequently, our methodology can easily be adapted to other universities in Wuhan.

We recommend a protocol prescribing that residents of affected buildings immediately go to their building's assigned shelter during a fire or earthquake. Since people cannot be expected to act rationally in an emergency and find the shelters themselves, the protocol's implementation should have a way to guide large groups of people at once. One possible implementation we propose is a training drill to familiarize residents with the paths to be taken in an emergency. This has the advantage that it can simply be incorporated into an existing routine fire drill. Another possibility is a text alert system that sends out campus-wide messages, with instructions on where to go when a fire or earthquake occurs. This can be very efficient for reaching large groups of people, but runs the risk of technological failure. We have decided to leave this implementation open-ended, so that the school can choose the most feasible option for themselves.

1.0 Introduction

An important element of urban infrastructure is having locations designated as emergency shelters, ensuring that residents have a safe place to which they may evacuate in the event of a disaster. Large, open spaces serve this purpose well, providing shelter from both fires and earthquakes due to their absence of flammable materials and structural hazards. Our project's objective was to select such locations on the Wuhan University of Technology's campus to be designated shelters, and to plan evacuation routes from buildings with a high risk of loss of life from disasters to the shelters. If optimal locations are chosen, these shelter paths may play a decisive role in saving lives in a fire or an earthquake.

2.0 Background

2.1 City of Wuhan

Figure 6: Wuhan's Location in China Map

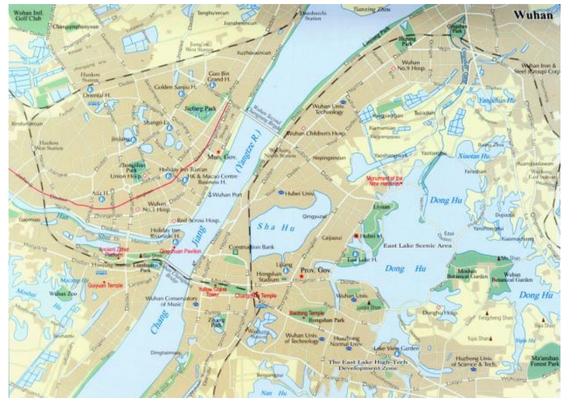


Figure 7: Wuhan's Map

Wuhan is the capital of Hubei province, People's Republic of China. It is the central city in China Central, and the core city in the Yangtze River Economic Zone. Wuhan is also an important industrial center, having science and education bases and being a junction of transportation. There are 13 municipal districts under the jurisdiction of Wuhan, the total area is 8494 square kilometers, and the permanent population of the whole city is 11.081 million. The regional gross domestic product is 1.48 trillion yuan.(武汉统计局.2019) When natural disasters hit this city, a considerable number of people will be affected, and it will cause enormous economic loss.

Wuhan is located in east of Jianghan Plain and the middle reaches of Changjiang (Yangtse) River. Changjiang River, the third largest river in the world, and its largest tributary Han River, both run through the city’s central area, and divide the city to three parts. There are many lakes and rivers in Wuhan.

Wuhan’s geographic location is a part of the seismic belt along a section of the middle and lower reaches of the Yangtze River, where the north and south China fault blocks intersect. The region includes around 30 faults of three different direction groups, mainly distributed across west Hubei, Macheng, Huanggang and Xianning-Chongyang. Given the number of faults, earthquakes are common and pose a threat to the city, as it is highly populated with crowded buildings. Because of this, we need to make sure our shelters will be able to function in the case of an earthquake. Below shows Wuhan’s major earthquakes and their severity.

Year	Location	Richter Scale
788	Wuhan: Zhushan	6.5
1470	Wuhan City	5
1605	Wuhan City	5
1856	Wuhan City	>6
1897	Wuhan City	5
1930	Wuhan City	4
1932	Wuhan: Macheng	6

Table 1: Timeline of Major Earthquake in Wuhan (武汉统计局 .2019)

Wuhan belongs to the north humid subtropical monsoon climate. This means there is abundant rainfall and heat, pluvial heat seasons, cold-winter and hot-summer, and distinct seasons. The annual average temperature is 15.8 C°-17.5 C°. The extreme maximum temperature has been 41.3 C° and the extreme minimum temperature was -18.1 C°. The annual precipitation is 1,150-1,450 millimeters, and the most rainfall happens June-August, which accounts for about 40% of the annual rainfall. Because there is a huge temperature difference between winter and summer, it is possible to have extreme temperatures in both seasons, making natural disasters more severe. (武汉统计局.2019)

2.2 GIS

GIS, or Geographic Information System, is a technology used for visualizing and analyzing geographic data. ArcGIS 9 is the GIS software that we were using for this project.
One technique of GIS is combining multiple layers of datasets, called rasters. Each individual raster depicts a single type of data, such as elevation, hydrology, or soil type. A raster divides a map into a matrix of smaller units called cells. Each cell has its own value of the type described by the raster. Combining different rasters allows us to find areas with specific combinations of

characteristics. We used this technique to locate accident-prone areas and suitable shelter locations.

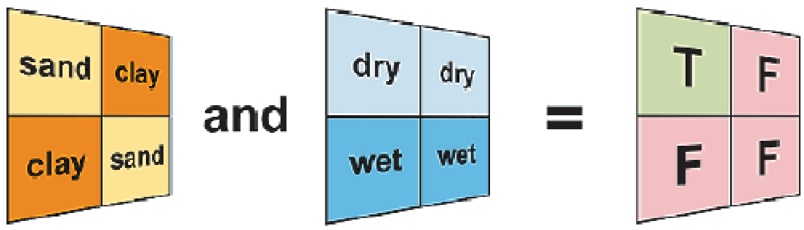


Figure 8: Visualization of Raster Analysis

Though there are many techniques that can be performed with ArcGIS, we restrict our attention to two relevant to our project, the Shortest Path Function and Vectorization. The Shortest Path Function automatically calculates the most efficient path from one cell to another. Vectorization is a method that simplifies maps by representing only relevant features, such as roads and buildings. More detail about these are discussed in our methodology section.

2.3 Shelter Design

Ground-type Emergency Shelters use the open spaces already provided in the city's infrastructure, such as parks, green spaces, schools' playgrounds, city squares etc. Normally these places have open empty spaces, so when designing shelters, these infrastructures are the most convenient for people to live in temporarily.

Ground-type shelters are classified into three levels, where each level indicates the different capacities.

Level of Shelter	Area of the Ground (m^2)	Area per Person (m^2)
Level I	over 50,000	5~7
Level II	10,000~50,000	3~5
Level III	2,000~10,000	1.5~2

Table 2: Levels of Ground-type Shelters

For these three levels of the ground-type shelters, different entrance requirements are also set.

Level of Shelter	Numbers of Entrances	Total Width for the Entrances (m)
level I	>4 (must be on different direction)	>=15
level II	2~4	>=10
level III	2	6~10

Table 3: Entrance Requirements for Ground-type Shelter

There are also requirements for the roads for level I and II shelters, the roads should be wider than 5 meters; for level III shelters, the road should be between 3.5 meters and 5 meters (应急避难所准则, 袁). There is a firebreak requirement in each level as well. Having firebreaks ensures that there will be enough distance between flammable materials and the potential fire. A firebreak can be a road, lake, or anything else that is difficult to ignite.

Level of Shelter	Distance for Firebreak (m)
level I	over 25
level II	20~25
level III	10~15

Table 4: Firebreak Requirements for Ground-type Shelters (应急避难所准则，袁）

Ground-type shelters are ideal for disasters such as earthquakes, fires, chemical leakages, etc., therefore this shelter will be our main focus.

2.4 Fire Emergency

In China there are six different types of fire emergencies, A through F:(中国消防应急网，2012)

Type A: Solid-fueled fires, caused by combustion of, e.g., wood, hay, or coal.

Type B: Liquid-fueled fires, caused by combustion of, e.g. kerosene, diesel oil, or methanol.

Type C: Gas-fueled fires, caused by combustion of, e.g. coal gas, natural gas, or methane.

Type D: Metal-fueled fires, caused by combustion of, e.g. Potassium, Sodium, or Magnesium.

Type E: Electrical fires.

Type F: Cooking fires, caused by combustion of, e.g., animal or vegetable oil.

There are four different level of fire emergencies: (中国消防应急网，2012)

Serious fire emergency: >30 dead, >100 injured or >1,000,000,000 yuan lost.

