Fire Station Site Selection in Wuhan, China

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Sponsored by Wuhan University of Technology

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Abstract

WPI students worked with Wuhan University of Technology (WUT) to create a framework for selecting fire station locations. ArcGIS analyses were used to research the viability of the locations of two fire stations close to WUT's campus. To justify the results, qualitative data collection in the form of interviews and surveys was performed at a local fire department. This report outlines the background, methodology, and the findings of this study. With this information, a conclusion and a number of recommendations were developed for the sponsors, which could change the current fire station layout servicing WUT.

Statement of Authorship

Elisabeth Christ: Contributed to the general outline and executive summary outline. Contributed to the project mission statement and objectives. Edited abstract. Vectorized buildings in ArcGIS and performed buffer analysis and network analysis in GIS. Analyzed the results of these analyses. Contributed to the creation of all scenarios. Created survey questions. Wrote sections 2.5, 3.3, 3.4, 4.1 (Case study), 4.3, 4.4, 4.5, Scenario 1, Scenario 2 (2.1, 2.2, 2.3), Scenario 3, Scenario 4, Scenario 5, 4.6, 4.7, Recommendations section. Edited sections 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 3.2, 3.3, 3.4, 3.5. Suggested the conclusion. Formatted final paper and did final quality check/editing before submission.

Moh'd Al-Talib: Wrote & Co-wrote sections: Abstract, List of Figures, Chapter 1, 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 3.1, 3.2, 3.3, 4.1 (Case study), 4.2, 4.3, 4.4, 4.5; Scenario 1, Scenario 2 (2.1, 2.2, 2.3), Scenario 3, Scenario 4, Scenario 5. Created appendices; A, B, C, D, E, F, G, H, I, J, K, L, M, N. Created figures: 2, 3, 5, 6, 10, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24. Edited sections: Executive summary, 3.4, 3.5. Vectorized roads in ArcGIS, performed buffer analysis and network analysis in GIS. Analyzed the results of these analyses. Contributed to the creation of all scenarios. Edited to improve flow and conciseness. Suggested the conclusion. Managed the references and in-text citations. Formatted final paper. Did final quality check before submission.

Anirban Mukherjee: General outline, introduction, mission statement review, editing and formatting. Wrote sections: abstract, executive summary, 1.0, 2.5, 2.6, 2.7, 2.8, 2.9, 3.2, 3.5, 4.3, and conclusion. Did research on ArcGIS before arriving on site. Created several diagrams. Filled in a lot of the Methodology Section. Added to intro and background. Outlined case study. Reviewed paper multiple times to check flow and cohesiveness. Did final editing before submission. Formatted final paper.

Javier Sibel: Managed IRB. Created multiple versions of the surveys. Translated surveys. Incorporated survey data into figures. Created and edited some presentation slides. Wrote the geographic and cultural background paragraph.

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Executive Summary

This project report is divided into 5 main sections: the introduction; the background; the methodology; the findings & analysis; and the conclusion & recommendations.

The background covers some contextual information about China and the city of Wuhan. This set the scene for this IQP project and provided some context for the work. Wuhan is rapidly developing. Thus, the importance of urban planning is critical for a variety of reasons such as efficiency and safety. Fire station location criteria terrain, surrounding road conditions, and traffic flow are covered in this section.

Wuhan University of Technology's (WUT) Safety Engineering department seeked to aid city planners in developing a framework for fire station site selection. There are two fire stations near WUT's campus. The fire station locations were analyzed in order to develop an optimized solution to the site selection problem regarding their ability to respond to emergencies on campus.

This analysis was conducted via ArcGIS. ArcGIS is a Geographic Information System (GIS) software that has a variety of tools for geo-spatial analysis, making this software crucial for research. In GIS, the map data, infrastructure data, and traffic speeds were inputted. These inputs allowed buffer analysis and network analysis to take place. The analyses made it possible to construct a model of the map and the two fire stations, showcasing their locations, their range, and their ability to respond to emergencies at various locations throughout the map.

After analyzing this model, it was found that the fire station layout may not be capable to respond to emergencies that could occur on WUT campus. To work towards a solution, some scenarios that could potentially solve the problem were simulated. Renovating, relocating, building new fire stations, and a combinations of these scenarios were simulated.

An expert opinion was needed to decide which scenario best suited WUT. Thus, we interviewed a fire captain at one of the biggest fire stations in Wuhan. Many fire-fighters were also surveyed.

These results showed the practicality of the scenarios that were simulated. Furthermore, this helped narrow down the conclusion to two possible outcomes.

It was deduced that building a new fire station would be the most cost effective and efficient solution to the problem. The data and analysis section provide a proposed area in which the fire station could be placed. Additionally, it was learned that taking no action is also viable, not only because it is the cheapest option, but because traffic congestion is often a bigger issue than the fire station location itself. The amount of effort and resources that go into constructing a new fire station is immense. Since only a small part of the WUT campus lies outside the service range of the two fire stations, it might be unnecessary to build a new one. The response time in these unserviced areas may simply add 1 to 2 minutes of travel time. Having reached this conclusion, we leave it up to the municipality of Wuhan and the sponsors to decide what must be done.

Chapter 1: Introduction

China is rapidly developing. Whether it be in the realm of technology and infrastructure or culture and people, there is a steady state of change that moves the nation forward. This idea is seen in developing cities where skyscrapers and city flats are erected monthly in order to house the country's increasing labor force and population. The ever-growing infrastructure raises many new obstacles that need to be conquered. One of these obstacles is closely tied to first responders in these areas, namely a city's fire departments. With more people, more traffic, and more buildings, there is a strong demand for fire stations to be placed in the most appropriate locations in order to optimize response times for emergencies.

Wuhan, about twice the size of Boston, is a good candidate city for the IQP project. Due to its growing activity and population, fire stations need to be erected in prime locations to maintain safety and prevent disasters within the area ("Wuhan", n.d.). Determining the locations of these fire stations requires the use of criteria and analyses that account for traffic behaviors and other risks. ArcGIS will be used as a tool to determine these locations. ("Using GIS to Revolutionize …", Fall 2017)

ArcGIS is a software recommended by PhD students at Tsinghua University and Wuhan University of Technology (WUT) for this project. ArcGIS is a Geographic Information System (GIS) software that enables the analysis of geographic data. Geo-databases contain information about the geography, topography, population, and buildings in specific regions. The use of different tools in ArcGIS will be critical in determining the risks and capabilities of different fire station locations ("What is GIS?", n.d.).

With that being said, the usefulness of ArcGIS is limited to the map data supplied by the sponsor. Geodatabases are limited depending on the restrictions of each country. Due to China's strict policies on public information, many geodatabases were not available ("Restrictions on geographic data in China", 2019). As a result, ArsGIS could not be solely relied upon to provide the necessary background and information about local fire stations in terms of how they operate; nor could it be used to obtain workable maps of the geography, topography, population, and buildings in the area without the help of some research from the sponsors. Therefore, to gain this knowledge, it is important to ask experts in the field regarding their opinions on how one should go about choosing optimal fire station locations, as well as their viewpoints on the strengths and vulnerabilities of current fire station sites. This approach considers the human aspect of site selection. Communicating with the stakeholders of this project is essential, as the deliverable will not be accepted if it is not conscientious of their needs.

Chapter 2: Background

2.1 Geographic and Cultural Background of Wuhan

Wuhan is the capital city of Hubei Province in China. It is located along the Yangtze River and is one of the largest cities in the central part of China. Wuhan is spread out across nearly 8495.2 km^2 (3,280 mi^2) with a population of roughly 10.61 million people. It is split into three sections: Wuchang, Hankou, and Hanyang, which are separated by the Yangtze River and the Han River. Wuchang is considered the cultural area of the city where many universities are located. Hankou is the commerce area of the city where a lot of businesses are located and is the most prosperous part of Wuhan. Hanyang is the industrial area of the city where a lot of developments have been taking place. Each of these areas have different types of fire safety protocols due to the type of buildings in the area (Wu, 2017; "Wuhan", n.d.)

2.2 Firefighting in Wuhan

Wuhan has at least 130 structures that are already at least 150 meters tall. There are also at least 85 additional structures being built that will soon reach above 150 meters. Because many of these buildings are high-rises, response time to emergencies in these structures needs to be carefully thought out ("List of tallest buildings", n.d.).

There are four ring roads in Wuhan. Ring roads can be thought of as highways, encircling the center of the city, each at different radii. The inner ring road is 28 km long, with roads connecting the commercial areas with the main central districts. The second ring road is 48 km long, consisting of an expressway that surrounds the downtown areas of Wuhan, crossing the Yangtze River. The third ring road is a 91 km expressway, which was completed in 2010. The fourth ring road is a 146 km ring expressway ("Ring roads of Wuhan", n.d.). Figure 1 shows the four ring roads of Wuhan and the adjacent main roads.

Figure 1: Ring Roads of Wuhan[1]

Understanding the infrastructure of the roads is important to effectively choose fire station sites. It is important to consider railroad crossings, bridges, and tunnels since they could change response times due to restrictions in traffic flow. Placing fire stations near main roads and highways is one of the most important criteria for fire station site selection. Locations near these roads are desirable because it allows fire trucks to quickly navigate within the city, since highways and main roads have more room for large fire trucks to maneuver between traffic (AMERICAN SOCIETY OF PLANNING OFFICIALS [ASPO], 1957).

2.3 Stakeholders

It is important to understand who the stakeholders are in this project, and to distinguish between not only groups that are already affected by the current firefighting infrastructure, but also groups that will be affected by the changes that may be introduced to Wuhan City. WUT and the municipality of Wuhan city are primary stakeholders. The outcome of this project will put WUT's reputation as a research institution on the line, meaning that it has a large stake in

[1] Howchou. (2012, February 18). Wuhan road network [Digital image].

the project. On top of that lies the municipality of Wuhan, who is looking to solve a potential issue with fire safety in the city. Failure to accommodate the needs and demands of these groups will not only bring about a project that is less than satisfactory, but also one that will cause issues for WPI in planning projects in China in the future.

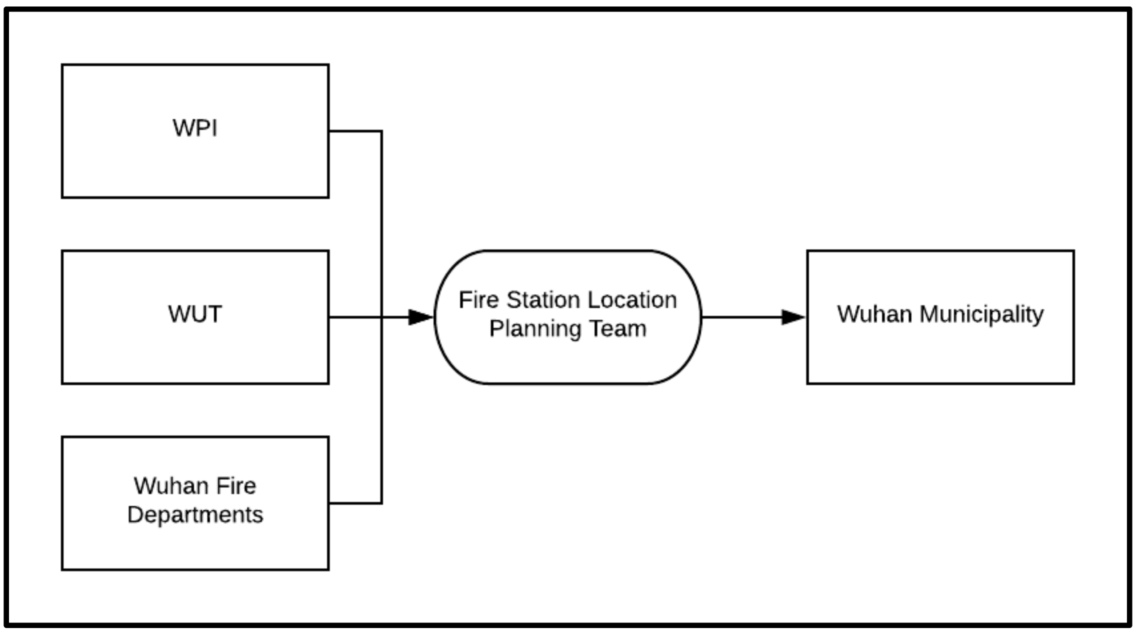


Figure 2: Shareholders Involved in the IQP Project

Fortunately, these organizations have been very helpful and involved in the planning of this project. The experts assisting with the proposal, especially professors at WUT, had a great hand in helping with this project. Other stakeholders such as the firefighters, the civilians who live nearby future potential sites which the project results may recommend, and those who travel near those sites will be affected, since introducing a fire station will lead to a change to traffic patterns during emergencies. Because the project will directly influence the lives of these people, they should have a clear voice in the development of the solution. The needs of all stakeholders must be addressed in order to deliver value. It is also important to understand the inter-departmental functions between the fire station and other stakeholders, such as 119 operators - emergencies in China is dialed as 119, the city's police force, and hospitals to deliver better outcomes and form a better understanding of the system (Monczka, Handfield, Giunipero, & Patterson, 2015).

2.4 Understanding the Basics of Optimization

This project relies heavily on benchmarking and optimization. Thus, it is important to understand the foundations of optimization and waste before discussing ArcGIS. To understand waste, one needs to understand non-value-added processes and value-added processes.

In Lean Six Sigma, non-value-added process does not directly change the product or service consumed. Examples of this would be deliveries, administrative processes, quality checks, etc. These processes are considered wasteful, because the final product or service has not been modified. A value-added process adds value directly to the product or service. Examples of this would be manufacturing, assembly, research & development, etc. (Evans & Lindsay, 2017; Monczka, et al., 2015)

The theoretical best-case scenario for zero non-value & value-add process times is zero. However, in the real world, this is not possible. Thus, it is best to prioritize minimizing non-value-added processes first. In the case of fire safety, non-value add process would include emergency case processing, filing, and travelling to incident points. Value-add processes would be the actual firefighting service once the firefighters arrive to the emergency area, upon which no changes were proposed. This means that only non-value-added processes were focused on in this project. Figure 3 below shows how different non-value & value add processes are optimized. (Evans & Lindsay, 2017; Monczka, et al., 2015)

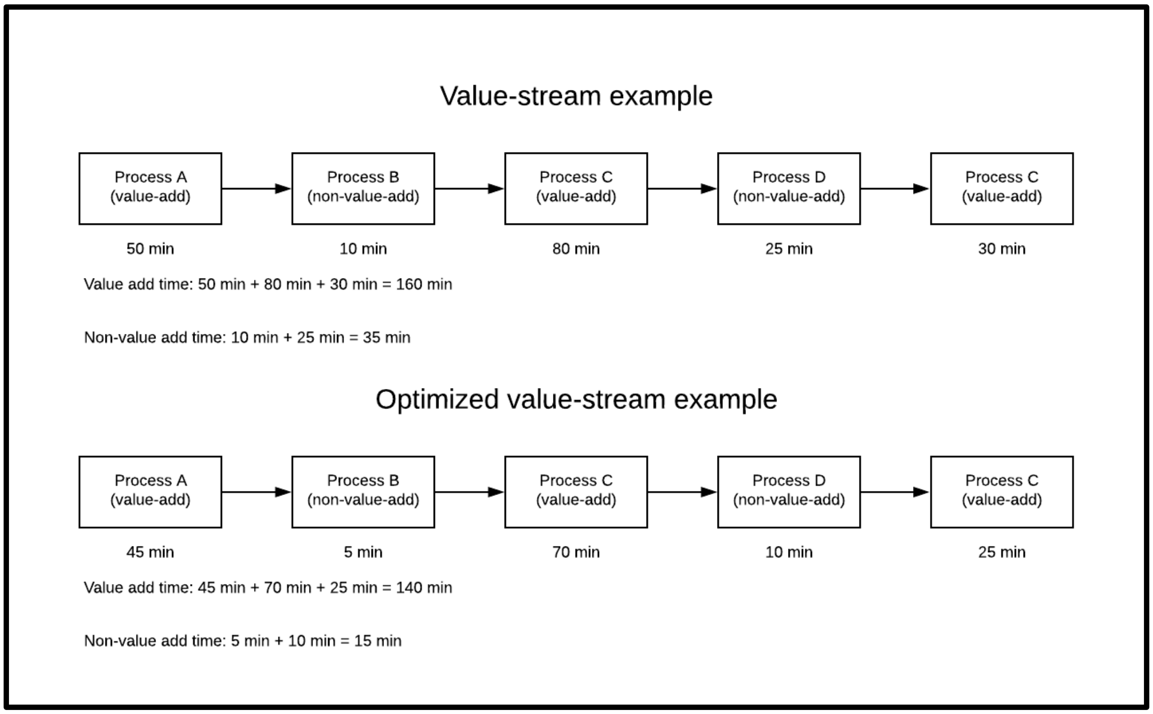


Figure 3: Value-Stream Mapping Example Contrasting a Normal Case to an Optimized Case

In order to minimize these times, the current fire station layout was benchmarked using certain ArcGIS functions such as the buffer analysis and network analysis functions. The combination of these functions allowed the average travel times from any fire station to incident points to be determined (Wenqi Cui, personal interview, 2019). These functions were used to determine if certain sites needed optimization within the station itself or possible relocation. Further discussion will be carried out in the methodology section of this report.

