Investigating Metropolitan Traffic Congestion in Albuquerque

An interactive Qualifying Project
Submitted to the Faculty of:

WORCESTER POLYTECHNIC INSTITUTE

In partial fulfillment of the requirements for the
Degree of Bachelor of Science

By
Rachel Aston, Dillon Bordeleau,
Ashley Kishibay, Ricardo Llorente Ruiz

October 10th, 2018

Professor Lauren Mathews
Worcester Polytechnic Institute

New Mexico Department of Transportation

Santa Fe Project Center

Executive Summary

Background

In a majority of densely populated cities, highways often present the only efficient means of travel through or across a city. Police activity, accidents, road work, and other traffic events can significantly congest highways and force travelers to seek alternate routes to their destinations, introducing additional traffic flow to smaller, city streets, stressing them with more traffic than they were designed to handle.

Albuquerque's major highways are I-25, running north to south, and I-40, running east to west. When a traffic incident occurs on a section of either highway, drivers may reroute through the metropolitan streets of Albuquerque (John DiRuggiero, personal communication). Tim Brown, the lead traffic engineer for the city of Albuquerque, estimates that "any considerable highway incident" will affect fifty thousand to one hundred and fifty thousand highway drivers before the incident is cleared. The Albuquerque metropolitan streets must be prepared to handle such a large and quick influx of cars off the highway.

Some solutions to ease congestion already in place include dynamic message signs, dynamic traffic lights, traffic cameras, variable speed limits, the NMRoads smartphone application, and vehicle detection systems (NMDOT, 2014). A number of these traffic solutions are overseen by the Intelligent Transportation System (ITS) bureau of the NMDOT, which aims to foster the application of ITS solutions in New Mexico by offering guidance to governmental decision makers, supporting public-private partnerships, advocating ITS deployment, encouraging innovative ideas, and encouraging interest and support of ITS in New Mexico (Masek, 2017).

The goal of this project was to assist the New Mexico Department of Transportation in assessing the impact of highway incidents on metropolitan congestion in Albuquerque.

Methods

Using interviews conducted with officials from New Mexico Department of Transportation, Mid-Region Council of Governments (MRCOG), Albuquerque Traffic Management, and the New Mexico Intelligent Transportation Systems Bureau, paired with data analysis with ArcGIS and Structured Query Language, the team located the 6 accident hotspots that would be researched more closely based on the severity of accidents that took place.

For these hotspots, the team then used ArcGIS to identify alternate routes using their COGID numbers, the serial numbers used by MRCOG in their searchable database called "Transportation Analysis & Querying Application" (TAQA) to identify sections of road in metropolitan Albuquerque. We then compiled TAQA data illustrating travel environments 90 minutes before and after an incident in 15 minute increments. Then we filtered through these segments to find road segments with a +/- 10% change in average vehicle speed, before calculating the travel time and speed differentials before and after the accidents.

Results

Alternate routes comprise individual segments. The group analyzed each segment individually as well as the routes as a whole to decide if they were capable of handling the extra traffic, or if they would become congested. With SQL and Python, the team calculated the average delays, for all major roads of Albuquerque, per mile, for city streets and off ramps. Overall, the average delay on Albuquerque interstate off-ramps was calculated to be 3 minutes per mile, while the average delay on Albuquerque metropolitan streets was 2 seconds per mile. This suggests that most of the congestion in Albuquerque resulting from highway incidents occurs on Albuquerque off-ramps rather than on city streets. The group gave the NMDOT recommendations regarding individual segments of road that are able to handle an influx of traffic from the highway and warn them of segments that should be avoided as rerouting options. From our interview in Albuquerque with traffic experts, as well as many conversations with our liaison, John DiRuggiero, the most serious issue our team discovered was not to do with the traffic in Albuquerque, but instead the lack of communication between agencies.

Conclusion

Through data analysis, the team discovered that highway incidents do not cause major metropolitan street congestion, but instead the backups are found mainly on off-ramps, presumably because some drivers choose to exit the interstate to avoid the accident. But overall, we found that drivers usually choose to stay on the highway and wait out the traffic instead of rerouting themselves or choosing to use GPS rerouting applications that could easily help them avoid congestion. In this report, we give written and visual summaries to the NMDOT that will help them understand the reroutes available for each of the 6 hotspots and how effective each reroute is at handling traffic. One unexpected insight from our work came from our interviews with the officials in charge of New Mexico traffic. Through these conversations, we learned that there are significant problems with communication. We suggest that these communication problems may be a significant limitation in how effectively agencies are able to manage traffic congestion. Our project will aid the NMDOT in receiving a federal grant that will help with roadway infrastructure as well as communication between different agencies. Overall, this project hopes to help make Albuquerque, and New Mexico, an ameliorated state to drive in.

Acknowledgements

First, we would like to recognize the New Mexico Department of Transportation, for sponsoring our project and allowing us this remarkable experience. We would also like to take time to recognize the following organizations and individuals:

John DiRuggiero, our liaison: For his dedication and support to the team. We are extremely grateful to have been able to work alongside you, constantly learning from you every step of the way.

Timothy Brown, Nathan Masek, and Charles Remeks: For your willingness to be interviewed by the team, allowing us to better understand the issues you deal with every day in Albuquerque and the issues you face. This project would have not been possible without you all.

Aaron Park, of Econolite: For your readiness to host our group and give a presentation detailing ITS solutions.

Ron Newman, of Amber Road: For your presentation on traffic patterns, autonomous vehicles, and connected cars, which gave the team a more complete understanding of traffic and the future of cars on the road.

Professor Lauren Mathews: For your constant support and guidance throughout the project. This project would not have been successful without your devotion and feedback to the team.

Professors Melissa Butler and Fabio Carrera: For your support and feedback to the team. We appreciate all the help you have offered to see this project become successful.

Abstract

Our project aimed to assist the New Mexico Department of Transportation in assessing Albuquerque congestion data. The team's analysis will be used to support an application for a one-million-dollar federal grant that will be used to work on roadway infrastructure and communication between the agencies that focus on roadway safety. We researched incident hotspots on I-25 and I-40 and then compared pre- and post-crash surface road conditions in order to understand how highway incidents affect surface congestion for the NMDOT. The end result of our project included a written report summarizing our findings as well as visuals that were presented to representatives of the NMDOT, Albuquerque Traffic Management, MRCOG, and the NMDOT ITS Bureau.

Authorship

	Primary author (s)	Primary editor (s)
Executive summary	All	All
Abstract	Rachel	All
Chapter 1 Background	Dillon	All
1.1 Traffic Overview	Rachel	All
1.2 Traffic Management	Rachel	All
1.3 GIS	Rachel	All
1.4 Data Mining	Dillon	All
1.5 Conclusion	Rachel	All
2. Methodology	Dillon	All
2.1 Identify Problematic Stretches of Highway	Dillon, Rachel	All
2.2 Analyze Congestion Resulting from Accidents of Interest	Dillon	All
2.3 Using Python to conduct automated rush hour surveillance	Dillon	All
3. Results	Ricardo	All
3.1 Identify problematic stretches of highway	Dillon	All
3.2 Analyze congestion resulting from accidents of interest	Ashley, Ricardo	All
3.3 Using Python to conduct automated rush hour surveillance	Dillon, Rachel	All
4. Discussion, Recommendations, and Conclusion	Rachel, Dillon, Ricardo. Ashley	All

Table of Contents

Background

Hundreds of major cities across the globe rely on highways to handle the majority of traffic throughput into and out of their limits on a daily basis. While highways and freeways are generally capable of maintaining a reliably efficient throughput, they often present the only feasible means of travel through or across a major city. Accidents, road work, police activity, and other traffic events can significantly hinder highway throughput and force travelers to seek alternate routes to their destinations. Rerouting and detouring often introduce unpredictable traffic flow to metropolitan, city-level roadways and stress comparatively weak infrastructure with highway-caliber throughput. Many major cities find themselves without a remedy for combating metropolitan congestion; a lack of preparation and planning oftentimes inhibits efficient and reliable travel through neighborhood and downtown streets.

The majority of vehicles traveling into, out of, and through Albuquerque, New Mexico rely on two major interstates: I-25, running north to south, and I-40, running east to west. When a section of either highway is impacted by any number of possible traffic incidents, drivers typically reroute through the metropolitan streets of Albuquerque (John DiRuggiero, personal communication). The city of Albuquerque estimates that "any considerable highway incident" will displace fifty thousand to one hundred and fifty thousand highway drivers before it is fully addressed and cleared (Tim Brown, personal communication). The city-level streets of Albuquerque are not able to handle large, steady influxes of traffic sourcing from either interstate. A lack of mitigation strategies and protocols for managing overflow from highway incidents has resulted in widespread congestion and stress across an ill-prepared infrastructure incapable of handling increased throughput (Tim Brown, personal communication). Nonetheless, several solutions have been presented to combat congestion on a broader scale. The NMDOT launched NMRoads, a smartphone app, in 2006 to advise New Mexico drivers of road conditions, weather conditions, construction, and congestion. The NMDOT has also made use of dynamic message signs to broadcast pertinent travel information and notifications to travelers, dynamic traffic lights, variable speed limits, traffic cameras to monitor traffic conditions, and vehicle detection systems to collect data regarding vehicle presence, volume, speed, and occupancy (NMDOT, 2014).

The Intelligent Transportation Society of New Mexico believes innovative transportation technologies can significantly improve the performance of New Mexico's transportation system by saving lives and reducing overall congestion. The society aims to foster the application of Intelligent Transportation System (ITS) solutions in New Mexico by encouraging innovative ideas, supporting public-private partnerships, advocating ITS deployment, offering guidance to governmental decision makers, and encouraging interest and support of Intelligent Transportation Systems in New Mexico (Masek, 2017).

Currently, operational intelligent transportation systems in New Mexico perform a variety of automated data collection and congestion mitigation functions that assist the NMDOT in handling a breadth of traffic events and scenarios. Some systems are able to gather, document, and analyze geo-spatial traffic throughput and incident data. Other systems make real time strategic mitigation suggestions and dynamically recommend the introduction of interim reversible traffic lanes. Even further, some systems dynamically produce and advocate detouring and rerouting options in response to major traffic incidents and events within the state of New Mexico (Tim Brown, personal communication).

While both low-tech and high-tech protocols are in place throughout New Mexico to combat congestion on a broader scale, specific research into the impacts of freeway traffic events on metropolitan street congestion in Albuquerque is sparse and lacking. The Department of Transportation is particularly interested in investigating the behavior of drivers immediately following the occurrence of significant traffic events on either of the major Albuquerque interstates. The Department of Transportation also aims to improve mitigation strategies in specific areas of the city, particularly in the newer, western areas, where existing roadway grid systems stray from linear convention. On this front, the Department of Transportation is interested in investigating the anticipated role of autonomous travel on freeways and metropolitan roadways and the effects of autonomous rerouting on existing congestion mitigation strategies (Tim Brown, personal communication).

1.1 Traffic Overview

Before identifying inefficiencies in the New Mexico Department of Transportation's current traffic incident management systems, it is important to become familiar with the breadth of congestion mitigation solutions currently being used in Albuquerque. With a working comprehension of existing strategies, the team will then conduct in-depth analyses and pinpoint areas of congestion mitigation inefficiency. Further investigation will then be conducted into these specific areas, lending the Department of Transportation with a product helpful in their pursuit of a more efficient response plan to freeway and highway incidents.

1.1.1 How Traffic Becomes a Problem

As the global population rises and metropolitan areas grow larger worldwide, the workforce density and the number of daily commuters increase. As shown in Table 1, the majority of European commuters take public transportation, walk, or bicycle to work, while commuters in major American cities utilize public transportation significantly as their main mode of travel ("How Green are the World's Cities?", 2012). Therefore, as the population increases, roads are more prone to traffic congestion. Over 80 percent of commuters drive to work in the United States (Muoio & Nudelman, 2017) and, in doing so, actively contribute to increasing amounts of congestion. Americans spend an average of 42 hours a year in traffic jams, wasting valuable time and $960 annually on fuel (AutoInsurance Center, 2015).

Table 1: Share of Citizens Walking, Cycling, or Taking Public Transit to Work ("How Green are the World's Cities?" [2012], using data from Economist Intelligence Unit [2012])

Green City Index **: Share of Citizens Walking, Cycling or Taking Public Transportation to Work**				
Overall Ranking	*Europe*		*U.S. and Canada*	
	City	*%*	*City*	*%*
1	Copenhagen	33.0	San Francisco	20.1
2	Stockholm	93.0	Vancouver	24.5
3	Oslo	57.0	New York City	37.2
4	Vienna	68.0	Seattle	13.2
5	Amsterdam	83.0	Denver	7.4
6	Zurich	62.0	Boston	18.3
7	Helsinki	44.7	Los Angeles	9.7
8	Berlin	54.8	Washington DC	17.9
9	Brussels	37.0	Toronto	28.0
10	Paris	40.4	Minneapolis	7.9
11	London	63.0	Chicago	15.3
12	Madrid	54.0	Ottawa	28.4

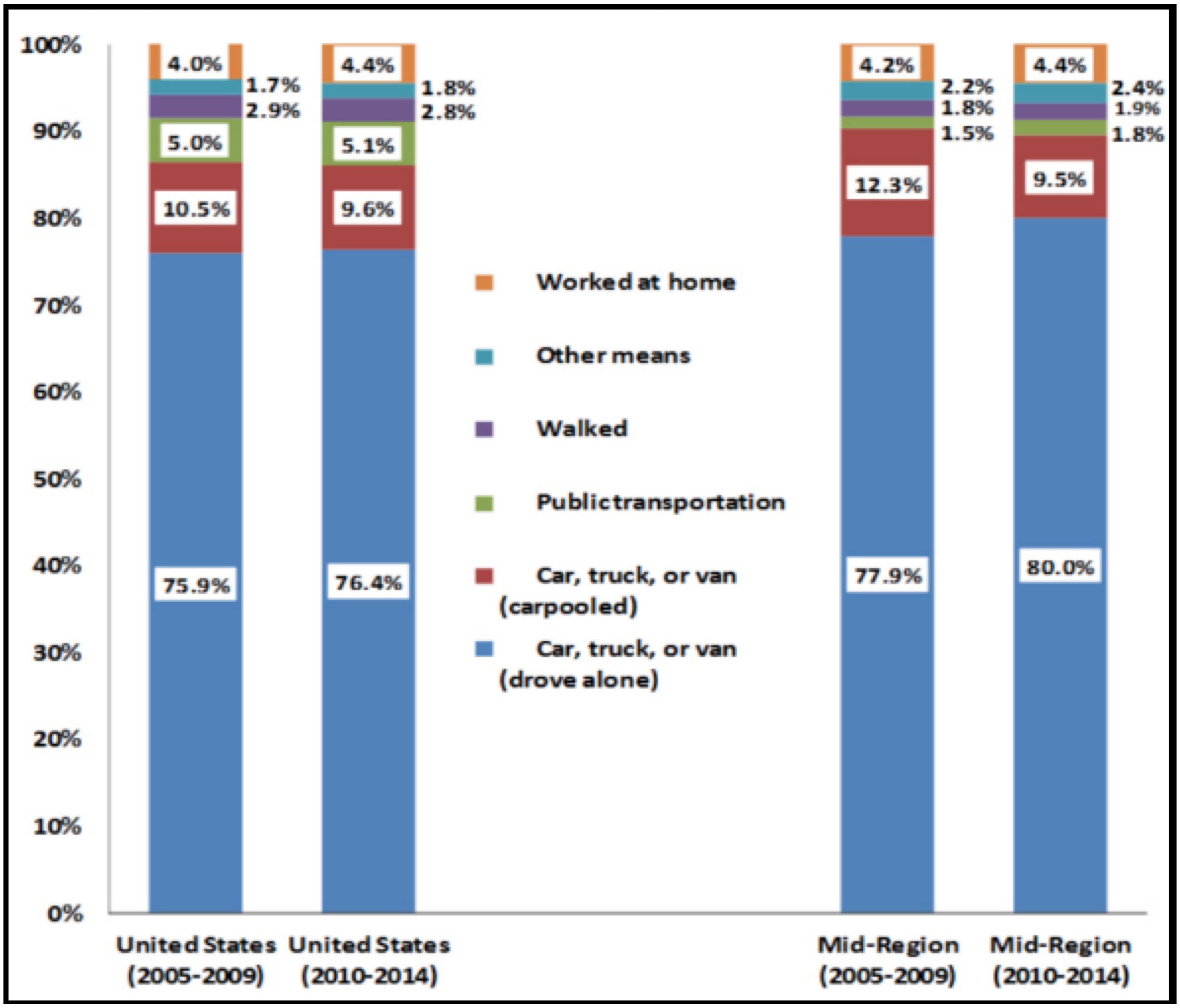


Figure 1: Mode of Transportation to work in New Mexico and the United States (MRCOG, 2014)

In New Mexico, 80 percent of the working population drives their car alone to work. Commuters traveling from Santa Fe to Albuquerque have the option to take the Rail Runner. The Rail Runner ridership has declined since 2010, due to fewer departure times from Santa Fe, making it an inconvenient commuting option. Officials blame the decreasing popularity on the low gas prices New Mexico has been experiencing in the last years. (Oxford A, 2017). We calculated the cost of driving the 60 miles compared to taking the train from Santa Fe to Albuquerque to see what the most economical choice was. Using the most sold vehicle in the US, a Honda Civic with a 33-mpg average, the cost of gas per month is $196 (Oxford, 2017) (Rosevear, 2017). Commuters choosing to take the Rail Runner will only be spending $110 a month between the ABQ and Santa Fe zones. Even with this comparison, the number of people using the Rail Runner has decreased by 6 percent in the last year and has been dropping since 2010 (Oxford A, 2018). Officials predict that the only reasons this trend would change would be if gas prices rise dramatically or if the traffic on I-25 worsens. When residents already have a car to travel places within the state, they choose the convenience and self-reliability of driving instead of relying on public transportation.

Car accidents are the main cause of congestion on roads, because they worsen traffic conditions and increase death tolls. With more privately-owned cars on the road, the chance of an accident, and consequently a death due to an accident, increases. Each year, approximately 1.24 million people worldwide die in car crashes, 400,000 of which are people under 25 (ASIRT, 2017). INRIX, a company that collects traffic data, ranked traffic congestion levels of cities around the world, with 7 out of the top 15 cities located in the US. By identifying and altering those cities' congestion relief and car accident prevention plans, the NMDOT can implement these traffic solutions to improve commute time and traffic congestion. The time and severity of car crashes can be unpredictable, but with planning and preset reroutes in already high crash-density sections of road, drivers will spend less time in traffic jams caused by crashes.

1.2 Traffic Management

The New Mexico Department of Transportation has several traffic management systems in place that try to organize and alleviate traffic issues throughout the state of New Mexico. The technology in use is constantly gathering real-time data that updates dynamic message signs, variable speed limits, dynamic traffic signals, the NMRoads app, and other ITS traffic management systems. The NMDOT hopes that the baseline work that our team creates will highlight the need for new and updated traffic management systems to better control Albuquerque traffic. Traffic management systems are expensive for cities, but the congestion relief benefits greatly outweigh the cost.

1.2.1 Intelligent Transportation Systems Solutions

Intelligent Transportation Systems (ITS) are in place across the nation to advance safety and mobility on roadways. ITS combines transportation infrastructure with high-tech communications technology to wirelessly connect cars on the roadways and electronic technologies (Pina, 2016). In short, ITS is technology that gathers information in specific areas, analyzes the data to understand impact, and communicates that information to drivers as a way to manage traffic and minimize traffic impacts (Masek, 2017). The Intelligent Transportation Society of New Mexico believes innovative technologies can "significantly improve the performance of [New Mexico's] transportation system by saving lives and reducing congestion" (Masek, 2017).

Dynamic Traffic Lights

Traffic lights have been used around the world since 1912 but have been upgraded in certain areas in an effort to alleviate traffic congestion (Ghazal, 2016). Dynamic traffic lights have the ability to change the timing of the lights, depending on time of day, peak hours of traffic, unexpected traffic flows due to accidents or roadwork, or holidays. New Mexico has found that the usage of dynamic traffic lights try to control the flow of traffic on city-level roads (John DiRuggiero, Personal Communication). If dynamic traffic lights are in use, but have a miscommunication, it is possible that traffic in this area will only worsen and lead to larger traffic jams. Dynamic traffic lights, when used properly, may be able to solve "severe traffic congestion, alleviate transportation troubles, reduce traffic volume and waiting time, minimize overall travel time, [and] optimize cars' safety and efficiency" (Ghazal, 2016).

Variable Speed Limits

Variable Speed Limits (VSL) are currently being used on certain stretches on I-40 that run through Albuquerque and other areas of New Mexico. The New Mexico Department of Transportation may alter the speed limits in the area for a multitude of reasons including "traffic speed, traffic volume, crashes, congestion, construction, ice, snow, fog, etc." (Davey, 2017). VSL are put in place to improve the safety of roadways, respond to dynamic conditions, provide real-time response to issues on interstates, and increase the efficiency of highways (Davey, 2017). The U.S. Department of Transportation Federal Highway Administration created a full report on VSL in use on I-40 in Albuquerque, which highlights how helpful this technology can actually be to local DOTs.

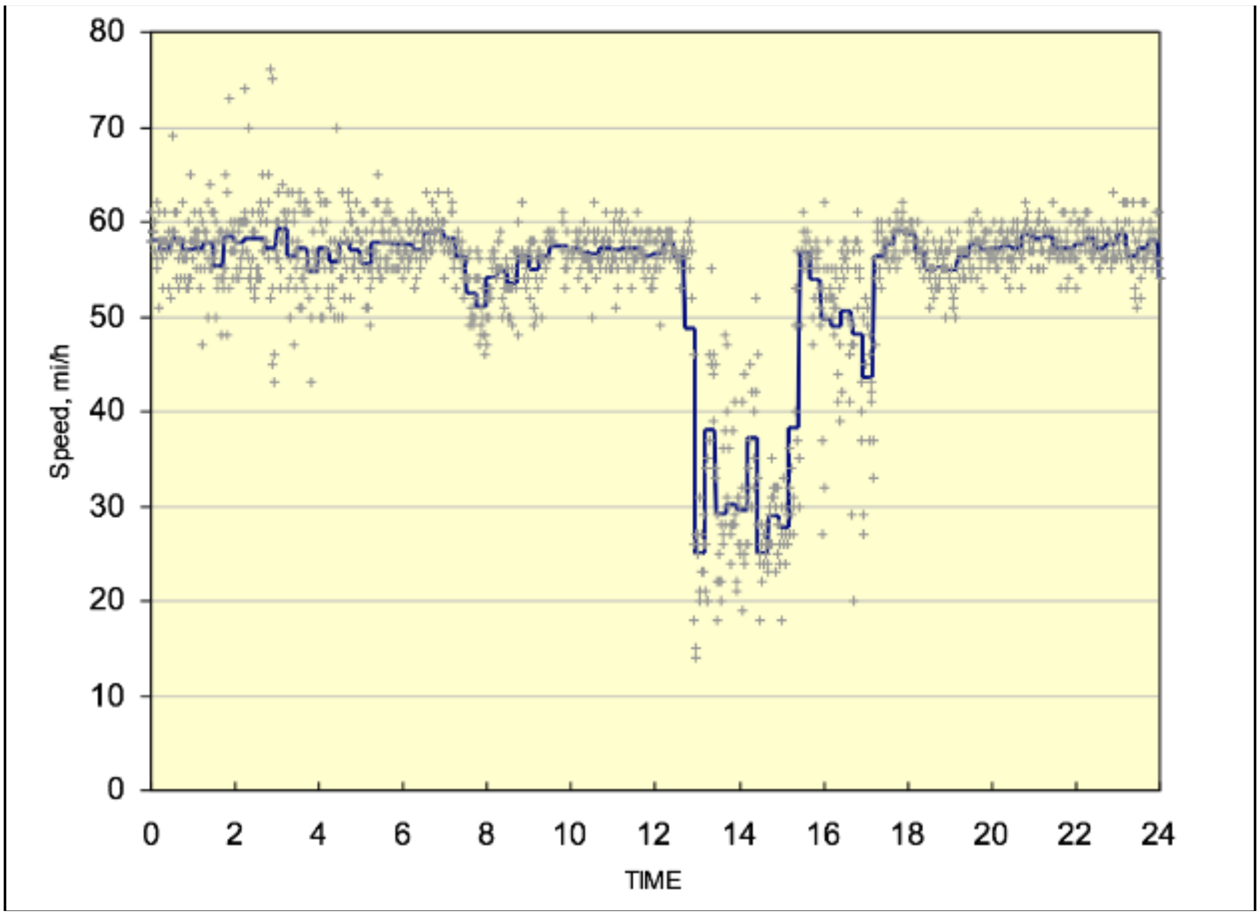


Figure 2: Graph of variable speed limits over a 24 hour period on I-40 (Warren, 2017)

Figure 2 shows an example of how variable speed limits were employed for a 24 hour period in Albuquerque. Over the 24 hour period, the speed limit on a stretch of I-40 was recorded along with the times and the conditions taking place when the speed was automatically changed. The speed for the day in a work zone was set at 45 mph, but the Federal Highway Administration found that this speed was too slow for normal traffic conditions on this stretch of I-40, so the speed for a majority of the day was raised 10 to 20 mph above 45 mph. Midday, between 1 and 5 pm, the speed limit drops 10 to 25 mph less than 45 mph due to the extra activity and congestion on the roadways. In this 24 hour period, the speed limit changed multiple times in order to adapt to the activity taking place on the roadways and make the interstate safer and less congested (Warren, 2017).

