Transportation Consortium of South-Central States

Tran-SET

Solving Emerging Transportation Resiliency, Sustainability, and Economic Challenges through the Use of Innovative Materials and Construction Methods: From Research to Implementation

Relationship between Road Network Characteristics and Traffic Safety

Project No. 17ITSTSA01

Lead University: University of Texas at San Antonio

Addressing Region 6 Transportation Needs

Final Report

December 2018

Disclaimer

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16. Abstract
The Transportation and Capital Improvement of the City of San Antonio, Texas Department of Transportation (TxDOT) and other related agencies often make several efforts based on traffic data to improve safety at intersections, but the number of intersection crashes is still on the high side. There is no one size fits all solution for intersections and the City is often usually confronted with doing best value option analysis on different solutions to choose the least expensive yet more advancements. The goal of this project was to obtain the relationship between road network characteristics and public safety with a focus on intersections; perform a thorough analysis of critical intersections with high crash incidents and crash rates within the city of San Antonio, Texas, and analyze key factors that lead to crashes and recommend effective safety countermeasures. Researchers conducted the following tasks: literature review, crash data analysis, factors affecting crashes at intersections, and the development of possible solutions to some of the identified challenges. Several variables and factors were analyzed, including driver characteristics, like age and gender, road-related factors and environmental factors such as weather conditions and time of day ArcGIS was used to analyze crash frequency at different intersections, and hotspot analysis was carried out to identify high-risk intersections. The crash rates were also calculated for some intersections. The research outcome shows that there are more male drivers than female drivers involved in crashes, even though we have more licensed female drivers than male drivers. The highest number of crashes involved drivers within the age range of 15 – 34 years; this is an indication that intersection crash is one of the top threats to the young generation. The study also shows that the most common crash type is the angle crash which represents over 23% of the intersection crashes. Driver's inattention ranked first among all the contributing factors recorded. The high-risk intersections based on crash frequency and crash rate show that the intersection along the Bandera Road and Loop 1604 is the worst in the city, with 399 crashes and 8.5 crashes per million entering vehicles. The research concluded with some suggested countermeasures, which include public enlightenment and road safety audit as a proactive means of identifying high-risk intersections.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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ACRONYMS, ABBREVIATIONS, AND SYMBOLS

AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway Transportation Officials
COSA	City of San Antonio
CRIS	Crash Record Information System
FHWA	Federal Highway Administration
GIS	Geographic information system
MEV	Million Entering Vehicles
NHTSA	National Highway Traffic Safety Administration
TCDS	Traffic Count Database System
TCI	Transportation and Capital Improvement
TxDOT	Texas Department of Transportation
USDOT	United States Department of Transportation

EXECUTIVE SUMMARY

Road crashes are a leading cause of death and serious injuries in the United States, and Texas is ranked first in the country with the highest number of fatal crashes. Intersections are recognized as being among the most dangerous locations on the roads. On an annual basis, a cost of over $40 billion is associated with intersection crashes, which account for more than 20% of fatalities nationwide. Due to the limited resources available for road safety, it is important to identify high-risk intersections so that they can be prioritized for infrastructure improvement. This study used crash frequency and crash severity as the two essential approaches to understanding the relationship between crash occurrences at intersections and contributing factors. Crash data from 2013 to 2017 were used in the analysis. 73,755 intersection crashes occurred in the City of San Antonio during that period. Results from the detailed analysis show that different factors had varying effects on crash severity levels. Driver inattention and disregard for traffic control and signals are the major cause of most of the intersection crashes within the city. Generally, male drivers were involved in intersection crashes more than female drivers, even though the City of San Antonio has more licensed female drivers than male. The predominant type of intersection crash was angle crashes, where vehicles involved are both going straight, while one motor vehicle going straight type has more occurrence in cases that involve fatal crashes.

The analysis further identified 52 intersections that had 100 crashes or more, and 36 intersections with a crash rate of greater than 1 crash per million entering vehicles. The crash rate helps to determine the relative safety of an intersection compared to similar intersections.

ArcGIS Spatial Analyst tool was used to identify the major high-risk intersections based on the volume of crashes within the City, and it revealed that there is a major concentration around the central part of San Antonio (Downtown), the northeast and north-west side, and west side of San Antonio. Some of the proposed countermeasures include: education of the public on dangers of intersections and further assessment of hotspot intersections with high frequency of crashes. The use of road safety audit for proactive identification of intersection risks is also advised.

There is a need for an ongoing study on the intersections with historically high number of crashes to better understand challenges associated with them and to develop specific effective countermeasures, and with the overall objective of reducing severe injuries and fatalities in San Antonio.

IMPLEMENTATION STATEMENT

After identifying the intersections with the highest crash counts and rates and conducting site visits, the research team, the Transportation and Capital Improvement (TCI), and San Antonio Police Department decided to take more observations and apply enforcement on four intersections for a period of two weeks. The research team is currently studying the impact of intervention on crash counts and rates.

1. INTRODUCTION

The motivation of this work was initiated by the city of San Antonio (COSA) public work engineers. The fast growth due to the economic development in south Texas as a result of booming oil and gas activities has created a spike in crashes and fatalities in the region over the last four years. Primarily, these crashes involved commercial vehicles within and outside urban city limits and across the south-Texas region. As a result, this forced the state of Texas, local governments, and municipalities to consider this area as a focus priority and direct funding to address this problem. The research team has been challenged to find the data sources to identify the root causes of these crashes and to identify effective countermeasures. Therefore, with direct contact with COSA and the Texas Department of Transportation (TxDOT), the research team decided that leveraging existing databases in state/city/county as the investigative data sources and conducting extensive data analysis with site visits to intersection hot spots as the first steps towards this aim.

1.1. Background

Road intersections are one of the most dangerous positions in a roadway network, because they are convergent spots for people moving in opposite paths. They also leave road users with the responsibility of making informed decision of when to cross the road to forestall unsafe situations. Intersections is one of the most complicated traffic situations that motorists come across, and with negligent high speeding drivers who often neglect traffic signals, it further compounds the problem *(1)*.

The average annual fatality due to car crashes has not considerably changed for many years. The safety of intersections is of national, state, and local importance. Thus, major agencies such as the Institute of Transportation Engineers, Federal Highway Administration (FHWA), Departments of Transportation (DOTs) in nearly all states in the US and related public and private entities are devoting capital and human resources to address this challenge; the United States Department of Transportation (USDOT) adopted the Road to Zero program to end traffic fatalities by year 2046 *(2)*.

FHWA defined criteria qualifying crashes near an intersection to be termed intersection crashes: "(1) crashes must occur within 250 feet (76 meters) of the intersection center and (2) they must be (a) vehicle-pedestrian crashes; (b) crashes in which one vehicle involved in the collision is making a left turn, right turn, or U-turn prior to the collision; or (c) multiple-vehicle crashes in which the accident type is either sideswipe, rear end, or broadside/angle" *(3)*. Road safety is often defined relative to injuries and fatalities that occur on the road, but many safety experts believe this should be defined with the crash severity as it is more representative of the actual occurrence *(4)*. The evolution of data science has caused a major shift in the way science of safety is viewed. Focus is now more on data and analysis versus sole dependence on standards, such as FHWA's Highway Safety Improvement Program (HSIP) Manual.

Consequently, intersection crashes are a major source of all traffic crashes as well as considerable number of crash causalities, ranging from minor injuries, incapacitating injuries, and fatalities. Earlier research has shown that about 44% of all reported traffic casualties were ascribed to intersection crashes during 2005 – 2007 in the Netherlands; and around 30% of all road crashes in Canada and Singapore occur at intersections or near intersections *(5)*.

In the United States, about 25% of road fatalities and about 50% of all traffic injuries over the last several years are attributed to intersections *(6)*. Intersection-related motor vehicle crashes accounted for 45% of all crashes and 22% of all fatal crashes in 2007 *(7)*. A study examining the characteristics of an estimated 787,236 motor vehicle intersection crashes from 2005 – 2007, as listed in the dataset from the National Motor Vehicle Crash Causation Survey (NMVCCS), showed that 96% of intersection crashes had critical factors attributed to drivers, while less than 3% had critical factors related to the vehicle or environment *(8)*.

Traffic crashes often occur at intersections due to numerous conflicts developed by users of the road as well as road developers. Hence the study of car crash causes and how to prevent them must include intersections as a major causative agent of crashes, with a view towards designing safer intersections and improving policy decisions. Ensuring safety of road intersections is a complicated issue and cannot always be mitigated by mere updates to signals or signs, but can be solved sustainably by a national comprehensive program of improved pedestrian safety and vehicle intersection management *(8)*. Significant economic loss to society is associated with every intersection crash in terms of fatality, severe injury, productivity loss, and property damage. Hence, proper identification of intersections associated with a high crash rate is vital to reduce future crash occurrences.

1.2. Texas Crash History

As of 2016, Texas has the highest number of fatal crashes in the United States with 3,406 crashes and 3,776 deaths. This is a 5% increase to 2015, which had 3,226 fatality crashes and 3,582 deaths. There was also a 5% increase in total miles traveled in 2016 (271.3 billion) compared to 2015 (258.1 billion). Over 800 of these deaths occurred at intersections or were related to an intersection. Also, in 2016, Texas had over 14,200 serious injury crashes, with over 17,000 people sustaining serious injuries. Bexar County had the third highest totals in 2016, with 52,633 crashes and 220 associated deaths *(9)*. San Antonio alone had 193 fatalities during this year and 34 (~18%) out of them occurred at intersections.

1.3. Factors Contributing to Intersection Crashes

Several factors contribute to crashes at intersections with driver behavior being the foremost contributor. Other factors include those related to the road and the vehicle involved. Road-related issues include traffic characteristics (e.g., traffic volume, geometric design, traffic control measures, state of line markings and signage, surface, and light condition) *(10)*. Another concern expressed in published literature is the acceptance of inadequate gaps when merging or crossing major roads with divided driveways. This is a hazard for all road users as the driver is looking at both directions for any incoming high-speed vehicle. American Association of State Highway Transportation Officials (AASHTO) defines a gap for small vehicles and trucks, calculated as summing travel time needed to cross a major road at the design speed plus certain buffer time: 6.5s gap is allowed for small vehicles and 10.5s for large trucks *(11)*. Another identified problem is the difficulty of many drivers in judging gaps during high-speed traffic situations on a divided highway with many lanes, as well as drivers attempting a left-turn or to cross into a divided highway *(12)*.

Right-angle crashes account for more than 35% of crashes at expressway intersections, which is significantly more than the 28% of right-angle crashes at intersections that occur at other road types. The common identified problem is drivers' safe gap judgement *(13)*. Some factors, such as weather conditions and natural lighting conditions, are considered external to human factors, since they are beyond human control. Human factors include driver error and road design and management issues. Driver errors include those committed while under the influence of alcohol, or otherwise violating traffic rules and regulations, and errors committed due to lack of training, etc. Roadway design and management issues include the geometric design of intersections and improper traffic management and control. Human factors are the main cause in over 90% of car crash incidents *(14)*. Understanding the factors contributing to crashes at hazardous locations are critical in the enhancement of road safety at San Antonio and to develop more targeted countermeasures to reduce crash injury severity to zero.

1.4. Effective Safety Strategies

For data analysis and safety consideration, three to five years of crash data is the most common time frame for necessary data representation. Though, in some cases less than five years may be needed, but a smaller sample size may not adequately represent the data; there might be need for some statistical adjustment *(15)*. There are many factors associated with each crash in the crash database. The most common are: crash severity, day of the week, month, direction of travel, weather and light conditions, type of collision, road design and vehicle body type.

The need for field assessment of intersection spots has also been identified as a major activity that can ensure further safety of intersections. This will help understand drivers' behaviors, and identify which may need improvement and periodic assessment *(16)*. One of the most common behavior is the drivers' speed, which has received minor attention, especially at intersections. Speed-profile is a valuable tool to ensure road safety and vehicle road worthiness. It is useful in the assessment of existing roads as well as the design of new ones because speed limits and their variation can be used for various safety considerations *(17)*.

There are many challenges in the execution of safety improvement projects, trying to balance and prioritize several locations/considerations based on the level of urgency. A fair ranking approach needs to be developed to prioritize projects to maximize return, get the best value at a minimal cost *(18)*. Potential mitigation measures have been identified in previous studies, which include proper signage and lighting, adding rumble strips, adding left-turn and right-turn parallel acceleration lanes on major roads, and designing intersection to be between 75 and 90 degrees.

As promising as some of these measures are, there is a need to evaluate intersection locations to understand if these solutions may provide benefit and to determine the best mitigation strategy *(19)*.

1.4.1. Enforcement and Education

- Peck *(25)* discusses a major difficulty inherent to evaluating driver education programs' effectiveness: crashes are rare events, and a very large number of drivers would need to be analyzed in order to attain statistical significance. Peck *(25)* estimates that 35,000 drivers would be required in a two-group design to reliably detect a 10% reduction in crash rates.

- The effectiveness of driver education programs and campaigns is not unanimously supported by all studies reviewed. Some reported education campaigns as effective in reducing crashes and/or fatalities and injuries *(26, 27)*. Others reported little or no impact for defensive driving and young driver education, or positive impacts only if implemented in conjunction with law enforcement *(25, 28)*. A review of 8 studies on effectiveness of mass media campaigns for reducing alcohol-impaired driving reports a median decrease in alcohol-related crashes of 13% (interquartile range: 6% to 14%). Economic analyses of campaign effects indicated that the societal benefits were greater than the costs *(29)*.
- A review of 42 studies about the effectiveness of young driver education in reducing crashes and traffic violations concluded that "there is little or no compelling evidence showing that driver training reduces the crash rate of novice drivers and that any small effects are offset by a tendency of high school driver training programs to increase licensure rates at younger ages" *(25)*. One study found that young driver attitude is better correlated to crashes than attending driver education programs *(30)*.
- Effectiveness of law enforcement is unanimously supported by all studies reviewed. A Norwegian study argues that automated enforcement is more effective than conventional to reduce crashes and violations *(31)*. Another study reported a 2% risk reduction from manual speed enforcement, a 19% reduction from automated speed enforcement, and 11 % reduction from red-light violation enforcement *(32)*.
- Leggett *(33)* reported that "before-and-after" evaluations of six types of enforcement implementations throughout Australasia generated an average 32% reduction in major casualty crashes, at an average benefit/cost ratio of approximately 70:1.
- Greer and Barends *(34)* performed a meta-analysis of studies investigating correlations between law enforcement and crashes. They concluded that "all studies reviewed suggested that there is a correlation between enforcement and the number of accidents, injuries and fatalities that result from traffic accidents." Mashhadi et al. *(35)* analyzed the impact of different types of traffic citations on crashes on two hazardous main US highways in Wyoming (US-30 and US-26) over 4 years of crash and citations data to identify. The results showed that higher numbers of speeding and seat belt citations reduce the number of crashes significantly.
- Redelmeier et al. *(32)* analyzed 10 years of driving records of all drivers involved in fatal crashes in Ontario, Canada. They contrasted a period immediately before the crash with a comparable period before the crash, for each driver involved in a fatal crash, and for several periods. Convictions were associated with a 35% reduction in the relative risk of a fatal crash over the next month. Longer control time periods yielded similar results; however, the decrease in risk was greatest for convictions close to the time of the crash. Therefore, the authors concluded that "increasing the frequency of traffic enforcement might further reduce total deaths."
- The Texas Traffic Safety Task Force's five-year plan to reduce crashes and fatalities on Texas roadways proposed seven general engineering countermeasures and five

education and enforcement campaigns. Safety campaigns targeting high schoolers and impaired driving had an estimated potential return per dollar of $37 and $35, respectively *(27)*. The plan also discusses enforcement strategies proved successful in other states that are not used in Texas.

1.4.2. Policies and Funding

According to the American Traffic Safety Services Association *(36)*, on June 29, 2012, the House of Representatives and Senate passed a new transportation authorization, Moving Ahead for Progress in the 21st Century (MAP-21). This new authorization funded federal transportation policy through September 2014 and nearly doubled the Highway Safety Improvement Program (HSIP). In Fiscal Year 2013, the HSIP was funded at $2.39 billion, and in Fiscal Year 2014, it was funded at $2.41 billion. MAP-21 was a tremendous success for the roadway safety industry, especially in an era of program consolidation, streamlining and very strict fiscal constraints.

According to the Federal Highway Administration *(37)*, a key feature of MAP-21 is the establishment of a performance- and outcome-based program. The objective of this performance- and outcome-based program is for States to invest resources in projects that collectively will make progress toward the achievement of the national goals. Fatalities and serious injuries—both number and rate per vehicle mile traveled--on all public roads, are listed in this reference as traffic safety performance *(38)*. Note: Statutory citation(s) in this reference: MAP-21 §§1106, 1112-1113, 1201-1203; 23 USC 119, 134-135, 148-150.

The Safety Performance Management (PM) Final Rule adds Part 490 to title 23 of the Code of Federal Regulations to implement the PM requirements under 23 U.S.C. 150. It establishes five performance measures as the five-year rolling averages for:

1. Number of fatalities,
2. Rate of fatalities per 100 million vehicle miles traveled (VMT)
3. Number of serious injuries
4. Rate of serious injuries per 100 million VMT, and
5. Number of non-motorized fatalities and non-motorized serious Injuries.

The Safety PM Final Rule also establishes the process for State Departments of Transportation (DOTs) and Metropolitan Planning Organization (MPOs) to establish and report their safety targets, and the process that FHWA will use to assess whether State DOTs have met or made significant progress toward meeting their safety targets. The Safety PM Final Rule also establishes a common national definition for serious injuries.

According to the Federal Highway Administration *(37)* fact sheets on performance monitoring, the Highway Safety Improvement Program (HSIP) is a core Federal-aid program with the purpose to achieve a significant reduction in fatalities and serious injuries on all public roads. The HSIP requires a data-driven, strategic approach to improving highway safety on all public roads that focuses on performance. The HSIP Final Rule updates the existing HSIP requirements under 23 CFR 924 to be consistent with MAP-21 and the Fixing America's Surface Transportation (FAST) Act, and to clarify existing program requirements.

Two-Way Stop Control: Installation of two-way stop controls was found to be effective in reducing crashes at low volume intersections, but evidence suggests lack of effectiveness for high-speed intersections (39). Evidence also suggests lack of effectiveness for intersections with under 150 vehicles per day *(40)*. This measure is particularly recommended for intersections with three to four crashes (i.e., side swipe, angle and rear end collisions) in a 3-year period that may be correctable by application of stop control. When considering this countermeasure, traffic engineers should also consider other measures shown to be effective at intersections such as sight distance improvements, speed control measures, and/or geometric improvements such as increased curb radii *(39)*.

Nighttime Lighting: Before and after analyses showed that the nighttime crash rate decreased by 35% after intersection lights were installed, while the daytime crash rate increased 30% during the same period *(41)*. The ratio of nighttime to total crashes decreased by 32% in the after period. Bhagavathula et al. *(42)* studied the relationship between lighting level and the night-to-day (ND) crash ratio at 131 intersections in the state of Virginia. The results showed that increasing the average horizontal illuminance at all the intersections (both lighted and unlighted) by one unit (1 lux) decreased the ND crash ratio by 7%. For the lighted intersections, the same increase in average horizontal illuminance decreased the ND crash ratio by 9%. The largest decrease in the ND crash ratio was for unlighted intersections, where a 1-lux increase in the average horizontal illuminance decreased the ND crash ratio by 21%.

Transverse Rumble Strips: Srinivasan et al. *(43)* investigated the safety effect of Transverse Rumble Strips (TRSs) on approaches to stop-controlled intersections using a state-of-the-art statistical methodology. Results indicated that TRSs were effective in reducing severe injury crashes (KAB and KA) at minor road stop-controlled intersections. Considering that many previous studies showed a reduction in speed following the implementation of TRSs, the decrease in KAB and KA crashes could be a result of reduced speeds. However, it was found that coupled with the reduction in KA and KAB, there was an increase in PDO crashes.

Turning Lanes: Adding turning lanes consistently resulted in significant crash reductions *(e.g. 44, 45)*. The longer the turning lane, the higher the crash reduction. Presence of additional traffic controls also influenced the crash rates. Left turning lanes resulted in larger crash reductions than right turning lanes. Estimated crash reduction rates varied between 12.6% and 70.3% for left turning lanes, and between 14% and 35% for right turning lanes.