2.5 Understanding the Rules of Fire Station Site Selection

To carry on optimizing the current layout of fire stations in Wuhan, not only must one understand the fundamentals of optimization, one must also understand how to choose suitable fire station sites. Learning so furthered the ability to assess the current fire station layout. Specific stations can be assessed not only by using benchmarks, but by also using the site selection criteria, allowing judgement on whether current site locations are optimal or not. A report dated on May 1957 will set the foundations of site selections. Although this report may be considered outdated, this report must not be overlooked, since the fundamental methods for selecting fire stations found within this report are still relevant. However, awareness must be brought to the fact that this report is based in the USA, and some aspects of this report may not be applicable to Wuhan City (ASPO, 1957). Another study by Erden and Coşkun, dated 2010, discusses the same methods for selecting fire station sites used in the dated report mentioned earlier. However, this study is based in Istanbul, Turkey, therefore the sections related to Turkish regulations were also disregarded. These two sources nonetheless established the foundations of fire station site selection in this section of the report. (Erden and Coşkun, 2010)

From the literature, it was deduced that the first step for site planning is to track the inventories of all existing stations. This is done to see what can be retained, replaced, and added. The items that may need to be inventoried may include the fire station number or name, its street address, date built, construction specifications, condition of structure, apparatus capacity, number of firefighters accommodated, and types of equipment available. Privately-owned businesses and public facilities should also be inventoried to ensure that their own protection could be served efficiently. These entities may include, private businesses, hotels, and airports, of which may need special equipment. (ASPO, 1957)

The second step is understanding what factors should be considered. Time, distance, population density, and regulations are the major factors that determine the distribution of fire stations. Prioritizing high-value property with higher coverage is also discussed in this report which may be applicable to this project. Regarding population density, the types of land may indicate high population concentrations, which should impact site selections. Lands used for hospitals, malls, schools, etc. increases the need for fire protection to ensure many lives can be saved if disasters happened. Other factors seem to be more relevant in the US regions, such as US regulations & fire districts. Hence, discussion about these factors found in this report is unnecessary. (ASPO, 1957)

The third section of this report discusses the principles and criteria of site selection: Fire stations must be distributed throughout the city, such that each fire station has their own primary service area. Service areas must be near high population densities. Fire stations must be located near highways and main roads. Sites on terrain that require detours must be avoided to minimize travel time. Finally, a fire station must be large enough to accommodate the total number of firefighters within it. These criteria are mandatory for choosing a suitable site. The next set of criteria are not mandatory but is nonetheless desirable: fire stations should not be on high traffic roads, nor on a major corner due to the difficulty of firetrucks making U-turns and the dangerous nature of traffic. Access to streets with a higher number of lanes is preferable, since fire trucks can maneuver easily. Finally, stations should avoid proximity near traffic lights to avoid congestion. (ASPO, 1957; Erden and Coşkun, 2010)

2.6 Understanding the Basics of ArcGIS Software

The ArcGIS software is a geographic information system used for analyzing geographic data on maps. Such geographic data includes population density, traffic congestion, and effects of weather over time. There are numerous types of GIS software available based on one's specific needs. (What is GIS?, n.d.)

In this project, ArcMap and ArcGIS Pro were used. ArcMap is the central application used in ArcGIS and is the sponsor's version of choice. The ArcMap application can display, explore, create, and edit GIS datasets, assign symbols, and create map layouts for printing or publication. It also has geoprocessing capabilities to automate work and perform analysis (Gokgoz, 2012; What is GIS?, n.d.). ArcGIS Pro was used to complete all GIS related analysis. This version of ArcGIS is newer and thus has a different user interface than that of ArcMaps. Nevertheless, the two versions are similar enough that both versions were able to perform the same analyses with ease.

The traffic data used with ArcGIS Pro was obtained online through BaiduMaps. While ArcGIS works with geographic information in numerous GIS file formats, it is designed to work with and leverage the capabilities a geodatabase (Gokgoz, 2012). The geodatabase was obtained through the sponsor. After obtaining the geodatabase for the WUT campus, three main factors were considered when analyzing the data: spatial distribution of fire stations, spatial distribution of buildings, and traffic patterns (Wenqi Cui, personal interview, 2019; He Xin, personal interview, 2019).

ArcGIS software has tools that can prove to be valuable for this project. Two of these tools are network analysis and buffer analysis. Network analysis in ArcGIS relies on the use of geography to analyze the distances between locations. Algorithms can be used to compile the minimum amount of time it takes to get from one location to another, especially when using buffer analysis. Buffer Analysis makes zones around objects such as rivers and buildings that can be used to mark different datasets such as response times or viable fire location distances (Chen & Ren, 2003).

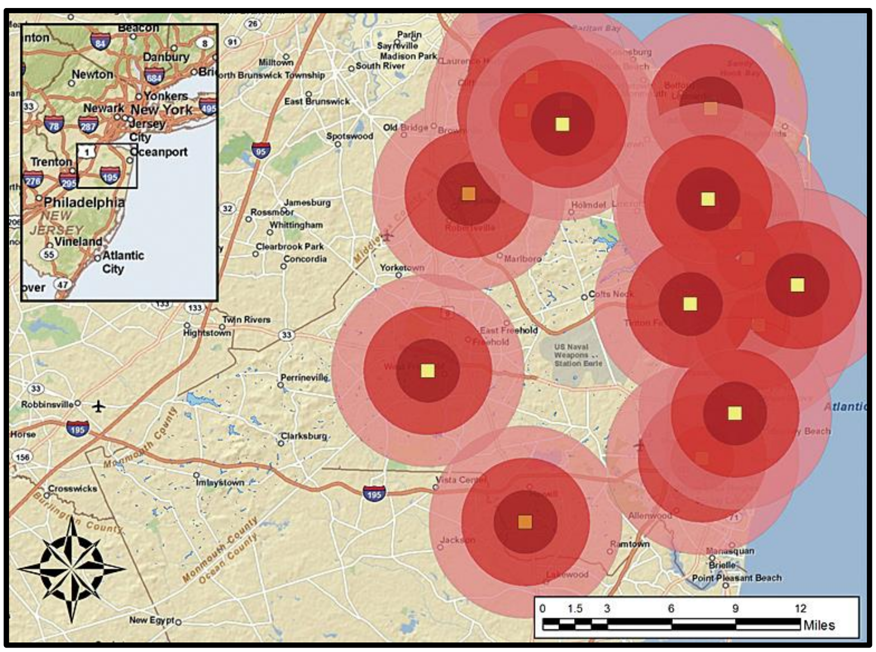


Figure 4: Buffer Analysis Example in ArcGIS[2]

This project relied heavily on the acquisition of traffic data in order to optimize the fire station locations. ArcGIS allowed for the creation of a detailed map data that showed available routes in traffic areas, but it did not show how traffic moved throughout the city. In order to remedy this

[2] González-Tennant, E. (2013). Simple buffer analysis of the zombie horde [Digital image].

situation, WUT volunteers aided in the use Baidu maps to collect traffic data. The traffic data provided the average speed vehicles moved at on congested roads. This information was used as an input in the impedance analysis, which will be discussed in the methodology (He Xin, personal interview, 2019).

Chapter 3: Methodology

3.1 Mission Statement

This project intended to develop a framework that can be applicable for general fire station site selection. The approach to this project was methodical. First, a satellite image supplied by the sponsor was vectorized, which allowed interpretation and manipulation of each shapefile's attributes. This made calculating the time travelled on routes possible. Second, the buffer analysis and network analysis functions were utilized in order to determine the rescue area and capabilities of the current fire station locations. The same analyses were performed on possible candidate sites. Candidate sites were chosen and analyzed based on a trial and error process. Fortunately, the sample size of the candidate sites chosen were minimized based on the ASPO criteria for choosing fire station locations. Additionally, fire station officials were interviewed and surveyed, allowing correct judgements to be made during the analyses. Many scenarios were considered, and thus 5 possible scenarios were proposed to the sponsor. Ultimately, the goal was to create a framework based on the methodology & analysis sections of this project, which can be applied to future fire station selection opportunities throughout China. Figure 5 below explains each objective, and how they aim to develop a solution to the problem.

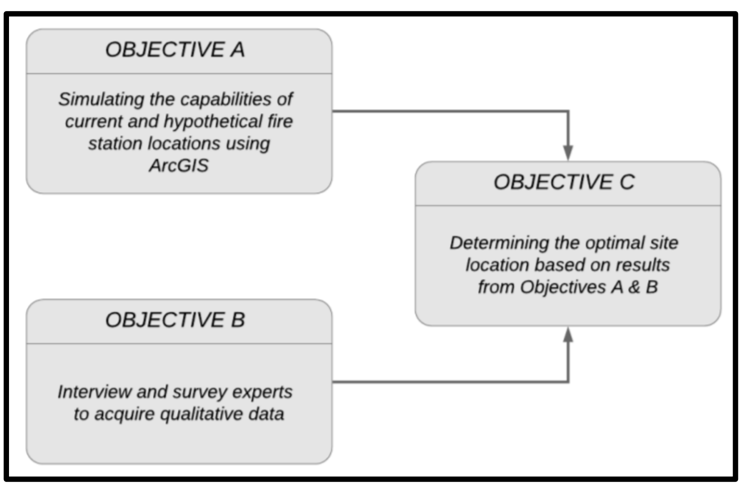


Figure 5: The Project's Goal

3.2 The Site Selection Strategy

In order to understand whether the current fire station locations are sustainable or not, methods must be developed to assess their effectiveness against emergencies. It is important to research the factors that make a fire station location favorable or unfavorable.

For this project, response time is the deciding factor in determining whether the location is appropriate (Wenqi Cui, personal interview, 2019). Much of this data was collected from the provided GIS databases, WUT and interviews and surveys with the fire station personnel. News reports regarding fires in Wuhan and other IQP projects researching similar fire history in Wuhan were read. Any relevant information to the project was noted and used to develop a better understanding of what factors may influence how fast first responders can reach a fire.

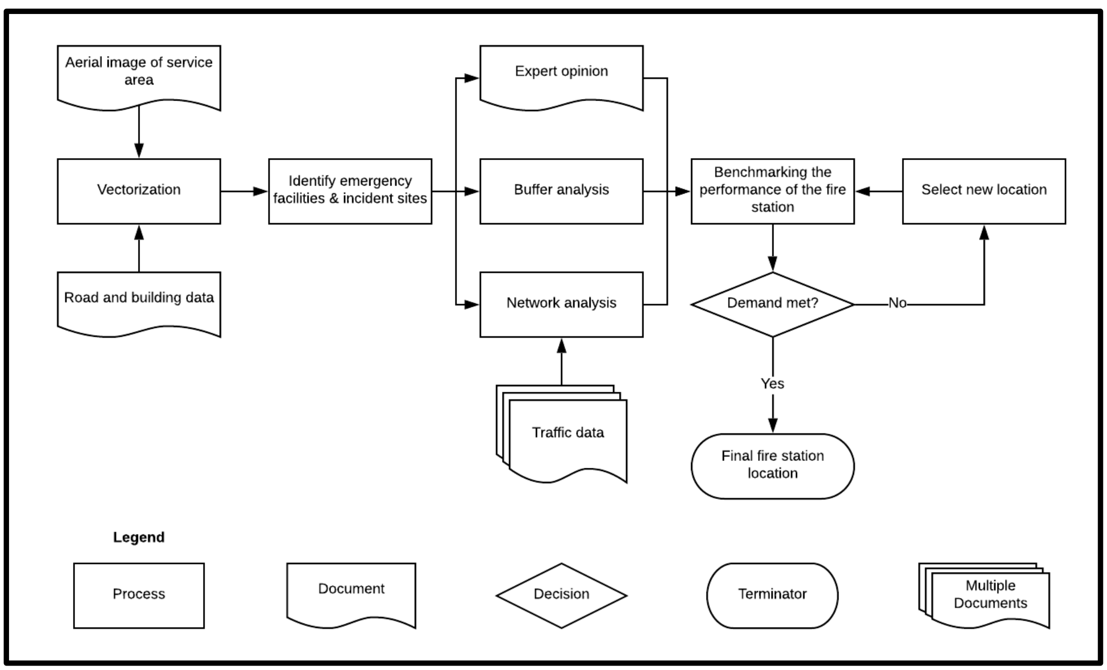


Figure 6: Process Flow Diagram

It is important to understand how fire stations are selected. Figure 6 above shows a process flow diagram providing the basis with which the project was completed. An aerial image of the area of interest was taken by satellite, and then input for vectorization. The vectorization process involves inserting shapefile layers onto the base satellite map within ArcGIS. Roadways were traced individually on the satellite map, creating a polyline vector image for the available roadways that vehicles responding to emergencies could travel on. Buildings were traced similarly to roadways, but with polygons instead of polylines. Once vectorization was completed, fire station sites and possible incident sites were defined. Possible incident sites were chosen arbitrarily. Sites were represented by squares in ArcGIS. From this stage, interviews and surveys, buffer analysis, and network analysis took place. These processes did not rely on one another, and hence could be done in parallel. Experts' opinions provided insight on what a good site location was, as well as the inner workings and resources of a fire station. This additional information could not be researched so easily and thus the expert interviews allowed a different perspective on urban planning to be seen. The buffer analysis showed the service range of each fire station on the satellite image. In an ideal scenario, the satellite image should be almost entirely covered by buffer zones, meaning any point within the range of the image is protected by a fire station. The network analysis showed the closest fire station to an incident point, and the quickest fire station to arrive at an incident point. Therefore, the analysis was done using either distance or time as the optimized factor. Once the interviews, surveys, and analyses were completed, a scenario for fire station relocation or addition was recommended. If the demand for fire safety was fulfilled, then the recommended location was suitable. In the case where the demand for fire safety had not been met, then it was necessary to select a new fire station location.

3.3 Using Buffer Analysis, Network Analysis, and Vectorization to Perform Risk Assessment in ArcGIS

This section will explain the use of ArcGIS in performing analysis in the project. It is worth noting that a full version of neither ArcGIS Pro nor ArcMap were provided to the IQP team. Therefore, a 21-day free trial of ArcGIS Pro was used for the project. The ArcMap application in ArcGIS Pro was used. The sponsor's guidance of the application was very helpful for this project, because it aided in gaining a deeper understanding of the software. Video tutorials from ESRI - the makers of ArcGIS - and YouTube were also used to learn about the basics of GIS applications during the

ID2050 course. Any questions about the software were directed to either the faculty at WPI during ID2050, or to the sponsors in WUT. Additionally, WUT provided training for the software during the first week of the project.

ArcGIS's buffer zone application was utilized to represent a certain distance from a central point at certain radii. Generally, the farther the point of interest to the station is, the longer the response time. The center of each buffer zone represented a fire station. This can be seen in Figure 7. Both buffer analysis and network analysis are types of spatial analysis, since they both use spatial information to perform tasks input by the user. Spatial analysis provides the basis with which geographic calculations, data interpretations, and simulations occur in GIS. This type of analysis uses datasets to solve spatial problems. The very edge of each buffer zone represented the maximum response distance for a fire station location. Depending on the capabilities of the fire station in question, different radii were applied to each buffer zone. Ideally, the entire map must be covered under these buffer zones so that in the event of an emergency, all locations can receive assistance (Wenqi Cui, personal interview, 2019). Since this project primarily deals with the service coverage of the WUT campus, the estimated buffer zones of both fire stations together would not be enough to service the whole campus. Due to this, there is a need to relocate or add a fire station. Network analysis can aid in this process.

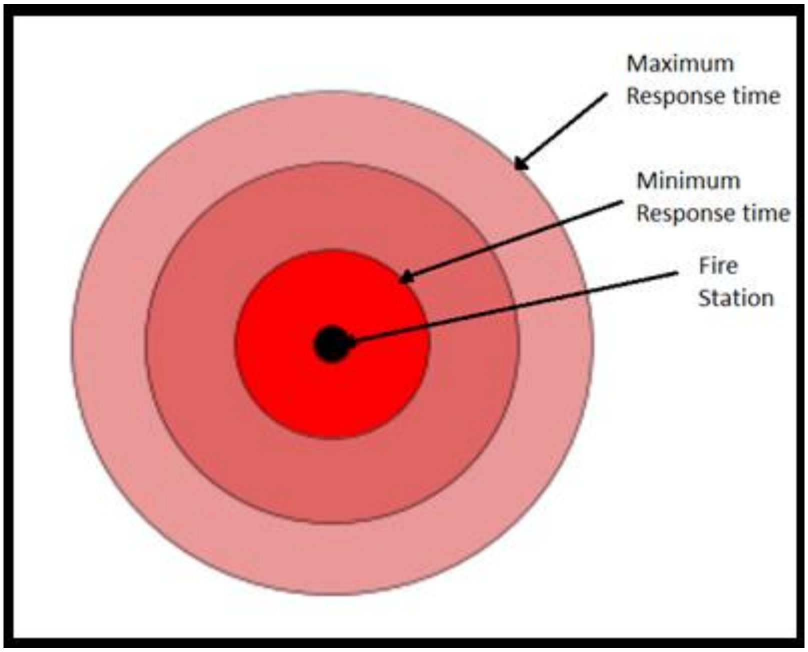


Figure 7: Buffer Zone for Fire Stations

Network analysis is defined as the geographic analysis and modeling of networks such as roads and highways. By analyzing the network and running simulations on the resource distributions inside of it, the network was optimized. This type of analysis required building a network on WUT's campus and the surrounding area that the fire stations serviced. This analysis showed how quickly resources can be distributed amongst different locations on the map. It also automatically planned the best route for accidents and fire stations, providing the most reliable rescue & evacuation routes (WUT). For this project, within the context of network analysis, the roads of the university campus and its surrounding areas served as the network and the firetrucks served as the resources. The way this analysis was carried out was through running simulations from proposed fire station locations to probable incident points that require fire safety. One way to do this was through path planning between 2 points. This simulation runs only between two points to obtain the arrival times from the most optimal fire station to the selected incident point. This method was a good way to understand how long a fire truck should need to arrive at a site. Path planning between two points allows each fire station to define their service range in terms of the maximum estimated time of arrival. The range is defined such that all points that lie within this service area is below tolerance. For example, a fire station might only service an area if it takes less than ten minutes to arrive at the emergency site, otherwise another fire station in the area will be called upon to fight the fire if its estimated time or arrival is shorter than that of the first fire station. This range may not necessarily resemble a circle extending outwards from the fire station, therefore proving that buffer analysis and network analysis must be used in tandem to determine the most accurate range a fire service vehicle travels from each fire station on the map (Wenqi Cui, personal interview, 2019). Figure 8 below is an example of network analysis, showing the location of a medical emergency incident and the pathways from that location to all the surrounding hospitals within a 15-minute driving period.

