CRASH COLISION ANALYSIS: EVALUATING ROAD SAFETY IN AUSTIN,

TEXAS 2014- 2016

by

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DEDICATION

For my late father who taught me to always keep moving forward. My entire academic career would not have been possible without the sacrifices you and mom made.

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LIST OF ABBREVIATIONS

Abbreviation	**Description**
TXDoT	Texas Department of Transportation
MSA	Metropolitan Statistical Area
MP/H	Miles per hour
SSBAT	Sustainable Safety Bike Audit Tool
STAC	Space and Temporal Analysis of Crime
PDI	Pedestrian Danger Index
ETC	Et Cetera

ABSTRACT

The purpose of this study is to determine road safety in Austin, Texas using detailed crash data and spatial analysis to identify statistically significant areas with high rates of pedestrian or cyclist collisions. This research uses a mixed-methods approach and applies the Sustainably Safe Dutch framework to road safety in Austin, Texas from 2014 through 2016. First, the study looks at demographic and descriptive crash collision data. Second, this research performs a Space and Temporal Analysis of Crime (STAC) analysis on collisions in Austin to determine the areas with the densest clusters of pedestrian and cyclist collisions. Finally, a policy analysis is conducted looking at characteristics in the built environment that impact the likelihood of future pedestrian or cyclist collisions, ending with policy recommendations to improving active transportation infrastructure.

1. INTRODUCTION

In recent years, the number of fatal car crashes, roadway fatalities, and pedestrian fatalities has steadily increased (National Highway Traffic Safety Administration 2017). In 2015, the national roadway fatality rates saw their first increase in deaths in nearly three years: 35,486 people lost their lives on U.S. roadways in 2015, compared to 37,461 people in 2016, a 5.6% increase (National Highway Traffic Safety Administration 2017). High-speed city streets commonly weave in and out of tight urban areas, which is a hazard for motorists, cyclists, and pedestrians. Indeed, the results of such road configurations often include roadway fatalities, increased congestion, and increased air pollution. Twenty-seven percent of the carbon emissions in the U.S. are attributed to the transportation sector, with infrastructure costs topping $295 billion in 2016 (Environmental Protection Agency, 2017: Cookson & Pishue, 2017).

This research uses a mixed-methods approach for analyzing road safety in Austin, Texas first with a hot spot analysis and then by examining the selected corridor in its built environment. The Austin, Texas hot spot analysis provide fourteen intersections and blocks that have statistically significant densities of pedestrian collisions. This results from the spatial study suggest that it is highly unlikely that these collisions clusters are merely a result of chance. Instead, this research asserts that roadway design facilitating high-speeds, extensive, multiple lane roadway facilities, poorly design pedestrian crosswalks, and other social factors exacerbate these dense pedestrian crash clusters in Austin, Texas.

The first portion of this paper is a literature review that discusses relevant literature to provide a current and historical context of road safety in America. The second portion reviews methodologies and findings of the spatial analysis. The research begins with a review of detailed crash data from 2014 to 2016 for Austin, Texas. Second, a spatial "Hot Spot" analysis of pedestrian and cyclist collisions in Austin. Finally, the research will draw on the Dutch Sustainable Safety Vision—a scientific and systematic approach to promoting road safety and preventing severe injuries or fatalities on roadways—to interpret the key statistical analyses. Specifically, two locations that were statistically significant collision clusters from the "Hot Spot" analysis will be discussed at the end of this research. Previous rash collision analyses have been done in the New Orleans, Louisiana by the Pedestrian Bike Resource Initiative, and the University of New Orleans (2012).

The remainder of this thesis is organized as follows. The next section reviews relevant literature and methods. From there, collected crash collision data will demonstrate the scope of severe road injuries and fatalities all road users. Then the paper will look at how the built environment and transportation networks impact one another and a historical overview of early U.S. urban planning policies. The literature review will conclude with a discussion of two road safety policies, Sweden's Vision Zero and the Netherlands Sustainable Safety Vision. Finally, methods section will discuss the methods and proposed steps of this crash data beginning with the statistical and spatial analysis and ending in the discussion of two tools that utilize Sustainable Safety principals which help to determine the "function, homogeneity, forgiveness, and awareness" of the given road segment (Wegman, et al. 2006, 13). The proposed research will examine collision data in Austin, Texas from 2014- 2016 to analyze road safety patterns and trends, with the goal of providing policy recommendations that encourage the implementation of safe and sustainable transportation.

2. LITERATURE REVIEW

This section begins with a review of the literature on vulnerable road users and why such users are an essential part of the road safety discussion. Following a discussion of vulnerable road users, the literature review will provide an overview of road safety statistics in the United States, Texas, and Texas's major metropolitan region. The purpose of the statistical evaluation of crash collision data is to impart to the reader the inherent flaw and safety hazards in current federal, regional, and local U.S. transportation policies.

After discussing the risks associated in current U.S. and Texan roadways, this literature review will examine the relationship between the built environment and transportation networks. This portion of the evaluation will include a brief historical summary of early modern U.S. planners and philosophies. The review looks at the relationship between historical transportation planning practices and land use patterns established during the mid-twentieth century. This review will preface the review of the road safety policies Vision Zero and Sustainable Safety.

Finally, the literature review examines two Safe Systems approaches, Vision Zero and the Sustainable Safety Vision. The primary framework focus for this research is the Dutch Sustainable Safety Vision of road safety. However, a brief overview of Sweden's Vision Zero will be discussed first. This brief overview is due in part to Sweden’s Vision Zero being the first national road safety policy ever implemented and because it is often credited as being the first road safety policy (Welle, Sharpin, et al. 2018, Belin, Tillgren and Vedung 2012). The ending portion of this literature review will examine Dutch Sustainable Safety and its scientific and systematic approach to reducing the number of road fatalities and severe injuries on roadways daily.

Vulnerable Road Users

This research aims to conduct crash collision analysis for all road users; however, a defense of why the pedestrian is particularly vulnerable in traffic is required. The following section will discuss the reasons for focusing on these vulnerable road users. High pedestrian fatality rates in communities suggest that their designs lack safe and accessible facilities for pedestrians and have high- speed, mono-modal transportation networks that endanger all road users. This transportation system places zero responsibility on the most significant and most dominant mode it caters to; instead, responsibility for road safety is placed on the most vulnerable of users, pedestrians, and cyclists (Wegman, et al. 2006).

Pedestrians and cyclists are, biologically, the most vulnerable participants in traffic because of the kinetic energy produced upon collision of two differential masses where one is traveling at a higher velocity and mass (Jacobsen and Rutter 2012). In the case of an automobile colliding with a pedestrian or cyclist, speeds above 30 kilometers per hour (km/h) or about 20 miles per hour (mp/h), increase the risk of severe road injury or fatality on the pedestrian (Jacobsen and Rutter 2012, Wegman, et al. 2006). High-speed urban corridors, therefore, automatically impose a real and perceived danger to pedestrians and cyclists, if not provided with safe and physically separate facilities for their use (Wegman, et al. 2006).

Among the 35,000 plus people killed in the U.S. last year, pedestrians and cyclists are consistently the two most vulnerable road users, by mode, that are disproportionately impacted by roadways fatalities (ITF 2017, Smart Growth America 2017). In a report, released by the U.S. Department of Transportation (USDoT), data showed that pedacyclist fatalities increased by 12.2% from 2014, but only compromised 0.6% of the U.S. mode share that year (National Highway Traffic Safety Administration 2017). Similarly, pedestrian fatalities increased 9%, but represented just 2.8% of modal share- the mode share jumps to 8% if public transit users are counted in the number (NHTSA 2017).

The road dangers imposed on pedestrians and cyclists are, often, the same deterrents to walking or cycling to work, class, or recreational activities, research has found (Pucher, et al. 2012). Simply put, most people see the risk of severe roadway injuries or fatality as too high a risk to walk or cycle for daily activities or as a primary means of transportation. The risk of severe injury or death resulting in a collision is present, always, whether the road user is a pedestrian or cyclist. The hazards and inherent flaws in the traffic system are not caused by the pedestrian or cyclist, but rather the design of our urban cores and peripheries, the lack of responsibility placed on all road users, and high-speed corridors explicitly designed for the automobile.

The risks associated with walking or cycling are connected to high- speed roads that force pedestrian or cyclists to participate in traffic without reduced speeds or physical buffers between road users (Furth, 2012: Wegman, Aarts, & Bax, 2006). In fact, high- speeds and poorly designed roads, intersections, and urban corridors are linked to higher risks of pedestrian and cyclist fatalities (Jacobsen and Rutter 2012). While some U.S. states and cities have established their version of a Safe Systems approach to their roads, data and research have demonstrated that current road safety standards in the U.S. appear to be less than adequate and has one of the highest rates of roadway fatalities among developed countries (ITF 2017).

Road Safety Data: United States

American roads are inherently unsafe. In fact, road related fatalities and collisions are so common and expected that they are described as an "accident" or a mistake made at the wrong place and wrong time. Most crashes and fatalities that occur on roadways, and in our communities, are preventable. What makes roads dangerous is their design.

In 2015, traffic fatalities were, again, the number four leading cause of all deaths in the U.S.- responsible for 5.4% of all fatalities (National Center for Health Statistics 2017). Further data reveals that, in 2015, traffic-related injuries were the number one leading cause of death for people ages 1 to 44 years old (National Center for Health Statistics 2017). In the United States, traffic-related fatalities have consistently been one of the five leading causes of death, seeing only a brief respite in the mid- 1990s until 2015 (National Center for Health Statistics 2017).

Road Safety in Texas And Metropolitan Regions

On a global scale, the U.S. has the highest rate of road-related fatalities, but, when analyzing collision data regionally, the Southern U.S. has the highest portion of pedestrian fatalities than any other region (Smart Growth America 2017). Among the 50 states and the District of Colombia, Texas ranked 9th, behind Delaware, as the worst state to walk in for 2016, of the top ten, nine were located in the south and only one in the northern U.S. (Smart Growth America 2017). The remaining portion of this section will turn its attention to the state of Texas and its major metropolitan areas.

In 2016, there were a total of 631,270 collisions on Texas roads; 3,480 of crashes reported resulted in at least one roadway related fatality, resulting in 9,330 people killed on Texas roadways (Texas Department of Transportation 2017). When averaged out, that is 26 people daily in Texas alone; furthermore, a report found that Texas had an increase of 3.6% on the pedestrian danger index (PDI) from 2014 to 2016 (Smart Growth America 2017). The PDI is calculated by taking the mode share of people that commute to work as a pedestrian, compared to the percent of pedestrian fatalities in that given location- the higher the PDI, the more dangerous it is to walk in that community (Smart Growth America 2017).

Walkability of Urban Regions in Texas

The Smart Growth America report found that five of Texas's most significant urban areas ranked above the national average as one of the worst places in the U.S. to be a pedestrian; on the high end is Cape Coral-Fort Myers, Florida, with a PDI of 283.1, and a national average of 53.8 on the PDI scale (Dangerous by Design 2016 2017). Among the twenty worst metro regions in the U.S. to walk, Houston- Woodlands-Sugar Land ranked 15th and McAllen- Edinburg- Mission 20th, with the remaining four most populous Texas metropolitan regions, Dallas- Fort Worth- Arlington (DFW) ranked 25th; San Antonio- New Braunfels ranked 28th, El Paso ranked 39th, and Austin- Round Rock ranked 47th on a national scale, examining 104 metropolitan regions in the U.S. (Smart Growth America 2017, Texas Demographic Center 2017).

This research pays attention to Austin- Round Rock's PDI of 77.8 (Smart Growth America 2017). While this was the lowest ranking of any major metropolitan region in the state of Texas, 77.8 is still well above the national average of 53.8 for pedestrian fatalities with a relatively small mode share of pedestrians (Smart Growth America 2017). However, the data provided to this review from Smart Growth America, while contributive, is merely a portion of pedestrians commuting to work, these numbers do not consider pedestrians in any other sense. A more accurate mode share count must be conducted to assess not only the walkability but the overall safety of Austin, Texas.

Fatalities in Texas, 2016, By Road Classification

According to the Texas Department of Transportation collision data, in 2016, 39% of deaths occurred on U.S. and state highways within Texas, 18% interstate roads, 17% farm to market roads, 16% city streets, 6% county roads, and 1.6% non-traffic roadways; the remaining 2.4% occurred on "other" roads and tollways (Texas Department of Transportation 2017). Incapacitating injuries or, severe injuries, in Texas by road class, however, show that the second most common roads for collisions are city streets, with 27% (Texas Department of Transportation 2017). The number one road class for a severe injury, 2016, in Texas were the US and state highways representing just 33% of severe collisions by road class (Texas Department of Transportation 2017).

This research is specifically interested in Austin, Texas, the capital and one of the states' larger urban areas by demographics and net migration. For one, the modern freeway dismantled the urban fabric of early- modern America, by placing highways through the heart of the urban core, disrupting urban environments and communities that had existed for decades (Brown, Morris and Taylor 2009). Additionally, urban sprawl is typical throughout most of the U.S., but the Southern U.S. was sold as the "American Dream" up until just recently, in Texas. The correlation between the U.S. highway and urban planning will be explored further in the next section. However particular interest should be given to the role of the highway in the urban core in future research, especially in Southcentral Texas along the IH-35 corridor.

Road Design and The Built Environment: A Symbiotic Relationship

Where we live, work, and congregate have direct impacts on who we are; and, the same is valid for how we travel. In Jan Gehl's book, *Life Between Spaces*, he states that the car's impact on the large city is "dispersive of people and events" if the built environment is tailored to its use (1971, 85). Gehl stated that by altering the needs of the community- government services, recreational and retail facilities, housing, and industry- to accommodate our mode of transportation, space reflects that; instead of a living community, the dependence on the car in the built environment dispersed both the community and their needs (1971).

Moderate scale dispersion occurs in single-family subdivisions and “functionalistic, detached” apartment buildings (Gehl 1971, 85). The general land use pattern common among these two moderate dispersal techniques is that while they share connectivity to the built environment around them, the buildings or spaces that surround them are empty or non-functional in the community they reside (Gehl 1971). Today, moderate scale dispersion communities can be seen both on the exterior and the interior of the urban periphery, spreading car dependence like virulent bacteria.

Jan Gehl's work explicitly stated that urban sprawl was the problem facing communities in the 1970s. What is most interesting concerning Ghel's work was he was able to point to the root of the issue which was that most urban transportation policies retrofit the city and its people to the needs of the automobile. What Gehl had observed were the U.S. transportation policies of the twentieth century. The urban planning policies of the early twentieth century shaped much of the built urban environment of American cities and will be reviewed in the following section.

Before World War I, in the U.S., the personal automobile was a symbol of the elite; due, in part, to the cost and upkeep of the car and that paved roads for cars were not common at this time (Brown, Morris and Taylor 2009). The automobile did not become a favorite mode of transportation until the 1920s when American urban planners viewed the car to stimulate the economy of cities (Brown, Morris and Taylor 2009). From the onset of America's mobility culture, planners sought to create linkages within the city, to create a uniform, hierarchical structure of road networks that could disperse traffic through residential neighborhoods and build systems that support various modes of transportation (Brown, Morris and Taylor 2009). The decision to make the automobile the official mode of transportation altered the urban footprint of cities everywhere and continues to do so to this day.

By the mid to late 1920s, Ford's assembly line production of the Model T and affordability helped the automobile's popularity skyrocket. The high volumes of drivers on American roadways brought congestion, high-speeds, and overall lawlessness into the urban corridors of the city (Brown, Morris and Taylor 2009). Registered motor vehicle data shows the chaos that would have taken place on American roadways; for instance, in 1925 there were 20.1 million cars were registered, however, by 1929 the number of registered vehicles shot to 26.7 million (Brown, Morris and Taylor 2009). The chaos of the automobile in the city led to the implementation of traffic codes, pedestrian islands, and the stop sign to help regulate traffic and protect motorists and pedestrians (Brown, Morris and Taylor 2009). The traffic and safety laws of early modern America were soon to change, however, as the urban and rural demographics began to shift, post-World War

II. This notable demographic shift from the city to the newly built suburbs was, in part, facilitated by American planners of the twentieth century.

In 1947, in Los Angeles, the first modern freeway was introduced to allow for larger volumes of cars to travel greater distances at higher speeds than currently permitted in the city (Brown, Morris and Taylor 2009). The invention of the limited access modern freeway was praised as being the solution to the city's congestion, and construction began in 1950 (Brown, Morris and Taylor 2009). The 1950s ushered in Eisenhower's Interstate era and, with it, Federal funding and transportation policies that established the modern freeway system in America (Brown, Morris and Taylor 2009). During this time in American transportation, freeways were constructed as a way to connect all of the U.S. however, the vast, concrete roadways built would segregate communities and the built environment for decades to come (Brown, Morris and Taylor 2009).

Historically, U.S. transportation policies could best be described as disorganized, chaotic, and unsafe. In fact, the solution of the modern freeway only further encouraged mobility as it dispersed community goods and services farther away from the urban core. The contemporary highway made matters worse, was built in a systematic, mathematical approach that intentionally carved up existing communities, segregated neighborhoods, redirected growth in urban areas, and dismantled vibrant, cultural centers (Brown, Morris and Taylor 2009).

Robert Moses is an excellent example of how transportation planners purposefully dismantled the urban core of New York City during the twentieth century. One of Moses's more famous projects was to "revitalize" Washington Square Park, and in doing so attempted to displace 22,000 family homes in Greenwich Village Park (Flint 2009). Initially, Moses's goal was to stop middle-class families from leaving the city and sought to eliminate public transportation through the construction of limited access freeways (Flint 2009). As suburban migration continued though, Robert Moses began to view the urban core as overcrowded and diseased; because of this, Moses turned his attention to creating a network of broad concrete highways in and out of New York City to provide suburban residents direct access to portions of the urban core (Flint 2009).

As discussed earlier in this section, place affects people, or, the places we live reflect the people of that community. So, when urban planners built the American city for the car, naturally, the car dominated the urban landscape. In the century since the advent of the automobile, U.S. transportation policies have yet to adequately address or reverse the dangerous and dysfunctional planning practices established from mobility culture. Across the globe, however, there have been transportation policies proposed to address road-related fatalities. In the next section, Sweden's Vision Zero and Dutch Sustainable Safety will be reviewed.

Road Safety Policies

Both Sweden and the Netherlands have developed scientific and systematic approaches to addressing severe injuries or fatalities on the roadway (Welle, Sharpin, et al. 2018). Starting in the early 1990s, Sweden's Vision Zero and the Netherlands' Sustainable Safety Vision integrated motorists and vulnerable road users with the concept of shared road responsibility to create homogeneous, multi-modal transportation networks that proactively prevent severe roadways injury or fatality (Welle, Sharpin, et al. 2018, Wegman, et al. 2006). Both, Sweden’s Vision Zero and the Dutch Sustainable

Safety policies are a part of the “Safe System” approach, a policy field which focuses on reducing roadway fatalities and severe injuries, while creating walkable, safe roadways and communities for all (Welle, Sharpin, et al. 2018).