Major fire emergency: 10-30 dead, 50-100 injured, 50,000,000 yuan lost.

Big fire emergency: 3-10 dead or 10-50 injured or >10,000,000 yuan lost.

Normal fire emergency: <3 dead, <10 injured or <10,000,000 yuan lost.

Fire emergencies do not have a high mortality rate, but most deaths in fire emergencies are caused by the following reasons.

Oxygen deprivation: When there are fires, oxygen is consumed by nearby flames and people who cannot escape in time may asphyxiate.

High temperatures: In a fire emergency, temperatures are usually several hundred degrees, while human circulatory systems cannot tolerate temperatures above 50 degrees Celsius. Unconsciousness may set in from heat stroke, leaving people unable to escape.

Smoke: Smoke is generated by carbon particles, tarry droplets and ashes. It may damage the eyes and respiratory system, potentially causing blindness and death.

Toxic Gases: The combustion of certain materials can produce toxic gases such as carbon monoxide, chlorine, phosgene, ammonia, sulfur dioxide, and liquefied petroleum. These gases can be fatal to humans.

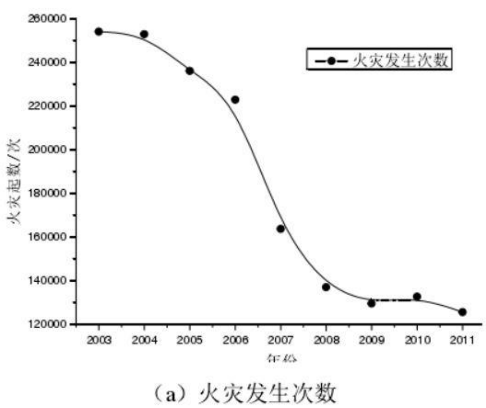
According to the official report, these graphs show the trends from 2003 to 2011 about. (“大空间建筑火灾数值模拟研究”， 李, 辛):

(a) Number of fire emergencies in a certain year

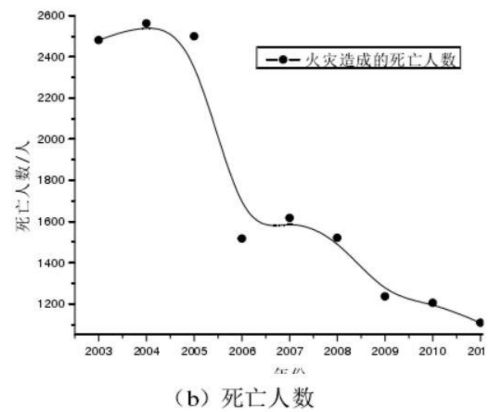
(b) Number of people that died in a certain year in fire emergencies

(c) Number of people injured in certain year in fire emergencies

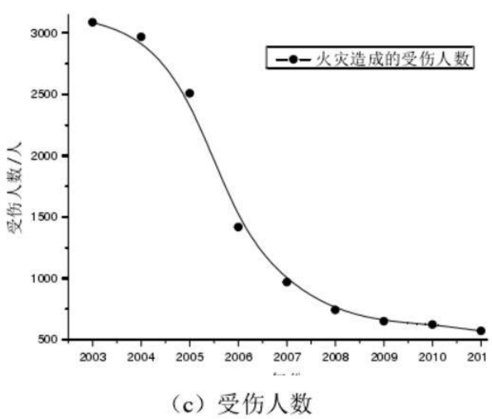
(d) Amount of money lost in certain year in fire emergencies



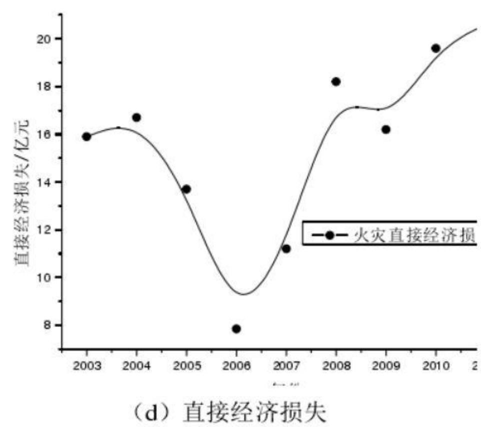
Graph.1 (a) Number of Fire Emergencies



Graph.2 (b) Number of Deaths



Graph.3 (c) Number of People Injured



Graph.4 (d) Money Lost

Figure 9: Graphs of Fire Emergency

These graphs show that in general, fire emergencies are not a huge threat to human life, because the ratio fire emergencies to human deaths is less than 1/100; and the graph of the amount of fires and the amount of deaths shows a decreasing trend. In addition, most of the deaths are caused during serious fires (the national classification of levels of fire emergency are 30+ people dead or 100+ people injured, or 100,000,000 Chinese Yuan lost is classified as a serious fire emergency).

This table includes information including date, location, number of deaths, number injured, money lost and cause of serious fires, 1991 to 2015. (“大空间建筑火灾数值模拟研究”， 李, 辛)

Number	Date	Location or Company	Deaths	Injuries	Loss(¥10,000)	Cause
序号	起火日期	起火单位名称或地址	死人	伤人	直接损失(万元)	火灾类别火灾原因
1	1991.5.30	广东东莞兴业雨衣制造厂	72	47	116	厂房吸烟
2	1993.2.14	河北唐山林西百货大楼	81	54	401.2	商场违章电焊
3	1993.11.19	广东深圳致丽玩具厂	84	40	260	厂房电气
4	1993.12.13	福建福州高福纺织有限公司	61	7	600	厂房放火
5	1994.6.16	广东珠海前山纺织城	93	156	9500	厂房违章操作
6	1994.11.27	辽宁阜新艺苑歌舞厅	233	20	12.8	歌舞厅玩火
7	1994.12.8	新疆克拉玛依友谊馆	325	130	210.9	礼堂电气
8	1995.3.13	辽宁鞍山商场	35	18	866	商场电气
9	1995.4.24	新疆乌鲁木齐凤凰时装城	52	6	41.6	录像厅电气
10	1996.7.17	广东深圳端溪酒店	30	13	13	酒店电气
11	1996.11.27	上海四川中路 401 号居民楼	36	19	178	居民楼用火取暖
12	1997.1.5	黑龙江哈尔滨长林子打火机厂	93	15	4.1	厂房违章操作
13	1997.1.29	湖南长沙燕山酒家	40	79	97.2	酒店违反安全规定
14	1997.4.12	福建晋江裕华鞋厂	32	4	80.4	厂房放火
15	1997.12.12	黑龙江哈尔滨汇丰大酒店	31	17	61.9	酒店放火
16	2000.3.29	河南焦作天堂音像俱乐部	74	2	20	录像厅电气
17	2000.4.22	山东青州一肉鸡加工车间	38	20	95.2	厂房电气
18	2000.12.25	河南洛阳东都商厦	309	7	275.3	歌舞厅电焊
19	2003.2.2	黑龙江哈尔滨天潭大酒店	33	10	15.8	商住楼违反操作规程
20	2004.2.15	吉林吉林中百商厦	54	70	426.4	商场吸烟
21	2004.2.15	浙江海宁黄湾镇五丰村	40	3	0.1	农村用火不慎
22	2005.6.10	广东汕头华南宾馆	31	28	81	酒店电气
23	2005.12.15	吉林辽源中心医院	37	46	821.9	医院电气
24	2007.10.21	福建莆田飞达鞋面加工场	37	19	30.1	厂房放火
25	2008.9.20	广东深圳龙岗区舞王俱乐部	44	64	27.1	歌舞厅发射烟花弹
26	2010.11.15	上海静安胶州路高层公寓大楼	58	71	15800	住宅楼违章电焊
27	2013.6.3	吉林德惠宝源丰禽业有限公司	121	76	18200	厂房电气
28	2015.5.25	河南平顶山康乐园老年公寓	39	6	37.1	养老院电气

Table 5 Raw Data of Serious Fires (1991-2015)

More analysis is done on this raw data and extracted out two data sheets; one about the cause of these fires and another about their location:

Reason	Times	Ratio
Electrical problem	11	39.3%
Inappropriate operation	7	25.0%
Careless fire use	3	10.7%
Smoking	2	7.1%
Arson	4	14.2%
Other	1	3.6%