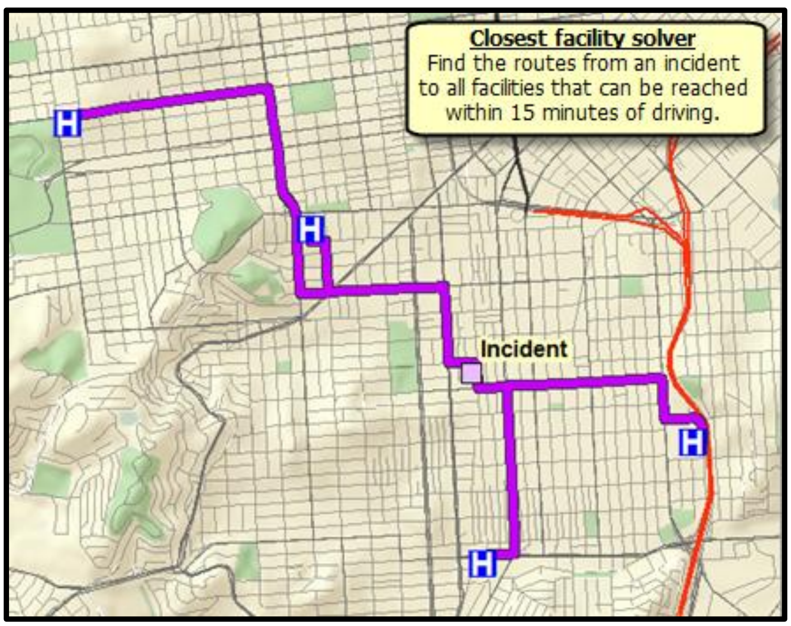


Figure 8: Network Analysis Example[3]

Vectorization is the process through which images are described geometrically to create vector images. This tool proved to be useful when translating geographic images into navigable diagrams describing roadways and walkways. In terms of the project, this data proved useful when paired with network analysis to simulate how fire-fighters approach an emergency. Figure 9 below shows an aerial view of a section of the WUT campus represented by a map of roads and walkways via vectorization.

[3] Rajput, S. (2014, March 12). Closest Facility [Digital image].

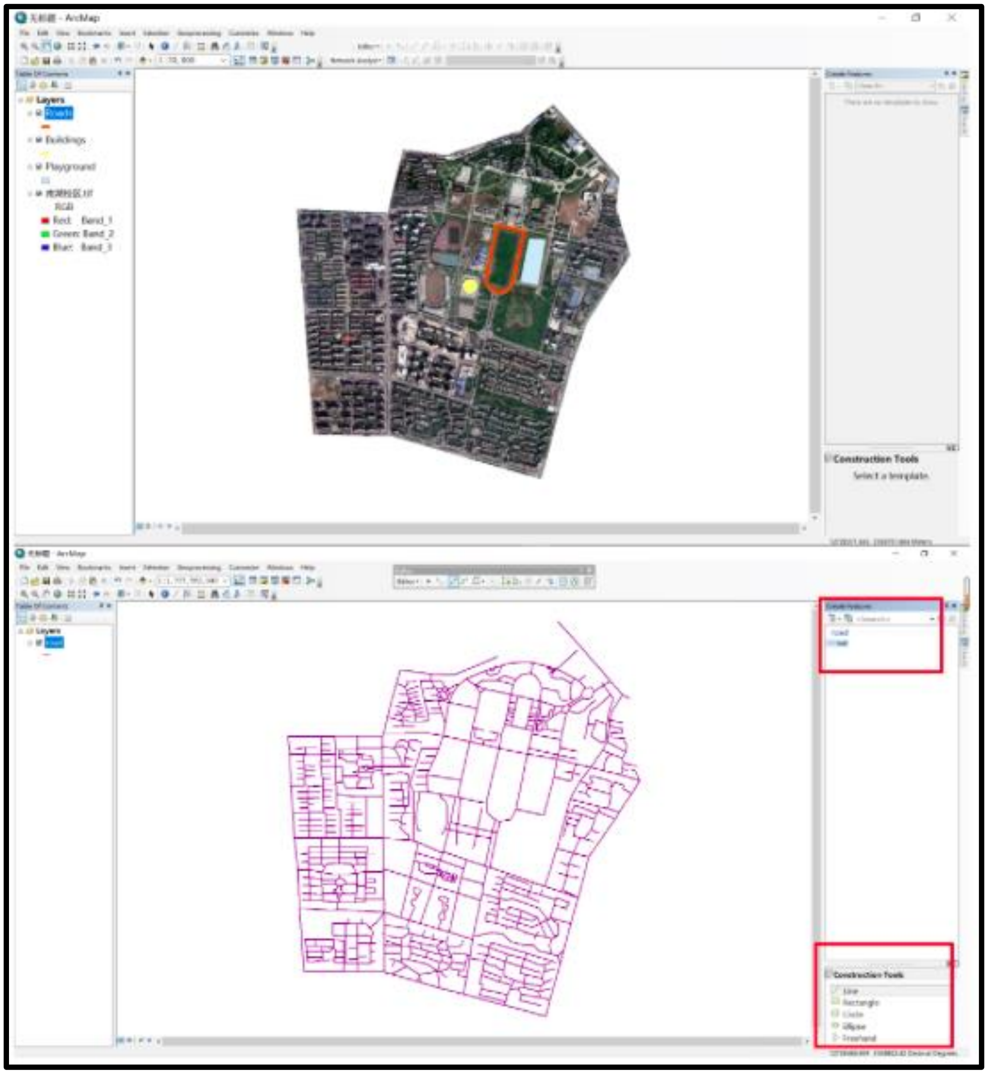


Figure 9: Vectorization Example

3.4 Interviews and Surveys

It was important to find out the opinions of those involved in plans regarding the risk of the current locations of fire stations surrounding WUT. Experts at WUT as well as personnel in charge of fire stations around Wuhan were the main source of these opinions.

Surveys and Interviews are great ways to find out information about people's general perceptions and outlook on a topic. Because this project is being done in a foreign country, it was even more important to gauge the opinions of the people. This study falls under the category of qualitative research; a style of research that utilizes qualitative data to make scientific claims. This research is very popular among psychological and political studies, and greatly helped in filling in the gaps of the quantitative analyses in ArcGIS.

There are three different types of interview formats: structured, semi-structured, and narrative. Structured interviews are like surveys in that they ask consistent questions to every subject and do not probe further after the subject answers the question. Semi-structured interviews have a set of standard questions prepared, but they leave room for further questioning. Narrative interviews are very open-ended and rely on conversation more than anything else to gather information on a topic. The focus is often on the subject, rather than on a study. (Interview Types for Qualitative Research, n.d.)

For this project, it was most effective to interview a few experts. This idea stemmed from the assumption that any information gathered would further justify whether the plan was feasible. The goal was to learn as much as possible about the operation of fire stations in Wuhan. Semi-structured interviews seemed like the best method for gathering such information because they provided the experts with important questions, whilst also allowing for them to elaborate on their thoughts on this project. Furthermore, structured interviews were not necessary because the purpose of the qualitative data in this project was not to compare interviews amongst each other.

As for expert interviews, high ranking officials at one of Wuhan's largest fire stations were questioned. In doing this, relevant information to the project regarding the processes and criteria of fire station selection was obtained. These findings were used to explore a conclusion that satisfied the sponsors the most.

The interviews would not have been enough to analyze a large-scale opinion of how a fire station's staff feels about location planning. For this reason, workers at this fire station were also surveyed using a written questionnaire. The complete survey in both English and Chinese can be found in appendix O and P. Some questions included were related to the following:

- What is the average response time for emergencies here? (这里的紧急情况的平均响应时间是多少?)
- Do you think the location for this fire station is suitable? (你认为这个消防局的位置是否合适？)
- On a scale of 1-10 what would you rate the city's safety based on the current number of fire stations? (根据目前的消防站数量，您可以根据1-10的等级对城市的安全性进行评级？)

After compiling the answers to these questions, it was possible to gain a basic understanding of how Wuhan's fire departments felt about the current standing of site locations and whether they should be changed. Afterwards, a few of these survey participants were asked if they had any other thoughts or points on the subject matter. The resulting conversation was open ended, as to not limit what information came from it. As expected, some roadblocks were encountered. It was not easy to get the firefighters to talk about their opinions as the researchers at WUT had no contacts within the fire department. Additionally, the fire station visited was not located on campus, meaning it did not solely service the WUT students.

3.5 Analyzing the Data

The framework developed revolved around a qualitative risk assessment of the fire station locations based on the surveys and interviews, as well as a quantitative analysis based on the average response time and number of emergencies per year in different areas of Wuhan. An educated conjecture about the current status of fire stations near WUT was developed through the research and ArcGIS simulations performed. Afterwards, to justify the results, expert opinions from interviews and surveys with the fire department were collected. This ensured a cohesive conclusion was created using qualitative and quantitative analyses.

Chapter 4: Findings and Analysis

4.1 Case Study A: Fire Station Visit

On July 18, the IQP team visited a firefighter training facility doubling as a fire station and gathered information regarding fire stations in Wuhan. The team was given a tour of what is known as a Type 1 fire station. A Type 1 fire station has a wide selection of vehicles and equipment and is staffed with the largest number of firefighters. Type 2 fire stations follow in terms of size, number of vehicles, and number of workers. The Type 1 fire station has a maximum service coverage area of $7km^2$. While the Type 2 fire station has a maximum service coverage area of $4km^2$. There is another class of fire station labelled as 'Special Type', which exceeds the capabilities and capacity of Type 1 fire stations depending on the specific needs of the surrounding area (Wei Bing, personal interview, 2019).

The fire station the team visited is about 6-7 stories high, built out of concrete and granite. The land area taken up by the facilities is very large. The fire station contains a track field, a soccer field, a mock high-rise building for training purposes, and the firefighters' dorms. This specific fire station currently houses 45 firefighters. The station is equipped with 14 firetrucks able to handle both fires and chemical hazards, as well as some rovers and some drones each purposed for different scenarios. For example, the rovers can float on water to handle waterborne emergencies. Some rovers can be remote controlled to handle chemical emergencies without compromising the safety of the firefighters.

The visit was hosted by the fire station's captain. The team interviewed him about certain challenges his team often faced while working. Some of the greatest of these challenges are chemical emergencies and dense traffic. Fortunately, any magnitude of an emergency can be handled by his team, due to the rigorous training fire-fighters endure and the variety of equipment available. Situations involving traffic will be discussed later in this case study (Wei Bing, personal interview, 2019).

In most cities, it is known that in any emerging construction, fire stations are erected before any surrounding developments are built. The location and size of each fire station is decided by city planners based on the expected population and usage of the surrounding developments. Regarding city planning for new cities, it is known that all civil and governmental departments such as hospitals, police stations, fire stations and municipal buildings are built before any commercial & residential areas. However, this may be done differently in other areas. The fire station captain confirmed that city planners operate in China under the basis of choosing high-priority buildings first (Wei Bing, personal interview, 2019). Figure 10 shows a picture of residential high-rise buildings under construction as seen from the front view of the fire station, confirming that the fire station was built before the construction of these buildings took place.

Figure 10: Construction Outside the Fire Station

The team had also learned about the execution of handling emergencies. It takes around 45 to 60 seconds for a firefighter to prepare for departure to an emergency. All fire truck drivers know the roads of the city very well and will take the best emergency route they see fit. Many roads in China are divided by a barrier or an island. A vehicle can only reverse its direction by either branching off the road to use an overpass or underpass to get to the other side, or by traveling down the road to the next available U-turn. Fire truck drivers will take the quickest route which minimizes U-turning during travel. Based on the type of emergency, different types of trucks will be dispatched to handle the emergency. However, no matter how trivial an emergency is, there is always at least one truck dispatched. The fire station captain explained trivial emergencies; an example would be having one’s keys stuck in their car or home. In those cases, even if it may seem unnecessary for a firetruck to be dispatched, it is nonetheless dispatched. According to the captain, trivial emergencies happen about 300 times a year. Small threat emergencies such as house fires happen about 35-45 times a year, depending on the season. Greater threat emergencies such as factory fires, chemical mishaps, building fires, mall fires, etc. happen about 2-4 times a year (Wei Bing, personal interview, 2019).

When discussing his experiences and challenges with work, discussion about traffic arose. Rush-hour traffic is a detrimental issue emergency responders face. Especially in China, since overly congested roads leave little to no room for traffic to yield to emergency vehicles. However, the captain informed the team that if high-threat emergencies took place near congested areas, the police will step in and aid in managing traffic-flow. In such cases, the police will clear out the roads by blocking inflowing traffic & by controlling traffic lights to free up the quickest route. Nevertheless, rush hour traffic can add up to 10-15 minutes onto an emergency response (Wei Bing, personal interview, 2019).

The fire station captain thinks that the location of their fire station is satisfactory, since he does not see any issues caused by the location. However, he does admit that handling emergencies is quite easy at the current moment. This is due to the population density of the serviced area being low, since most of the buildings in the area are still under construction (Wei Bing, personal interview, 2019).

In terms of relocating a fire station location, the captain thinks that changing locations for fire stations is very hard and is not feasible in many already-developed areas, since land will need to be purchased and the previous building will need to be demolished. In most cases, these buildings would be at least a few stories tall (Wei Bing, personal interview, 2019). After interviewing the fire station captain, the IQP team invited the captain and his team to answer some survey questions prepared for them. Those results will be analyzed below.

4.2 Survey Results from Fire Station

During the fire station visit, around 20 of the fire station's personnel were surveyed. They were asked a variety of questions about locations of fire stations and traffic behaviors. Figure 11 shows that around 70% of fire safety personnel think their current fire station location is suitable, while the other 30% think the site is satisfactory, but could use some improvements. The firefighters justified the suitability of the location with the centricity of the location within the city and the convenience of entering and exiting the station.

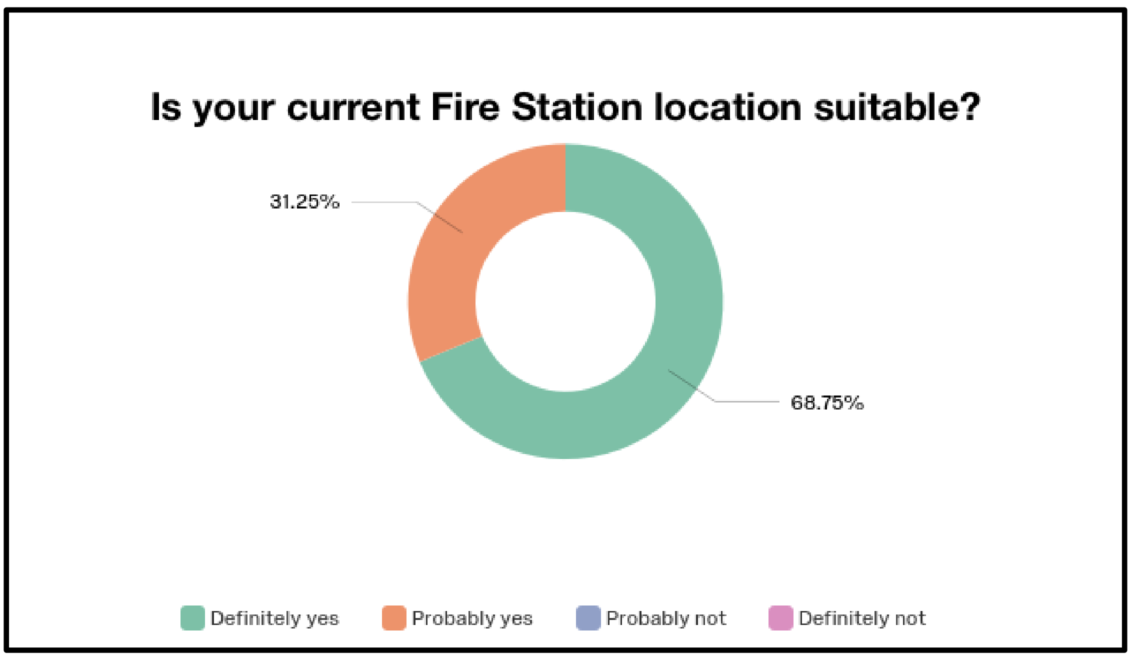


Figure 11: Survey Data Regarding Location Suitability

From figure 12, it was understood that people typically yield to fire trucks. However, the data indicate that cars do not yield as often as pedestrians, possibly due to the heavy congestion on roads. Figure 13 also shows that most emergencies happen at factories, malls, and hotels, which account for around 90% of all emergencies. This information was used in the GIS analyses in order to pick some locations of possible emergencies. These locations were used to perform buffer analysis and network analysis.