Road safety is a global issue with an estimated 1.25 million deaths per year and impacting low or middle- income countries most (World Health Organization 2015, Welle, Sharpin, et al. 2018). However, road safety policies that seek to reduce the number of severe injuries or fatalities on roadways have been employed by countries like Sweden and the Netherlands since the 1990s (Welle, Liu, et al. 2015). Vision Zero and Dutch Sustainable Safety are both policies that fall under the Safe System approach; the Safe Systems approach seeks to form a dynamic transportation system that integrates all road users in a safe and sustainable environment (Welle, Liu, et al. 2015). For this research, Sweden's Vision Zero will be looked at first, with the remainder of the section focusing on Dutch Sustainable Safety.

Vision Zero: Sweden’s Guide to Zero Road Deaths

Sweden has one of the best road safety records globally with 2.7 out of 100,000 deaths being caused by roadway fatalities- for comparison, the U.S in 2016 had a death rate of 11.6 per 100,000 people (Welle, Sharpin, et al. 2018, Insurance Institute for Highway Safety Highway Loss Data Institute 2017, ITF 2017). It is worth noting that Sweden's fatality rates have increased 4% since 2014; in 2016, there were a total of 270 traffic-related fatalities nationally, which is an increase of 11 persons from 2015 (ITF 2017). By U.S. standards, Sweden's road fatality rates look more similar to fatality rates of pedestrians in urban areas, and this is due to Sweden's innovative scientific and systematic approach to road safety, Vision Zero (Belin, Tillgren and Vedung 2012, Welle, Liu, et al. 2015).

First and foremost, Vision Zero's policy approach to traffic regulation is the proactive protection of all road users, accomplished through design standards built so that the most vulnerable road user in traffic would be able to avoid fatality or severe injury (Belin, Tillgren and Vedung 2012). Traffic safety regulations and road designs built for the vulnerable road user act as a "safety net" in the built environment (Wegman, et al. 2006). The safety net anticipates human behaviors and errors so that in the event of a collision the result is not severe injury or fatal for either colliding body (Belin, Tillgren and Vedung 2012, Welle, Sharpin, et al. 2018, Jacobsen and Rutter 2012). To accomplish this goal, Sweden shifted its traditional view of traffic fatalities and their causes. This approach led to policy measures that focused on preventing severe or fatal road collisions through reduced speeds, roadway design, and the concept of shared road responsibility (Belin, Tillgren and Vedung 2012).

Shared responsibility in Vision Zero asserts that all who participate in traffic play an active role in road safety. The individual road user has an obligation to obey traffic laws and exercise discretion in traffic and the government or "system designer" shares responsibility with the road user to prevent serious injuries or fatalities on roads, maintain proper road design and infrastructure, and improve designs of roadways in the event of severe injury or deat (Belin, Tillgren and Vedung 2012). Sweden's Vision Zero established a framework for a scientific and systematic approach to providing safe roadways through preventative road design solutions (Welle, Sharpin, et al. 2018, Belin, Tillgren and Vedung 2012). The review of Vision Zero establishes both a timeline and context for the Netherlands Sustainable Safety framework. Vision Zero and Dutch Sustainable are both examples of a safe systems approach for road safety. In the next section, this research will turn its focus to the Dutch Sustainable Safety policy which this research utilizes as its guide for policy recommendations.

Dutch Sustainable Safety

The Netherlands has one of the safest road networks in the world due to its road safety systems approach, Sustainable Safety. With a road fatality rate of 3.67 per 100,000 people in 2016 and an astonishing 47% decrease in the number of roads fatalities since 2000, the Netherlands focuses on protecting the safety of its road users (ITF 2017). Low numbers of roadway-related deaths can be attributed to Sustainable Safety's road network that has low- speed neighborhood streets and physically separate facilities, so that all modes of traffic can participate together in the road network (Wegman, et al. 2006). Additionally, in the event of a collision, severe or fatal is all but excluded because of a network of roadways that anticipate human error by providing a “forgiving” road environment to its users (Wegman, et al. 2006).

Sustainable Safety’s objective, which is to, “prevent road crashes from happening and where not feasible, reduce the incidence of severe injuries whenever possible” (Wegman, et al. 2006, 13). The prevention of severe and fatal road collisions requires the policy to address what causes fatal or serious injuries in collisions. First, Sustainable Safety understands that humans have limited cognitive and physical capabilities and that errors are a common part of being human (Wegman, et al. 2006). This understanding meant that for Sustainable Safety to reduce fatal roadway collisions through infrastructure road design must depend on the individual user “as little as possible”

(Wegman, et al. 2006, 13). In this way, Sustainable Safety shares the responsibility of road safety between road users, designers, and other key stakeholders in the implementation and maintenance of roadways (Wegman, et al. 2006).

Creators of Sustainable Safety provide a five principal approach to implementing Sustainable Safety, they are: 1) functionality of roads ordered in a hierarchical, structured road network; 2) homogeneity of speed, direction, and mass at medium and high speeds; 3) forgiveness of the road and road users, where forgiving street design anticipates and prevents serious injury; 4) predictability of road course and road designs should be consistent and should support road user expectation; and 5) state awareness of the road user (Wegman, et al. 2006). Each principal of Sustainable Safety relates to the other, for instance, functional roadways are dependent on the homogeneity of speed, direction, or mass, predictable road courses, and forgiving roads that anticipate error (Wegman, et al. 2006). In this way, Dutch Sustainable Safety protects the vulnerable road user by creating "generic measures" so that the road course meets the road user's expectations (Wegman, et al. 2006).

Most essential to Dutch Sustainable Safety policy framework is the management of high speeds since high speeds are more likely to increase the risk of severe injury or fatality on roads (Wegman, et al. 2006). Speed becomes a detrimental factor in collisions when differences in mass, velocity, and direction are too high; pairing the physical vulnerabilities of humans with the mass of an automobile, speed then becomes the determining factor of the severity of collision (Wegman, et al. 2006). Data suggest that speeds above 20 mp/h increase the risk of severe or fatal injury to pedestrian or cyclists because of differences in mass, speed, and direction (Jacobsen and Rutter 2012). For example, a two-ton vehicle moving at 30 mp/h has 200 times more kinetic energy than that of a 187-pound male (Jacobsen and Rutter 2012).

In the Netherlands Sustainable Safety Vision framework, all roads lead back to speed management. Reasons being the inherent risks associated with high speeds on roadways, to reduce the speeds traveled by road users, Sustainable Safety enforces slow speeds through a "constant" and "continuous" road network to reinforce driver behavior and increase state awareness (Wegman, et al. 2006, 14). These “constant” and “continuous” roads are designed according to their roadway function (Wegman, et al. 2006, 14). Functions of the roadway and class, in the Dutch model, determine the speed of that roadway, creating a homogenous, predictable road network that meets and anticipates all road user’s actions (Wegman, et al. 2006).

Road Class is determined by its location and the actual purpose of the corridor or segment. For instance, dense urban cores in large cities tend to have higher shares of pedestrians and risk of collision (Wegman, et al. 2006). In the Dutch Sustainable Safety model, however, the urban core would consist of a network of low- speed streets with a speed limit of about 20 mp/h to reduce injury risk (Wegman, et al. 2006). In areas where vulnerable road users and automobiles mix at high- speeds, physically separate facilities are designed to protect pedestrians or cyclists from severe injury or fatality (Wegman, et al. 2006). To keep safe road infrastructure simple, the Sustainable Safety framework categorizes road functions by speed in four categories: 30 km/h roads, where conflicts between cars and road users are possible, but pose a sustainably lower risk of serious injury; 50 km/h intersections where potential tensions in the built environment arise between cars; 70 km/h where strains and risk of severe injury between motorists increase;

and 100 km/h or above where there are no roads that do not increase the risk of severe injury (Wegman, et al. 2006).

Once road class is determined and speed assigned to the road segment, the Dutch model separates roads into residential and traffic function (Wegman, et al. 2006). Residential or neighborhood street functions are simple in principle, the road is shared by all users, where motorists speed should not exceed 30 km/h (Wegman, et al. 2006). Traffic function streets are corridors with high speeds and high volumes of traffic, most often described as motorways, boulevards, major arterials, or thoroughfares and within the traffic function are two traffic road sub-types, flow, and access (Wegman, et al. 2006). The Sustainable Safety Vision provides flow access to automotive traffic, allowing higher- speeds on the roadway, while allowing access to land-use to non-motorized transport in a protected environment (Wegman, et al. 2006).

This has resulted in the Netherlands consistently ranking as one of the countries with the lowest rates of road-related fatalities and with one of the highest mode share of pedestrians and cyclists (Pucher, et al. 2012, Jacobsen and Rutter 2012, Wegman, et al. 2006, World Health Organization 2015, ITF 2017). The data show that the scientific and systematic approach used by the Dutch Sustainable Safety policy framework is effective in drastically reducing the number of road fatalities and severe injuries (Wegman, et al. 2006). The approach integrates the motorist, road user, and government so that all three parties share road safety responsibility (Wegman, et al. 2006). By doing this, Dutch Sustainable Safety reduces the number of fatalities or severe injuries on the roadway by anticipating human error in the built environment, speed management, and “continuous and constant" road design that educates, encourages, and engages road users (Wegman, et al. 2006, 14).

3. DESCRIPTIVE CRASH DATA ANALYSIS

This chapter analyzes Austin, Texas's existing road conditions. The conditions examined to provide a baseline for understanding the crash collision analysis and will help to inform this research and the reader on possible road safety and design policy measures that will be discussed in the final chapter of this paper.

The following chapter provides a demographic profile of Austin, Texas using U.S. Census data to examine the composite makeup of Austin's population. The demographic profile will review increased growth rates, median ages, ethnicities, educational attainment, and rates of poverty population in Austin, Texas' modal share. Next, the chapter will conduct a crash corridor analysis on Austin's road network. The corridor analysis expands on the previously reviewed demographic data and will provide a portrait of the communities most affected by pedestrian and cyclist collisions.

The demographic profile and crash corridor analysis provide this research with an understanding of the existing relationship between Austin's community and its current network conditions. Ultimately, this chapter examines who was involved in collisions, where they took place, and when they occurred; allowing this research to understand *why* these collisions occurred and *how* they might be avoided in the future.

Demographic Profile of Texas

Texas is growing exponentially, from 2015 to 2016, Texas grew 1.6%, the largest growth rate of any U.S. state that year (S. White, L. B. Potter, et al. 2017). According to the Texas Demographic Center (TDC), as of 2010, 84.7% of Texas residents lived in an urban area, with projections suggesting by 2050 90% of the state's population will be in urbanized areas (S. White, L. B. Potter, et al. 2017). Further data from the TDC report on the rapid urbanization and migration to Texas suggest that by 2020, Texas will have likely grown by 4.3 million people from 2010 (S. White, L. B. Potter, et al. 2017). Most of Texas' growth comes from its six largest MSA's: Dallas-Fort Worth- Arlington, Houston- The Woodlands-Sugar Land, San Antonio- New Braunfels, Austin- Round Rock, El Paso, and McAllen- Edinburg- Mission

The steady urbanization of Texas occurred over the last century, 1910- 2010, shifting the population from rural Texas to its "Big Four" (S. White, L. B. Potter, et al. 2017). Austin- Round Rock, Houston- Sugar Land- the Woodlands, San Antonio- New Braunfels, Dallas- Fort Worth- Arlington, since 1910 have compromised 77.8% of the population increase, while DFW and Houston- Sugar Land- Woodlands is responsible for over 50% of that, Austin- Round Rock had the highest net- migration rate of 19.87% (S. White, L. B. Potter, et al. 2017). Furthermore, Austin- Round Rock and San Antonio- New Braunfels MSA's, according to the Texas Demographic Center, are soon to be the leading urban centers in Texas for population growth (S. White, L. B. Potter, et al. 2017).

The next section of this chapter will explore the specific demographics of the City of Austin, Texas. It is important to note that the growth rates attributed to the Austin- Round Rock MSA reflect only a portion of the growth for the specific search area. For instance, the influx of Asian immigrants to the Austin- Round Rock MSA, is not particular to the City of Austin, but rather to Travis County (S. White, L. B. Potter, et al. 2017). Meaning, the growth pattern in Central Texas is distributed along the IH 35 corridor, beginning in Austin- Round Rock and ending in San Antonio.

Demographic Profile of Austin, Texas

According to the U.S. Census, five- year survey, the City of Austin's population in 2016 was 907, 779, a population increase of 117, 389 people since the 2010 census (2016, U.S. Census Bureau, 2010). Austin's population is not specific cause, however, in general, Austin attracts young adults and professionals to the city due to its large tech field, the University of Texas- Austin, and its tendency to be more socially accepting than other rural areas across the state. The U.S. Census Bureau estimates that the average median age of Austin is 32.4 years old (American Community Survey 5-Year Estimates Demographic and Housing Estimates 2012- 2016 2016). The population of 25 to 34-year olds, in 2016 made up 22% of the city's population, which has doubled in less than six years, when the 2010 Census cited Austin's population of 24 to 34-year olds to be 11% of the city's population (2016, 2010).

Additionally, Austin has a relatively high rate of educated individuals having an educational attainment rate of 47.7% of the population having a Bachelor's degree or higher (U.S. Census Bureau 2016). The rate of poverty in the Texas capitol was 16.7% in 2010, with highest percentages affecting children under the age of 18 and 15.4% were adults aged 18 to 64 years old (U.S. Census Bureau 2016). When analyzing the rates of poverty for adults, aged 18 to 34 years old account for 21% of adult poverty (U.S. Census Bureau 2016). When looking at median household income, Austin becomes even more disparaging in equity, with 54.8% of full-time, individual workers that make below the national median income of $55, 322 (U.S. Census Bureau 2016).

Existing Conditions of Austin's Road Network

This section ends with a review of mode share data for Austin, Texas from the U.S. Census. This data will help provide the baseline for the crash collision statistics to be reviewed in the next section. In general, the mode share data collected and presented in this section only represent a portion of those that walk or bike in the city. Specifically, mode share data from the U.S. Census only accounts for those that work and are 16 years old or above. Therefore, this study assumes that mode share data for Austin, Texas is higher, due its popularity in the city and that walking or biking is seen as a recreational hobby or is used as a primary mode of transportation for those that are under the age of 16 years-old or not working.

Austin, Texas' main mode of transportation to and from work, according to the 5-Year Census estimates, is the personal motor vehicle, with 83.4% selecting it as their main mode of transportation and 73.7% of motorists driving to work alone (U.S. Census Bureau 2016). Carpooling to work was the second highest mode of transit, with 9.7%; however, the average worker per car for the city was only 1.07 (U.S. Census Bureau 2016). Driving is so prevalent in Austin that walking and biking to work in Austin is smaller than those that work from home, which has a higher percent at 7.4% of Austin's citizens (U.S. Census Bureau 2016).

Public transportation is on a downward trend in Austin, as well, the 2010 Census said that taking public transit represented 4.8% of Austin's mode share, however, in 2016 the modal share of public transportation was 4% (2010, U.S. Census Bureau 2016). In addition, the modal share of pedestrians or cyclists in Austin only 2.3% for walking to work and 1.4% for cycling (U.S. Census Bureau 2016).

Compared to the rest of Texas, Austin has a high mode share of those who walk or cycle to work in the state of Texas. For 2016, the state of Texas had a mode share of .3% for people who cycle to work and 1.6% for those that walk to work (U.S. Census Bureau 2016). Furthermore, the city of Austin has an extremely high rate of citizens using public transit with 4% in Austin, compared to the state share of 1.5% in 2016 (U.S. Census Bureau 2016, U.S. Census Bureau 2016). The data suggests, based on state and the city of Austin's modal share, that Austin is the top city in Texas for cycling as an alternate mode of transportation.

Looking at mode share data for Houston, Dallas, and San Antonio[1], Austin's cyclist mode share is 1.2% higher than Dallas or San Antonio's at .2% and .9% higher than Houston's (U.S. Census Bureau 2016). In addition, Austin's mode share of pedestrians at 2.3% is higher than Houston at 2.1%, Dallas at 1.9%, and San Antonio at 1.7% (U.S. Census Bureau 2016). Surprisingly though, Dallas surpasses Austin in ride share of public transit at 4.3%, however compared to Capitol Metro[2], DART[3], has a much larger network which reaches the suburbs of Dallas to its east and west (U.S. Census Bureau 2016).

Last, for Austin, Texas this research looks at commute times to work and peak hours for commuting to work. According to Census data, the most popular time to leave for work in Austin is between 9:00 a.m. to 11:59 p.m. at 28.2% of the estimated workers 16 years-old or older (U.S. Census Bureau 2016). When looking at strictly morning peak

[1] These three cities are the largest of Texas' "Big four" MSA's; Houston- Sugar Land- Woodlands, San Antonio- New Braunfels, Austin- Round Rock, and Dallas- Fort Worth- Arlington.
[2] The City of Austin, Texas' public transportation
[3] Dallas Area Rapid Transit is the City of Dallas' public transportation system that covers most of the DFW region.

commute times, 7:00 a.m. to 8:30 a.m. is the highest morning commute times were 42.3% of Austin commuters leave to go to work (U.S. Census Bureau 2016). Of equal importance is the time it takes to travel to work, where Austinites spend an average of 23.8 minutes commuting work, but 11.7% of Austin's commuters work outside Travis County[4]And 13.5% work outside their area of residence (U.S. Census Bureau 2016). The percent of residents living and working outside their county or city of residence is essential when looking at commute times, as well as Austin's road network. At least a quarter of Austin, according to Census estimates, works outside its city, exaggerating commute times and exacerbating the system.

In the case of Austin, this could be a telling example of why city streets have the highest rates of collisions for the city. For most commuters, avoiding limited access highways is the best way to limit commute time to work. This diverts traffic onto the city street network where cyclists and pedestrians mix with high-speed motorists during peak commute times. The next section of this chapter explores Austin's existing road network regarding crash data.

Detailed Analysis of Crash Data

Demographic data of Austin, Texas only provides a small portion of the crash analysis. To ensure a holistic view of collisions that occur between cyclists and pedestrians this section will analyze crash collision data by looking varying factors in the crash data. The data analyzed came from the Texas Department of Transportation (TxDOT) and was gathered using the Crash Records Information System (CRIS) query tool for the period of record 2014- 2016 for all the entire city of Austin, Texas.

[4] Austin resides in Travis County.

This analysis of crash data of pedestrians and cyclists in Austin, Texas only provides a portion of this analysis. The relationship between cyclists/pedestrians and motorists is a complicated relationship that involves the design of the built environment, for which this analysis only provides a portion. The spatial relationship between cyclists/pedestrians, motorists, and the built environment will be discussed later.

