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

Final Report

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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Abstract

This study evaluates whether current fire station coverage in the growing city of San Marcos, Texas meets National Fire Protection Agency (NFPA) response guidelines. San Marcos currently has six fire stations, and a spatial analysis of the optimal location for the seventh station is necessary to most effectively make use of city resources. We revised station districts and quadrants for improved efficiency, assessed the impact of the proposed station seven, and identified alternative optimal locations for that station. A GIS-based network analysis was used to generate 4-minute service areas for existing stations and identify coverage gaps. A site suitability analysis was then conducted to identify potential parcels for a new fire station based on land availability, acreage, slope, road access, proximity to planned developments and call density. District and quadrant boundaries were adjusted to improve travel time and efficiency, including the removal of split streets. As hypothesized, the most suitable locations for a new station were concentrated in northern San Marcos, near current low coverage areas and areas with high projected growth. Results showed that several areas, particularly in northern San Marcos, fell outside the recommended response threshold. Further analysis identified two alternative Station 7 sites that provide improved coverage as compared to the current proposed location. Spatial analysis of the city's existing and proposed fire stations service areas was completed to improve outcomes for residents and the quality of emergency response they receive.

Introduction

Summary

The city of San Marcos has a growing population and is proposing 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 promptly when there is an emergency. 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.

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. A GIS-based network analysis will be used to identify stations with service areas that fall outside of the four-minute guideline. Based on these findings, 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. This step is necessary to ensure that a station could realistically be constructed, and will encompass criteria such as vacancy of parcels, slope of the land, distance to roadways, and other spatial considerations.

We predict that the new station will fall in northern San Marcos close to Station 5 due to the concentration of new development in conjunction with lower service coverage in the surroundings.

Problem Statement

NFPA standards are research-driven benchmarks that have been developed to ensure that the minimum loss of life and property occurs in the event of fires. Due to the irregular nature of the San Marcos city limits (Figure 1), it is challenging to develop and maintain a network of fire stations that meets these guidelines. Additionally, San Marcos is a rapidly growing city, so the fire department needs to expand to meet the growing demand and population. Resources for this expansion are limited, so it is necessary to optimize and make sure that the new stations in the network are having the most positive impact possible

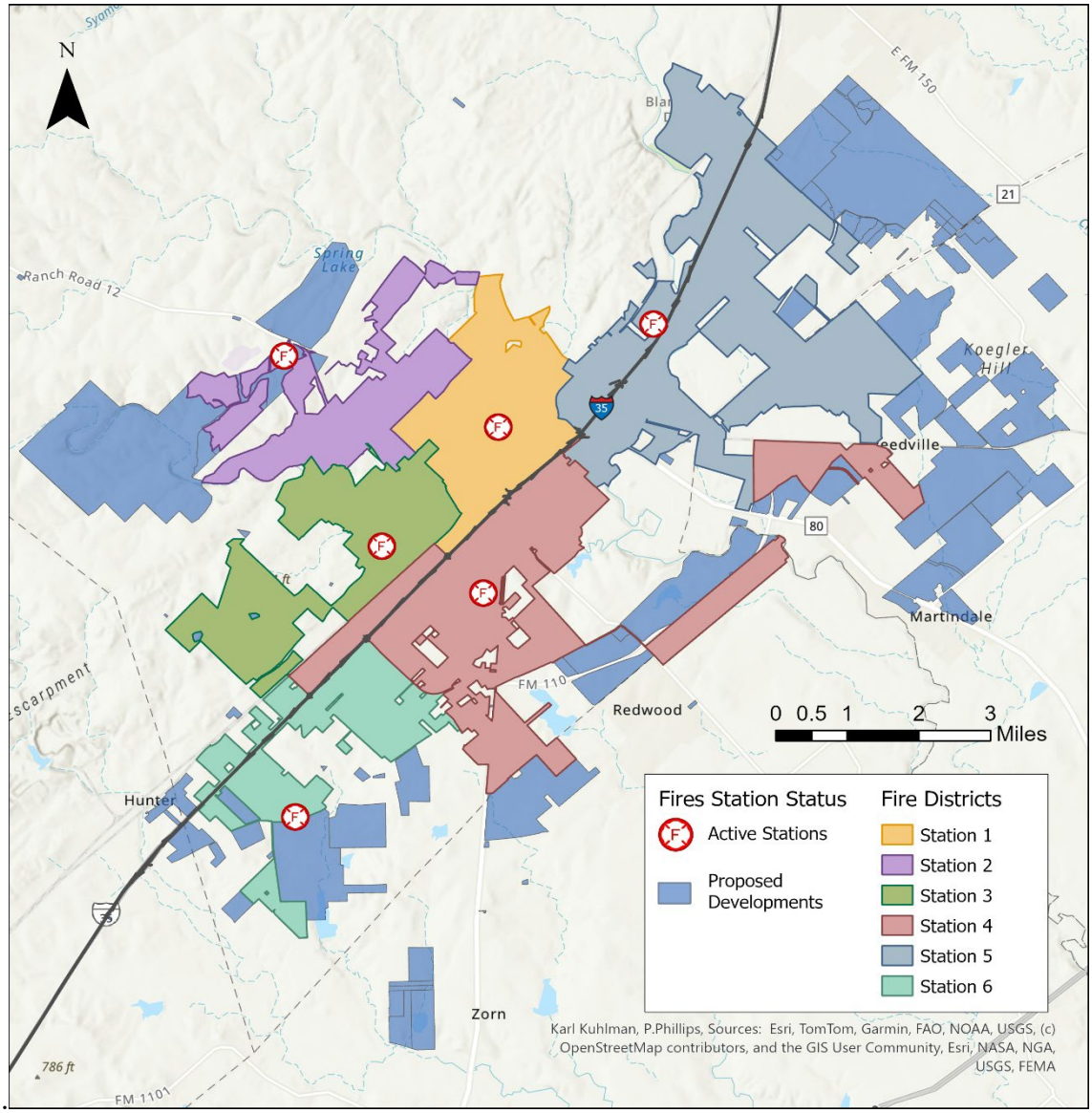

Figure 1: Current Station Coverage of Irregular City Limits

Data

Most of the data used in this project was provided by the City of San Marcos (CoSM) and the San Marcos Fire Department (SMFD), with some supplemental information the team acquired for analysis coming from TxDOT, USGS, and the U.S. Census. NFPA standards were necessary as those were the guidelines that determined the required response time for the network analysis. The spatial data for this project mostly used already existing data layers that are publicly available on the CoSM website. Since the spatial data we acquired is highly specific and designed for our area of study, it was ready to be used for analysis with minimal to no adjustment or cleaning. Supplemental data that we did require was used to shore up the road network as well as provide more categories for the location allocation selection process. The data acquired from TxDOT, USGS and the U.S. Census were state and nationwide in their scale, so they needed to be clipped to our study area – the city limits. The 'Target Hazards' layer of data that was provided by the CoSM was not used for analysis in the project but was instead used in the ideation and research phase of the project. This layer is confidential because it contains sensitive information regarding how vulnerable each building in the CoSM is to fire emergencies. The table on the next page (figure 1) details each layer of data with their attributes and source.