Navigation Smartphone Applications

Drivers have many navigation applications available to aid them when they are driving. The most popular, including Google Maps, Apple Maps, and Waze, are available on all smartphones and will give recommendations to drivers based on upcoming road conditions (Zahradnik, 2018). Waze gathers information through reports that users issue to the application. The app monitors the speeds of its users, offers rerouting options real-time, and estimates the traffic jam time for drivers. Google Maps and Apple Maps offer a less personal feel to the navigation options compared to Waze because users cannot report incidents they feel should be communicated to oncoming traffic; these apps recommend routes that are computer generated based on data they receive on current traffic conditions (Coomes, 2018). Locally, NMRoads, an app available for all smartphones, advises drivers in New Mexico of current conditions that they may find helpful. For example, over 70 popular locations are live-broadcasted to users, providing a real-time view of the roadways and traffic conditions. There are more than 3 dozen dynamic message boards available on the app, as well as real-time travel times available for commuters into the Albuquerque area, alerts for drivers on incidents and road work that may affect them on the roadways, and links to NM Rail Runner train services as well as Park and Ride locations (ITS Bureau, n.d.a; NMRoads, 2017). While this app has a plethora of more specific information for New Mexico drivers, not all drivers will download this app or even are aware that there is a specific New Mexico application available to them. For the NMDOT, the NMRoads app would be most effective in communicating the most important messages to New Mexico drivers.

Dynamic Message Signs

The New Mexico Department of Transportation or NMDOT uses dynamic message signs that broadcast important messages along roadways, cameras that give a live view of the most traveled roads, and vehicle detection systems (VDS) which collects data regarding “vehicle presence, volumes, counts, speed, and occupancy” (NMDOT, 2014). Dynamic message signs are an example of traveler information systems, systems that update drivers on any pertinent information on their current route, using ITS that are put in place to inform drivers of road conditions. If drivers are aware of an incident ahead, they are 50% more likely to alter their regular route, which would result in better traffic flow around the incident and avoid a major build-up of traffic (Knoop, 2010). Expected travel times, delays, accidents, and emergency alerts are conveyed through ITS to drivers to allow them to make informed decisions. These messages have a major impact on the decisions drivers make; for example, “nearly 80% of drivers use traveler information to make daily decisions about route or departure time” (TAMU, 2014).

Most states are currently collecting the information needed to update drivers, but there is a gap in solutions being put into action, preventing the proper information from being broadcasted. In Houston, Texas, a traveler information system called TranStar is used to reach more than 500,000 drivers each month (TAMU, 2014). This system was developed by the Texas DOT in order to update drivers in the area with current information to inform drivers of problem areas. TranStar sends around 2 million messages regarding travel times and incidents affecting the roadways to 200 roadside messaging signs all around the city each year (TAMU, 2014). By messages being broadcasted to the Houston area, drivers made better decisions which helped alleviate congestion in the area. Drivers cannot make educated decisions to change their route or plan ahead if they are never warned of a possible inconvenience, so dynamic message signs may be able to greatly impact the habits of drivers. Houston is using the information being gathered to assist their drivers, which is the disconnect between information gathered and communication to drivers that occurs in Albuquerque. Learning from other cities and what has worked best for them is a great way to better Albuquerque traffic protocol.

1.3 Geographic Information Systems

The application of Geographic Information Systems (GIS) in urban traffic management allows for dynamic and comprehensive analysis of recurring congestion. GIS is a programmable interface useful for investigating both traffic anomalies and traffic patterns through presentation of quantitative datasets. Geographic Information Systems are typically developed over the following timeline: 1) develop a base map illustrating a static road network, 2) map vehicle travel and associated timestamps using provided datasets, and 3) develop an interactive interface for use in traffic management and analysis (Xiao, 2010).

Existing implementations of Geographic Information Systems such as Google Maps, Apple Maps, and Waze provide real-time visual representations of traffic situations. In using these applications, a traveler dynamically avoids congestion and responds to arising delays and incidents on the fly. Though these implementations provide a rich traveler-oriented experience, their datasets offer little insight towards a more efficient traffic management sought by departments of transportation across the country. The New Mexico Department of Transportation purchased datasets from Google Maps, Apple Maps, and Waze that add to the extensive datasets available to analyze in order to find traffic patterns.

The team will foreseeably develop Geographic Information Systems to demonstrate traffic flows throughout the metropolitan Albuquerque area. Historical traffic datasets provided by the New Mexico Department of Transportation will offer mappable data points. Displayed data points will contribute to the development of traffic flow classification and observation. The GIS will provide associative queries of hyper-localized vehicle travel at and through real-world and technological observation gates–maintained roadside by the Department of Transportation (Xiao, 2010). The system will also establish an effective mechanism for information publication, traffic management operation, and real-world and real-time incident response (Xiao, 2010). The team will use data mining techniques to parse large traffic datasets for pertinent insights that could lend themselves to conclusive theories of congestion causation and correlation.

1.4 Data Mining

Data mining is the process of discovering patterns in large datasets using methods at the intersection of machine learning, statistics, and database systems. The team will receive a wealth of traffic data upon arrival in Santa Fe detailing traffic counts and congestion-causing incidents on I-40, I-25, and the immediate surrounding metropolitan roadways. The New Mexico Department of Transportation has yet to conduct analysis in specific pursuit of identifying congestion-causing factors on freeways. Further, the Department of Transportation has yet to have analytically examined metropolitan traffic propagation resulting from freeway incidents. While in Santa Fe, we will comb extensive traffic datasets in search of congestion causation and will pursue a defined illustration of any recurring congestion propagation through street-level Albuquerque.

Nine iterative steps are generally applied to data mining: 1) develop an understanding of the application, of the relevant prior knowledge, and of the end user's goal, 2) create a target data set to be used for discovery, 3) clean and preprocess data (including handling missing data, noise in the data, accounting for time series, etc.), 4) reduce the number of variables and find invariant representations of data if possible, 5) choose the data mining task (classification, regression, clustering, etc.), 6) choose the data mining algorithm, 7) search for patterns of interest, 8) interpret the pattern mined, and 9) consolidate knowledge discovered and prepare a report (Chung, 1999).

Data mining tasks generally yield at least one of five conclusions: 1) associations, which identify things done together, 2) sequences, which identify events occurring repeatedly over time, 3) classifications, which establish rules for organizing new patterns, 4) clusters, which define previously unknown teamings, and 5) forecasting, which formulated predictions from a time series (Chung, 1999). Data mining techniques are usually employed using "siftware," or software that provides data mining algorithms and various models of interpretation such as neural networks, multidimensional analysis, data visualization, and decision trees (Chung, 1999).

Hyperlocal traffic pattern and congestion data for the Albuquerque metropolitan areas will be provided by the New Mexico Department of Transportation upon arrival. The datasets are expected to be robust but loosely correlated; data mining and related traffic analysis techniques will assist the team in developing actionable traffic pattern theories and conclusions. For instance, traffic analysis studies oftentimes make use of a branch of data mining known as cluster analysis. Cluster analysis in the context of traffic study teams similarly behaving roads into clusters and then studies them collectively; cluster teams are initially formed on grounds of similar existing road functionality and behavior. Traffic flow anomalies and behaviors are typically homologous within these teams, lending basis for overarching conclusion.

1.5 Conclusion

The goal of this project was to assist the New Mexico Department of Transportation in investigating the impact of highway incidents and closures on metropolitan street congestion in Albuquerque. The team analyzed extensive traffic datasets, identifying recurring congestion and rerouting patterns that result from traffic events, and produced a range of products identifying particularly inefficient aspects of current metropolitan congestion mitigation strategies. The team developed a report discussing existing intelligent transportation system infrastructure, noticeably problematic roadway and throughput infrastructure, and significant crash frequencies and locality patterning through Albuquerque. In all, the team hoped to assist the New Mexico Department of Transportation in developing a safer and more efficient protocol for responding to traffic incidents and congestions throughout Albuquerque. The team's report will help the Department of Transportation create an educated baseline assessment establishing the need for improved traffic incident management systems citywide. The recommendations and products of this project could potentially be used as platforms for further intelligent transportation system and traffic incident management system research both in Albuquerque and in other major cities across the United States.

2.0 Methodology

The goal of this project was to assist the New Mexico Department of Transportation (NMDOT) in assessing the impact of highway incidents on metropolitan street congestion in Albuquerque. The team accomplished this goal in pursuit of three objectives:

1. Identify problematic stretches of highway,
2. Analyze congestion resulting from accidents of interest, and
3. Observe driver behavior in real time

The culmination of the team's work is a set of insights 1) assessing post-incident travel environments on metropolitan roadways and 2) characterizing the post-incident behavior of highway drivers. The team interviewed field experts of various jurisdictions, assessed historical highway crash and metro congestion data using advanced analysis tools, validated findings with a state-of-the-art traffic surveillance program, and produced written and visual assessments of Albuquerque's post-incident travel environment and driver behavior.

2.1 Identify problematic stretches of highway

The NMDOT was primarily interested in 1) characterizing metropolitan congestion propagating from highway incidents and 2) assessing the rerouting behavior of highway drivers in response to highway incidents. In order to best characterize propagated metropolitan congestion, the team first needed to identify epicenters of congestion-causing activity on I-40 and I-25.

2.1.1 Conduct interviews with field experts

On August 30th, the team gathered insight into problematic stretches of highway by interviewing officials from the New Mexico Department of Transportation (NMDOT), the Mid-Region Council of Governments (MRCOG), Albuquerque Traffic Management, and the Intelligent Transportation Systems Bureau of the Department of Transportation (ITS) (Appendix A). The interview was casual, as it was a follow-up to a task meeting that the group attended to better understand the project and the goals they had for us. Most of the questions were to follow-up something that was previously mentioned that required more explanation in order to be useful to our group. Representatives of these departments outlined their objectives for the team and discussed the roles of their respective departments in the traffic management efforts of Albuquerque and the state of New Mexico. The team spoke with Charles Remeks, Manager of NMDOT ITS Operations, Nathan Masek, Senior Transportation Planner for MRCOG and President of ITS, and Tim Brown, Lead Traffic Engineer for the city of Albuquerque. The team presented the group with questions stemming from the following:

1. Can the NMDOT, MRCOG, or ITS Bureau provide insight into any metropolitan roadways or highway stretches with recurring congestion or congestion-causing incidents, i.e. comment on possible causation, plausible solutions or remedies?
2. Which existing congestion alleviation methods are most effective on roadways with recurring congestion, i.e. comment on the effectiveness of traffic enforcement, dynamic reroutes, incident management?

The group provided the team with insight into 1) specific sections of roadway and highway known to have recurring congestion and 2) existing congestion remedies. The team was therein tasked with identifying problematic areas of highway and analyzing the metropolitan congestion resulting from incidents occurring in these areas. The team's research and reporting will be appended the Department of Transportation's pending application for a million-dollar federal grant to improve traffic management systems in Albuquerque.

2.1.2 Finding "hotspots" of congestion-causing activity on I-40 and I-25

The New Mexico Department of Transportation provided the team with a comprehensive dataset detailing over forty thousand traffic incidents in the state of New Mexico for 2015. Each incident contained in this dataset is associated with over three dozen fields of metadata. For the investigatory purposes of the project, the team primarily made use of the following fields:

- Time of crash: this field denotes the time of day at which an incident occurred.
- Primary street: this field denotes the roadway on which the incident occurred.
- Secondary street: this field denotes a secondary roadway near or at which the incident occurred, perhaps indicating the incident occurred at a specific intersection or on/off ramp.
- City: this field denotes the city in which an accident took place
- Latitude coordinate: this field denotes an estimated latitude coordinate at which the incident occurred; this field allowed the team to geolocate areas of recurring congestion and incidents.
- Longitude coordinate: this field denotes an estimated longitude coordinate at which the incident occurred; this field allowed the team to geolocate areas of recurring congestion and incidents.
- Crash direction: this field denotes the travel direction for which the incident occurred, i.e. northbound or southbound, or eastbound or westbound; this field allowed the team to pinpoint crash location even further.
- Number of people killed in crash: this field denotes the number of people killed in an incident; this field provided the team with a primary indicator of incident severity.
- Number of people with class A injuries in crash: this field denotes the number of people that sustained a class A injury during an incident; this field provided the team with a secondary indicator of incident severity.
- Number of people with class B injuries in crash: this field denotes the number of people that sustained a class B injury during an incident; this field provided the team with a

tertiary indicator of incident severity.

- Number of people with class C injuries in crash: this field denotes the number of people that sustained a class A injury during an incident; this field provided the team with a quaternary indicator of incident severity.

The 2015 crash dataset, and particularly the data fields noted above, provided the team with a queryable knowledge base of all incidents occurring in the state of New Mexico in 2015. The team aimed to establish a cause and effect relationship between highway incidents and metropolitan congestion: this dataset detailed the "cause."

Processing New Mexico crash data for 2015

The 2015 crash dataset contained metadata for over forty thousand traffic incidents occurring throughout the entire state of New Mexico. First, the team used Structured Query Language (SQL) to isolate incidents that occurred 1) on either I-40 or I-25 and 2) within Albuquerque city bounds. The resulting incidents were the only incidents of interest to the team. The remainder of the incidents, such as metropolitan incidents or incidents in remote regions of the state, were disregarded. In this process, the team ensured the following for each incident of interest:

1. Either I-40 or I-25 was noted as the incident's primary street in metadata, or
2. Either I-40 or I-25 was noted as the incident's secondary street in metadata, and
3. Albuquerque was noted as the incident's city in metadata

Each isolated incident had the following metadata of interest relating to incident location:
1. Primary street: a field noting the primary street on which the incident occurred,
2. Secondly street: a field denoting the secondary street on which the incident occurred,
3. Latitude coordinate: a field denoting the incident's latitude, and
4. Longitude coordinate: a field denoting the incident's longitude.

In review of the isolated incident location metadata, the team made the following observations:

1. The primary street and secondary street fields were not always populated and were often left blank in the dataset, and
2. The latitude and longitude coordinate fields were always populated and were never left blank in the dataset.

In consideration of the above observations, the team elected to 1) temporarily disregard primary and secondary street names as listed in the dataset and 2) use dataset coordinate pairs to reference incident location.

The latitude and longitude coordinate pair for each incident, as it existed in the crash dataset and as it was originally provided to the team, was derived directly from ArcGIS. In compiling the list of forty thousand incidents, the NMDOT referenced datasets external to those provided to the team (John DiRuggiero, personal communication). These external datasets contained *pseudo-exact* coordinate pairs for all incidents. In assigning coordinate pairs to incidents in the dataset, the NMDOT used a practice of *pseudo-exactness.* In the case of highway incidents, exact incident location was abandoned for 1) the highway overpass location, or 2) the highway underpass location nearest the actual incident location (John DiRuggiero, personal communication). This adjusted location was slightly different from the actual location where the incident occurred. The exact locations of highway crashes were not provided to the team; the group suspects the NMDOT does not maintain a dataset detailing *exact* crash locations. Nonetheless, adjusted crash locations harbor exact coordinate pairs unique to each location. These adjusted coordinate pairs, although pseudo-exact to the actual incident locations, were the coordinate pairs the NMDOT 1) assigned to each incident and 2) provided to the team in the crash dataset.

Second, the team used SQL to group the isolated highway incidents by *pseudo-exact* coordinate pairs. The team obtained a table that 1) listed every coordinate pair that appeared in the crash dataset and 2) listed every incident occurring at each. Using SQL again, the team counted the number of incidents occurring at each coordinate pair, ranking the tallies of incidents in descending order. From this, the team obtained a list of the pseudo-exact coordinate pairs appearing *most commonly* in the isolated highway crash dataset. The team selected the three most commonly appearing coordinate pairs on I-40 and the three most commonly appearing coordinate pairs on I-25. The team then labeled these six coordinate pairs as *hotspots* of congestion-causing activity.

Third, the team used Google Maps to assign *new* primary and secondary street names to each of the six *hotspots*. As aforementioned, the team re-assigned street locations solely because it found the dataset's original street locations to be inconsistently populated. The team used Google Maps' coordinate search capability to 1) visualize the locations of coordinate pairs, 2) assign road name descriptors to each coordinate pair, and 3) verify that each coordinate pair was indeed on either I-40 or I-25. The team found that all *hotspot pseudo-exact* coordinate pairs corresponded roughly to 1) a nearby highway overpass location or 2) a nearby highway underpass location. With this, the group used 1) the highway on which each incident occurred and 2) the name of the street passing over or under the highway closest to each coordinate pair to name each *hotspot*. The team knew that accidents occurring at these coordinate pairs were 1) actually on the highway and 2) not on an underpass road or overpass road because the coordinate pairs did not correspond exactly to overpass and underpass locations.

2.2 Analyze congestion resulting from accidents of interest

In section 2.1, the team identified 1) *hotspots* of congestion-causing activity on I-40 and I-25 and 2) specific high-severity accidents occurring at these *hotspots*. The team aimed to assess driver behavior following these accidents. In this, the team 1) identified alternate metropolitan routes and 2) compiled pre-crash and post-crash datasets for each.

2.2.1 Identify alternate metropolitan routes

MRCOG provided the team with a map of all major routes in the city of Albuquerque. MRCOG defines "major routes" as roadways that support a level of daily throughput equal to or more than that of an average "urban collector" roadway; an urban collector roadway moves low to moderate traffic from neighborhood streets onto arterials (John DiRuggiero, personal communication). As they were provided to the group, each road segment of each major route denoted in the map was assigned a COGID. A COGID is a number used by MRCOG to uniquely identify a segment of road in 1) the "major routes" map and 2) TAQA. As aforementioned, highway drivers in Albuquerque typically make use of alternate metropolitan routes to avoid highway congestion and incidents (John DiRuggiero, personal communication). In consideration of this, the team definitely identified alternate routes that drivers could use in response to incidents occurring at each of the six hotspots. The process for identifying alternate routes at a hotspot was as follows:

1. Manually locate the hotspot in the major routes map,
2. If the hotspot is on I-25, find 1) the nearest highway interchange north of the hotspot accessible to drivers traveling both north and south and 2) the nearest highway interchange south of the hotspot accessible to drivers traveling both north and south,
3. If the hotspot is on I-40, find 2) the nearest highway interchange east of the hotspot accessible to drivers traveling both east and west and 2) the nearest highway interchange west of the hotspot accessible to drivers traveling both east and west,
1. Use roadways in the major routes map to connect the first interchange to the second interchange by 1) using the major routes map to obtain the COGID of each road segment utilized in the alternate route and 2) by ensuring the route can be used by all rerouting drivers regardless of their original direction of highway travel,
2. Using Google Maps, 1) place a pin at each highway interchange and 2) enable routing between the two pins, verifying that Google Maps displays the reroute and would direct drivers to the reroute.

For each highway accident, the team first considered the direction of highway travel on which the incident occurred. The team adhered to the following procedure in making its multi-directional reroutes specific to the direction of travel on each incident:

- If the incident took place on I-25 northbound, use TAQA to 1) begin at the interchange south of the incident, 2) visually trace the multi-directional reroute, noting the direction of travel used for each segment, 3) end the route at the interchange north of the incident
- If the incident took place on I-25 southbound, use TAQA to 1) begin at the interchange north of the incident, 2) visually trace the multi-directional reroute, noting the direction of travel used for each segment, 3) end the route at the interchange south of the incident.
- If the incident took place on I-40 eastbound, use TAQA to 1) begin at the interchange west of the incident, 2) visually trace the multi-directional reroute, noting the direction of travel used for each segment, 3) end the route at the interchange east of the incident.
- If the incident took place on I-40 westbound, use TAQA to 1) begin at the interchange east of the incident, 2) visually trace the multi-directional reroute, noting the direction of travel used for each segment, 3) end the route once the Rio Grande has been crossed - here, the team was instructed to investigate alternate routes for crossing the Rio Grande because 1) there are a limited amount of available crossings and 2) these crossings frequently become congested during rush hour (John DiRuggiero, personal communication).

In this practice, the team 1) created detours circumventing hotspots and 2) defined direction-specific routes and road segments that would *very likely* bear an increase in traffic following a highway incident. The team judged an increase in traffic to be very likely on the basis that 1) it identified all assumed reroutes, 2) Google Maps recommended the reroutes as alternatives to the corresponding sections of highway, and 3) drivers in Albuquerque often make use of alternate metropolitan routes to avoid highway congestion and incidents.

2.2.2 Compile pre-incident and post-incident data for alternate routes

The team identified three accidents at each of the six hotspots that were believed to have caused the most congestion. The NMDOT has observed that highway incidents with human injury have caused congestion levels higher than accidents without human injury (John DiRuggiero, personal communication). The team developed a mathematical scale to illustrate the injury-related severity of each accident. Then, the team summed severity points for each accident and identified three of the most severe accidents for each hotspot:

1. Each class c injury in an accident equates to 1 severity point
2. Each class b injury in an accident equates to 2 severity points
3. Each class a injury in an accident equates to 3 severity points
4. Each death in an accident equates to 4 severity points

The team used TAQA to compile pre-incident and post-incident data for each of the three events (at each of the six hotspots). In compiling pre-incident and post-incident data, the team adhered to the following:

1. Use the crash database to determine the fifteen-minute time window in which the incident occurred,
2. Collect TAQA data for six fifteen minute windows preceding the incident window,
3. Collect TAQA data for the incident window itself, and
4. Collect TAQA data for six fifteen minute windows following the incident window

For each incident at each hotspot, the team collected the following data for 1) all assumed alternate routes, both individually and as an average, and 2) for all road segments each route was comprised of,

1. The average travel time before and after an incident: the actual amount of time a driver takes to traverse a route or road segment in travel conditions of a specific time window, and,
2. The average vehicle speed before and after an incident: the actual vehicle speed of a driver traveling across a route or road segment in travel conditions of a specific time window

The team computed 1) the change in average travel time and 2) the change in average vehicle speed for 1) all assumed alternate routes, both individually and as an average, and 2) for all road segments each route was comprised of. A high, positive change in travel time suggested a travel time delay. A low, negative change in average vehicle speed suggested slowed speeds of travel. Both suggest the presence of congestion. The team used these values to assess pre-incident and post-incident travel environments for all of the previously identified alternate metropolitan routes and roadway segments.

2.3 Observe driver behavior in real time

The team developed a novel automated traffic surveillance program using Python. In brevity, the software captured Google Maps traffic conditions for established locations through specific time windows in real time. The team used the product of this surveillance program to assess present-day driver rerouting behavior throughout the city of Albuquerque as a whole.

2.3.1 Establish time windows and map area for observing driver behavior

First, the team established time windows for observing driver behavior. The team sought to use time windows with high crash likelihoods, since this would increase the likelihood of metropolitan congestion occurring. The team decided to observe morning and evening rush hours because of all time windows in a day, rush hour windows have 1) the highest volume of drivers and therefore 2) the highest likelihood of congestion or crash occurrence (John DiRuggiero, personal communication). Morning rush hour is defined as 6:30 am to 9:30 am; evening rush hour is defined as 3:30 pm to 6:30 pm.

Second, the team established locations for observing driver behavior. The team aimed to observe driver behavior 1) through the entirety of Albuquerque and 2) at each of the six identified hotspots. First, the team manually zoomed Google Maps to a view that encompassed the entirety of Albuquerque as well as the six hotspots. Next, the team enabled live traffic display in Google Maps. With this, the team was supplied a Google Maps URL describing the exact map area that the team wished to screenshot.

For example, the URL *https://www.google.com/maps/@35.0975647,-106.6317954,13z/data=!5m1!1e1* contains a latitude (35.0975647), longitude (-106.6317954), zoom level (13z), and data field indicating that live traffic is enabled (data=!5m1!e1). This URL is automatically generated by Google Maps when a user manually zooms to a map area in a web browser. The team used a similar URL to capture screenshots of Albuquerque traffic in real time.

2.3.2 Autonomously collect Google Maps traffic data

The team autonomously collected Google Maps traffic data using the Python program. The operating logic of the program can be followed below:

1. Wait until the current time is within either morning or evening rush hour,
2. Take a screenshot of Google Maps live traffic data at the specific location every minute,
3. Save and timestamp each screenshot, and
4. Overlay each image with text denoting the time and date at which the image was taken

This process provided the team with surveillance images showing congestion, closures and incidents, and accidents as they were displayed in Google Maps at the time the screenshot was captured. The team autonomously collected morning and evening rush hour data for an entire work week. Screenshots were taken every sixty seconds because Google Maps updates live traffic conditions in roughly sixty second intervals (John DiRuggiero, personal communication). In total, the team surveilled thirty hours of rush hour traffic data, lending approximately 1800 high-resolution images of live traffic conditions in Albuquerque.

The team used iMovie to create stop motion videos of each rush hour window. The surveillance program had collected roughly 180 still images for each rush hour window. By dragging the collection of images into iMovie, the team was able to create a video stringing together all images. The team elected to include a 0.1 second pause between each image for aesthetic purposes. In this process, the team developed an easy method for visualizing traffic conditions and an alternative to reviewing each and every image individually. The stop motion videos allowed the group to visualize the flow of traffic through rush hour and the behavior of drivers following incidents.

2.3.3 Review collected data and assess driver behavior

The team adhered to the following process when reviewing a stop motion video of collected traffic data:

1) Begin watching the stop motion video,
2) When Google Maps traffic colors a section of I-40 or I-25 red (indicating congestion) or a Google Maps crash icon appears on I-40 or I-25,
   a) Use the overlay timestamp to make note of the time at which the congestion began to occur,
   b) Assign a name to the congested location by referencing the highway name and the name of the nearest roadway overpass or underpass, making particular note if derived name corresponds to that of an identified hotspot,
3) Observe metropolitan roadways immediately surrounding the congested area, making note of roadways that,
   (i) Offer *plausible alternate routes* for drivers affected by the highway congestion, and
   (ii) Indicate red or yellow congestion on Google Maps following the initial highway congestion

Of important note, the group assessed plausible alternate routes on a case by case basis. The locations of incidents occurring in real time were too unpredictable and varied for the group to establish definitive reroutes. Regardless, in this practice, the team identified specific highway locations and metropolitan roads that experienced recurring congestion through rush hour windows. This data allowed the team to visually assess rerouting behavior of highway drivers throughout Albuquerque.