Signals Installation and Operations: Srinivasan et al. *(46)* found that the introduction of signals without the addition of left turn lanes resulted in a reduction in total crashes, injury and fatal crashes, and frontal impact crashes (both types), and an increase in rear end crashes at intersections. When left turn lanes were added, rear end crashes decreased as well. Injury and fatal crashes and rear end crashes benefited the most from the addition of left turn lanes. Overall, frontal impact crashes did not benefit from the addition of the left turn lanes.

Michigan Left Turn: A synthesis conducted by FHWA *(47)* that the safety performance of a Michigan left turn, Median U-Turn Intersection Treatment (MUTIT), is better than conventional intersections because they have fewer vehicle-vehicle conflict points. Typical total crash reductions ranged from 20% to 50%. Head-on and angle crashes that have high probabilities of injury are significantly reduced for the MUTIT compared to conventional intersections. However, unacceptance of MUTIT by the public, force the city of Plano, TX to revert to the original intersection design in 2014.

Roundabout Intersections: Roundabouts are seldom seen in Texas. They are expensive to build only in cases where right of way is expensive, which is rarely the case in isolated areas but are inexpensive to maintain, and. The FHWA Office of Safety identified roundabouts as a Proven Safety Countermeasure because of their ability to substantially reduce the types of crashes that result in injury or loss of life. Roundabouts are designed to improve safety for all users, including pedestrians and bicycles.

Roundabouts reduce the types of crashes where people are seriously hurt or killed by 78-82% when compared to conventional stop-controlled and signalized intersections, per the AASHTO Highway Safety Manual. An Ohio study reported an 89% decrease in fatal crashes, 76% decrease in injury crashes, 35% decrease in total crashes. A before-and-after study indicated that a 62% to 67% reduction in total crashes and an 85% to 87% reduction in injury crashes at these intersections. Furthermore, results showed that injury-producing crash types, such as the angle crash, were reduced by 91%, and were statistically significant.

The main purpose of this project is to understand the relationship between road network characteristics and traffic safety with a focus on intersections. The study was carried out by the University of Texas at San Antonio (UTSA), and TCI with a focus on eliminating traffic fatalities and severe injuries. The project was partially supported by a TxDOT grant.

2. OBJECTIVE

The main objective of this project is to perform a comprehensive evaluation of crash causes and risk factors to identify the root causes of crashes in the city of San Antonio, Texas. The research team will develop a database of hotspot roadway sections and intersections, calculate crash rate for various types of roads, and identify locations with the highest crash rates. The crash data analysis will be based on road type, traffic control, and proximity to other safety treatments and will cover signalized and unsignalized intersections. The evaluation will also include operational and physical characteristics of the hotspot locations and observation of drivers/pedestrians/cyclists' behavior. The above evaluation will allow the research team to determine ways to address safety issues at hotspot roadway sections and intersections and provide the safest possible solutions for motorists and members of the local communities.

3. SCOPE

To have a detailed overview of intersection crashes in San Antonio, the project includes all intersections in San Antonio with City ID of 379 in the TxDOT Crash Records Information System (CRIS), which is the main source of our raw data for our analysis. Also, the project will identify major factors responsible for intersection crashes focusing on the drivers. Finally, identify major hotspot intersections by analyzing the intersections with the most crashes and using the average traffic volume to evaluate these hotspots. The study is limited to CRIS data from 2013 – 2017.

4. METHODOLOGY

4.1. Retrieval of Data

The initial step in the analysis process involved downloading crash data for San Antonio from 2013 – 2017 from the TxDOT CRIS database. The data included all crash information in San Antonio including: time and date of the crash, the location of the crash with latitude and longitude, the severity of crashes, weather conditions, and likely contributing factors. The CRIS data has eight data files per year, but for our analysis we used only four: crash, unit, primary persons, and charge files.

From the crash data file, we obtained the date, time, location details, and severity of crashes; from the unit file, vehicle types and possible contributing factors to the crashes; from the primary person file, the characteristics of the driver, such as age, gender, nationality; from the charge file, the charges associated with each unique crash. All these data files were merged for 2013 – 2017 for our analysis.

4.2 Data Sorting

These data were sorted for only the city of San Antonio and those that occurred at an intersection or related to an. The subset of the intersection crashes that resulted in severe crashes (either a fatality or incapacitating injuries) were also sorted. Most of the variables have different levels and all were sorted, except for some cases that were reported invalid or not reported at all. For example, the weather conditions include clear, rain, snow, or fog, and the details of each sub-element of this variable was analyzed for the 5-year period.

4.3. Variables Analyzed

There are over 170 variables in the CRIS database. The 14 variables below (Table 1) were analyzed in this study and were selected based on their important in related past studies (e.g., *4*, *5*, *6*, *8*).

Table 1. List of variables considered.

S/N	Variables
1	Day of Week
2	Gender and Age of Driver
3	Hourly distribution
4	Monthly distribution
5	Intersection relations
6	Crash severity
7	Collision Type
8	Weather conditions
9	Light conditions
10	Traffic Control Type
11	Road Type
12	Road Alignment
13	Vehicle Body
14	Contributing factors

4.4. Safety Analysis

In this study, we focused our intersection analysis on understanding the effects of selected variables on crash severity. We also identified intersections with high-volume crashes during the 5-year period under study. The intersection crash rates for these high-volume crash intersections were calculated, and these intersections were reclassified based on the crash rate and mapped. For the hotspot analysis, the ArcGIS spatial analyst tool was used to identify intersections with high clusters of crashes.

"At Intersection or Intersection Related Crashes" are traffic crashes in which the first harmful event occurs: within the limits of an intersection, occurs on an approach to or exit from an intersection, and results from an activity, behavior, or control related to the movement of traffic units through the intersection.

4.4.1. Intersection Crash Frequency

Based on the coordinates of the intersection crash locations obtained from the CRIS files (crash file), the R program was used to sort unique coordinates and show the number of crashes per unique intersection. These were mapped using ArcGIS 10.5.

4.4.2. Intersection Crash Rate Calculation

Crash rate was evaluated at the high-volume crash intersections with more than 100 crashes during the 5-year period. Though there can be some intersections with a high crash rate due to low traffic volume and less crashes less than 100, we used this approach to focus our analysis on high-traffic intersections. The Annual Average Daily Traffic (AADT) data were extracted from traffic count database system (TCDS) of TxDOT *(48)*, and the total entering volume (total number of entering vehicles) were calculated for each intersection. 2015 AADT data was used for this analysis as it was the most recent data available, and a 2% growth rate was assumed to make it up-to-date.

$$Number\ of\ Entering\ Vehicles = \sum \frac{ApproachADT}{2} \qquad [1]$$

Note: The intersection volume is not exactly half the sum of all ADTs in the combined database, since the ADT section often do not start and end at intersection (20) but is a reasonable assumption since we are using a large sample of data.

The actual intersection crash rate for each intersection is calculated using the below formula

$$Crash\ Rate = \frac{C_i * 1{,}000{,}000}{5 * 365 * ADT_i} \qquad [2]$$

where:
C_i = number of crashes at the intersection and
ADT_i = total entering ADT at the intersection.

4.4.3. Hotspot Analysis

The most widely used method of crash analysis and determination of hotspots using GIS are the combination of Moran's I statistic (MI) and Getis-Ord *(21)*. MI is one of the oldest indices of spatial autocorrelation and can be used to evaluate the local and global spatial autocorrelation among continuous data. Moran's I statistic checks the clustering of the spatial pattern in crash spots and provides a value of the spatial correlation *(22)*. Since we are interested in areas with numerous incidents, where we have high/low values for an attribute cluster spatially, we conducted the hot spot analysis on the raw incident points.

The ArcGIS hotspot analysis tool works by viewing each feature (intersection point) within the context of neighboring features. The incremental spatial autocorrelation tool is used to automatically allocate at least one neighbor to each feature. Features with high values may not be a statistically significant hot spot unless it is surrounded by other features with high values as well *(23)*.

The procedure for the hotspots analysis involves 5 stages as represented in Figure 1.

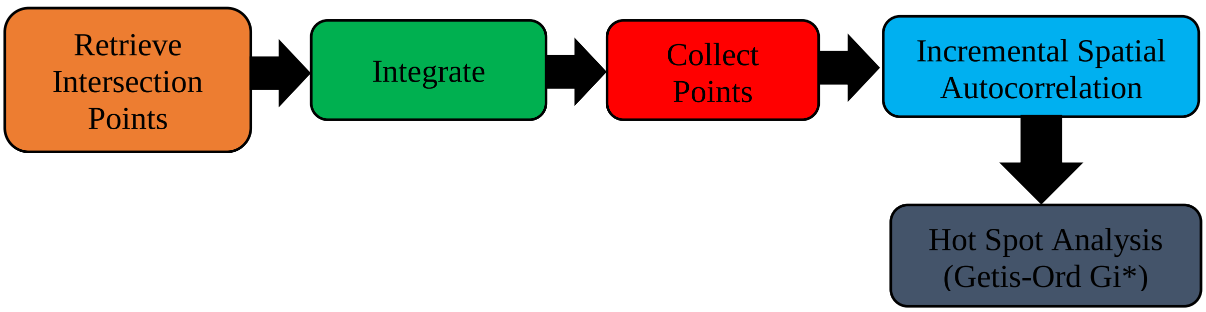

Figure 1. The Five stages of the hotspot analysis.

Integrate: this tool modifies the input feature (all the intersection points). This tool moves features within an x, y tolerance and inserts vertices where features intersect.

Collect Points: this combines coincident points and creates a new output feature class containing all the unique locations found in the input feature class with a z-score, p-value, and confidence level bin (Gi_Bin) for each feature. It then adds a field named ICOUNT to hold the sum of all incidents at each unique location.

Incremental Spatial Autocorrelation: This was used because it is not easy to justify any fixed distance for the autocorrelation of the intersection point features. The function measured the spatial autocorrelation for a series of distances and optionally creates a line graph of those distances and their corresponding z-scores. The z-scores reflect the intensity of spatial clustering, and statistically significant peak z-scores indicate distances where spatial processes promoting clustering are most pronounced.

Hot Spot Analysis: The Getis-Ord local statics was used in the analysis and is defined below:

$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j} x_j - X_{avg} \sum_{j=1}^{n} w_{i,j}}{S\sqrt{\frac{[n\sum_{j=1}^{n} w_{i,j}^2 - (\sum_{j=1}^{n} w_{i,j})^2]}{n-1}}} \quad [3]$$

where:
x_j = the attribute value for feature j,

w_{ij} = the spatial weight between feature *i* and *j*,
n = the total number of features, and

$$X_{avg} = \frac{\sum_{j=1}^{n} x_j}{n} \quad [4]$$

$$S = \sqrt{\left(\frac{\sum_{j=1}^{n} x_j^2}{n} - (X_{avg})^2\right)} \quad [5]$$

Interpretation: Statistically significant positive z-scores indicate hotspots, and the larger the values, the higher the density of crashes at the hotspot. Also, for statistically significant negative z-scores, the smaller the z-score is, the more intense the cold spots.

All the analysis performed in this project were done using R studio software version 1.0.136; a strong programming language for statistical analysis *(45)*, Microsoft Excel 2016 and Esri ArcGIS 10.5.

4.4.4. Field Observations

The research team developed a set of measures to conduct field studies and observe driver/pedestrian behavior at hotspot locations and used different data collection techniques during the observation. Several hotspot locations were visited based on operational and safety data analysis results, traffic volumes, intersection type, geographical distribution, and recommendations by the City transportation planners and engineers.

5. FINDINGS

In this study, we investigated the impact several factors, including gender and age of the driver, weather and light conditions, time of day, type of vehicle body, road type, and collision type on the severity of intersection crashes in San Antonio from 2013 – 2017. There were 250,600 crashes in San Antonio during this 5-year period, out of which 73,755 occurred at intersections. The crash frequencies were evaluated based on the number of crashes that occurred at each unique intersection. The intersection crash rates were calculated for high-volume intersection crash locations that had more than 100 crashes during the study period. The crash rate evaluates the safety of different intersections and is calculated using Equation 2.

5.1. Analysis of Safety and Operational Data

Comparing the total number of crashes against the number of intersection crashes in San Antonio shows an increasing trend from 2013 – 2016, while there was a slight downward trend in 2017, possibly due to some mitigation strategies that the City has implemented. Also, the average of intersection crashes to total crashes was 29% (Figure 2), which confirms the significance of intersection crashes and the need for urgent mitigation.

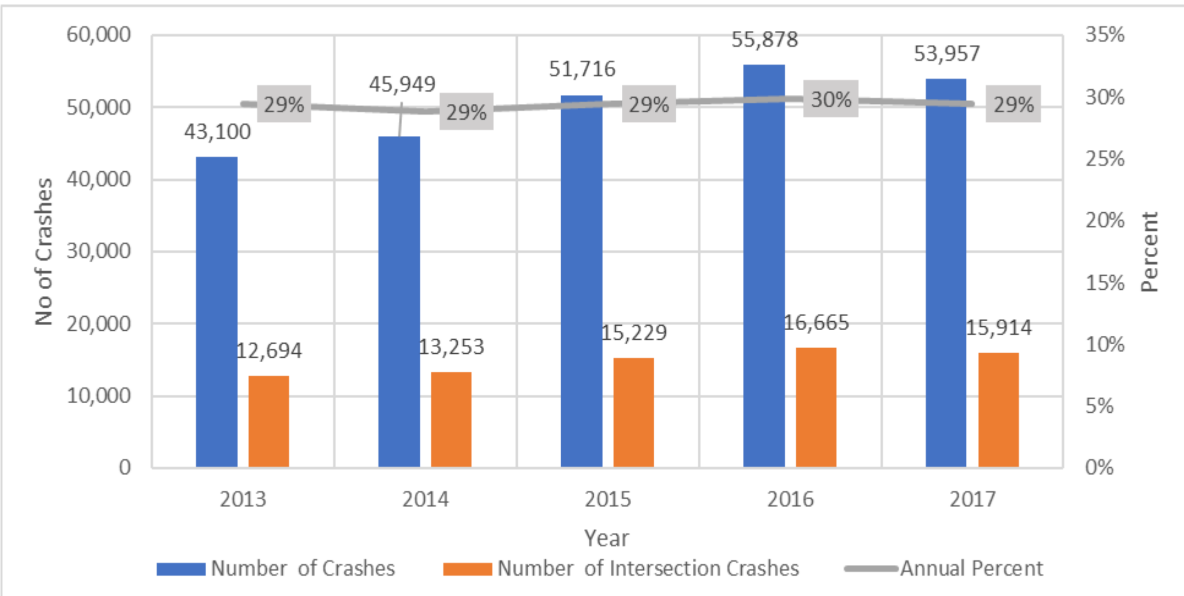

Figure 2. Annual distribution of intersection crashes.

Day of Week: The total number of intersection crashes for 2013 was lower than the mean for the 5-year period, but crashes largely followed the same distribution as Fridays tend to have the highest number of intersection crashes, possibly due to fatigue or eagerness to have an enjoyable weekend (Figure 3). However, travel on Fridays is also likely to be the highest *(24)*.

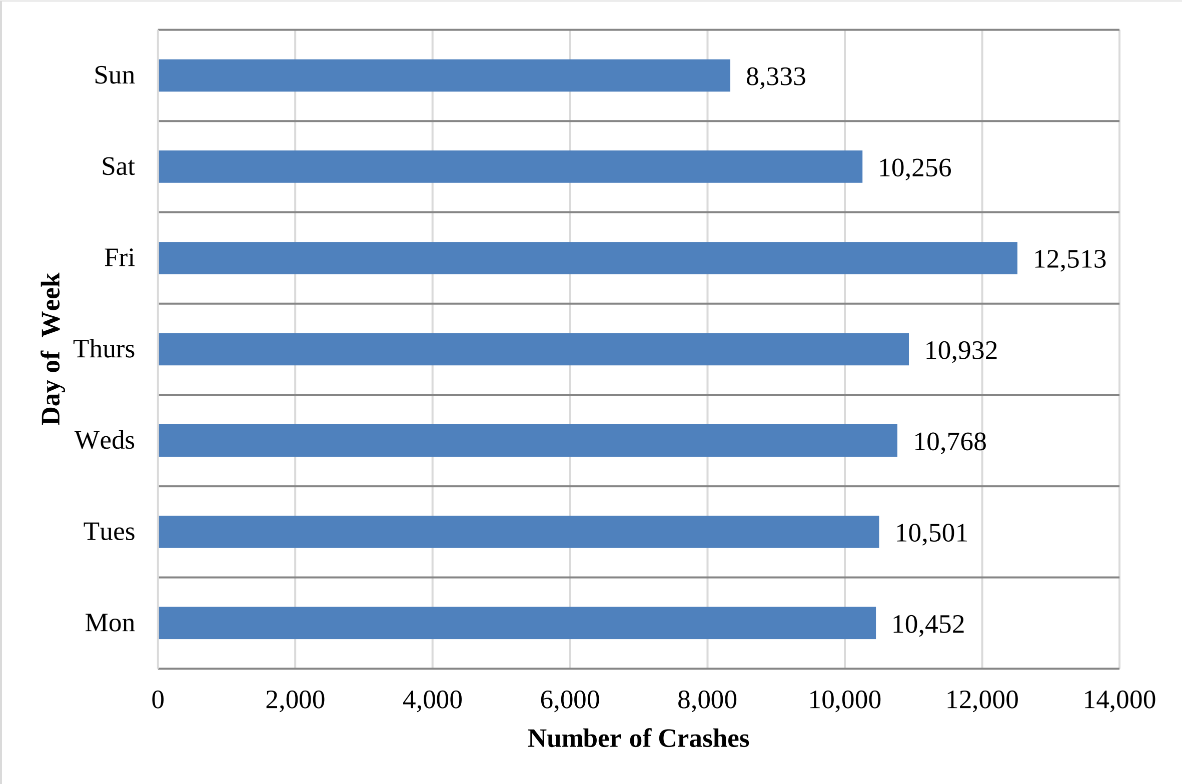

Figure 3. Daily distribution of intersection crashes.

Age and Gender: Approximately 24% of crashes happened with drivers under 25 years old and almost 48% when extended to 34 years old. 65 years old plus have the lowest crash involvement at 9%. Overall, there are more male than female drivers (54% vs 46%) involved in crashes; though there are more female licensed drivers than male COSA as shown in Figure 3. The age and gender distribution are shown in Figure 4.

Hour of Day: Figure 5 displays the number of crashes by time of day for each of the five years; Figure 6 shows the number of crashes by time of day for the five years combined. There were differing traffic patterns during the week due to such factors as schools being open only on weekdays. Such differences are not shown in the Figures. However, the highest number of intersection crashes occurred between 4:00 p.m. and 5:00 p.m. during the 5-year period, possibly due to the rush hour period when workers are leaving their offices.

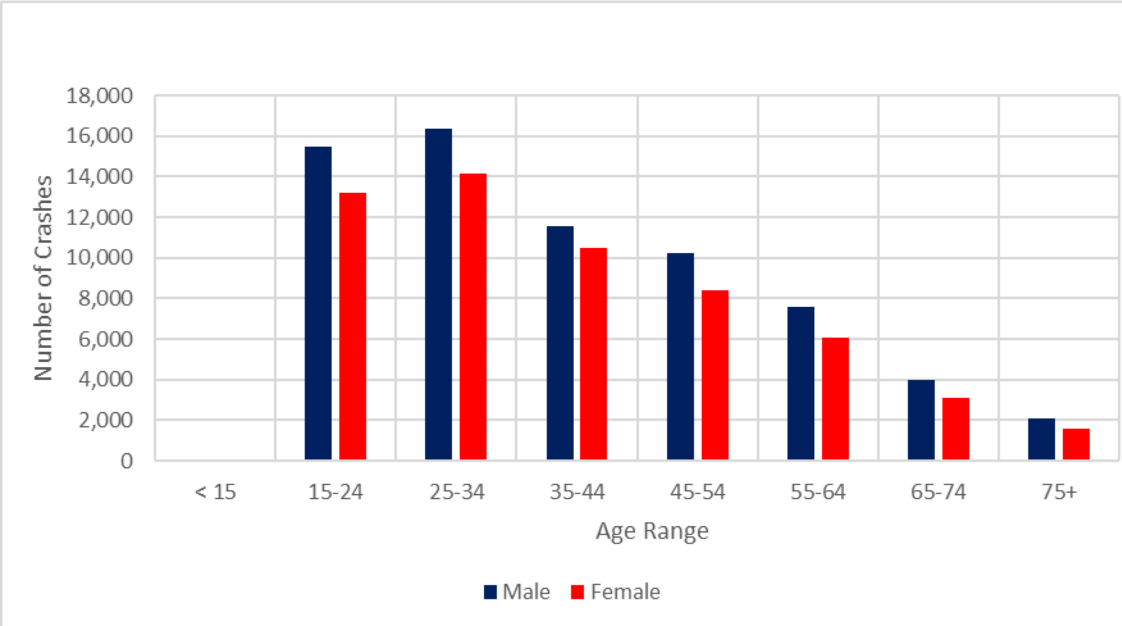

Figure 4. Age and gender of drivers involved in intersection crashes.