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
Major Roads	Highways, FMs and Country Roads within Area of Interest	Line	Available	TxDOT	Mi	2026
Digital Elevation Model	Slope	raster	Available	USGS	Elevation (meters)	2021
Census Blocks	Population	polygon	Available	U.S Census	Count	2020
Entity	**Attributes**	**Spatial Object**	**Status**	**Source**	**Unit**	**Year**

Table 1: Data Provided for Project

Methods

The analysis of this project was split into two main portions – site selection and analysis of current coverage. The following diagram is an overview of the analytical process that will be explored in more depth in this section.

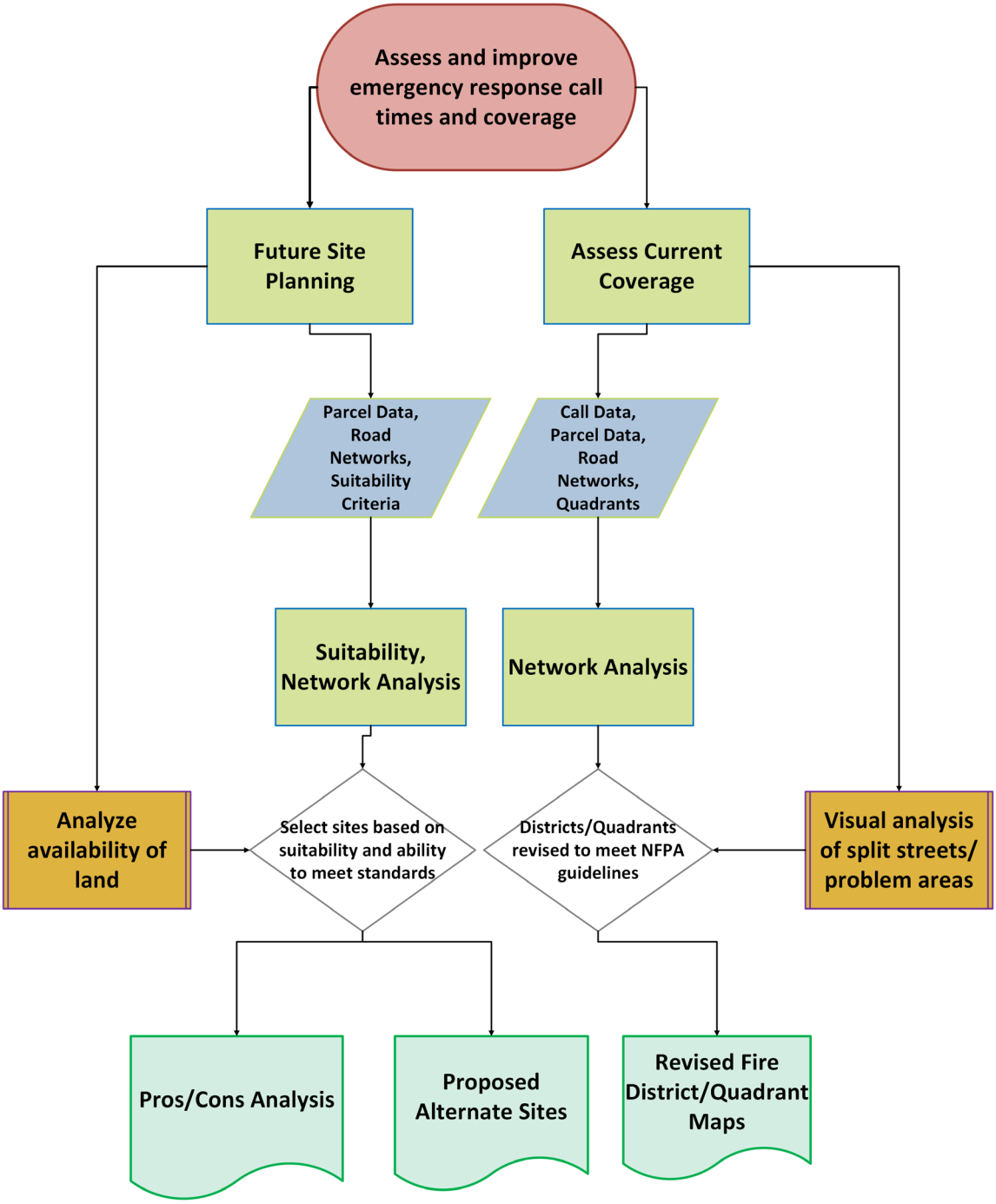

Figure 2: Project Flow Chart

Current Coverage Analysis:

To analyze the current fire station coverage, we made a service area network for each existing station individually and all together setting cutoffs for 4, 8, and 12 minutes at a speed of 35 mph, to show what areas are within NFPA standards going at the average fire engine speed (Figure 3). We also considered the many railroad crossings in the CoSM, so an added cost of 30 seconds was added to any roads that intersected with a railway. We arrived at the 30 second buffer with consultation from our clients; there is no available data for how many trains pass through the CoSM and at what times, so a flat buffer accounts for the possibility of a train being there at any given moment.