Before beginning the detailed analysis of crash collision data for Austin, Texas from 2014- 2016, this research must acknowledge its limitations. Despite the 1,783 collisions for pedestrians and cyclists in Austin, Texas, the data is not an accurate representation of all crashes that occurred in Austin during this three- year period. In fact, one study conducted found that underreporting of pedestrian or cyclist collisions in university towns is common (Medury, et al. 2017). Additionally, the data provided by TXDoT does not have complete data for every collision. For instance, there were 1, 783 collisions between cyclists, pedestrians, and motorists in Austin, Texas from 2014- 2016 for which there is geographic data; however, the total reported number of collisions (with and without latitude and longitude data) were 2, 148 collisions for the three- year period. Despite the limitations of the data, the crash data provide a broad overview and glimpse of the collisions and the frequency of collisions in Austin, Texas.

Summary Statistics of Pedestrian Collisions, Austin, Texas

The following data for pedestrian and cyclist collisions in Austin, Texas from 2014- 2016 were examined to determine how many people are involved in crashes, the severity of injuries sustained from the collisions, when the collisions occurred, and who is included in the collisions. The portion of this analysis is descriptive and will allow the research to gain a better understanding of collision clusters of pedestrians and cyclists.

The first portion of the section will analyze pedestrian collisions in Austin, Texas for 2014- 2016 and then finish by analyzing cyclist collisions in Austin for the same period of record.

Pedestrian collisions in Austin, Texas for the three- year period of record from 2014 to 2016 is shown in Figure 1. The highest number of collisions occurred in the year 2016 with just two more collisions than in 2015 with 359 collisions. Based on just this three- year analysis and with the demographic data, Austin, Texas is likely to see an increase in collisions for pedestrians.

Another way to analyze crash data is to look at the percent severity of pedestrian collisions for the entire period of record in Austin (Figure 2). This helps to analyze the trend of pedestrian collisions, as well as, provide a better understanding of the potential environmental characteristics parts of Austin that have high rates of pedestrian traffic. Another way to analyze pedestrian collision data is to look at the severity of collisions by year. Figure 3 shows the severity of pedestrian collisions by year for Austin, Texas. The Data shows that while pedestrian collisions are increasing in Austin, Texas, the most severe collisions occurred in 2015, with 32 fatalities and 63 incapacitating injuries.

In 2016, the data shows that there were more pedestrian collisions, however fatal and incapacitating injuries were slightly less than in 2015. The general trend from 2014, suggests that while 2016 experienced less pedestrian fatalities and severe injuries, that pedestrian collisions are increasing across Austin, regardless of severity. incapacitating injuries were slightly less than in 2015. The general trend from 2014, suggests that while 2016 experienced less pedestrian fatalities and severe injuries, that pedestrian collisions are increasing across Austin, regardless of severity.

Looking at when collisions occurred by month of the year helps to determine when the largest number of pedestrians might be on roadways. When analyzing pedestrian collisions by month (Figure 4) this research finds that the highest rate of collisions for pedestrians is March. According to TXDoT crash data, the highest rate of collisions in the state of Texas by month is October and March (Fatal and Non-Fatal Crashes by Month and Day of Week Texas 2016 2017). Some possible reasons for March having the highest percent of pedestrian collisions might be Spring Break in Austin, or the popular South by South West Festival (SXSW), an international film, media, and music festival, the fact that temperatures tend to be milder in Texas in March, or a combination of all three factors could contribute to the increase in pedestrian fatalities.

Figure 5 shows the percent of pedestrian collisions for Austin, Texas by day of the week. Wednesday has highest percent of pedestrian collisions for all of Austin, Texas, followed by Tuesday and Thursday. According to TXDoT data, however, Friday is the most common day of the week for pedestrian collisions, followed by Thursday (Texas Department of Transportation 2017).

Another interesting way to look at pedestrian collision data is the time of day the collision occurred. This data provides the crash analysis with a better view of Austin, Texas' peak commute times. For instance, 6 p.m. in Austin has the highest number of pedestrian collisions at 98, followed by 7 p.m. with 81, and 5 p.m. at 80 collisions. These times correspond with traditional rush hour traffic, beginning at around 4 p.m. until 7 or 7:30 in the evening. What is interesting to note from Figure 6 is that 2 a.m. in Austin has a high rate of pedestrian collisions, this could be attributed to the popular nightclub scene that Austin has throughout its downtown, however, further analysis should be conducted to determine the accuracy of that assumption.

The age of pedestrians involved in collisions in Austin is seen in Figure 7 with 24-year-olds having the highest frequency of collisions for the three- year period of record. The second largest frequency of collisions by age are 22-year-olds. Figure 7 suggests that young-adults have the highest incidence of pedestrian collisions in Austin, Texas. This data is consistent with two studies when analyzing age distribution of pedestrian collisions (Rothman, et al. 2010, Pour, et al. 2018). According to previous research, children are more likely to be involved in severe or fatal collisions, especially in school zones and after school is released for the day; however, despite this, pedestrian collisions are more frequent for adults 18 years or older (Pour, et al. 2018).

Figure 8 demonstrates Rothman, et al., and Pour, et al., and findings that juveniles represent a smaller portion of collisions than adults in Austin, Texas (Motor Vehicle and Pedestrian Collisions: Burden of Severe Injury on Major Versus Neighborhood Roads 2010, Influence of Pedestrian Age and Gender on Spatial and Temporal Distribution of Pedestrian Crashes 2018). Another way to look at pedestrian collisions is by life stage. Figure 9 demonstrates, in better detail, the age groups in Austin, Texas with the highest frequency of pedestrian collisions. The data indicate that young adults, aged 19 to 24-years- old, have the third highest distribution of pedestrian collisions in Austin for the three-year period of record. This is likely due a few things: 1) Austin is a university town, with the University of Austin being centrally located in downtown Austin; 2) The high amount of young adults in Austin has doubled within a six-year term, as mentioned in the previous section, meaning there may just be more young adults out on the road; and 3)

Austin, Texas is known for its nightlife, also located in downtown, that attracts young adults regionally.

Next, this analysis will look at the lighting conditions at which the pedestrian collisions occurred. Figure 10 shows the light condition of pedestrian collisions by year in Austin, Texas. The data shows that the majority of pedestrian collisions occur during the daylight, with the second highest incidence of collisions being at night, but with light. The reason for a higher number of pedestrian collisions during the daytime would be that people are more active during daytime hours and general concern of safety.

Finally, for pedestrians the descriptive analysis ends with a look at gender and pedestrian collisions. The data shows that males are far more likely to be invovled in a pedestrian collision, representing 61% of pedestrians collisions and females representing 38% of all pedestrian collisions. This finding is consistent with studies that suggest males have a higher distribution of pedestrian collisions, although women responded in surveys that they walk more than males (Bentley, Jolley and Kavanagh 2010, Kingma 1994, Pour, et al. 2018).

Cyclist Summary Collision Data, Austin, Texas

The last portion of this chapter looks at cyclist collisions in Austin, Texas from 2014 to 2016. Of the 1,652 cyclist collisions in Austin, Texas for the three-year period of record, a total of 767 had available latitude and longitduinal data. Figure 12 shows the number of bicycle crashes per year in Austin, Texas. Unlike the pedestrian collision data, where 2015 had the highest number of pedestrian collisions, cyclist collisions peaked in 2014 and then dropped in 2015. Another way to look at the cyclist colision data is to look at severity, shown in Figure 13. The data shows that severe or fatal cyclist collisions in

Austin are lower than pedestrian collisions. The data suggest that even with a higher than average mode share of cyclists in Texas, severe or fatal collisions are limited. Figure 14 shows severity of cyclist collisions by year. The data shows that while 2015 had fewer cyclists collisions, the severity of the cyclist collisions was worse than in 2014 or 2016. With two fatalities in 2015, twenty-five incapacitating injuries, and a drop of 28 non-incapcitating injuries from 2014. The data suggests that there was a drop in ridership in 2015 from 2014, which is consistent with the continuing rise in vehicles miles traveled both in Texas and nationally (Federal Highway Administration 2016).

Figure 15 shows cyclist collisions by month for Austin, Texas. Unlike with pedestrian collisions, cyclist collisions in Austin, Texas had the highest rate of incidence in October. This corresponds to TxDOT data where October had the highest number of collisions (Texas Department of Transportation 2017). The spike in cyclist collisions in October may correspond with a large music festival in Austin, Texas at this time, Austin City Limits Festival (ACL). The location of ACL is located in Zilker Park, where Barton Springs Road is a well-known cyclist road, where in recent years, cycling to and from the event has become a growing trend. Another possible reason for the sharp increase in cyclist collisions for October and September could be the return of university students to the area. Again, it is important to note that two major universities are located in Austin's city center.

Figure 16 shows cyclists collsions by day of the week. The data show that Tuesday's have the highest incidence of cyclist collisions, followed by Friday. According to the TXDoT, Thursday's are the most common day of the week for collisions in the state (Fatal and Non-Fatal Crashes by Month and Day of Week Texas 2016 2017).

Reasons as to why Tuesday has the highest incidence of cyclist collisions and Wednesday has the highest incidence of pedesrian collisions should be analyzed further. In addition to looking at the day of the week for cyclist collisions, time of day of collisions data for cyclists helps to determine peak commute hours in Austin.

Figure 17 shows the number of bicycle crashes by the hour for Austin, Texas, 2014 to 2016. The data shows that 5 p.m. has the highest rate of cyclist collsisons in Austin with 81 collisions over three years, followed by 4 p.m. with 73 collisions. Cyclist collision data for time of day support the pedestrian collision data in that 3 p.m. until 8 p.m. are the peak commuting times for pedestrians and cyclists in Austin, Texas.

The frequency of cyclist collisions by age for Austin is shown in Figure 18. The highest frquency of cyclist collisions by age occurs for young adults aged 27- years- old, with the second highest being 26- year- olds. Figure 19 displays the cyclist collisions between juveniles and adults. The data shows that cyclist collisions among those 18-years-old or younger is 10%, compared to adults. Figure 20 supports frequency of collisions by age data for cyclists in Austin, Texas from 2014- 2016 showing that the age group with the highest incidence of cyclist collisions occurs in the 25 to 44- years- old age group. The data from Austin, Texas for the three-year period of record contridicts other findings that found the highest incident of collisions to be among youths and mature adults (Ferster, et al. 2017, Martínex-Ruiz, et al. 2014).

Furthmore, while Martínez-Ruiz et al., found a slightly higher rate of cyclist collisions in young adult males, no other data supports the findings of Austin's age distribution of cyclist collisions (Association of Cyclists' Age and Sex with Risk of Involvement in a Crash Before and After Adjustment for Cycling Exposure 2014). Figure

21 demonstrates the gender of those involved in cycling collisions in Austin, Texas. The data found here is consistent with past research which suggests that the rates of female cyclists are lower than that of males, with a signifigant drop amongst female cyclists for adolescent women (Garrard, Handy and Dill 2012, Martínex-Ruiz, et al. 2014, Ferster, et al. 2017).

Finally, this chapter concludes its descriptive analysis by analyzing the incidence of cyclist collisions by lighting condition. Figure 22 is consistent with pedestrian collision findings, in that the highest rate of collisions occur during the daylight. Additionally, the data here shows that cyclist collisions for 2015 were less than those for 2014 or 2016 in the daylight, but were higher in almost every other category. This supports the previous claim that in 2015 cyclist collisions were more severe than in 2014 and 2016, even though the amount of collisions was less than the other two years.

Climate

Walking and biking are outdoor activities that are dependent upon the environment of a region. Austin, Texas has a humid, subtropical climate with hot summers and traditionally mild winters (National Oceanic and Atmospheric Administration 2011). Furthermore, Austin, Texas is located at the crossroads of the Balcones Escarpment and the Colorado River where the Blackland Prairies meet the Texas Hill Country (National Oceanic and Atmospheric Administration 2011). T

he climate of Austin, Texas, while humid, is arguably one its largest attractors to the city with a realtively moderate climate with little fluctuation in weather extremes between Spring and Autumn. Summer in Austin brings high humidity and high daytime temperatures, from the Southern Coastal Plains, but the Balcones Escarpment helps to cool down by bringing cool winds; this lends to high fluccuation of precipitation in Austin with an average of 4 inches of rain in May and June (National Oceanic and Atmospheric Administration 2011). This climate would explain the seemingly fewer pedestrians and cyclists in the summer months given the high humidity and average rainfall of the region for May through August.

It is important to note though that with rapidly changing climate, Austin, Texas will begin to experience weather extremes within this region. Austin's average summer temperatures are expected to increase by at least two degrees by 2040 (Hayhoe 2014). Additionally, precipitation is projected to change by adding one extra day of two or more inches of rain every two years (Hayhoe 2014). Finally, the number of nights where the area reaches temperatures of freezing or below is projected to fall from an average of 15 days per year to just 11 days per average year by 2040 (Hayhoe 2014). To mitigate the expected warming temperatures and climate extremes shaded sidewalks with natural vegetation and grass along sidewalks, roadways, and cycle lanes would help reduce the heat island in the city, decrease environmentally dangerous water runoff, flooding, and encourage higher shares of active transportation users.

In conclusion, the provided demographics and descriptive crash data analysis allow the reader to better understand the current conditions for pedestrians and cyclists in Austin. The existing data for cyclists and pedestrians in Austin suggest that high-speeds, low connectivity, and dangerous roadways may impact the decisions of other potential pedestrians or cyclists. In the next chapter the data will explore these hypotheses using GIS and CrimeStat III to spatially analyze cyclist and pedestrian collisions across Austin, Texas for 2014 to 2016.

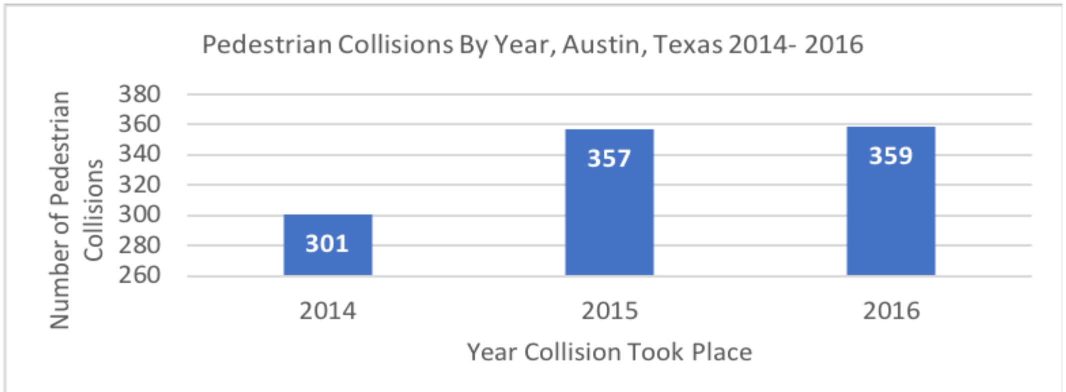


FIGURE 1

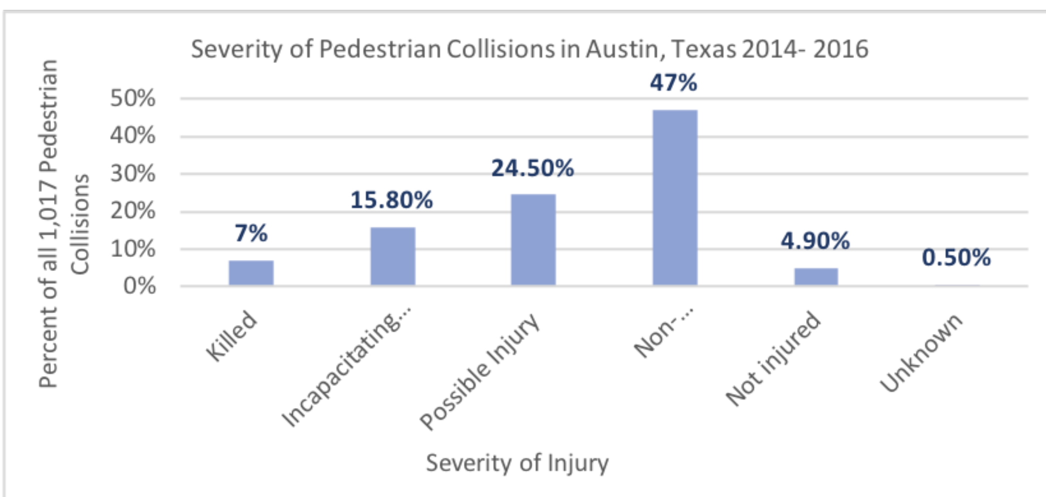
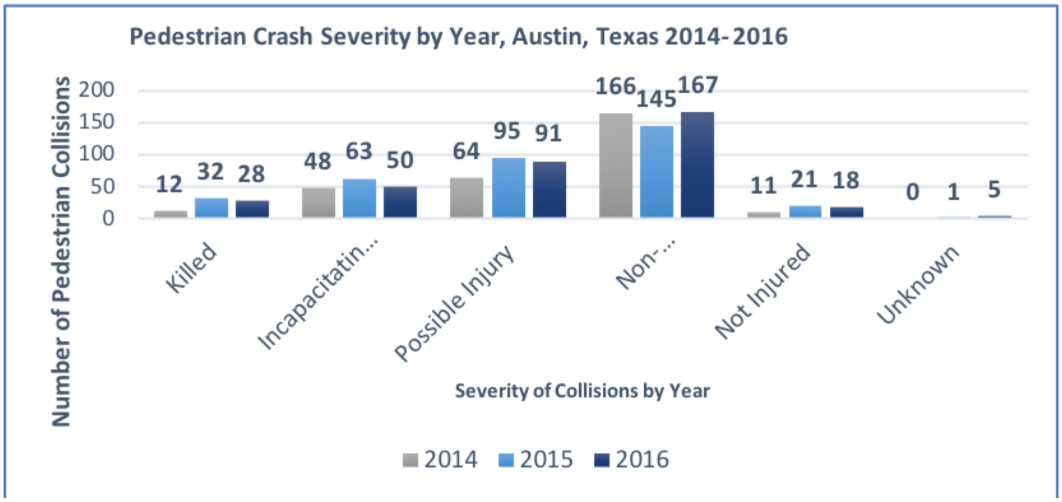