3.0 Results

3.1 Identify Problematic stretches of highway

The NMDOT was most interested in investigating the effects of highway accidents on driver rerouting behavior and metropolitan congestion. With this in mind, the team used Structured Query Language and the 2015 crash database to find three "hotspots" of congestion-causing activity on both I-40 and I-25.

3.1.1 Conduct interviews with field experts

Through our interview at the Traffic Management Center with officials from the NMDOT, the team gathered all information needed to get started with the project. This meeting was the first time that the team was made aware of how our work would be used: a baseline in the NMDOT's application for a federal grant that would be used to improve traffic management infrastructure and mitigation strategies. Having representatives from four different agencies in one room was extremely helpful and helped us gather all the information we needed, instead of having to track down each representative separately and possibly receive conflicting answers.

Before this meeting, the team was still unsure of how broad or specific its research needed to be, but we quickly learned that Tim Brown, the lead traffic engineer for the city of Albuquerque, was mainly interested in what happens on metropolitan streets after highway incidents.

This meeting also gave the team a clear end goal. Our report to the NMDOT will serve to establish the baseline of Albuquerque congestion data after an incident takes place on the highway. The NMDOT wanted to know where they should focus their roadway-improvement efforts once they receive the federal grant, and were particularly interested in roadways experiencing the highest levels of recurring congestion. The officials expected a written summary of our results as well as circumstantial visual representations of the data in the form of heat maps or live surveillance videos of traffic conditions.

By the end of the meeting, one thing was very clear to our team: there is a lack of communication among all of the agencies that play a role in traffic management. Our team asked for access to a variety of different data sets and there was confusion among the experts regarding which agency had different data sets, and what steps they would have to go through to get these for our team. When we asked "Which existing congestion alleviation methods are most effective on roadways with recurring congestion?", no one was really sure who should handle that question or if there was data on the existing methods that have made an impact. By the end, we were given a direction to head and great advice, but it was clear that there was miscommunication between agencies that would hinder the group when we requested data sets.

3.1.2 Finding "hotspots" of congestion-causing activity on I-40 and I-25

The team authored and executed an advanced SQL query over the NMDOT 2015 crash database to group and sum highway incidents by their latitude and longitude coordinates. The SQL code is shown below, in Figure 4.

```
select gis_derived_latitude_coordinate as lat,
gis_derived_longitude_coordinate as lon, count(*
from 2015_crash
where primary_street like '%I-40%'
or primary_street like '%I-25%'
or secondary_street like '%I-40%'
or secondary_street like '%I-25%'
and city = 'Albuquerque'
group by lat, lon
order by count(*) desc;
```

Figure 3: SQL code used to identify “hotspots” of congestion

First, the SQL code selects the latitude and longitude field of each crash entry in the database. Second, the SQL code ensures that a crash entry relates specifically to either I-40 or I-25. Here, the code verifies that either “I-40,” or “I-25” is found in either the primary street or secondary street data field of the entry. Third, the code ensures that the crash took place in the city of Albuquerque. Fourth, the SQL code determines whether or not the coordinate pair of a crash entry has already been seen elsewhere in the database. If it has, the SQL code adds the entry to an existing tally of entries containing the same coordinate pair. Finally, the SQL code neatly prints a results table detailing highway incident coordinate pairs that appeared most frequently in the NMDOT 2015 crash database.

Through SQL, the team obtained a list of incident coordinate pairs that occurred most frequently in the crash database. It is important to note that unlike NMDOT data, TAQA data exclusively references street names and does not represent data in terms of coordinate pairs. With this being the case, the team needed to convert the list of hotspot coordinate pairs to an equivalent list of road names using Google Maps, shown in Figure 5. By doing this, the team located which incident hotspots took place on the highways, and ignored hotspots that took place on surrounding streets. Using the previously obtained coordinate pair tallies and the newly obtained corresponding street names, the team ascertained a list of highway incident hotspots on which it could concentrate its research into resulting metropolitan congestion. The team chose the six highway hotspots from this list with the highest incident tallies, three from I-40 and three from I-25. The hotspots that were used are located in Table 2. The complete table of results is located in appendix B.

Table 2: Results table of the 6 hotspots detailing coordinate pairs from incidents

latitude	**longitude**	**# of incidents**	**street names**
35.1064256	-106.6238518	72	I-40 and University Blvd
35.10493978	-106.6041916	65	I-40 E and Carlisle Blvd.
35.10523286	-106.6707716	50	I-40 and Rio Grande Blvd NW
35.1743029	-106.5835535	47	I-25 and Paseo Del Norte NE
35.06979804	-106.6394244	47	I-25 and Avenida Cesar Chavez
35.15338484	-106.5888104	40	I-25 and San Mateo Blvd. NE

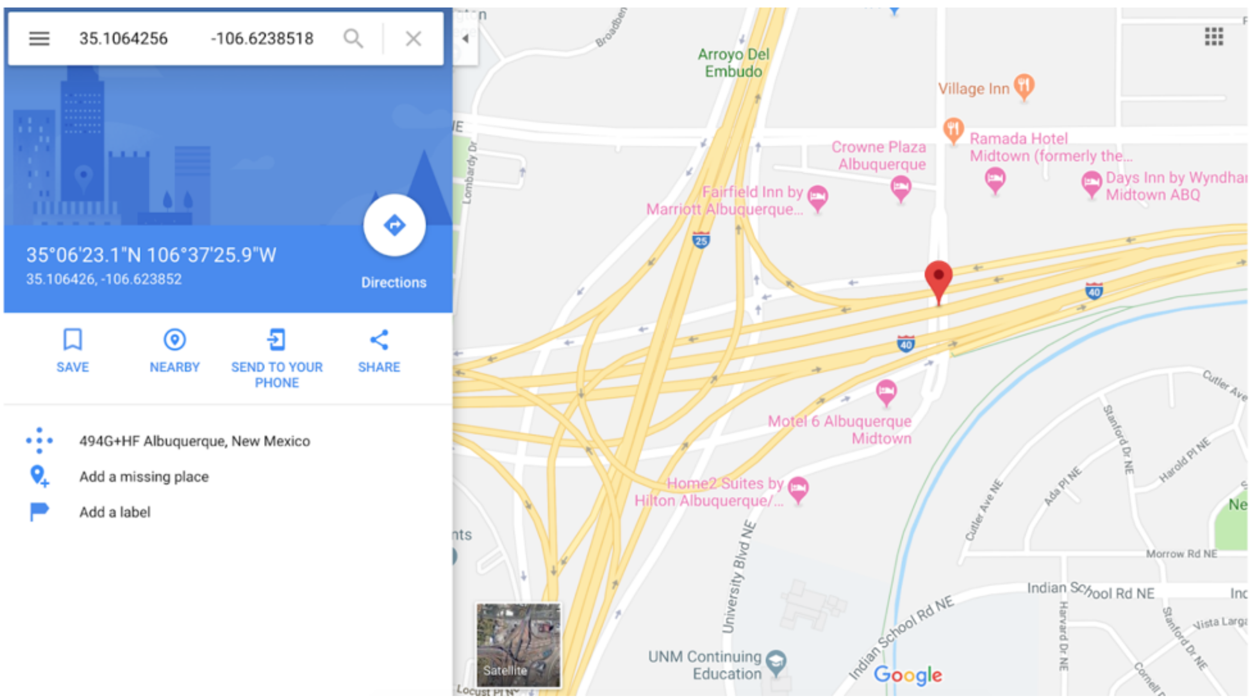


Figure 4: Cross-referencing coordinates in Google Maps to obtain street names (retrieved from maps.google.com)

3.2 Analyze congestion resulting from accidents of interest

With TAQA data, we identified any change in congestion, at our 6 targeted hotspots, after the 3 accidents we targeted for full analysis of each hotspot. We used change in average travel speed and change in average travel time as measures of congestion in these areas. Then we identified which road segments, in our alternative routes around the accident sites, had a significant change in congestion, denoted by a +/- 5 mph change in average vehicle speed. In each hotspot description below, we include a map of our chosen alternate routes in teal, and identify road segments with a +/- 5 mph change in average vehicle speed in green or red. The red shows that average speed decreased and average travel time increased, while green shows that average speed increased and average travel time decreased. The graphs of this data for each road segment and accident are located in Appendix B.

3.2.1 Identify alternate metropolitan routes

Alternate route maps display the different options that drivers have to take if they choose to reroute in order to avoid an incident on the highway. As illustrated in Figure 6, the alternate routes are highlighted in teal, potentially rerouting drivers around the accident that took place on the highway. As these routes are split into segments, the team identified the route as a whole and the individual segments that the route was comprised of. After the team analyzed these segments, we found which segments had decreases in congestion and which had increases in congestion. With this data, the team made conclusions of which roads were viable for rerouting and which were not.

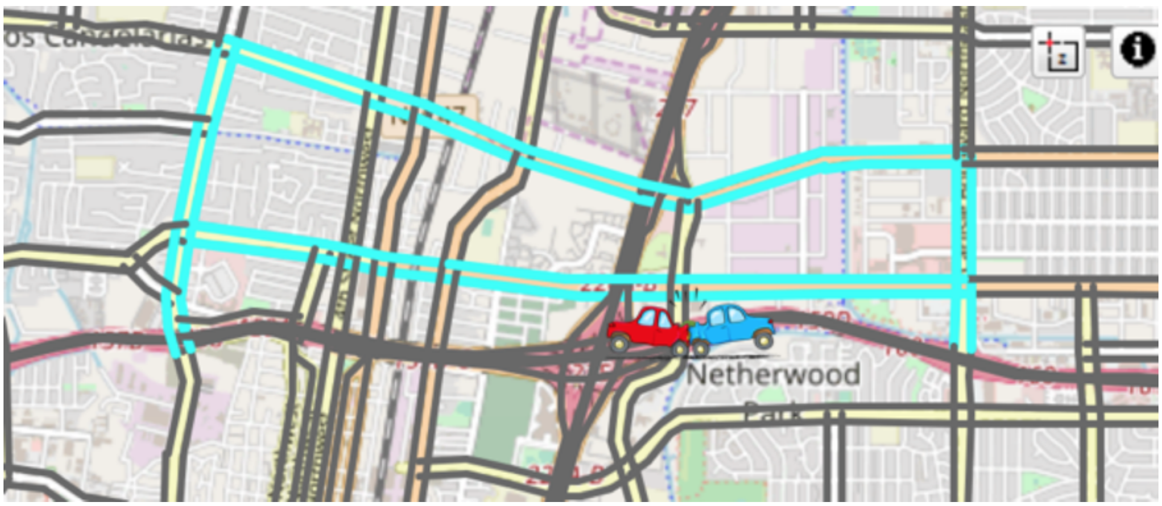


Figure 5: Example of alternate routes at I-40 & University Blvd.

3.2.2 Compile pre-crash and post-crash data for alternate routes

Hotspot 1: I-40 near University Boulevard

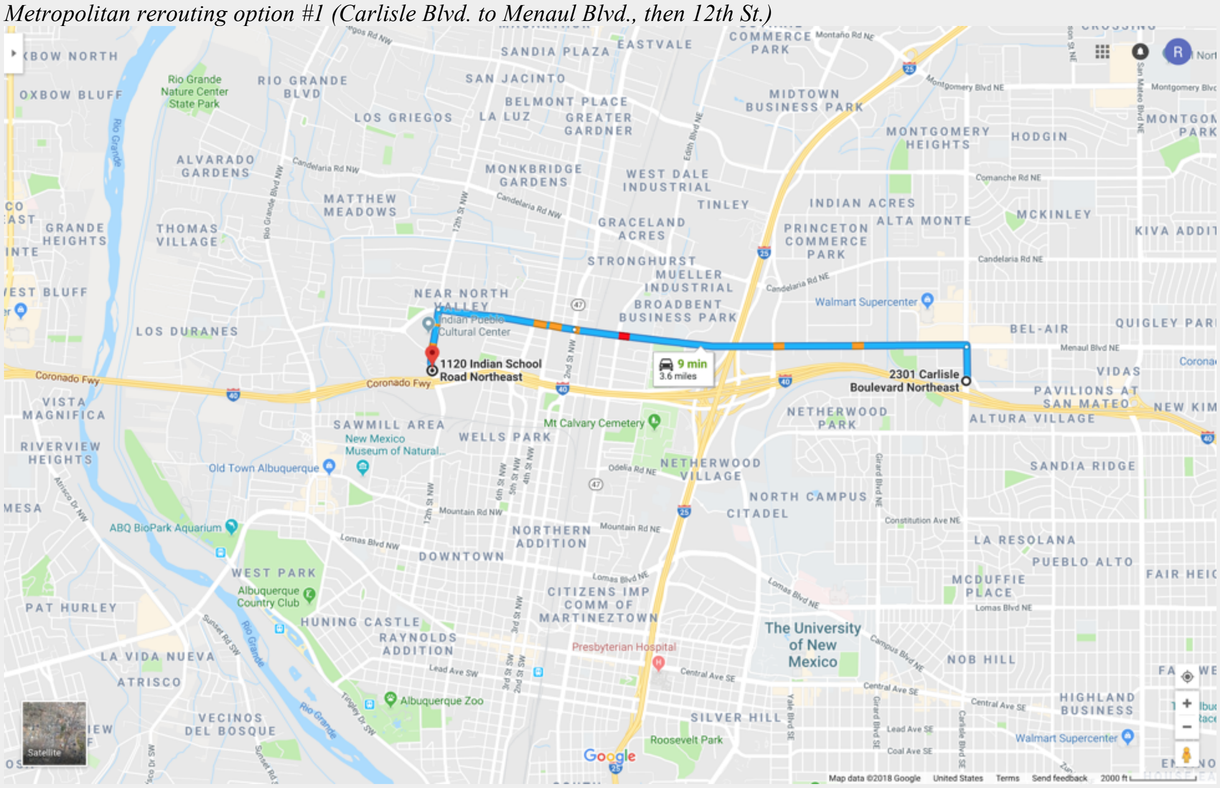
Incidents occurring at this hotspot in 2015	72

Incidents analyzed by team (3)	**Incident severity**
Incident 710213664, I-40 westbound, 6:27 p.m., January 8, 2015	6
Incident 710255619, I-40 westbound, 4:58 p.m., June 16, 2015	4
Incident 710255616, I-40 westbound, 3:57 p.m., June 11, 2015	2

Average change in rerouting travel time caused by all analyzed incidents for all alternate routes	- 0.4 seconds per mile
Average change in rerouting vehicle speed caused by all analyzed incidents for all alternate routes	- 0.1 mph

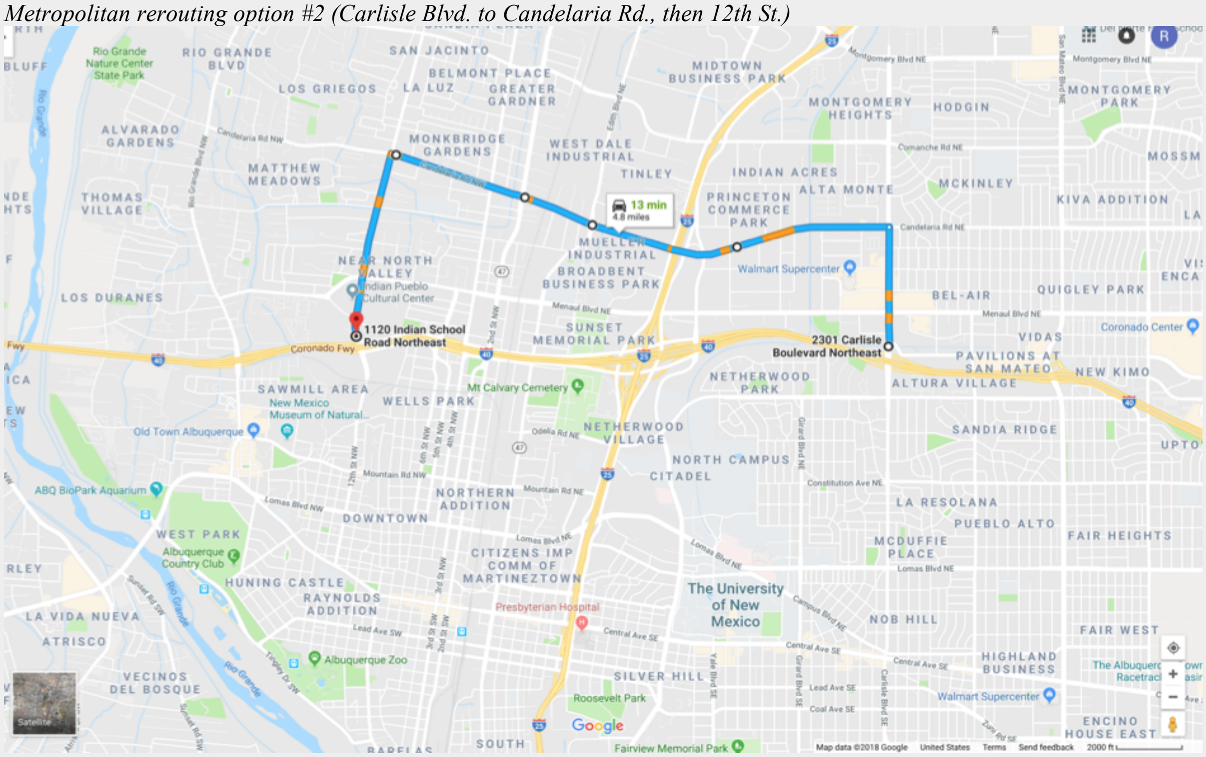
Metropolitan rerouting options analyzed by team

Metropolitan rerouting option #1 (Carlisle Blvd. to Menaul Blvd., then 12th St.)



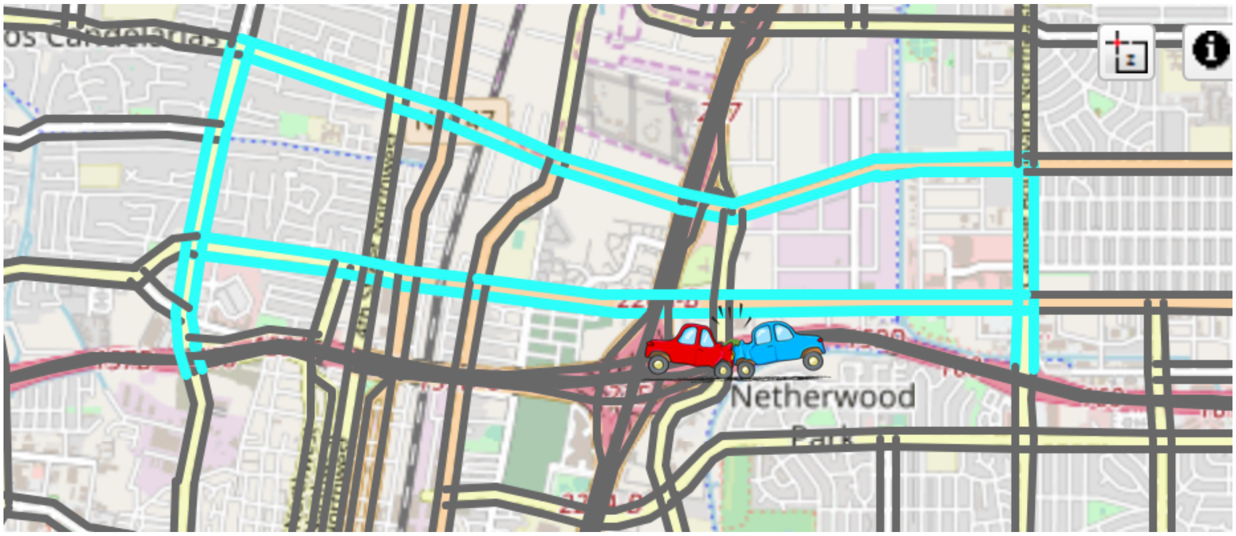
Average change in rerouting travel time caused by all analyzed incidents for this alternate route	+ 3.7 seconds per mile
Average change in rerouting vehicle speed caused by all analyzed incidents for this alternate route	- 0.2 mph

Metropolitan rerouting option #2 (Carlisle Blvd. to Candelaria Rd., then 12th St.)



Average change in rerouting travel time caused by all analyzed incidents for this alternate route	- 6.6 seconds per mile
Average change in rerouting vehicle speed caused by all analyzed incidents for this alternate route	- 0.5 mph

Incident 710213664, I-40 westbound, 6:27 p.m., January 8, 2015



Of all the road segments highlighted, none experienced a change of +/- 5 mph.

Average change in rerouting travel time caused by incident	+/- 0.0 seconds per mile
Average change in rerouting vehicle speed caused by incident	- 0.1 mph

Metropolitan rerouting option #1

Change in travel time on rerouting option #1 caused by incident	+ 0.4 seconds per mile
Change in vehicle speed on rerouting option #1 caused by incident	- 0.1 mph

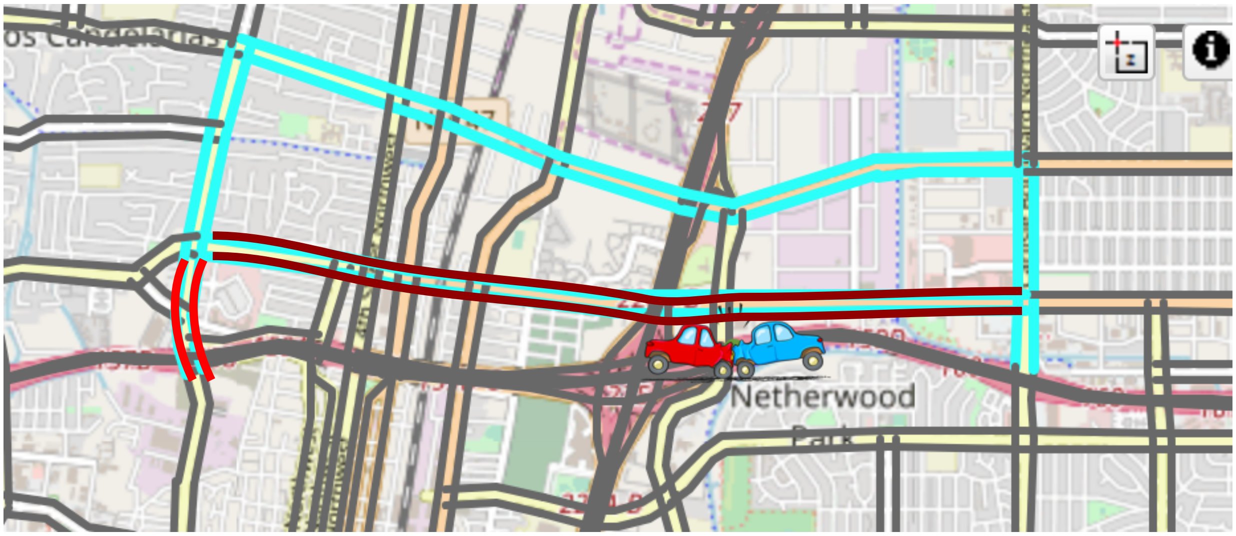
Metropolitan rerouting option #2

Change in travel time on rerouting option #2 caused by incident	- 0.3 seconds per mile
Change in vehicle speed on rerouting option #2 caused by incident	+/- 0.0 mph

Metropolitan road segments with significant changes caused by incident

None

Incident 710255619, I-40 westbound, 4:58 p.m., June 16, 2015



Highlighted in **red** is 12th street interchange showing a 7.8 mph decrease in speed and highlighted in **dark red** is Menaul Blvd showing a 5.8 mph decrease in speed.

Average change in rerouting travel time caused by incident	+ 20.1 seconds per mile
Average change in rerouting vehicle speed caused by incident	- 1.7 mph

Metropolitan rerouting option #1

Change in travel time on rerouting option #1 caused by incident	+ 37.0 seconds per mile
Change in vehicle speed on rerouting option #1 caused by incident	- 2.6 mph

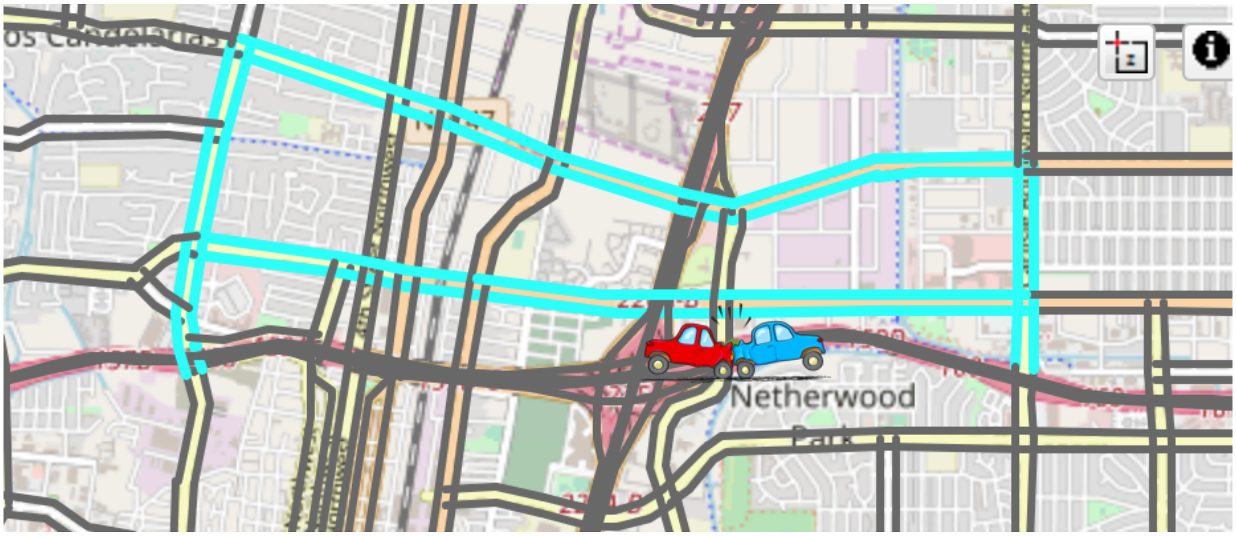
Metropolitan rerouting option #2

Change in travel time on rerouting option #2 caused by incident	+ 3.1 seconds per mile
Change in vehicle speed on rerouting option #2 caused by incident	- 0.8 mph

Metropolitan road segments with significant changes caused by incident

12th Street Interchange	
Change in travel time caused by incident	+ 18.9 seconds per mile
Change in vehicle speed caused by incident	- 7.4 mph
Menaul	
Change in travel time caused by incident	+ 123.5 seconds per mile
Change in vehicle speed caused by incident	- 5.8 mph

Incident 710255616, I-40 westbound, 3:57 p.m., June 11, 2015



Of all the road segments highlighted, none experienced a change of +/- 5 mph.

