Improving Fire Station Coverage and Response Times Across San Marcos with Network Analysis

In conjunction with City of San Marcos and San Marcos Fire Department represented by Emilee Freeman and Karl Kuhlman

Bobcat Burn Battalion -

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Table of Contents

Introduction

Summary

The city of San Marcos has a growing population and is proposing new development to meet the needs of its new residents. It is the responsibility of the San Marcos Fire Department to ensure that regardless of where someone lives in the city, they can respond to them in case of an emergency promptly. Guidelines for the speed of response and number of responders are set out by the National Fire Protection Association (NFPA). This study aims to examine if current coverage meets NFPA guidelines, update fire station quadrants and district boundaries to best meet these guidelines, analyze the impact of the future planned station on coverage, and suggest alternative locations for the future Station 7.

Purpose

The city of San Marcos currently has six fire stations, and each station has a designated response area. To address the increasing population and projected growth of the city, a seventh station is being built. Before a location is decided for this new station, it is necessary to evaluate the current speed of response for existing boundaries. Using GIS tools and network analysis of the roads in the city, combined with spatial reference to current stations, areas that have response times that fall outside the NFPA guidelines will be identified. Based on these findings, if necessary, station response areas will be revised to adhere to NFPA guidelines.

After gaps in desired travel time to the scene of emergencies are identified, a site analysis for potential station seven locations will be conducted in order to filter locations that will best fill the gaps. This step is necessary to ensure that the station can realistically be built - e.g. is on already reserved land, the construction site is level, there is enough space, etc.

Scope

Analysis will encompass the City of San Marcos along with proposed development in the immediate areas surrounding the city (Figure 1). GIS data, reports, and presentations will be prepared from February 2026 through May 2026.