Table 6: Reason of Fire Emergency

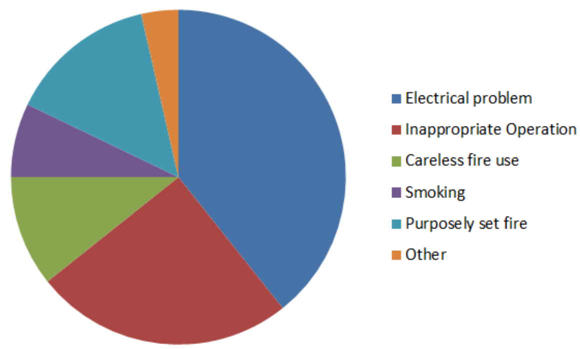


Figure 10: Reason of Fire Emergency

Location	Times	Ratio
Factory	9	32.1%
Entertainment	6	21.4%
Hotel	4	14.2%
Supermarket	3	10.7%
Residential Area	3	10.7%
Other	3	10.7%

Table 7: Location of Fire Emergency

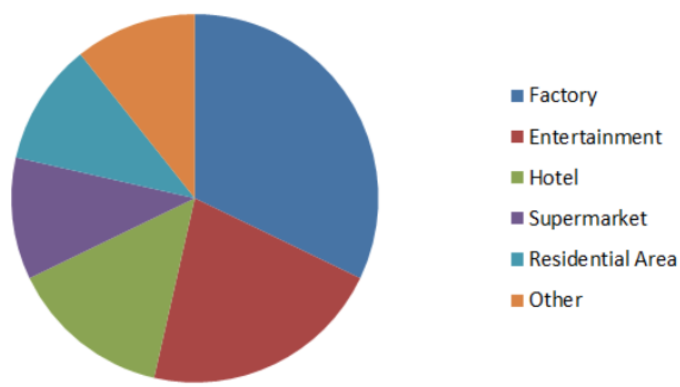


Figure 11: Location of Fire Emergency

2.5 Earthquake

Earthquakes occur when two blocks of earth suddenly slip past each other, releasing energy and seismic waves that eventually cause earthquakes. On average, earthquakes are responsible for 10,000 to 15,000 deaths and billions dollars' of economic loss around the world every year.(历史上湖北地震全记录. (n.d.))

Level of Earthquake (Richter Scale)	Description
< Level 2.5	Small earthquake, usually people can't feel it.
Level 2.5 ~ Level 5	Moderate earthquake, people near the center of the earthquake will feel it.
Level 5 ~ Level 10	Strong earthquake will cause damage to the buildings and can be felt over 150 miles away.

Table 8: Earthquake Level

On average there are around 5,000,000 earthquakes across the world every year. Of the 5,000,000 earthquakes, 5,000 of them are small earthquakes, 1,000 of them are moderate earthquakes, and 10 of them are serious earthquakes, classified as a level 7 or greater.

Earthquakes also lead to a series of ramifications. Destruction of toilets in houses and buildings can result in sewage accumulation, and therefore serious water pollution. Shelter areas are often densely populated, which increases the chance disease and infection. Many shelters also lack sufficient isolation facilities for infectious diseases, increasing transmission. Lack of access to clean water, cooking equipment, and food preserving equipment also increases the chances of food pollution.

In 2008, a level 7.9 earthquake hit Wenchuan, Sichuan, China. The damage of the earthquake cost 845,200,000,000 Yuan. This earthquake affected more than 100,000 km^2, 69,227 people died, 374,643 people were injured, and 17,923 people went missing.("5.12 汶川地震".n.d)

Since the earthquake was so strong in Wenchuan, people didn't have enough time to react properly and lots of buildings fell instantly. The simulation for an earthquake of this magnitude is nearly impossible to plan for.

In 2010, in Qinghai, Qinghai, China, 2,698 people died in an earthquake, 2,687 of them were identified, and 270 people went missing. (青海大地震案例分析. (2014, April 9))

This type of earthquake is manageable, and the simulation is possible because people had more time to react to the earthquake. Even though the principle for our simulations is to take the worst case, in the scenario of a serious earthquake, like the Sichuan earthquake, there is very little humans can do to prepare. Because of this, simulation based on a moderate earthquake is chosen.

2.6 Example Simulation

After potential emergency locations have been done by field observations and GIS analysis, we further simulated possible emergencies by examining case studies and developing the most efficient evacuation plan. Criteria for the shelters are crucial for simulations, since we did our own simulations for different emergencies. We learned different emergencies in depth and developed our own criteria to design the simulation and collect enough data to get a conclusive result.

The first thing this paper (李, 德. (2013). 城市复杂区域公共安全分析及评价研究) discussed is where to put the simulation point. First, the paper researched the most fatal part of the emergency, and then developed a situation where these fatal contents will be enlarged the most and cause the most casualties.

As for processing the simulation, this paper uses statistic formulas including estimation by chemical formulas, the speed of the chemical contents, the burning point and spreading speed of the fire, the possibility of related accident, and how long can people safely stay in the extreme environment.

The software this paper uses is Building EXODUS which is the professional evacuation simulation about human reaction. The yellow dots indicate the humans that behave irrationally, and the black dots indicate the humans that behave rationally, and the result for this is the time needed for everyone to evacuate.

Figure 12: Building EXODUS

First thing we learned from this case study is that it is best to always use the worst case scenario to do the simulation. If the worst case is properly handled in the simulation, then the other cases would be easier and will decrease potential danger.

The second thing we learned is that our simulation should be based on science and papers, since we don't have that much of knowledge on every area. But for the decisions we make, we must have information to back it up.

Finally, we used software to help us to do the simulation. In this study, we used GIS to help carry out the simulation.

3.0 Methodology

3.1 Vectorization

Vectorization is the analyzation of urban emergency shelters and path planning. In this section, we transformed the elements in the map, such as roads and buildings, into vector data. Doing this clearly showed the structure of the focus area and helped us analyze the path planning.

First, we added our map into ArcGIS by creating a new shape-file and adding a coordinate system to it. Then we used the editing tool to vectorize the potential shelters, buildings, and roads. There are 3 kinds of feature types: Point, Polyline and Polygon. We used polyline to display the shapes of roads and use polygon to display the outlines of shelters. We then got the map

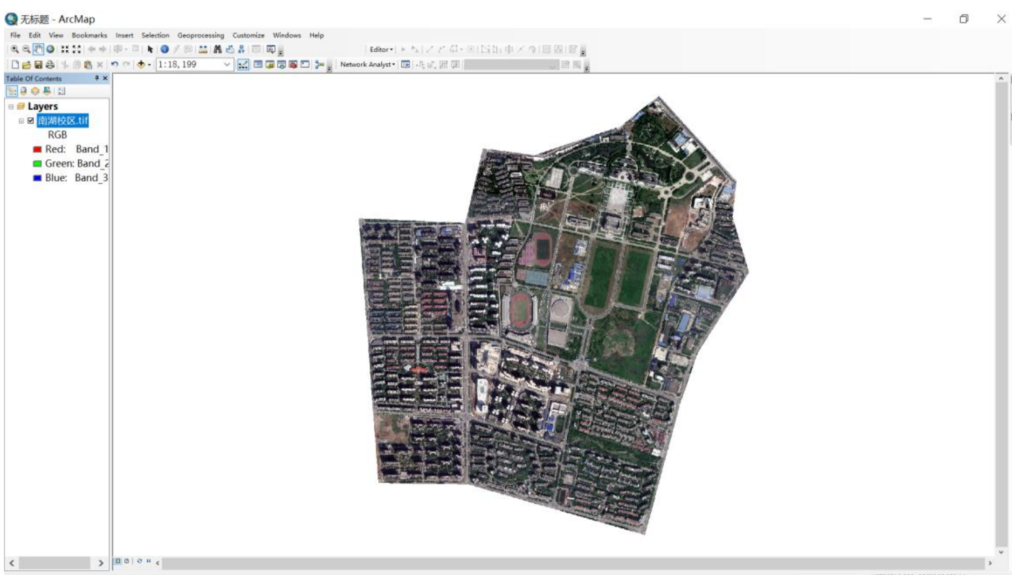


Figure 13: Map in ArcGIS

after vectorization, shown in figure 16.