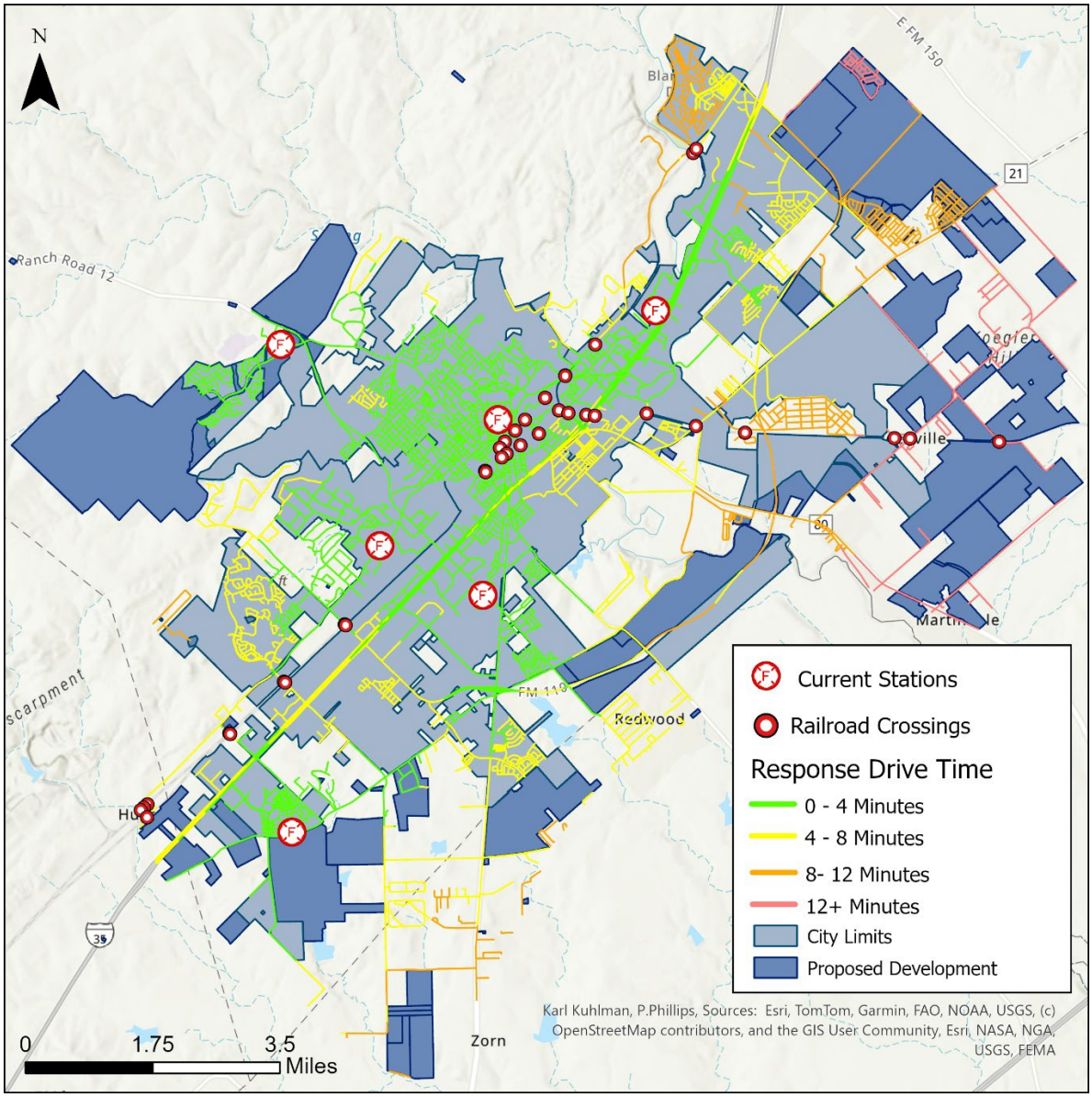

Figure 3: Drive Time Coverage for Current Stations Including Rail Crossings

To further analyze the current coverage of fire stations, we used the location-allocation tool to determine how many people are currently serviced by each station (Figure 4). We used two different types of demand points to achieve this, the first being call points which our client wanted to be considered more heavily than our second option being population which came from census tracts turned into points. MUAP was considered when trimming census tracts as well as turning them into points. Using these location allocations, we were able to see that the northern portion of San Marcos had a large amount of both call points and population points that could not be reached within the NFPA 4 minutes standard. Through this discovery, we decided to shift our focus to that area.

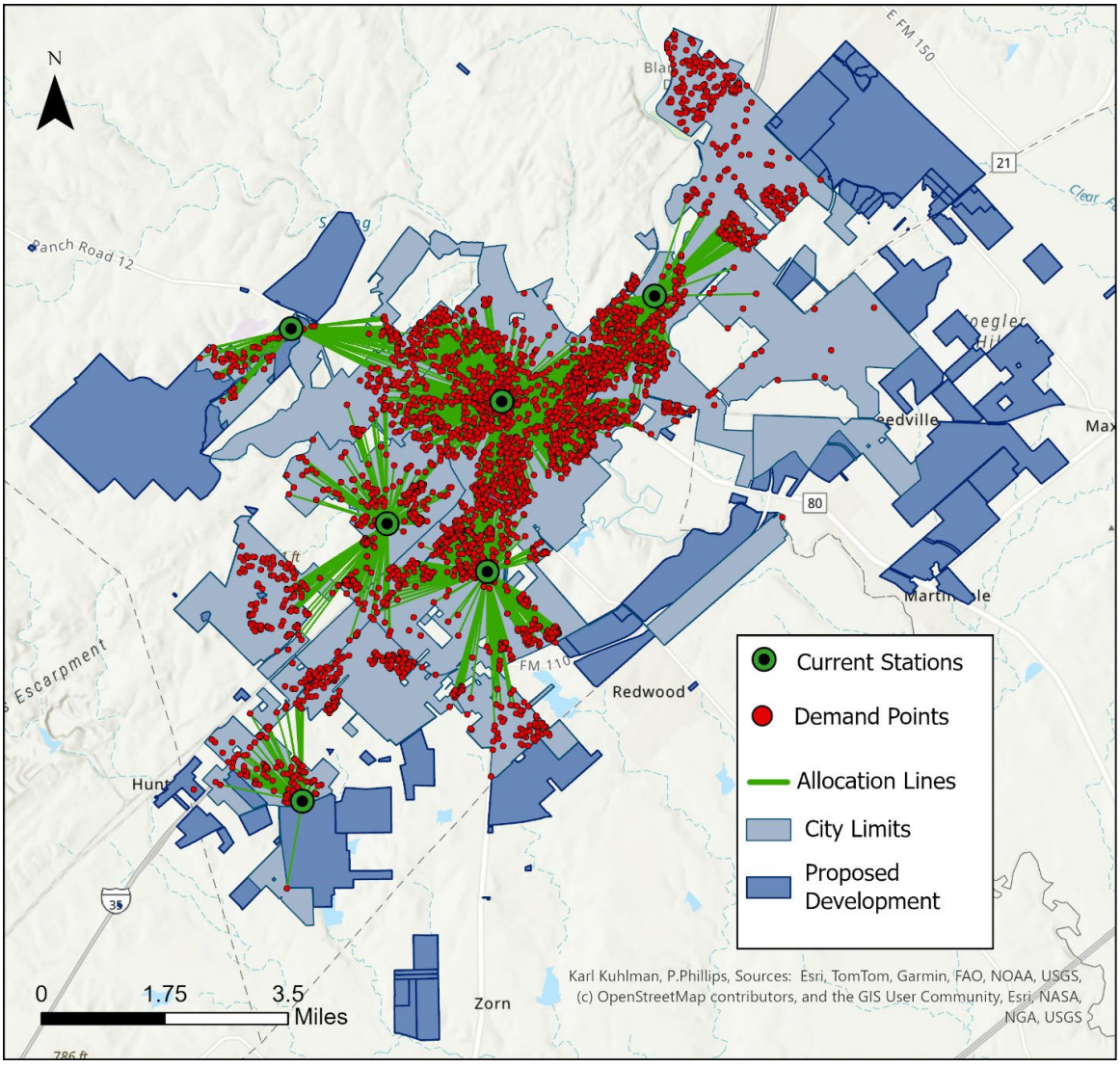

Figure 4: Location Allocation of Current Stations

District and Quadrant Remapping:

For the district and quadrant remapping portion of this project we used the travel times generated by the road network analysis to determine if the stations were responding to appropriate areas of San Marcos. Many of the districts were accurate and fit the NFPA standard times or used the best station for the areas that did not meet NFPA times from any station. The main areas of change were in the downtown area for Station 1. Figure 5 on the following page shows the light-yellow areas that were annexed into Station 1 area from Station 2's area. There were also areas that were taken away from Station 1 and given to Station 3, 4 and 5 respectively to maximize efficiency. We recognize that the reason why the Station 1 district did not originally include these areas is based on the high call volume that downtown experiences and the fact that the other stations may have more availability to respond. However, these changes and analysis are solely based on the data of travel times.

Our client specifically asked to avoid and correct street splitting where different sides of the same street were responded to by different districts. The areas of splitting found were mostly resolved by this new quadrant draft. The lines for new quadrants were based on parcel data rather than streets.

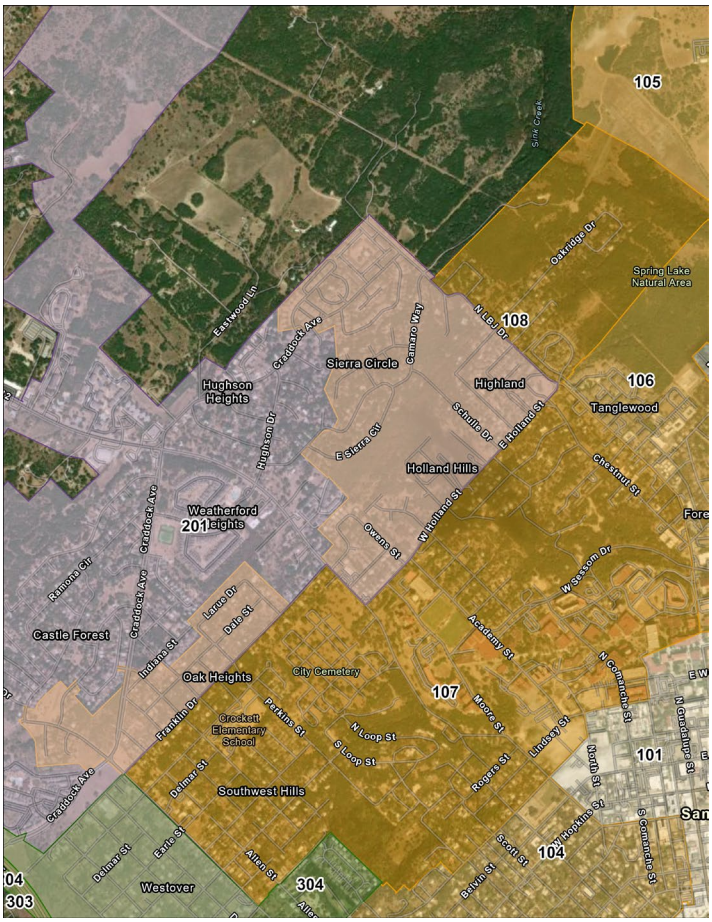

Figure 5: Downtown Districts Remapped

Figure 6 shows the Travis Elementary School which was previously responded to by Station 5. However, as the lower half shows Station 5 takes over 4 mins to respond to this area, while the upper half of the map shows that Station 1 can respond in 4 or less minutes.

Figure 6: Travis Elementary New Districts. Top – before redistricting, Bottom – after redistricting

Site Selection:

In the initial stage of parcel filtering, we narrowed the dataset down to 289 parcels from the City of San Marcos parcel data using the *Select by Attributes* tool in ArcGIS Pro. Parcels were selected based on the following criteria: vacant land, greater than 3 acres in size, located within city limits, and outside of the immediate floodplain. These selected parcels were then exported into a new layer for further analysis.

Additional filtering was completed manually to remove parcels that were not suitable for development. This included parcels with physical obstructions, lack of road access, irregular or incompatible shapes, and parcels located too close to existing fire stations. After applying these constraints, the number of candidate parcels was reduced to 77.

We further analyzed and filtered our parcels by ruling out parcels in areas with already adequate coverage by using the response time network created in our network analysis of all currently active stations. By using this response time network, we were able to narrow down the area in North San Marcos that currently has a significant area that lies outside of the 4-minute response time. Furthermore, this area has a considerable amount of proposed development area that will require coverage in the future growth of the City of San Marcos.

Parcels in this area were then narrowed down further by removing parcels that had an area above 25 acres, since it may be more difficult and expensive to acquire these parcels for the development of a new station. Finally, candidate parcels were narrowed down to five remaining options after a comprehensive analysis of call volume and address points (Figure 7). We also analyzed the results of our suitability analysis of our raster surface output in this decision, which considered slope, distance to major roads, and distance to new development.