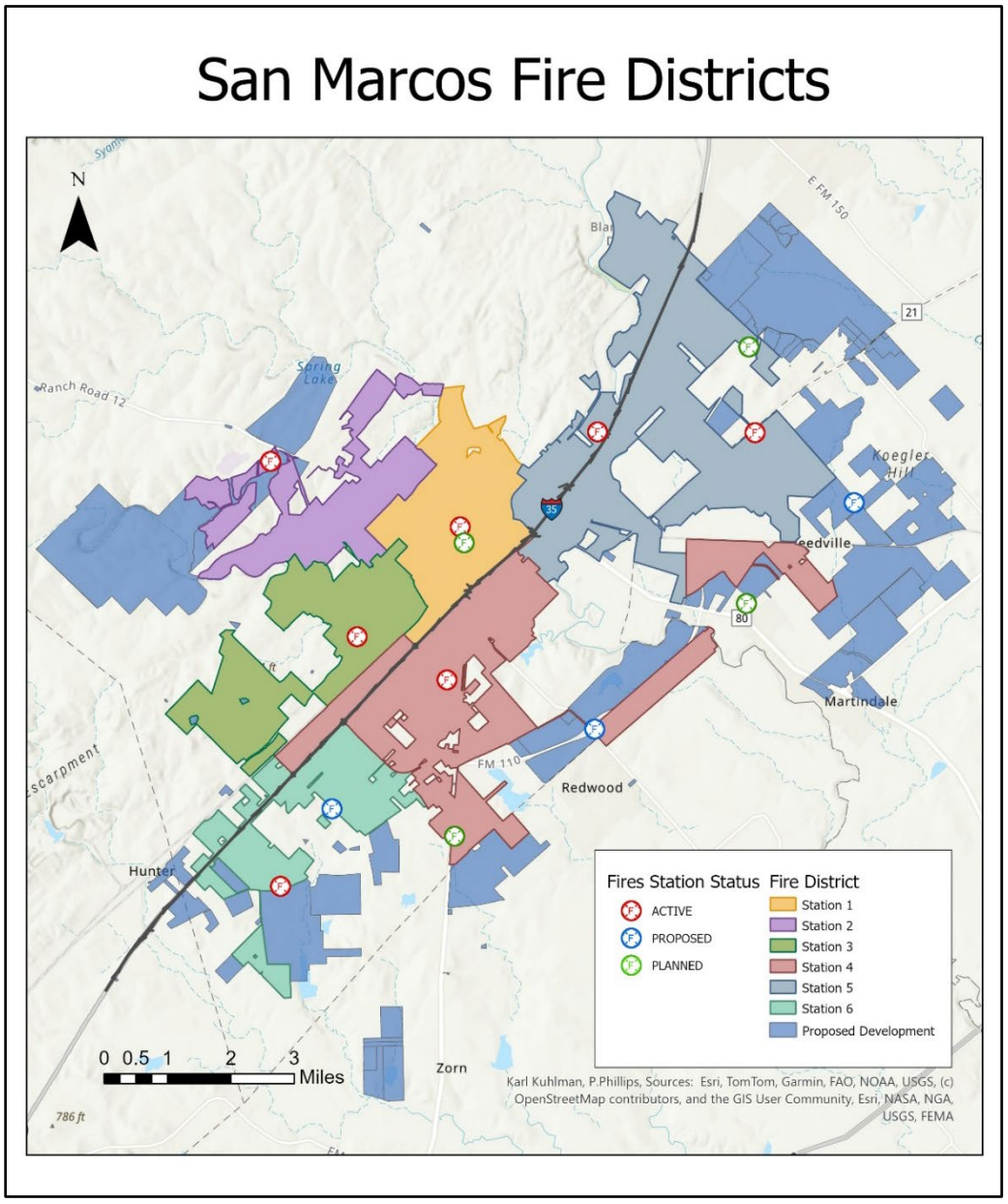

Figure 1 – City of San Marcos Fire Districts and Stations

Literature Review

2.1 - Network Coverage Analysis

ArcGIS provides powerful spatial tools to use on networks and has been used around the world to perform network coverage analysis. Network analysis is the process of evaluating interconnected systems to better understand patterns and relationships between phenomena in a data-driven manner. With respect to public safety and emergency response, network coverage analysis is vital to examine a multitude of different variables.

Many fire departments use network coverage analysis to investigate roads and how they relate to coverage and call times of their responders. A study by Jabbar et al. (2024) exemplifies this approach by using a comparative frequency study of the road networks in Malaysia to identify areas of high concern based on whether response times of their fire fighters were falling within guidelines. This type of analysis allows for an efficient use of resources and lets departments make more informed decisions about what areas need more support to ensure adequate coverage is provided.

Although network analysis is often examining the relationship between two variables, it is possible to expand the scope of analysis when required. In such cases like the study by KC, K., Ardianto, R. & Wang (2024) a bivariate analysis was used alongside network information to determine areas at higher risk of experiencing fires based on environmental factors and current coverage of existing stations. When network analysis is paired with other tools and types of analysis, it allows for even more precise and accurate models to make better predictions and decisions.

2.2 - Site Assessment & Selection

Spatial science and the use of GIS is a comprehensive approach that can be very beneficial for optimizing the crucial decision-making process of selecting the site of a new fire station. Traditional site selection methods that are based upon subjective judgement or administrative boundaries may not be sufficient and can result in inefficient response times or gaps in coverage (Sen et al., 2011). A GIS-based suitability model can help the initial process of narrowing down land parcels that meet the requirements of a new site for a fire station. Through the ArcGIS Pro software, preferences for important criteria such as distance from major roads, land acreage, within a study area etc. can be classified as suitable and can then be combined into a streamlined algorithm-based model that is able to narrow down these candidate sites (Esri n.d).

Once feasible parcels are identified through suitability analysis, further evaluation can be conducted using network-based modeling. Network analysis tools incorporate travel times and road network characteristics to simulate realistic emergency response scenarios. This analysis can help establish the baseline for the standards that must be met upon the establishment of a

new station and use these to create the new service areas that would be created depending on the location of the new site (Sen et al., 2011).

The Location-Allocation tool in ArcGIS Pro can use these networks to assign locations to the facility that are within the four-minute travel time outlined in the NFPA 1710 guidelines. This can help to optimize the new site decision-making process by showing what coverage would look like for each proposed site and where the revised district boundaries would lie.