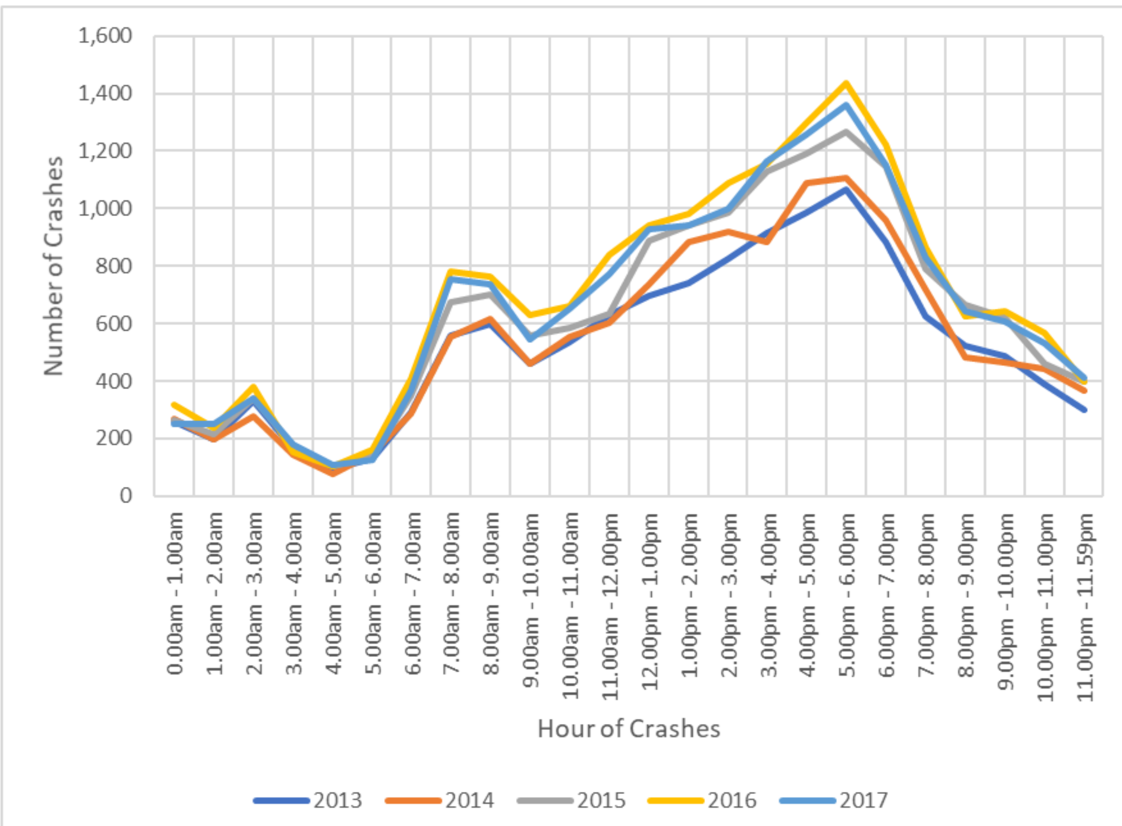

Figure 5. Hourly distribution of intersection crashes.

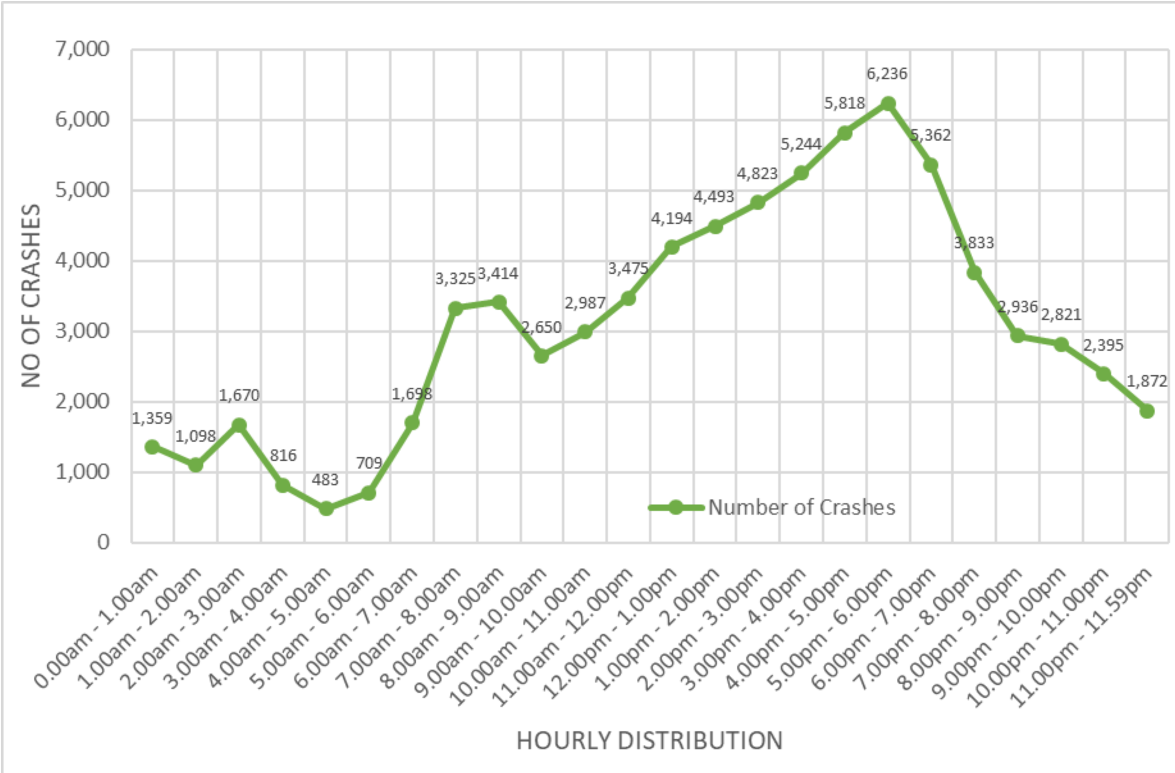

Figure 6. Total hourly distribution of intersection crashes.

Crashes by Month: Figure 7 provides a comparison of the intersection crashes by month from 2013 – 2017. There was an increasing number of crashes monthly and as the year increased; though, in 2017, there was some slight reduction in the number of crashes compared to 2016, but the number in 2017 is still greater than the average over the five-year period. October has the highest number of crashes, possibly due rain, and wet roads.

Intersection Related: The summation of all crashes that occurred on the cross road and the main road produce the total number of crashes at an intersection. Because of the allowable boundaries limit for an intersection, the crash report could include crashes where the intersection did not contribute to the crash. The crash variable "Intersection Related" was used to restrict the analysis to only those crashes that are identified in the CRIS reports as being at an intersection, related to an intersection, or at a driveway access. Nearly 60% of all crashes occurred at actual intersections, about 32% are related to intersections. However, there were some cases of non-intersection crashes that were reported as "At intersection"; these situations made the percentage less than 100 and introduced some error. There was only one non-reported case. Therefore, the crashes were categorized as follows: intersection, intersection related, driveway access, non-intersection, and not reported. Figure 8 shows details of intersection-related crashes.

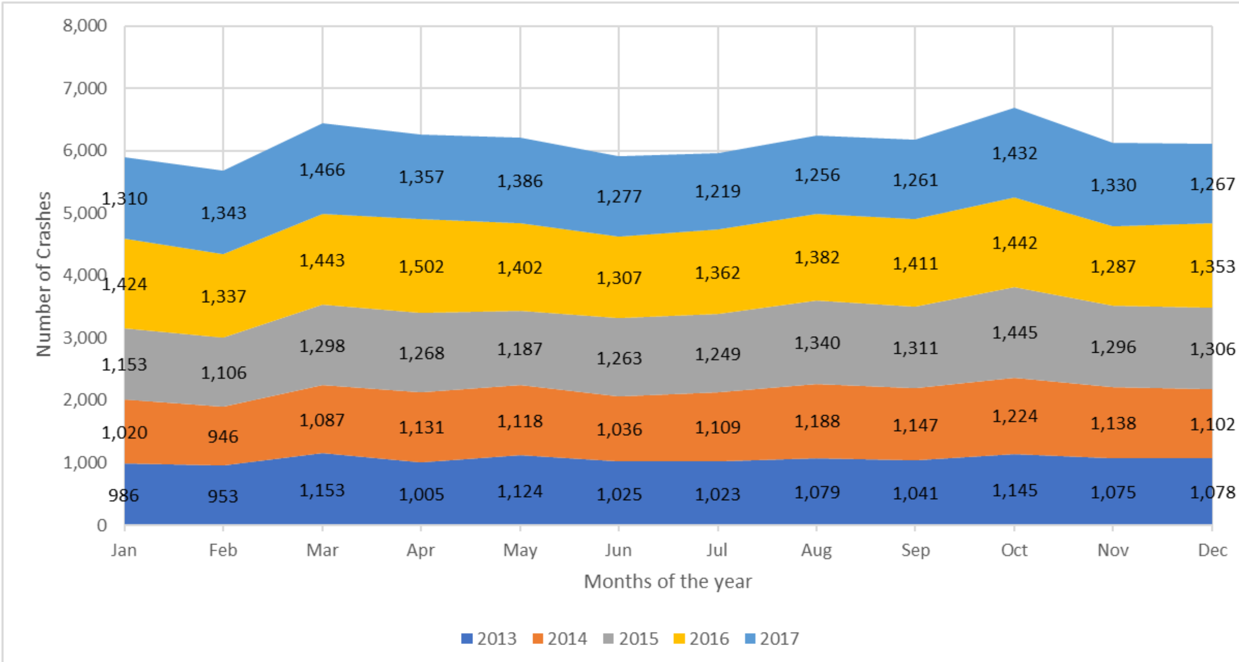

Figure 7. Monthly distribution of intersection crashes.

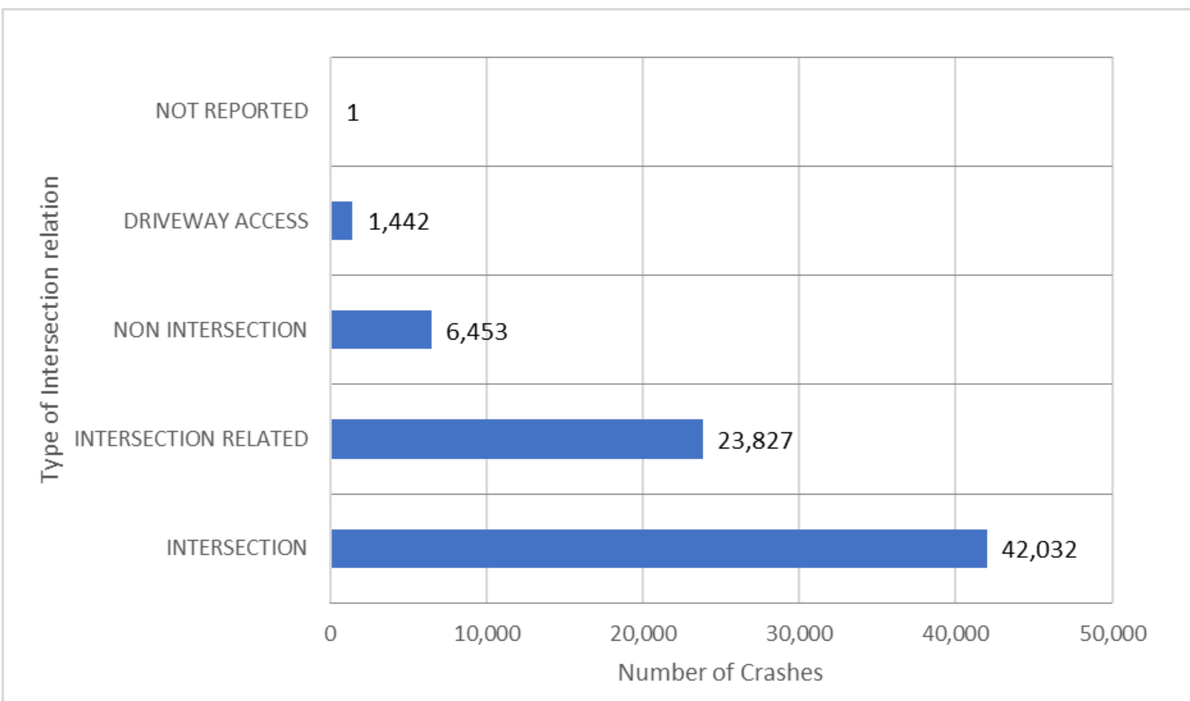

Figure 8. Number of intersection crashes by intersection relationship.

Crash Severity: For the variable crash injury severity, all categories were extracted: incapacitating-injury (A), non-incapacitating injury (B), possible injury (C), killed (K), and not injured. The outcome of the analysis shows that the percentage of severe injuries (K and A) for all the intersection crashes (over the 5-year period) is about 2.2%, while 23% of the case resulted in a possible injury. When the severe injuries are compared to total crashes in San Antonio, its less than 1%. Figure 9 shows the distribution of values.

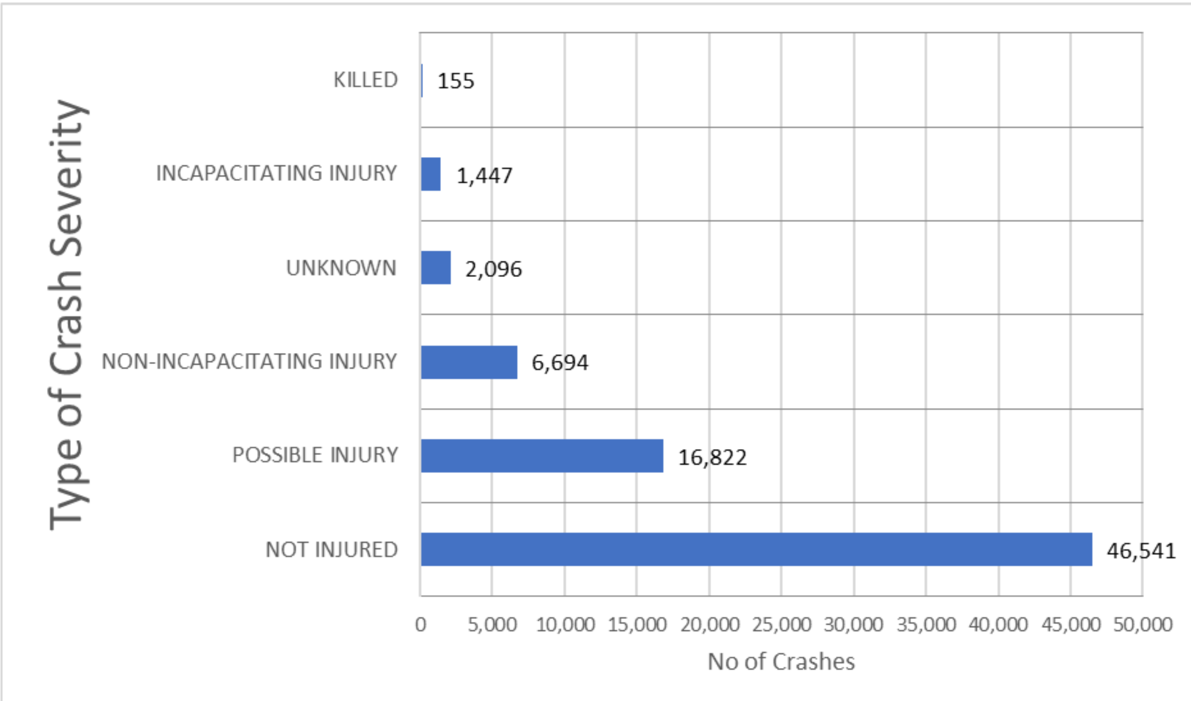

Figure 9. Severity of intersection crashes.

The analysis shows that the average number of K from 2013 – 2017 is more than the K in 2017 alone, which shows improvement, except for 2014 which recorded the lowest number of K. The number of incapacitating injuries (A) also does not show a clear pattern, but 2017 has the highest number of A, while the non-incapacitating injuries increases over the 5-year period (Figure 10). Overall, the total number of K+A+B increases annually. Figure 11 – 13 also shows the map of the K, K+A and K+A+B respectively.

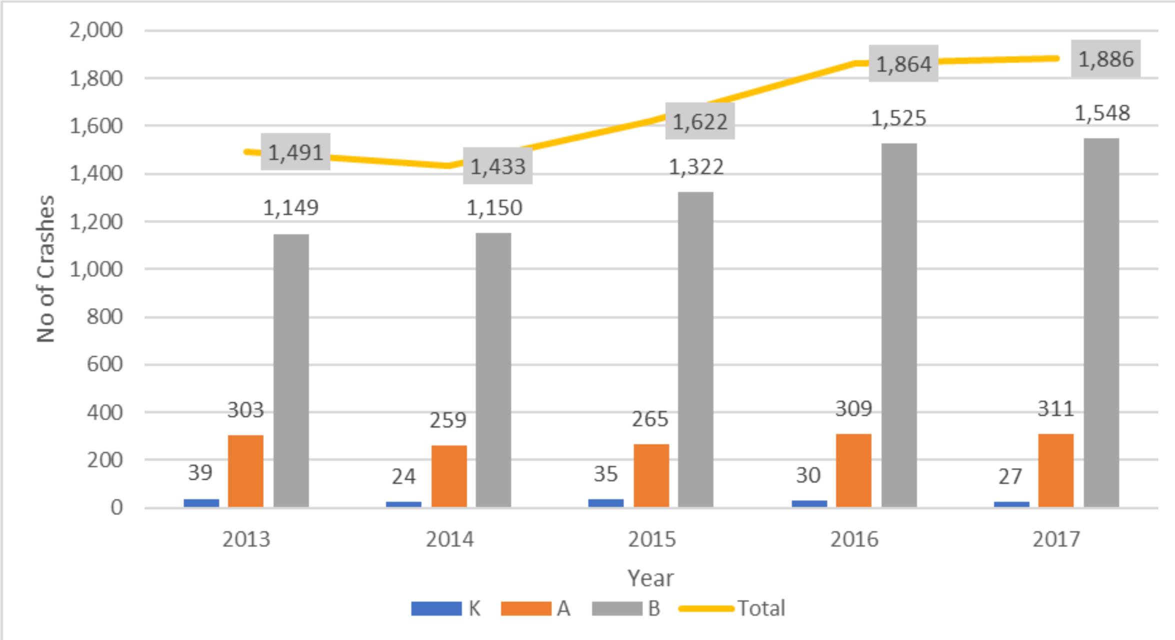

Figure 10. Annual killed, incapacitating, and non-incapacitating injuries (K+A+B).