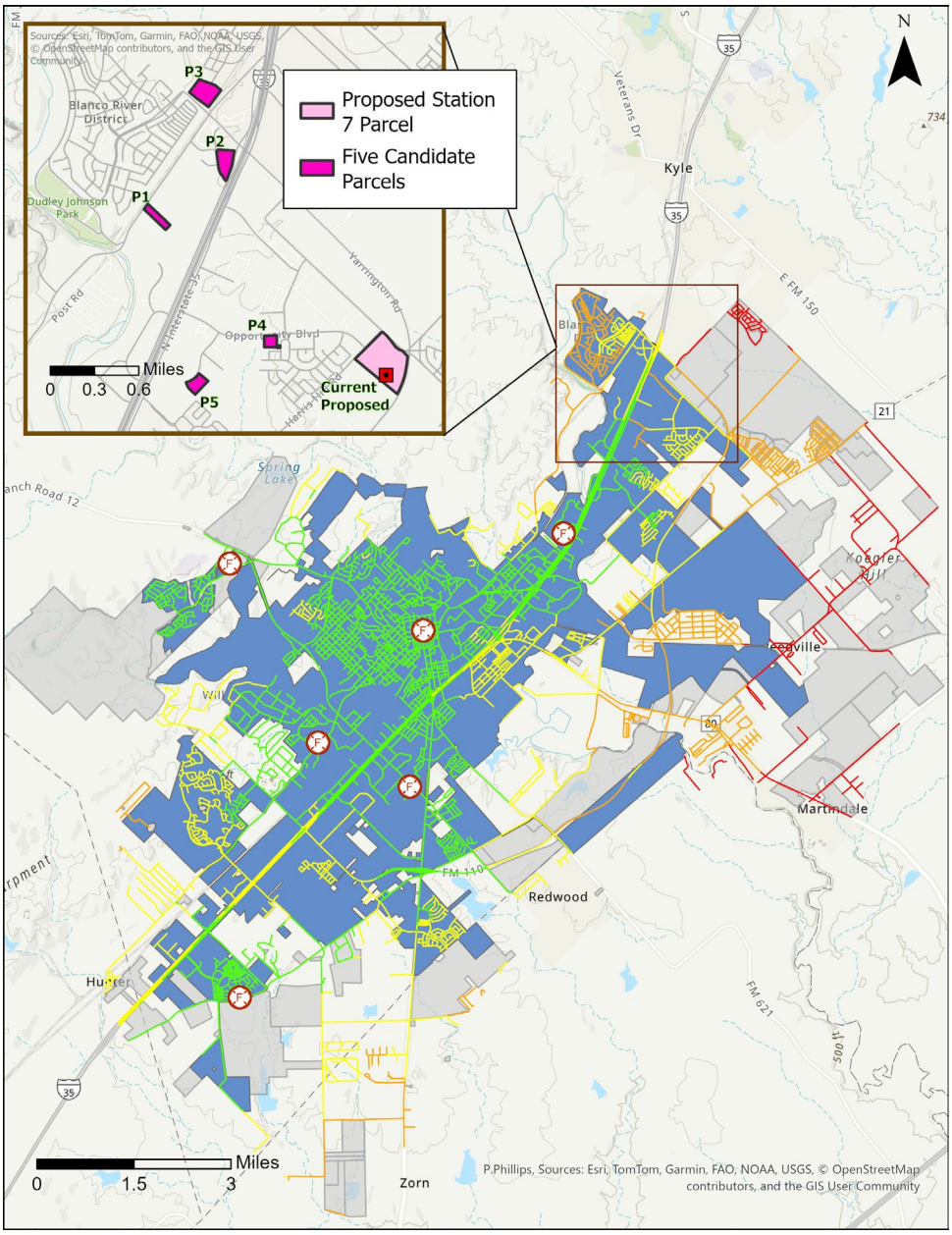

Figure 7: Five Candidate Parcels Chosen for Further Analysis

To further analyze these five remaining parcels and select our top two choices, we calculated several key characteristics for each parcel that would summarize their coverage, which included miles of road network, number of call points, and population served within a 4-minute response time. We also calculated these statistics for the site proposed by the City of San Marcos to see how our candidate parcels compared in coverage.

For each of the five parcels and the current proposed, we ran a location-allocation analyses to compare the call points and population that could be covered within 4 minutes for each of the

five proposed parcels, as well as the current proposed. This tool enabled us to assign demand points, which is where we input our call points and population points. This means that any of the points that fall within the 4-minute travel time are assigned to that proposed site (Figure 8).

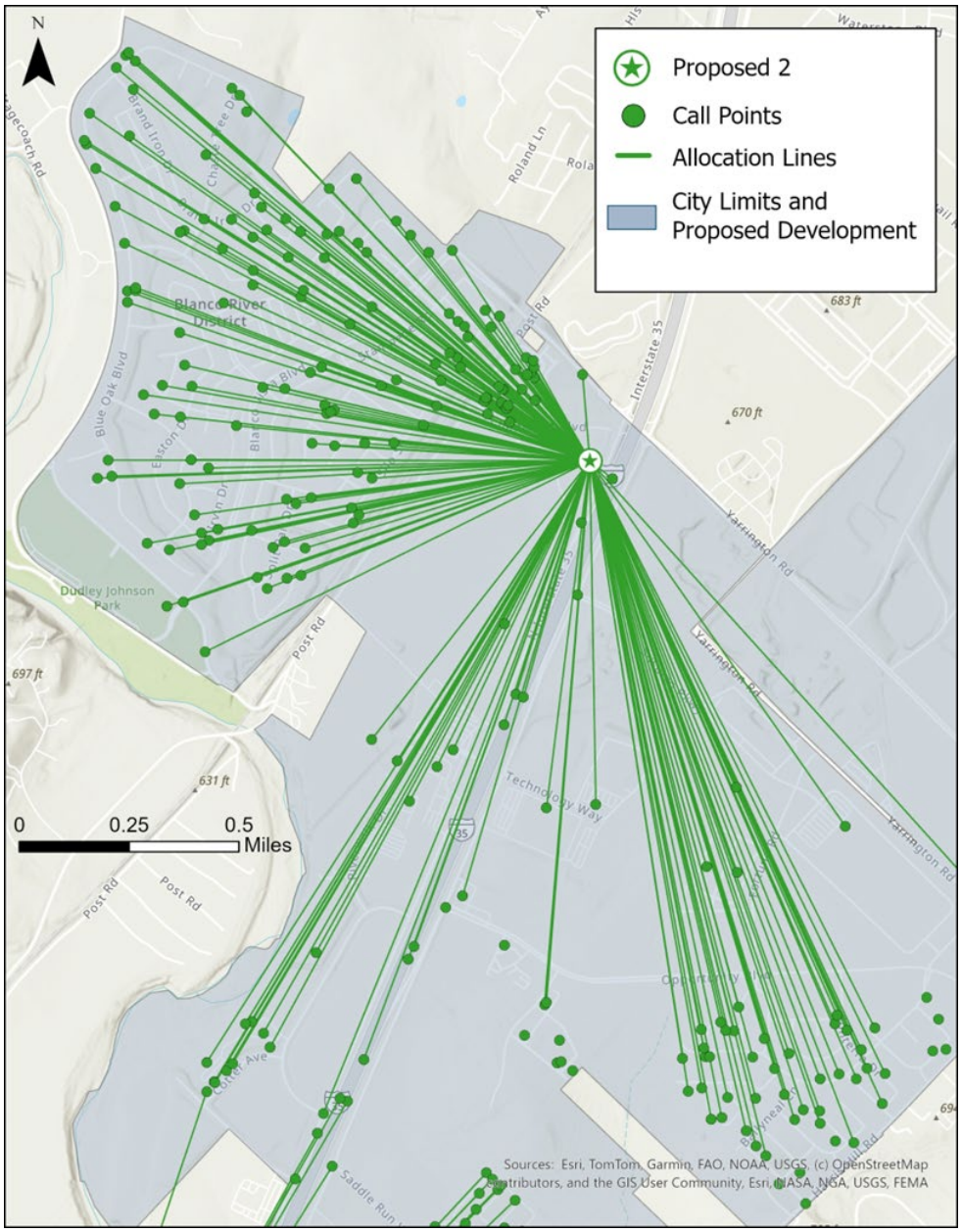

Figure 8: Location-Allocation distribution of call points to P2 Candidate Site

Similarly to the network analysis performed to evaluate the current City of San Marcos coverage areas, we created service areas for each of the five selected parcels as well as the fire department's currently proposed Station 7, following the same methodology used in the previous service area analysis.