Average change in rerouting travel time caused by incident	- 21.3 seconds per mile
Average change in rerouting vehicle speed caused by incident	+ 1.6 mph

Metropolitan rerouting option #1

Change in travel time on rerouting option #1 caused by incident	- 26.3 seconds per mile
Change in vehicle speed on rerouting option #1 caused by incident	+ 2.4 mph

Metropolitan rerouting option #2

Change in travel time on rerouting option #2 caused by incident	-16.3 seconds per mile
Change in vehicle speed on rerouting option #2 caused by incident	+ 0.7 mph

Metropolitan road segments with significant changes caused by incident

None

Hotspot 2: I-40 near Carlisle

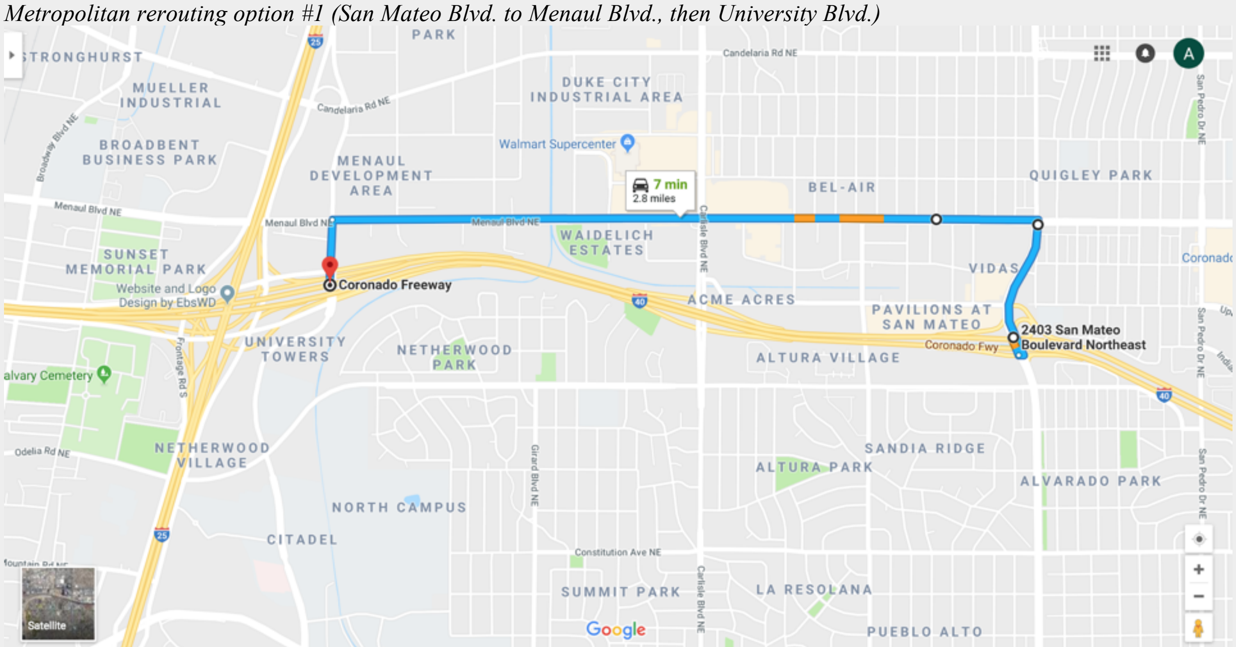
Incidents occurring at this hotspot in 2015	66

Incidents analyzed by team (3)	**Incident severity**
Incident 710206024, I-40 westbound, 8:46 a.m., September 29, 2018	3
Incident 710235617, I-40 westbound, 7:37 a.m., January 28, 2015	5
Incident 710255622, I-40 westbound, 5:25 p.m., June 30, 2015	3

Average change in rerouting travel time caused by all analyzed incidents for all alternate routes	+ 4.4 seconds per mile
Average change in rerouting vehicle speed caused by all analyzed incidents for all alternate routes	- 0.8 mph

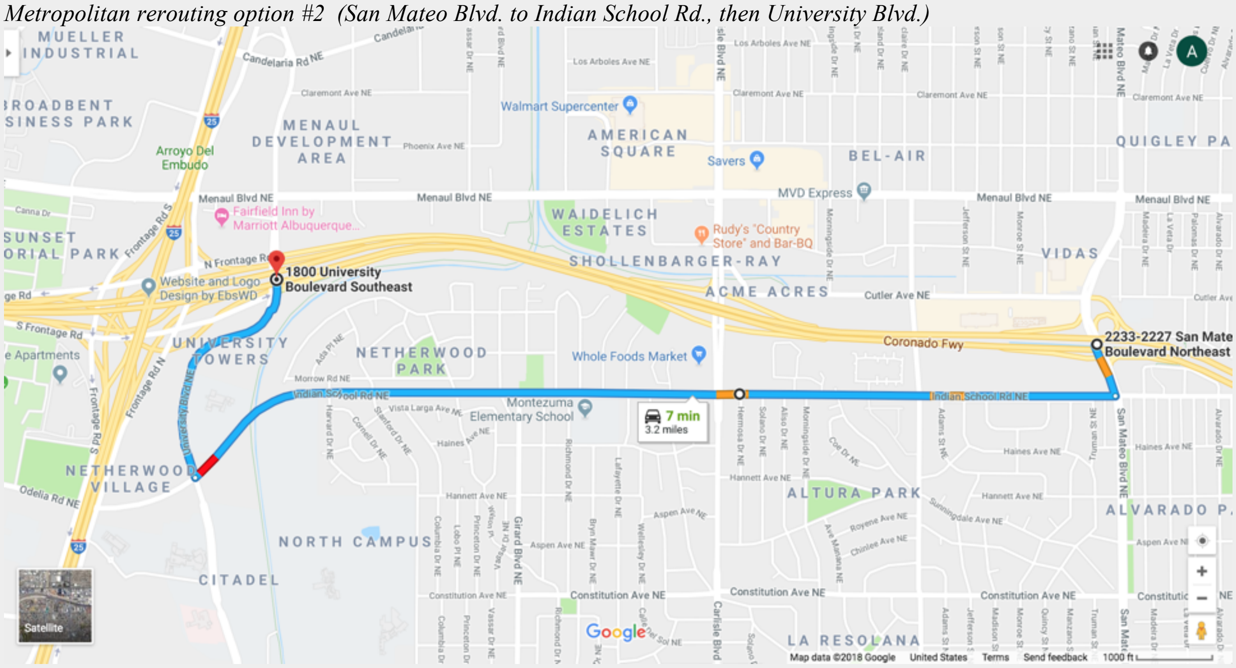
Metropolitan rerouting options analyzed by team

Metropolitan rerouting option #1 (San Mateo Blvd. to Menaul Blvd., then University Blvd.)



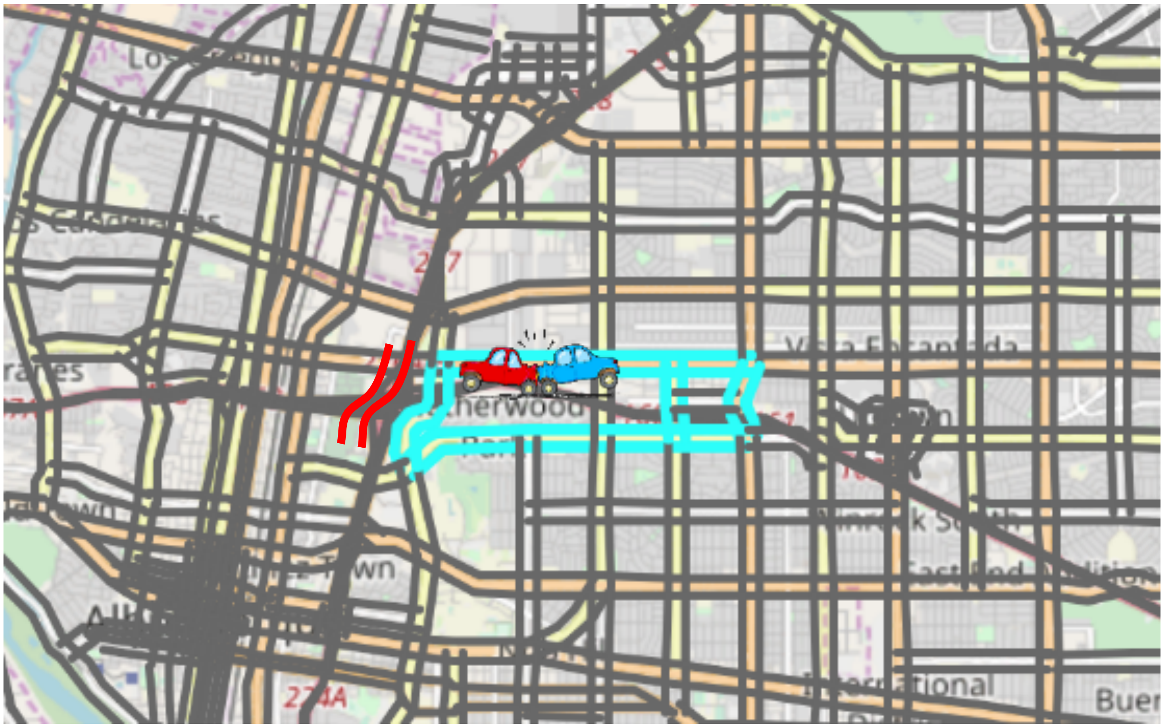
Average change in rerouting travel time caused by all analyzed incidents for this alternate route	+ 3.7 seconds per mile
Average change in rerouting vehicle speed caused by all analyzed incidents for this alternate route	- 7.3 mph

Metropolitan rerouting option #2 (San Mateo Blvd. to Indian School Rd., then University Blvd.)



Average change in rerouting travel time caused by all analyzed incidents for this alternate route	+ 1.4 seconds per mile
Average change in rerouting vehicle speed caused by all analyzed incidents for this alternate route	- 0.1 mph

Incident 710206024, I-40 westbound, 8:46 a.m., September 29, 2015



Highlighted in red is university Blvd showing a 5 mph decrease in speed.

Average change in rerouting travel time caused by incident	+ 5.4 seconds per mile
Average change in rerouting vehicle speed caused by incident	- 0.9 mph

Metropolitan rerouting option #1

Change in travel time on rerouting option #1 caused by incident	+ 8.9 seconds per mile
Change in vehicle speed on rerouting option #1 caused by incident	-1.3 mph

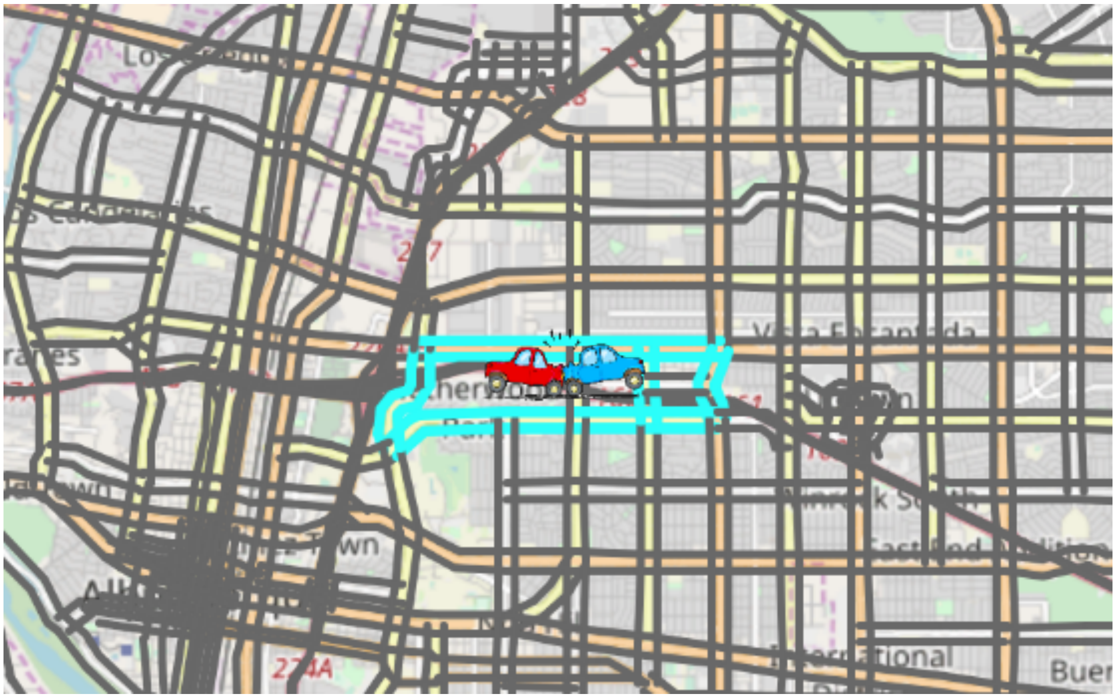
Metropolitan rerouting option #2

Change in travel time on rerouting option #2 caused by incident	+ 2.0 seconds per mile
Change in vehicle speed on rerouting option #2 caused by incident	- 0.4 mph

Metropolitan road segments with significant changes caused by incident

University	
Change in travel time caused by incident	+ 31.2 seconds per mile
Change in vehicle speed caused by incident	- 5.0 mph

Incident 710235617, I-40 westbound, 7:37 a.m., January 28, 2015



Of all the road segments highlighted, none experienced a change of +/- 5 mph.

Average change in rerouting travel time caused by incident	- 3.7 seconds per mile
Average change in rerouting vehicle speed caused by incident	+ 1.0 mph

Metropolitan rerouting option #1

Change in travel time on rerouting option #1 caused by incident	- 0.5 seconds per mile
Change in vehicle speed on rerouting option #1 caused by incident	+ 0.3 mph

Metropolitan rerouting option #2

Change in travel time on rerouting option #2 caused by incident	- 7.0 seconds per mile
Change in vehicle speed on rerouting option #2 caused by incident	+ 1.8 mph

Metropolitan road segments with significant changes caused by incident

None

Incident 710255622, I-40 westbound, 5:25 p.m., June 30, 2015

University is highlighted in **bright red** and Indian school road is highlighted in **dark red.**

Average change in rerouting travel time caused by incident	+ 11.4 seconds per mile
Average change in rerouting vehicle speed caused by incident	- 2.5 mph

Metropolitan rerouting option #1

Change in travel time on rerouting option #1 caused by incident	+ 13.6 seconds per mile
Change in vehicle speed on rerouting option #1 caused by incident	- 3.4 mph

Metropolitan rerouting option #2

Change in travel time on rerouting option #2 caused by incident	+ 9.3 seconds per mile
Change in vehicle speed on rerouting option #2 caused by incident	- 1.6 mph

Metropolitan road segments with significant changes caused by incident

University	
Change in travel time caused by incident	+ 21.0 seconds per mile
Change in vehicle speed caused by incident	- 5.2 mph
Indian School	
Change in travel time caused by incident	+ 35.5 seconds per mile
Change in vehicle speed caused by incident	- 5.0 mph

Hotspot 3: I-40 near Rio Grande

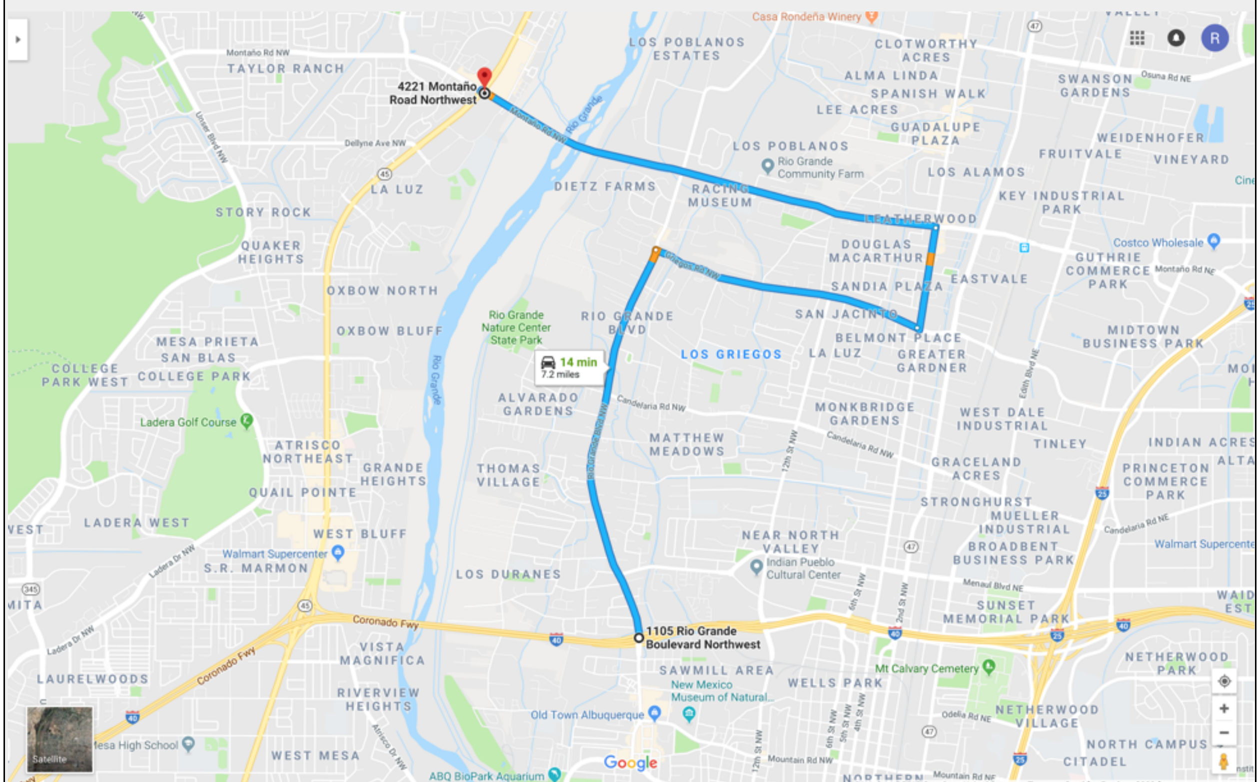
Incidents occurring at this hotspot in 2015	54

Incidents analyzed by team (3)	**Incident severity**
Incident 710237574, I-40 westbound, 4:22 p.m., May 1, 2015	4
Incident 710243645, I-40 westbound, 8:38 p.m., April 25, 2015	4
Incident 710208239, I-40 westbound, 6:06 a.m., April 24, 2015	3

Average change in rerouting travel time caused by all analyzed incidents for all alternate routes	-4.2 s/m
Average change in rerouting vehicle speed caused by all analyzed incidents for all alternate routes	0.35 mph

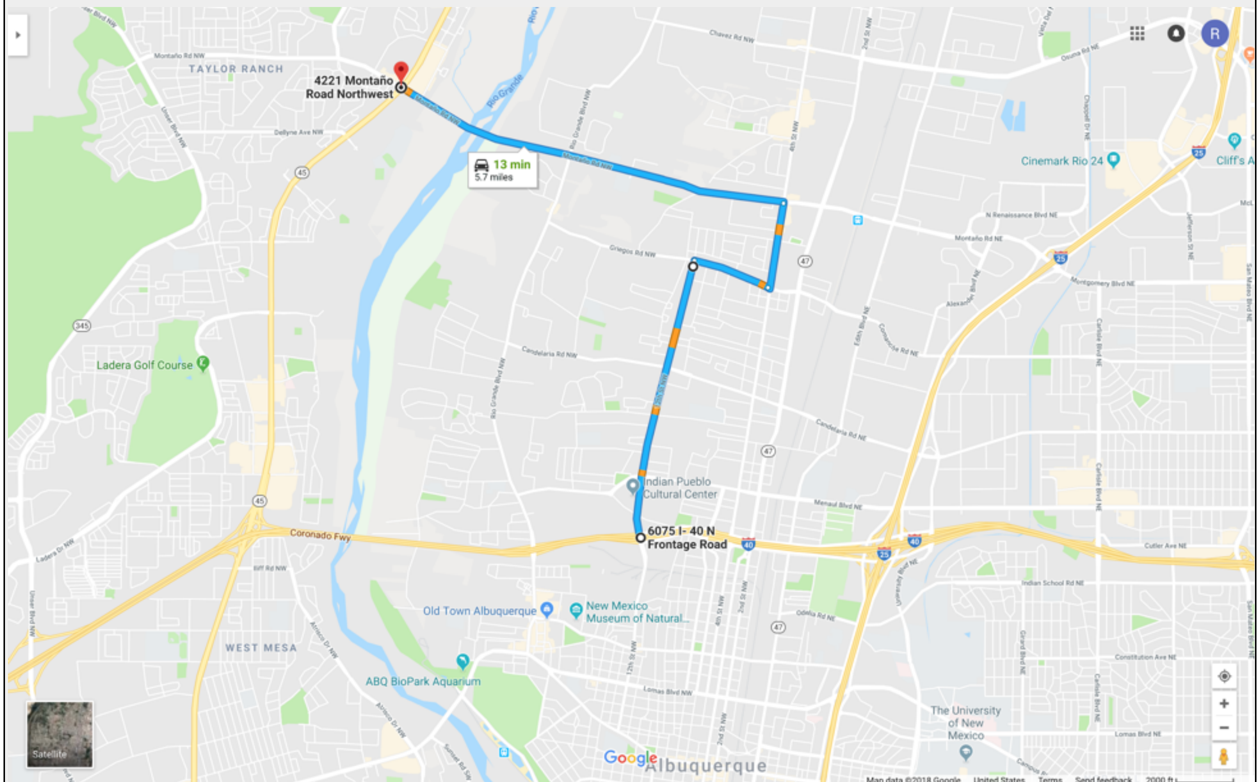
Metropolitan rerouting options analyzed by team

Metropolitan rerouting option #1 (Rio Grande Blvd. to Griegos Rd., then 4th St. to Mountain Rd.)



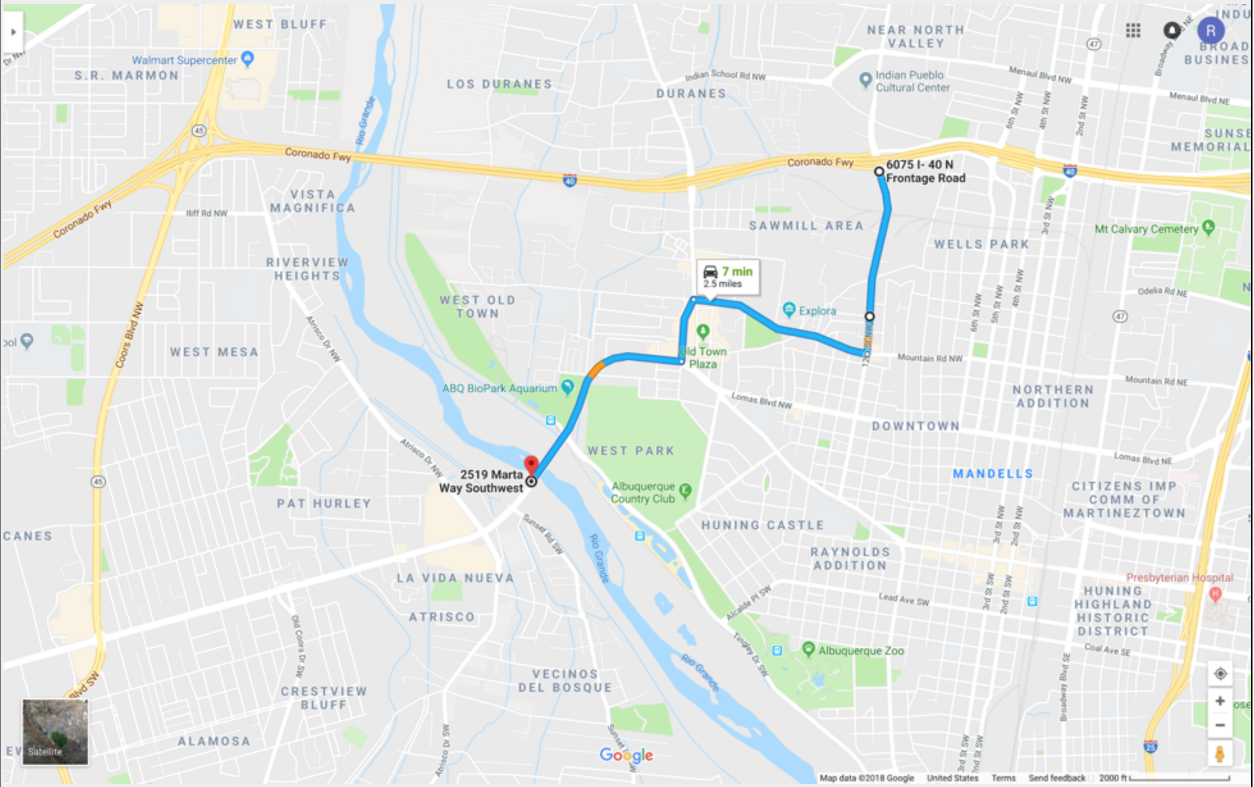
Average change in rerouting travel time caused by all analyzed incidents for this alternate route	2.4 seconds per mile
Average change in rerouting vehicle speed caused by all analyzed incidents for this alternate route	- 0.4 mph

Metropolitan rerouting option #2 (12th St. to Griegos Rd., then 4th St. to Mountain Rd.)