FIGURE 2



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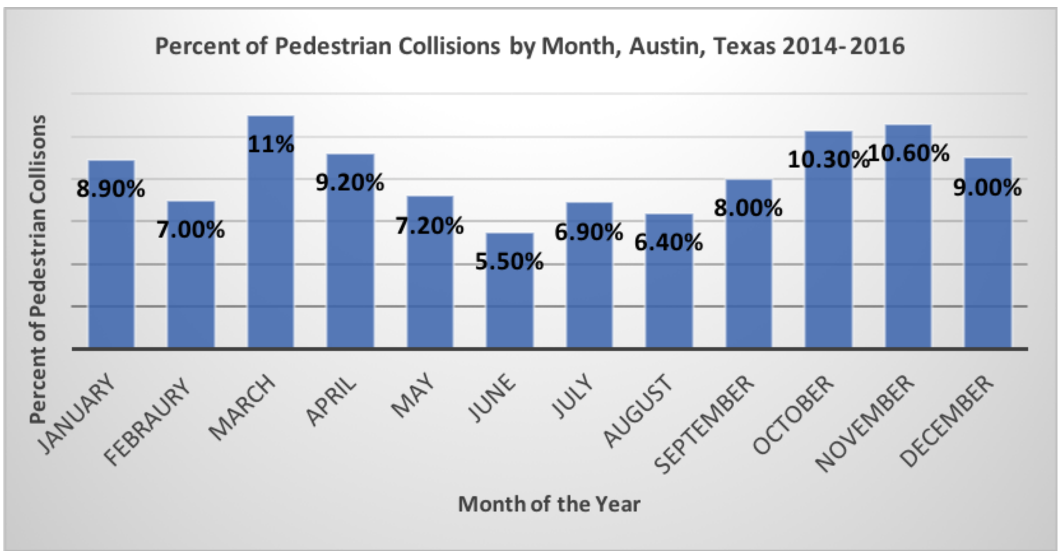

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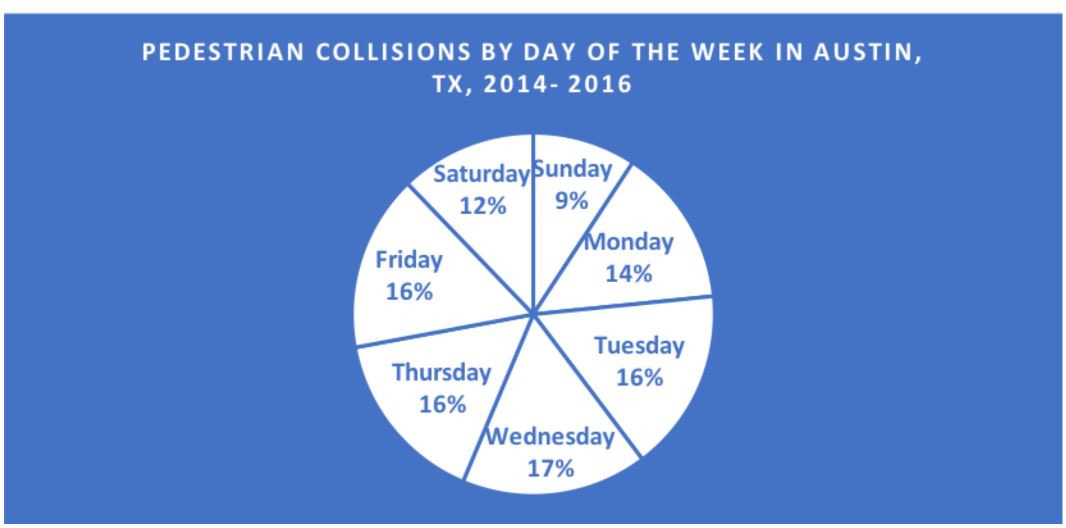
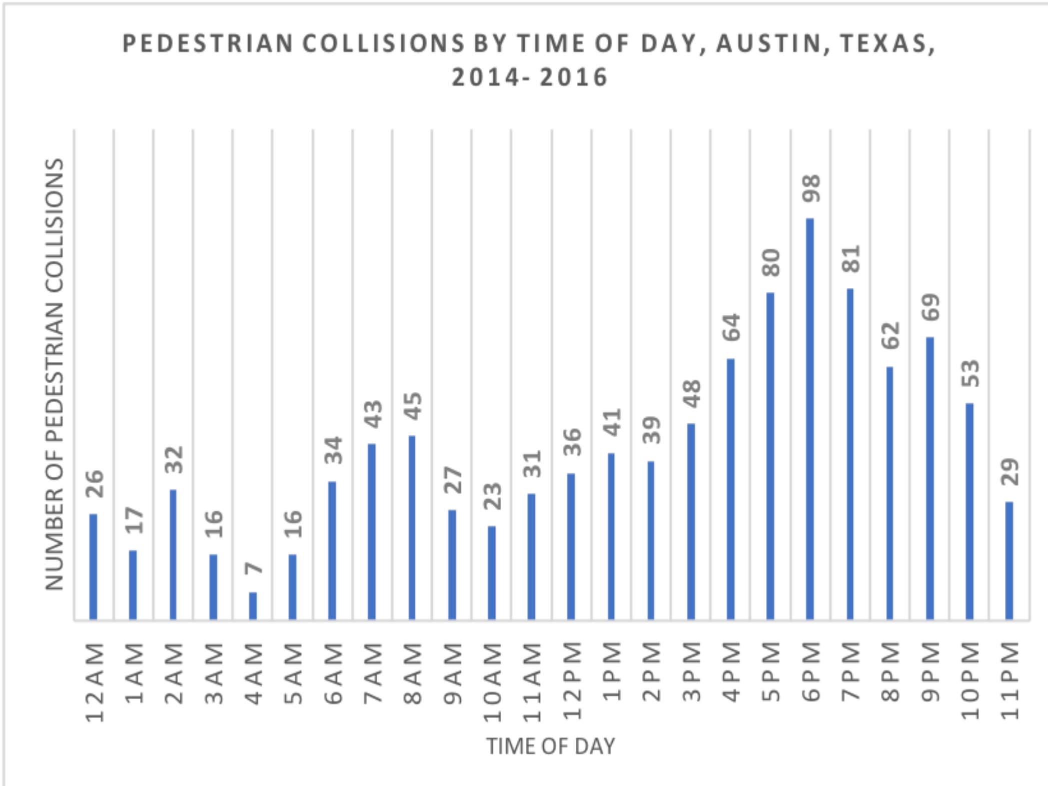


FIGURE 5



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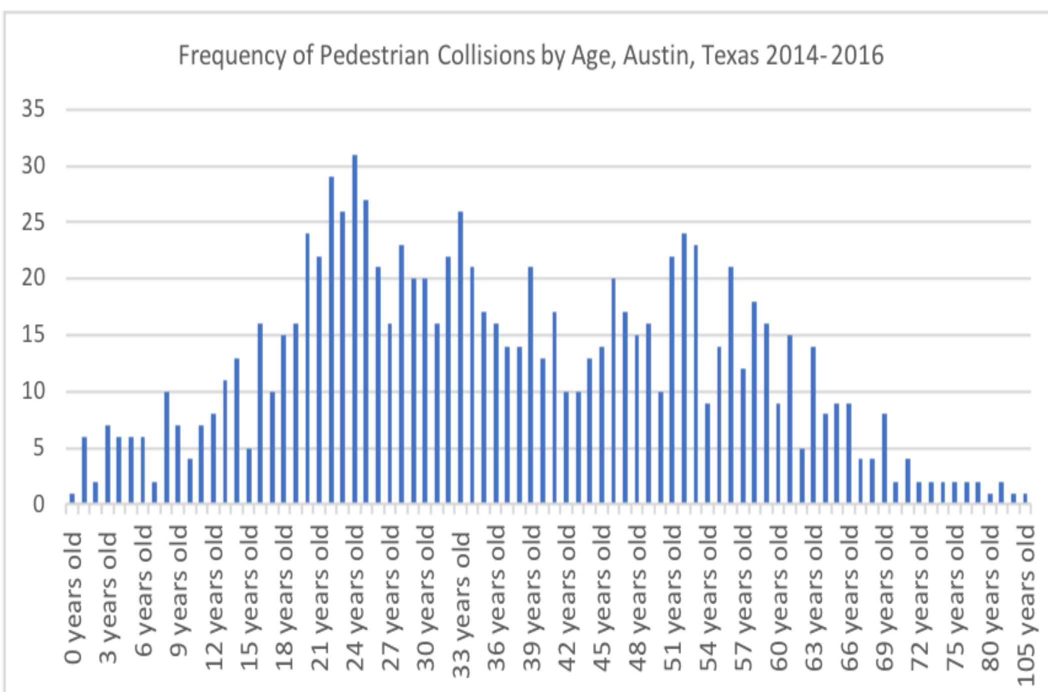