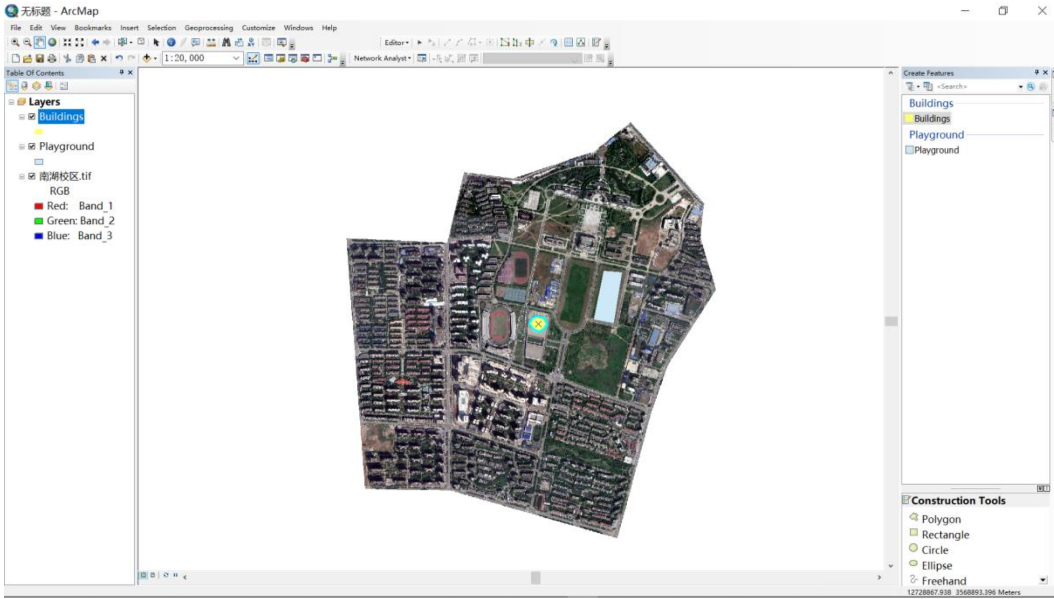


Figure 14: Using Polygons to Display the Outlines of Buildings

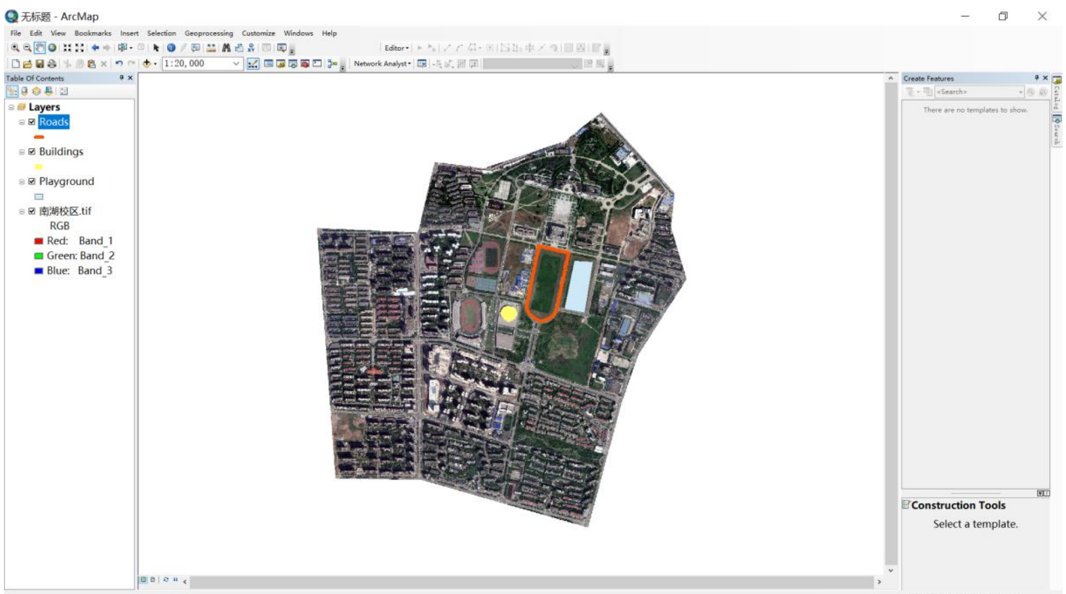


Figure 15: Using Polylines to Display the Shapes of Roads

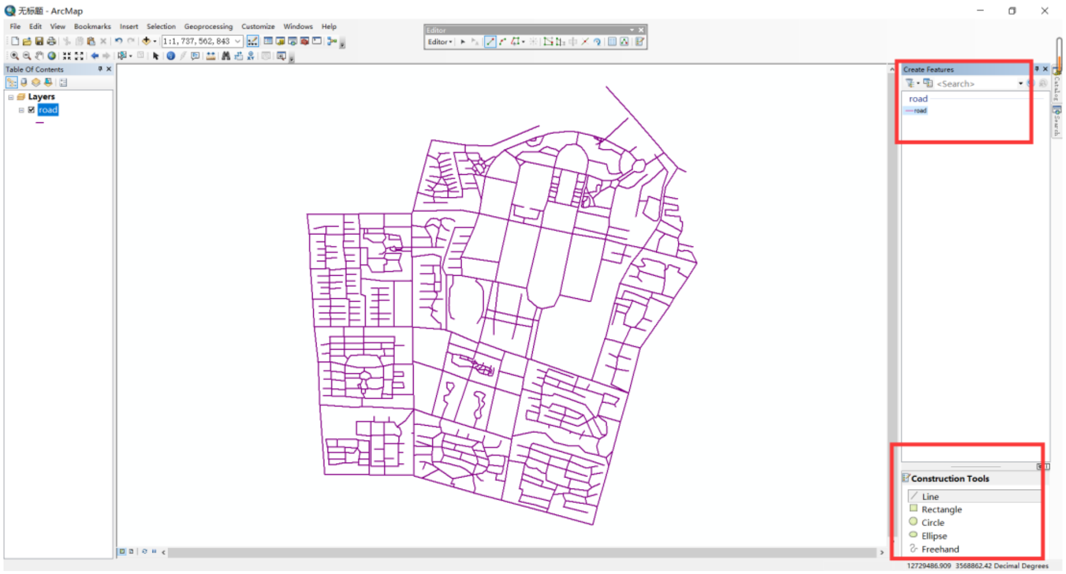


Figure 14: Example of Vectorization

Figure 15: The Map after Vectorization

When we look at the map, we choose the open spaces as our potential shelters. After we vectorized the map, we got a vision of our target area in figure 17. Roads and potential shelters are shown on this map.

3.2 Area Calculation

We calculated the area of each potential shelter using the measurement tool in GIS, and the data are displayed in Table 9.

Figure 16: Numbered Shelter Displayed

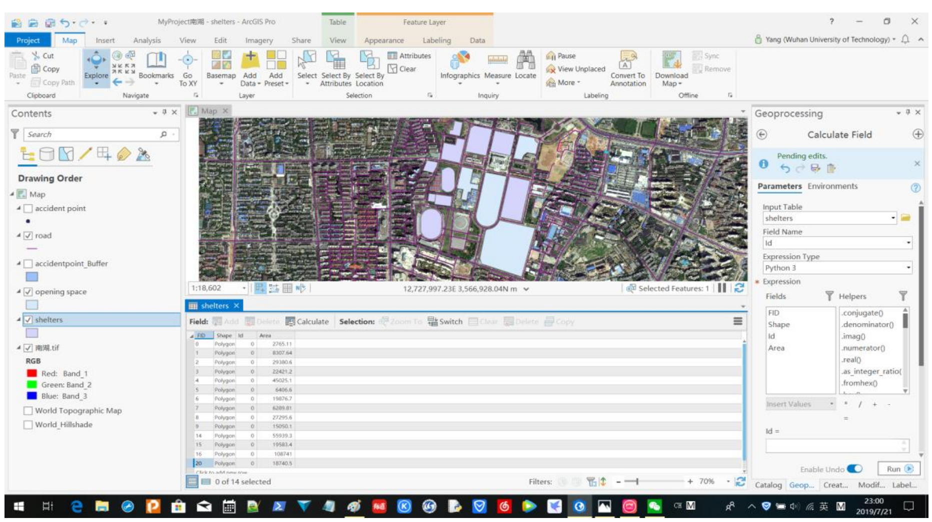


Figure 17: GIS UI Display for Area

Shelter Number	Shelter Areas(m^2)
0	2765.11
1	8307.64
2	29380.6
3	22421.2
4	45025.1
5	6406.6
6	19876.7
7	6289.81
8	27295.6
9	15050.1
14	55939.3
15	19583.4
16	108741
20	18740.5

Table 9: Data Displayed

3.3 Field Investigation

We have found 13 open spaces in map as our potential shelters, because we are looking for ground-type shelter thus the first thing we are looking for is the area of empty space. Since it is the most important criteria we can consider other criteria later. The graph below Shows the potential shelters A-M. After investigating the spots, we chose nine locations, A-I, as our shelters.