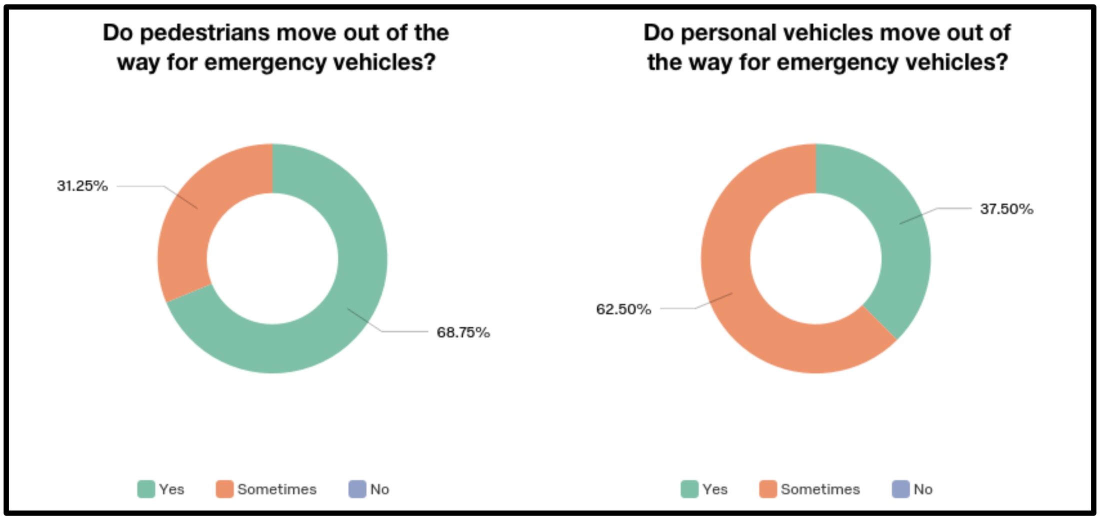


Figure 12: Survey Data Regarding Traffic Behaviors

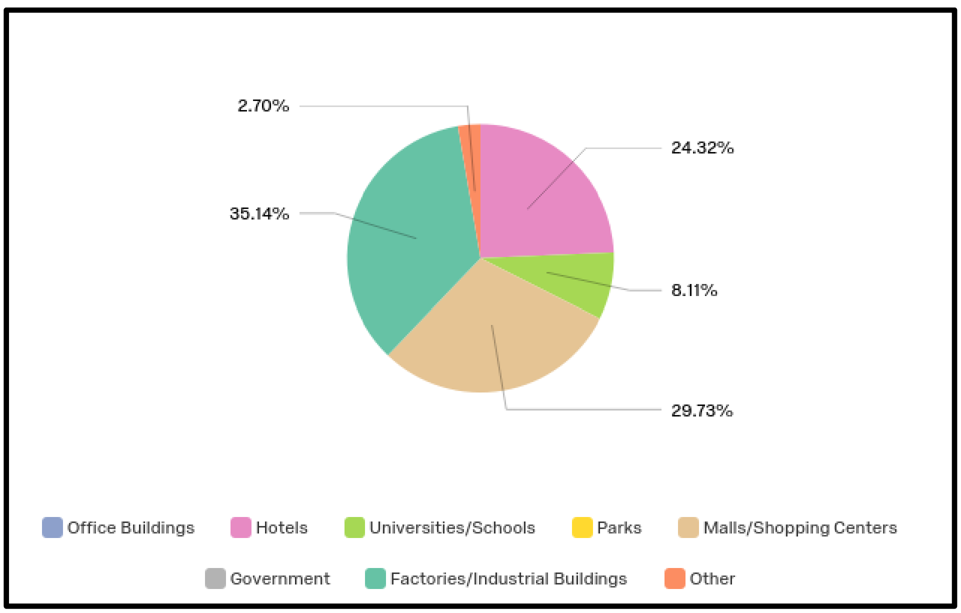


Figure 13: Survey Data Regarding Common Incident Locations

4.3 ArcGIS: Vectorization of Roads and Buildings

Recalling the strategy to evaluate the performance of the current locations of two Fire Stations in Wuhan, a network of roads and buildings using the vectorization feature was created in ArcGIS Pro to analyze emergency scenarios. This network used the vector image derived from the aerial photo. The image outlines all major roads and buildings within the scope of the university campus that the project is focusing on. Each of these roadways and buildings were outlined one by one using care and consideration, as an inaccurate map would lead to false conclusions upon analysis of the network. Baidu Maps, a popular mobile navigation application amongst the people of China was used to remedy situations where the satellite photo was unclear. Baidu Maps obtains much of its data through its users, so it is a useful aid in determining roadways and buildings surrounded by haze or foliage. Figure 14 shows a screenshot of the WUT campus and its surrounding are in Baidu Maps.

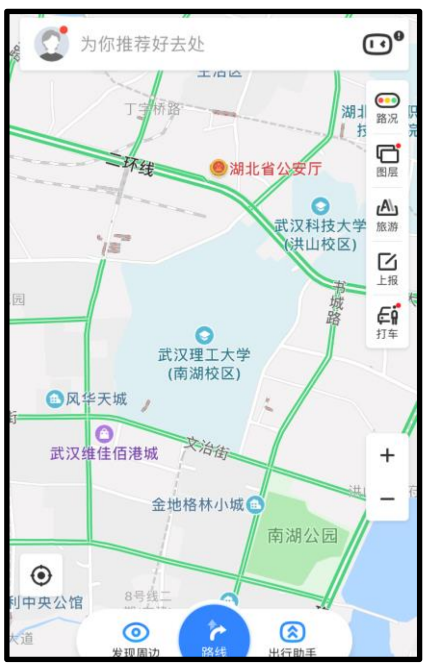


Figure 14: Baidu Maps Screenshot

Figure 15 shows the complete vectorized image. The vectorized buildings were created using the polygon feature under 'Create Features' in ArcGIS and can be seen in light blue. The vectorized roads were created using the polyline feature and can be seen in dark blue.

Figure 15: Complete Vectorization

Great detail that was taken into account during vectorization. Each building was outlined with the polygon tool by hand to showcase the building's base area in order to later calculate the area most accurately. Each road was also outlined with the polyline tool by hand and each line represents a route, which a service vehicle would be able to travel on. Since the road infrastructure in Chinese cities is different from that of most of America, observations from traveling around Wuhan were used to make educated guesses about the road structure and the flow of traffic on those roads. In real life, service vehicles can travel down one-way roads in both directions, which eliminated the need to assign any direction to the polyline, therefore only one line was drawn. On two-way roads that have dividers or islands to separate either side, two lines had to be drawn. On such roads, in a real-life scenario, a vehicle must either exit the main road and use a bridge or make a U-turn at the nearest intersection in order to reach a building on the opposite side of the road. Looking around Wuhan, it was found that many roads in China have these dividers to account for the large traffic flow. When traveling by car, one may have to take multiple U-turns on multiple different streets in order to start travelling on the direction towards their destination. Therefore, to be safe, almost every intersection on the map was vectorized like that of Figure 16. In this figure, each road branching from the intersection was equipped with the ability for a vehicle to U-turn as well as the ability to turn onto any other adjacent streets. A yellow divider can be seen splitting the northernmost road, and a barricade of trees can be seen splitting the southernmost road. Roads to the east and west might not have a divider or barricade, but the quality of the image was too low to make an accurate assumption. In these cases, a U-turn was also added as an extra precaution.

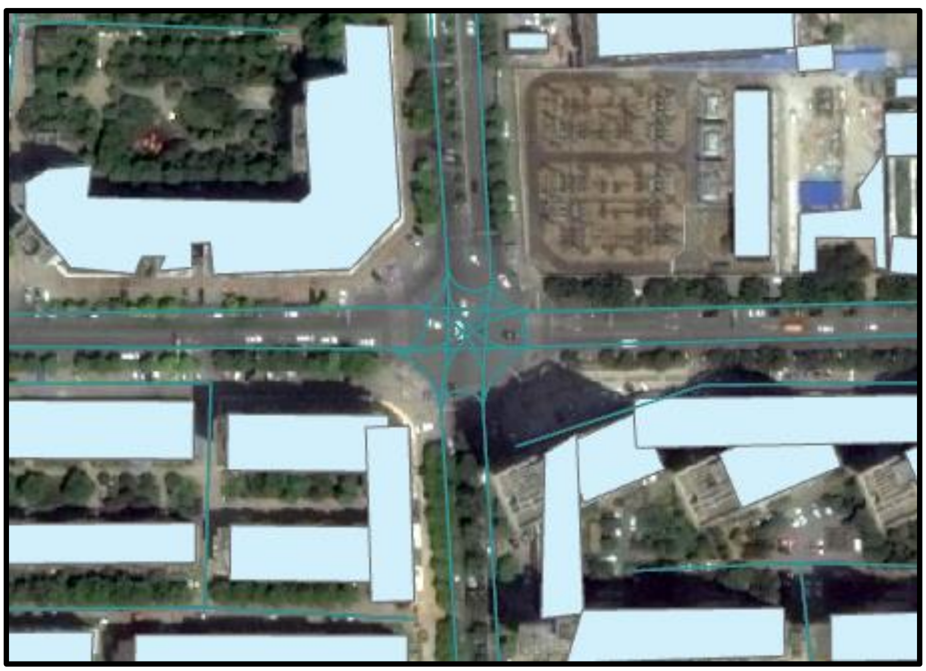


Figure 16: Vectorized Intersection Close-up

The vectorization of buildings was done before the vectorization of roads. Although building placement and area are not necessary for the completion of buffer and network analysis, the appearance of buildings aided immensely during the road vectorization process as it was easier to tell where a road was leading to if the buildings surrounding it were outlined. After vectorization was completed, attributes had to be assigned to different types of buildings and roadways in an attribution table. Attributes were given to the polylines and polygons to differentiate factors such as distance, area, and time. Calculations were done automatically by ArcGIS Pro based on the scale of the coordinate system of the inputted image. Appendices A, B, C, D, E & F show a step by step guide of the vectorization and attribution process.

4.4 ArcGIS: Buffer Analysis, Network Analysis, and Impedance

After vectorizing the image and assigning attributes to each building and road, the locations of the fire stations were labelled. Using Baidu Maps, it was possible to locate two existing fire station locations within the range of the image: Fire Station A and Fire Station B. Fire Station A is located on the western border of the image while Fire Station B is located on the southern border. Upon discussion with the sponsor and GIS master's students, it was concluded that Fire Station B was bigger and better equipped than Fire Station A. Neither fire station was as big as the fire station that the team visited to conduct the interviews and surveys. However, because Fire Station A was visibly smaller than Fire Station B, and there are only two types of fire stations, Fire Station B must have been a Type 1 fire station, just like the one visited, and Fire Station A must have been a Type 2 fire station. By searching on the internet search engine Baidu, it was understood that the range of a Type 2 Fire Station is 4 km2 and that of a Type 1 Fire Station is 7 km2. In order to perform buffer analysis, the buffer zone radii of both fire stations were found using the equation:

$$Area = \pi * radius^2$$

$$Hence, \qquad Radius = \sqrt{\frac{Area}{\pi}}$$

The radius of Fire Station A was found to be 1130m and the radius of Fire Station B was found to be 1500m. After applying the two buffer zones to the two fire stations respectively, the following image was created. The process of obtaining these buffer zones is shown in appendix G. Figure

17 shows the outcome of the buffer analysis. Note that the vectorized roads are highlighted in green so they are easier to see.

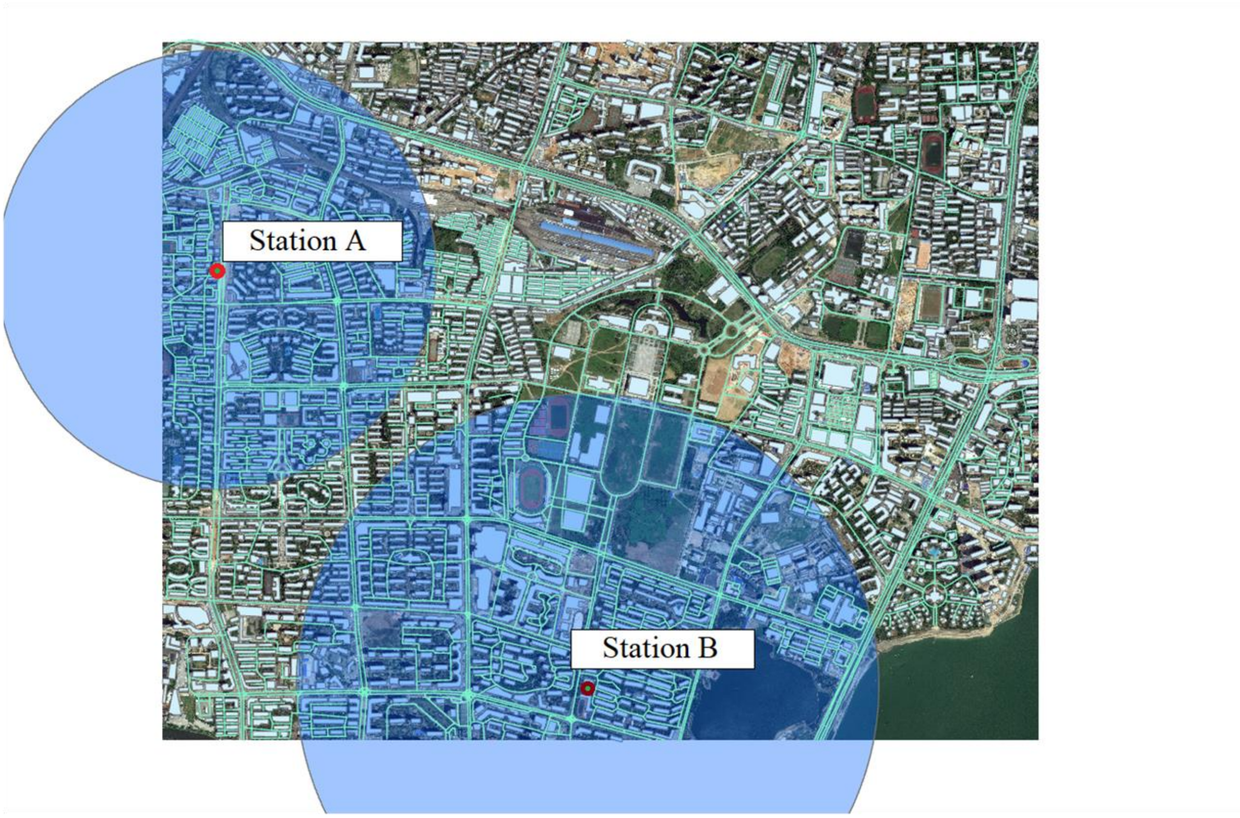


Figure 17: Buffer Analysis

It was made clear from the buffer analysis result that the service ranges of both fire stations together did not cover the whole area of the map. Parts of the WUT campus focused on by this project were not covered under the buffer zones.

In order to perform network analysis, impedance data must be inputted into the attribute table. Impedances are required for different optimization scenarios in the analysis. From each fire station point, the most optimal route to an incident point can be determined in different ways. In this case, network analysis was performed based on two different optimization scenarios: shortest distance to the incident point and shortest time to the incident point. For the distance-optimized scenario, ArcGIS summed and minimized the lengths of roads on the map towards the incident points. The lengths of the roads were previously calculated during the vectorization process. For the time-optimized scenario, the average speeds of vehicles traveling on each road were input into the attribute table for roads. This speed data was provided by the sponsors, who obtained it from Baidu maps. Once the average speeds were obtained and assigned to each road on the map, ArcGIS was able to calculate how much time it would take to get from a fire station to an incident point. No data relating to traffic light wait time was needed. This is because unlike normal vehicles, fire service vehicles will run through intersections no matter what the traffic lights dictate. In many cases, the city's police will control the traffic lights to allow fire service vehicles to pass without interruption or delay from other vehicles along the determined service route. A step by step process of how average speed data was inputted into ArcGIS can be found in appendices F, K & L.

From there, network analysis can begin. 40 evenly spaced incident points were chosen on the map and both fire station locations were included in the analysis. This means that for analyzing one incident point, both fire station locations will be included in the analysis and whichever location produces the most optimal route for the selected impedance will be chosen as the route's starting point. Out of the 40 routes analyzed by shortest distance; 15 routes originated from Fire Station A while 25 routes originated from Fire Station B. With time-optimized scenarios, 14 routes originated from Fire Station A while 26 routes originated from Fire Station B. This means that out of all the incident points on the map, only one point within the northeast section would be better serviced by Fire Station B based on the time-optimized scenario but is better serviced by Fire Station A based on the distance-optimized scenario. All other incident points were found to be optimally serviced by the same fire station based on time and distance constraints. However, these analyses do not consider the previously determined buffer zones. Out of the 40 incident points, only 9 incident points were within Fire Station A's range and only 13 incident points were within Fire Station B's range. This leaves 5 points unreachable within the southwest section of the map and 13 points unreachable within the northeast/middle section of the map. Appendices I, J, K & L show the steps of work leading to this conclusion.

4.5 Scenario Analysis

Based on the findings, five different scenarios were analyzed which urban planners can execute in order to maximize the coverage of fire service area for WUT and its surrounding areas. All scenarios were simulated in ArcGIS Pro and all scenarios take both the quantitative GIS analyses and the qualitative interview and survey data into consideration. The yellow dots represent a fire station's location. The purple squares represent a possible incident point.

Scenario 1: Change Nothing About the Current Situation

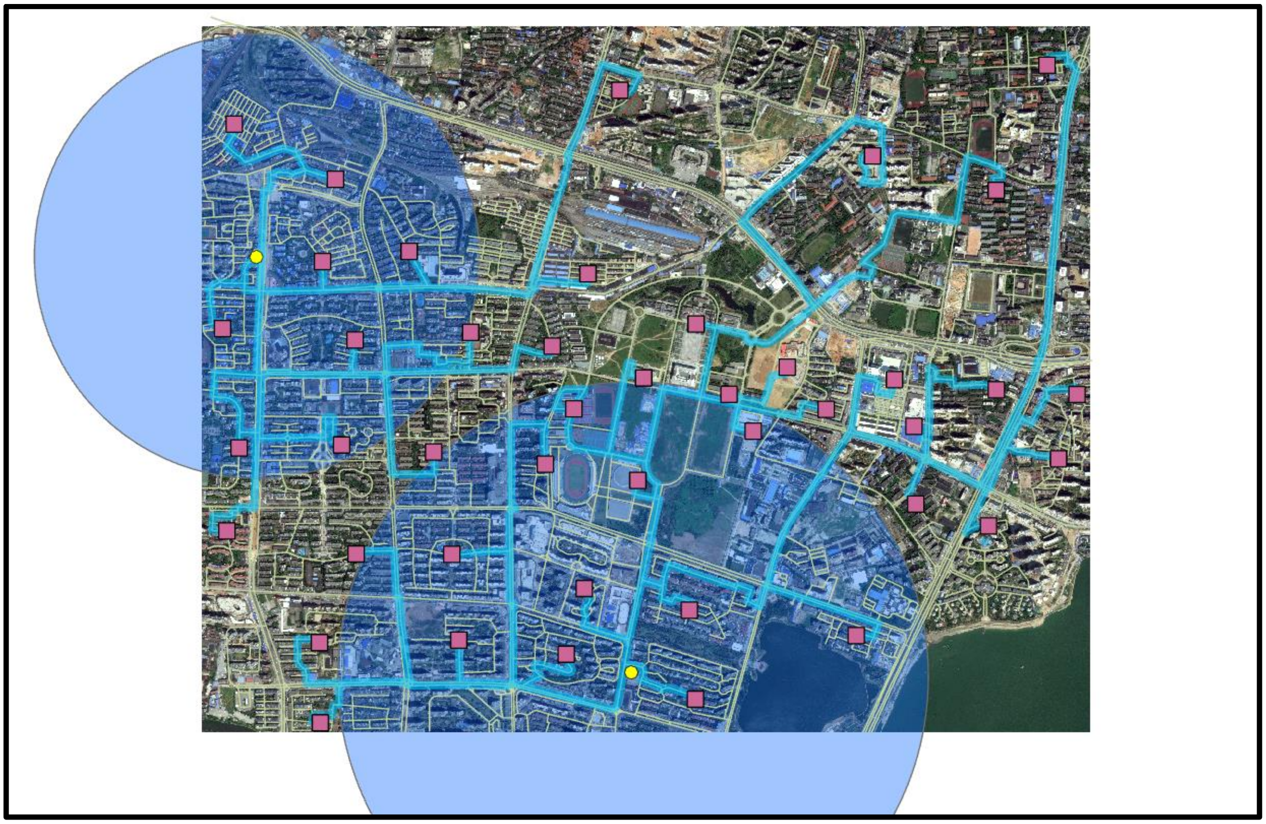


Figure 18: Picture of the Current Fire Station Layout

It is completely appropriate for a city planner to take no action. It is possible that the current fire station layout nearby the WUT campus is capable of handling emergencies in their respective areas. Fire station A's current location is not directly next to a main road, and thus firetrucks need to take an arterial road south towards the main road before making their way towards their destination. However, this may have changed since the main road construction has been completed, since this satellite image is a 2016 Google image, meaning that fire station A, as of today, may have direct access to the main road. No investment is required in this scenario because no changes to the infrastructure will be made.