FIGURE 7

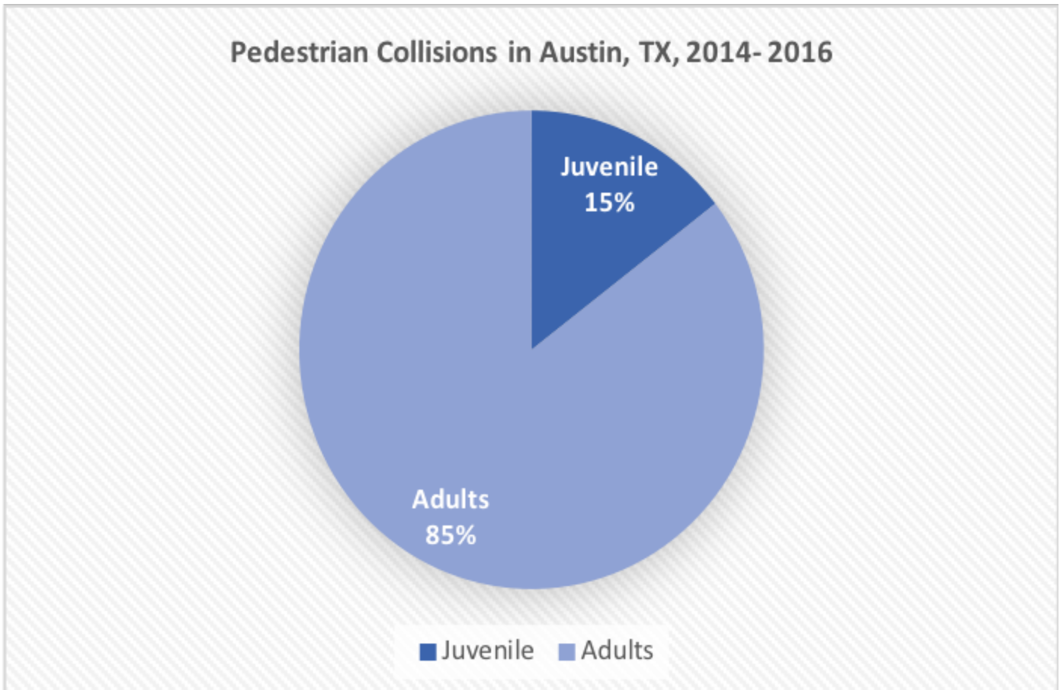


FIGURE 8

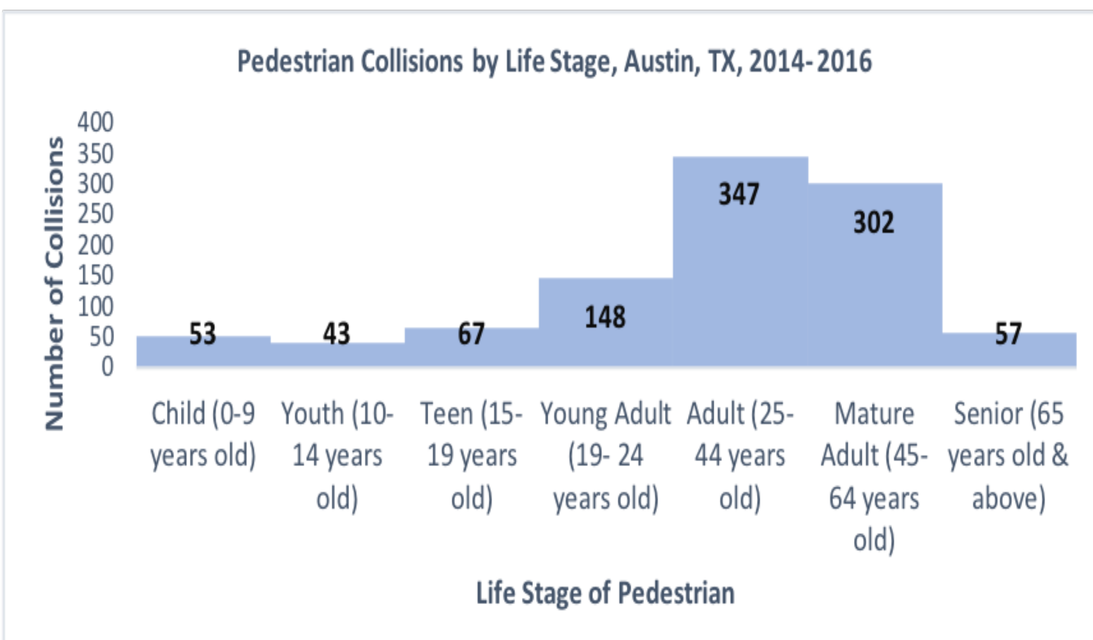


FIGURE 9

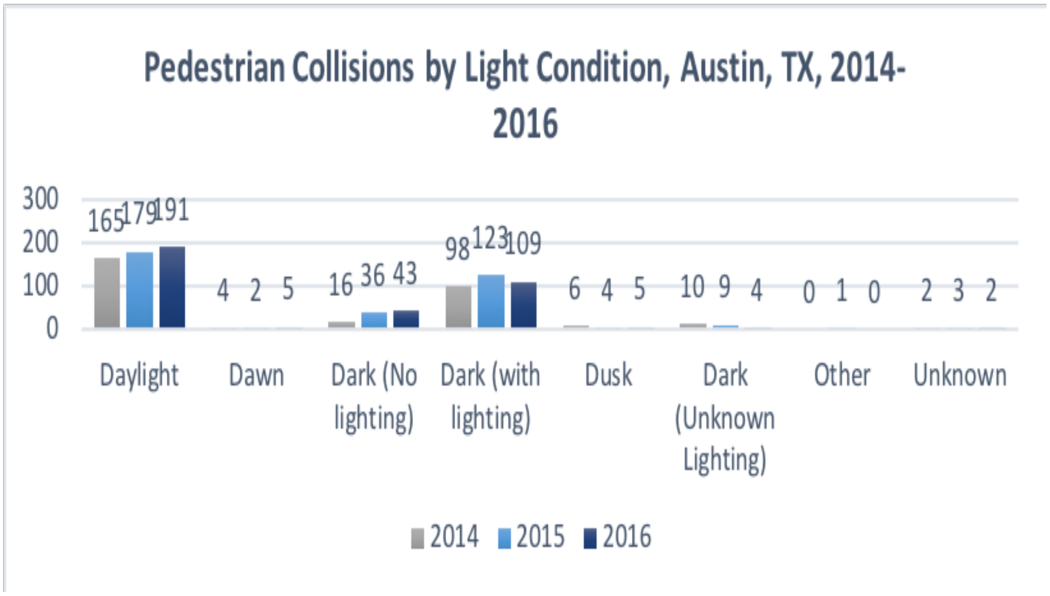


FIGURE 10

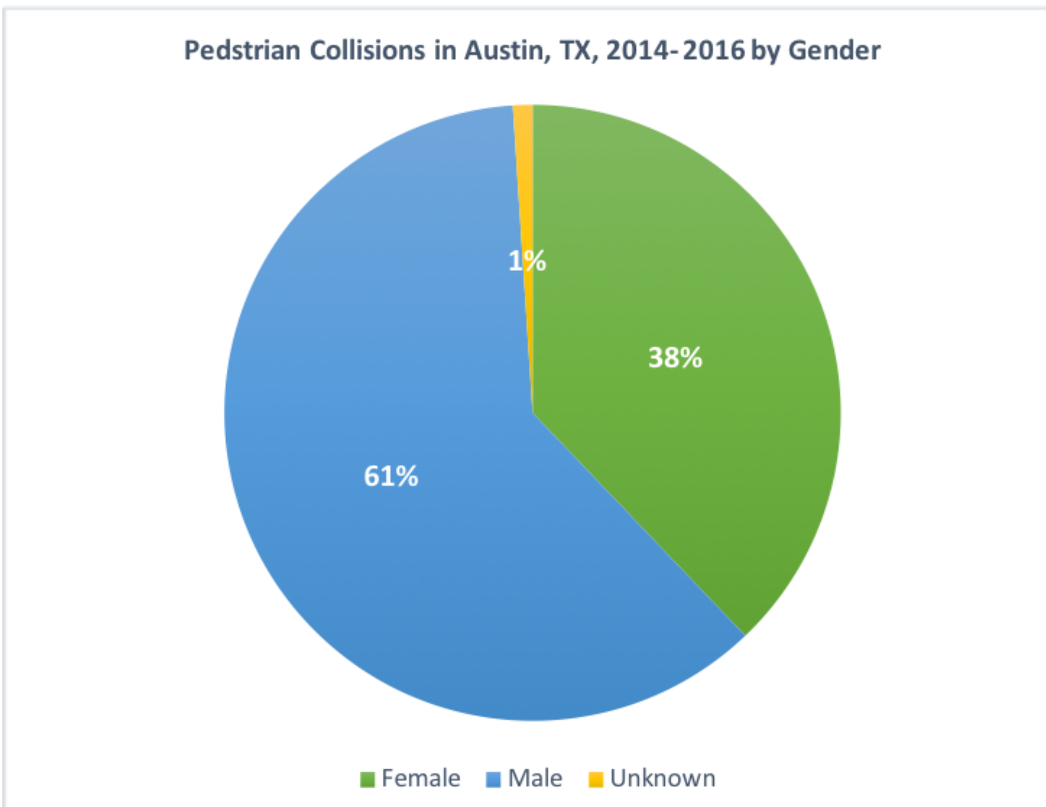


FIGURE 11

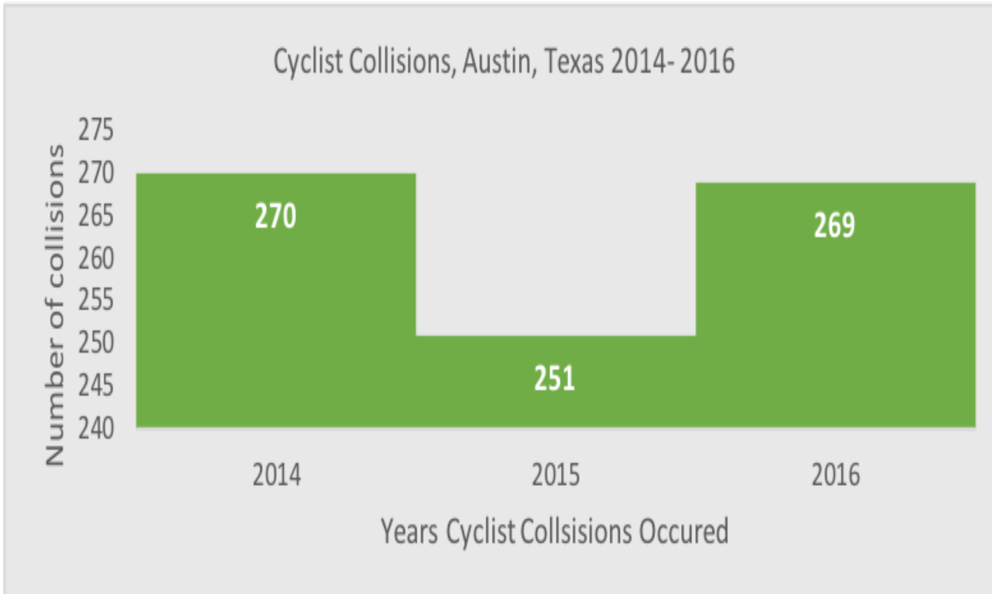


FIGURE 12

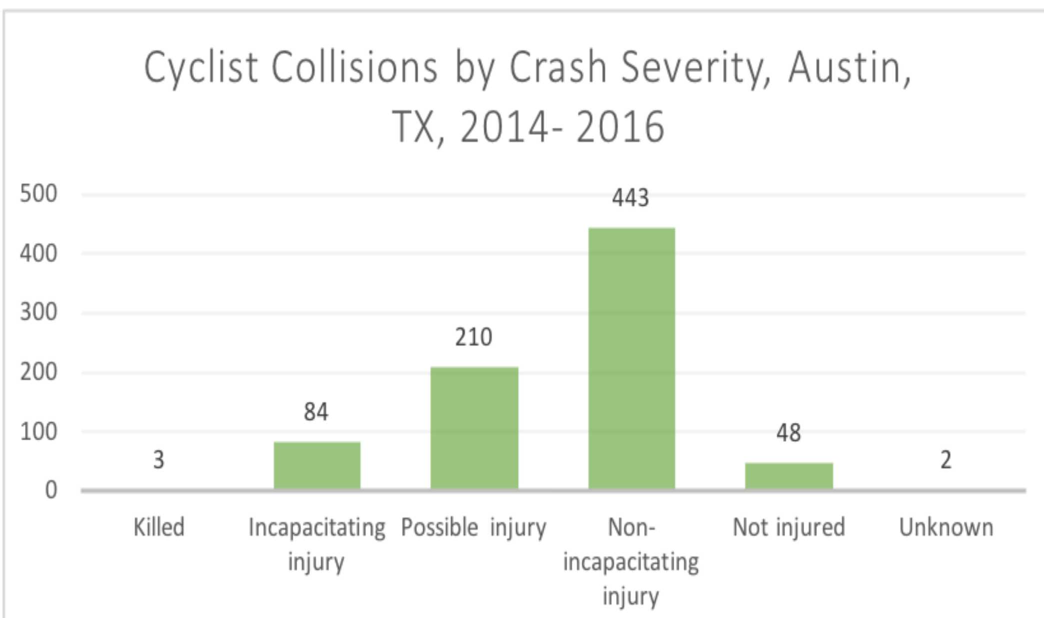
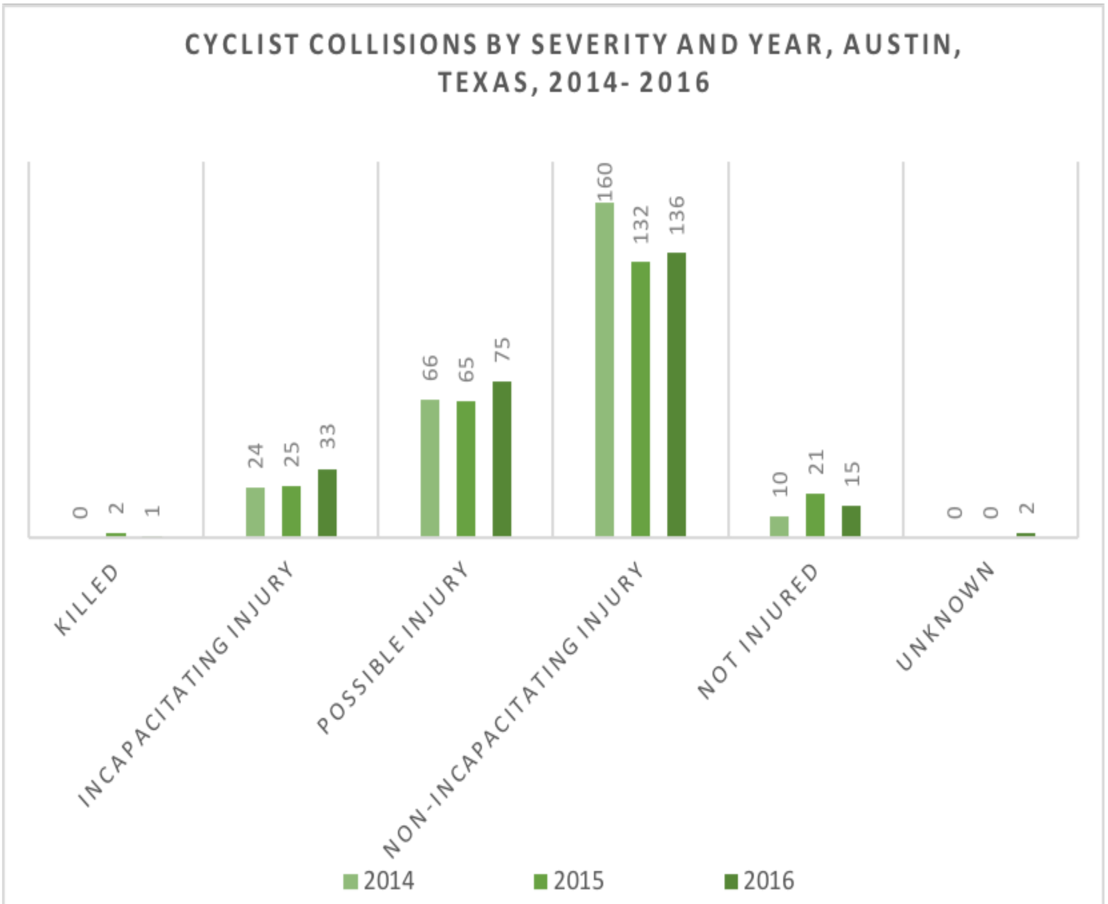


FIGURE 13



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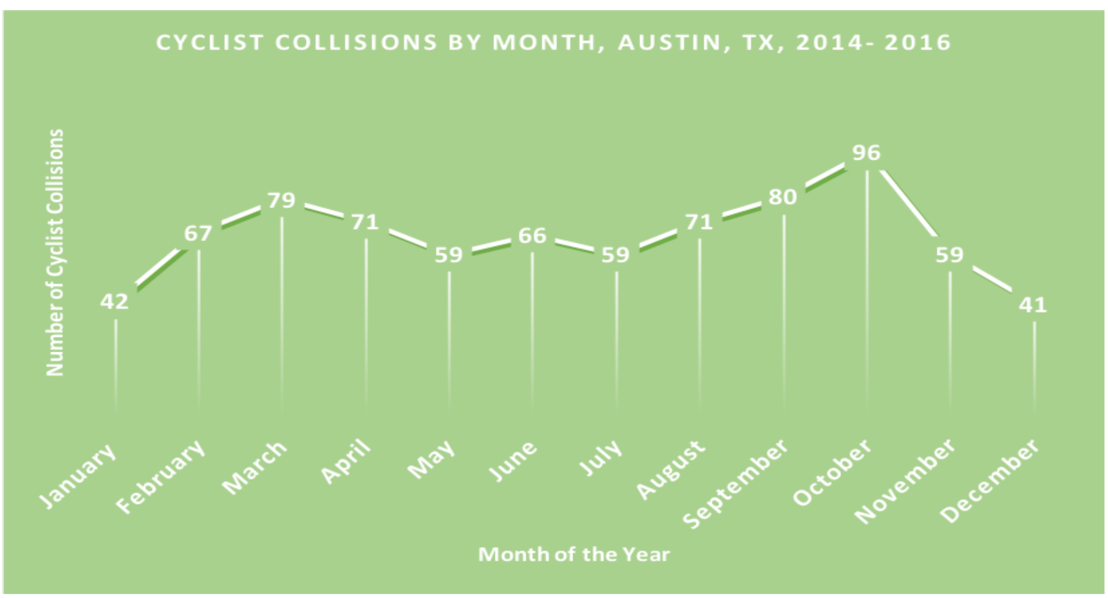


FIGURE 15

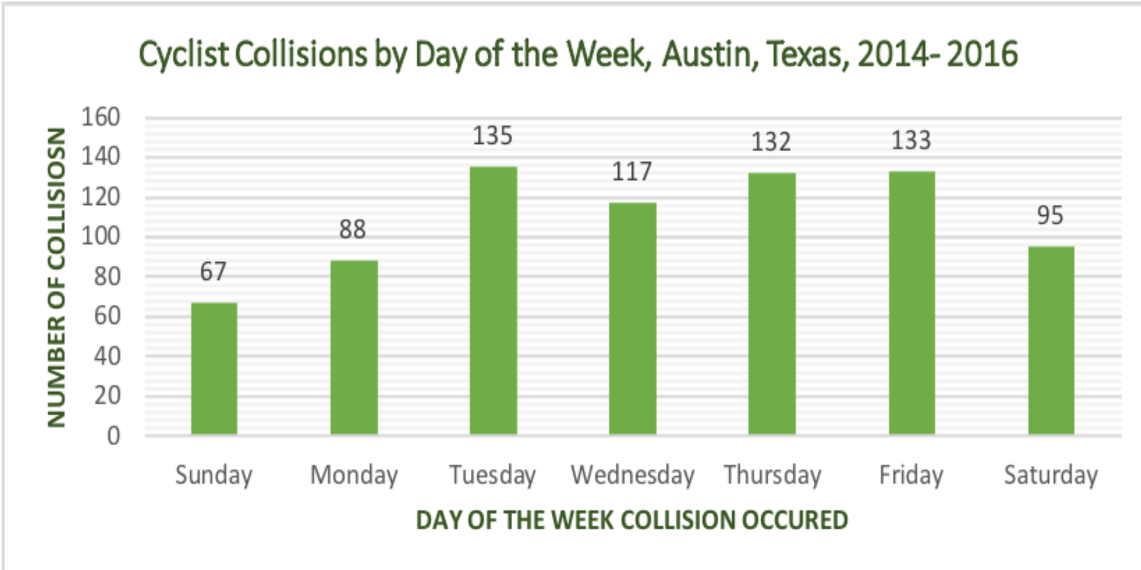
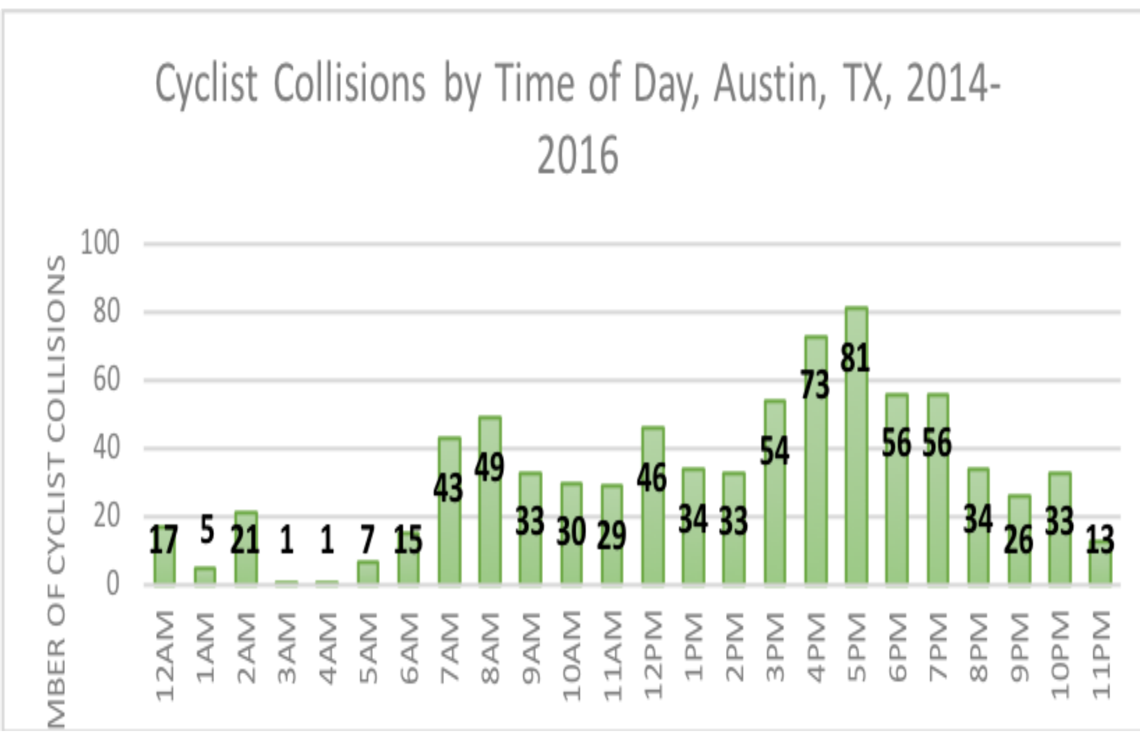


FIGURE 16



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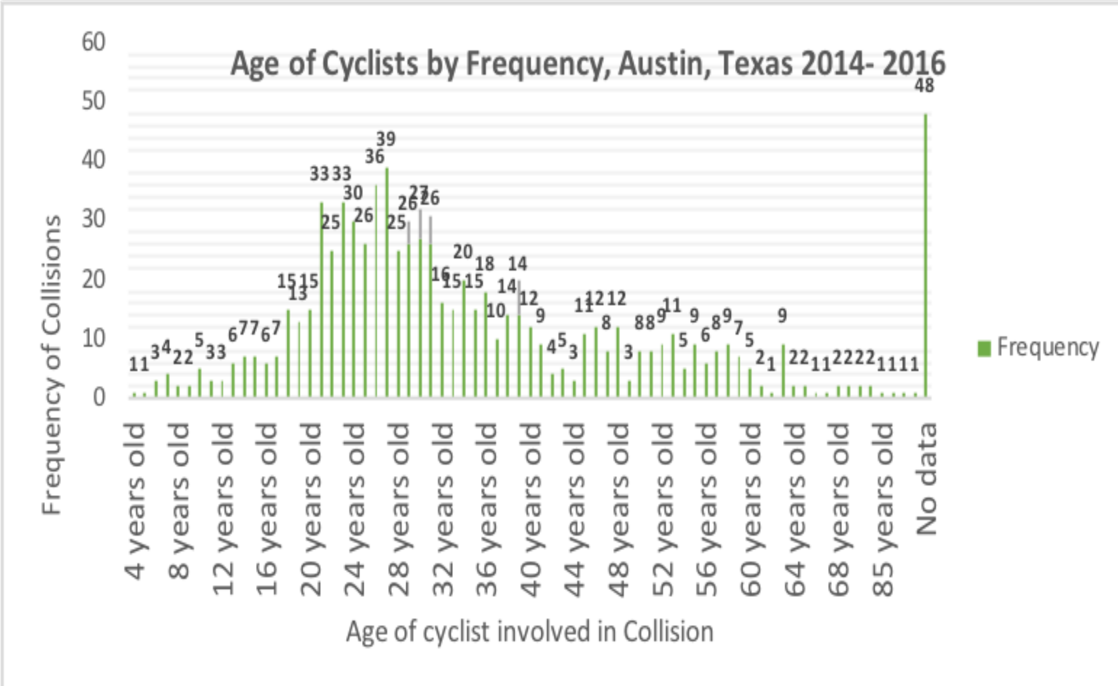

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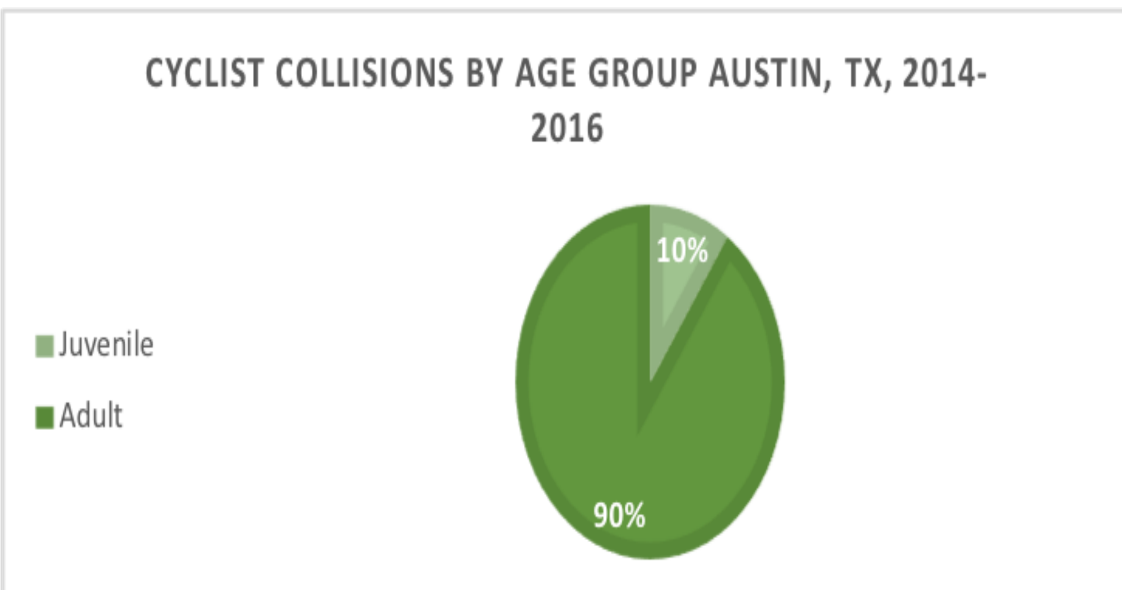

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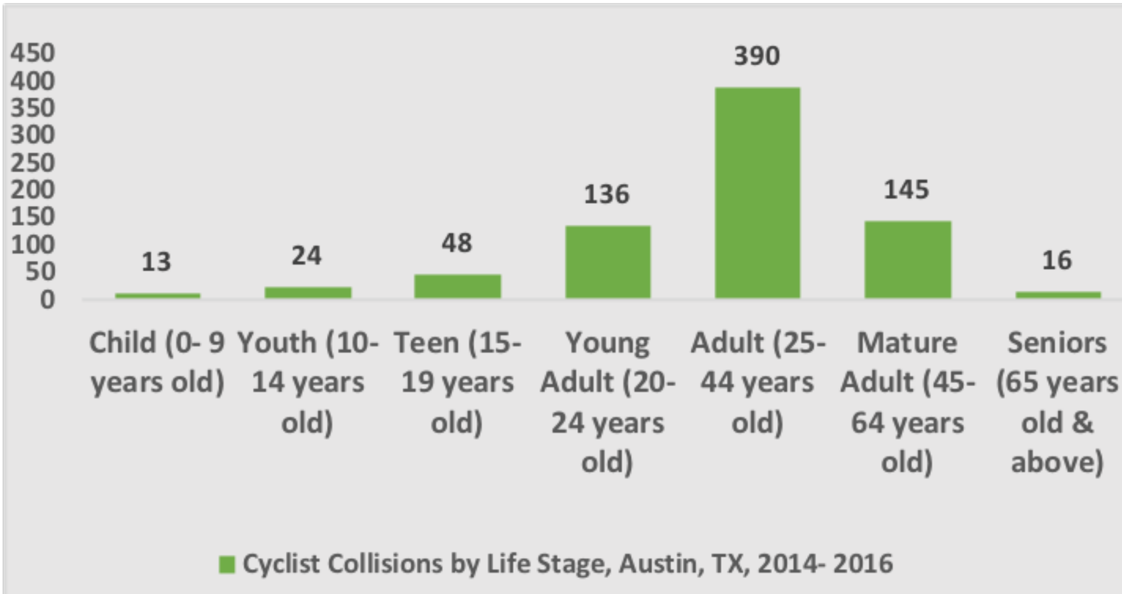