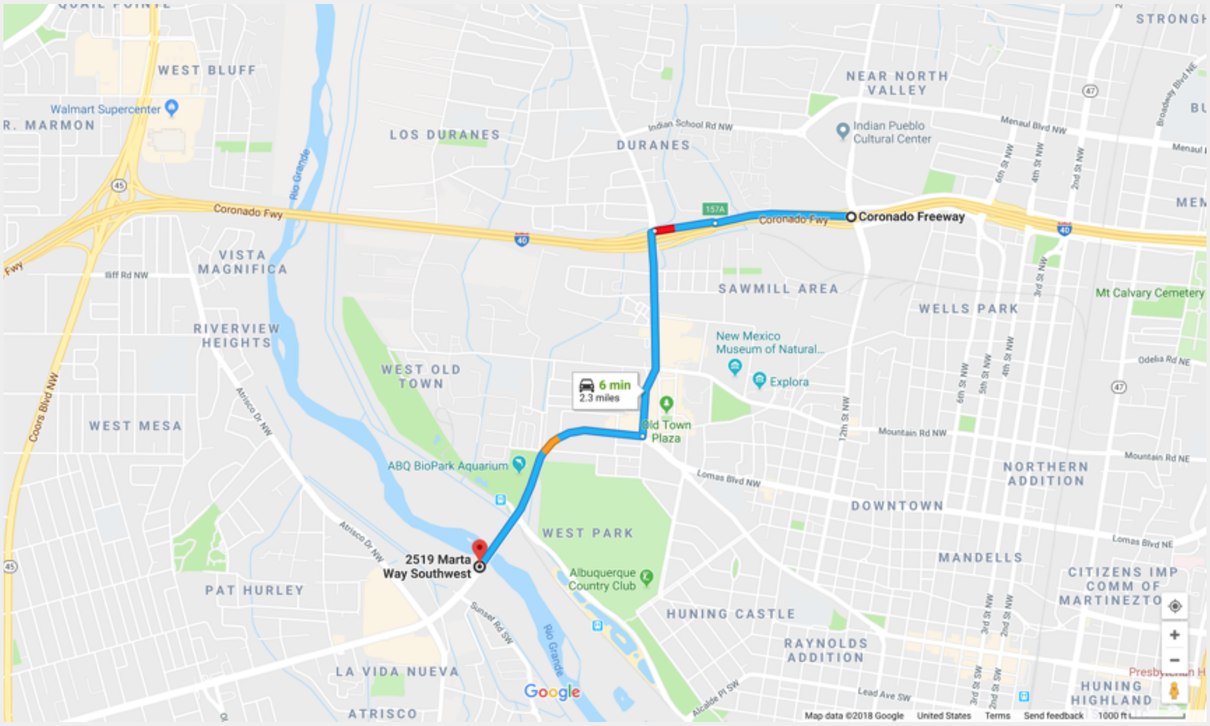
Average change in rerouting travel time caused by all analyzed incidents for this alternate route	- 0.9 seconds per mile
Average change in rerouting vehicle speed caused by all analyzed incidents for this alternate route	0.25 mph

Metropolitan rerouting option #3 (12th St. to Mountain Rd., then Rio Grande Blvd. to Central Ave.)



Average change in rerouting travel time caused by all analyzed incidents for this alternate route	- 20.3 seconds per mile
Average change in rerouting vehicle speed caused by all analyzed incidents for this alternate route	0.9 mph

Metropolitan rerouting option #4 (I-40 to Rio Grande Blvd., then Central Ave.)



Average change in rerouting travel time caused by all analyzed incidents for this alternate route	- 9.7seconds per mile
Average change in rerouting vehicle speed caused by all analyzed incidents for this alternate route	- 0.7 mph

Incident 710237574, I-40 westbound, 4:22 p.m., May 1, 2015

Of all the road segments highlighted, none experienced a change of +/- 5 mph.

Average change in rerouting travel time caused by incident	+ 4.1 seconds per mile
Average change in rerouting vehicle speed caused by incident	+ 0.8 mph

Metropolitan rerouting option #1

Change in travel time on rerouting option #1 caused by incident	-1.8 s/m
Change in vehicle speed on rerouting option #1 caused by incident	0.4 mph

Metropolitan rerouting option #2

Change in travel time on rerouting option #2 caused by incident	+1.07 s/m
Change in vehicle speed on rerouting option #2 caused by incident	+ 0.2 mph

Metropolitan rerouting option #3

Change in travel time on rerouting option #2 caused by incident	- 9.8 s/m
Change in vehicle speed on rerouting option #2 caused by incident	+ 1.7 mph

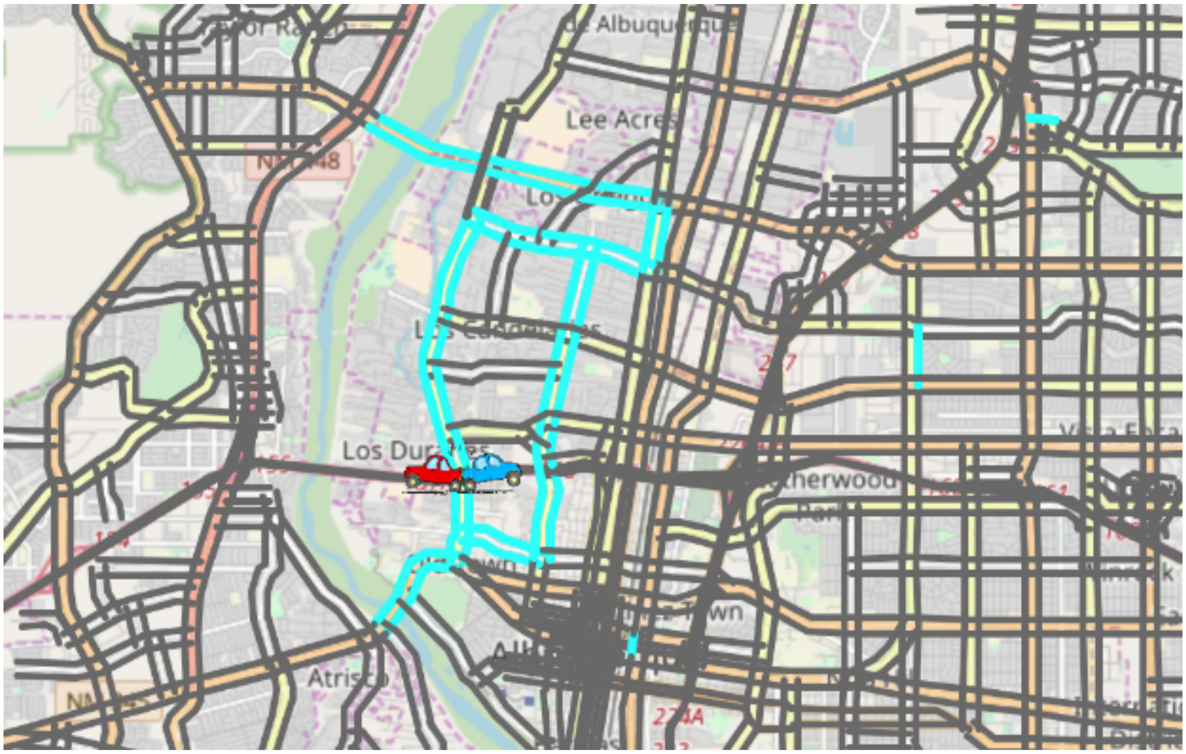
Metropolitan rerouting option #4

Change in travel time on rerouting option #2 caused by incident	- 0.3 seconds per mile
Change in vehicle speed on rerouting option #2 caused by incident	+/- 0.0 mph

Metropolitan road segments with significant changes caused by incident

12th Street	
Change in travel time caused by incident	-31.4 seconds per mile
Change in vehicle speed caused by incident	5.3 mph

Incident 710243645, I-40 westbound, 8:38 p.m., April 25, 2015



Of all the road segments highlighted, none experienced a change of +/- 5 mph.

Average change in rerouting travel time caused by incident	- 14.7 seconds per mile
Average change in rerouting vehicle speed caused by incident	+ 1.3 mph

Metropolitan rerouting option #1

Change in travel time on rerouting option #1 caused by incident	+/- 0.0 seconds per mile
Change in vehicle speed on rerouting option #1 caused by incident	+ 0.1 mph

Metropolitan rerouting option #2

Change in travel time on rerouting option #2 caused by incident	+ 11.1 seconds per mile
Change in vehicle speed on rerouting option #2 caused by incident	+ 1.6 mph

Metropolitan rerouting option #3

Change in travel time on rerouting option #1 caused by incident	-20.3 s/m
Change in vehicle speed on rerouting option #1 caused by incident	1.7 mph

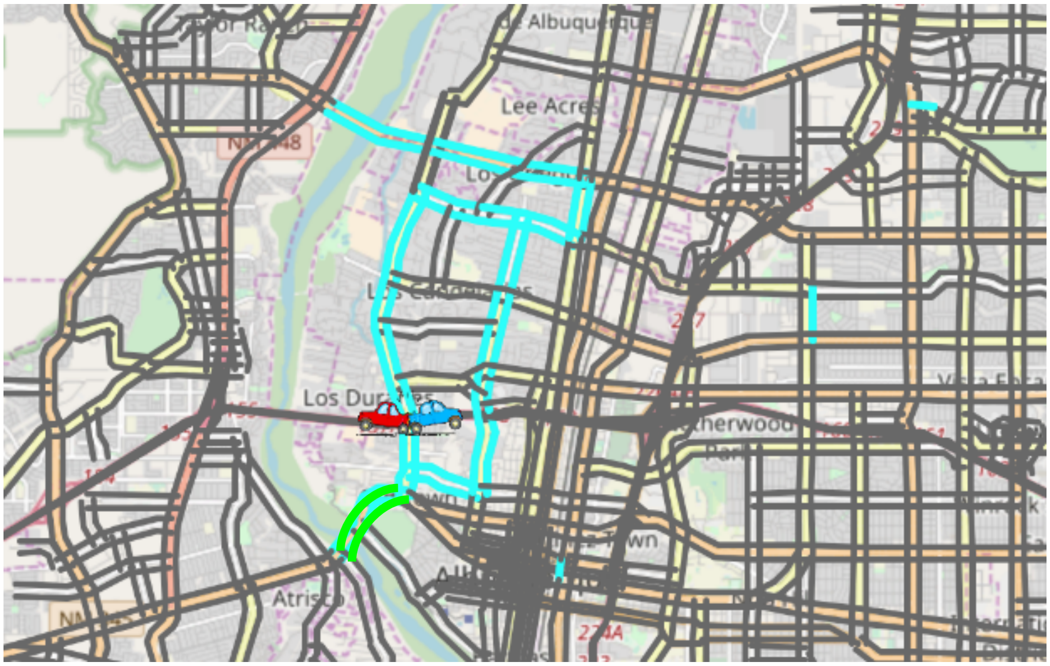
Metropolitan rerouting option #4

Change in travel time on rerouting option #1 caused by incident	-27 seconds per mile
Change in vehicle speed on rerouting option #1 caused by incident	1.9 mph

Metropolitan road segments with significant changes caused by incident

None

Incident 710208239, I-40 westbound, 6:06 a.m., April 24, 2015



Highlighted in green is Central Ave. showing an increase of 6.03 mph.

Average change in rerouting travel time caused by incident	- 21.3 seconds per mile
Average change in rerouting vehicle speed caused by incident	+ 1.6 mph

Metropolitan rerouting option #1

Change in travel time on rerouting option #1 caused by incident	+ 8.9 seconds per mile
Change in vehicle speed on rerouting option #1 caused by incident	+ 1.6 mph

Metropolitan rerouting option #2

Change in travel time on rerouting option #2 caused by incident	+7.4seconds per mile
Change in vehicle speed on rerouting option #2 caused by incident	- 1.1 mph

Metropolitan rerouting option #3

Change in travel time on rerouting option #2 caused by incident	+ 3.8 seconds per mile
Change in vehicle speed on rerouting option #2 caused by incident	- 0.8 mph

Metropolitan rerouting option #4

Change in travel time on rerouting option #2 caused by incident	+ 4.4 seconds per mile
Change in vehicle speed on rerouting option #2 caused by incident	- 0.7 mph

Metropolitan road segments with significant changes caused by incident

Central	
Change in travel time caused by incident	- 56.2 seconds per mile
Change in vehicle speed caused by incident	+ 6.03 mph

Hotspot 4: I-25 near Paseo Del Norte

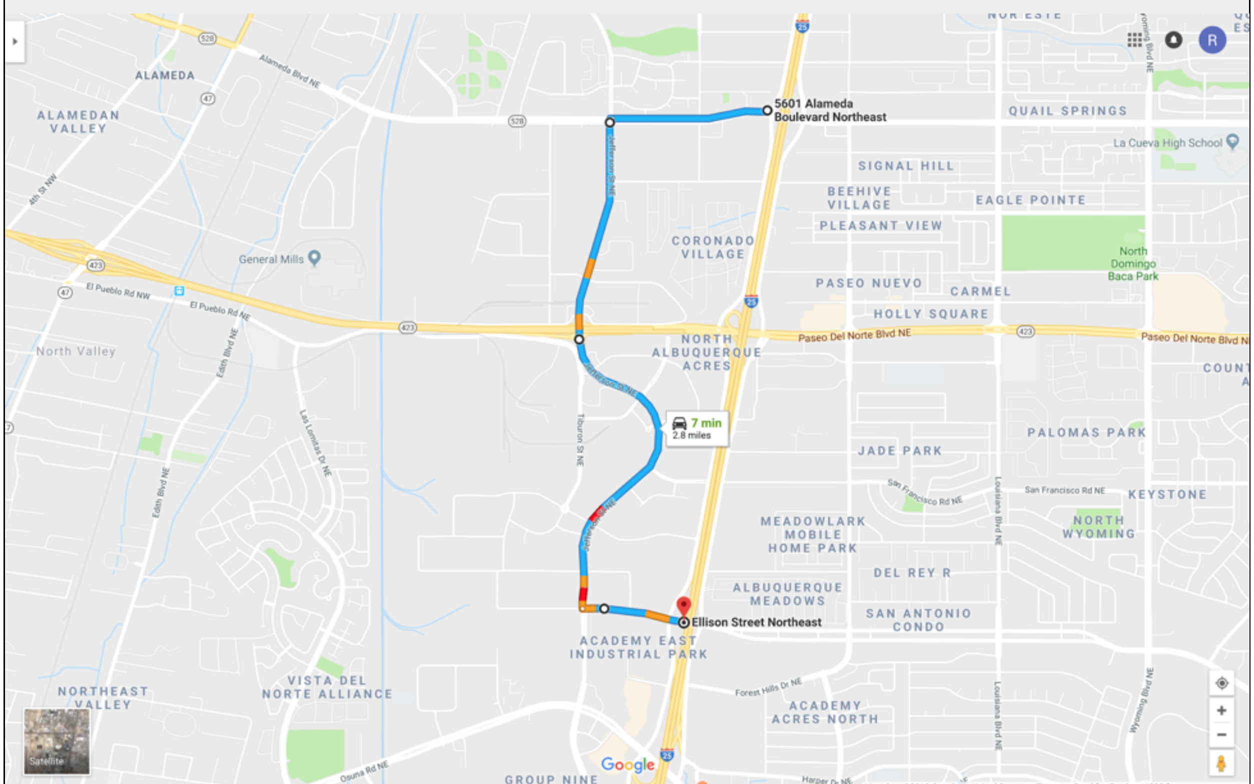
Incidents occurring at this hotspot in 2015	47

Incidents analyzed by team (3)	**Incident severity**
Incident 710215608, I-25 northbound, 11:43 a.m., February 28, 2015	2
Incident, 710242992, I-25 northbound, 10:24 a.m., June 14, 2015	6
Incident 710264992, I-25 northbound, 8:38 p.m., August 23, 2015	4

Average change in rerouting travel time caused by all analyzed incidents for all alternate routes	+ 2.2 seconds per mile
Average change in rerouting vehicle speed caused by all analyzed incidents for all alternate routes	+ 0.1 mph

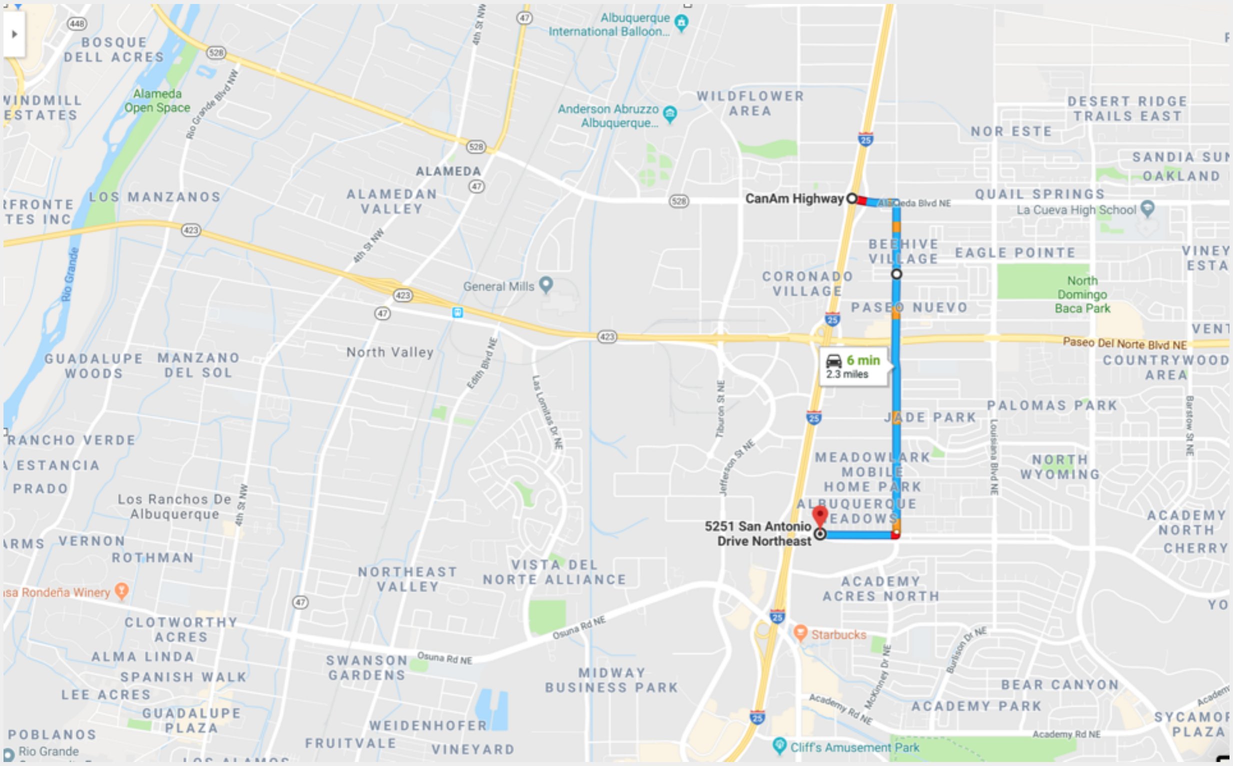
Metropolitan rerouting options analyzed by team

Metropolitan rerouting option #1 (Alameda Blvd. to Jefferson St., then San Antonio Blvd.)



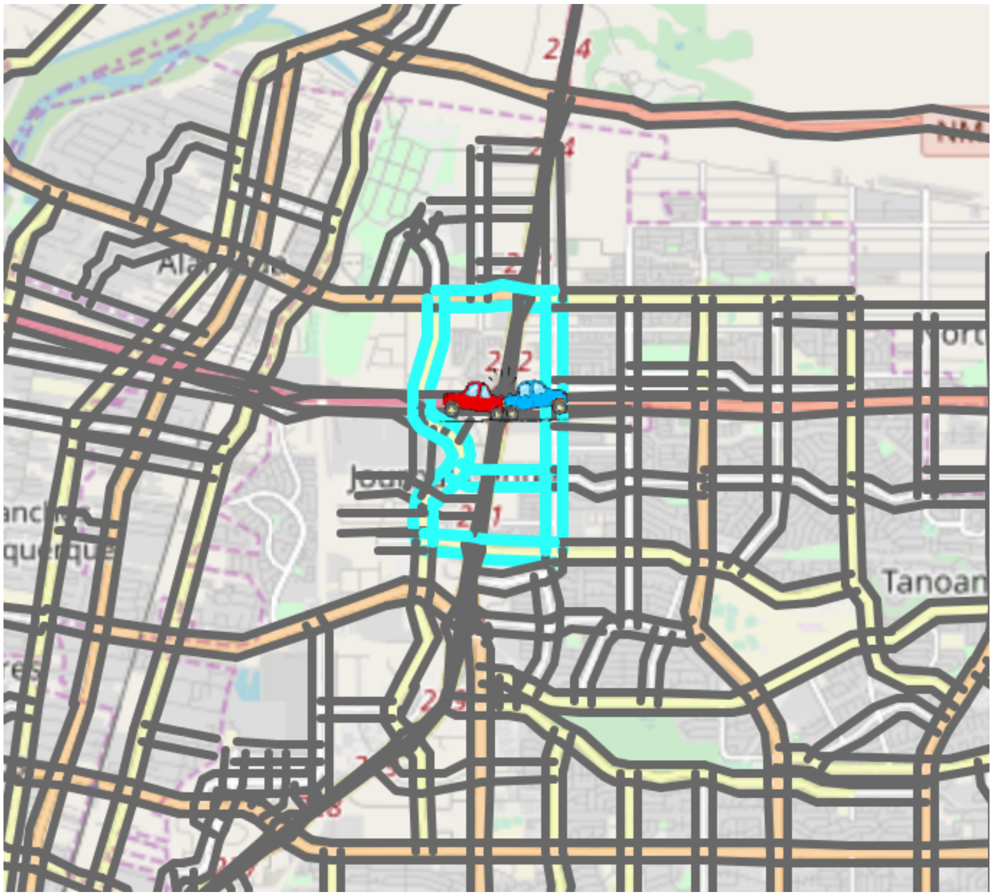
Average change in rerouting travel time caused by all analyzed incidents for this alternate route	- 5.3 seconds per mile
Average change in rerouting vehicle speed caused by all analyzed incidents for this alternate route	+ 1.2 mph

Metropolitan rerouting option #2 (Alameda Blvd. onto San Pedro Dr., then San Antonio Dr.)



Average change in rerouting travel time caused by all analyzed incidents for this alternate route	+ 9.5 seconds per mile
Average change in rerouting vehicle speed caused by all analyzed incidents for this alternate route	- 1.0 mph

Incident 710215608, I-25 northbound, 11:43 a.m., February 28, 2015



Of all the road segments highlighted, none experienced a change of +/- 5 mph.

Average change in rerouting travel time caused by all analyzed incidents for all alternate routes	- 0.7 seconds per mile
Average change in rerouting vehicle speed caused by all analyzed incidents for all alternate routes	+ 0.2 mph

Metropolitan rerouting option #1

Change in travel time on rerouting option #1 caused by incident	- 1.9 seconds per mile
Change in vehicle speed on rerouting option #1 caused by incident	+ 0.5 mph

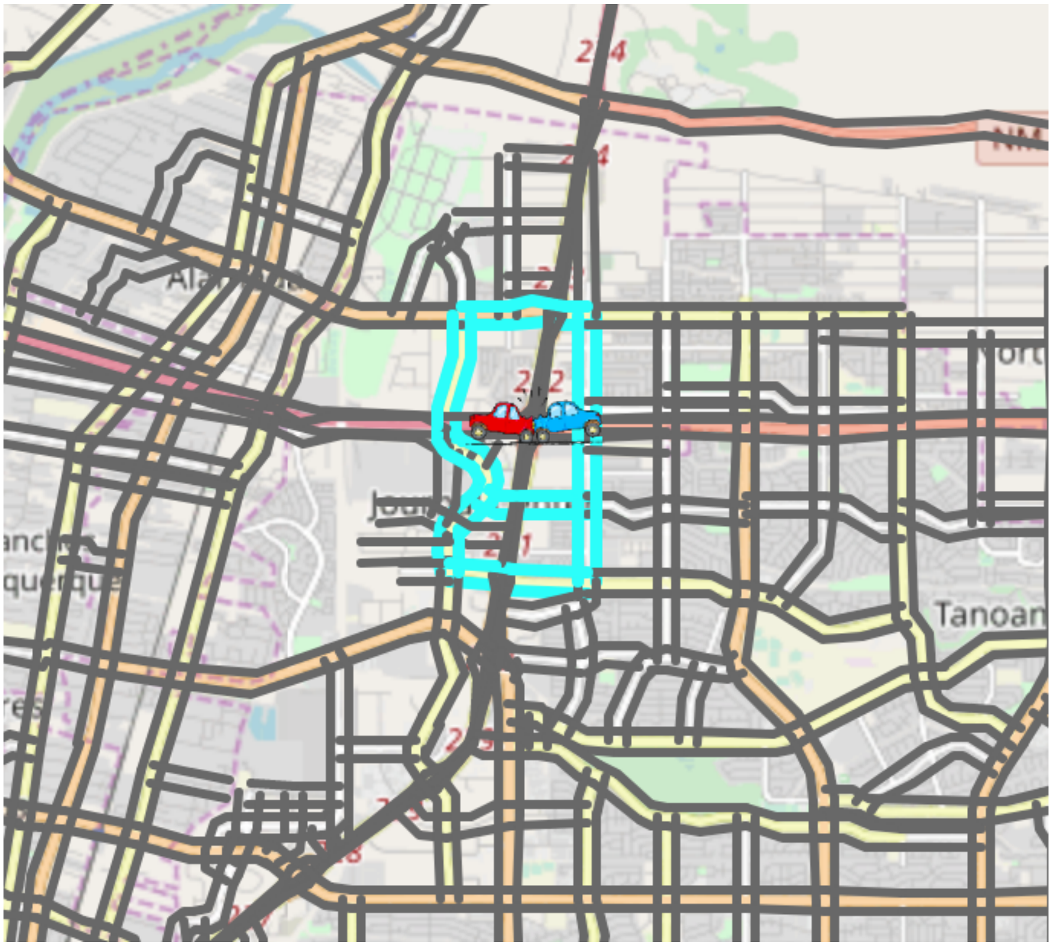
Metropolitan rerouting option #2

Change in travel time on rerouting option #2 caused by incident	+ 0.6 seconds per mile
Change in vehicle speed on rerouting option #2 caused by incident	- 0.1 mph

Metropolitan road segments with significant changes caused by incident

None

Incident, 710242992, I-25 northbound, 10:24 a.m., June 14, 2015



Of all the road segments highlighted, none experienced a change of +/- 5 mph.