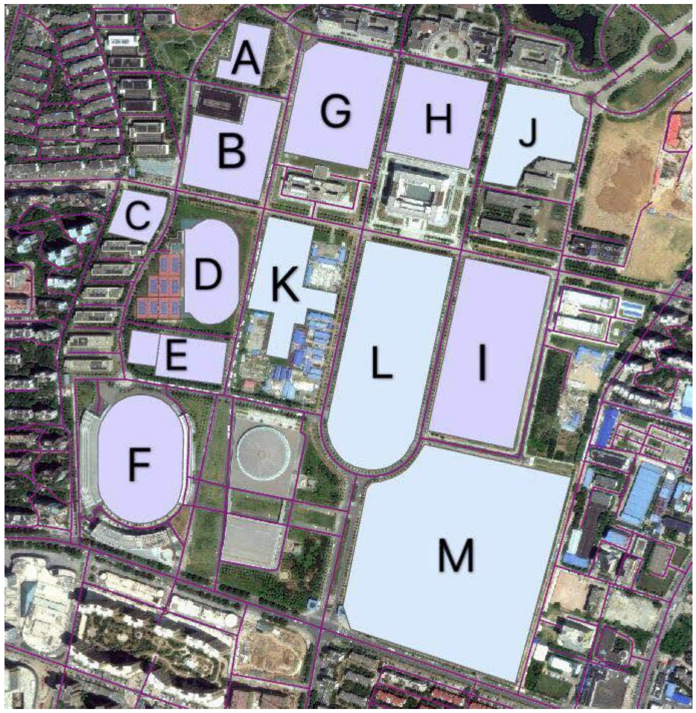


Figure 18: Potential Shelters

Shelter A is a basketball court without a fence. It will be easy to enter the shelter. This shelter is relatively small, so it will have low capacity.

Figure 19: Shelter A

Shelter B is a large lawn with no barrier, making it a good place for a shelter and it has a high capacity.

Figure 20: Shelter B

Shelter C is a small lawn beside the dormitories. It can't hold very many people, but if the dormitories are on fire, students can evacuate and reach the shelter quickly.

Figure 21: Shelter C

Shelter D is a playground with fences. There are two entrances for the playground. Because the entrances are quite small, the evacuation speed might be slow if we use this shelter.

Figure 24: Entrances of Shelter D (1)

Figure 22: Entrances of Shelter D (2)

Figure 26: Shelter D

Shelter E is a basketball court with a fence. It has one small entrance. Shelter E can be an alternative shelter, which can be used if the main shelter is not able to hold enough people.

Figure 23: Shelter E (1)

Figure 24: Shelter E (2)

Shelter F is a playground with a wall around it. There are several entrances, but they are all locked. If the playground is able to open to the public, it could be an ideal shelter.

Figure 25: Entrances of Shelter F (1)

Figure 26: Entrances of Shelter F (2)

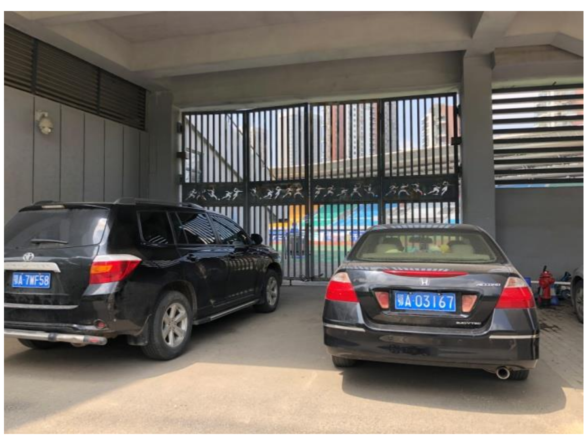


Figure 27: Shelter F

Shelter G and shelter I are lawns. They both have a large area and high capacity.

Figure 28: Shelter G

Figure 29: Shelter I

Figure 30: Shelter H

Shelter H is a square in front of the library.

Open space J and K are surrounded by trees, so they are not suitable for being shelters, as the trees could be hazardous in a fire or earthquake.

Figure 31: Open Space L

Open space L and M are in the process of construction, they can't be shelters if schools decide to build facilities there.

4.0 Data Analysis

4.1 Recommended Shelter Locations

According to the vectorization and field investigation, the qualified shelters are A-I, totally 9 spaces as our shelters. The level of the shelter is calculated by the criteria introduced in the background sections.

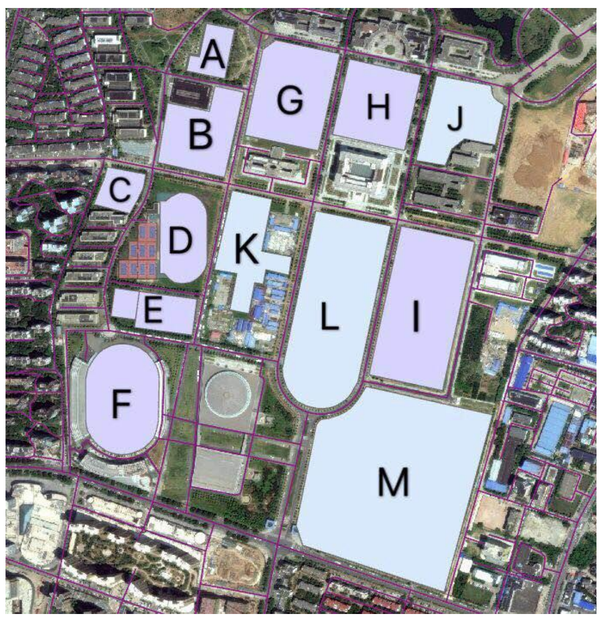


Figure 32: Label of Shelters

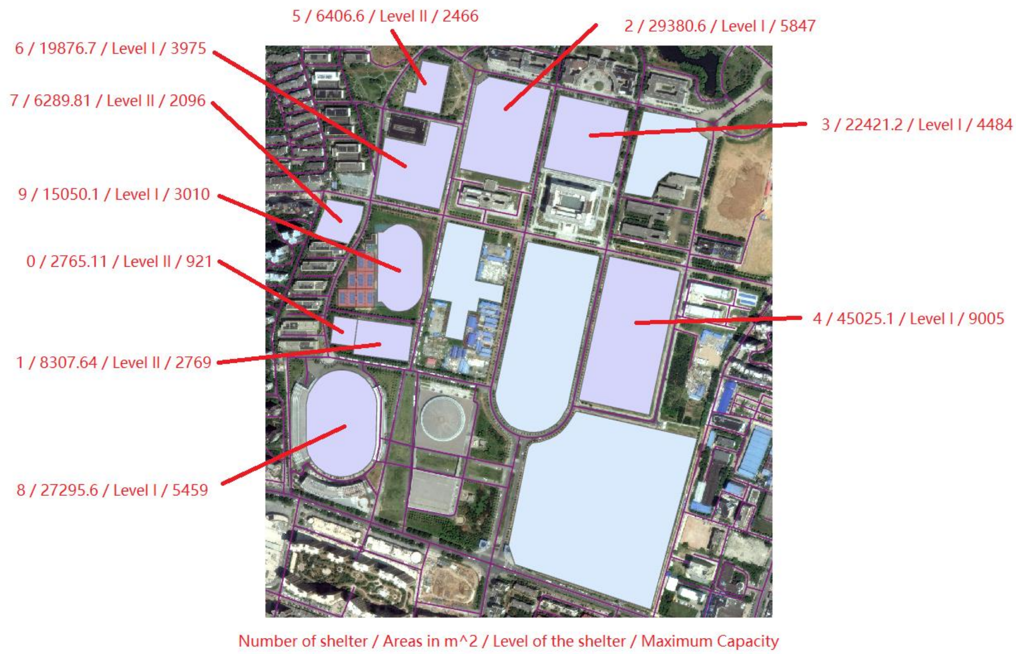


Figure 33: Data Visualization

Shelter Number	Shelter Areas(m^2)	Level of Shelter	Capacity
A	6406.6	Level III	2466
B	19876.7	Level II	3975
C	6289.81	Level III	2096
D	15050.1	Level II	3010
E	11072.75	Level II	3690
F	27295.6	Level II	5459
G	29380.6	Level II	5876
H	22421.2	Level II	4484
I	45025.1	Level II	9005

Table 10: Shelter Information

4.2 Simulation - Fire Emergency

Simulation's locations were picked by several criteria. First of all, the incident location must be on campus. Secondly, places with highest population density for different time slots of evening and afternoon should both be included in the simulation.