Scenario 2: Relocate One or Both Fire Stations

Scenario 2.1: Relocate Fire Station A

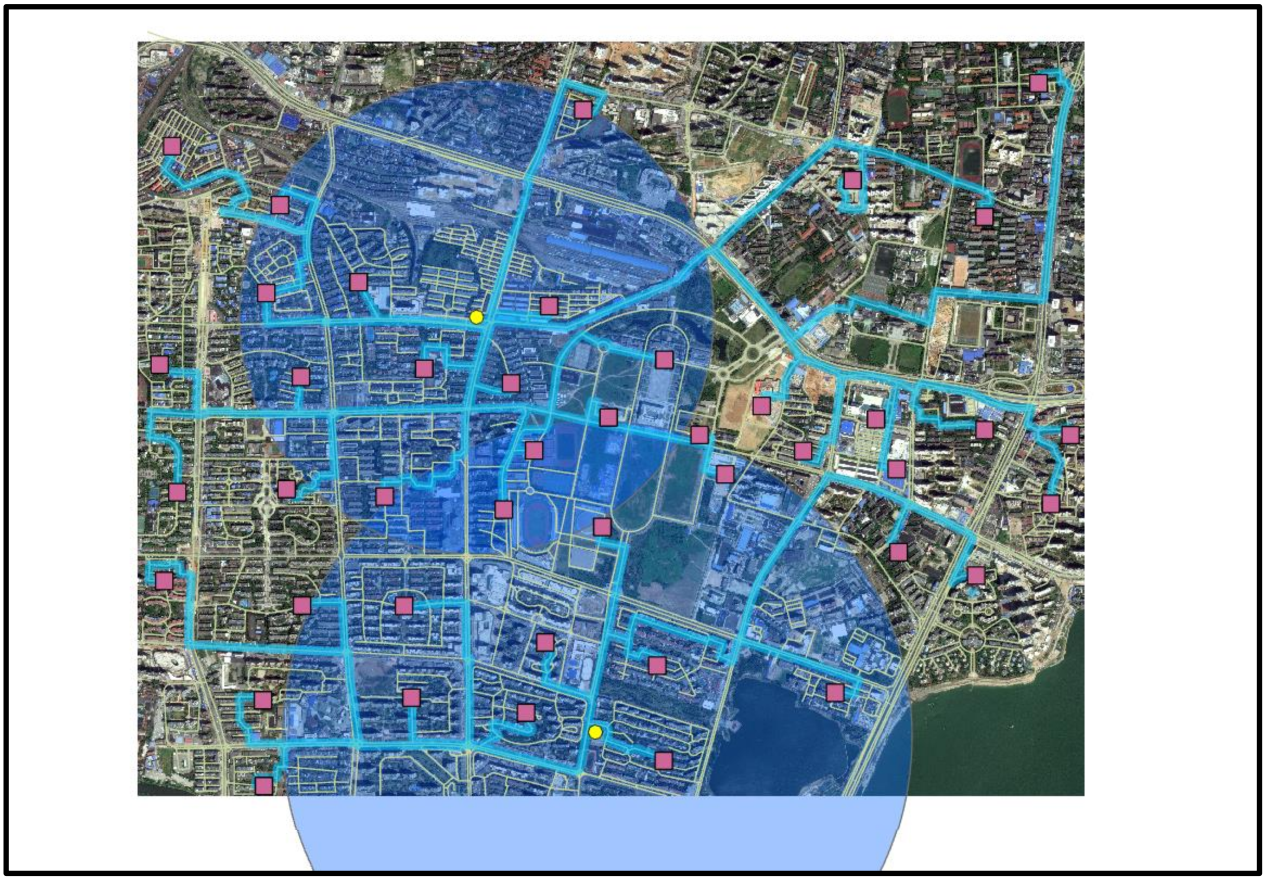


Figure 19: Station A's New Location Scenario

It could be beneficial for Fire Station A to be moved onto a main road because its old location did not meet this criterion, nor did its range cover the northern part of the WUT campus. Thus, in the above image, it has been moved slightly eastwards from its old location. It is also beneficial for fire station A to be near an intersection despite higher traffic densities at intersections, since this strategic location enables a fire station with a small service area to take less detours before approaching their destination. Thus, decreasing the arrival times to incident points. However, relocation requires two processes, demolition and construction. Thus, it is a higher cost. The costs of construction include the costs for purchasing land, contractor fees, permit fees etc. This scenario would also decrease the total service area of both fire stations on the map, since the service area of Stations A and B will overlap. An urban planner would be hesitant to move the location of Station A more northward because the next closest intersection to the north would be too far from the WUT campus and would be located too close to the railway yard which is not an area that exhibits a need for fire protection often.

Scenario 2.2: Relocate Fire Station B

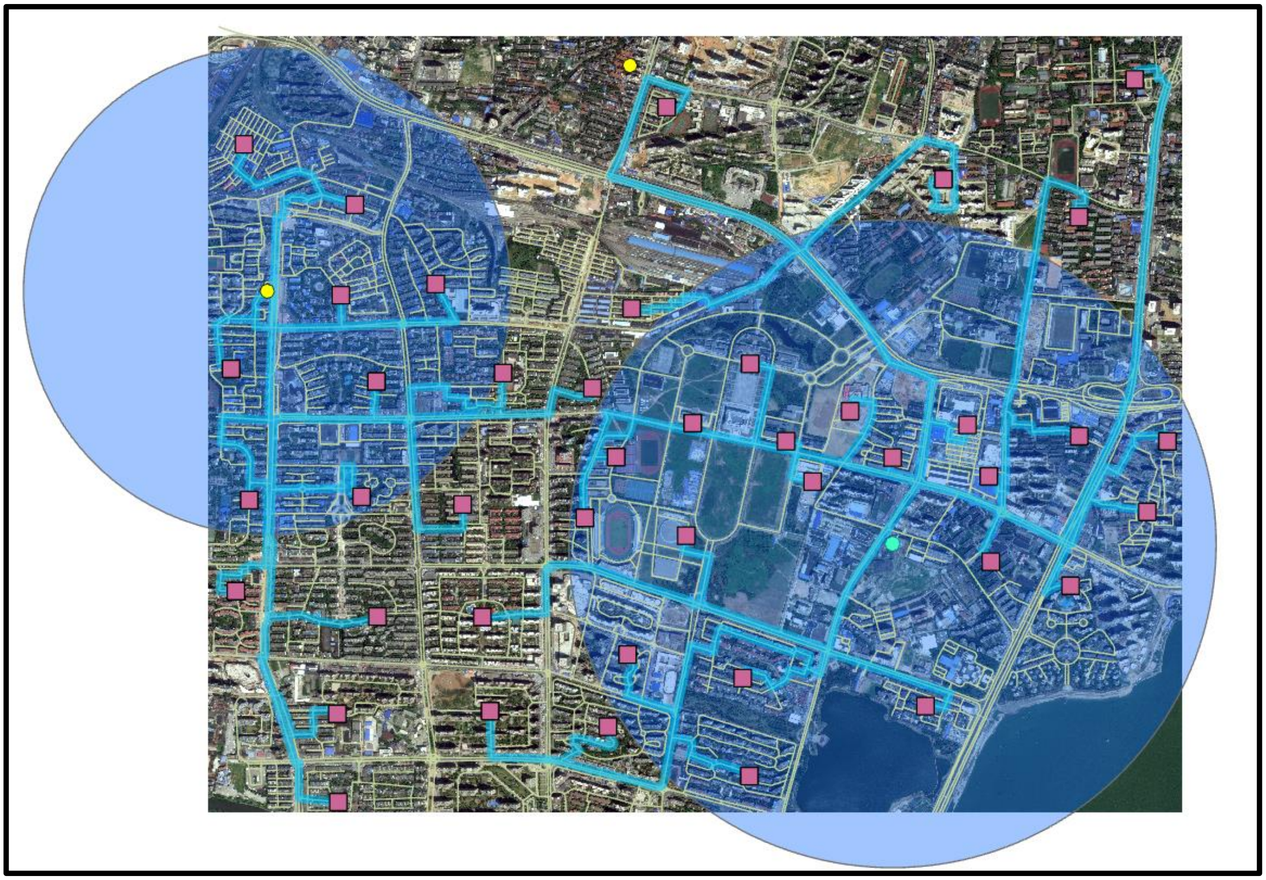


Figure 20: Station B's New Location Scenario

Fire station B's new location is currently satisfactory. Its new location has been moved slightly Northeast to service the majority of the WUT campus. Although not located directly next to a four-way intersection, the station is on a main road and has better access to the highway to its east. The new location also covers more land area and less water area than the old location, ultimately servicing more buildings. This scenario would be very expensive to execute because the city will have to spend money on demolition costs, building costs and labor for slight changes from the original location. There is little return on investment.

Scenario 2.3: Relocate Both Fire Stations

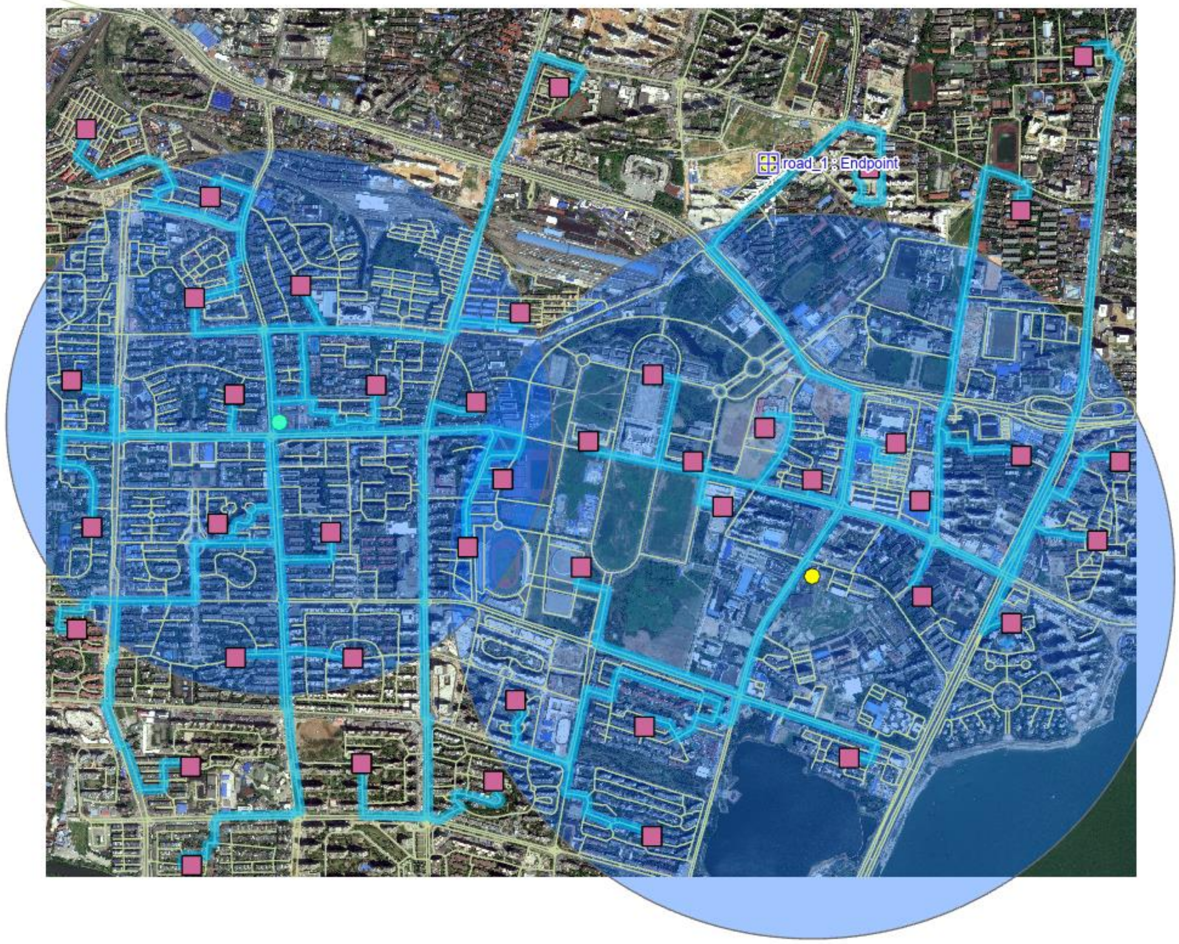


Figure 21: Both Stations' New Location Scenario

This scenario provides the best coverage for the map under the constraint of relocation only. The WUT campus is fully serviced by a combination of both fire stations with little overlap between the two service ranges. However, this is not feasible, since there is little return on investment moving two buildings slightly away from their original positions. It is important to understand that this is the ideal scenario for protecting the WUT campus and some of the surrounding areas but does not account for the residential areas outside of this satellite image. This problem applies to all scenarios relating to moving fire stations, not just this scenario. This is a biased outlook because this project only focuses on the WUT campus and the immediate areas surrounding it. In the real world, if fire stations were to be relocated, urban planners must take into consideration all other stakeholders' needs. In addition to schools and universities, real world stakeholders include residents, travelers, business owners, police departments, taxpayers, and many others. Depending on the priorities of the city, stakeholder importance can be weighted differently and it might not be fair to relocate a fire station closer to a university when there could be a hospital or a thickly settled residential area just outside the borders of the map that was not taken into account. Relocation of two fire stations would also be the most expensive scenario for a city due to demolition and building costs.

Scenario 3: Add a New Fire Station

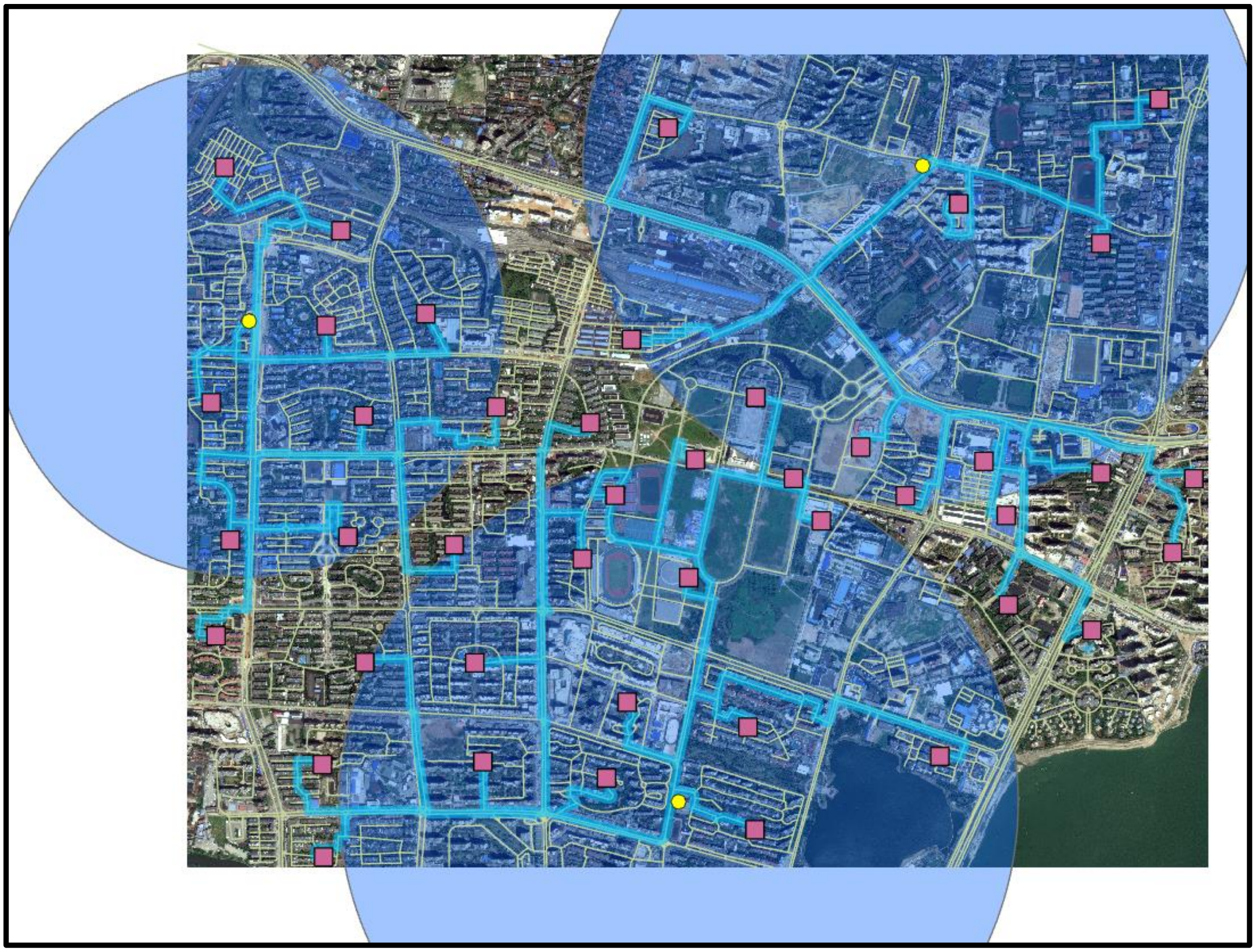


Figure 22: New Fire Station Scenario

It is clear from scenario 2 that it is not feasible to relocate a fire station. On the other hand, it is much more reasonable to build another station. Building a third fire station on the map would still be costly due to construction and labor costs, but there will be no demolition fees. It would also increase the capability of the current fire station layout since the service area coverage would significantly increase with no overlap. If this scenario were executed, as of 2016, the fire station will be put next to a four-way intersection on an empty plot of land in the northeast section of the map. Almost the entirety of the WUT campus would be serviced and a total of 29 incident points would be covered under the three buffer zones. The new fire station would be a Type 1 fire station, meaning it has a total service area coverage of 7km2 and a service radius of 1500m. Choosing a Type 2 fire station would not have been able to cover the entirety of the

WUT campus. It is beneficial for newly built fire stations to be of the Type 1 fire station in order to avoid future costs and downtime from renovations and expansions.