To calculate the miles of road network covered, we selected all road segments that fell within the 4-minute travel time for each parcel and exported them into new layers. Using the "Shape_Length" field, we calculated the geometry in U.S. survey miles and then used the "Explore Statistics" tool to determine the total sum of the road network length within each service area.

These values were compared alongside our location-allocation population point and call point results, to help us guide our final candidate site selections (Table 2).

	Miles of Road Network (4 minutes)	**Call Points (4 minutes)**	**Population (4 minutes)**
Proposed Station 7	23.75	51	468
P1	41.03	438	4246
P2	50.90	557	4686
P3	45.45	476	4142
P4	27.72	323	2101
P5	10.55	130	375

Table 2: Coverage Statistics Results

Based on these results, parcels P2 and P3 provided the highest levels of coverage across all metrics. These two sites consistently outperformed the other candidates, as well as the currently proposed Station 7 location.

Using these findings, we selected P2 and P3 as the top candidate sites for the new fire station. We then incorporated these locations into the updated district boundaries developed in the current coverage analysis. Using the network-based service areas for the proposed sites, we created a hypothetical district boundary map that includes the addition of Station 7 to help show its potential impact on overall system coverage.

Results and Discussion

Current Coverage Analysis:

Our baseline service area of the current 6 fire stations had a total drive time area at or under 4 minutes of 274.61 miles. Using that data alongside 2025 call point data, and 2020 census data we identified the northern area of the city as a problem area to focus our study on.

After conducting an analysis for each of our 5 proposed stations and the fire department's proposed station 7 we took the total network area within 4 minutes in miles for each location to compare the proposed stations to one another and further justify our selections.

Site Selection:

We selected P2 (Figure 9, below) as our first choice for the station 7 candidate site. This proposed station site had the highest overall coverage, reaching about 50.90 miles of road network, 557 call points, and a population of 4,686 within 4 minutes. The pros of this parcel are its immediate highway access and excellent coverage within 4 minutes. The cons of this site are that it appears to have high tree cover, which could have minor impacts on buildability. Furthermore, it is currently owned by a development company, and we have limited knowledge on the ability of the City of San Marcos to acquire this parcel.

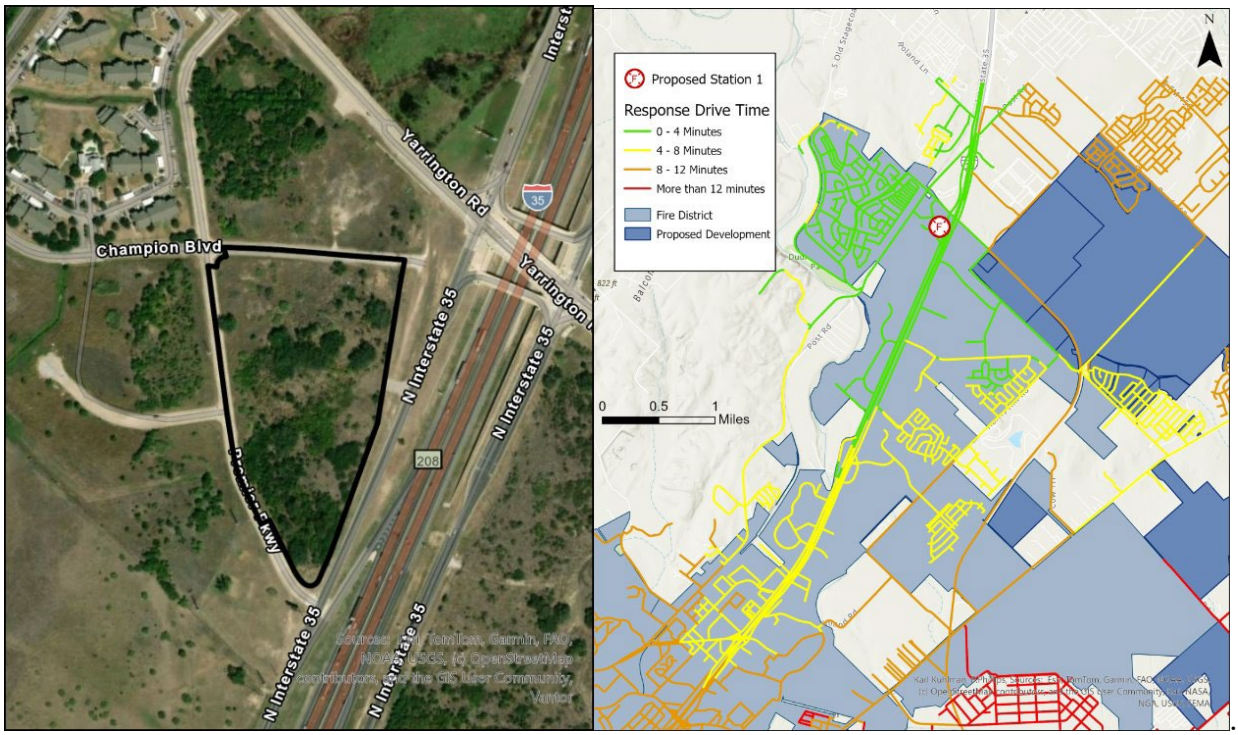

Figure 9: Satellite image and coverage network of first choice candidate site, P2

P3 (Figure 10, below) was selected as our second choice Station 7 candidate site. This location also performed well, with 45.45 miles of road network, 476 call points, and 4,142 people covered within 4 minutes. The pros of this site are its proximity to the highway and great coverage within 4 minutes. The primary con of this site is its larger acreage, which is likely to increase the cost of this parcel. Like our other proposed site, we have limited information on the feasibility of acquiring this land from the current owner.

Figure 10: Satellite image and coverage network of second choice candidate site, P2

Both parcels, (P2 and P3) are in northern San Marcos, which matches what we expected going into the project. This area currently has a large gap in coverage and includes a lot of planned development. This makes both options strong as candidates for a new station, both for current needs and future population growth.

In comparison, the city's proposed Station 7 location (Figure 11, below) covers 23.75 miles of road network, 51 call points, and 468 people within 4 minutes. Because of this, P2 and P3 are stronger options in terms of improving overall coverage. However, the ability to acquire the land for P2 and P3 may be more difficult since they are not already owned by the City of San Marcos.