Integrating suitability analysis with network-based location-allocation modeling is crucial because it ensures that both land feasibility and emergency response performance are considered simultaneously. A study by Yao et al. (2019) further supports this approach, by emphasizing that optimal facility placement must account for both accessibility and service coverage under the predetermined standards.

Data

Determining the status of fire station coverage and an optimal location of a new fire station will require access to various types of data. The guidelines to which we will hold our analysis will be set out in the 1710 standards, and we will be performing analysis on spatial data. The following data comes from three sources, the National Fire Protection Association (NFPA), the San Marcos Fire Department (SMFD) and the City of San Marcos (CoSM).

Entity	Attributes	Spatial Object	Status	Source	Unit	Year
NFPA 1710 Standards	Response time & # of responder guidelines	n/a	Available	NFPA	n/a	2020
Call Data	Response time, # of responders	n/a	Available	SMFD	Time (min), Count	2025
Parcel	Coverage area	polygon	Available	CoSM	Sq mi	2025
Address Point	Latitude, Longitude	point	Available	CoSM	Degrees (Decimal)	2025
Road Network	Routing, Travel time	polyline	Available	CoSM	mi	2025
Fire Stations	Latitude, Longitude	point	Available	CoSM	Degrees (Decimal)	2025
Fire Districts	Coverage area	polygon	Available	CoSM	Sq mi	2025
Fire Quadrants	Order of response	polygon	Available	CoSM	Sq mi	2025
Target Hazards	ESRI Target Hazard Analysis solution	polygon	Available (confidential)	CoSM	Risk Assessment	2025
Proposed Development	Future coverage area	polygon	Available	CoSM	Sq mi	2025

Methodology

4.1-Project Flow Chart

Our project flow chart (figure 2) provides a general outline of our project processes, subprocesses, data used, and final deliverables. It is branched to show our two differing areas of analysis: 1) assessing the current coverage and 2) future site planning for the proposed new fire station.