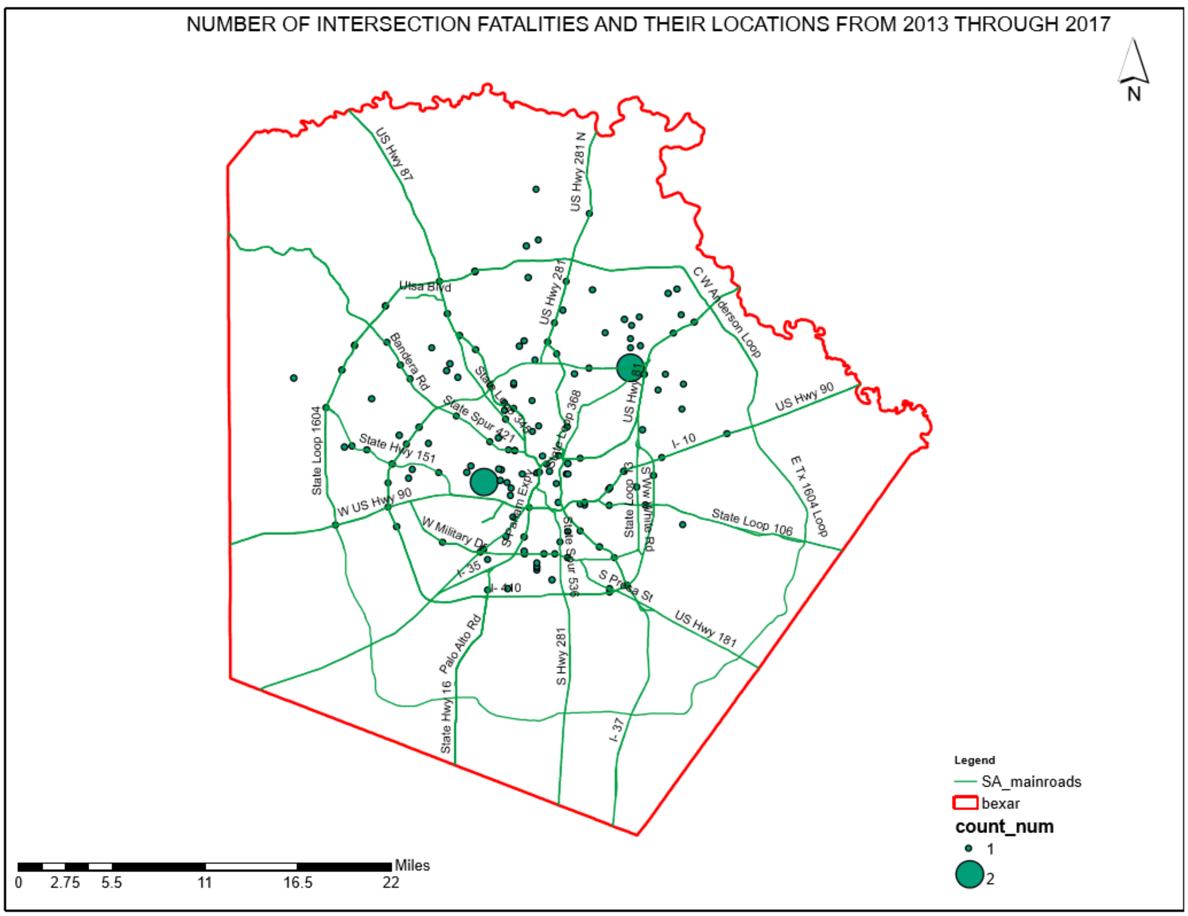

Figure 11. Map of intersection fatalities (K).

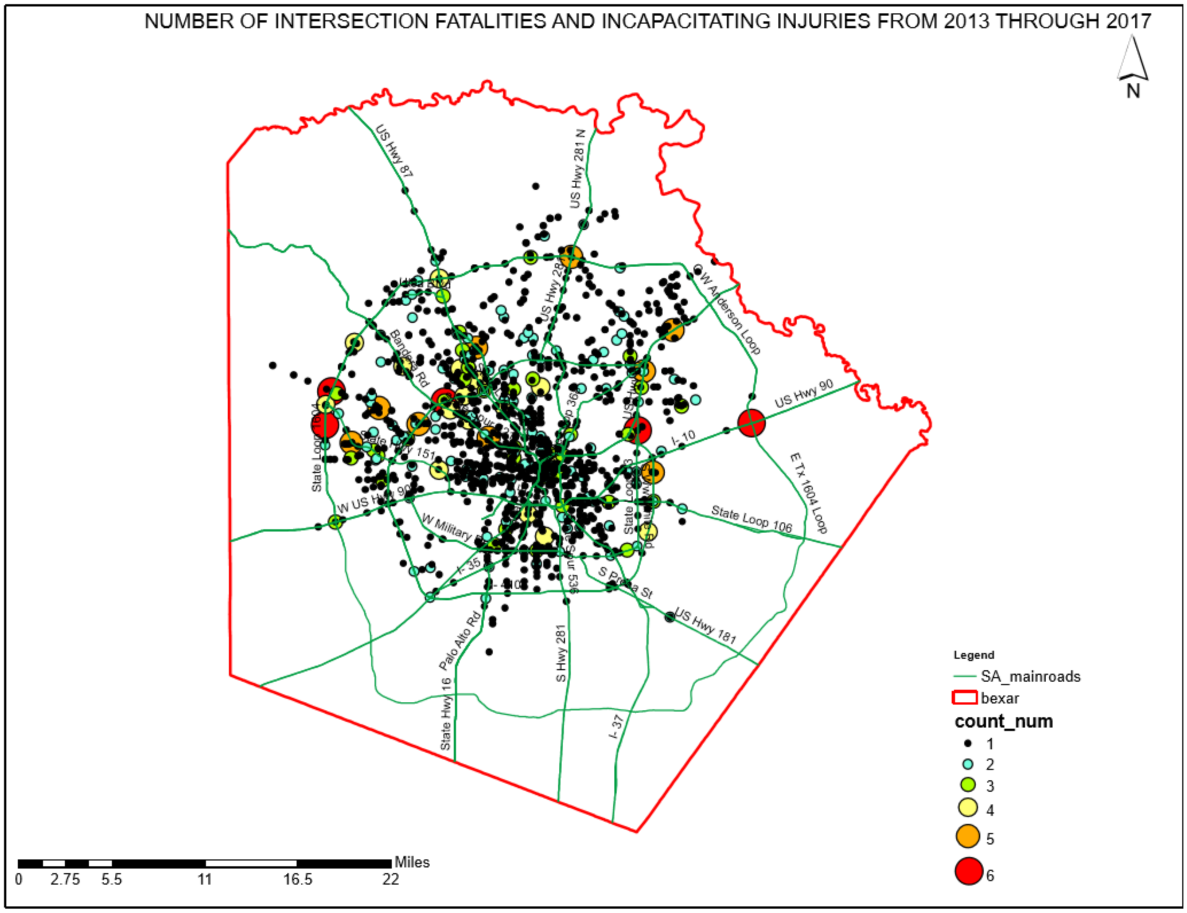

Figure 12. Map of intersection fatalities and incapacitating injuries (K+A).

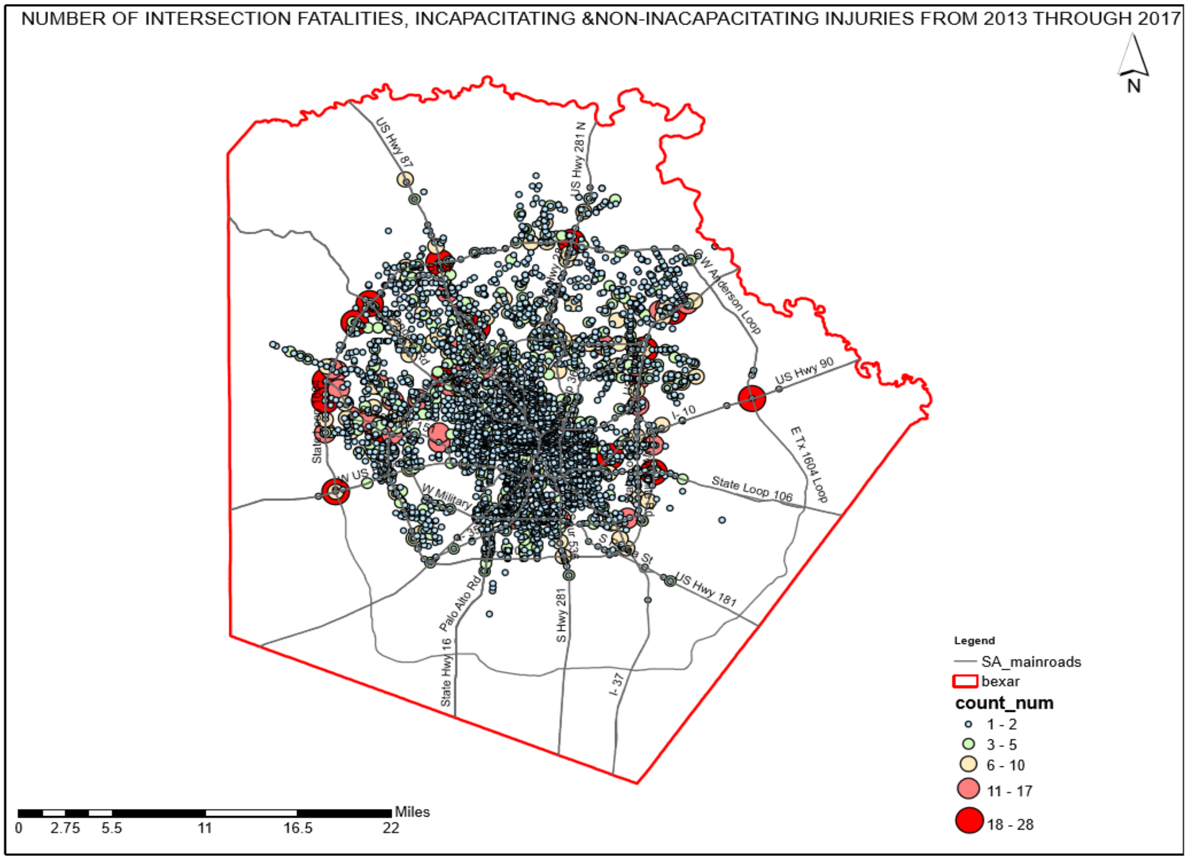

Figure 13. Map of K+A+B.

Collision Type: Table 2 lists the number of intersection crashes based on collision type, as recorded in the CRIS database. The collision types are listed in order of descending frequency.

Table 2. Collision type and percentage of the total number of intersection crashes.

Collision Type	Percent of Total Crashes
Angle - Both Going Straight	23.5%
Opposite direction - One Straight-One Left Turn	16.3%
Same direction - One Straight-One Stopped	15.9%
One Moving Vehicle - Vehicle Going Straight	8.5%
Angle - One Straight-One Left Turn	6.1%
Same direction - Both Going Straight-Rear End	5.5%
Same direction - One Straight-One Left Turn	4.4%
Same direction - Both Going Straight-Sideswipe	4.3%
Angle - One Straight-One Right Turn	2.6%

About 24% of intersection crashes in this study are angle crashes, which is reported from literature to be the highest in most cases. Left-turning collisions are also relatively frequent, with the three different ways in which they can occur totaling to over 27%.

Weather Conditions: In most intersection crashes (73%) in San Antonio, the condition of the roadway is dry. 19% of all intersection crashes occurred in cloudy weather, but only 8% occurred when the pavement was wet, and less than 1% occurred in snowy, sleet, or hail conditions. Figure 14 summarizes intersection crashes by weather condition, through which roadway condition is suggested.

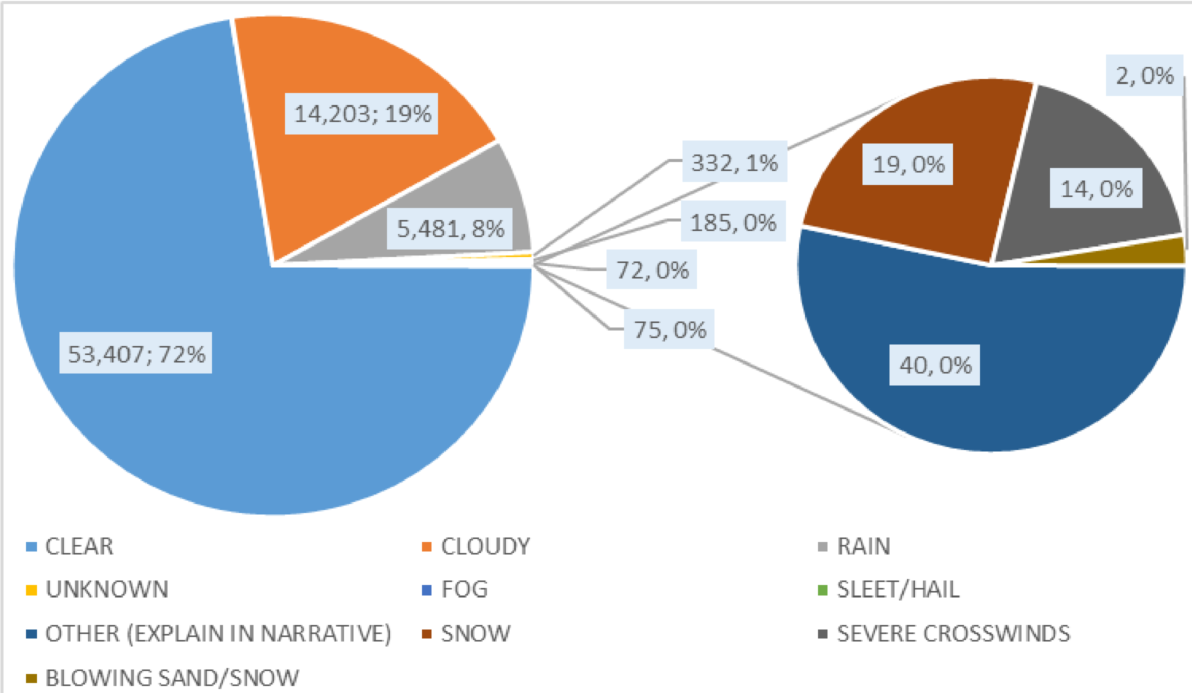

Figure 14. Intersection crashes by weather condition.

Light Conditions: According to Figure 15, 70% of intersection crashes in San Antonio occurred during the day, between sunrise and sunset. A small percentage occurred at dawn or dusk, while 24% occurred after dark but on lighted roadways.

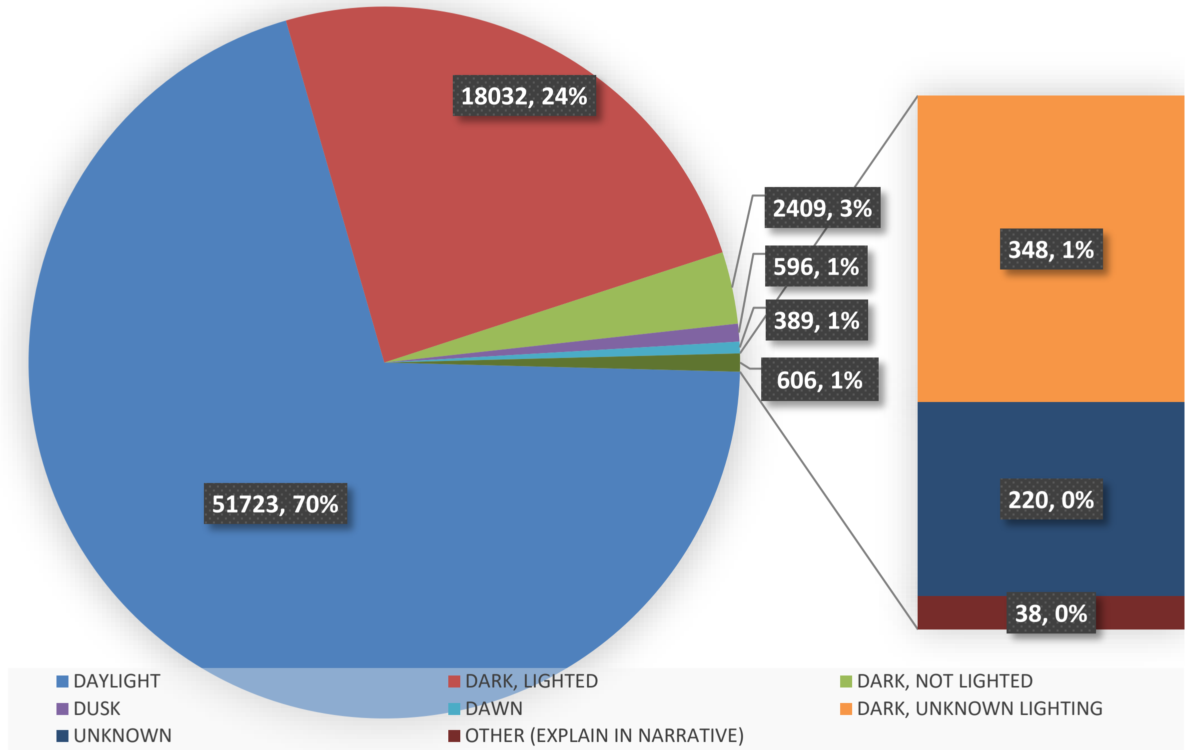

Figure 15. Intersection crashes by light condition.

Crash by Traffic Control: As shown in Figure 16, 46% of all crashes occurred at intersections controlled by a traffic signal light, while 22% occurred at stop sign controlled intersections and 11% at uncontrolled intersections.

Road Type: Figure 17 shows the distribution of road types in intersection crashes during the five-year period under study, and it shows that more than 95% of the crashes happened on a road divided into four or more lanes.

Road Alignment: Road alignment is a major consideration when designing intersections. Hence, the CRIS report includes the description of the road alignment at crash locations. About 85% of the intersection crashes occurred on a straight road and less than 6% on curves as shown in Figure 18.

Vehicle Body Style: A comparison of the different vehicle body styles is shown in Figure 19. A 4-door passenger vehicle was the most common vehicle during intersection crashes. However, the 4-door cars are likely the most common vehicle used in San Antonio. Sports utility vehicles and pick-up trucks is the next major ones, then others. A more detailed table appears as Table A-15 in the Appendix.

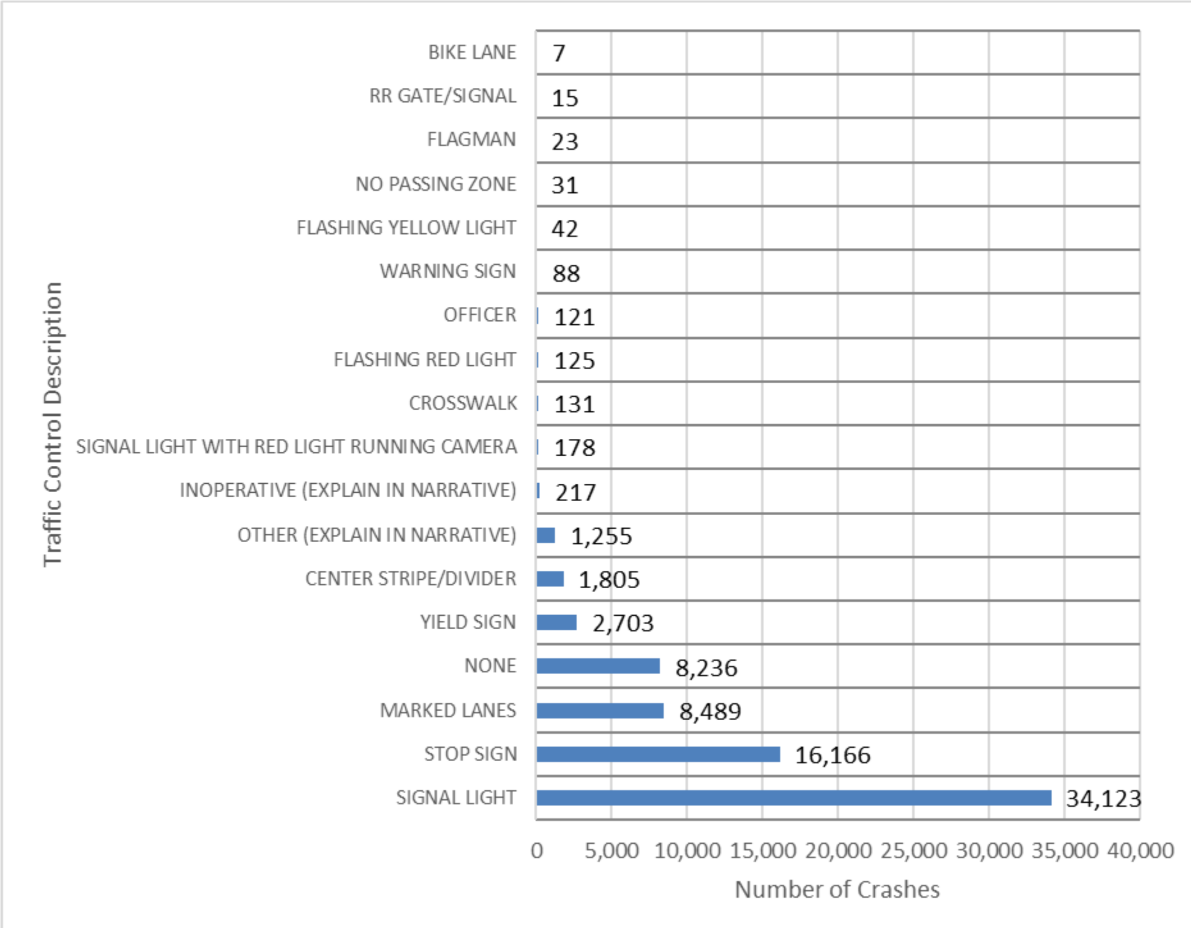

Figure 16. Intersection crashes by type of traffic control.