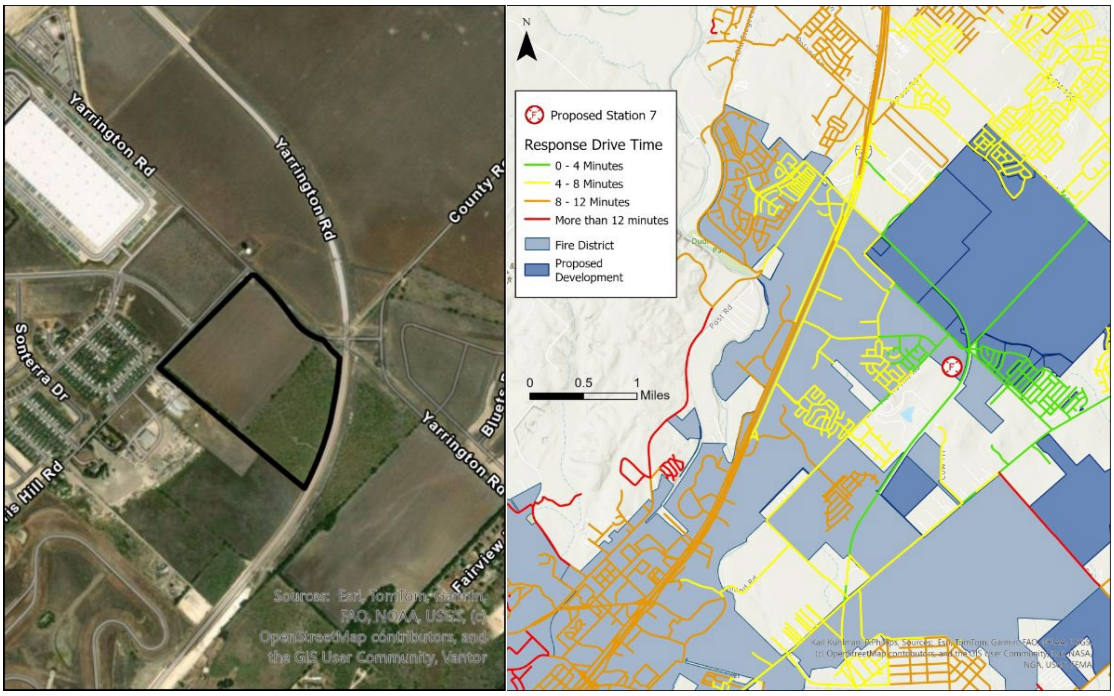

Figure 11: Satellite image and coverage network of current proposed Station 7 site

As a result of our network coverage analysis for these proposed sites, as well as the network coverage for the current active stations, we created a map that shows the hypothetical districts and quadrants (Figure 12). Furthermore, this map depicts coverage as though the current proposed development areas in Station 7's service area were adopted into the city limits.

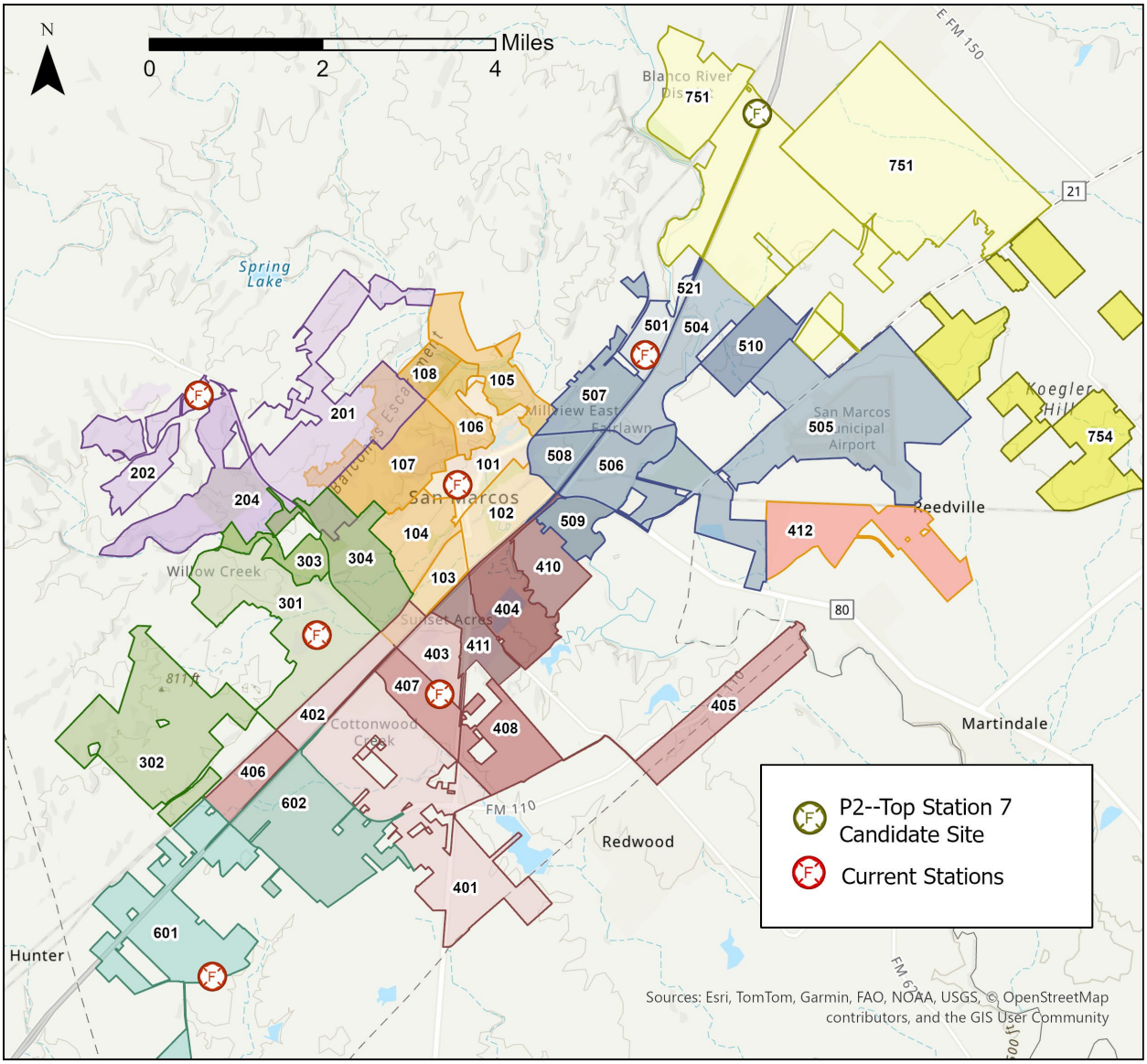

Figure 12: Hypothetical Station 7 boundaries with proposed development considered

Based on these hypothetical districts and quadrants, we can conclude that implementing station 7 at any of these candidate sites would help improve current coverage, as well as effectively account for future growth. While the current proposed location 7 offers decent coverage, it may not be most optimal in terms of meeting the NFPA 1710 response time standards. It may be beneficial to inquire further into building Station 7 at one of our proposed candidate sites.