Scenario 4: Increase the Type level of Fire Station A

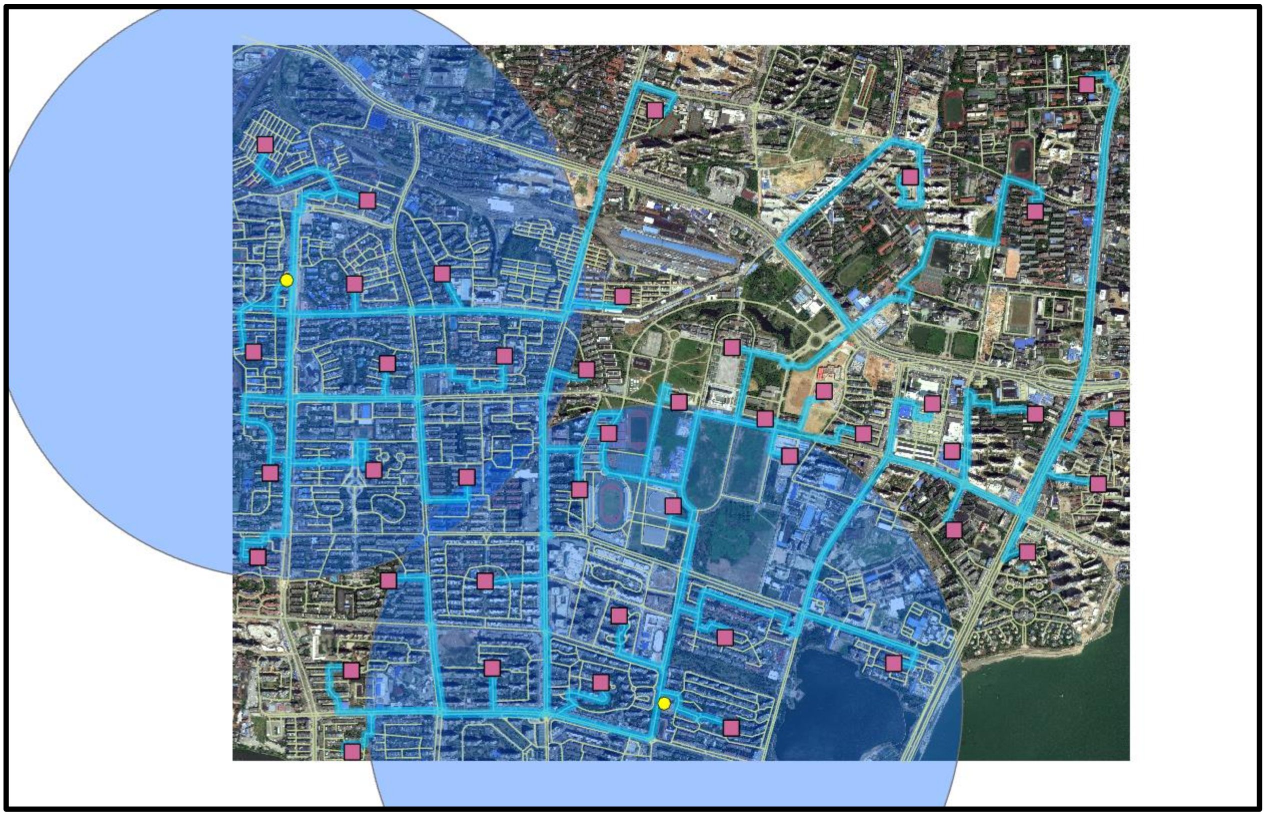


Figure 23: Upgrading Station A Scenario

It is possible to increase spending in a specific fire station to improve the capability of a station. In this scenario, Fire Station A would upgrade from a Type 2 to a Type 1 fire station. However, the likelihood of finding chances to improve is low. For example, if a fire station would undergo an expansion, the neighboring land will first have to be purchased. The chances of the neighboring land to be available for this scenario is low. There are workarounds though, floors could be added to house more firefighters to achieve expansion, extra rooms on the ground floor can be renovated to become garages for additional fire trucks. However, it is quite difficult to gauge how easy these changes can be made in the real world. Further questioning regarding renovations and expansions of fire stations should be made in future IQPs. In this scenario, Fire

Station A's range still does not reach the WUT campus and therefore re-typing Station A at its current location would be redundant.

Scenario 5: Increase Type Level of Fire Station A & Add a New Fire Station

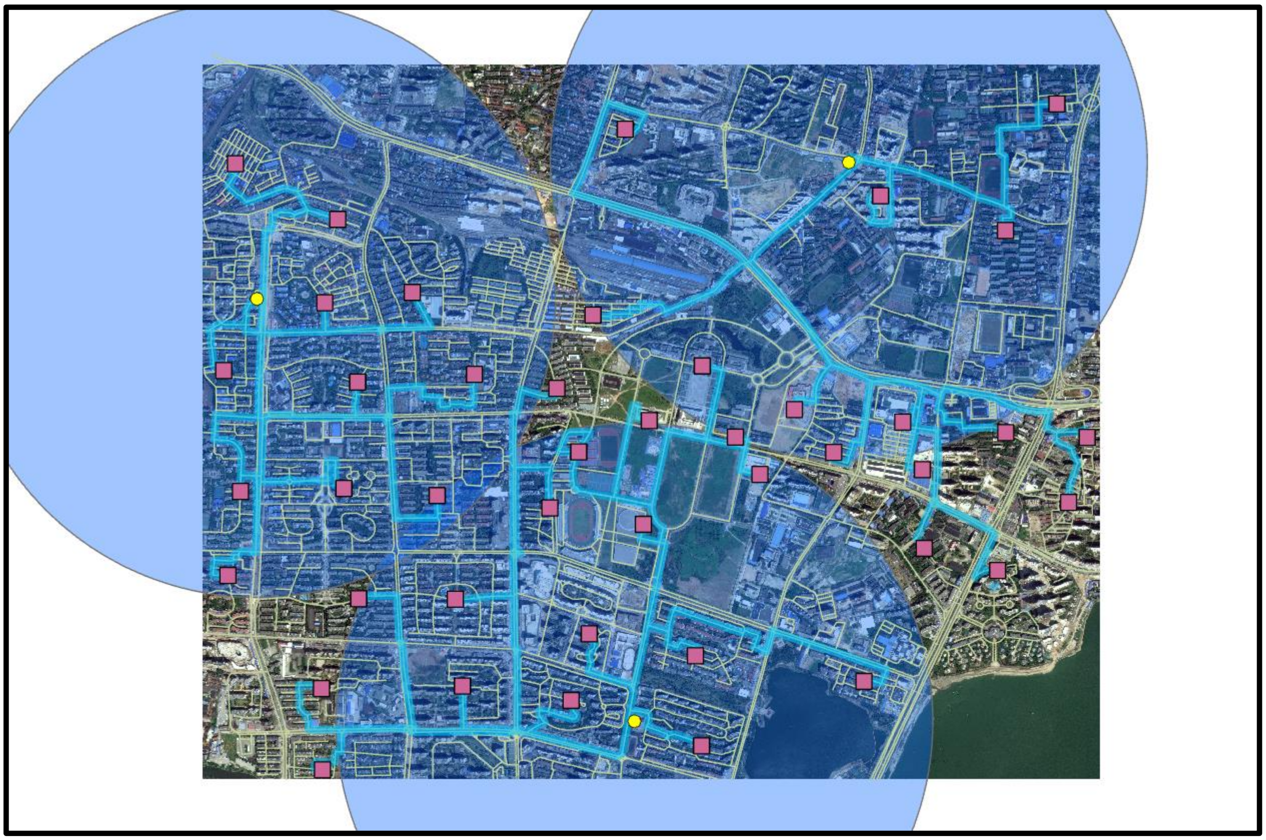


Figure 24: Upgraded Station A & New Station Scenario

This is the idealistic case that provides the maximum amount of fire service coverage using two methods deemed cheaper than relocation: adding a new fire station and re-typing Fire Station A. In this scenario, all three fire stations would be Type 1 fire stations and most of this satellite map would be serviced. Out of the 40 incident points, 33 would fall within the fire stations' buffer zones. This option is the second most expensive option due to the building, construction labor costs. This scenario also employs the highest number of firefighters and therefore their salaries must be factored into the cost as well.

4.6 Analysis Constraints

Note that a sixth scenario is also possible: increasing the type level of Fire Station A, relocating one or both fire stations, and adding a new fire station all simultaneously. The reason this scenario is not listed with the other possible scenarios is because it is unnecessarily complex. Upon the GIS analyses, any combination of simultaneously relocating, re-typing, or adding of fire stations can produce a fire service area just as effective as one of the previously listed scenarios. All scenarios listed consider the information regarding fire station site selection obtained by the interviews and surveys. One important consideration is the cost of relocating, re-typing, and adding a fire station. Even if the most optimal service range can be configured by using a combination of these three techniques, an almost identical scenario can be replicated for a fraction of the cost by only using a combination of two techniques.

It should also be noted that not every combination of two techniques is feasible. It is possible to increase type level of one of both fire stations and add a new fire station, but it is not possible to relocate one or both fire stations while also re-typing either of those fire stations. It is also not possible to relocate one or both fire stations while also adding a third fire station. This is because the demolition and building costs of relocating a fire station can be greater than that of adding a new fire station and staffing said fire station. Therefore, there is no need to relocate one or both fire stations while also re-typing either of those fire stations, nor is there a need to relocate a fire station while also adding a new fire station, because the relocation money spent on building and staffing could more effectively be used to build and staff an entirely new station that will ultimately create a larger overall service area.

4.7 Framework for Future Site Selection

Recalling the introduction and background, the project intended on building a framework for optimizing fire station locations by using the two fire stations near WUT's campus as a practical case study. Using the research and literature regarding the placement and operation of fire stations, as well as some general information about the culture, infrastructure, and geography of

Wuhan, a plan was devised with the sponsors. This plan can serve as a model for selecting the sites for fire stations in the future, as well as evaluate the viability of current sites. The method used two separate approaches to assess a site based on multiple criteria such as: traffic density, population density, opinions of local fire-fighters, geography, infrastructure, and available resources at current sites. The assessment was achieved through interviews and surveys from experts, as well as analyses and simulations in ArcGIS.

For the ArcGIS analyses, vectorization, buffer analysis, and network analysis were used to simulate responses to emergencies in Wuhan. Recalling Figure 6 in the Methodology section, each of these steps had a very important role in the data analysis. Vectorization created a vector image of roadways and buildings that, when combined with attributes, was used to create a time impedance for the network analysis.

This analysis utilized factors such as the lengths of the roads as well as the speed of traffic. With these two metrics combined, the time it took to get to a location on the map was measured. From this point, potential emergency locations were assigned to important buildings and residential areas. The network analysis showed the team how long it took to get to these locations. Based on this information, it was possible to see how efficient fire stations were responding to emergencies in the area.

However, one more point of view was required to analyze the range of a fire station to assess the current situation even more accurately. According to government regulations, each fire station type has a specific radius that each fire station should oversee. In order to replicate this, buffer zones were assigned to each fire station.

The results showed that the current locations of the two fire stations on the map did not entirely insure the WUT campus. Therefore, some changes had to be made in order to properly support the school.

To decide the best course of action, the team designed a few scenarios regarding possible solutions to the problem. Five different tests were performed, each yielding a different result. These tests can be described by the following: taking no action; relocating the first, second, or both stations; adding a new station; increasing the level of the first station; and increasing the level of the first station while also adding a new station. The results showed a few viable options simply in terms of theory, but not necessarily in practicality. For that, information needed to be borrowed from the qualitative data collection.

In scheduling the interviews and surveys, it was decided that the best candidates would be firefighters at a nearby fire station in Wuhan. With the help of WUT's Dean of Safety Engineering, a trip was scheduled to a fire station near the campus. Upon visiting the station, it was possible to interview the captain, as well as survey all the available firefighters. The fire-fighters overwhelmingly believed the location of the station was appropriate and efficient. In addition, the fire captain mentioned that the fire station locations in Wuhan are, as far as he knew, well placed. The survey and interview and data also supported the assumption that relocating a fire station is not feasible. It required demolition, construction, and stress on management to relocate and repurpose all the workers and equipment. To have built a new fire station is also rather taxing, because it would have required construction and equipment. However, the fire captain mentioned that there were more than enough firefighters to fill vacant spots in a new building. Upgrading an existing fire station was even more feasible because it would have required less effort and investment than building a new one. However, it is rare for such opportunities to occur, especially in a densely populated environment.

By following the method described above, a successful completion of fire station site selection is warranted.

Chapter 5: Recommendations and Conclusion

5.1 Conclusion

After following through with our analysis and after our framework for general site selection was created, we concluded that increasing the type level of Fire Station A did not increase the radius enough to reach the campus. We are now left with two options; a decision between them is entirely dependent on the ability of Wuhan's municipality to meet the needs of WUT. These choices are:

To proceed with scenario 1: Take no action.

To proceed with scenario 3: Build an entirely new fire station in the location we have proposed in our findings and analysis section. The new location completely encompasses the campus and would provide excellent response time. However, it there will be construction and staffing costs.

We leave this information with our sponsors and with the fire department so that they may choose what they feel is the best course of action. We hope our methodology for analyzing fire station sites can be applied to Wuhan and all cities in China. China is rapidly developing and as a result, many city planners will run into problems like this in the future. Our framework can not only aid them in evaluating the viability of current sites, but also help them to plan where to build new sites as well. We hope that this framework will be shared by WUT with anyone in need of it.

5.2 Recommendations

We recommend using a more sophisticated method of fire station site selection for next time. Many location selections such as ours are done by simple analysis and require only rudimentary calculations and data gathered from interviews. We propose a method that makes use of statistical tools in ArcGIS as a precursor to the GIS analyses that we performed. We would have liked to take advantage of the GIS's capability to handle both spatial and non-spatial data by creating an attractiveness matrix for different areas on our image in order to perform a "closeness analysis" (Gokgoz 2012). Originally, we performed network and buffer analysis on our image's existing fire stations, then picked random points on the map to analyze and contrast the feasibility between them. Instead, we would have liked to use GIS's spatial and network analysis to find attractiveness values of grids and therefore find a coverage table of alternative locations for fire stations. In short, we would have utilized GIS's capabilities to find potential locations rather than guessing locations by ourselves, eliminating human error. From there we could use the data gathered from interviews and surveys to choose the best fire station location based on the needs and wants of the firefighters. This can be done by first using ArcGIS's geodatabases to load hospitals, educational buildings, cultural facilities and shopping malls (places most in need of fire protection) as well as main and arterial roads. This saves time and eliminates human error since we would not have to manually vectorize every building and every road. It would eliminate the need for any aerial image and thus eliminate boundary restrictions caused by the image. Next we would determine the speed rates of the roads. Estimated speed rates (30, 40, 50, 60 km/h) can be assigned to major roads, arterial roads and residential streets separately. This would allow us to learn where a vehicle is able to reach in required travel time by using network edges and junctions in network analysis. A model should be created in the Model Builder of ArcGIS. This is an application which creates, edits and manages models for the hospitals, educational buildings, cultural facilities and shopping malls as well as soil types. Each of these areas would be given attractiveness values between 0 and 10 with higher values being more suitable. Soil type values can be determined according to the capacity of the soil for construction pressure. Other values may follow a percentage of influence, such as: distance to hospitals-30%, educational buildings-25%, distance to cultural facilities-25%, distance to shopping malls-10%, soil types-10%. We recommend all areas be composed of cells with different percentages of influence overlaying each cell in order to compose the attractiveness matrix. The chosen cell size is recommended to be between 120 meters and 200 meters depending on the constraints and special needs of the city.

The following are our recommendations for future continuous research into this topic:

1. The vectorization of the aerial image should ignore one-way restrictions. This means that instead of building U-turns into the end of each road like how vehicles would normally travel in real life, the vectorized road acts as a normal two-way road without a divider. In the literature, A GIS Approach to Fire Station Location Selection (Gokgoz 2012), we noticed that this study also ignored one-way restrictions. The reason for this was not specified. However, when we performed network analysis, we noticed that all routes from a fire station to an incident point did not include U-turns, meaning that in every case, the route devoid of U-turns was the better route in terms of both time and distance optimization. Furthermore, when interviewing the fire station chief, we learned that the drivers of firetrucks will take routes to an incident point by using the least number of U-turns possible in order to save time.

2. A bigger aerial image that encompasses more of the surrounding area of WUT's campus and encompasses more existing fire stations should be used. This is because our current aerial image only encompasses two fire stations whose service area ranges extend beyond the limits of the image. A bigger area would give the researcher a broader understanding of the consequences of relocating and enlarging fire stations.