Figure 34: Overview of the School

4.2.1 Simulation: Night – Fire Emergency

For evening, the places with highest population density are the dorms. There are three different areas of dorms on the campus.

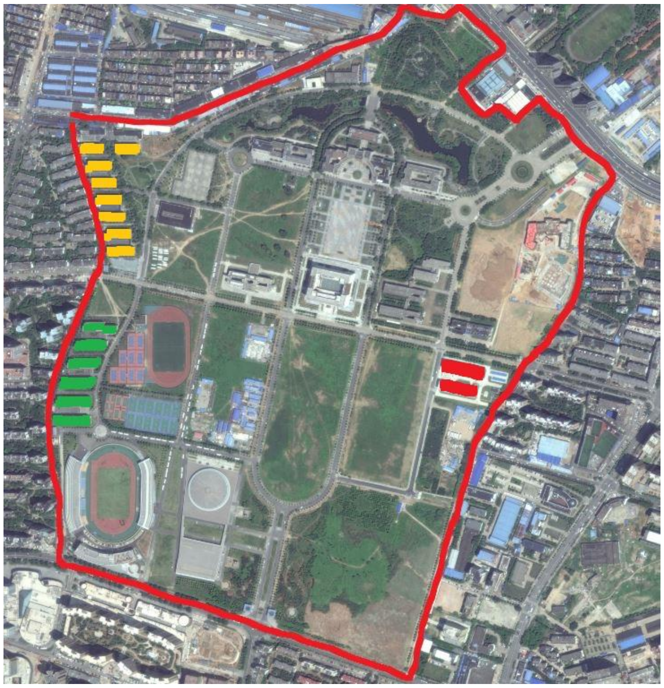


Figure 35: Dorms on Campus

The area shaded in yellow, green, and red are all the dorms on campus. Since it is a fire emergency, the accident point for this is only be one building. Thus, estimation of the general population in certain dorms is made by counting the total number of rooms in each building.

For yellow area dorms:

Figure 36: Yellow Area Dorms (1)

Figure 37: Yellow Area Dorms (2)

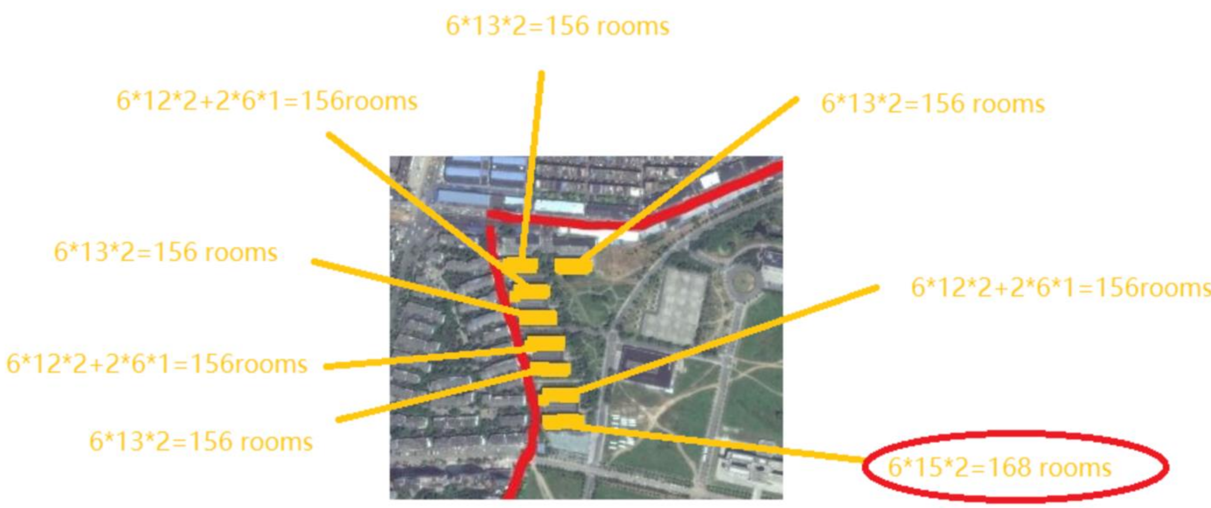


Figure 38: Number of Rooms in Yellow Area

In yellow area dorms, the south most building has the most rooms, and in average there are 4 people per room, being able to hold 672 students.

For green area dorms:

Figure 39: Green Area Dorms (1)

Figure 40: Green Area Dorms (2)

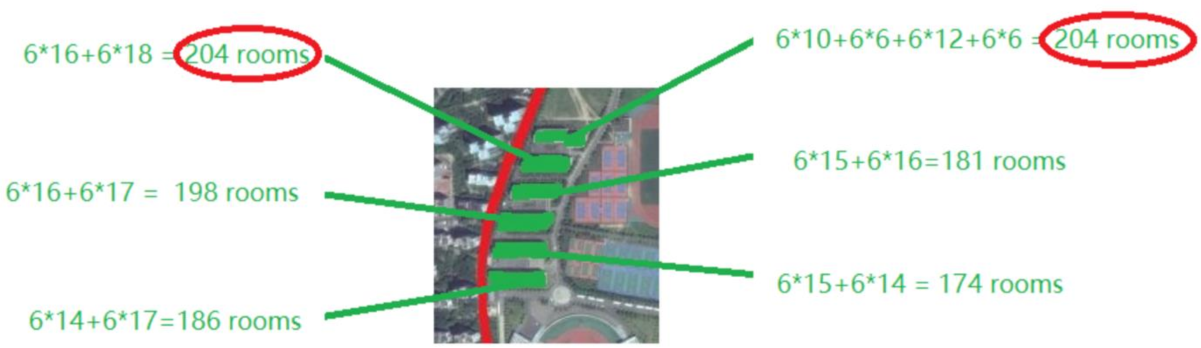


Figure 41: Number of Rooms in Green Area

In green area dorms, the north most building has the most rooms, and in average there are 4 people per room, holding up to 816 students.

For red area dorms:

Figure 42: Red Area Dorms (1)

Figure 43: Red Area Dorms (2)

Figure 44: Number of Rooms in Red Area

In red area dorms, the only two buildings had the same amount of rooms, so 856 students could be in these buildings.

Due to the worst-case principle, everyone was in their dorm which would account for the maximum number of people in the dorms at one given time.

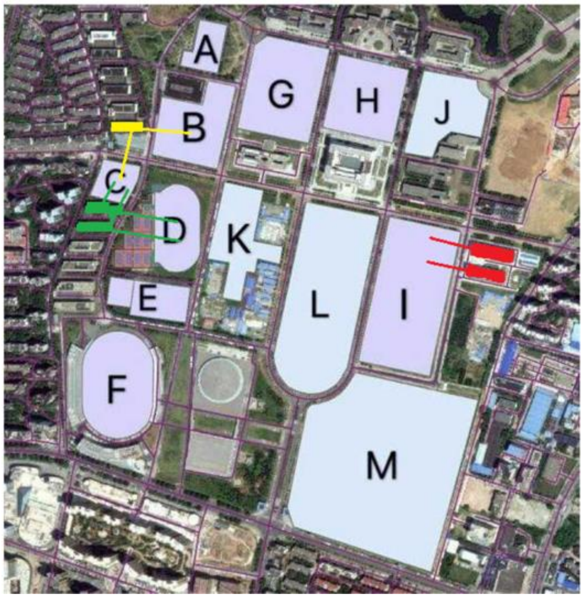


Figure 45: Result Evacuation Graph

Analysis for accident point (Yellow area):

population = 6*15*2(rooms) * 4 (4 people/room) = 672

Capacity for shelter B is 3975 people, capacity for shelter C is 2096.

If x people go to shelter B:

Then 3975 >> x, 2096 >> (672-x) which is the safe result.

Analysis for accident point (green area):

population = (6*16+6*18) (rooms) * 4 (4 people/room) = 816

Capacity for shelter D is 921 people, capacity for shelter C is 2096.

If x people go to shelter D:

Then 921 > x, 2096 >> (672-x) which people should be informed that more people should be going to the shelter C because the maximum capacity in shelter D is close to full.