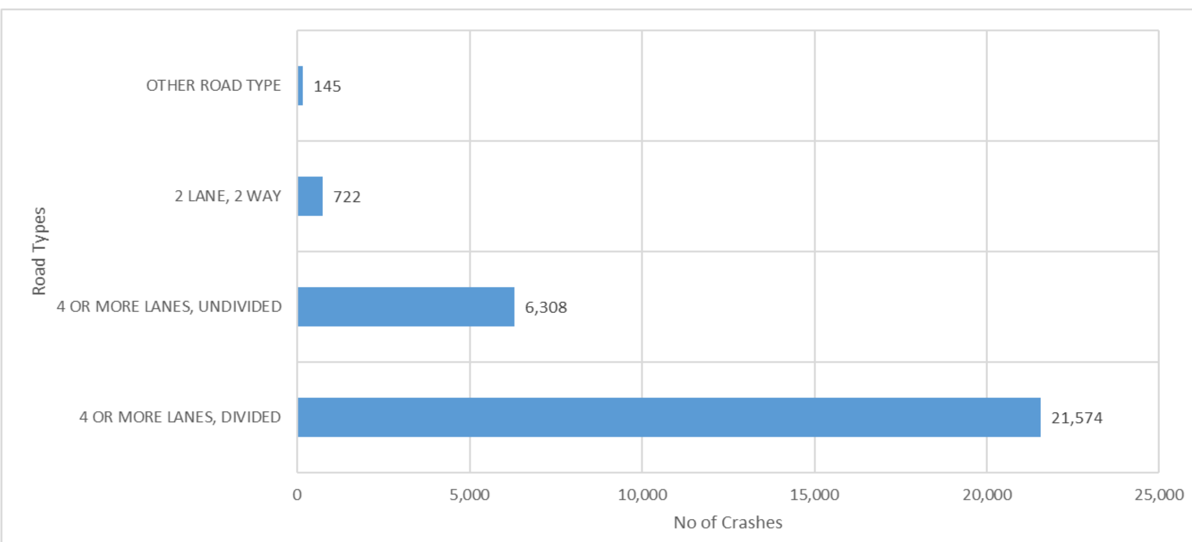

Figure 17. Intersection crashes by road type.

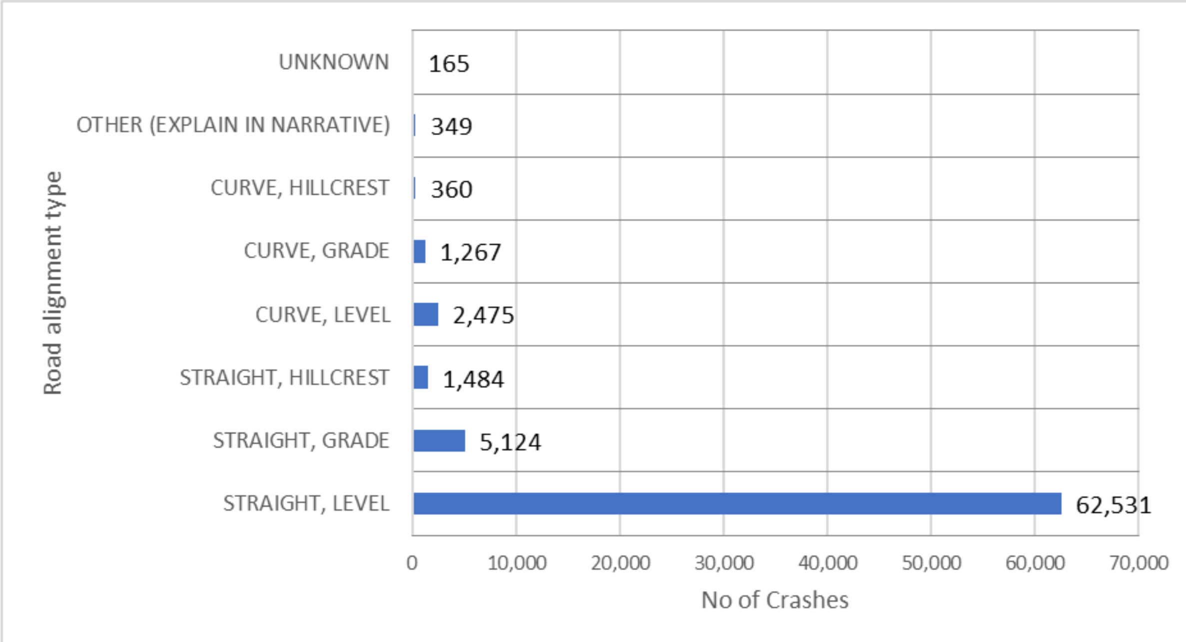

Figure 18. Intersection crashes by road alignment type.

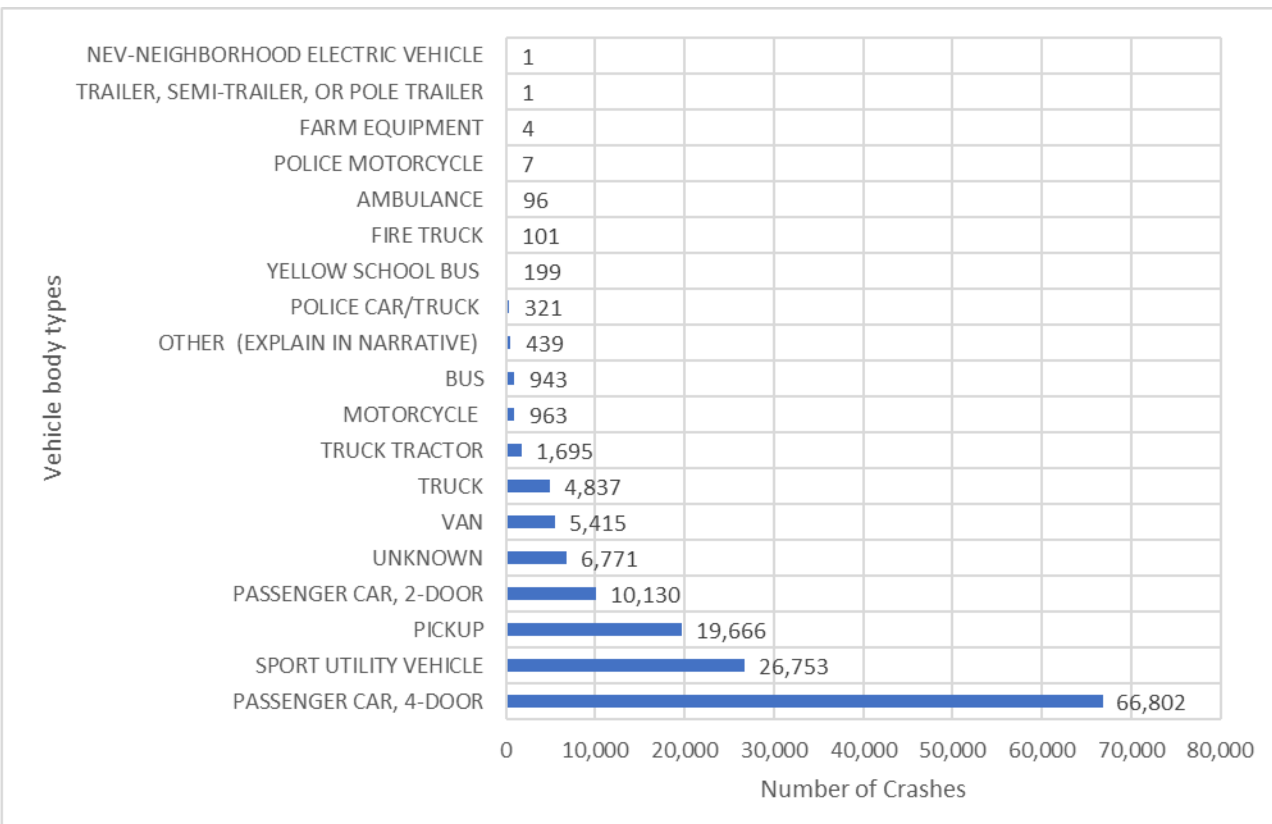

Figure 19. Intersection crashes by vehicle type.

Contributing Factors: In almost half of the intersection crashes, contributing factors were not recorded. For those that were recorded in CRIS, up to three contributing factors were reported by the officers. Figure 20 summarizes the frequency with which various factors were reported. Approximately 35% of crashes for which factors were recorded have "driver inattention" reported as a factor, and 23% have disregard of a traffic signal (stop and go signal, or a stop sign or stop light) as a contributing factor.

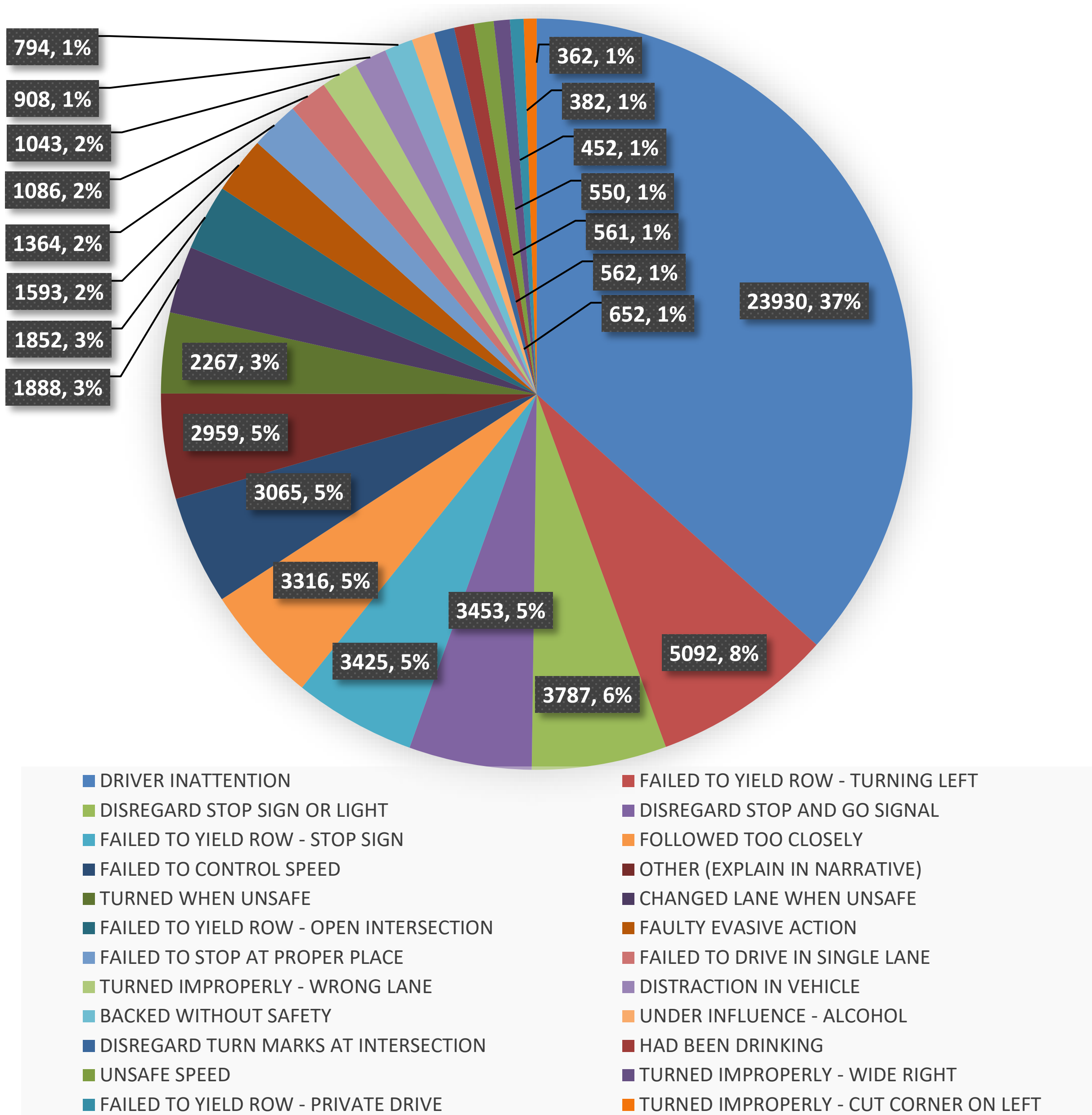

Figure 20. Intersection crashes by contributing factor.

Objects Involved: Figure 21 below shows the number of intersection crashes by objects involved. In more than 95% of the cases, the crashes occurred between vehicles and less than 4% involved pedal cyclist and pedestrian. Crashes involving vehicles and train is very rare.

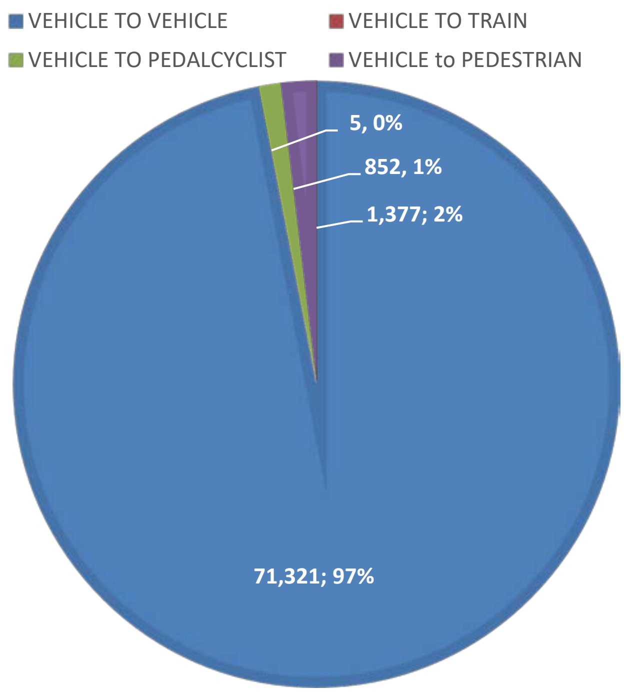

Figure 21. Intersection crashes by objects involved.

5.2. Fatalities Analysis

More detailed analysis was done on only the fatalities that occurred at the intersections. Results obtained showed that there were more male fatalities than female and most of them happened on Sunday. Ages between 15 and 44 represented 55% of the deaths at intersections, and ages above 75 years old represented less than 4%. It was also evident that more than 50% of the deaths occurred during the evening hours (6 pm – 5 am).

Also, about 41% of the fatalities involved one moving vehicle going on a straight road, 27% are angle crashes where both cars are going straight, and 14% are due to vehicles moving in the opposite direction, one straight and one left turn. Most of the fatality locations have a traffic signal, and almost 40% cases have only marked lanes and stop signs.

5.3. Hotspot/High-Crash Volume Intersections

5.3.1. Using Crash Frequency and Intersection Crash Rate

All the intersection crashes were analyzed based on their latitude and longitude. This result was used to identify the intersections with more than 100 crashes within the 5-year study period for further analysis. The data was put into ArcGIS 10.5 to view the crash locations and areas with the most crashes as shown in Figures 22 and 23. Top 20 intersections based on frequency are shown in Table 3.

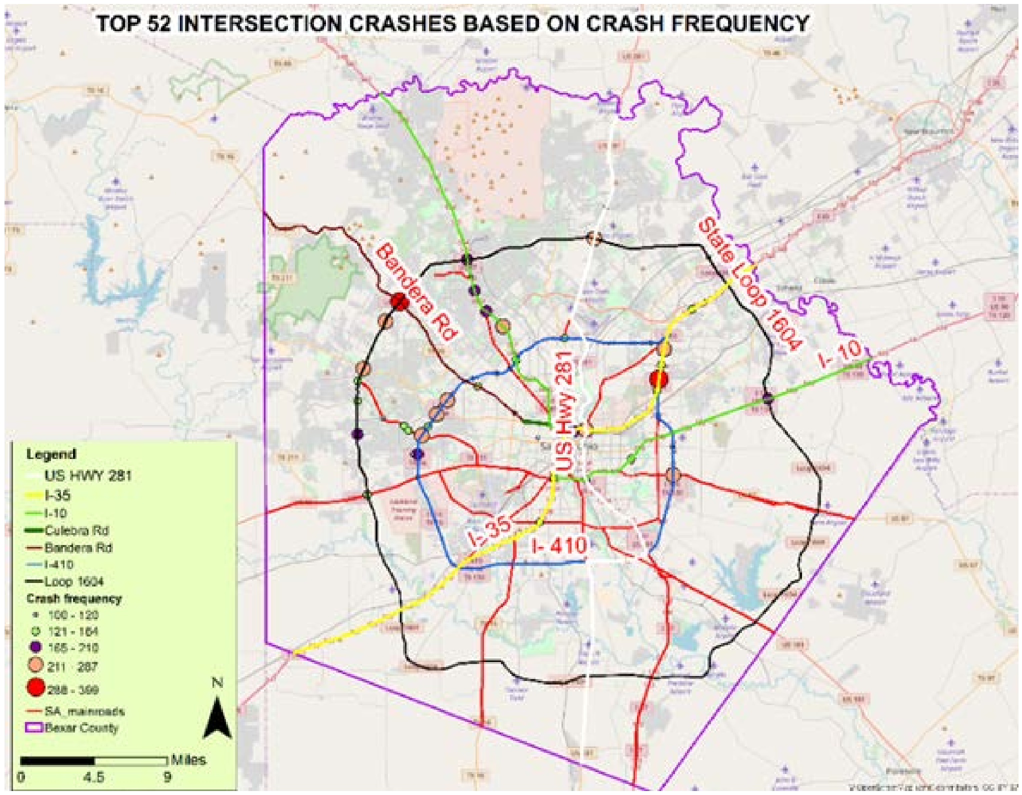

Figure 22. Top 52 intersections based on crash frequency.