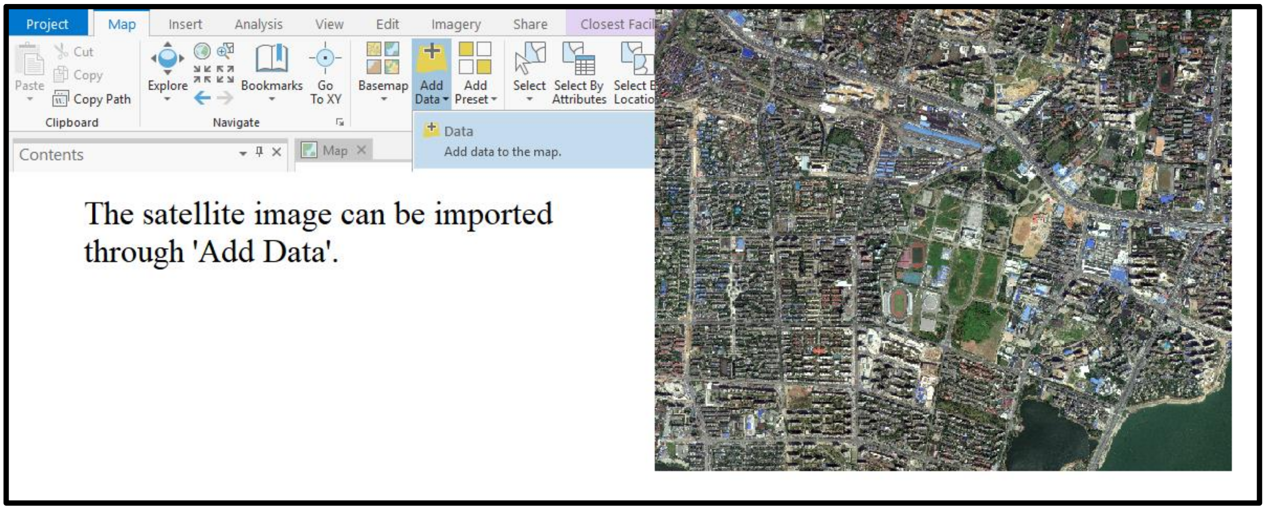
3. More experts should be interviewed in order to get a broader opinion of fire station site selection. We would have liked to interview some professors of urban planning and safety engineering. However, because this IQP is during the summer, they were all on vacation. We would ask them about the feasibility of our project scenarios and any

insight they could give us about urban planning, especially the planning of municipalities.

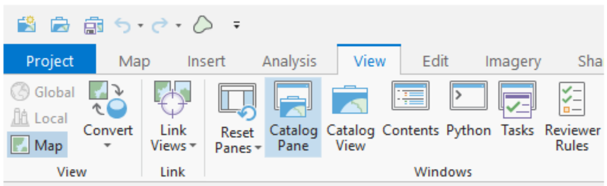
4. We would like to make use of translation apps such as Google Translate and Baidu Translate more often in order to more effectively communicate with our sponsors and the professionals we interviewed. Apps that allow the user to speak into their phone and automatically translate what they are saying would have aided immensely.

Appendices

Appendix A: Importing a Satellite Image

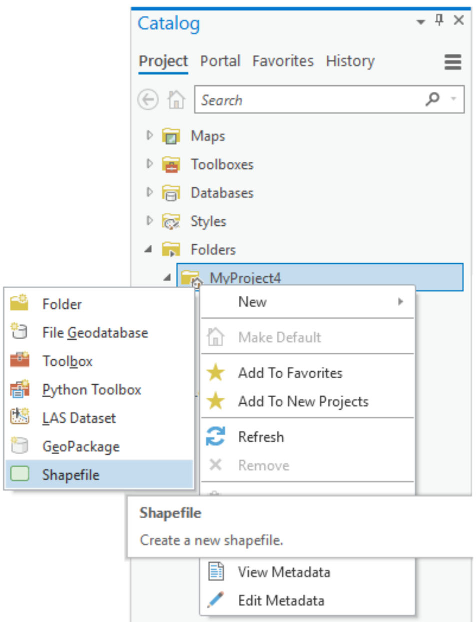


Appendix B: Creating Shapefiles for Vectorization



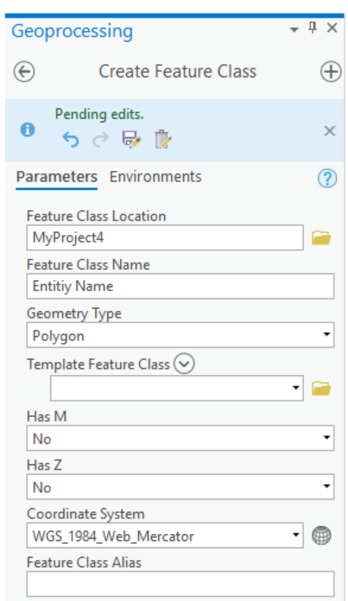
To vectorize an image, we must create shapefiles.

The catalog must be opened, this can be done by clicking Catalog Pane, under the view tab.



The catalog will appear on the right side of the screen.

To create a shapefile, follow:
Folders > 'Project Name' > New > Shapefile



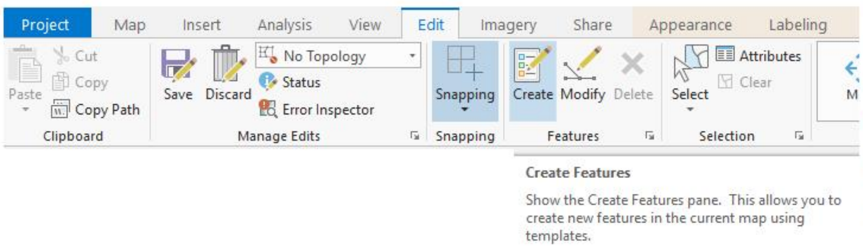
To create the shapefile, simply fill out the parameters.

Polygons are used to vectorize buildings.

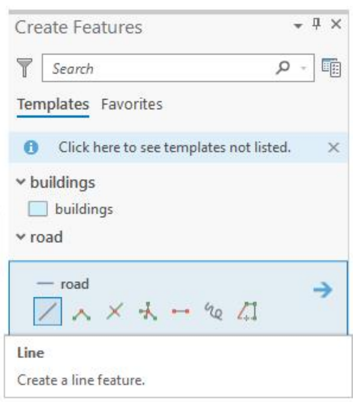
Polylines are used to vectorize roads.

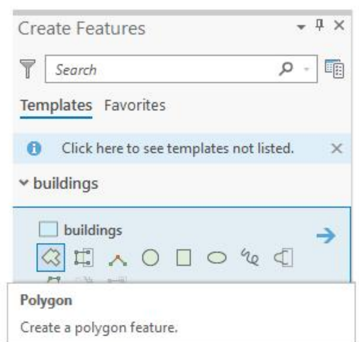
It is important to selected the 'current map' option for the Coordinate System, which will automatically select the WGS_1984_Web_Mercator option. Otherwise, any attempt to vectorize without this option will lead to an error.

Appendix C: Vectorization of Roads and Buildings



Once shapefiles are created, on the Edit tab, click Create. This will open the Create Features panel on the right side of the screen.





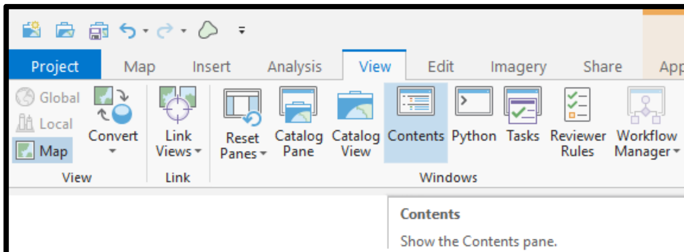
Use the Line feature to trace roads.

Use the Polygon feature to trace builsings.

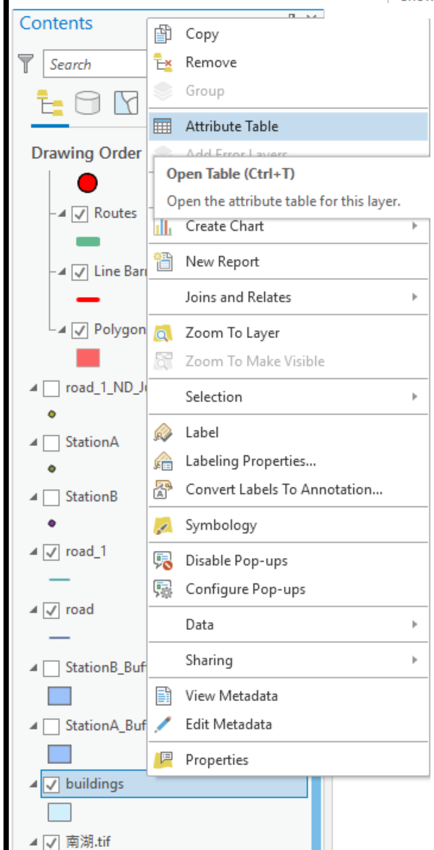
This is a small sample of the vectorized map.

This is the expected result.

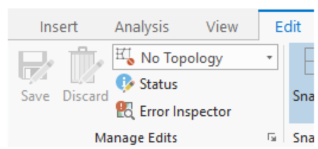
Appendix D: Inputting Attributes



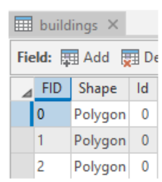
To assign attributes to the polylines & polygons, click on Contents from the View tab.



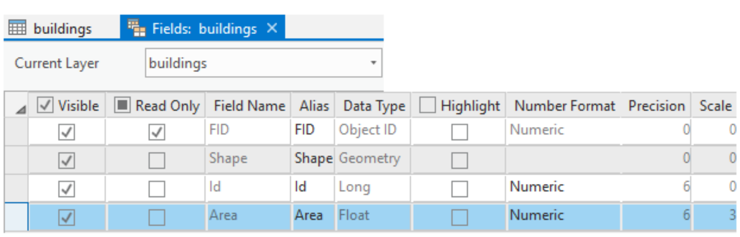
Right-click on the shapefile, then click on attribute table.



Before making changes to the attribute table, click Save under Edit

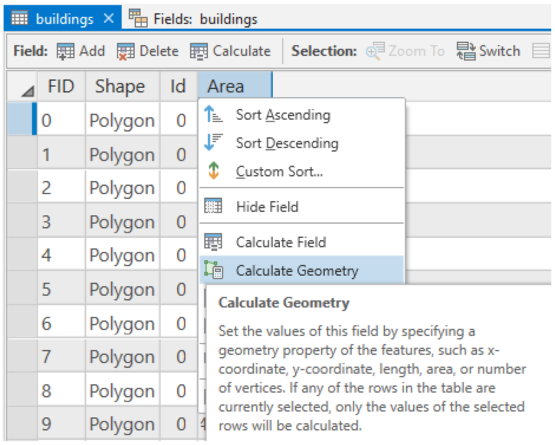


Click Add

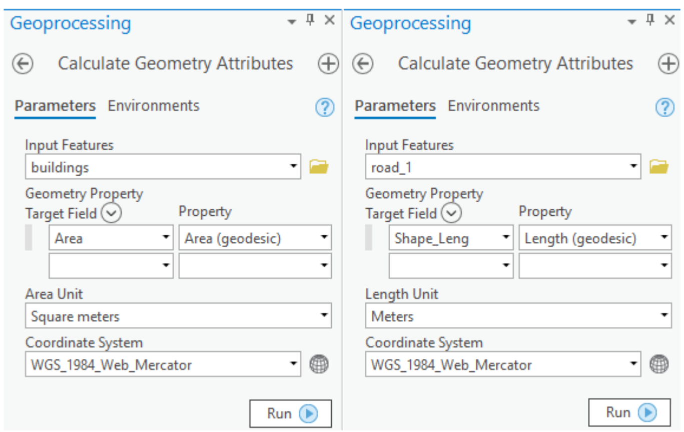


Name the data you would like to collect, then name the Alias similarly. Assign the data type as Float. The Number Format is Numeric.
Precision needs to be at least 3 significant figures.
Scale is set to 3.

Appendix E: Assigning Attributes



Once a field has been added, the geometry of the shapefile can be calculated.



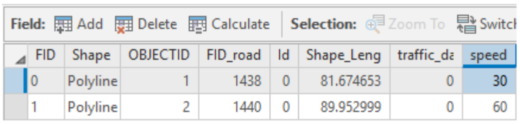
Choose which field needs to be filled.

Then, for polygons, choose Area.

For polylines, choose Length.

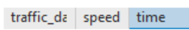
Choose the units, do not forget to choose a coordinate system.

Appendix F: Inputting Traffic Data

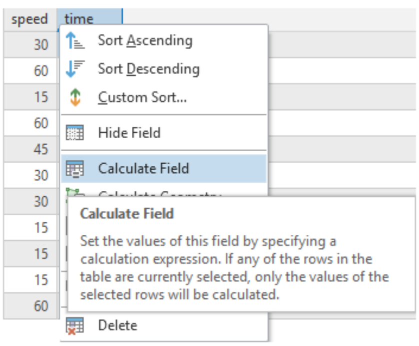


To add the traffic data, we must obtain the average speed (km/h) of each road.

Our sponsor has supplied us this information, which we imported into our road shapefile.

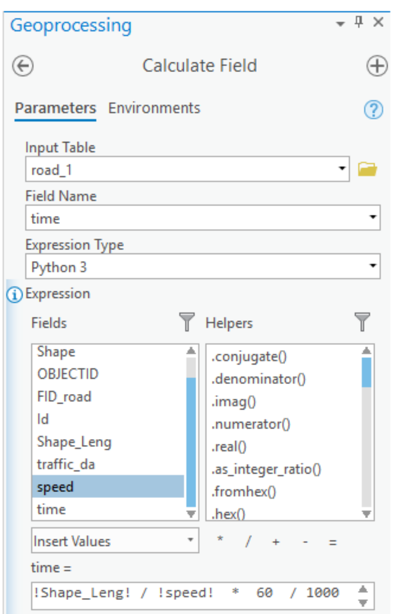


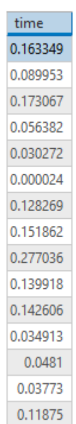
Add a field called 'time'. This will represent the time needed to travel the road.



Right click the time field, click calculate field.

This will open the geoprocessing panel on the right side of the screen





The input data will be taken from 'Road_Name' for the 'time' field.

The expression will be:

Road Length/Speed (km/h) * 60/1000

This expression will give the time taken to travel a road in minutes. (For all roads)

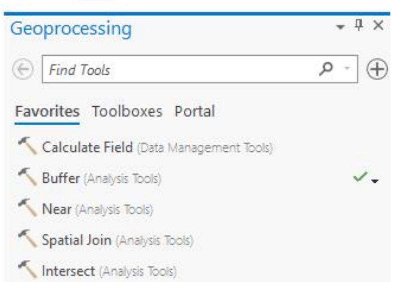
Appendix G: Buffer Analysis

We must represent the firestations in the map with a point.

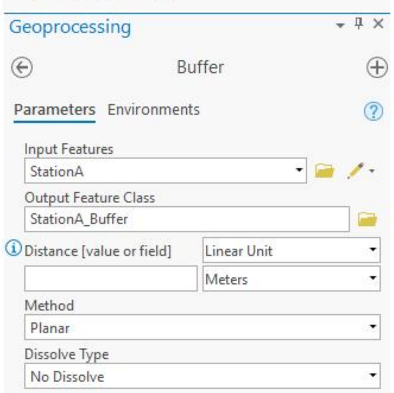
The point can be created through the same method used to create the polylines and polygons (create shapefile).

There are two firestations in this picture. It is safer to assume the firestations are not identicial, thus needing to create a unique point shapefile for each station.

To begin with buffer analysis, click on Tools under the Analysis tab.

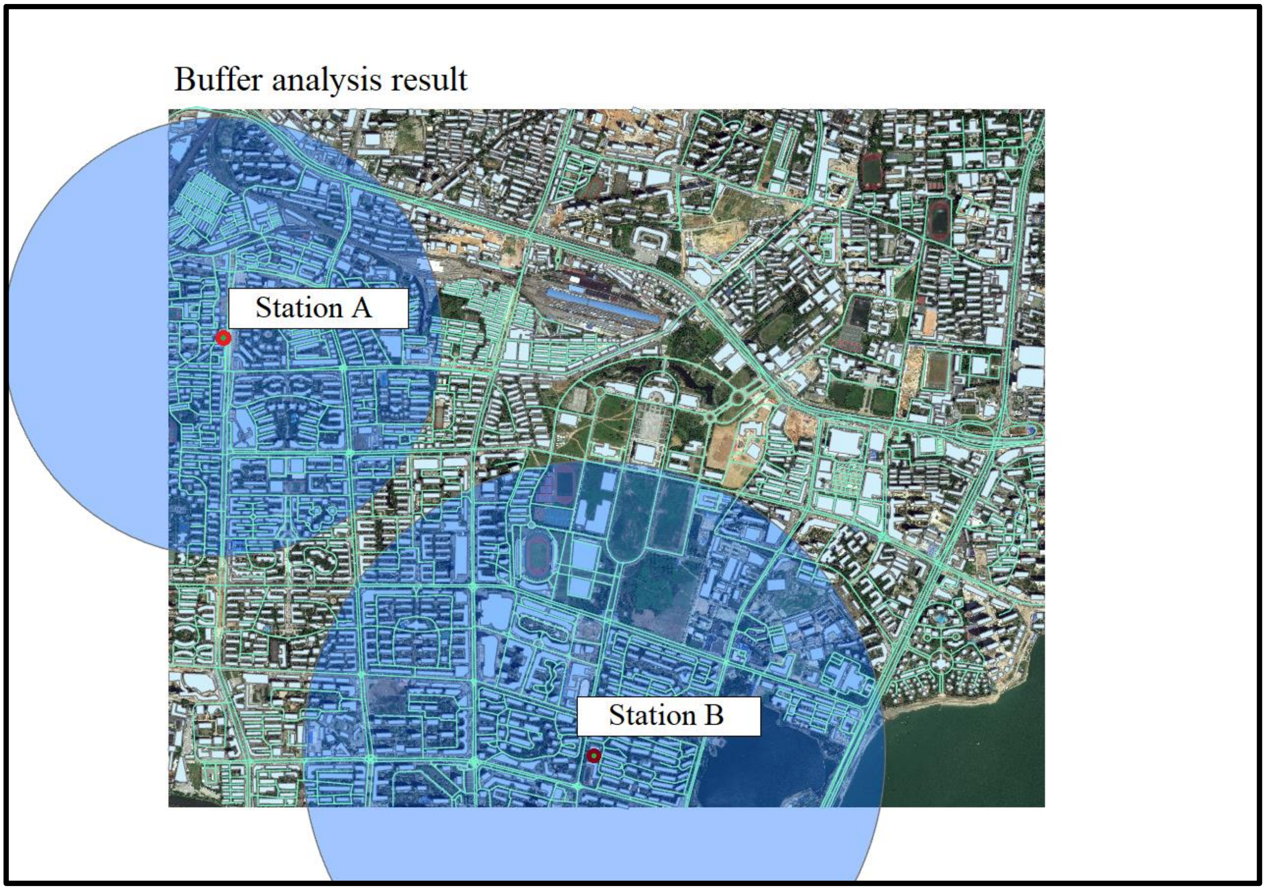


The geoprocessing panel will open, click on Buffer to open the Buffer Analysis tool.