Limitations:

There were some issues with the data available. The road network used was missing some roads, primarily around areas of construction. This is a limitation because much of our analysis is being done to meet future demand in those areas of construction. Additionally, when performing analysis, the location allocation tool automatically attributed points to the nearest road centerline. We found that this didn't exclude any points from being included in the selection process but could have introduced an error in how many seconds were added or subtracted to each demand point. Another area where our analysis was limited was the availability of land for construction purposes. Ease of acquisition weighs heavily in how favorable each site and parcel is in the real world for our client, and we could not secure much information in that regard. Lastly, when using census and population data for analysis, we began to run into the modifiable areal unit problem (MAUP). To address and mitigate these statistical errors, we clipped the census tracts and created centroids for the tracts in the relevant study area.

Conclusion

This study was a compelling deep dive into an integral service of San Marcos that is often taken for granted until you personally need it – emergency fire response. Through the course of the semester working in conjunction with the San Marcos Fire Department and the City of San Maros our group gained a deeper understanding and appreciation for all the work that goes into making important spatial decisions at a municipal level. Through multifaceted research and analysis, two alternative locations for the newest fire station were suggested. Our prediction in the beginning of the semester was validated by our analysis, as our most optimal location that we found is in northern San Marcos.

This project really highlighted the impact that data and technical analysis can have on planning decisions, especially in something as critical as emergency response. The implementation of GIS and network analysis helped us to more clearly identify where gaps in coverage may exist, and how different locations can improve coverage and response times. However, it also showed that these decisions come with challenges, especially when trying to meet standards like the 4-minute NFPA 1710 response time, while also keeping up with the continued population growth in San Marcos. As the city expands, maintaining adequate coverage becomes increasingly complex and requires ongoing analysis and adjustment.

Furthermore, we also learned that there are many other important considerations beyond just the results of data. For example, a model may identify an optimal location, but other real-world factors such as land availability, land cost, and future development plans will ultimately determine the feasibility of implementing a station at a certain site.

Overall, this project strengthened our understanding of how GIS can be applied to real-world public safety challenges. It emphasized both the broader impact of improving emergency response coverage for a growing community and the value of applying technical tools to solve complex spatial problems. For future work, this analysis could be expanded by incorporating projected population growth and using more up to date population data and road networks as it becomes available, to better plan for long-term service needs.

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Appendix

Appendix I - Group Member Contribution

Aryssa Camenisch – Narrowed down parcels for site selection based on current coverage, call points, suitability raster, and size. Organized further steps for analysis and selection of final parcels. Calculated the miles of road covered within 4 minutes for each proposed site and current station 7 site. Wrote out and inserted figures for methods, results and discussion for site selection portion of project. Created the hypothetical station 7 district map. Revised and added onto the abstract and conclusion. Revised paper, slides, and poster, fixing any grammatical errors or inconsistent language.

Alexander Garana – Created service area network for current and proposed stations, helped James with Location Allocations. produced layouts for service areas, location allocations, and scope map. Wrote and made slides for current service area analysis, as well as the results and discussions.

Aubree Dorman – Poster creation with Aryssa, timetable, district and quadrant remapping section including maps and slides.

Jacob Buchman – slide creation formatting and proof reading, final paper layout creation and formatting. Wrote abstract, introduction, data, and conclusion sections of paper. Data table and flowchart creation and formatting.

James Hezel – Group Logo generation (Grok), Location Allocations for census and call data, Budget, helped Alexander with Service Areas

Appendix II - Metadata

File Name	Description
Location-Allocation 4 minute census	A network analysis layer that uses the CensusBlocksin_FeatureToPoint layer as demand points, the original fire stations(1-6) as required facilities, and our proposed sites(Five_Candidate_Sites_FeaturetoPoint) + proposed station 7 as our candidate facilities. Used to pick which of the proposed sites would best serve the population.
Location-Allocation 4 minute call	A network analysis layer that uses the Callpoints layer as demand points, the original fire stations(1-6) as required facilities, and our proposed sites(Five_Candidate_Sites_FeaturetoPoint) + proposed station 7 as our candidate facilities. Used to pick which of the proposed sites would best cover areas that have requested assistance in the year of 2025.
Five_Candidate_Sites_FeaturetoPoint	A polygon to point generated layer that turns our proposed parcels into points to be suitable for input into the location allocations and service area analyses
CensusBlocksin_FeatureTopoint	A polygon to point generated layer that turns the clipped census blocks into points to be suitable for input into the location allocations and service area analyses
Callpoints	Fire department call data from 2025 provided by CSM put into point form from excel
FireDistrict_Merge	Merged Shapefile showing the current service districts of fire stations in San Marcos combined with San Marcos' proposed development areas
Railroad_Intersect	A multi-point feature class showing where Railroads intersect with roads in San Marcos
ServiceAreaWRailroads	Service area of existing San Marcos fire stations including a 30 second added cost for railroad crossings
FDStation7ServiceArea	Service area for the San Marcos fire departments proposed station 7 using 30 second added cost at railroad crossings, 4-, 8-, and 12-minute cutoffs

ProposedStation1ServiceArea	Service area for our first proposed fire station using added cost at railroad crossings, 4-, 8-, and 12-minute cutoffs
ProposedStation2ServiceArea	Service area for second first proposed fire station using added cost at railroad crossings, 4-, 8-, and 12-minute cutoffs
ProposedStation3ServiceArea	Service area for our third proposed fire station using added cost at railroad crossings, 4-, 8-, and 12-minute cutoffs
ProposedStation4ServiceArea	Service area for our fourth proposed fire station using added cost at railroad crossings, 4-, 8-, and 12-minute cutoffs
ProposedStation5ServiceArea	Service area for our fifth proposed fire station using added cost at railroad crossings, 4-, 8-, and 12-minute cutoffs
Fire_District_Remapping	Edits to districts provided by City of San Marcos, new shapes created and merged into existing shapes to create new districts
Hypothetical_Station_7_Districts.Shp	Shapefile of the hypothetical districts and quadrants with appropriate response sequence considering the addition of Station 7 at the top proposed site, P2. Original quadrants and attributes were derived from City of San Marcos district/quadrant and were used as the template data.
P2_Parcel_Boundary	Shapefile of P2 candidate parcel, contains original attributes from City of San Marcos sourced parcel data.
P3_Parcel_Boundary	Shapefile of P3 candidate parcel, contains original attributes from City of San Marcos sourced parcel data.

Appendix III - Contact Information

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James Hezel – ity7@txstate.edu (830)-730-8857

Appendix IV – AI Use 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”.