FIGURE 20

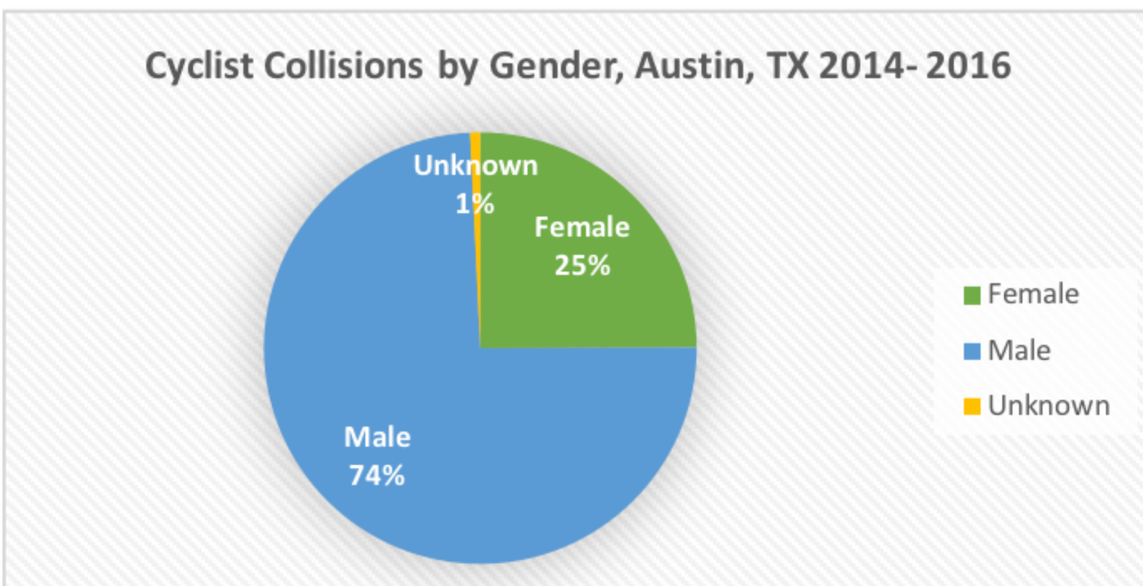


FIGURE 21

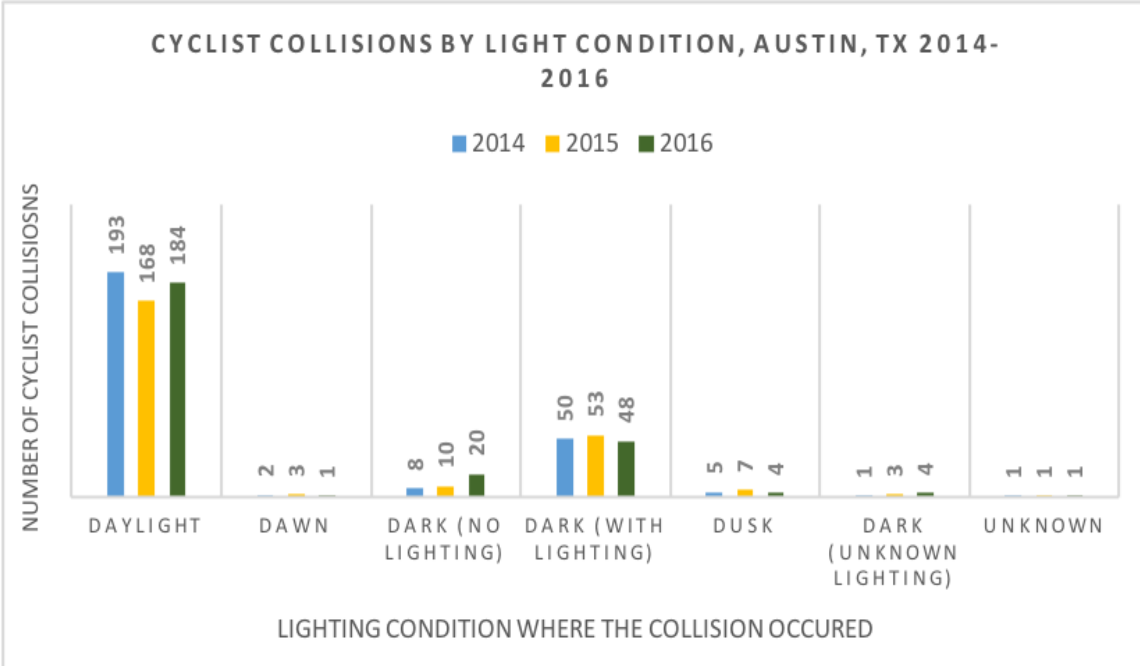

CYCLIST COLLISIONS BY LIGHT CONDITION, AUSTIN, TX 2014-2016
2014
2015
2016
NUMBER OF CYCLIST COLLISIOSNS
193
168
184
2
3
1
8
10
20
50
53
48
5
7
4
1
3
4
1
1
1
DAYLIGHT
DAWN
DARK (NO LIGHTING)
DARK (WITH LIGHTING)
DUSK
DARK (UNKNOWN LIGHTING)
UNKNOWN
LIGHTING CONDITION WHERE THE COLLISION OCCURED

FIGURE 22

4. IDENTIFYING STATISTICAL HOT SPOTS IN AUSTIN, TEXAS

Crashes occur due to a series of complex interactions between cyclists and pedestrians, motorists, and the built environment. A hot spot analysis on pedestrian and cyclist collisions is conducted and in this chapter. The methods used in this chapter are the first step in this mixed-methods analysis of road safety. Chapter 5 reviews the intersections and corridors identified in this section and discusses the commonalities in land-use from collision clusters identified in this chapter. This proximity analysis will help to highlight design features and land use patterns in Austin that are more likely to experience high rates of collisions in Austin and, therefore, will help to form the final policy recommendations for the City of Austin.

First, however, this chapter will explain what hot spot analyses do and why they are useful for understanding crash collisions. In short, hot spot analyses spatially demonstrate recorded phenomena as point data within a GIS model for a predetermined geographic boundary. The data can be events within the geographic boundary like, roadway collisions, criminal activities, or voting behaviors; whatever the identified phenomena, a hot spot analysis examines these events in an area to identify high incidences of the given phenomena. When identified, these high incidence zones create a "hot spot" in the region, identifying areas for further analysis. Multiple routines can utilize to determine the hot spots for a geographic boundary. These include K-Means routines[5] Near Neighbor Hierarchal Clusters routine[6], and point locations,[7]To name a

[5] This routine separates point data into predetermined groups.
[6] Measures intensities of phenomena and then groups them into first and second order groups to identify hot spots.
[7] The most basic form of hot spot analysis. This analysis employs mode and fuzzy mode, looking for the highest frequency of point data on a map.

few; but, this research uses the STAC hot spot routine (Levine 2010). The STAC hot spot analysis looks at point data dispersed across a map using a map grid and deviational ellipse.

The key advantage with hot spot analyses is that the researcher can select data and scan the map grid or geographic location for possible correlations between specific phenomena and the locations they occur. This allows policymakers to pinpoint dense intersections or corridors of collisions, allowing them to study complexities of collisions in the road network. More specifically, the STAC hot spot routine, used in this research, is useful for policymakers because it allows them to scan the network in whole or on a neighborhood level, allowing block ranges or specific corridors to be analyzed alone or in whole with the network. Ultimately, however, the hot spot analysis provides policymakers with collision incidence intervals highlighting probable tensions that exist in the built environment. These returned confidence intervals allow policymakers to accurately assess areas of the highest collision incidence, which require their immediate correction.

Hot Spot Analysis Methodology

The following section reviews the methods involved with the STAC tool and explains the significance of findings in this spatial analysis. Finding statistically significant crash clusters of pedestrian and cyclists with the STAC tool was done by the University of New Orleans in conjunction with the Pedestrian Bicycle Resource Initiative (2012). The STAC tool is useful in analyzing crash collision data because it can analyze large volumes of point data and then identify significant clusters.

In the case of a crash collision analysis, STAC is useful for identifying clusters of collisions across a city's road network. The tool requires the user to provide geographic identifiers, like latitude and longitude, to set the network boundaries, and to determine the land-use boundaries. STAC scans the city grid looking for the predetermined number of point data within a given radius. For instance, a minimum number of five phenomena can be set by the user, with a half mile search radius from a nodal linkage, the deviational ellipse then overlays onto the grid, combining overlapping clusters until no overlapping clusters remain. The tool then provides an output of hot spots or clusters in the geographic region. Lastly, to check for significance, the user sets simulation runs to test for significance of the crash collision clusters. The Monte Carlo simulation returns credible intervals, that, when returned indicate significant dense crash collision clusters.

Pedestrian Hot Spot Analysis

Pedestrian crash data from the Texas Department of Transportation (TxDOT), Crash Records Information System (CRIS) query tool, provided this research with descriptive crash data and available latitude and longitudinal data for pedestrians and cyclists. For pedestrians, there were 1,289 crashes in Austin, Texas for the period of record. Of the pedestrian data, 1,017 had available latitude and longitudinal data. The pedestrian collisions were geocoded into a GIS model of Austin, using street and land data shapefiles from the City of Austin's open portal data system.

Figure 23, below, shows pedestrian collisions in Austin, Texas from 2014 to 2016. The point data are shown in Figure 23, however, only represent the location of pedestrian collisions, Not the number of people affected or involved in the collision. The data, while challenging to discern due to overlapping point data, show that pedestrian collisions are densely situated west of IH 35 in and around downtown Austin. The visual and spatial representation of pedestrian collisions in Austin, Texas only provide a glimpse of where collisions have occurred in Austin, but do not inform the reader of where collisions are likely to continue or which areas have higher than “normal” rates of pedestrian collisions across the city. A spatial analysis was performed to look for the densest intersections or neighborhoods in Austin, Texas. The previously discussed descriptive crash collision statistics will be discussed throughout this chapter.

Figure 24 shows the hot spot analysis performed on the available pedestrian crash data from Austin, Texas from 2014- 2016. The STAC tool analyzed pedestrian collisions with these parameters a quarter- mile tolerance, with a minimum of five collisions (points), and a triangular grid scan. The STAC tool returned fourteen crash hot spots, shown in Table 1, of which nine were statistically significant based on 100 Monte Carlo simulation runs. Table 2 shows the intersections identified in the hot spot analysis with confidence intervals, all but five pedestrian hot spots had return confidence intervals of 90% or higher. The density of the clusters is what is most important in this analysis Table 3 displays the cluster density of the pedestrian hot spot analysis.

The returned results from the hot spot analysis demonstrate that, at the very least, these fourteen intersections and blocks have statistically significant densities of pedestrian collisions. Furthermore, when looking at the geographic locations of these intersections in Austin, Texas all but five intersections are in downtown or South Austin. Additionally, with only five intersections that did not return confidence intervals of 90% or higher it is unlikely that the collisions are merely a result of chance, but rather roadway design that facilitates high-speeds, extensive roadway facilities, poorly design pedestrian crosswalks, and other social factors that exacerbate these dense pedestrian crash clusters. Finally, while the hot spot analysis does not provide the research with reasons why these collisions occur it does highlight blocks in Austin that require further review and policy considerations to ensure pedestrian safety.

Cyclist Hot Spot Analysis

Cyclist collisions were less frequent than pedestrian collisions for Austin from 2014 to 2016. In total, for the three years, there were only 860 cyclist collisions reported, of those 860 collisions 767 were geocoded into GIS, Figure 25 show the geocoded cyclist collisions in Austin. The point data below only represent if a cyclist collision took place at that location, the actual amount of people affected by these collisions are 1,860 people. Additionally, the absence of a data point is not present does not mean that a collision has not occurred. Underreporting of cycling collisions is common (Medury, et al. 2017). Finally, incomplete collision datasets and missing geographic identifiers mean that all cyclist (and pedestrian) collisions cannot be represented within this model.

The STAC tolerances set for cyclist collisions in Austin, Texas for 2014 to 2016 were a quarter-mile search radius, a minimum of five collisions per search radius, with a triangular scan. Monte Carlo simulation runs were set to 100 to test for the confidence intervals of the hot spots returned. Figure 26 shows cyclist hot spots in Austin, Texas for the period of record. Table 4 shows the intersections returned from the hot spot analysis; as shown in the table, all twelve clusters returned with a 100% confidence interval rate. Tables 5 and 6 demonstrate the density of cyclist collisions in Austin, Texas for 2014-2016.

The hot spot analysis for cyclist collisions reveals that cyclist collisions in Austin, Texas are more dispersed than pedestrian collisions. Given the distances that cyclists can travel in a shorter amount of time, compared to pedestrians, this is consistent with expectations. One interesting thing observed through the hot spot analyses of pedestrian and cyclist collisions is the dispersion of east to west collisions for cyclists, compared to the more north to south concentration of pedestrian collisions. The lack of an east to west route in Austin is one of its main network issues. In Austin two highways connect the city from east to west, these roadways are for motorized traffic only, U.S. Route 290 and 183. Austin's two highways are unable to manage the high volume of motorized traffic; this leads to the east to west city streets becoming high-speed corridors for motorized traffic.

In summary, cyclist collisions are more dispersed than pedestrian collisions. However, there were 250 more recorded collisions for pedestrians than for cyclists for the three years of active transportation collisions analyzed. Furthermore, when looking at the location of the hot spots, cyclist clusters are situated west of Interstate 35 and more centrally located to the city center. The next section of this chapter will examine the top crash corridors in Austin for both pedestrians and cyclists, along with their connectivity and built environment characteristics.

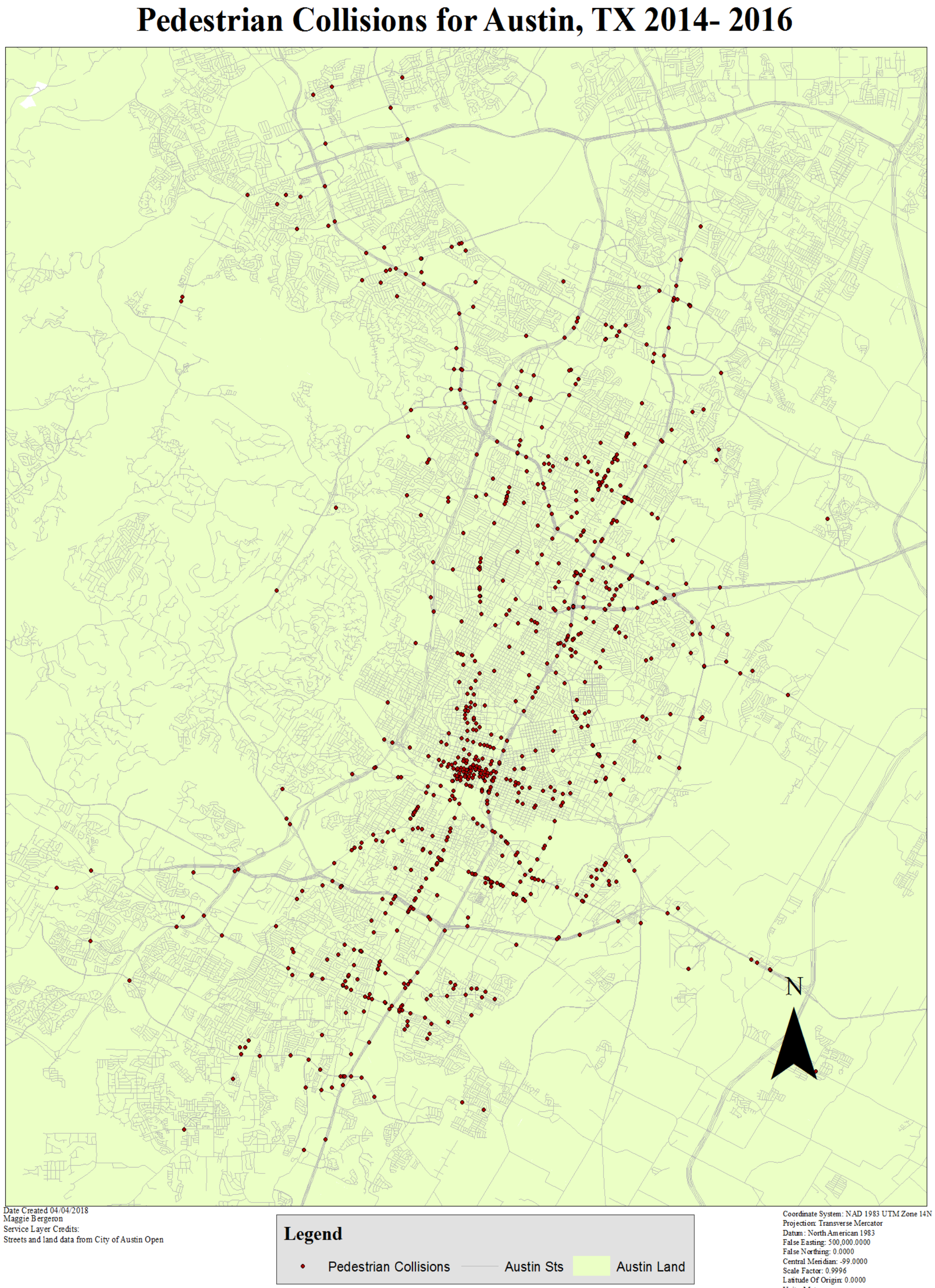

Pedestrian Collisions for Austin, TX 2014- 2016
N
Date Created 04/04/2018
Maggie Bergeron
Service Layer Credits:
Streets and land data from City of Austin Open
Legend
Pedestrian Collisions
Austin Sts
Austin Land
Coordinate System: NAD 1983 UTM Zone 14N
Projection: Transverse Mercator
Datum: North American 1983
False Easting: 500,000.0000
False Northing: 0.0000
Central Meridian: -99.0000
Scale Factor: 0.9996
Latitude Of Origin: 0.0000
Units: Meter