Average change in rerouting travel time caused by incident	- 7.0 seconds per mile
Average change in rerouting vehicle speed caused by incident	+ 1.2 mph

Metropolitan rerouting option #1

Change in travel time on rerouting option #1 caused by incident	- 23.0 seconds per mile
Change in vehicle speed on rerouting option #1 caused by incident	+ 3.5 mph

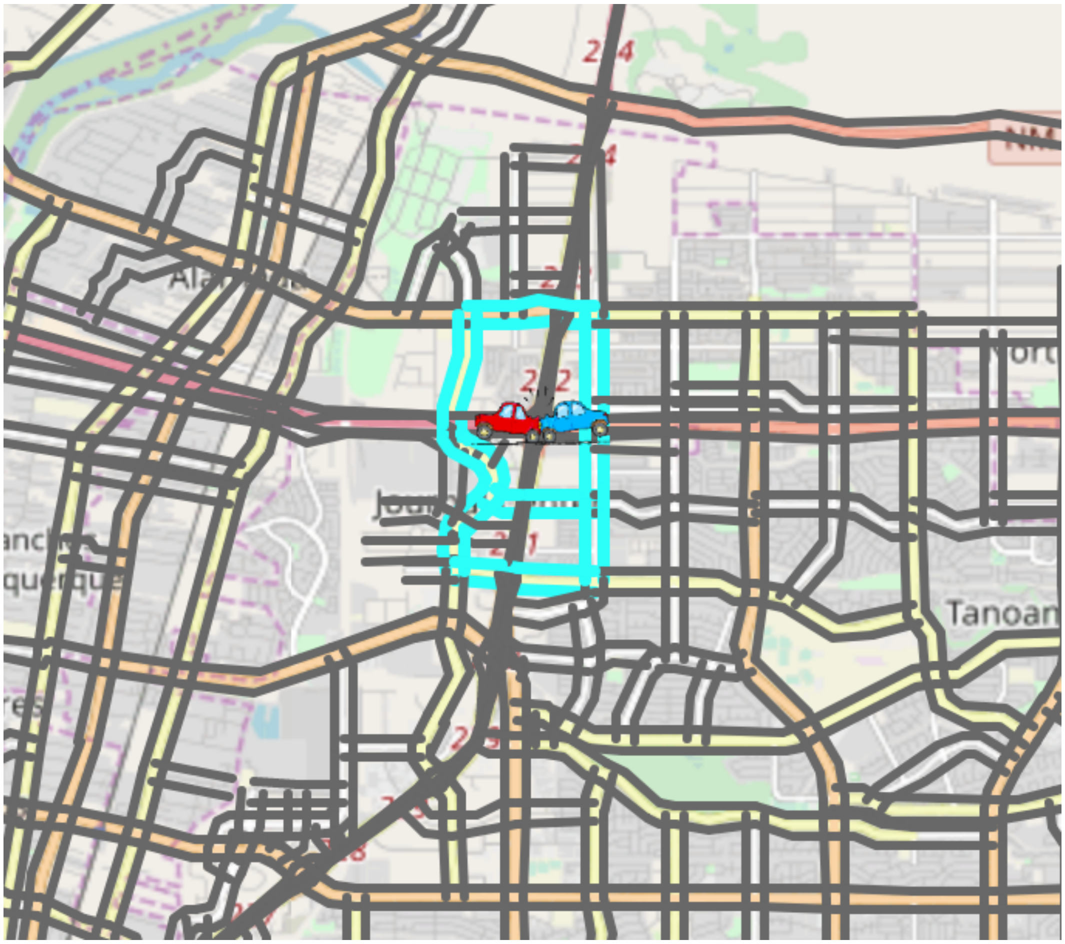
Metropolitan rerouting option #2

Change in travel time on rerouting option #2 caused by incident	+ 9.2 seconds per mile
Change in vehicle speed on rerouting option #2 caused by incident	- 1.2 mph

Metropolitan road segments with significant changes caused by incident

None

Incident 710264992, I-25 northbound, 8:38 p.m., August 23, 2015



Of all the road segments highlighted, none experienced a change of +/- 5 mph.

Average change in rerouting travel time caused by incident	+ 14.1 seconds per mile
Average change in rerouting vehicle speed caused by incident	- 1.1 mph

Metropolitan rerouting option #1

Change in travel time on rerouting option #1 caused by incident	- 26.3 seconds per mile
Change in vehicle speed on rerouting option #1 caused by incident	+ 2.4 mph

Metropolitan rerouting option #2

Change in travel time on rerouting option #2 caused by incident	+ 9.4 seconds per mile
Change in vehicle speed on rerouting option #2 caused by incident	- 0.3 mph

Metropolitan road segments with significant changes caused by incident

None

Hotspot 5: I-25 near Avenida Cesar Chavez

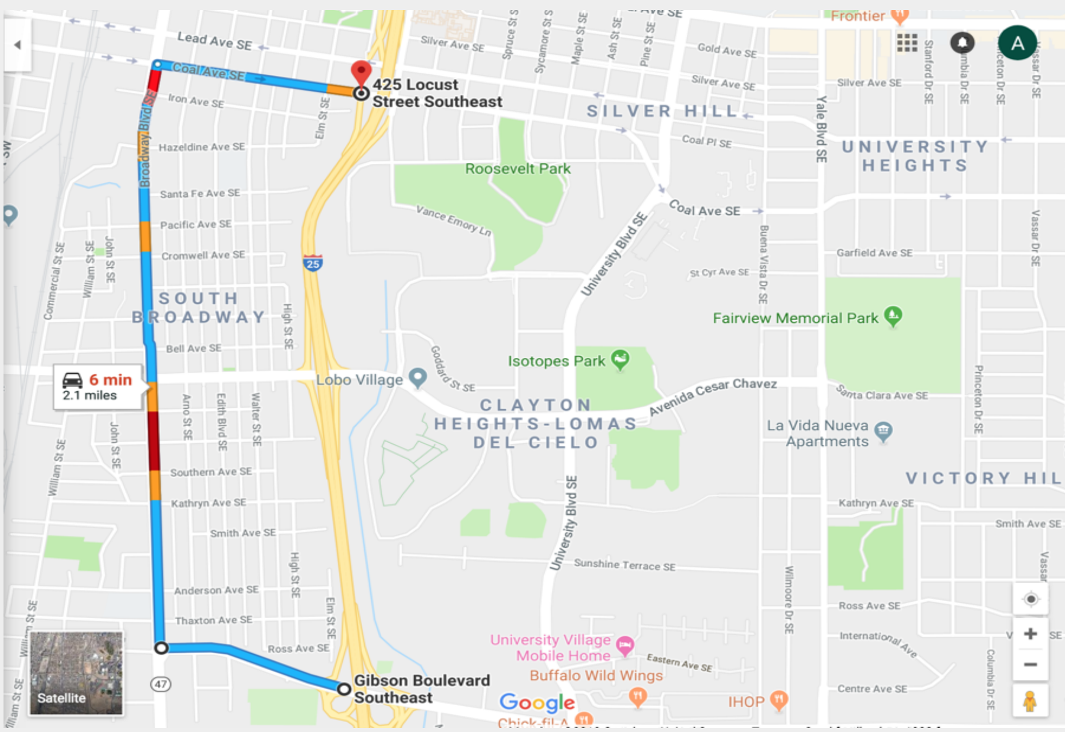
Incidents occurring at this hotspot in 2015	47

Incidents analyzed by team (3)	**Incident severity**
Incident 710236355, I-25 southbound, 7:31 p.m., May 3, 2015	3
Incident 710236423, I-25 southbound, 10:10 p.m., June 4, 2015	4
Incident 710252798, I-25 northbound, 4:52 p.m., August 1, 2015	3

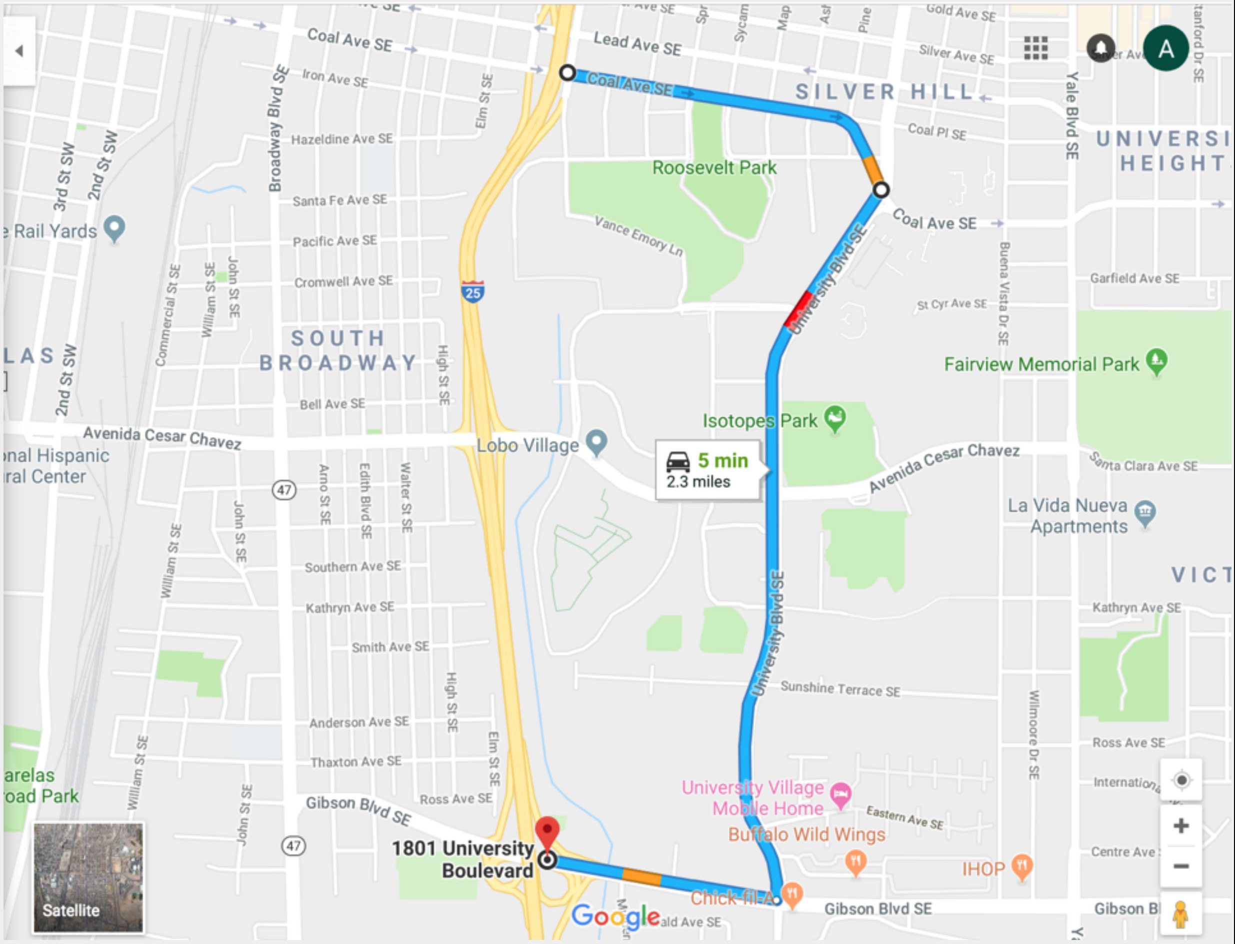
Average change in rerouting travel time caused by all analyzed incidents for all alternate routes	2.3seconds per mile
Average change in rerouting vehicle speed caused by all analyzed incidents for all alternate routes	- 0.4 mph

Metropolitan rerouting options analyzed by team

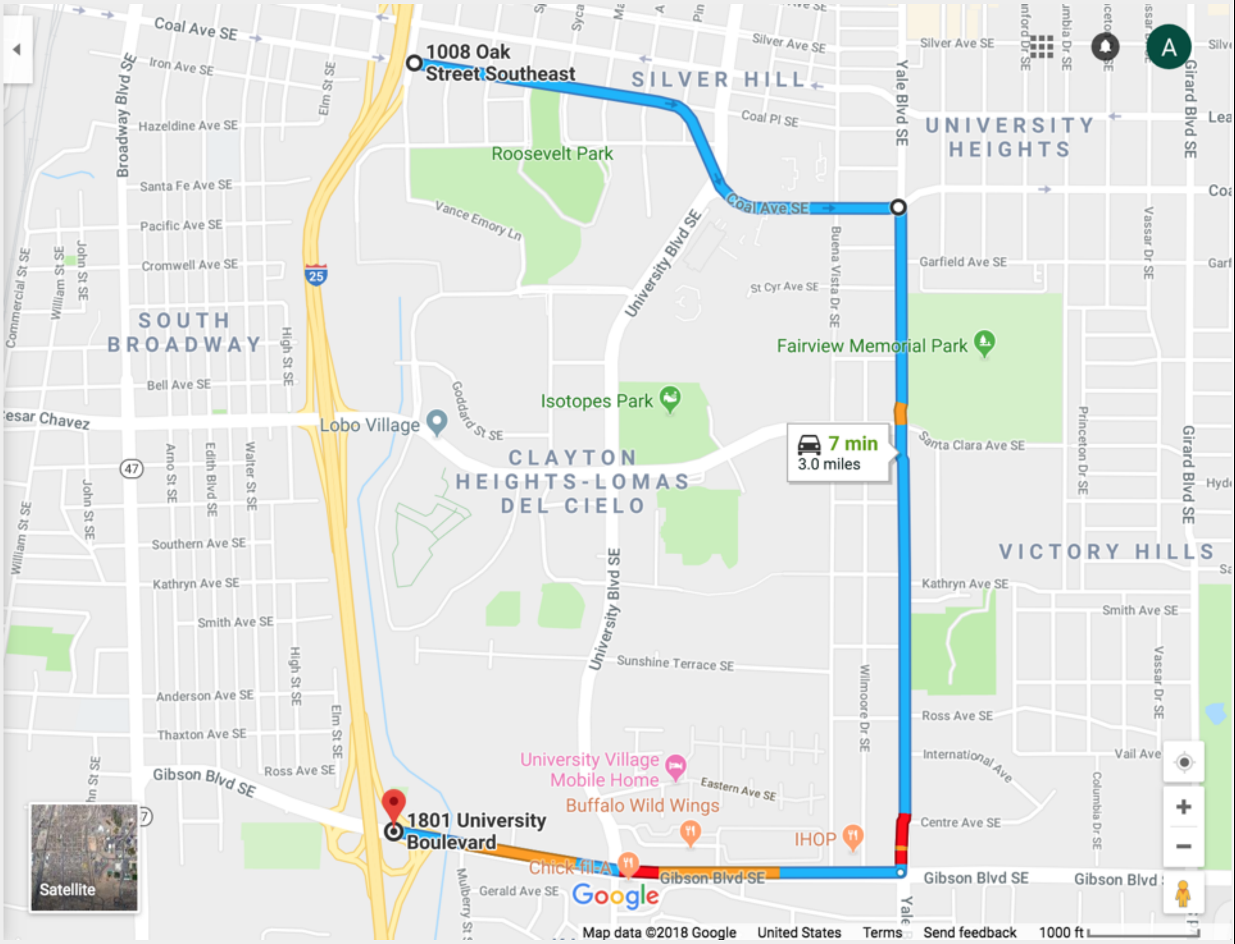
Metropolitan rerouting option #1 (Gibson Blvd. towards Broadway Blvd., then Coal Ave.)



Average change in rerouting travel time caused by all analyzed incidents for this alternate route	3.4 seconds per mile
Average change in rerouting vehicle speed caused by all analyzed incidents for this alternate route	- .314 mph

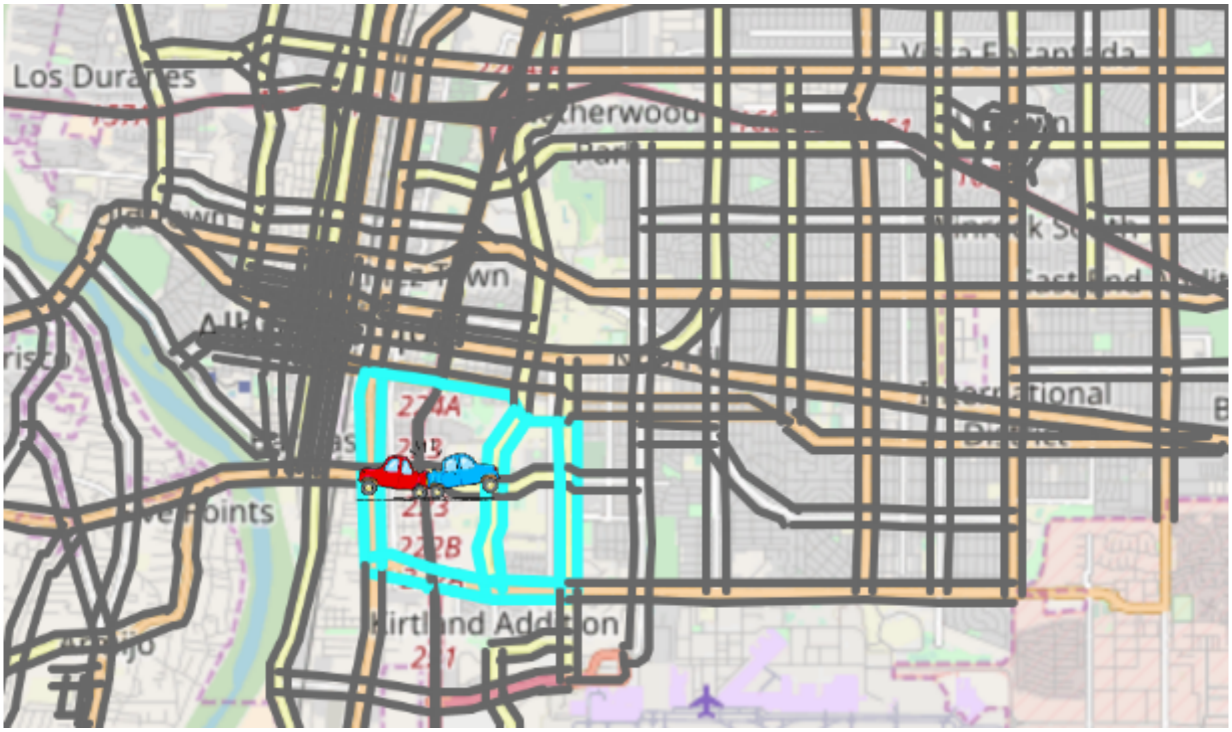
Metropolitan rerouting option #2 (Coal Ave. to University Blvd., then Gibson Blvd.)	
	
Average change in rerouting travel time caused by all analyzed incidents for this alternate route	4.20 seconds per mile
Average change in rerouting vehicle speed caused by all analyzed incidents for this alternate route	- .46 mph

Metropolitan rerouting option #2 (Coal Ave. towards Yale Blvd., then Gibson Blvd.)



Average change in rerouting travel time caused by all analyzed incidents for this alternate route	-0.57 seconds per mile
Average change in rerouting vehicle speed caused by all analyzed incidents for this alternate route	- .02 mph

Incident 710236355, I-25 southbound, 7:31 p.m., May 3, 2015



Of all the road segments highlighted, none experienced a change of +/- 5 mph.

Average change in rerouting travel time caused by incident	-1.17 seconds per mile
Average change in rerouting vehicle speed caused by incident	0.09 mph

Metropolitan rerouting option #1

Change in travel time on rerouting option #1 caused by incident	-2.99 seconds per mile
Change in vehicle speed on rerouting option #1 caused by incident	0.4 mph

Metropolitan rerouting option #2

Change in travel time on rerouting option #2 caused by incident	- 1.7seconds per mile
Change in vehicle speed on rerouting option #2 caused by incident	0.2 mph

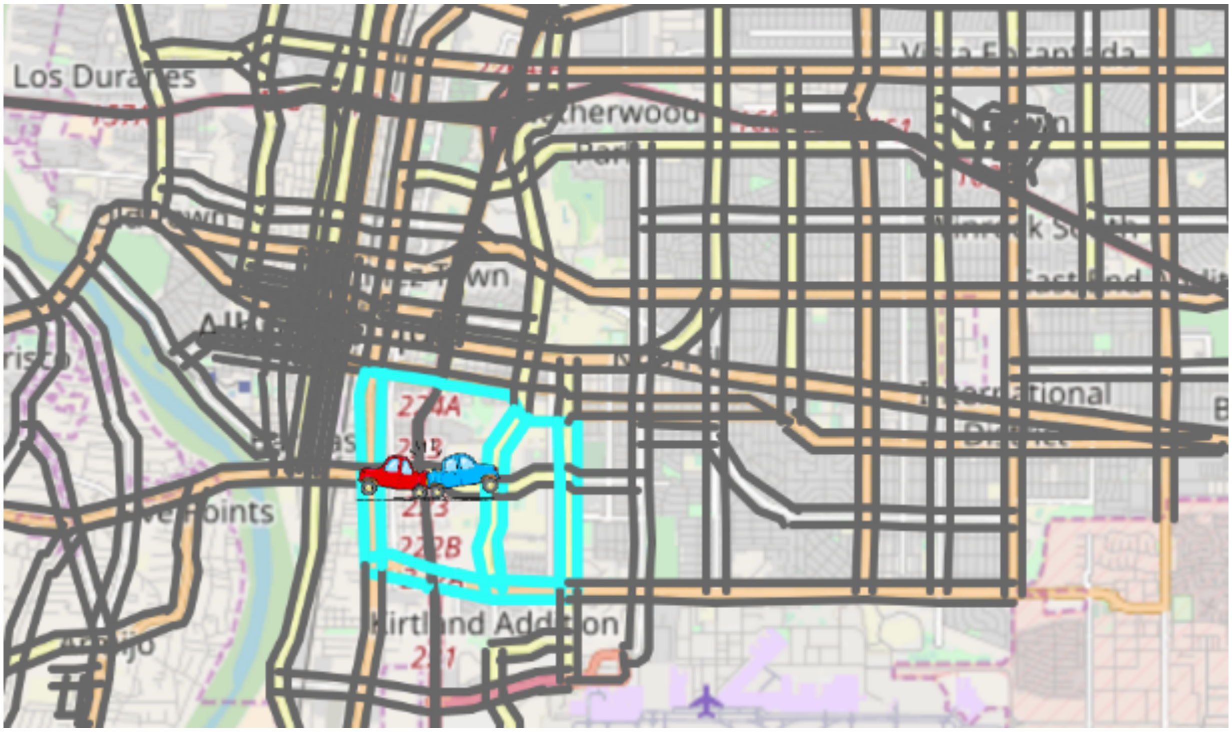
Metropolitan rerouting option #3

Change in travel time on rerouting option #3 caused by incident	1.16 seconds per mile
Change in vehicle speed on rerouting option #3 caused by incident	-0.33 mph

Metropolitan road segments with significant changes caused by incident

None

Incident 710236423, I-25 southbound, 10:10 p.m., June 4, 2015



Of all the road segments highlighted, none experienced a change of +/- 5 mph.