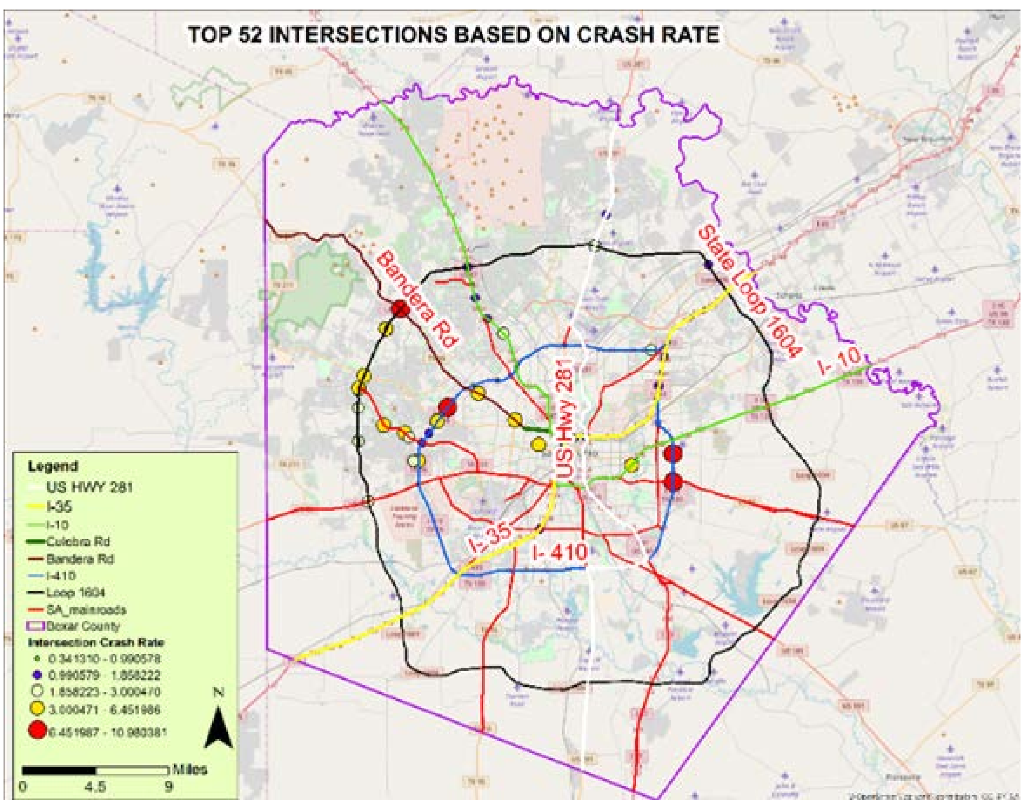

Figure 23. Top 52 intersections based on crash rate.

Table 3. Top 20 intersections with the highest number of intersection crashes.

ID	Intersection Name	Number of Intersection Crashes
1	Bandera Rd & W Loop 1604 N	399
2	IH 35 N & Rittiman Rd	324
3	Ingram Rd & NW Loop 410 Access Rd	287
4	Braun Rd & W Loop 1604 N	264
5	State Hwy 151 & SW Loop 410	249
6	Broadway & IH 35 N	246
7	Rigsby Ave & SE Loop 410	236
8	Culebra Rd & NW Loop 410	235
9	IH 10 W & Wurzbach Rd	229
10	FM 1976 & IH 35 N & Walzem Rd	228
11	Culebra Rd & W Loop 1604 N	227
12	N Loop 1604 E & US Hwy 281 N	218
13	Marbach Rd & SW Loop 410	210
14	Huebner Rd & IH 10 W	203
15	E Loop 1604 N & IH 10 E	202
16	IH 35 N & Mccullough Ave	189
17	De Zavala Rd & IH 10 W	180
18	IH 10 W & N Loop 1604 W	180
19	Potranco Rd & W Loop 1604 N	173
20	Potranco Rd & State Hwy 151 & State Hwy 151 Access Rd	164

Using the extracted AADT for all the selected locations and calculating the respective intersection crash rate for each intersection, the research team identified high-risk intersections and their spatial distribution within the city of San Antonio (Figure 25). Thirty-Six intersections were identified with a crash rate of 1 or more crashes per million entering vehicles (MEV). Though the crash rate uses different traffic variables (i.e., hourly traffic flow, volume per lanes, the direction of traffic flow etc.), which often may not be consistent with the traffic flow levels at the time of the crash, it gives a reasonable assessment of the intersections if the size of the data is large (e.g. more than one year of data). Intersections along Bandera Rd and W Loop 1604 N appears to be the most dangerous intersection based with 399 crashes and 8.5 crash per MEV based on this study; though Rigsby Avenue and SE Loop 410 have the highest crash rate but lower number of crashes. Table 4 shows the top 20 high-risk intersections based on crash rate. More than half of the intersections highlighted are also in the top 20 locations based on crash frequency.

Table 4. Top 20 hotspot intersections based on intersection crash rate.

ID	Intersection Name	Number of Intersection Crashes
1	Rigsby Ave & SE Loop 410	10.98
2	Ingram Rd & NW Loop 410 Access Rd	8.75
3	E Houston St & SE Loop 410	8.57
4	Bandera Rd & W Loop 1604 N	8.50
5	Braun Rd & W Loop 1604 N	6.45
6	N Zarzamora St & W Martin St	4.94
7	Culebra Rd & NW Loop 410	4.82
8	Bandera Rd & N General McMullen	4.34
9	Marbach Rd & SW LOOP 410	4.10
10	Potranco Rd & State Hwy 151 & State Hwy 151 Access Rd	3.77
11	Bandera Rd & Callaghan Rd	3.64
12	State Hwy 151 & W Loop 1604 N	3.61
13	Culebra Rd & W Loop 1604 N	3.60
14	State Hwy 151 & W Military Dr	3.57
15	IH 10 E & Martin Luther King Dr	3.57
16	N Loop 1604 E & US Hwy 281 N	3.00
17	Potranco Rd & W Loop 1604 N	2.92
18	W Loop 1604 N & Wiseman Blvd	2.77
19	Horal Dr & Marbach Rd	2.72
20	IH 10 W & Wurzbach Rd	2.53

5.3.2. Using ArcGIS Spatial Analyst Tool

The study also uses Getis-Ord Gi* statistic to identify the hotspots intersections using incremental spatial autocorrelation tool which creates a line graph of those distances and their corresponding z-scores. Points in the +/-3 bins show statistical significance with a 99% confidence level; points in the +/-2 bins reflect a 95% confidence level; features in the +/-1 bin reflect a 90% confidence level, and the clustering for features in bin 0 is not statistically significant.

The Gi* statistic returned for each feature in the dataset is a z-score. For statistically significant positive z-scores, the larger the z-score is, the more intense the clustering of high values (hot spot). For statistically significant negative z-scores, the smaller the z-score is, the more intense the clustering of low values (cold spot).

Open Street map for San Antonio was superimposed on hotspots analysis map (as shown in Figure 24). The most prominent hotspot intersections are in the central part of San Antonio (Downtown and its environs), then the northwest area that has major intersections along I10 and Wurzbach, DE Zavala, Huebner and Fredericksburg Road. The Western area of San Antonio is another major region which includes Loop 1604, Culebra, Potranco, Marbach and FM 1957, and the last part if the northeast area with include intersections along I35 Highway, Walzem road, Rittiman road and Eisenhauer road.

Some of the contributing factors for the occurrence of these crashes include a higher percentage of angle-end crashes and rear-end crashes, which may be due to high AADT.

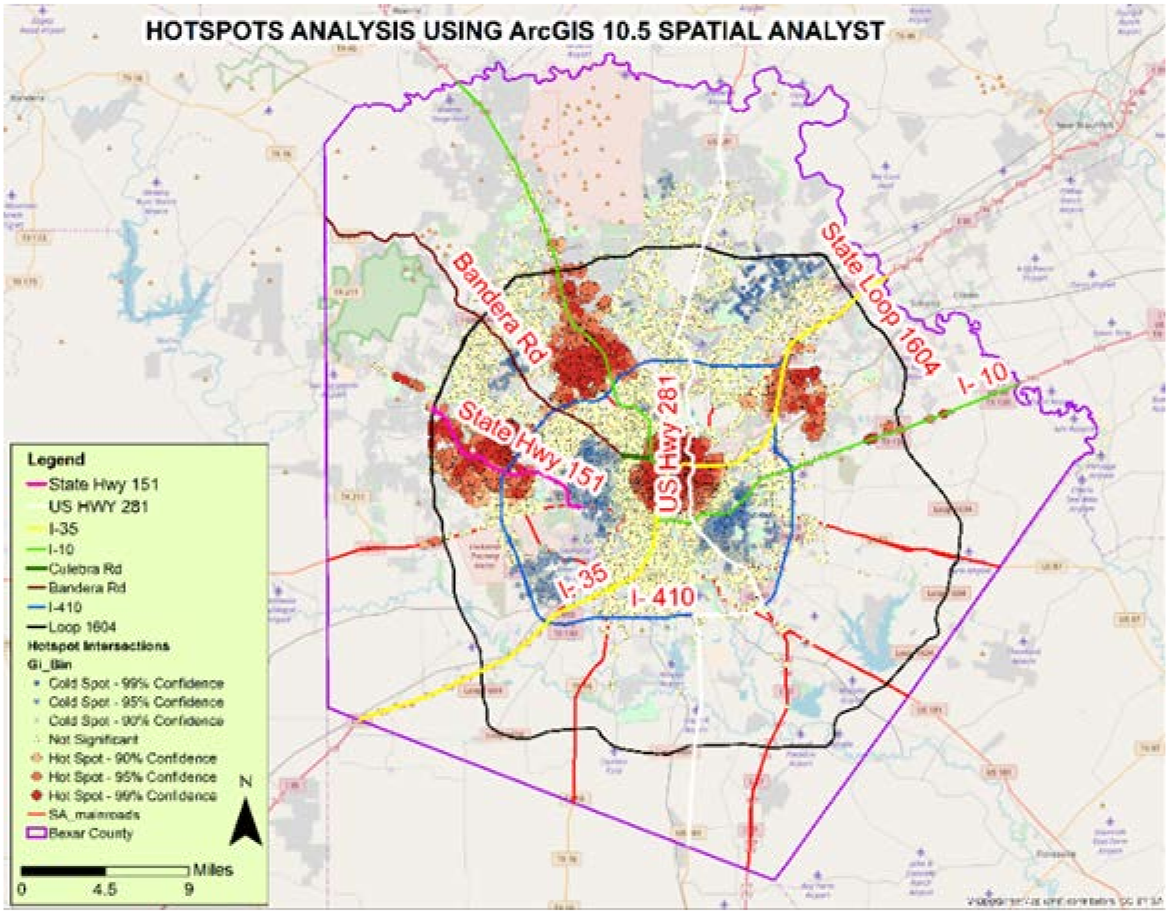

Figure 24. Map of hotspot analysis using ArcGIS spatial analyst tool.

5.4. Key Findings

The CRIS is an adequate database and provides adequate information associated with most crashes in Texas; though there are some opportunity in terms of standardization of keywords used in the documentation, and the possible introduction of multiple choice-like responses to some of the questions in the report.

To better identify appropriate treatments for Texas intersections, the study reviewed the San Antonio intersection crashes to identify the major characteristics of intersections and crash frequencies at these intersections.

About 59% of the reported intersections had only one crash (intersection, Intersection-related, or driveway access) in the 5 years, while about 2% of the intersections have an average of 80 crashes per year.

The number of male drivers involved in intersection crashes is higher than female drivers, even though the City of San Antonio has more licensed female drivers than male drivers. The highest number of crashes involved drivers of the age range of 15 – 34 year. This is an indication that intersection crashes are one of the top threats to youths in San Antonio.

The two most common types of intersection crashes were (a) angle crashes and (b) opposite direction-one straight and one left-turn. These crash types represented about 40% of the intersection crashes.

Based on analysis of drivers' behavior and contributing factor that lead to crashes, driver's inattention was ranked first, while disregard for the traffic control device and failure to yield right-of-way ranked second.

The intersection fatalities analysis also revealed that more than 50% of the crashes occurred between 6 pm and 5 am, with almost 50% in dark spots that are lighted. There is more males' death versus females' (113 male deaths versus 43 female deaths).

Also, intersection fatalities account for about 20% of all fatalities in San Antonio versus the 30% intersection crashes, which can mean intersections are still safer than other parts of roadways (possibly due to relatively low speeds).

Among high-risk intersections, based on crash frequency and crash rate, the intersection of Bandera Road and Loop 1604 is the worst in the City, with 399 crashes and 8.5 crashes per million entering vehicles; though Rigsby Avenue has the highest crash rate but has fewer crashes than Bandera.

5.5. Field Observations

The data collection techniques included note taking by onsite observers and video recording. Special attention was required at intersections that include a main and a secondary road. The observers noted the 1) approach speed during free-flow traffic, 2) speed when diver is approaching from a secondary road of turn signals, 3) speed after turning into a secondary road, 4) stopping behavior at intersections with stop signs, 5) use of turn signals when required, 6) headways while entering the intersection, and 7) gap acceptance when entering a main road. Observations were taken when roadway surface was dry and weather conditions good.

5.5.1. Identifying Intersections to Visit

The crash severity is defined as the total number of severe injuries as a result of crashes in the same study period divided by the mean ADT multiplied by 1000. The thresholds chosen in this study to identify the critical (hot spots) intersections are as follows

- For the crash rate per 1000 AADT, if crash rate per 1000 AADT greater or equal to 8 and number of crashes greater of equal to 15 and
- For the casualty rate per 1000 AADT, if casualty rate per 1000 AADT greater or equal to 5 and number of crashes with casualties greater or equal to 2.

From these thresholds 100 intersections have been identified in the study. For the purpose of this task, a selective group from each threshold (crash rate and crash severity rate) was chosen for site visits. These intersections represent different characteristics: signalized and unsignalized (stop controlled), high and low ADT, low and high crash rate, and different geographic locations in San Antonio.

5.5.2. Site Visits

The research team conducted site visits to 24 intersections to perform evaluation of the traffic operation and geometric characteristics. The visits were conducted from September to December 2017. At each site the following tasks were performed:

1. Inspecting the site geometric plan and the nearby area using Google maps.
2. Identifying potential geometric constrains that could lead to crashes such as: limited horizontal sight distance, blocking due to vegetation or buildings, etc.
3. At the site, documenting a complete description of intersection signs, traffic lights, marking, and control devices.
4. Monitoring and assessing the intersection safety through observing the traffic operation from all directions.
5. Examining primarily factors that lead to crashes and propose potential improvement to reduce them.
6. Taking snap shots from all directions and documenting all site characteristics.

The research team met with traffic engineers and obtained more insight on intersection safety in San Antonio. The following were asked by the research team at these meetings:

- What are the current safety projects that are expected to be let?
- What are the projects that received improvements in traffic control devices in the last 2-3 years and proved to be effective or not effective?
- What are the safety concerns related to intersections and how do the Districts identify the best modifications and upgrades?
- What is the current practice for identifying the safety projects and how to assess current problems?

After concluding these meetings, the research team obtained examples of sites to proceed with the observation and survey.

The following descriptions are a detailed summary of parameters for some of the intersections collected during two of the site visits. Photos of each direction towards intersection were taken, as needed, and presented. Google maps were used to identify the approximate upgrade year.

5.5.3. US 181 and Loop 1604

Site Characteristics: This is a signalized 4-legged intersection between US 181 and South Loop (SL) 1604 access roads in Bexar County, San Antonio District. The US 181 intersection has two segments: east access and south access road which are 600 ft apart. The San Antonio District is projected to let the south access road intersection for signal interconnection in 2019. The US 181 is a divided two-lane highway in each direction with a left turn bay at the approaches. The SL 1604 access road is a two-way two-lane ramp access to LP 1604. The approach speed on US 181 is 65 mph. The intersection seems perfectly at 90 degrees as seen in Figure 25.

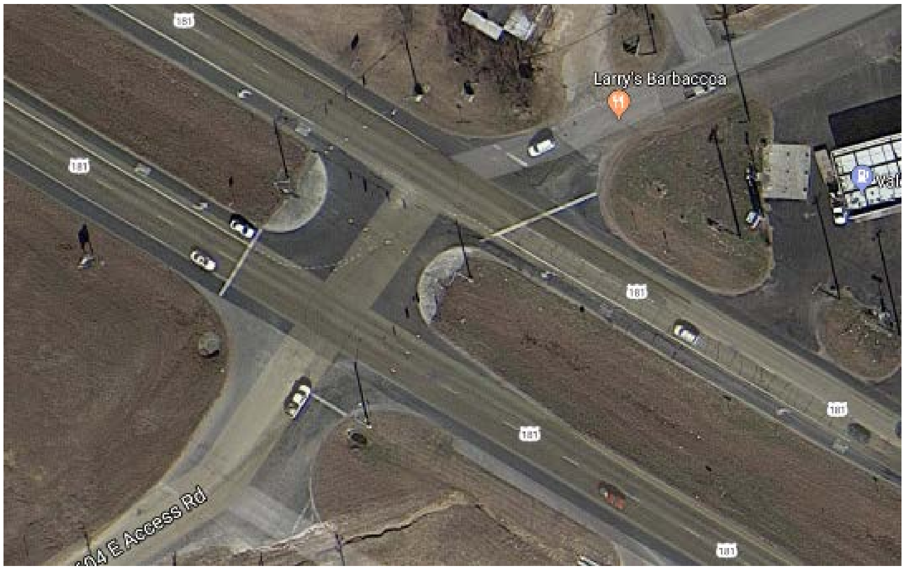

Figure 25. Overview of the intersection of US 181 and SL 1604.

Traffic Control Devices: The intersection is controlled by signal lights on span wire across the four approaches. Due to the overpass bridge, two sets of traffic lights are used at the east and south intersections, respectively (Figure 26). Advanced warning signs on the access road and an active warning sign on the US 181 with flashing beacons are also used.

Figure 26. The signal control at the SL 1604 and US 181.

Traffic and Pavement Observations:

- Video footage suggests that the traffic light is not in synchronization when green phase starts as evident in the traffic accumulation at the second set of light after passing the bridge.
- Light poles seem to be sufficient to cover the intersection.
- Pavement surface is generally in fair condition except at the access roads where it is primarily poor.
- The access roads are generally in poor pavement condition, lacking of visible lane markings and with shoulder drop off.
- Intersection seems to be cleared from obstructions in all approaches.

- Rumble strips are located in the shoulders of US 181 in all approaches.

Motorists Observation:

- At the time of the visits, it was noticed that motorists have multiple incidents of running the red light. The primary reason is that after crossing the first light with full speed they are not aware of the second light just after the bridge. Lack of warning of another light and the traffic light being hidden by the bridge contributes to the red light crossing.
- Incident of turn around (U-turn) at the left turn bay of US 181 at red light phase was observed. This has caused interruption with another green phase traffic in place.
- It was observed that the right turn traffic from the SL 1604 to US 181 may yield from stationary and merge with the through traffic of 65 mph.
- The right turn traffic from US 181 to SL 1604 sometimes is using the shoulder as a turning bay. This happens frequently due to the wide shoulder width (Figure 27).

Figure 27. Right turn traffic (left side) using the shoulder as a turn bay.

5.5.4. FM 78 and Walzem Road

Comments: A fully signalized intersection. FM 78 has two lanes in each direction plus a bike lane. Median lane and side curbs are in all directions. The intersection seems to be in low elevation of a sag curve making it very visible from the approaches. All directions have separate left-turn lanes while only FM 78 has separate right-turn lanes. Drainage water seems to pond at sides and median lane at time of visit. Table 5 summarizes intersection characteristics, while Figure 28 shows each approach.

Table 5. FM 78 and Walzem Road intersection characteristics.

Element	FM 78	Walzem Road
Signs	10, 11 and 16	10, 11 and 16
Speed (mph)	45	45
Marking	Clear/visible	Clear/visible
Lighting	Yes	Yes
Traffic	Following signal lights	Following signal lights
Obstruction	90-degree angle intersection with no obstructions	90-degree angle intersection with no obstructions

Figure 28. FM 78 and Walzem Road from different approaches: (a) plan view, (b) northbound, (c) eastbound, (d) eastbound down the road, (e) southbound, and (f) westbound.

Findings from the Site Visits:

- Four-legged intersections with one-way stop control for one direction and a non-stop right of way for the other direction has shown a higher causality rate. Intersections upgraded to two-way stop control have shown reduced crash count and causality rate.
- Intersections with crossing overpasses and lower grade profiles are potential flooding zones. These intersections according to traffic engineers' experiences drivers crossing on red as they do not notice the traffic light located after the overpass. Other factors that need more investigation is to correlate the crashes time with flooding events at these intersections.
- Intersections that have no illumination have a higher causality rate.
- Intersections with no reduced approach speed before reaching complete stop have shown higher crash rate counts.
- Intersection with several traffic control devices (signage and lights) have shown smaller crash counts.

- Common practice is that if an intersection does not warrant signalization, engineers make an effort to introduce modification to the existing traffic operations. That includes:
    - Reduce speed at the approaches using active advanced warning, speed radar signs, or rumble strips with pavement speed markings.
    - Active LED and flash beacon stop signs and overhead flashers at the intersection. Tyler District in one attempt removed the overhead across the diagonal direction of wire and installed the flashers only for the minor road on mast arm poles.
    - Introduce active advanced warning at the approaches particularly in the minor roads. That includes yield to right of way of major intersection.
    - Improve marking visibility and pavement surface conditions.
    - Separate left turn traffic from the main lane through left turn bays.
    - Introduce rumble strips in driving lanes particularly close to the advanced warning signs.
    - For signalized intersections, improve phase timing and detection for minor roads.