FIGURE 23

Pedestrian Hot Spot Analysis for Austin, TX 2014- 2016

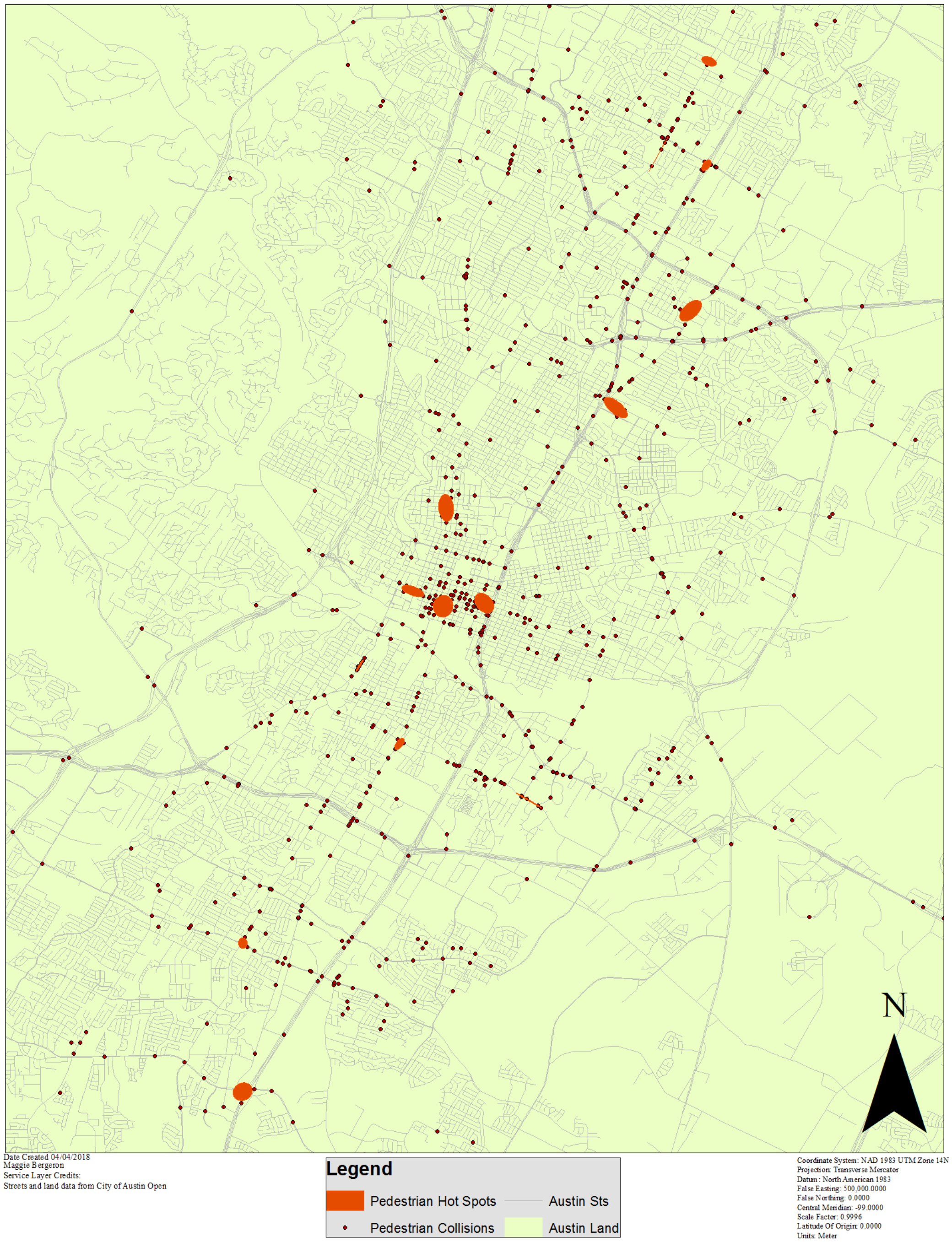
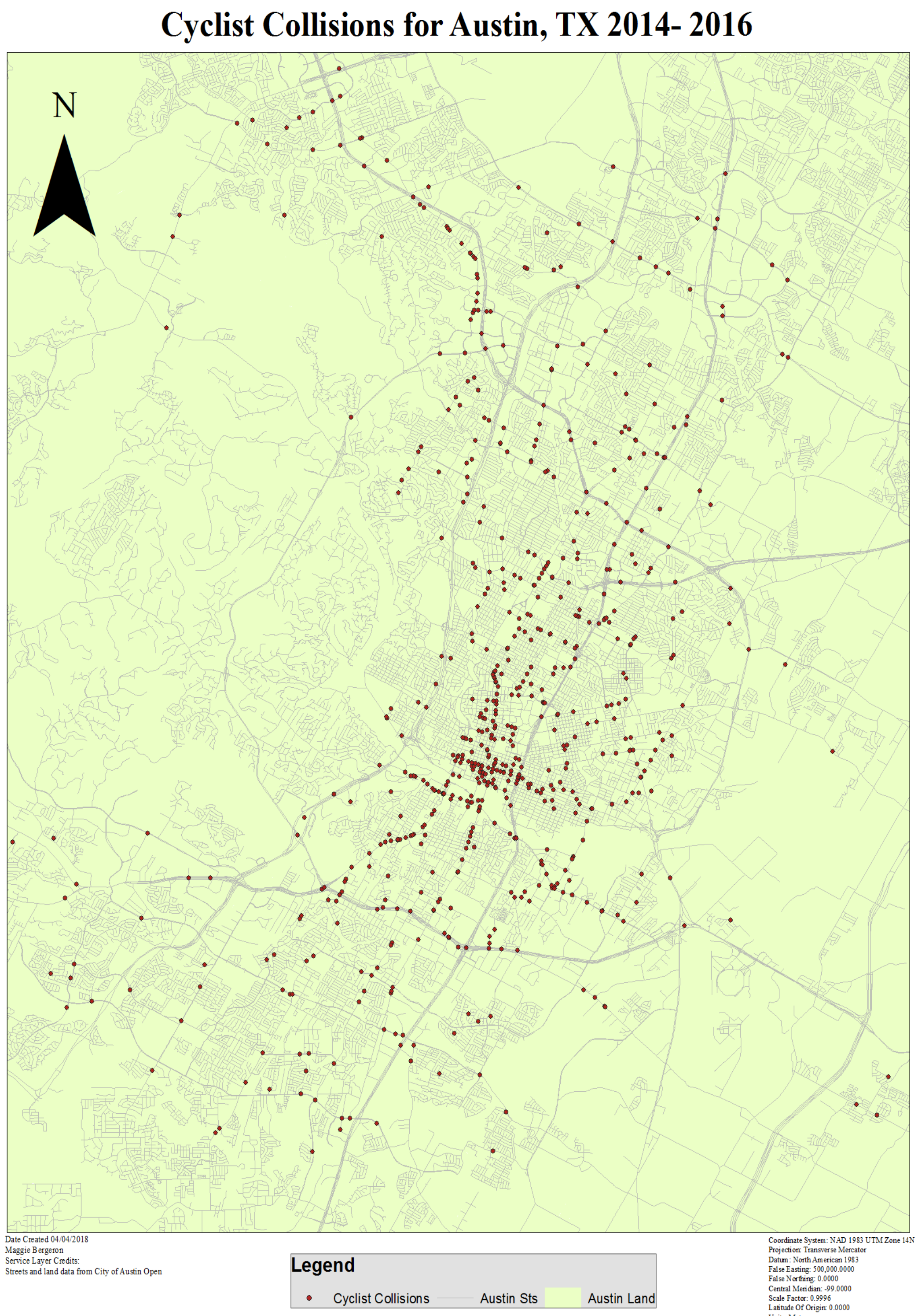


FIGURE 24


Cyclist Collisions for Austin, TX 2014- 2016
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Date Created 04/04/2018
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False Northing: 0.0000
Central Meridian: -99.0000
Scale Factor: 0.9996
Latitude Of Origin: 0.0000
Units: Meter

FIGURE 25

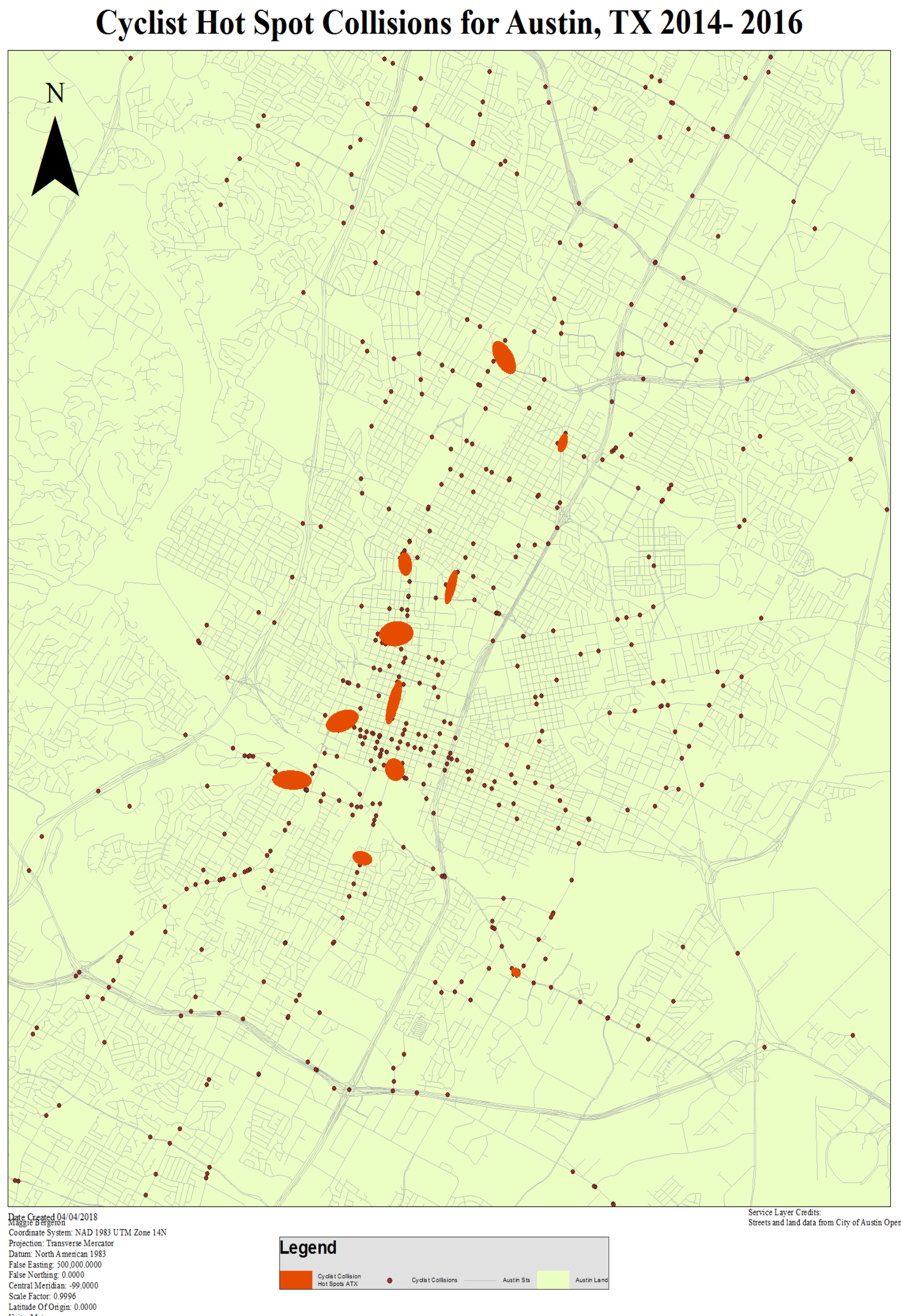
Cyclist Hot Spot Collisions for Austin, TX 2014- 2016
N
Date Created 04/04/2018
Maggie Bergeron
Coordinate System: NAD 1983 UTM Zone 14N
Projection: Transverse Mercator
Datum: North American 1983
False Easting: 500,000.0000
False Northing: 0.0000
Central Meridian: -99.0000
Scale Factor: 0.9996
Latitude Of Origin: 0.0000
Units: Meter
Legend
Cyclist Collision Hot Spots ATX
Cyclist Collisions
Austin Sts
Austin Land
Service Layer Credits:
Streets and land data from City of Austin Open

FIGURE 26

Table 1		
	Identified Pedestrian Hot Spots	
Cluster Number	**Intersection**	**Statistical Significance**
1.	Colorado Street & W. 4^{th} Street	100%
2.	E. 7^{th} Street & Sabine Street	100%
3.	E. Oltorf Street & S. Pleasant Valley Road	100%
4.	E. Rundburg Rd & IH 35 South	100%
5.	S. Lamar Boulevard & S. 8^{th} Street	100%
6.	W. 23^{rd} Street & Nueces Street	>90%
7.	S. Congress Avenue & W. Olftorf street	100%
8.	W. 5^{th} Street & West Avenue	> 90%
9.	Cameron Road & Fairbanks Drive	> 90%
10.	W. William Cannon Drive & S. 1^{st} Street	100%
11.	W. Slaughter Lane & S. IH 35 Frontage Road	>90%
12.	East 51^{st} Street & Lancaster Road	> 90%
13.	N. Lamar Boulevard & Cooper Drive	100%
14.	N. Lamar Boulevard & Kramer Lane	≅ 90%

Table 2				
Pedestrian Collisions Confidence Intervals for Austin, Texas 2014- 2016				
Percentile	**Clusters**	**Area**	**Points**	**Density**
min	1	0.01243	5	32.831825
0.5	1	0.01243	5	32.831825
1.0	1	0.01243	5	32.831825
2.5	1	0.01243	5	32.831825
5.0	1	0.01243	5	32.831825
10.0	1	0.02005	5	43.982786
90.0	1	0.11368	5	249.342294
95.0	1	0.15229	5	402.262315
97.5	1	0.15229	5	402.262315
99.0	1	0.15229	5	402.262315
99.5	1	0.15229	5	402.262315
max	1	0.15229	5	402.262315

Table 3		
Hot Spot Pedestrian STAC Results		Cluster Density
1	36	586.443549
2	21	414.337323
3	11	2464.801299
4	11	913.798846
5	10	3313.940985
6	9	156.320641
7	7	570.521719
8	6	201.207850
9	6	108.910973
10	6	458.969256
11	6	121.988037
12	5	100.088423
13	5	5723.491495
14	5	273.799959

Table 4		
Identified Cyclist Hot Spots		
Cluster Number	**Intersection**	**Statistical Significance**
1.	E. 2nd Street & Congress Avenue	100%
2.	Guadalupe Street & Furth Street	100%
3.	W. 21st Street & Nueces Street	100%
4.	W. Koeing Lane & N. Lamar Boulevard	100%
5.	W. 6th Street & Henderson Street	100%
6.	Guadalupe Street & W. 11th Street	100%
7.	S. Pleasant Valley Road & S. Lakeshore Drive	100%
8.	Duval Street & Elmwood Place	100%
9.	Barton Springs Road & Barton Place Trail	100%
10.	E. Riverside Drive & S. Pleasant Valley Road	100%
11.	Airport Boulevard & E. 51st Street	100%
12.	S. Congress Avenue &W. James Street	100%

Table 5				
Confidence Intervals for Cyclist Collisions Hot Spots Austin, Texas 2014- 2016				
Percentile	Clusters	Area	Points	Density
min	1	0.06188	5	65.454578
0.5	1	0.06188	5	65.454578
1.0	1	0.06188	5	65.454578
2.5	1	0.06188	5	65.454578
5.0	1	0.06188	5	65.454578
10.0	1	0.06188	5	65.454578
90.0	1	0.07639	5	80.795572
95.0	1	0.07639	5	80.795572
97.5	1	0.07639	5	80.795572
99.0	1	0.07639	5	80.795572
99.5	1	0.07639	5	80.795572
max	1	0.07639	5	80.795572

Table 6

STAC Cyclist Hot Spots Returned		Cluster Density
1	14	413.829461
2	12	492.718713
3	9	134.706755
4	9	176.274004
5	8	147.137659
6	7	176.369662
7	7	2235092.793425
8	6	243.744694
9	6	101.430991
10	5	830.481974
11	5	378.107073
12	5	237.872307

5. CRASH CORRIDOR ANALYSIS

The closing portion of the chapter will examine the top crash corridors in Austin, Texas for 2014- 2016. The frequency of collisions for pedestrians and cyclists were the determining factor in the crash corridor analysis. The crash corridor analysis will find similarities in the built environment, the speed of the roadway, and social other factors that increase the density of a pedestrian or cyclist collision clusters by examining descriptive collision data and the hot spot analysis together. This section will begin by examining the top ten crash corridors for pedestrians for the period of record and end with the top ten cyclist crash corridors.

The following corridor analysis does not include interstate highways in its analysis of pedestrian collisions in Austin, Texas. Interstate highways are not included in the crash corridor analysis because city streets represent most of the pedestrian collisions at 72.8% for the three-year period analyzed. Further examination of the crash locations revealed that many of the collisions along the U.S. highways were on high-speed boulevards that intersect with the highway or interstate. If a pedestrian or cyclist collision occurred on a city street while crossing a highway, that collision is in the corridor analysis by the city street name.

Pedestrian Crash Corridors

There were a total 1,017 pedestrian collisions in Austin, Texas from 2014 to 2016 with 2, 666 people involved in the collisions. The highest frequencies of pedestrian collisions on an Austin roadway or corridor were analyzed and ranked by the frequency of pedestrian collisions on that roadway.

Table 7 shows the top ten pedestrian crash corridors in Austin based on the frequency of collisions that occurred on that roadway, in Austin, for the three-year period of record. Five pedestrian crash corridors correspond with pedestrian crash clusters from the hot spot analysis. In total, North Lamar Boulevard has the highest amount of pedestrian collisions for the three-year period of record, followed by Congress Avenue. When examining similar characteristics in the built environment on North and South Lamar Boulevard clusters and their respective corridor each location- North Lamar Boulevard & Cooper Drive, North Lamar Boulevard & Kramer Lane, and South Lamar Boulevard and South 8th Street- is located across the street from a Capitol Metro bus stop. In fact, all statistically significant pedestrian crash clusters are located near public transportation stops.

Bus stops are often a reliable indicator of high-density pedestrian crash clusters (Chen and Zhou 2016). Bus stops are associated with high densities of pedestrian collisions due to the high volume of traffic on most public transit roadways, wide intersections with short pedestrian crosswalk signals, and limited visibility when bus or transit has stopped. These contribute to higher incidences of pedestrian collisions in this area. To mitigate bus stops being a hazard and an indicator of pedestrian collisions, physical buffers need to be placed to protect the road user and act as a warning signal. Additionally, lower speeds on the roadway, both by motorists and public transit operators alike, can lower the high rate of pedestrian collisions in this area.