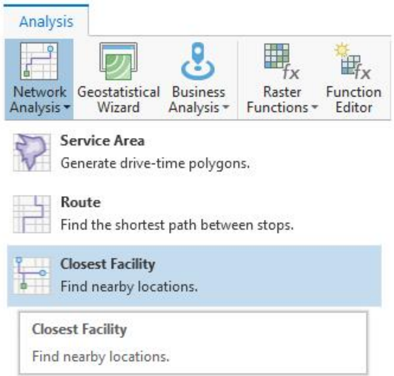


Under input features, select the point that represents the firestation. In this case, we have chosen StationA. The radius of the buffer zone can be derived from the service area of the station, which depends on the class of the fire station.

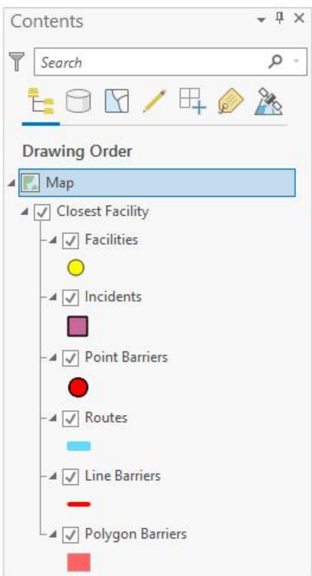
Appendix H: Buffer Analysis Image

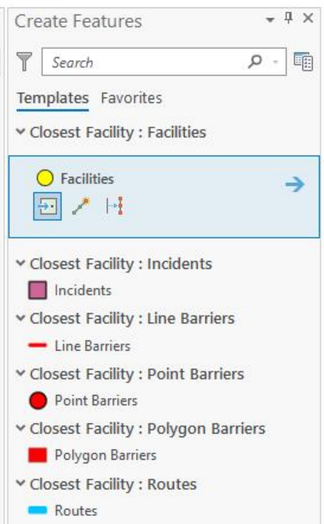


Appendix I: Network Analysis Setup



To begin network analysis, click the Closest Facility option under the Analysis tab.





The Closest Facilities layer will appear in the contents panel.

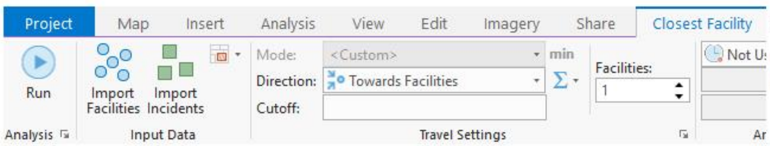
In the Create Features panel, facility points and incident points can be placed.

This is what to expect

Facility points can be put on the fire station points.

Incident points can be arbitrarily placed on polygons or on polylines.

Appendix J: Running Network Analysis

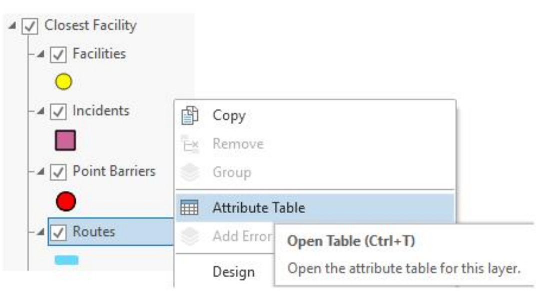


For the closest facility tab to appear, click on the closest facility layer on the contents panel.

Click on Run to execute the analysis.

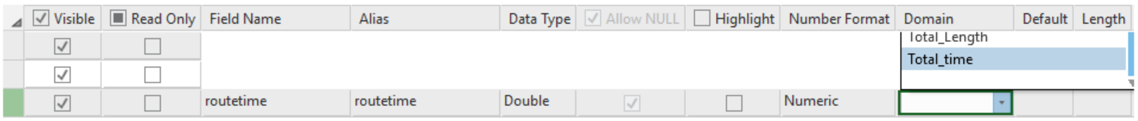
This is the expected result.

We still need to input the impedances



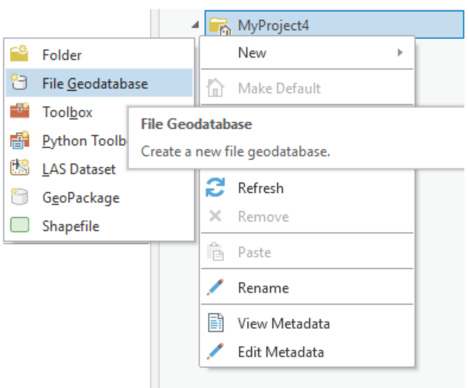
To input impedances, under the contents panel, right-click on Routes then click on attribute table.

Appendix K: Adding Impedance



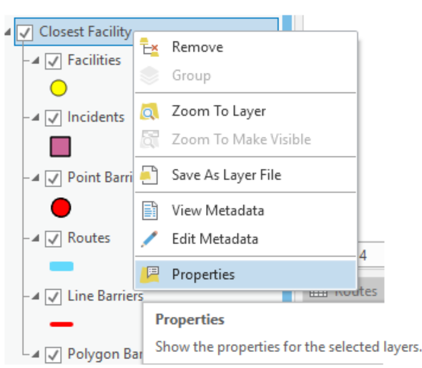
Add a field for time. Make sure the Data Type is Double. Make sure the Domain is Total_time.

This will be inputted into the network dataset.



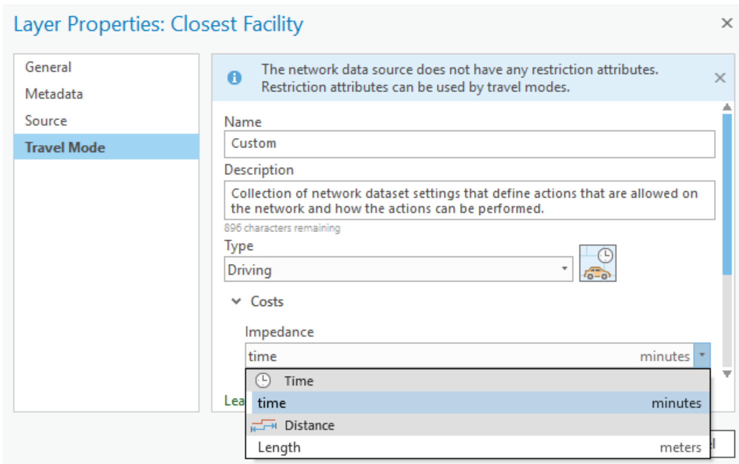
This requires a geodatabase to be created.

Our sponsors supplied us with the geodatabase and helped import the database onto our project.



To select the impedance for the network analysis, right click the network analysis layer under the Contents panel and click on Properties.

Appendix L: Optimizing Network Analysis Using Impedance

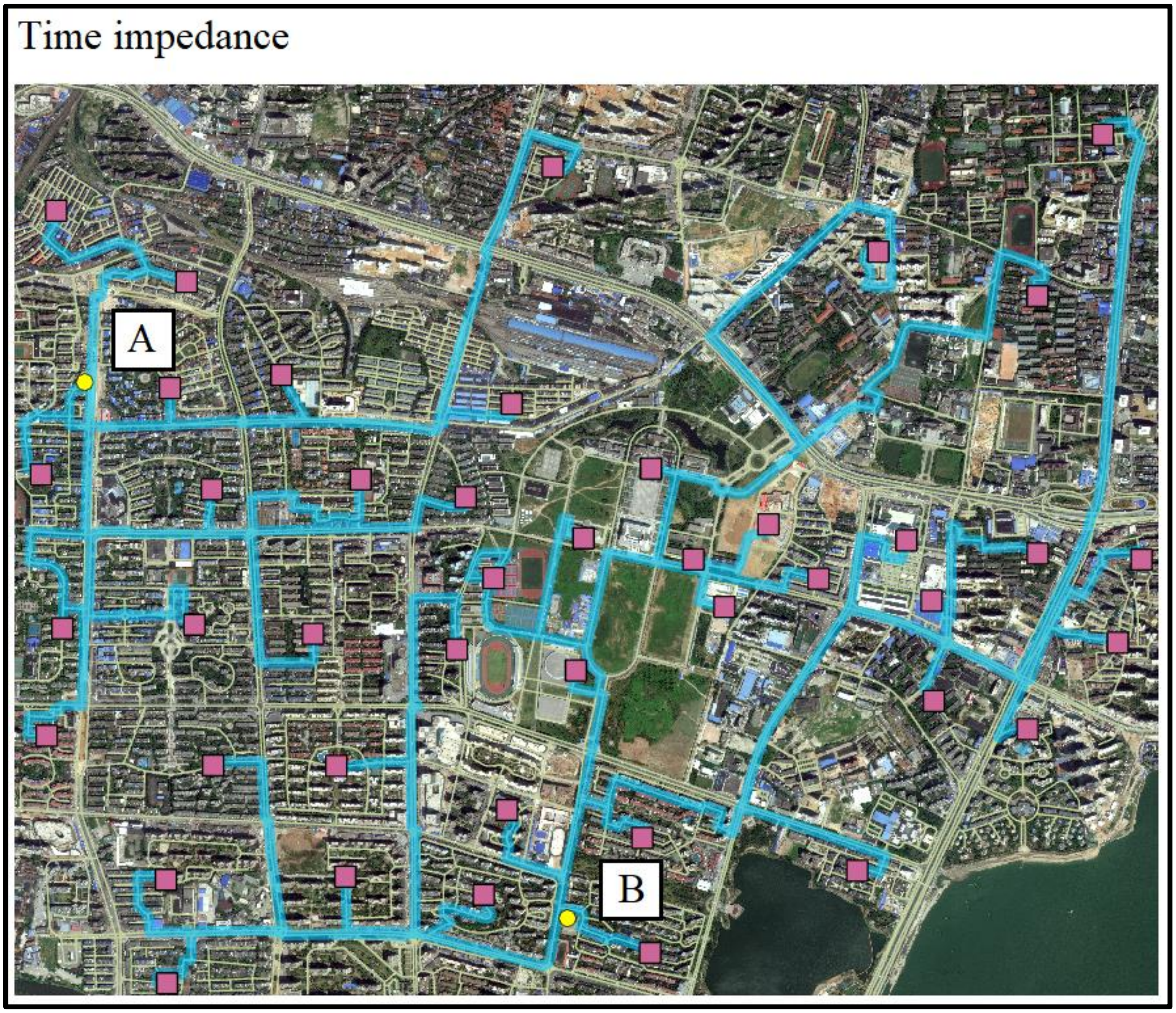


When the properties window opens, click on the Travel mode tab, then click on Impedance.

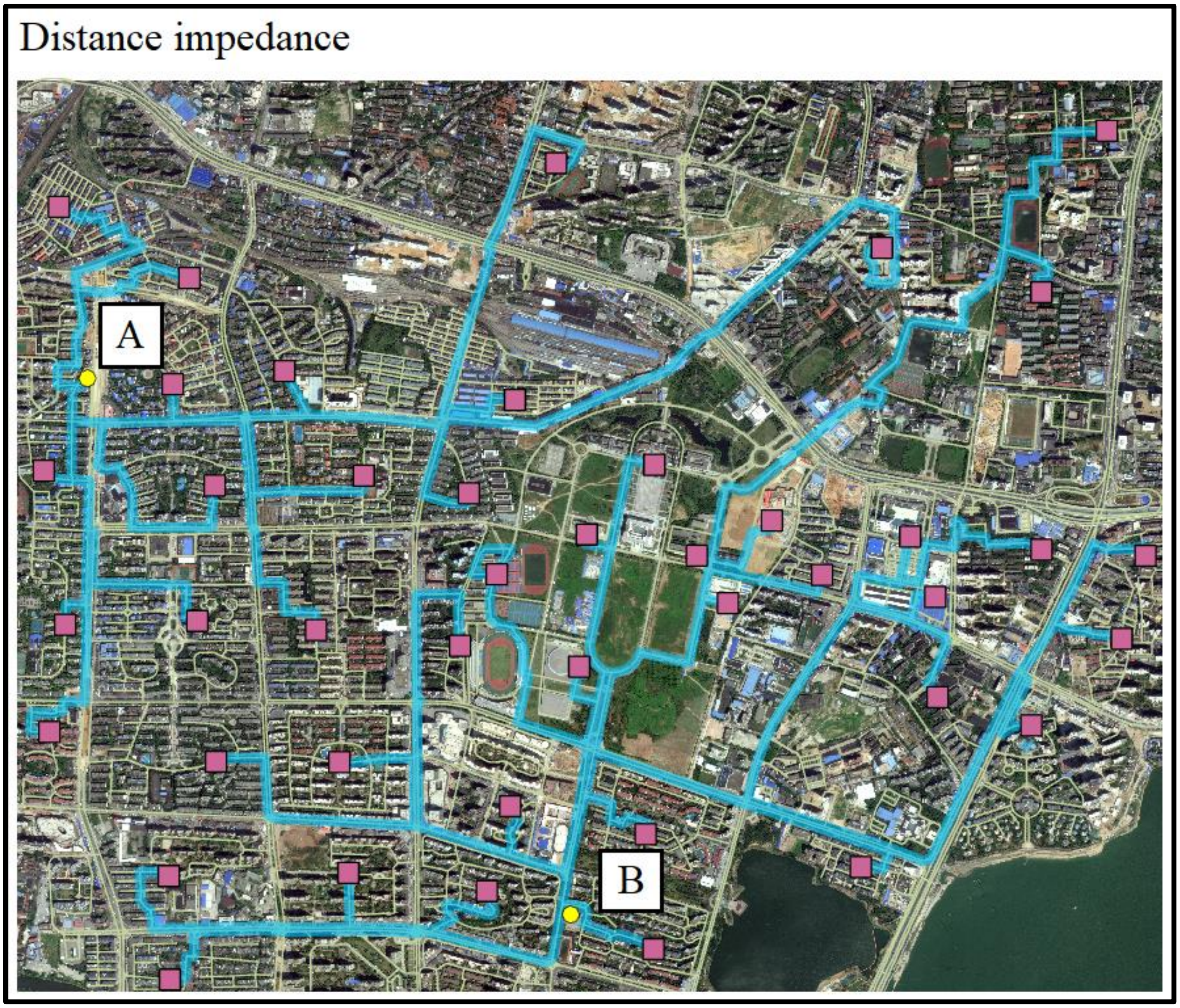
There will now be two options: time and length.

Now it is possible to do network analysis based on a time-optimized scenario, or a distance-optimized scenario.

Appendix M: Time Impedance Image



Appendix N: Distance Impedance Image



Appendix O: English Survey

Fire Station survey

Q1 What is your job title?

____

Q2 Where do most emergency responses take place?

- ☐ Office Buildings (1)
- ☐ Hotels (2)
- ☐ Universities/Schools (3)
- ☐ Parks (5)
- ☐ Malls/Shopping Centers (6)
- ☐ Government (7)
- ☐ Factories/Industrial Buildings (8)
- ☐ Other (9) ____

Q3 Do personal vehicles move out of the way for emergency vehicles?

- Yes (46)
- Sometimes (47)
- No (48)

Q4 Do pedestrians move out of the way for emergency vehicles?

- Yes (25)
- Sometimes (26)
- No (27)

Q5 What is the average response time for emergencies here?

Over 30 Min

	0	5	10	15	20	25	30
Minutes ()							

Q6 Do you think the location for this fire station is suitable?

- ◯ Definitely yes (1)
- ◯ Probably yes (2)
- ◯ Probably not (3)
- ◯ Definitely not (4)

Q6.1 Why do you think this is a suitable location for this fire station?

____

____

____

____

____

Q6.2 What would you change about the location of this fire station?

Example: Location, Size, Cost

Q7 On a scale of 1-10 what would you rate the city's safety based on the current number of fire stations?

	1	2	3	4	5	6	7	8	9	10
City Safety ()										

Appendix P: Chinese Survey

Fire Station survey

Q1 你的职称是什么？

____

Q2 大部分应急响应在哪里发生？

- ☐ 办公大楼 (1)
- ☐ 酒店 (2)
- ☐ 大学/学校 (3)
- ☐ 公园 (5)
- ☐ 商场/购物中心 (6)
- ☐ 住宅楼 (7)
- ☐ 工厂/工业建筑 (8)
- ☐ 其他 (9) ____

Q3 私家车会为紧急车辆让道吗？

◯ 是 (46)

◯ 有时 (47)

◯ 不是 (48)

Q4 行人是否会为紧急车辆让路？

◯ 是 (25)

◯ 有时 (26)

◯ 不是 (27)

Q5 这里的紧急情况的平均响应时间是多长？

再过30分钟

	0	5	10	15	20	25	30
分钟 ()							

Q6 你认为这个消防局的位置是否合适？

◯ 肯定是的 (1)

◯ 可能是 (2)

◯ 可能不是 (3)

◯ 当然不 (4)

Q6.1 你为什么认为这里是消防站的合适位置？

____

____

____

____

____

Q6.2 你认为这个消防站需要什么改进？

例子：地点 规模 成本

Q7 根据目前的消防站数量，您可以根据1-10的等级对城市的安全性进行评级？

	1	2	3	4	5	6	7	8	9	10
城市安全 ()										

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