Analysis for accident point (Red area):

population = 6*18*2(rooms) * 4 (4 people/room) = 856

Capacity for shelter I is 9005 people.

Then 9005 >> x, which is the safe result.

Area	Accident point's population	Nearby shelter(A)'s Capacity	Status of Shelter A	Nearby shelter(B)'s Capacity	Status of Shelter B
Yellow	672	3975	Safe	2096	Safe
Green	816	921	Safe	2096	Safe
Red	856	9005	Safe	/	/

Table 11: Data of Accident Points

4.2.2 Simulation: Daytime – Fire Emergency

For the afternoon, the place with highest population density is the library.

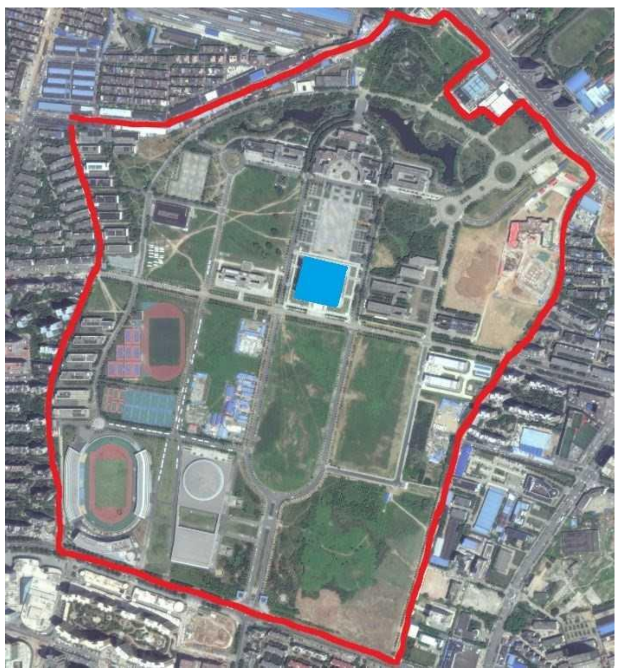


Figure 46: Library on Campus

The area shaded in blue is the library, it is in the center of the campus, and there are 11 floors in the building. The total area for this library is 47,000 meters squared, there are around 4,000 seats in the library, and the maximum capacity is 6, 5000 students. Assumption of evacuate 5,000 students at one time is made because it is between the number of seats and the maximum capacity.

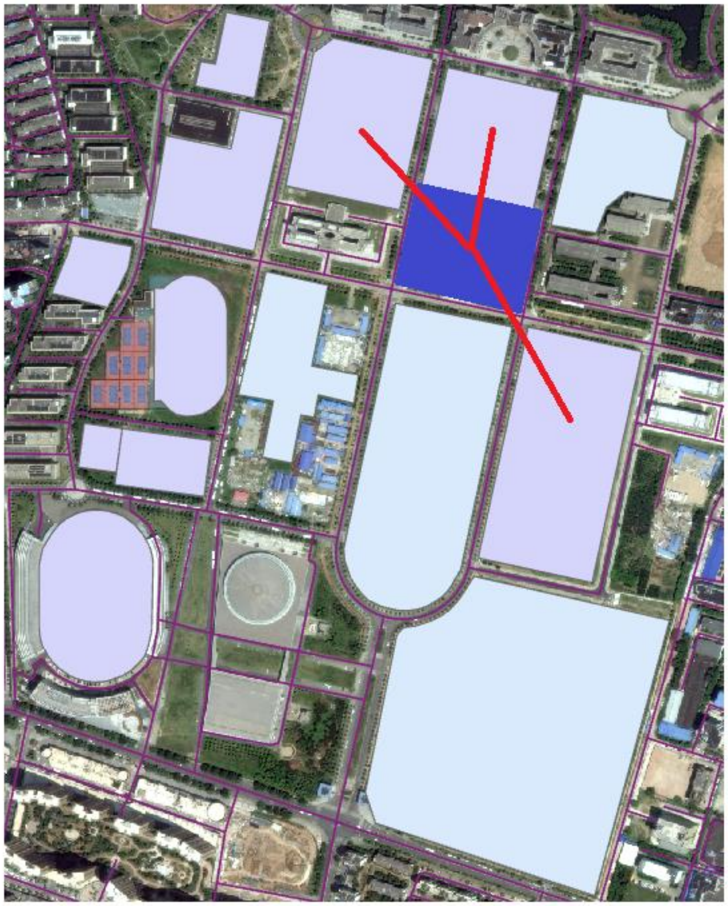


Figure 47: Result Evacuation Graph

Analysis for accident point (blue area):

population = 5000

Capacity for shelter G is 5847 people, capacity for shelter H is 4484, capacity for shelter I is 9005.

If all the people go to shelter G or H, the shelter will be not be able to hold everyone. Thus, the proper plan in this case should be for a reasonable portion of students to go to different shelters.

4.3 Simulation – Earthquake

Since earthquakes usually affect a large area, empty spaces are necessary for peoples' temporary stay. So, the consideration is for the whole campus, including different amounts of people and different time slots.

The classification is daytime and nighttime, because the people living on campus does not equal the amount of people in classes or other school facilities.

4.3.1 Simulation: Night – Earthquake

Earthquakes are unlike fire emergencies, which usually affect one building, so all surrounding areas in this simulation are considered.

Figure 48: Dorms on Campus

From our estimation in section 4.2 about the capacity of the dorms:

The yellow area has total:

(156+156+156+156+156+156+156+168) (rooms) * 4(people/room) = 5040 students

The green area has total:

(204+204+198+186+186+174) (rooms) * 4(people/room) = 4608 students

The red area has total:

(216+216) (rooms) * 4(people/room) = 1728 students

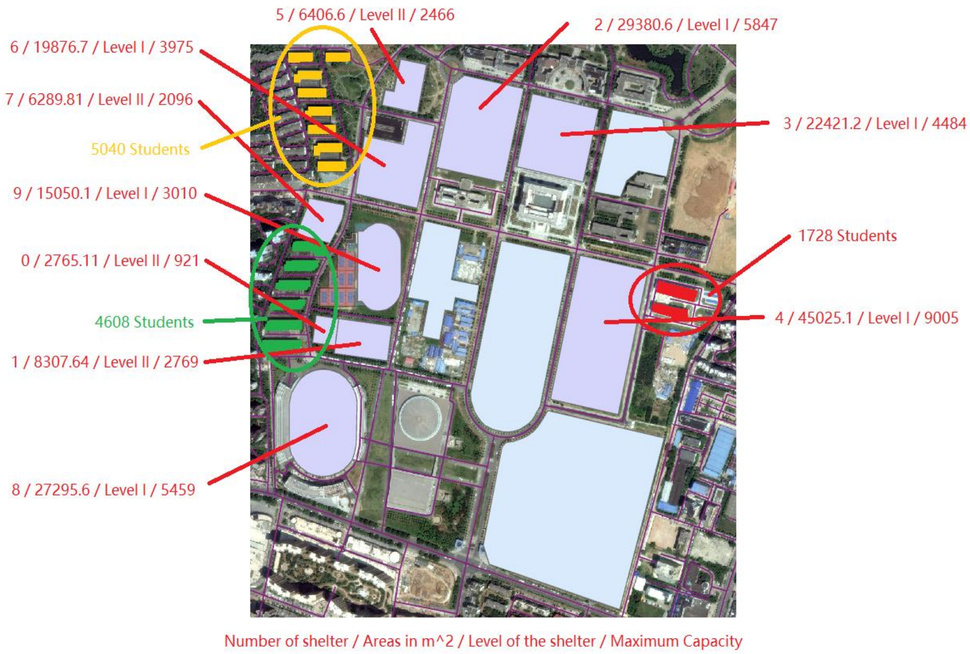


Figure 49: Integrated Data Graph

Since all students need to evacuate, the people should be divided among different shelters and also have some extra space for every shelter used in this simulation.