Average change in rerouting travel time caused by incident	+ 8.66 seconds per mile
Average change in rerouting vehicle speed caused by incident	- 1.5 mph

Metropolitan rerouting option #1

Change in travel time on rerouting option #1 caused by incident	+ 4.51 seconds per mile
Change in vehicle speed on rerouting option #1 caused by incident	- 0.75 mph

Metropolitan rerouting option #2

Change in travel time on rerouting option #2 caused by incident	+ 17.4 seconds per mile
Change in vehicle speed on rerouting option #2 caused by incident	- 2.81 mph

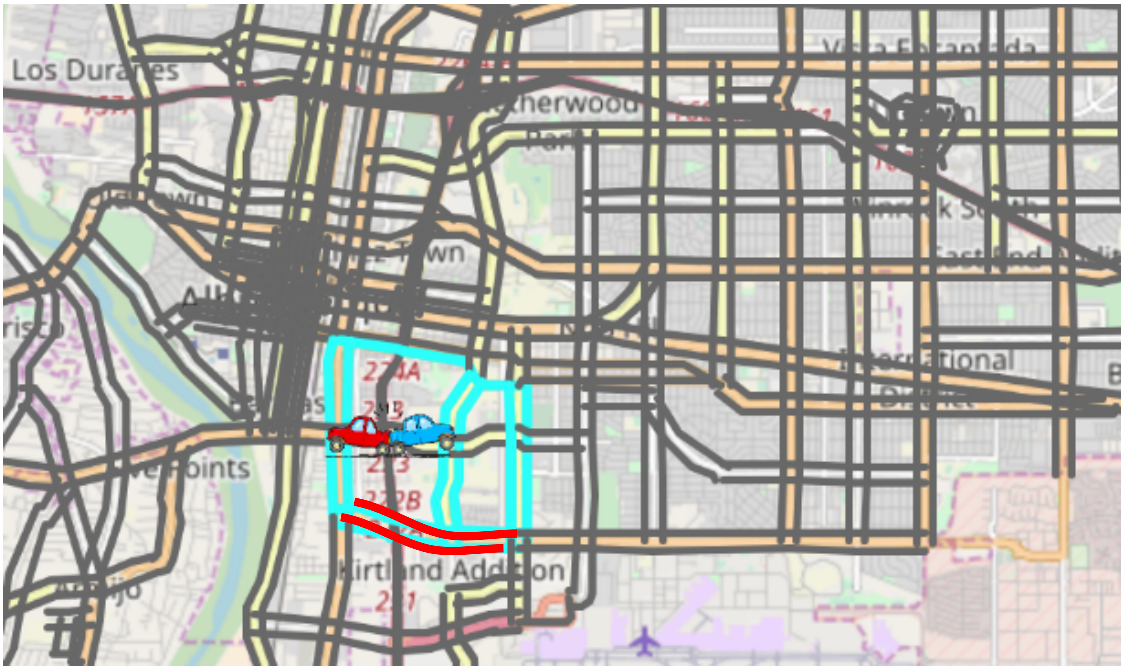
Metropolitan rerouting option #3

Change in travel time on rerouting option #3 caused by incident	4.06 seconds per mile
Change in vehicle speed on rerouting option #3caused by incident	-0.81 mph

Metropolitan road segments with significant changes caused by incident

None

Incident 710252798, I-25 northbound, 4:52 p.m., August 1, 2015



Gibson Blvd. is highlighted in **bright red**.

Average change in rerouting travel time caused by incident	- 0.45 seconds per mile
Average change in rerouting vehicle speed caused by incident	+ 0.27 mph

Metropolitan rerouting option #1

Change in travel time on rerouting option #1 caused by incident	8.66 seconds per mile
Change in vehicle speed on rerouting option #1 caused by incident	-0.6 mph

Metropolitan rerouting option #2

Change in travel time on rerouting option #2 caused by incident	—3.1 seconds per mile
Change in vehicle speed on rerouting option #2 caused by incident	-.33 mph

Metropolitan rerouting option #3

Change in travel time on rerouting option #3 caused by incident	-6.93 seconds per mile
Change in vehicle speed on rerouting option #3 caused by incident	1.09 mph

Metropolitan road segments with significant changes caused by incident

Gibson	
Change in travel time caused by incident	-16. 7 seconds per mile
Change in vehicle speed caused by incident	5.3 mph

Hotspot 6: I-25 near San Mateo

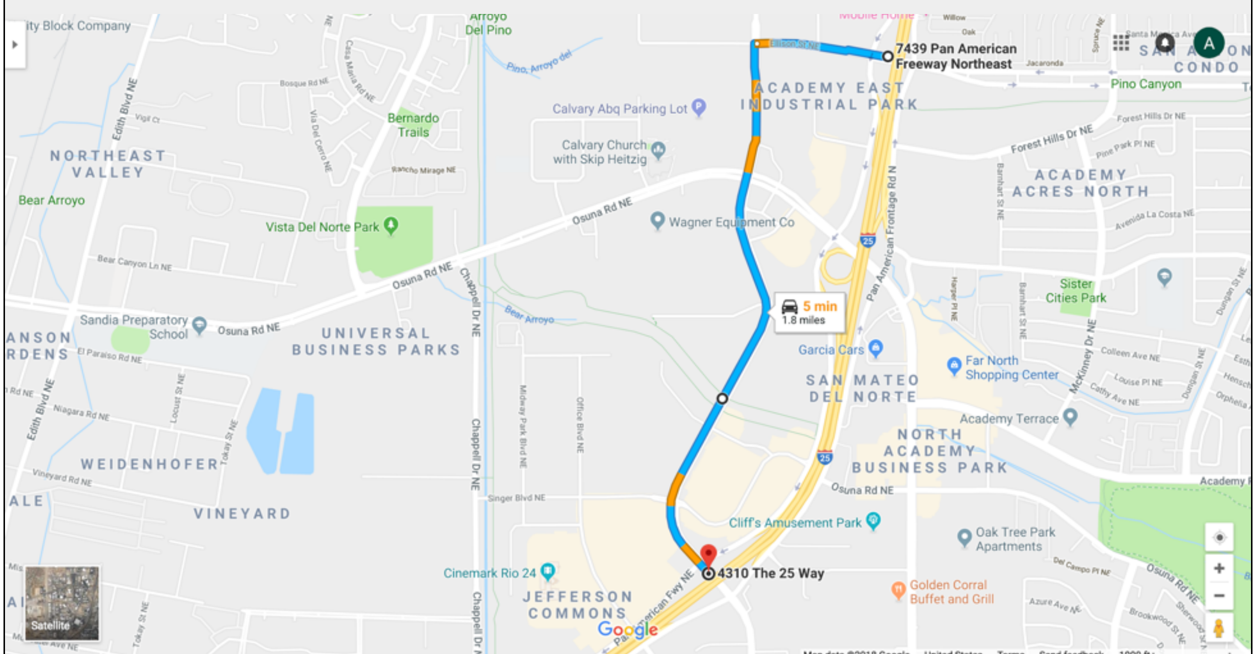
Incidents occurring at this hotspot in 2015	40

Incidents analyzed by team (3)	**Incident severity**
Incident 710241246, I-25 southbound, 10:06 a.m., March 25, 2015	2
Incident 710242478, I-25 southbound, 5:51 p.m., September 24, 2015	4
Incident 710251216, !-25 southbound, 10:05 a.m., April 28, 2015	3

Average change in rerouting travel time caused by all analyzed incidents for all alternate routes	8 seconds per mile
Average change in rerouting vehicle speed caused by all analyzed incidents for all alternate routes	- 0.9 mph

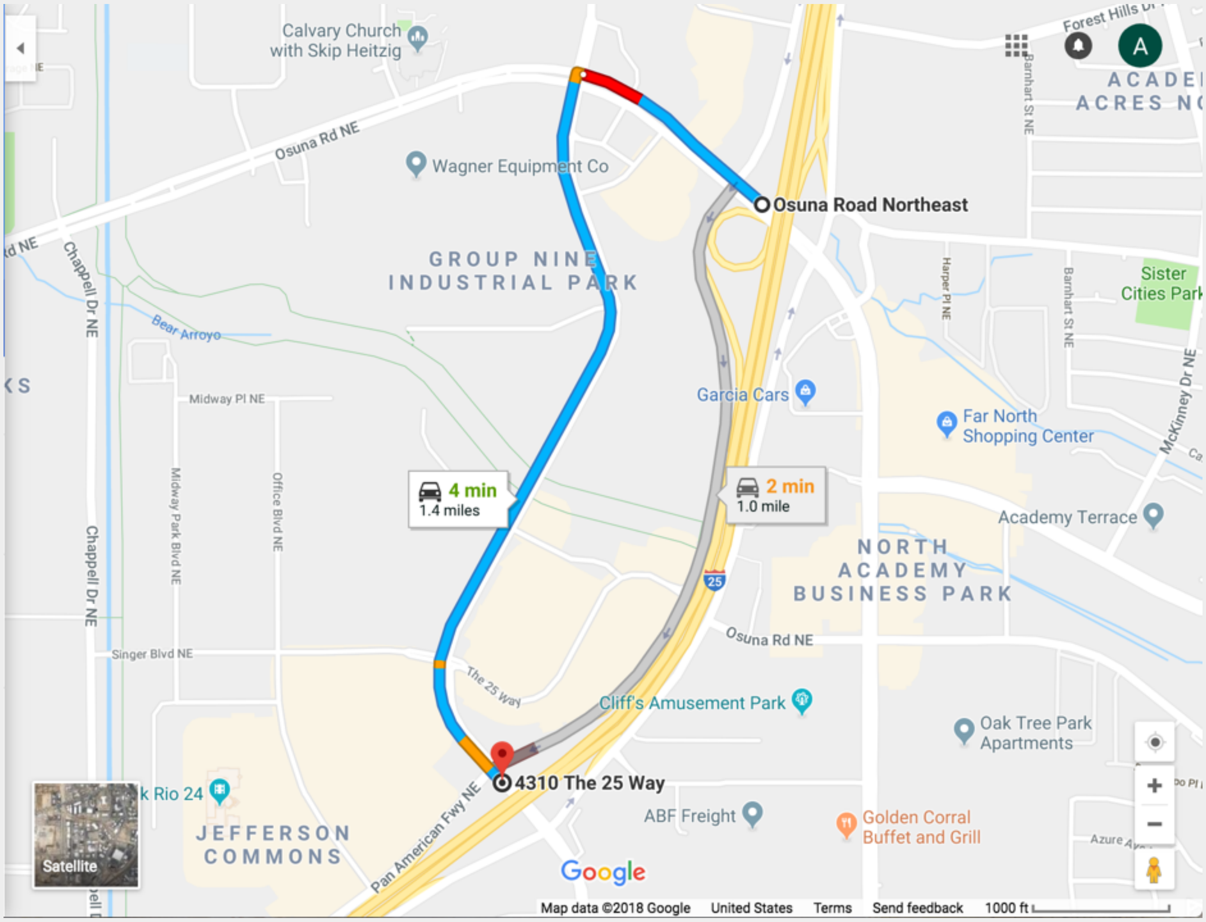
Metropolitan rerouting options analyzed by team

Metropolitan rerouting option #1 (San Antonio Dr. to Jefferson St.)



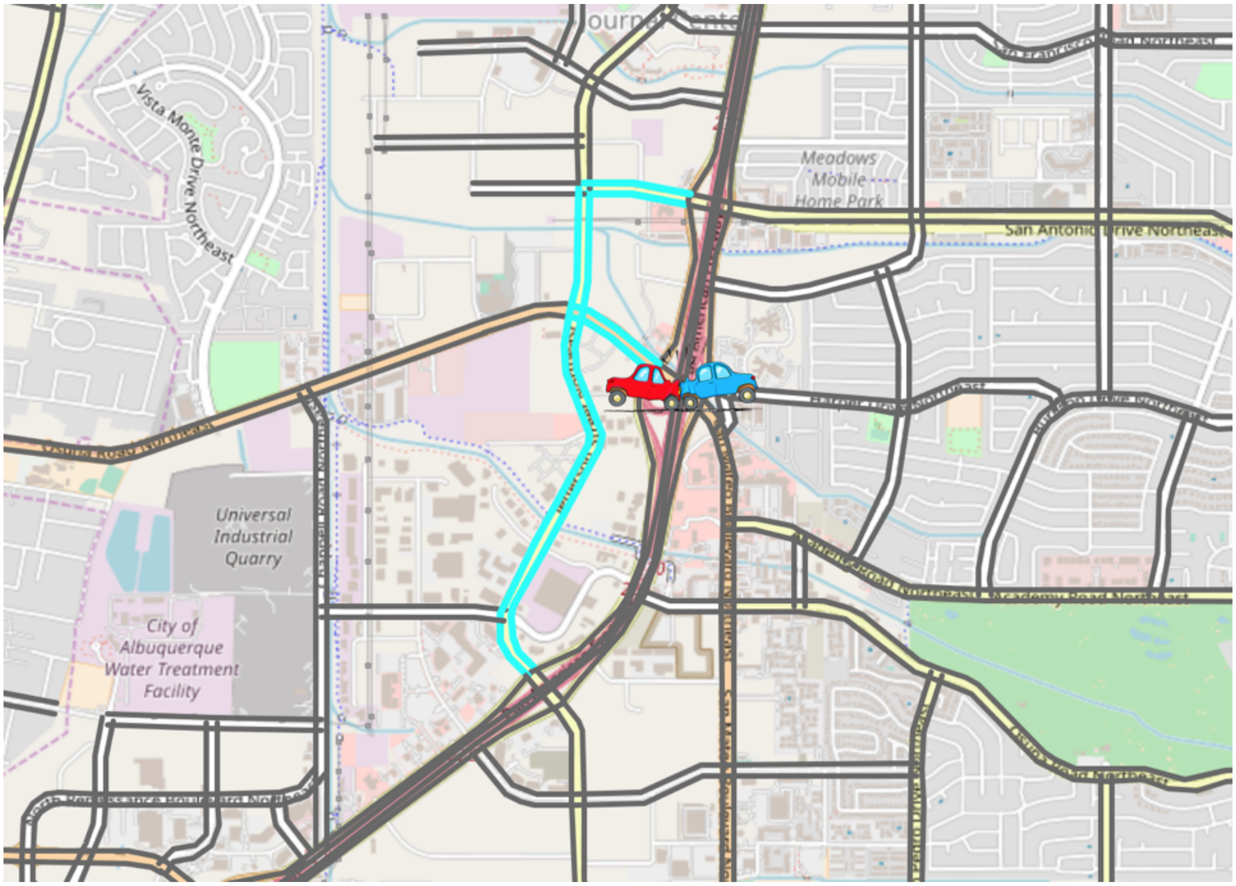
Average change in rerouting travel time caused by all analyzed incidents for this alternate route	+ 8.7 seconds per mile
Average change in rerouting vehicle speed caused by all analyzed incidents for this alternate route	- 3.5 mph

Metropolitan rerouting option #2 (Osuna Rd. to Jefferson St.)



Average change in rerouting travel time caused by all analyzed incidents for this alternate route	6.7 seconds per mile
Average change in rerouting vehicle speed caused by all analyzed incidents for this alternate route	- 0.6 mph

Incident 710241246, I-25 southbound, 10:06 a.m., March 25, 2015



Of all the road segments highlighted, none experienced a change of +/- 5 mph.

Average change in rerouting travel time caused by incident	- 0.8 seconds per mile
Average change in rerouting vehicle speed caused by incident	+ 0.2 mph

Metropolitan rerouting option #1

Change in travel time on rerouting option #1 caused by incident	+/- 0.0 seconds per mile
Change in vehicle speed on rerouting option #1 caused by incident	- 7 mph

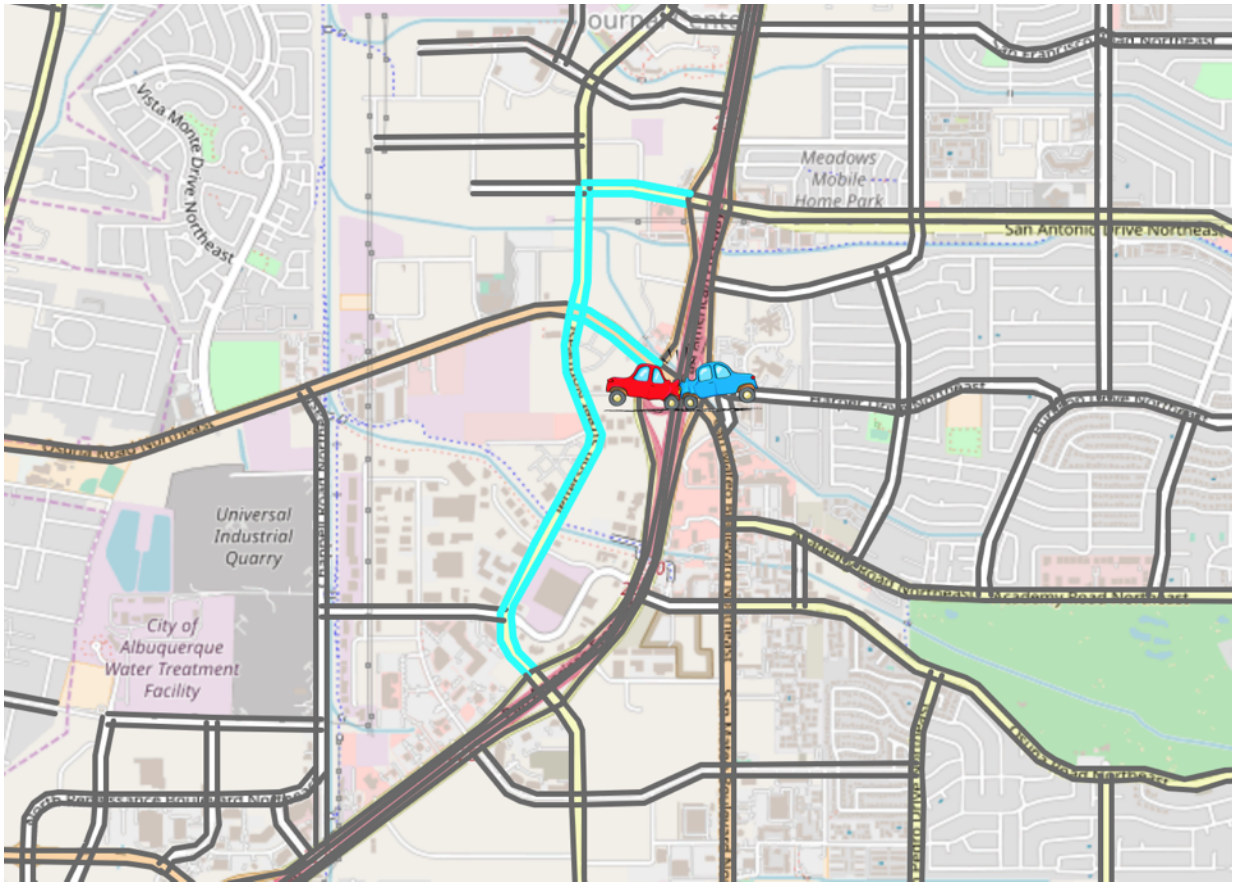
Metropolitan rerouting option #2

Change in travel time on rerouting option #2 caused by incident	- 2 seconds per mile
Change in vehicle speed on rerouting option #2 caused by incident	+ 0.3 mph

Metropolitan road segments with significant changes caused by incident

None

Incident 710242478, I-25 southbound, 5:51 p.m., September 24, 2015



Of all the road segments highlighted, none experienced a change of +/- 5 mph.

Average change in rerouting travel time caused by incident	+ 20.1 seconds per mile
Average change in rerouting vehicle speed caused by incident	- 1.7 mph

Metropolitan rerouting option #1

Change in travel time on rerouting option #1 caused by incident	+ 24.3 seconds per mile
Change in vehicle speed on rerouting option #1 caused by incident	- 3 mph

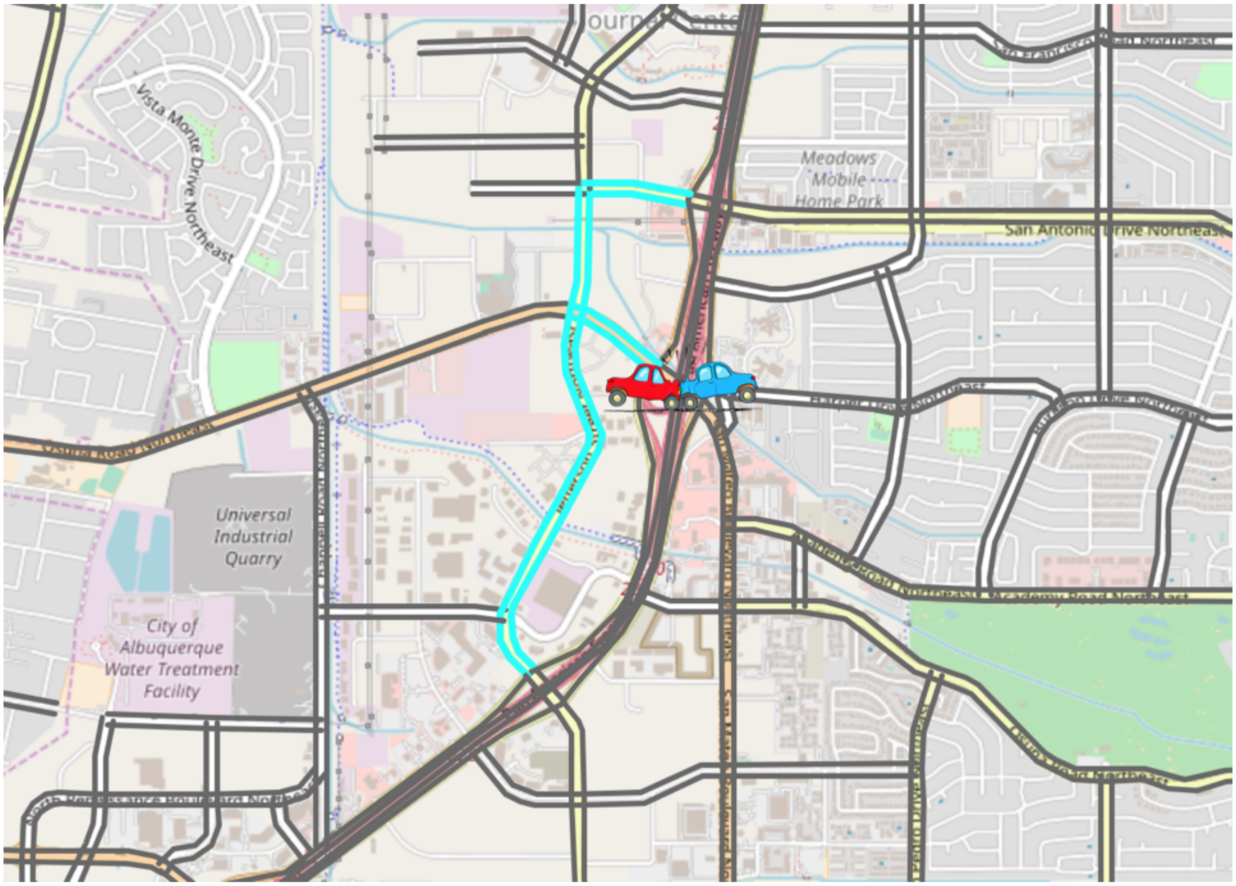
Metropolitan rerouting option #2

Change in travel time on rerouting option #2 caused by incident	+ 21.5 seconds per mile
Change in vehicle speed on rerouting option #2 caused by incident	- 2.4 mph

Metropolitan road segments with significant changes caused by incident

None

Incident 710251216, I-25 southbound, 10:05 a.m., April 28, 2015



Of all the road segments highlighted, none experienced a change of +/- 5 mph.

Average change in rerouting travel time caused by incident	- 21.3 seconds per mile
Average change in rerouting vehicle speed caused by incident	+ 1.6 mph

Metropolitan rerouting option #1

Change in travel time on rerouting option #1 caused by incident	+ 2.3 seconds per mile
Change in vehicle speed on rerouting option #1 caused by incident	- 0.4 mph

Metropolitan rerouting option #2

Change in travel time on rerouting option #2 caused by incident	-16.3 seconds per mile
Change in vehicle speed on rerouting option #2 caused by incident	+ 0.7 mph

Metropolitan road segments with significant changes caused by incident

None

3.3 Observe driver behavior in real time

The traffic surveillance program we wrote allowed the team to assess present-day driver rerouting behavior throughout the city of Albuquerque. First, the team autonomously collected traffic data for a determined map area over determined time windows. Second, the team reviewed collected data and assessed driver rerouting behavior.

3.3.1 Establish time windows and map area for observing driver behavior

As discussed in the methodology chapter, the team decided to observe morning and evening rush hours because of all time windows in a day, rush hour windows have 1) the highest volume of drivers and therefore 2) the highest likelihood of having a crash occur (John DiRuggiero, personal communication).

Using Google Maps, the team manually zoomed to a map area observing the entirety of Albuquerque and containing each of the six established hotspots. Once the team arrived at the above map area indicated above, it enabled live traffic and copied the resulting Google Maps URL as follows:

https://www.google.com/maps/@35.0975647,-106.6317954,13z/data=!5m1!1e1

As intended, the map area corresponding to this URL observed the entirety of Albuquerque and contained all hotspot locations. The team fed this URL to the Python surveillance program, which then monitored traffic conditions across the designated map area in established time windows.

3.3.2 Autonomously collect Google Maps traffic data

The Python program autonomously collected Google Maps traffic data for the designated map area during established time windows. In total, the group collected roughly 1800 high-resolution images of live traffic conditions in Albuquerque. The team's photoset detailed five morning rush hour windows and five evening rush hour windows from October 1-5, 2018. For each rush hour window, the team developed a stop motion video animating traffic conditions. The stop motion videos the team created can be viewed below:

(10/01) Monday, October 1, 2018; morning rush hour here, evening rush hour here.
(10/02) Tuesday, October 2, 2018: morning rush hour here, evening rush hour here.
(10/03) Wednesday, October 3, 2018: morning rush hour here, evening rush hour here.
(10/04) Thursday, October 4, 2018: morning rush hour here, evening rush hour here.
(10/05) Friday, October 5, 2018: morning rush hour here, evening rush hour here.

The team then manually reviewed each of the ten stop motion videos and assessed driver behavior.

3.3.3 Review collected data and assess driver behavior

10/ 01 Morning rush hour

During morning rush hour on 10/01, no accidents took place, but congestion built on I-25 and I-40. On I-25, drivers seemed to exit the highway south of the Big I and use Odella Road, which quickly became congested. Instead of Odella, drivers might benefit from rerouting to Mountain Road, which is located parallel to Odella, but did not seem to be congested by the extra traffic. Also, on I-25, the section of highway closest to Osuna Road became congested, but the traffic quickly dispersed onto Osuna Road. The congestion did not become severe, which may mean that drivers chose to reroute in order to avoid the congestion taking place. Avenida Cesar Chavez became congested during this rush hour period. We saw here that drivers were rerouting, but running into more congestion. Our analysis indicates that if drivers are going to take Avenida Cesar Chavez, they should choose to travel through Gibson to Broadway and Coal or from Coal to University to Gibson instead.