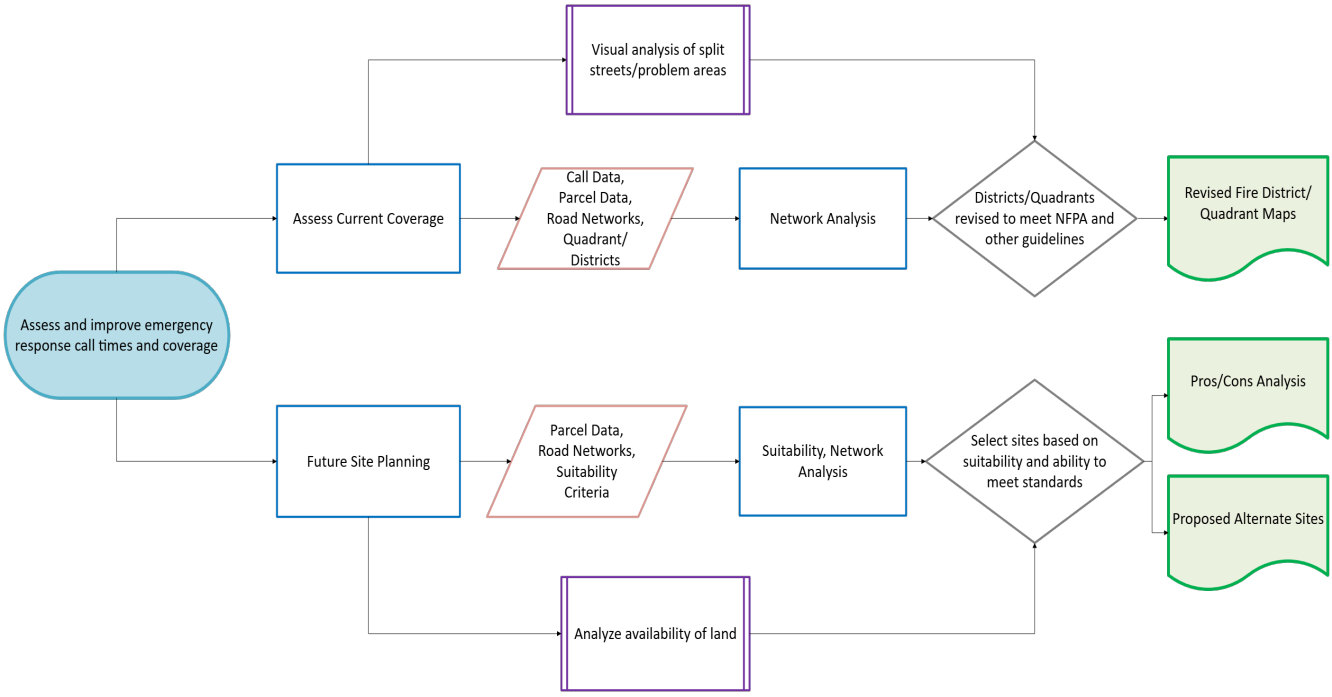

Figure 2- Project Flow Chart

4.2-Network Coverage Analysis

4.2.1: Determine Status of Current Coverage

The first step in analyzing the coverage of our quadrants and districts will be to find out how well they currently align with NFPA guidelines. To accomplish this, the network analyst tool will be used in each district. The origin point of each quadrant will be the respective fire station of that quadrant, and each station needs to be evaluated on their coverage. The parameters of the tool will be based on travel time of response vehicles, with the goal time of first responders arriving at the scene in four minutes 90% of the time. In consultation with our client, we will be using the average speed of 35mp/h for emergency vehicles on their way to emergency scenes. Once this tool is run, it will allow for an estimate of the areas that stations will be able to respond to in the allocated time required by the NFPA. Limitations of this strategy are that it does not

account for all the variables that come with real life such as traffic conditions, weather, or other events like train crossings. Due to these factors, it is essential that we consult with the SMFD to see if they agree with our preliminary findings and their lived experiences before we continue and revise quadrants.

4.2.2: Revise Quadrants/Districts

After the ideal service area of each fire station is determined, quadrants and districts need to be revised to reflect that new information. The coverage areas will first be generated by ArcGIS after the tool is run, but they need to be manually revised to ensure that individual streets are not split. It is important that street splitting is avoided to make sure that houses on one side of a street are not covered by a different station than their neighbors across the street. Although this is a straightforward section conceptually, it is anticipated that this will be one of the more labor-intensive portions of analysis.

4.2.3 Validate Revised Quadrants/Districts

Once each station has a revised quadrant and district, it is vital to compare the newly generated coverage to existing coverage. This will be done with a simple overlay and visual conformation along with some client support and advice from the people working out of those stations. This validation will aim to identify gaps in coverage to begin the preliminary process of finding new locations for stations.

4.3-Site Assessment and Selection

4.3.1: Initial filtering of parcels

For our initial filtering of candidate sites for a potential new fire station site, we will utilize the City of San Marcos parcel data. We will then use the “Select by Attributes” tool within ArcGIS Pro to query out the parcels that meet all of the following criteria: >2 acres, a status of vacant, location that is within city limits, as well as outside of flood plains, parks, and protected areas. We will then further analyze these candidate sites using a suitability analysis.

4.3.2: Suitability Analysis

To further analyze these candidate sites, so that we ensure we are choosing the optimal site, we will run a weighted suitability analysis. We will consider several key spatial variables and assign higher scores to the more desirable traits within these variables.

For example, we will assign higher suitability scores to areas with lower slope because flatter land is easier and more cost-effective to develop on. We will also analyze proximity to major roads due to their potential to improve response times. Additionally, proximity to new development areas will be incorporated into our model as well, so that we can best accommodate the areas seeing the most population growth.

We will further strengthen our analysis by adding or revising onto this proposed suitability criteria based on input from the client and additional research we may conduct as we are running our analysis.

4.3.3: Location-Allocation Analysis

After narrowing down approximately 10 sites that best fit our suitability criteria, we will assess the coverage areas that would come about with the establishment of each potential location using the location-allocation analysis tool within Network Analyst. A network dataset will be created or validated from the street centerline layer using travel time as the impedance cost. The network will incorporate turn restrictions and other available driving constraints to reflect realistic emergency response conditions.