6. CONCLUSIONS

A detailed analysis of all intersection crashes in San Antonio for the five-year period from 2013 – 2017 was conducted to understand the contributing factors of intersection crashes in the City. The crash data was downloaded from the Crash Records Information System (CRIS), and it includes detailed information on crash location and time, driver and passenger characteristics, vehicle information, roadway and environmental conditions. The hourly, daily, and monthly distribution of crashes were analyzed. The characteristics of drivers such as age and gender were also examined. This study shows that the number of crashes varies by the hour of day and day of the week with the most prevalent occurrence on Fridays and between the hour of 4:00 p.m. and 5:00 p.m. Female drivers were involved in fewer intersection crashes than male drivers, even though there are more licensed female drivers than male drivers. Also, male young drivers are more likely to be involved in intersection crashes than elderly drivers. The collision types also show that angle crashes where both vehicles are going straight are the most common form of intersection crashes. Left-turning vehicles were also involved in a high number of crashes. For more than half of the drivers, the CRIS report shows "not applicable", indicating no contributing factor connected to the driver. When contributing factors were analyzed, it typically involved driver's inattention, failure to yield right of way, or disregard for the traffic control signals. The findings from this analysis also show that more than two-thirds of the total intersection and fatal vehicle crashes happened under clear weather condition in a stationary manner. This pattern is well suited for novel self-driving technology, which can handle simple, monotonous tasks much more proficiently and effectively than human beings. This technology can radically reduce the number of deaths at intersections and most of part of road networks within a few decades. More than 50% of the fatalities occurred in the evening through early morning, which can be partly due to not well-lighted roads. There are more male deaths versus female (113 male deaths versus 43 female deaths).

The high-volume crash intersections, based on crash frequency and their crash rate results, show that intersections along San Antonio's Loop 1604 and Bandera is one of the most dangerous in the City with 399 crashes and 8.5 crash per MEV. A total of 52 San Antonio intersections, all having 100 or more crashes from 2013 – 2017, made the high-volume crash intersections, causing 1,447 incapacitating injuries and 166 deaths. The hotspot analysis using the ArcGIS spatial analyst identified four main regions within the City that are susceptible to intersection crashes. The areas include the central part of San Antonio (Downtown and its environs), then the northwest area that has major intersections along I10 and Wurzbach, DE Zavala, Huebner and Fredericksburg Road. The western area of San Antonio is another major region which includes Loop 1604, Culebra, Potranco, Marbach and FM 1957. The level of detail in the CRIS report was informative, but would be improved with more standard key words when recording crashes for ease of analysis and uniformity.

More work is needed to better identify factors contributing to high crash frequencies in some selected intersections, which will help to develop countermeasures to improve public safety and protect life on San Antonio roadways.

Further GIS spatial analysis can also help to reinforce the identified intersection hotspots and understand the effects of spatial autocorrelation as well as develop models to enhance the robustness of the output. An example of such analysis is the Kernel density estimation (KDE).

7. RECOMMENDATIONS

Following the study carried out on the intersection crashes that occurred from 2013 – 2017 in San Antonio, the following actions are hereby recommended to further enhance the safety of intersections:

7.1. Roadway Improvements

7.1.1. Stop Sign with Flashing Beacons

Installing flashing beacons at intersection approaches could be a cost-effective safety improvement. Flashing lights can be added to signs, either through beacons or embedded light-emitting diodes (LEDs), to attract attention and convey a message to drivers at intersection.

7.1.2. Nighttime Lighting

Studies showed that the nighttime crash rate decreased significantly after intersection lights were installed.

7.1.3. Transverse Rumble Strips

Studies indicated that Transverse Rumble Strips were effective in reducing severe injury crashes (KAB and KA) at intersections.

7.1.4. Turning Lanes

Adding turning lanes was shown to result in significant crash reductions. The longer the turning lane, the higher the crash reduction. Left turning lanes was shown to result in larger crash reductions than right turning lanes.

7.1.5. Signals Installation and Operations

The introduction of signals, even without the addition of left turn lanes, was found to reduce total crashes, injury and fatal crashes, and frontal impact crashes (both types), and increase in rear end crashes at intersections. Adding left turn lanes decreased rear end crashes as well.

7.1.6. Roundabout Intersections

Roundabouts are seldom seen in Texas. They are expensive to build only in cases where right of way is expensive. The FHWA Office of Safety identified roundabouts as a Proven Safety Countermeasure because of their ability to substantially reduce the types of crashes that result in injury or loss of life. Roundabouts are designed to improve safety for all users, including pedestrians and bicycles.

7.1.7. Access Management

A 2010 FHWA publication addresses conflicts between driveways and the main traffic flow, separately for urban areas. The publication recommends the following approaches to help to improve motorist safety and mobility in the vicinity of intersections:

- As development occurs in near intersections, early communication and coordination with property owners, jurisdictional staff and all stakeholders in planning processes can help to establish the location and number of driveways that can be permitted to the major roadway as part of the land subdivision process.

- Provide adequate throat depth and on-site circulation for vehicles to easily exit a major roadway. This will minimize speed differential between through vehicles and vehicles slowing to turn into a driveway.
- Provide driveways onto the minor street instead of on the major street in order to preserve mobility on the major street.

7.1.8. Recommendations Based on Site Evaluations

- Increase the size of the all traffic lights, Stop sign and Stop Ahead signs, traffic ahead sign, etc.
- Adjust phasing to accommodate traffic volume,
- Add advanced warning sign
- Provide a more reflective sign.
- Post an additional (left-side mounted) sign in the approach lane
- Add “STOP AHEAD” pavement markings.
- Improve marking visibility and pavement surface conditions
- Add transverse rumble strips.

CRIS data analysis suggest that the majority of crashes leading factors at intersections have been primarily due to fail to yield ROW, and control speed at the intersection approaches. Although driver fatigue and distraction contribute to these factors, however implementation of additional countermeasures can provide another layer of crashes mitigation strategy. For instance, targeting the improvement at this particular sign can raise the driver attention.

1. Use temporary or permanent radar driver speed feedback signs with display in advance of intersections. Also, improve conspicuity by using red/yellow retro-reflectorized border around signs.

Figure 29. Permanent radar speed detector with active display and speed limit pavement marking.

2. Observe site obstructions from growing vegetation, new development and construction of access points.
3. Combining multiple countermeasures at the approaches. For instance, advanced active warning signs with reflective post and transverse rumble strips can be used.

4. Improve pavement surface texture and pavement marking reflectivity.

Figure 30. Transverse rumble strips and new reflective striping.

5. Utilize fresh and new coat as a cost-effective surface treatment. The high surface texture may help in skid resistance, but it affects longevity of pavement marking and the contrast with pavement surface that tends to fade faster. Utilizing dense graded hot mix asphalt at the approaches provide better contrast between lane marking and pavement surface. It also, reduces the absorption into pavement surface as opposed to seal coat open course surface.

7.2. Educational Campaign Programs

1. Publicize high crash locations and point out the contributing crash factors (e.g., Stop sign running, not yielding ROW, speeding, texting, phone/electronics use).
2. Improve and emphasize safe driving behaviors in teenager driver education courses and defensive driving courses.
3. Create educational graphics and social media friendly information highlighting the statistics of injuries and fatalities result from contributing factors.
4. Develop and implement a young driver educational campaign relating to intersections.

7.3. Law Enforcement Emphasis

1. Increase the presence of law enforcement at hot-spot intersections with multiple incidents.
2. With limited law enforcement resources, promote automated enforcement to control speed and reduce stop sign running violations. Educate decision makers and the public on the effectiveness and appropriate use of automated enforcement.
3. Utilize red light enforcement cameras and photo radar speed detectors to provide local law enforcement the ability to enforce traffic laws remotely.

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APPENDIX

Table A-1. Annual intersection crashes versus total crash distribution in San Antonio.

Year	Number of Crashes	Number of Intersection Crashes	Annual Percent
2013	43,100	12,694	29%
2014	45,949	13,253	29%
2015	51,716	15,229	29%
2016	55,878	16,665	30%
2017	53,957	15,914	29%

Table A-2. Intersection crashes in San Antonio by day of week.

Day of Week	Number of Crashes	Percent
Mon	10,452	14.2%
Tues	10,501	14.2%
Weds	10,768	14.6%
Thurs	10,932	14.8%
Fri	12,513	17.0%
Sat	10,256	13.9%
Sun	8,333	11.3%
Total	73,755	100.0%

Table A-3. Drivers' age and gender distribution of intersection crashes.

Age Range	Female	Male	Percent of Female	Percent of Male	Percent Total
< 15	11	26	0.02%	0.04%	0.03%
15-24	13,176	15,483	23.11%	23.02%	23.06%
25-34	14,174	16,339	24.86%	24.30%	24.56%
35-44	10,488	11,552	18.40%	17.18%	17.74%
45-54	8,381	10,222	14.70%	15.20%	14.97%
55-64	6,058	7,596	10.63%	11.30%	10.99%
65-74	3,123	3,954	5.48%	5.88%	5.70%
75+	1,599	2,074	2.80%	3.08%	2.96%
Total	57,010	67,246	100.00%	100.00%	100.00%

Table A-4. Hourly distribution of intersection crashes.

Hour	Number of Crashes
0	1,359
1	1,098
2	1,670
3	816
4	483
5	709
6	1,698
7	3,325
8	3,414
9	2,650
10	2,987
11	3,475
12	4,194
13	4,493
14	4,823
15	5,244
16	5,818
17	6,236
18	5,362
19	3,833
20	2,936
21	2,821
22	2,395
23	1,872
Total	73,711

Table A-5. Hourly distribution of intersection crashes.

Hour	2013	2014	2015	2016	2017
0	260	268	265	317	249
1	198	199	215	236	250
2	331	278	341	382	338
3	167	145	174	152	178
4	93	76	102	103	109
5	131	150	141	163	124
6	292	288	347	405	366
7	559	554	673	783	756
8	600	615	699	763	737
9	459	459	559	628	545
10	535	554	585	662	651
11	629	605	633	838	770
12	696	736	890	943	929
13	741	885	943	983	941
14	827	920	988	1,088	1,000
15	913	883	1,128	1,154	1,166
16	984	1,087	1,193	1,298	1,256
17	1,064	1,106	1,268	1,438	1,360
18	883	961	1,146	1,221	1,151
19	626	719	790	866	832
20	521	483	666	623	643
21	487	464	619	642	609
22	390	443	461	568	533
23	301	368	396	396	411

Table A-6. Monthly distribution of intersection crashes.

Month	2013	2014	2015	2016	2017	Average	Total
Jan	986	1,020	1,153	1,424	1,310	1,179	5,893
Feb	953	946	1,106	1,337	1,343	1,137	5,685
Mar	1,153	1,087	1,298	1,443	1,466	1,289	6,447
Apr	1,005	1,131	1,268	1,502	1,357	1,253	6,263
May	1,124	1,118	1,187	1,402	1,386	1,243	6,217
Jun	1,025	1,036	1,263	1,307	1,277	1,182	5,908
Jul	1,023	1,109	1,249	1,362	1,219	1,192	5,962
Aug	1,079	1,188	1,340	1,382	1,256	1,249	6,245
Sep	1,041	1,147	1,311	1,411	1,261	1,234	6,171
Oct	1,145	1,224	1,445	1,442	1,432	1,338	6,688
Nov	1,075	1,138	1,296	1,287	1,330	1,225	6,126
Dec	1,078	1,102	1,306	1,353	1,267	1,221	6,106

Table A-7. Intersection crashes by intersection relationship type.

Intersection Relationship Type	No. of Intersection Crashes	Percent
Intersection	42,032	57.0%
Intersection Related	23,827	32.3%
Non-Intersection	6,453	8.7%
Driveway Access	1,442	2.0%
Not Reported	1	0.0%
Total	73,755	100.0%

Table A-8. Intersection crash severity distribution.

Injury Severity	No. of Intersection Crashes	Percent
Not Injured	46,541	63.1%
Possible Injury	16,822	22.8%
Non-Incapacitating Injury	6,694	9.1%
Unknown	2,096	2.8%
Incapacitating Injury	1,447	2.0%
Killed	155	0.2%
Total	73,755	100.0%

Table A-9. Intersection crashes by collision types.

Collision Types Description	No. of Intersection Crashes	Percent
Angle - Both Going Straight	17,364	23.5%
OD One Straight - One Left Turn	12,022	16.3%
SD One Straight - One Stopped	11,721	15.9%
OMV Vehicle Going Straight	6,242	8.5%
Angle - One Straight - One Left Turn	4,471	6.1%
SD Both Going Straight - Rear End	4,061	5.5%
S One Straight-One Left Turn	3,211	4.4%
SD Both Going Straight-Sideswipe	3,180	4.3%
Angle - One Straight-One Right Turn	1,911	2.6%
OMV Vehicle Turning Left	1,658	2.2%
SD One Straight-One Right Turn	1,422	1.9%
SD Both Left Turn	1,218	1.7%
OMV Vehicle Turning Right	1,093	1.5%
OMV Vehicle Backing	488	0.7%
OMV Other	434	0.6%
OD One Backing-One Stopped	377	0.5%
Angle - One Left Turn-One Stopped	357	0.5%
OD Both Going Straight	345	0.5%
Angle - One Right Turn-One Stopped	342	0.5%
SD Both Right Turn	340	0.5%
OD One Right Turn-One Left Turn	253	0.3%
OD One Straight-One Backing	204	0.3%
Angle - One Straight-One Backing	143	0.2%
Angle - One Right Turn-One Left Turn	134	0.2%
SD One Right Turn-One Stopped	115	0.2%
Other	105	0.1%
OD One Straight-One Stopped	104	0.1%
Angle - Both Left Turn	96	0.1%
Angle - One Straight-One Stopped	92	0.1%
One Straight-One Enter Or Leave Parking Space	76	0.1%
OD Both Left Turns	63	0.1%
SD One Left Turn-One Stopped	30	0.0%
OD One Left Turn-One Stopped	22	0.0%
Both Backing	15	0.0%
SD One Right Turn-One Left Turn	13	0.0%
One Enter Or Leave Parking Space-One Stopped	13	0.0%
OD One Straight-One Right Turn	11	0.0%
Both Entering Or Leaving A Parking Space	6	0.0%
Not Reported	2	0.0%
One Right Turn-One Enter Or Leave Parking Space	1	0.0%

Table A-10. Intersection crashes by weather conditions.

Weather Conditions	No. of Intersection Crashes	Percent
Clear	53,407	72.4%
Cloudy	14,203	19.3%
Rain	5,481	7.4%
Unknown	332	0.5%
Fog	185	0.3%
Sleet/Hail	72	0.1%
Other (Explain In Narrative)	40	0.1%
Snow	19	0.0%
Severe Crosswinds	14	0.0%
Blowing Sand/Snow	2	0.0%
Total	73,755	100.0%

Table A-11. Intersection crashes by light conditions.

Light Conditions	No. of Intersection crashes	Percent
Daylight	51,723	70.1%
Dark, Lighted	18,032	24.4%
Dark, Not Lighted	2,409	3.3%
Dusk	596	0.8%
Dawn	389	0.5%
Dark, Unknown Lighting	348	0.5%
Unknown	220	0.3%
Other (Explain In Narrative)	38	0.1%
Total	73,755	100.0%

Table A-12. Intersection crashes by traffic control device/system.

Traffic Control Device/System	No. of Intersection Crashes	Percent
Signal Light	34,123	46.3%
Stop Sign	16,166	21.9%
Marked Lanes	8,489	11.5%
None	8,236	11.2%
Yield Sign	2,703	3.7%
Center Stripe/Divider	1,805	2.4%
Other (Explain In Narrative)	1,255	1.7%
Inoperative (Explain In Narrative)	217	0.3%
Signal Light with Red Light Running Camera	178	0.2%
Crosswalk	131	0.2%
Flashing Red Light	125	0.2%
Officer	121	0.2%
Warning Sign	88	0.1%
Flashing Yellow Light	42	0.1%
No Passing Zone	31	0.0%
Flagman	23	0.0%
RR Gate/Signal	15	0.0%
Bike Lane	7	0.0%
Total	73,755	100.0%

Table A-13. Intersection crashes by road type.

Road Type	No. of Intersection Crashes	Percent
4 or More Lanes, Divided	21,574	75.0%
4 or More Lanes, Undivided	6,308	21.9%
2 Lane, 2 Way	722	2.5%
Other Road Type	145	0.5%
Total	28,749	100.0%

Table A-14. Intersection crashes by road alignment type.

Road Alignment	No. of Intersection Crashes	Percent
Straight, Level	62,531	84.8%
Straight, Grade	5,124	6.9%
Straight, Hillcrest	1,484	2.0%
Curve, Level	2,475	3.4%
Curve, Grade	1,267	1.7%
Curve, Hillcrest	360	0.5%
Other (Explain In Narrative)	349	0.5%
Unknown	165	0.2%
Total	73,755	100.0%

Table A-15. Intersection crashes by vehicle body style.

Vehicle Body Style	No. of Vehicles Involved in Intersection Crashes	Percent
Passenger Car, 4-Door	66,802	46.02%
Sport Utility Vehicle	26,753	18.43%
Pickup	19,666	13.55%
Passenger Car, 2-Door	10,130	6.98%
Unknown	6,771	4.67%
Van	5,415	3.73%
Truck	4,837	3.33%
Truck Tractor	1,695	1.17%
Motorcycle	963	0.66%
Bus	943	0.65%
Other (Explain In Narrative)	439	0.30%
Police Car/Truck	321	0.22%
Yellow School Bus	199	0.14%
Fire Truck	101	0.07%
Ambulance	96	0.07%
Police Motorcycle	7	0.00%
Farm Equipment	4	0.00%
Trailer, Semi-Trailer, Or Pole Trailer	1	0.00%
NEV-Neighborhood Electric Vehicle	1	0.00%
Total	145,144	100.00%

Table A-16. Intersection crashes by contributing factor.

Contributing Factors Description	No. of Crashes	Percent
Driver Inattention	23,930	35%
Failed To Yield Row - Turning Left	5,092	7%
Disregard Stop Sign Or Light	3,787	5%
Disregard Stop And Go Signal	3,453	5%
Failed To Yield Row - Stop Sign	3,425	5%
Followed Too Closely	3,316	5%
Failed To Control Speed	3,065	4%
Other (Explain In Narrative)	2,959	4%
Turned When Unsafe	2,267	3%
Changed Lane When Unsafe	1,888	3%
Failed To Yield Row - Open Intersection	1,852	3%
Faulty Evasive Action	1,593	2%
Failed To Stop At Proper Place	1,364	2%
Failed To Drive In Single Lane	1,086	2%
Turned Improperly - Wrong Lane	1,043	2%
Distraction In Vehicle	908	1%
Backed Without Safety	794	1%
Under Influence - Alcohol	652	1%
Disregard Turn Marks At Intersection	562	1%
Had Been Drinking	561	1%
Unsafe Speed	550	1%
Turned Improperly - Wide Right	452	1%
Failed To Yield Row - Private Drive	382	1%
Turned Improperly - Cut Corner On Left	362	1%
Failed To Yield Row - Turn On Red	296	0%
Failed To Yield Row - Yield Sign	294	0%
Pedestrian Failed To Yield ROW To Vehicle	293	0%
Failed To Yield ROW - To Pedestrian	279	0%
Fatigued Or Asleep	265	0%
Impaired Visibility (Explain In Narrative)	246	0%
Failed To Pass To Left Safely	231	0%
Ill (Explain In Narrative)	137	0%
Speeding - (Over Limit)	129	0%
Failed To Pass To Right Safely	121	0%
Animal On Road - Domestic	113	0%
Fleeing Or Evading Police	101	0%
Road Rage	98	0%
Wrong Side - Approach Or Intersection	80	0%
Passed In No Passing Lane	77	0%

Contributing Factors Description	No. of Crashes	Percent
Failed To Yield Row - Emergency Vehicle	74	0%
Drove Without Headlights	67	0%
Wrong Way - One Way Road	67	0%
Overtake And Pass Insufficient Clearance	65	0%
Failed To Give Half Of Roadway	57	0%
Animal On Road- Wild	48	0%
Oversized Vehicle Or Load	48	0%
Load Not Secured	46	0%
Disabled In Traffic Lane	41	0%
Cell/Mobile Phone Use	37	0%
Failed To Signal Or Gave Wrong Signal	35	0%
Under Influence - Drug	35	0%
Improper Start From Parked Position	25	0%
Wrong Side - Not Passing	23	0%
Passed On Right Shoulder	22	0%
Handicapped Driver (Explain In Narrative)	21	0%
Failed To Heed Warning Sign	19	0%
Parked In Traffic Lane	18	0%
Parked And Failed To Set Brakes	15	0%
Taking Medication (Explain In Narrative)	15	0%
Disregard Warning Sign At Construction	11	0%
Fire In Vehicle	6	0%
Opened Door Into Traffic Lane	2	0%
Failed To Stop For School Bus	1	0%
Subtotal	68,901	100%
No Record	70,560	51%
Total	139,461	

Table A-17. Intersection crashes by objects involved.