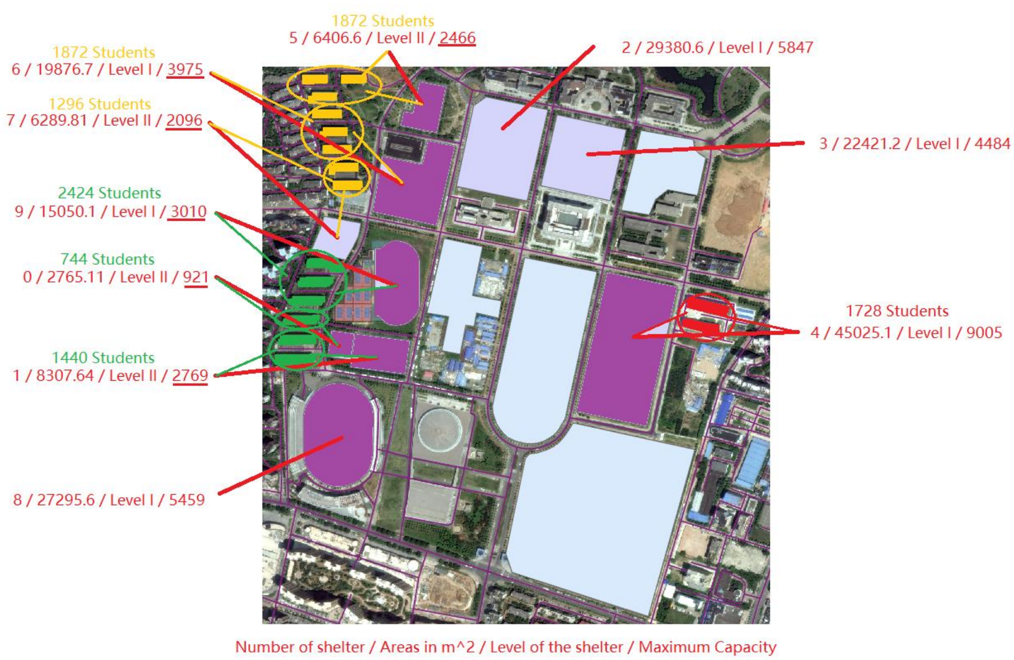


Figure 50: Shelter Allocation

In the figure above, all the shelters used are shaded in purple and each of them will have enough capacity. According to this simulation, the shelter on the north and the east still has enough space for more people, so there is enough space for 18,000 more people.

4.3.2 Simulation: Daytime – Earthquake

The daytime is different than night cases because there is no accurate population estimate about who is on campus and which specific building they are in.

As for the population, estimation is from the official database of WUT, stated that all freshmen, STEM sophomores/juniors/seniors (around 2,150 students), and masters/PhD students (400) live and study on campus.

Figure 51: Main Academic Building

This simulation is different from the night cases, because the population density is not stable, as people might be having class, in their bedroom, in the library, or not on campus. Even with the amount of unknowns, the population density in the main academic buildings will be dramatically higher than the other places.

The nearby shelters have a great capacity, which can almost contain all people on campus, but lots of the shelters are not used.

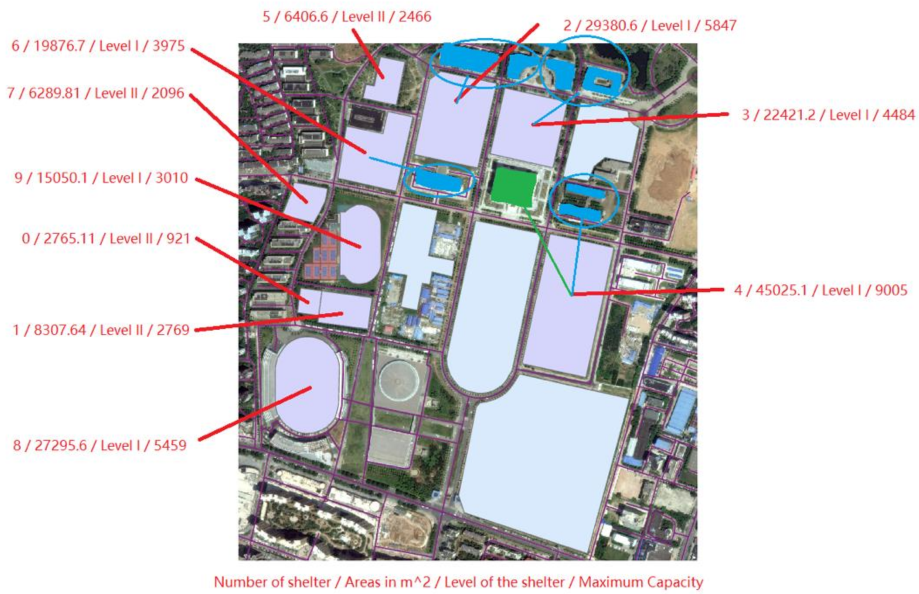


Figure 52: Shelter Allocation for Main Academic Building

For this simulation, the shelter allocation is very general, the only thing need to do is allocate the shelters for academic buildings. Thus, in the graph, nearby shelter is marked for the people in the academic building, and used GIS to do the path planning. Since the capacity of the nearby shelter is way greater than the people need to be evacuated, which in this case is relatively easy for evacuation.

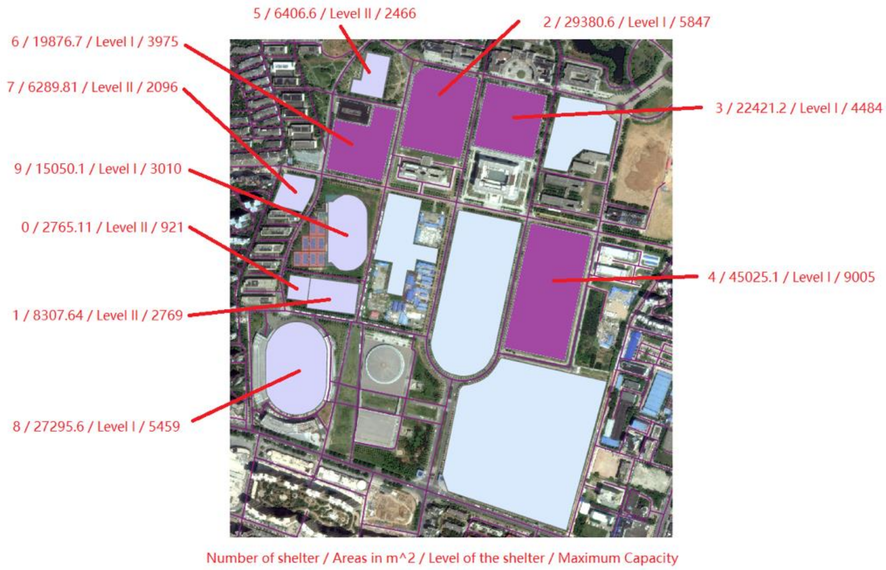


Figure 53: Shelters Used in This Simulation

4.4 Simulation Conclusion

In the two simulations we did, we found that the shelters we recognized are valid under fire emergency and earthquake in different time periods. The main differences are the evacuation plan. For small area of emergency, we think it is better to just put the people in the closet shelter, which can save the most time. For the emergency which will affect a huge area such as earth-quake, floods etc., we should allocate the shelters beforehand. Because in most cases, there will be buildings with high population density, the nearby shelter probably will not have enough ca-pacity for all the people who needed to be evacuate nearby. So, we have to put different people into different shelters according to the geographic information of that area.

5.0 Conclusion

We have developed a versatile protocol for emergency evacuation which accounts for two types of emergencies, fire emergency and earthquake, with separate cases for daytime and nighttime. After determining which residential and academic buildings on the WUT campus were most at risk for loss of life in a fire or earthquake, we selected shelter locations providing coverage to each. Our protocol is validated by case studies, which set a precedent for the criteria used, and computational methods which let us find optimal evacuation routes. However, the protocol we have developed is only a virtual simulation; to work in real life, people must be trained to implement it in response to an emergency. We have decided to leave the details of this protocol's implementation open-ended to allow for flexibility in future implementations; consequently, our methodology can easily be adapted to other universities in Wuhan.

6.0 Recommendation

We recommend a protocol prescribing that residents of affected buildings immediately go to their building's assigned shelter during a fire or earthquake. Since people cannot be expected to act rationally in an emergency and find the shelters themselves, the protocol's implementation should have a way to guide large groups of people at once. One possible implementation we propose is a training drill to familiarize residents with the paths to be taken in an emergency. This has the advantage that it can simply be incorporated into an existing routine fire drill. Another possibility is a text alert system that sends out campus-wide messages, with instructions on where to go when a fire or earthquake occurs. This can be very efficient for reaching large groups of people, but runs the risk of technological failure. We have decided to leave this implementation open-ended, so that the school can choose the most feasible option for themselves.

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