Existing fire stations will be set as required facilities to establish current baseline coverage within a four-minute travel time threshold. Demand locations will be weighted using census population to measure residents served and assessed structure value to measure property protection. Service Area outputs will also be generated to calculate total roadway length within each response boundary.

Candidate parcels will then be entered as potential facilities in the model. The analysis will be configured to maximize demand coverage within the defined travel time. Separate model runs will evaluate coverage based on population, structure value, and roadway length. Results will be summarized using service area maps and comparison tables to identify the site that provides the greatest overall increase in fire protection coverage.

Budget

We determined our budget using data from Glassdoor. Aryssa, as the team lead, was considered a GIS Manager, which has a salary of $71,000 on the low end, and the other 4 members are currently considered GIS Technicians, which have a salary of $58,000 on the low end. Assuming full time employment, that would make Aryssa's pay $34/hour and the rest of our pay $28/hour, which comes out to $146/hour for the whole team. Our total lecture and lab time per week is 8 hours plus an additional 2 hours to account for any work done outside of class. The project time span is 12 weeks, so our per-week pay is $1,168.00 for the team and multiplying that by the 12-week time span, we get a projected total team pay of $14,016. For additional costs, we included the licensing fee for ArcGIS, which for the 12 weeks would be $1,050 per person or $5,250 total, and the cost of equipment, which we valued at $5,000 for 5 computers. We also incorporated the estimated equipment costs for computers and monitors at about $5,000. This makes our total expected budget $24,266.00.

Item List	Hours	Cost
Hourly – Aryssa (Team lead/ GIS Manager)	8	$ 34.00
Hourly – Jacob (GIS Technician)	8	$ 28.00
Hourly – James (GIS Technician	8	$ 28.00
Hourly – Aubree (GIS Technician)	8	$ 28.00
Hourly – Alexander (GIS Technician)	8	$ 28.00
Combined Hourly Pay	N/A	$ 146.00
Combined Weekly Pay	N/A	$ 1,168.00
Projected Total Team pay (12 weeks)	N/A	$ 14,016.00
Equipment Costs	N/A	$ 5,000.00
ArcGIS Licensing Fee	N/A	$ 5,250.00
Total Projected Cost		$ 24,266.00

Timetable

First Client meeting and proposal writing: January 21st – February 24th

Main data analysis and map creation, creating new districts, and proposing new fire station locations: February 25th – March 29th

Final Project presentation and poster creation: March 29th – April 29th

Jan 2026						
S	M	T	W	T	F	S
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

Feb 2026						
S	M	T	W	T	F	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28

Mar 2026						
S	M	T	W	T	F	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

Apr 2026						
S	M	T	W	T	F	S
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

Expected Results

Upon completion of this project, our client will receive the following comprehensive set of GIS-based analyses and map products:

- Updated fire districts and quadrants to meet NFPA standards
- Two alternate station locations with pro / con analysis
- Hypothetical fire districts and quadrants of proposed alternate stations for visualization

All GIS datasets will be transferred in a format that is compatible with existing City of San Marcos workflows and systems and will be accompanied by map layouts and proper documentation to help support internal planning.

Conclusion

In addition to those deliverables, constant communication with the client will be maintained and reports detailing methodology and decision process will be created. Based on preliminary research and anecdotal conversation with members of the client's staff, it is expected that the current proposed location of station seven will be suboptimal. Through our data-driven GIS approach, we hope to identify an alternate solution that is more strategically placed to optimize coverage and response time. Ultimately, our primary objective is to support safer and more efficient operations for first responders' while ensuring the residents of San Marcos continue to get excellent coverage through our comprehensive analysis.

References

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Appendix

Participation:

Aryssa Camenisch – literature review, methodology, flow chart

Alexander Garana – scope map, budget, data normalization

Aubree Dorman - time table, slides, continuity and design

Jacob Buchman – introduction, literature review, methodology, data table, flow chart

James Hezel - budget, logo design, data normalization

AI Disclosure:

Grok.AI was used to generate the bobcat logo graphic. Prompt – “generate a classic bobcat mascot wearing a fireman’s helmet that has no station markings”