Description	Total No. of Intersection Crashes	Percent
Vehicle to Vehicle	71,321	96.96%
Vehicle to Train	5	0.01%
Vehicle to Pedalcyclist	852	1.16%
Vehicle to Pedestrian	1,377	1.87%
Total	73,555	100.00%

Table A-18. Details of top intersection crashes locations based on crash frequency.

Latitude	Longitude	Frequency of Crashes	Street Name	Second Street Name
29.5536	-98.6673	399	SL1604	SH0016
29.4839	-98.4032	324	IH0035	Rittiman Rd
29.4657	-98.6194	287	IH0410	Ingram Rd
29.5361	-98.6820	264	SL1604	Braun Rd
29.4342	-98.6456	249	IH0410	SH0151
29.4389	-98.4783	246	US0281	N/A
29.3983	-98.3893	236	IH0410	US0087
29.5312	-98.5622	229	IH0010	Wurzbach Rd
29.5103	-98.3978	228	IH0035	FM1976
29.4940	-98.7048	227	SL1604	FM0471
29.6091	-98.4684	218	US0281	SL1604
29.4178	-98.6496	210	IH0410	Marbach Rd
29.5447	-98.5789	203	IH0010	Huebner Rd
29.4654	-98.2922	202	IH0010	SL1604
29.4377	-98.4905	189	IH0035	Mccullough Ave
29.5633	-98.5910	180	IH0010	De Zavala Rd
29.5909	-98.5985	180	IH0010	SL1604
29.4356	-98.7109	173	FM1957	SL1604
29.4431	-98.6636	164	SH0151	FM1957
29.4389	-98.6590	163	SH0151	Ingram Rd
29.5456	-98.3691	159	IH0035	Oconnor Rd
29.5205	-98.4994	155	IH0410	San Pedro Ave
29.3566	-98.5258	154	IH0035	SL0013
29.3951	-98.4782	149	IH0037	IH0010
29.4829	-98.7103	149	SH0151	SL1604
29.5014	-98.5490	146	IH0010	IH0410
29.4131	-98.4318	143	IH0010	Martin Luther King Dr
29.3961	-98.5112	141	IH0035	IH0010
29.4964	-98.4007	140	IH0035	Eisenhauer Rd
29.4781	-98.5880	135	SS0421	Callaghan Rd
29.4425	-98.6388	133	IH0410	W Military Dr
29.4731	-98.4053	133	IH0035	IH0410
29.3819	-98.7009	130	US0090	SL1604
29.4530	-98.6301	235	IH0410	Culebra Rd
29.4653	-98.7110	127	SL1604	Wiseman Blvd
29.6369	-98.4565	120	US0281	Evans Rd
29.4297	-98.5008	119	IH0010	W Martin St
29.4941	-98.5546	116	IH0410	SL0345
29.5918	-98.3519	115	FM2252	SL1604
29.4501	-98.6849	112	SH0151	Military Dr W
29.3973	-98.6495	111	IH0410	US0090
29.4894	-98.5680	111	IH0410	Babcock Rd
29.4234	-98.3893	110	IH0410	FM1346
29.4850	-98.5933	110	IH0410	Evers Rd
29.5160	-98.4110	110	IH0410	FM2252
29.5522	-98.3554	105	IH0035	Judson Rd
29.4178	-98.6548	103	Marbach Rd	Horal Dr
29.5755	-98.5948	103	IH0010	Utsa Blvd

Latitude	Longitude	Frequency of Crashes	Street Name	Second Street Name
29.3294	-98.4159	102	IH0037	IH0410
29.4540	-98.5507	101	SS0421	N General Mcmullen Dr
29.4321	-98.5265	100	N Zarzamora St	W Martin St
29.4383	-98.4895	100	IH0035	Brooklyn Ave
29.3806	-98.6415	98	IH0410	New Valley Hi Dr
29.6008	-98.4184	97	SL1604	Bulverde Rd
29.3520	-98.4311	93	SL0013	Goliad Rd
29.5206	-98.5067	93	IH0410	FM2696
29.4597	-98.4042	91	FM0078	IH0410
29.5168	-98.4641	91	IH0410	Broadway St
29.6056	-98.6019	90	IH0010	La Cantera Pkwy
29.4551	-98.6340	89	FM1957	Culebra Rd
29.5160	-98.4523	89	IH0410	Nacogdoches Rd
29.4895	-98.5747	88	IH0410	Callaghan Rd
29.4196	-98.5280	87	Guadalupe St	S Zarzamora St
29.4780	-98.6634	87	Culebra Rd	Westover Hills Blvd
29.5205	-98.4992	85	IH0410	FM2696
29.4265	-98.5994	82	SH0151	S Callaghan Rd
29.5117	-98.5350	82	IH0410	Vance Jackson Rd
29.5332	-98.3895	82	IH0035	Thousand Oaks Dr
29.4395	-98.6412	80	IH0410	Richland Hills Dr
29.4479	-98.7110	80	SL1604	Military Dr W
29.3219	-98.4780	79	IH0410	Roosevelt Ave
29.4750	-98.6980	79	SH0151	Wiseman Blvd
29.5200	-98.4770	79	IH0410	Airport Blvd
29.5204	-98.4917	79	IH0410	Mccullough Ave
29.4799	-98.6580	78	FM0471	Timber Path
29.5045	-98.5841	78	Babcock Rd	Wurzbach Rd
29.3879	-98.5120	77	IH0035	W Theo Ave
29.4350	-98.5996	77	S Callaghan Rd	W Commerce St
29.4024	-98.6284	76	US0090	W Military Dr
29.4392	-98.5095	75	N Colorado St	W Poplar St
29.4840	-98.3718	75	Rittiman Rd	Castle Cross Dr
29.5170	-98.4835	75	E Rector St	Jones Maltsberger Rd
29.5489	-98.4884	75	US0281	E Nakoma St
29.3527	-98.4281	74	IH0037	SL0013
29.4847	-98.5350	74	IH0010	Vance Jackson Rd
29.5135	-98.5783	74	Wurzbach Rd	Floyd Curl Dr
29.5237	-98.5998	74	Huebner Rd	Babcock Rd
29.4452	-98.5250	73	SS0421	N Zarzamora St
29.5459	-98.3823	73	Oconnor Rd	N IH 35
29.4229	-98.4873	72	S Alamo St	E Market St
29.4489	-98.6902	72	Military Dr W	N Ellison Dr
29.5871	-98.6315	72	SL1604	Babcock Rd
29.3688	-98.4960	70	S FLORES ST	E Southcross Blvd
29.6667	-98.6317	70	IH0010	Boerne Stage Rd
29.3517	-98.4351	69	SL0013	City Base Lndg
29.3819	-98.7009	69	US0090	SL1604
29.4358	-98.3901	69	IH0010	IH0410

Latitude	Longitude	Frequency of Crashes	Street Name	Second Street Name
29.5308	-98.5625	69	Mcdermott Fwy	Wurzbach Rd
29.6088	-98.4928	69	SL1604	Stone Oak Pkwy
29.3555	-98.4812	68	SL0013	SS0536
29.4293	-98.4945	68	W Martin St	N Flores St
29.3423	-98.5532	67	IH0035	Poteet Jourdanton Fwy
29.4024	-98.6284	67	US0090	W Military Dr
29.5283	-98.4838	67	US0281	Jones Maltsberger Rd
29.4162	-98.5559	66	Castroville Rd	S General Mcmullen Dr

Table A-19. Details of crash rates for the high-volume crash intersections.

Latitude	Longitude	No. of Crashes	Intersection	AADT (2015)	2% Growth	No. of Vehicles	Crash Rate
29.3983	-98.3893	236	Rigsby Ave & SE Loop 410	23,092	23,554	11,777	10.98
29.4657	-98.6194	287	Ingram Rd & NW Loop 410 Access Rd	35,223	35,928	17,964	8.75
29.4234	-98.3893	110	E Houston St & SE Loop 410	13,789	14,065	7,032	8.57
29.5536	-98.6673	399	Bandera Rd & W Loop 1604 N	50,453	51,462	25,731	8.50
29.5361	-98.6820	264	Braun Rd & W Loop 1604 N	43,962	44,841	22,421	6.45
29.4321	-98.5265	100	N Zarzamora St & W Martin St	21,735	22,169	11,085	4.94
29.4530	-98.6301	235	Culebra Rd & NW Loop 410	52,388	53.436	26,718	4.82
29.4540	-98.5507	101	Bandera Rd & N General Mcmullen	25,010	25,510	12,755	4.34
29.4178	-98.6496	210	Marbach Rd & SW Loop 410	55,003	56,103	28,052	4.10
29.4431	-98.6636	164	Potranco Rd & State Hwy 151 & State Hwy 151 Access Rd	46,686	47,619	23,810	3.77
29.4781	-98.5880	135	Bandera Rd & Callaghan Rd	39,845	406,412	20,321	3.64
29.4829	-98.7103	149	State Hwy 151 & W Loop 1604 N	44,336	45,223	22,611	3.61
29.4940	-98.7048	227	Culebra Rd & W Loop 1604 N	67,656	69,009	34,505	3.60
29.4501	-98.6849	112	State Hwy 151 & W Military Dr	33,669	34,342	17,171	3.57
29.4131	-98.4318	143	IH 10 E & Martin Luther King Dr	43,026	43,887	21,943	3.57
29.6091	-98.4684	218	N Loop 1604 E & US Hwy 281 N	78,061	79,622	39,811	3.00

Latitude	Longitude	No. of Crashes	Intersection	AADT (2015)	2% Growth	No. of Vehicles	Crash Rate
29.4356	-98.7109	173	Potranco Rd & W Loop 1604 N	63,608	64,880	32,440	2.92
29.4653	-98.7110	127	W Loop 1604 N & Wiseman Blvd	49,328	50,315	25,157	2.77
29.4178	-98.6548	103	Horal Dr & Marbach Rd	40,752	41,567	207,814	2.72
29.5312	-98.5622	229	IH 10 W & Wurzbach Rd	97,252	99,197	49,599	2.53
29.5160	-98.4110	110	NE Loop 410 & Perrin Beitel	49,037	50,018	25,009	2.41
29.4389	-98.6590	163	Ingram Rd & State Hwy 151	83,345	85,012	42,506	2.10
29.3819	-98.7009	130	US Hwy 90 W & W Loop 1604 S	67,749	69,104	34,552	2.06
29.4839	-98.4032	324	IH 35 N & Rittiman Rd	187,333	191,080	95,540	1.86
29.3566	-98.5258	154	IH 35 S & SW Military Dr	98,871	100,848	50,424	1.67
29.6369	-98.4565	120	E Evans Rd & US Hwy 281 N	87,924	89,683	44,841	1.47
29.4389	-98.4783	246	Broadway & IH 35 N	189,181	192,965	96,482	1.40
29.5103	-98.3978	228	IH 35 N & Walzem Rd	185,449	189,158	94,579	1.32
29.4342	-98.6456	249	State Hwy 151 & SwWLoop 410	203,729	207,804	103,902	1.31
29.4425	-98.6388	133	NW Loop 410 & W Military Dr	110,550	112,761	56,381	1.29
29.4297	-98.5008	119	IH 10 W & W Martin St	104,914	107,012	53,506	1.22
29.5918	-98.3519	115	N Loop 1604 W & Nacogdoches Rd	102,528	104,579	52,289	1.21
29.5633	-98.5910	180	De Zavala Rd & IH 10 W	169,826	173,223	86,611	1.14
29.5447	-98.5789	203	Huebner Rd & IH 10 W	195,741	199,656	99,828	1.11
29.4377	-98.4905	189	IH 35 N & Mccullough Ave	192,790	196,645	98,323	1.05
29.5909	-98.5985	180	IH 10 W & N Loop 1604 W	188,199	191,962	95,981	1.03
29.3973	-98.6495	111	SW Loop 410 & US Hwy 90 W	120,393	122,801	61,400	0.99
29.4654	-98.2922	202	E Loop 1604 N & IH 10 E	247,339	252,285	126,143	0.88
29.5522	-98.3554	105	IH 35 N & Judson Rd	130,643	133,256	66628	0.86
29.3294	-98.4159	102	IH 37 S & Se Loop 410	130,992	133,612	66,806	0.84

Latitude	Longitude	No. of Crashes	Intersection	AADT (2015)	2% Growth	No. of Vehicles	Crash Rate
29.4964	-98.4007	140	Eisenhauer Rd & IH 35 N	185,022	188,722	94,361	0.81
29.5456	-98.3691	159	IH 35 N & Oconnor Rd	218,833	223,210	111,605	0.78
29.4894	-98.5680	111	Babcock Rd & NW Loop 410	164,172	167,455	83,728	0.73
29.3951	-98.4782	149	IH 10 E & IH 37 S	227,708	232,262	116,131	0.70
29.5755	-98.5948	103	IH 10 W & UTSA Blvd	158,611	161,783	80,892	0.70
29.3961	-98.5112	141	IH 10 E Access Rd & IH 35 S Access Rd	227,558	232,109	116,055	0.67
29.5205	-98.4994	155	NW Loop 410 & San Pedro Ave	273,044	278,505	139,252	0.61
29.4383	-98.4895	100	Brooklyn Ave & IH 35 N	177,174	180,717	90,359	0.61
29.4850	-98.5933	110	Evers Rd & NW Loop 410	198,959	202,938	101,469	0.59
29.4941	-98.5546	116	Fredericksburg Rd & NW Loop 410	250,554	255,565	127783	0.50
29.4731	-98.4053	133	IH 35 N & NE Loop 410	314,769	321,064	160,532	0.45
29.5014	-98.5490	146	IH 10 W & NW Loop 410	459,590	468,782	234,391	0.34

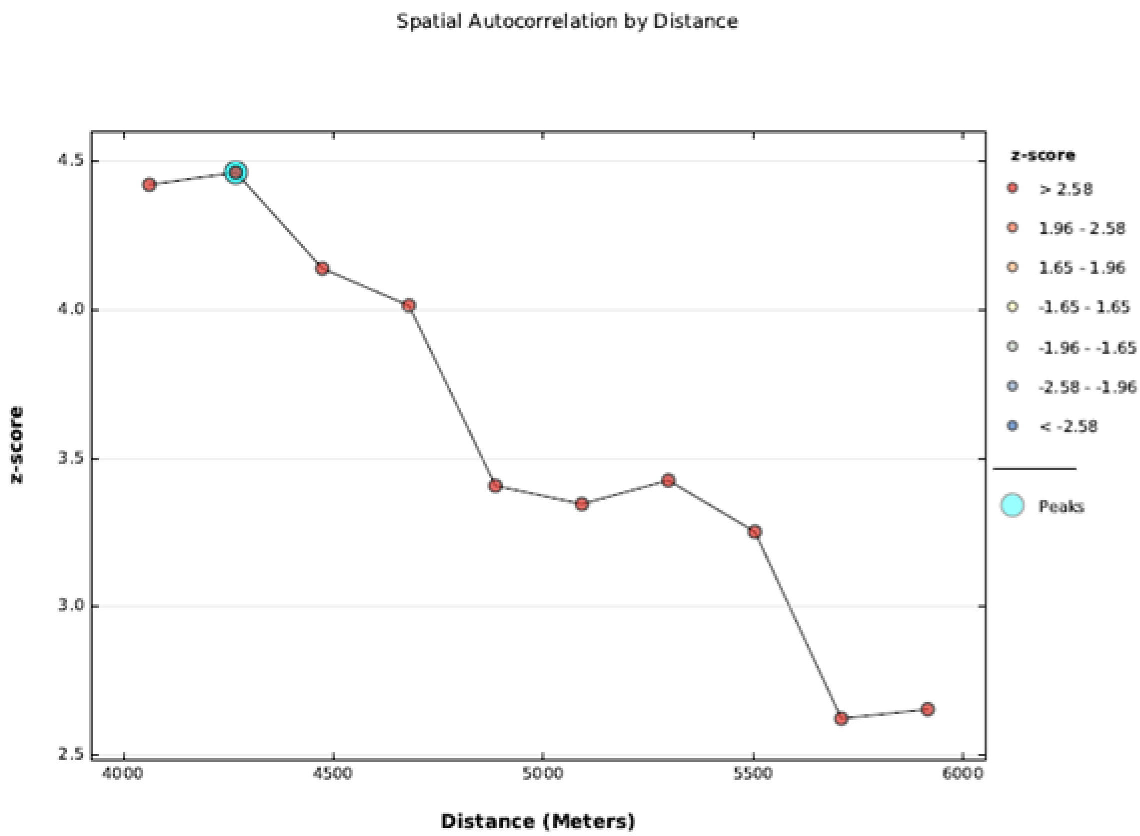

Figure A-1. Spatial autocorrelation for hotspot analysis for all intersection crashes.

Table

Hotspot Intersections

OBJECTID *	Shape *	SOURCE_ID	ICOUNT	GiZScore Fixed 4250	GiPValue Fixed 4250	NNeighbors Fixed 4250	Gi_Bin Fixed 4250
206	Point	206	1	3.001395	0.002687	139	3
207	Point	207	140	2.779796	0.005439	148	3
209	Point	209	30	2.883143	0.003937	184	3
215	Point	215	2	2.775406	0.005513	217	3
218	Point	218	1	2.725353	0.006423	266	3
219	Point	219	69	2.982872	0.002856	261	3
220	Point	220	4	2.872918	0.004067	267	3
221	Point	221	3	3.031622	0.002432	273	3
230	Point	230	1	3.167188	0.001539	233	3
2357	Point	2357	12	0.963673	0.33521	193	0
2358	Point	2358	2	0.902531	0.366775	211	0
2359	Point	2359	10	0.750892	0.452718	215	0
2360	Point	2360	5	1.005101	0.314848	12	0
2361	Point	2361	3	0.864158	0.387501	14	0
2362	Point	2362	1	0.864158	0.387501	14	0
2363	Point	2363	5	1.038325	0.299119	15	0
2364	Point	2364	11	0.932841	0.350902	16	0
2365	Point	2365	34	1.13132	0.257921	21	0
2367	Point	2367	1	1.162226	0.245144	11	0
2368	Point	2368	1	0.536136	0.591865	203	0
2369	Point	2369	1	0.424819	0.670969	211	0
2370	Point	2370	1	0.706925	0.479613	212	0
5403	Point	5403	3	-2.963611	0.003041	580	-3
5404	Point	5404	7	-2.674306	0.007488	564	-3
5405	Point	5405	7	-2.807266	0.004996	576	-3
5408	Point	5408	16	-2.667641	0.007639	552	-3
5410	Point	5410	2	-2.691267	0.007118	548	-3
6362	Point	6362	1	-2.767515	0.005649	259	-3
6363	Point	6363	1	-2.75502	0.005869	263	-3
6364	Point	6364	1	-2.635708	0.008396	257	-3
6365	Point	6365	3	-2.788979	0.005287	264	-3
6367	Point	6367	2	-2.630892	0.008516	265	-3

Figure A-2. Output feature class of hotspot analysis.

Table A-20. Incremental autocorrelation parameters.

Parameter Name	Input Value
Input Features	Collective points
Input Field	ICOUNT
Number of Distance Bands	10
Beginning Distance	4062.000000
Distance Increment	205.940591
Distance Method	EUCLIDEAN
Row Standardization	True
Section Set	False