10/01 Evening rush hour

During evening rush hour on 10/01, an accident took place east of the Big I on I-25 between exits 161 and 160 at 3:50pm. For the first 10 minutes, all of the congestion stayed on the highway, but it seemed to lessen when drivers chose to travel on San Mateo in order to avoid the highway congestion. The congestion that built on San Mateo did not last long and was not severe. Avenida Cesar Chavez saw severe congestion once again. The team's analysis suggests drivers should take Gibson Blvd. to Broadway Blvd. and Coal Ave. or from Coal to University to Gibson. The morning rush hour on 10/03 saw no accidents and most congestion stayed on I-25 and I-40 respectively. The only congestion that traveled to metropolitan roads took place on Avenida Cesar Chavez, which we found experiences congestion during all rush hour periods.

10/02 Morning rush hour

Around 7:09 am, during morning rush hour, on 10/02, an accident took place on I-40 west of the Big I between exits 158 and 159A. The highway became congested, but the surrounding roads saw little to no congestion, which is consistent with our inferences from objective 2, indicating that drivers generally stay on highways instead of rerouting themselves. The closest major road that drivers could use is Menaul Blvd, but after the team's analysis of surrounding roads, discussed in 3.2.2, we found Menaul Blvd. became congested and would not be recommended rerouting option.

10/02 Evening rush hour

During evening rush hour on 10/02, no accidents took place on I-40 or I-25, but the impact of rush hour congested the highways. On I-25, the major congestion took place south of the Big I, around Avenida Cesar Chavez. During the entire time period (3:30pm-6:30pm) this section of I-25, as well as Avenida Cesar Chavez, became severely congested. The team recommends that instead of staying on Avenida Cesar Chavez, drivers could exit the congested highway and avoid the congested Avenida Cesar Chavez by traveling through Gibson [MLM1] Blvd. to Broadway Blvd. and Coal Ave. or from Coal to University to Gibson. On I-40, the highway became severely congested for the entirety of rush hour, but drivers chose to sit through the congestion instead of rerouting themselves onto surrounding major roads.

10/03 Morning rush hour

The morning rush hour of 10/03 saw no accidents and most congestion stayed on I-25 and I-40 respectively. The only congestion that traveled to metropolitan roads took place on Avenida Cesar Chavez, which we found experiences of congestion during all rush hour periods.

10/03 Evening rush hour

During evening rush hour on 10/03, two different accidents took place east of the Big I, one at 4:10pm and 5:10pm. The surrounding streets saw no congestion, but the highways became more backed up over time, which may explain why a secondary accident took place so close to the first. Carlisle or Menaul would have been good options to reroute some of the highway traffic, lessening traffic and the chance of secondary incidents.

10/04 Morning rush hour

During morning rush hour on 10/04, three accidents occurred on I-40. One took place at 7:15am between exits 164 and 165. Drivers did not reroute, and instead stayed on I-40, building congestion as the morning commute continued. West of the first accident, the second took place in an already congested stretch of highway at around 7:35am. East of the first accident, the third crash took place at 7:45am. The first accident created secondary crashes along the same highway, increasing congestion. During our interviews with the NMDOT, they were clear in their goal of clearing incidents within 30 minutes in order to avoid higher risks of secondary crashes. Here, we saw that within 30 minutes, two secondary accidents took place. On I-25, nothing unexpected took place on this day. Avenida Cesar Chavez became congested, but this was nothing surprising for Albuquerque drivers.

10/04 Evening rush hour

Evening rush hour on 10/04 saw two accidents on I-40 east of the Big I, but congestion continued to build on the highway instead of spreading into the surrounding metropolitan routes, supporting our hypothesis that drivers stay on the highways instead of rerouting to avoid congestion. An accident occurred on I-40, south of the Big I, conveniently at the Avenida Cesar Chavez exit. As expected, congestion formed on Avenida Cesar Chavez, supporting our recommendation that the NMDOT should make a larger effort of broadcasting alternate routes that would aid in avoiding congestion.

10/05 Morning rush hour

The morning of 10/05 saw normal rush hour conditions with congestion in the usual spots. No accidents took place, but congestion built on I-25 as well as I-40. Congestion on metropolitan roads never became severe and cleared up quickly, but often these roads were not easily accessible by highways which once again supports our analysis that drivers stay on highways instead of rerouting themselves.

10/05 Evening rush hour

Evening rush hour of 10/05 saw more excitement than the usual rush hour congestion due to four accidents that took place. The first, took place at the beginning of rush hour, and was cleared within 20 minutes. The second accident took place at 5:30pm on I-25 south of Paseo Del Norte which caused severe congestion. Following this accident, a third accident took place on Paseo Del Norte at 6:15pm as that road saw more activity than usual due to the second accident.

From the team’s analysis, none of the roads surrounding Paseo Del Norte became overly congested or handled congestion better than others, so there was no better route for drivers to take. Before the second accident had cleared, a fourth took place just south of the second at 6:21pm. Because the accident was not cleared within 30 minutes, the chance of a secondary accident on I-25 was higher, and this resulted in a second accident taking place.

4.0 Discussion, Recommendations, and Conclusion

Discussion

The goal of this project was to assist the New Mexico Department of Transportation in assessing the impact of highway incidents on metropolitan congestion in Albuquerque. First, the team identified historical hotspots of traffic incidents on both Interstate 40 and Interstate 25. These hotspots represented specific, predetermined areas of recurring congestion-causing factors on either of the interstates. Second, the team analyzed metropolitan congestion in Albuquerque resulting from incidents occurring at each of the historical hotspots. The team determined rerouting options for highway drivers impacted by the incidents, identifying specific roadway segments of significance. Through this practice, the group pinpointed road segments that could handle additional traffic rerouted from highway incidents, and also identified road segments that are apparently susceptible to becoming overburdened after such incidents.

The team identified six hotspots of recurring highway congestion and incidents through research: I-40 near University Blvd., I-40 near Carlisle, I-40 near Rio Grande, I-25 near Paseo Del Norte, I-25 near Avenida Cesar Chavez, and I-25 near San Mateo, identified in Figure 15. First, the team identified plausible rerouting options for drivers seeking to avoid congestion at each of these hotspots. Second, the team assessed the viability of all possible reroutes, drawing congestion-related conclusions about specific roadways affected by metropolitan drivers circumventing highway congestion. Across the six hotspots, the team identified two road segments that demonstrated a pattern of recurring congestion resulting from highway incidents: Carlisle Interchange and Carlisle Blvd. The team assessed that these particular roadways are not capable of efficiently accommodating traffic rerouted from highway congestion. Likewise, the team identified seven road segments that demonstrating a pattern of recurring efficiency when handling traffic rerouted from highway incidents: 12th Street Interchange, University Blvd., Alameda Blvd., Broadway Blvd., Osuna Rd., San Mateo Blvd., and McLeod Rd. The team assessed that these particular roadways are capable of efficiently accommodating rerouted highway traffic and therefore offer themselves as viable rerouting options.

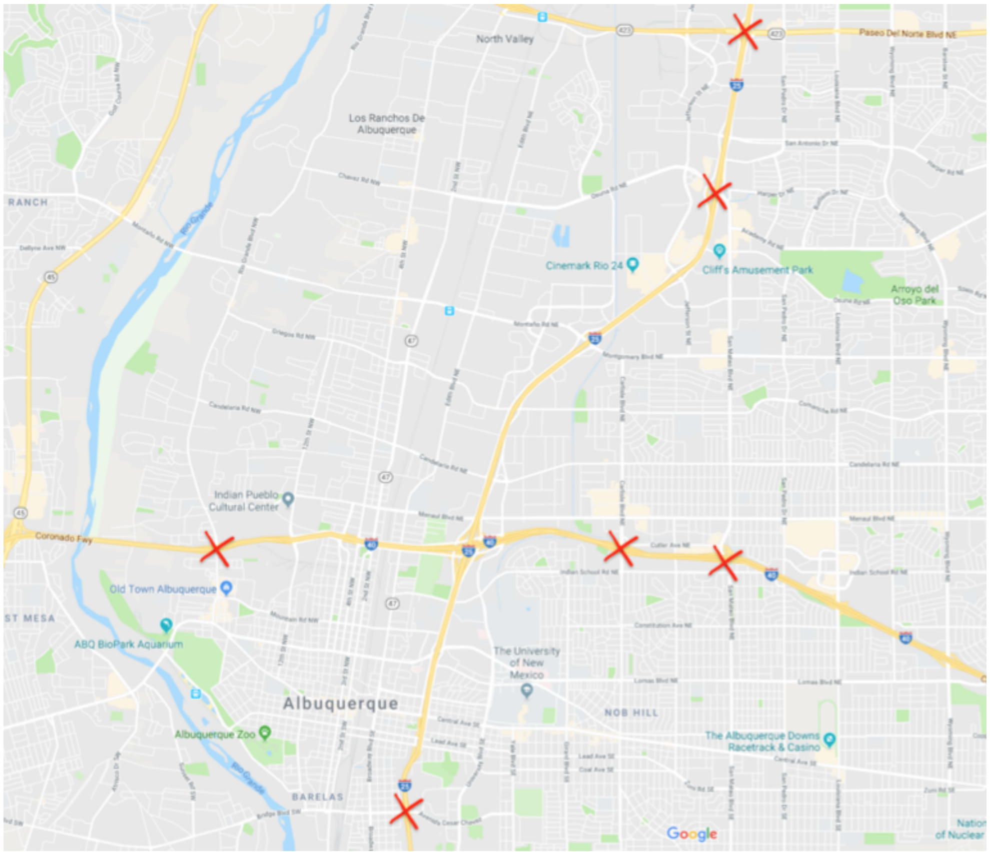


Figure 6: All 6 hotspot locations

For this project, the team analyzed congestion resulting from highway incidents on five distinct types of metropolitan roadways: urban principal arterials, urban minor arterials, urban collectors, urban off ramps, and rural major collectors. The team assessed that, on average, a driver who took an urban off ramp at or near one of the six hotspots was delayed nearly three minutes per mile because of congestion resulting from highway incidents. In total, delays on urban off ramps accounted for the majority of metropolitan delays resulting from highway incidents; the average delays on all other road types were under thirty seconds per mile. With this, the team assessed that urban off ramps slow highway-to-metropolitan throughput and inhibit drivers from efficiently entering the metropolitan road network from highways more significantly than other Albuquerque streets.

The group assessed that highway incidents, although congestion-causing, do not account for a significant amount of congestion in metropolitan Albuquerque. While specific roadway segments are recurrently incapable of efficiently accommodating increased throughput resulting from highway incidents, based on our analysis, the team hypothesizes the majority of urban minor arterials, urban collectors, and rural major collectors have potential to handle rerouted traffic effectively. However, this cannot be proven because most drivers apparently choose to not reroute, meaning there is no data that shows a large influx of drivers on these alternate routes. If drivers decided to reroute themselves, there would be data to test this hypothesis and clearly understand which roads can handle the traffic. Our interpretation of these results is that drivers simply are not getting off the highway when an incident takes place. The simplest explanation for the lack of significant surface road congestion is that drivers chose to wait for the incident to be cleared instead of rerouting themselves. With this, the group assessed that highway incidents do not necessarily cause significant metropolitan congestion. Because congestion patterns on the surface roads we analyzed did not correlate with the occurrence of highway accidents, we believe it is likely that the majority of metropolitan congestion is caused by factors external to this report, such as rush hour traffic, weather, lane closures, construction, and police activity.

Drivers have alternate route information on their smartphones, which made the team wonder why these routes are not traveled nearly as often when necessary. Through research using Waze at midday, we compared 3 cities with similar populations to Albuquerque: Tucson, Milwaukee, and Seattle. Tucson, with a population of 530,000, had 930 active Waze users, Milwaukee, with a population of 595,000, had 1141 users, and Seattle, with a population of 670,000, had 4349 users, and finally, Albuquerque, with a population of 560,000, had only 211 users. While we cannot confirm, we assume that the pattern of users would be the same throughout other GPS applications such as Google Maps and Apple Maps. Albuquerque drivers are not trained to be searching for the fastest route at all times which could explain the lack of GPS usage, but drivers would benefit from GPS information in order to use metropolitan roads to avoid highway congestion.

An aspect to take into consideration is the time intervals the team had access to. The team was able to analyze TAQA data, which is reported in 15 minute intervals. During our interviews with representatives of the NMDOT, they made it clear that their goal is to clear accidents within 30 minutes of the accident taking place. If accidents are cleared within this time frame, our group was only able to analyze 2 time frames with TAQA. During a 15-minute period, traffic could easily have congested and been cleared on metropolitan roads, so our team would not see the full effect of the highway incident because everything has already been cleared. While we feel that our results are dependable, this is a detail to consider and could lead to further research by the NMDOT. In order to review our data with more recent data, the team was able to analyze driver behavior in the present day, and find that the patterns found in 2015 had not changed.

Recommendations

Our analysis led us to identify a number of approaches we think the Albuquerque traffic agencies could take in order to improve data analysis and congestion mitigation. Below, we describe our specific recommendations and provide some guidelines on how they could be implemented. Our recommendations to the NMDOT are as follows:

1. We recommend that all MRCOG agencies should uniformly record where accidents take place, whether that be by coordinates or mile markers, to greatly increase the accuracy and efficiency of what these agencies can do to mitigate the situation. During our research, we were given data that recorded accident location by exact coordinates, closest exit, and the closest mile marker. Because the team was given information in varying formats, it was up to us to create a baseline of how to find the exact location for our data purposes. While we were able to come up with a solution, the process would have been much smoother if there was one uniform way to record where accidents took place.
2. We recommend that traffic data be kept in a uniform format. Right now, different MRCOG agencies use different formats to keep and analyze data, complicating our team's data analysis. If all the agencies working on New Mexico roadways used the same data or represented data the same way, as well as keeping it up to date, the team would have had access to recent data and not have to analyze incidents with data from 3 years ago. The team developed the third step to our methodology, observing driver behavior in real time, for the main purpose of checking the results we gathered. The data

we are using is from 2015, 3 years ago, so it was important for the group to connect our findings back to real-day information which would make them more helpful for the NMDOT.

3. We recommend that inter-agency communication be improved. If all agencies can act jointly, and use the same methods of recording data, managing accidents, and communicating, the traffic issues in Albuquerque would become easier to oversee and control. It was clear during our interviews with Mr. Brown, Mr. Masek, and Mr. Remeks that there was confusion between agencies because all information is gathered differently and recorded in different formats. Our liaison, John DiRuggiero, told our team on multiple occasions that the communication is not ideal and that halted our team's progress during certain weeks because we knew what we needed, but the NMDOT would have to ascertain where the information was and who would be able to share it with the team.
4. The team suggests that alternate routes are better broadcasted to the public. Dynamic message signs are available to the NMDOT, but are used during select occasions. We think this could be done with a more aggressive use of dynamic message signs around accidents, or a push from the NMDOT to have the public use GPS apps on their smartphones. I-40 and I-25 are the two highways that drivers travel on to enter and exit Albuquerque, but it seems that drivers are unaware that there are more options available. If the NMDOT could effectively broadcast viable options to drivers, they would hopefully have a higher chance of avoiding congestion altogether. Another option available to drivers is GPS applications on their smartphones. Waze, Google Maps, Apple Maps, and the local NMRoads app are all available to drivers, but are not being used when they should be. Drivers in New Mexico are not trained to constantly be searching for the fastest route, and are fine with sitting through some congestion, which means that these options need to be broadcasted clearly for the public.
5. Finally, we recommend that the NMDOT focus their efforts on interchanges, better known as off-ramps and on -ramps, such as 12th street and Carlisle, which were affected more by accidents that occurred on the highway. For the most part, alternate routes were not affected by the highway throughput.

Conclusion

Working with the New Mexico Department of Transportation allowed our team the opportunity to highlight the traffic management issues that are burdening the Albuquerque area. Our team's methods are replicable by any other state DOTs in order to analyze areas inconvenienced with congestion. Traffic issues in Albuquerque go beyond how drivers are choosing to reroute and extend to how different agencies are receiving traffic data and how they choose to use this in order to be effective. Our project will help the NMDOT apply for a federal grant that will work on the New Mexico road infrastructure as well as communication between different agencies. Overall, this project hopes to improve driving in Albuquerque and New Mexico.

References

AutoInsurance Center. (2015). Jammed: The Cost of Traffic Congestion. Retrieved April 04, 2018, from https://www.autoinsurancecenter.com/traffic-jammed.htm

Chung, H., & Gray, P. (1999). Special Section: Data Mining. *Journal of Management Information Systems, 16*(1), 11-16. Retrieved from http://www.jstor.org/stable/40398415

Coomes, K. (2018, August 30). Waze vs. Google Maps: Which Map App Should You Be Using? Retrieved September 6, 2018, from https://www.digitaltrends.com/mobile/waze-vs-google-maps/

Economist Intelligence Unit. (2012). A Summary of the Green City Index Research Series. *The Green City Index*. Retrieved April 04, 2018, from https://www.siemens.com/entry/cc/features/greencityindex_international/all/en/pdf/gci_report_summary.pdf

Ghazal, B., Elkhatib, K., Chahine, K., & Kherfan, M. (2016). Smart Traffic Light Control System. *2016 Third International Conference on Electrical, Electronics, Computer Engineering and their Applications (EECEA)*, 140-145.

How Green are the World's Cities? (2012). Retrieved August 28, 2018, from http://globalsherpa.org/green-city-index/

ITS Bureau. (n.d). ITS Bureau's 2015-2016 Goals and Objectives Plan (Annual Plan). Retrieved April 04, 2018, from http://dot.state.nm.us/content/dam/nmdot/ITS/ITSGoalsandObjectives.pdf

Knoop, V. L., Hoogendoorn, S. P., & Van Zuylen, H. (2010). Rerouting Behaviour of Travelers Under Exceptional Traffic Conditions: An Empirical Analysis of Route Choice. *Procedia Engineering, 3,* 113-128. Retrieved April 04, 2018, from http://www.narcis.nl/publication/RecordID/oai:tudelft.nl:uuid:6bcc09dd-4720-4462-92de-8d0798df7333

Masek, N., DiRuggiero, J., Remkes, C. & Barricklow, P. (2017). Intelligent Transportation Society of New Mexico. Retrieved September 20, 2018, from http://newmexicoits.com/

MRCOG. (2014). Commuting. Retrieved April 04, 2018, from https://www.mrcog-nm.gov/region-a-people/regional-data/commuting-income-a-housing

Muoio, D., & Nudelman, M. (2017, October 11). Americans' Commuting Habits Haven't Changed at All in the Last 10 Years. Retrieved April 07, 2018, from https://www.businessinsider.com/how-people-commute-work-us-2017-10

NMDOT. (2014). *Special Provisions for VDS.* NMDOT. Retrieved April 07, 2018, from http://dot.state.nm.us/content/dam/nmdot/ITS/SECT750-G_02-01-13_VEHICLE_DETECTION_SYSTEM.pdf

Oxford, A. (2017). Rail Runner Commuter Train: Worth the Ride? Retrieved September 01, 2018, from http://www.santafenewmexican.com/news/local_news/rail-runner-commuter-train-worth-the-ride/article_27b364fc-8c3b-5a67-beb7-fc3ef216e056.html#comments

Oxford, A. (2018). Rail Runner Numbers Continue to Decrease. Retrieved September 01, 2018, from http://www.santafenewmexican.com/news/local_news/rail-runner-numbers-continue-to-decrease/article_97afd415-33cf-556d-b799-73043ab107ba.html

Pina, M. (2016). Intelligent Transportation Systems - Benefits of Intelligent Transportation Systems Fact Sheet. Retrieved August 30, 2018, from https://www.its.dot.gov/factsheets/benefits_factsheet.htm

Rosevear, J. (2017). These are the 10 Best-selling Cars of 2017 -- So Far. Retrieved September 14, 2018, from https://www.usatoday.com/story/money/cars/2017/11/06/these-are-the-10-bestselling-cars-of-2017/107395786/

TAMU. (2014). Retrieved April 07, 2018, from https://mobility.tamu.edu/mip/strategies-pdfs/traffic-management/executive-summary/traveler-information-systems-1-pg.pdf

Warren, D. (2017). *Variable Speed Limits* [Powerpoint slides]. Retrieved April 11, 2018, from https://ops.fhwa.dot.gov/wz/workshops/accessible/Warren.htm

Xiao. J. "Design of Urban Basic Traffic Management System Based on Geographic Information System," Proceedings of the 29th Chinese Control Conference, Beijing, 2010, pp. 5353-5357.

Zahradnik, F. (2018). Best iPhone GPS Navigation Apps. Retrieved September 14, 2018, from https://www.lifewire.com/iphone-gps-navigation-apps-1683498

Appendices

Appendix A: Interview with New Mexico Department of Transportation, the Mid-Region Council of Governments, Albuquerque Traffic Management, and the New Mexico Intelligent Transportation Systems Bureau

This is an interview conducted orally with NMDOT and ITS representatives. The purpose of this interview was to learn more about traffic issues on certain stretches of Albuquerque roads and to collect data sets that will aid us in our research.

Preamble

We are a team of students from Worcester Polytechnic Institute in Massachusetts. We are conducting interviews with NMDOT and ITS officials to get a more in depth understanding of the roadways we will be conducting research on and to get a better grasp on the kind of data we will be receiving to analyze. This is a collaborative project between the NMDOT and we as WPI students. Our goal is develop a report with our findings on resulting congestion from highway incidents that the NMDOT will use to apply for a federal grant to renovate their roadways in Albuquerque.

Your participation in this interview is completely voluntary and you may withdraw at any time. If you would like, we would be happy to include your comments as anonymous.

If interested, a copy of our results can be provided at the conclusion of the study.
Would you mind if we recorded this interview? May we use your name in our paper?

1. Does the Department of Transportation have existing concerns surrounding roadway infrastructure that bear significant relevance to traffic and congestion in metropolitan Albuquerque (i.e. street width and high volume/capacity ratios)?
2. Are there any sections of the highway that you would like to be highlighted in our report (i.e. river-crossings)?
3. Does the Department of Transportation possess datasets detailing the locations and heights of underpass bridges?
4. What methods are currently most effective in alleviating traffic on congested roadways (i.e. traffic cops, dynamic road signs, variable speed limits)?
5. Would it be possible to obtain access to the Neighborhood Traffic Calming requests sent in by the Albuquerque community?
6. Is there any data that the Albuquerque Police Department has access to that the DOT does not, that you feel would be helpful to the broad scope of the project?
7. What data sets will you be able to provide us that our sponsor, John DiRuggiero, will not have access to?
8. What is the timeline that you expect to see connected cars/ autonomous vehicles control the roadways?

Appendix B: Table of all accident counts

latitude	**longitude**	**# of incidents**	**street names**
35.14963716	-106.6862029	73	Coors Blvd. and Montaño Rd
35.1064256	-106.6238518	72	I-40 and University Blvd
35.13094927	-106.5864361	66	San Mateo Blvd. and Montgomery Blvd.
35.10493978	-106.6041916	65	I-40 E and Carlisle Blvd.
35.18619806	-106.6625778	64	Coors Blvd. and Irving Blvd
35.10554104	-106.6292346	59	Big I
35.1153557	-106.7016486	59	Coors Blvd. and Quail Rd.
35.17792409	-106.6223799	58	Paseo Del Norte Blvd. (423) and 2nd St.
35.18092589	-106.6681462	58	Coors Blvd. and Paseo Del Norte Blvd.
35.07999025	-106.7105283	57	Coors Blvd. and Central Ave. (Rt 66)
35.18092584	-106.6681462	57	Coors Blvd. NW and Paseo Del Norte Blvd. NE
35.20560433	-106.659107	54	Coors Blvd. Bypass NW and Ellison Dr. NW
35.10523286	-106.6707716	50	I-40 and Rio Grande Blvd NW
35.07192057	-106.5324164	49	Central Ave SE and Eubank Blvd SE
35.1743029	-106.5835535	47	I-25 and Paseo Del Norte NE
35.06979804	-106.6394244	47	I-25 and Avenida Cesar Chavez
35.0872463	-106.5325608	46	Lomas Blvd. NE and Eubank Blvd NE
35.17446245	-106.5934452	46	Paseo Del Norte Blvd. NE and Jefferson St. NE

35.17421662	-106.5599188	45	PDN Blvd. NE and Wyoming Blvd. NE
35.10911817	-106.5688467	44	Louisiana Blvd. NE and Menaul Blvd NE
35.10514148	-106.629384	44	Big I
35.10922554	-106.5508938	43	Wyoming Blvd. NE and Menaul Blvd. NE
35.20311011	-106.6471674	42	Alameda Blvd. NW and Corrales Rd.
35.02716895	-106.7140138	42	Rio Bravo Blvd SW and Coors Blvd. SW
35.07778158	-106.5861882	42	Central Ave NE and San Mateo Blvd NE
35.1461379	-106.5537937	42	Academy Rd NE and Wyoming Blvd NE
35.10645736	-106.7045472	42	Coors Blvd. NW and I-40
35.10665668	-106.704466	41	Coors Blvd. NW and I-40
35.09903031	-106.5729738	41	I-40 E (near Dakota St. NE)
35.12381174	-106.6208855	40	P. A. Frontage Rd N and Comanche Rd. NE
35.07588169	-106.5685874	40	Central Ave SE and Louisiana Blvd. SE
35.15338484	-106.5888104	40	I-25 and San Mateo Blvd. NE
35.13063482	-106.5333335	40	Montgomery Blvd NE and Eubank Blvd NE
35.1033781	-106.7057906	39	Coors Blvd. NW and Iliff Rd NW
35.08676731	-106.5150085	39	Lomas Blvd. NE and Juan Tabo Blvd. NE
35.10499363	-106.6707615	39	I-40 and Rio Grande Blvd NW
35.13281898	-106.6098849	38	I-25 and Montgomery Blvd. NE