Another common land use characteristic that the pedestrian clusters and high pedestrian crash corridors have in common is their proximity to schools. Five intersections from the pedestrian hot spot analysis are located within less than half a mile from a school. These intersections are South 1st Street & West William Cannon Drive, Cooper Drive & North Lamar Boulevard, North Lamar Boulevard & Kramer Lane, South Congress Avenue & West Oltorf Street, and East Rundberg Road & IH 35. The high density of pedestrian crash clusters near schools is consistent with previous research, which finds that pedestrian collisions are likely to occur in school zone areas (Chen and Zhou 2016).

The pedestrian hot spot analysis helps to identify the dense areas of pedestrian collisions, when analyzing these clusters, a spatial pattern emerges showing an almost continuous cluster moving east to west north of the Colorado River. As mentioned previously, Austin's road network lacks a reliable east to west route, especially for cyclists or pedestrians. Furthermore, the pedestrian hot spot analysis map shows a high density of pedestrian clusters located just within downtown Austin. The pedestrian collision clusters move from east to west, the cause of this is unknown, but this study assumes that high-speed motorists leaving the urban core might why; another cause for this could be that West Cesar Chavez Street and the area along the Colorado River are highly trafficked areas for pedestrians and cyclists. Physically buffered lanes for cyclists or pedestrians, low-speeds on city streets in the urban core, and traffic calming techniques to slow motorized traffic and mitigate severe or fatal injury need to be implemented in Austin's downtown to mitigate the future, avoidable collisions.

Cyclist Crash Corridors

Table 8 above shows the top ten crash corridors for cyclists in Austin, Texas for the years 2014 to 2016.

Guadalupe Street has the highest frequency of cyclist collisions in all of Austin with 55 over the span of three years. The Guadalupe Street corridor runs through a popular area in Austin known as The Drag. The Drag is teeming with the University of Texas at Austin students where Guadalupe Street is a major thoroughfare for university students. Additionally, this area of Austin has high mode shares of cyclists.

The one statistically significant cluster from the Guadalupe Street corridor that is not located near the University of Texas is Guadalupe Street and West 11th Street. This intersection is right next to Texas' Capitol building and is a sizeable four-lane roadway which pedestrians and cyclists frequent. Picture 1, shown above, shows both Congress Avenue and one block before Guadalupe Street & West 11th Street. Both Congress and Guadalupe Street offer cyclists designated bike lanes but provide no physical buffer from speeding traffic. Illustration 2 shows cyclists on Congress Avenue are mixing with 35 mp/h speeds and no protected bike lanes or protected intersections.

While researching the built environment and design of downtown Austin, this analysis noticed that physically protected cycling infrastructure runs east to west in downtown Austin, but not south to north- like Congress Avenue or Guadalupe Street. Illustration 3 shows Brazos Street and West 3rd Street in Austin. West 3rd moves east to west through Austin and Brazos moves south to north through downtown. Reasons to not apply road safe designs equitably for Austin might be that the north to south corridors is homogenous in direction. However, there are mass and speed differences that pose a safety hazard to both cyclists and pedestrians. Recommendations for the City of Austin would be to implement safe road design equitably, primarily through the urban core. Additionally, speeds in downtown Austin are too high for the volumes of pedestrian and cyclists that live and work and enjoy Austin. Some ways to lower speed in downtown Austin are narrow roadways traffic furniture that will physically impose lower speeds on motorized vehicles and encourage more sustainable forms of transportation in Austin, Texas.

Illustration 1

Illustration 2

ILLUSTRATION 3

TABLE 7

Top 10 Crash Corridors for Pedestrians in Austin, TX, 2014- 2016	Collisions
North & South Lamar Blvd	52
Congress & South Congress Ave	39
Burnet Road	23
East Oltorf St	22
East Riverside Dr	21
S. 1st Street	20
Cameron Rd	15
East & West 6th St	13
East 7th St	12
Guadalupe St	12

Table 8 **Cyclist Crash Corridor Analysis**

Cyclist Crash Corridor Analysis	Number of Cyclist Collisions
Guadalupe St	55
Congress Ave	45
Cesar Chavez Blvd	31
Barton Springs Rd	18
Jollyville Rd	15
South Pleasant Valley Rd	14
North Lamar Blvd	13
South 1st St	13
East Riverside Dr	12
Manor Rd	11

6. SUSTAINABLY SAFE ANALYSIS OF AUSTIN

In the final analysis of Austin, this research will look at Congress Avenue as its major corridor to analyze. In chapters 2 and 3, the analysis discovered that Congress Avenue and South Congress Avenue were second for crash corridors for pedestrians and cyclists active in Austin, Texas. Furthermore, when combined, these collisions for all three years in Austin totaled 84 active transportation collisions for an eight-mile stretch of road.

The following analysis uses Sustainable Safety as its framework. Previously mentioned in the literature review, the Dutch model of road safety framework has five basic principles that ensure road safety for all road users. "Functional" roadways; "homogeneity" of the road course, users, and speeds; "predictable" roadways and road user behavior; "forgiveness of the environment and road users;" and "state awareness by the road user" (Wegman, et al. 2006). These five-basic principle's form the basis of this analysis and apply to any roadways, but for this analysis is applied to one corridor-Congress Avenue in Austin, Texas.

Speed Management in Dutch Sustainable Safety

The key to Sustainably Safe roadways is speed management (Wegman, et al. 2006). While collisions have a series of influences before, high speeds make collisions more severe and more likely to occur, this is especially true when in the urban core (Wegman, et al. 2006). Managing speeds for city streets falls under principle three in the Sustainably Safe Framework, however, upon closer analysis, *every* principle in Sustainable Safety requires the speed of the roadway to match the built environment and its corresponding category (Wegman, et al. 2006). For this reason, the Sustainably Safe analysis of Austin, Texas will begin with a discussion on the speed of Congress Avenue's corridor, the impacts that the high speeds have on all road users, and the result of the high speeds maintained through the corridor.

Congress Avenue runs from the Texas Capitol South until it eventually ends at West Slaughter Lane just within Austin's Southern city limits. Due to Congress' location, the street attracts many people daily. Furthermore, the southern portion of Congress, beginning at Lady Bird Lake[8] is a cultural hub in Austin's community. The street segment that ends at Congress Avenue Bridge, is lined with restaurants, housing, and shops from East Riverside Drive in an almost continuing street range until West Oltorf Street. This portion of South Congress is consistently congested with cyclists, pedestrians, and motorists alike, which is why the speed limit, lack of protected cycle lane, and on-street parking for this street create road safety hazards for the thousands of people on it daily.

Starting at the Capitol building, Congress Avenue has no posted speed limit sign until right after the Congress Avenue Bridge. The roadway through downtown, however, is a six-lane, two-way. Due to road width on Congress Avenue, speeds often reach as high as 35 miles per hour. These speeds are unsafe for areas with high volumes of cyclists and pedestrians. Studies show that speeds higher than ~20 mph/h increase the risk of severe injury or fatality in the vulnerable road user (Wegman, et al. 2006, Pucher, et al. 2012).

As the road user moves South along Congress Avenue, the traffic volume grows and with that higher speeds. Past the Congress Avenue Bridge, onto the South Congress

[8] Also known as the Colorado River

portion of the corridor, the roadway widens even further, to allow for on-street parking. Speed limits that often change along the same corridor have consistency issues and therefore confuse road users (Wegman, et al. 2006). This causes tension on the roadway and within and along the corridor. For instance, Congress Avenue has no posted speed limit, until South Congress Avenue and East Riverside Drive; however, this segment of Congress Avenue has two schools within a four-block range and meaning that there is no consistent speed limit for South Congress during the afternoon or evening commute.

In chapter 3, this research discussed descriptive statistics for the City of Austin. This analysis looked at peak hours of commute in Austin and found that the morning collisions for active transportation users were lower than in the afternoon or evening. Census data supported this claim when looking at average commute times for the City, finding that further Census data supported this claim showing that 28.9% of the city places their commute time in the afternoon hours (U.S. Census Bureau 2016). Based on peak commute times and the frequency of pedestrian and cyclist collisions beginning at or around three o'clock in the afternoon, the fluctuation of speeds within such a short segment of roadway could contribute to higher than average collisions.

A traffic study done on the South Congress published by the City of Austin in 2013 has a suggested speed limit of 20 miles per hour for this portion of Congress Avenue (Bollich 2013). This recommendation of a 20 mile per hour speed limit for Congress was not adopted. Instead, the 30 miles per hour speed limit was adopted upon investigation of a reduction in collisions (Bollich 2013). The minor speed reduction on Congress was an improvement. However, the speed limit does not match its social environment. In the Sustainably Safe Framework for road safety, motorized traffic, when mixed with vulnerable road users, requires the speed limit to be reduced and separation of vulnerable road users (Wegman, et al. 2006).

Furthermore, the lack of a functional roadway category for Congress Avenue contributes to the corridors high-speeds and high density of collisions. Both principles apply to Congress Avenue. When functional roadway categories are established, speed limits are established alongside it, for a roadway to be functional one must understand the road's purpose. In other words, the principle of functionality refers to the roadway's function in the built environment. Looking at South Congress Avenue and Congress Avenue, the motorized traffic establishes the roadway category as a distributor road when the Congress Avenue corridor is an access road. Access roads are roads that provide the local community with access to stores, entertainment, or other social activities, a distributor road act as both an access and through road[9] (Wegman, et al. 2006).

This paper recommends that Congress Avenue from the Capitol until at least East William Cannon Drive adopt a speed limit of 20 miles per hour. Establishing a 20 mp/h speed limit here, contrary to popular belief, would not create congestion or slow the flow of traffic for motorists. Cycling or walking on city streets during peak hour commutes are often faster and more effective mode of transportation than the automobile when accounting for external costs of driving, research shows (Tranter 2012). Additionally, the common practice of roadway expansion, in conjunction with high-speeds on city streets, do not relieve congestion in urban settings (FLOW Project 2016). Literature focused on relieving urban roadway congestion found that multimodal transportation networks were

[9] Through roads are higher speed roadways in the Netherlands. Overall, the functional roadways principle names roads based on their actual use and need, so a 'through road' is a road you would you to travel *through* an area to get to (Wegman, et al. 2006).

most effective in reducing congestion on roadways and increasing roadway safety in the city (FLOW Project 2016).

Further findings suggest that the Congress Avenue corridor has too many pedestrian and cyclist collisions for only three years and too many social functions to have inconsistent and high speeds for vulnerable road users. In the next section, mode share on Congress Avenue is discussed; however, it is important to note that until the speed is lowered and subsequently managed in the Congress Avenue corridor, motorized traffic will continue to dictate its speed. As motorized traffic continues to dictate acceptable speed limits in areas with a significant amount of pedestrian and cyclist traffic, collisions between motorized traffic and vulnerable road users will continue to pose a safety risk to all road users.

Site Analysis of Austin

This sub-chapter will review the characteristics of the Congress Avenue corridor. First, the portion of the Congress Avenue corridor that runs from the Texas Capitol through downtown is discussed, followed by the southern portion of the corridor from East Riverside Drive until Elizabeth Street. This site analysis of the Congress Avenue corridor will include discussion of: the “functionality” of the corridor, the “homogeneity” of the corridor, the “predictability” of the corridor, the “forgiveness” of the corridor, and the “awareness” that the corridor provides to road users (Wegman, et al. 2006).The questions applied to the Congress Avenue corridor site analysis can is found in Table 9.

The functionality of the northern portion of the Congress Avenue corridor is a mix of social and functional. A mix of businesses is downtown and Texas Capitol creating a functional feel for it. However, Congress Avenue effectively dead-ends at the

Capitol grounds, making it as social as functional. Further down the Congress Avenue corridor, the roadway becomes an almost strictly social roadway, mixed with nightclubs, restaurants, parks, theatres, and boutique shops, the roadway serves a social purpose both in the daytime and the nighttime. The Congress Avenue bridge is also another social area in the evening time in March and April as many people gather to watch the large colonies of bats fly out from underneath the bridge.

Past the Congress Avenue bridge, South Congress becomes a mix of social and functional. The social aspect of South Congress is witnessed through the number of shops, bars, and restaurants that line its sidewalk. Additionally, just behind South Congress are residential areas, schools, and additional housing quarters. Meaning that, at the very least, this segment of the South Congress should have naturally lower speeds and less than the five-lane roadway it is currently.

Last, the functionality of South Congress' corridor is from its road design and that it is used as a north to south corridor by locals to avoid Interstate 35 congestion and long commute times to South Austin. For this reason alone, Congress Avenue *might* be labeled as a distributor road; however, the number of social activities that take place along the Congress Avenue corridor, especially in the late afternoon, evening, and at night dictate the roadway as a social space (Wegman, et al. 2006).

The Congress Avenue corridor lacks homogeneity of mass, speed, and volume. The purpose of having a homogenous roadway is solely to protect the most vulnerable of road users (Wegman, et al. 2006). If a street lacks a homogenous speed, for example, the vulnerable road user is at a biophysical disadvantage given the kinetic energy released from a collision with an object that has a large differential mass (Wegman, et al. 2006).

Therefore, to prevent severe or fatal collisions between motorists and pedestrians or cyclists, a roadway that is homogenous in direction (one-way road), speed, or volume (peak commute times should not put the road user at any higher risk of collision) serves as a buffer within the built environment. This principle seeks merely to *prevent* severe or fatal collisions. The concept of anticipating an accident on the roadway is the key for homogeneity.

The anticipation of roadway behavior brought this site analysis to the third question of predictable road design. For Congress Avenue that moves through Austin's downtown, road users supported the expected roadway behavior. This portion of the corridor is broader, and yet, speeds while still high were not as noticeably dangerous as South Congress. The feeling of predictable road user behavior for the northern portion of the Congress Avenue corridor may have been a result of being in the urban core. This follows the idea that when road users anticipate high pedestrian or cyclist traffic volume, their driving patterns adapt to lower speeds and they, usually, avoid the area unless necessary. The southern portion of the Congress Avenue corridor is different. Road users are aware that they are approaching downtown, yet speeds exceed the 30 mp/h speed limits. This could be due to commuters using South Congress as a distributor road to avoid the highway or could be reinforced by the road width and space for motorists, but more than likely a combination of both road design and road user behavior.

Forgiveness in the built environment for the Congress Avenue corridor does not apply. There are sidewalks provided for pedestrians, crosswalks, and pedestrian signage to alert motorists of intersection crosswalks along the corridor. Forgiveness for cyclists in the corridor is non-existent. Given the speed and volume of traffic, a designated cycle lane is not forgiving enough if or when a collision occurs along this roadway. Recommendations for this principle for the Congress Avenue corridor would be to give Congress Avenue and South Congress Avenue a road diet and then designate cycle paths along both sides of Congress Avenue. This would ensure that collisions between pedestrians, cyclists, and motorists are less severe and lessen traffic volume through corridor by narrowing the roadway.

Last, this subchapter looks at the state awareness of the road user along the Congress Avenue corridor. This directly relates to the amount of signage along the roadway and assess if the road user is aware of their surroundings, as well as, if the road user is prepared for the next road segment. Portions of Congress Avenue have minimal signage, creating confusion and putting vulnerable road users at considerable risk.

Road Users and Mode Share, Congress Avenue

In this section mode share data collected from Congress Avenue is discussed, the data provided in this section help to determine the appropriate speed and road design of the Congress Avenue corridor. As previously mentioned, Congress Avenue has two portions to its roadway- Congress Avenue which is north of Lady Bird Lake and South Congress which is south of the lake. The mode share data that collected for the corridor only captures a portion of the average daily traffic volume (ADT), because of this ADT values are compared to available ADT from the City of Austin.

Mode Share Data

Mode share data was collected for Congress Avenue and East 11th on March 14th, 2008 at 8 in the morning until 9 in the morning. Mode share data was then collected at the intersection of South Congress and East Riverside Drive from 3:30 in the afternoon until 4:30 in the afternoon that same day. The modal data collected counted automobiles, pedestrians, and cyclists from a predetermined line of sight. The second round of data collection was gathered, since the mode data gathered on March 14th was incomplete, however not collected. For this reason, ADT from the City of Austin supplements this mode share data.

The mode share for Congress Avenue at East 11th Street and South Congress Avenue and East Riverside Drive are listed in Table 10 below. The mode share data collected was collected during Spring Break, limiting the validity and accuracy of the data count. Furthermore, the accuracy of the numbers may be skewed since it is almost impossible to count every car, pedestrian, or cyclist alone. Last, some pedestrians may have been counted twice due to the line of sight and having crossed multiple times.

In all, the mode share for both the morning and afternoon count match available mode share data from the U.S. Census with 1.4% share of cyclists in the morning near the Texas Capitol and 2.3% share of pedestrians (U.S. Census Bureau 2016). The ADT listed on the City of Austin's website, last taken in 2002, lists Congress Avenue's ADT at 24, 467, but the mode count was taken at Congress and East 11th Street, if consistent in volume, would place that intersection's ADT for a twenty-four-hour period at 31, 536 for all modes combined (City of Austin 2002). The afternoon count at South Congress and East Riverside Drive had a modal share of 99% for automobiles. Based on available ADT from 2003, this area of South Congress Avenue has a traffic volume of 32, 665 in a twenty-four-hour period (City of Austin 2002). Based on the mode share data gathered in this research, ADT would be closer to 38, 784 for a twenty-four-hour period.

The reason for such a high modal share of automobiles at this intersection is likely due to its design, speeds from the intersection and that separate trails and paths for pedestrians and cyclists have located nearby the lake. These paths do not require cyclists to mix with motorized traffic making it a safer option. The data collected at these locations were assumed to have higher rates of active transportation users. The research found the data collected to be shocking since the higher share of active transportation users were found in the morning in downtown Austin. For this reason, consistent collection of mode share data should be gathered.

The Sustainable Safety Bicycling Audit Tool

The Sustainable Safety Bicycling Audit Tool (SSBAT) is a tool developed to gauge the cycle "friendliness" of a roadway (Tolford, Bike Easy Audit Tool (BAT): A Bicycle Encouragement Evaluation 2013). The tool combines road safety design with a scoring system to provide a numeric value or grade of the street for the cyclist or pedestrian (Tolford, Bike Easy Audit Tool (BAT): A Bicycle Encouragement Evaluation 2013). Using a systematic approach, the tool asks the interviewer to look for provided cyclist facilities, continuous facilities through the block or intersection, and if there are any obstructions or debris in the road. Finally, the tool integrates the score of the street from prior observation with the speed and ADT of the road to give a final recommendation for road design and safety.

Congress Avenue at East 11th Street and South Congress Avenue at East Riverside Drive received an audit with the SSBAT. The SSBAT results are listed in Table 12 for Congress at East 11th Street and Table 13 for South Congress Avenue at East Riverside Drive. Below, Table 11 explains the scoring system.

Congress Avenue at East 11th Street received a score of 1, while South Congress Avenue at East Riverside Drive received a score of 1 on the bike audit tool. These results are disappointing given the high rate of cyclists and pedestrians reported in the area. More importantly, the tool recommends infrastructure changes, speed changes, and volume changes. For Congress Avenue at East 11th Street, the street scored 1 due to its high ADT, mixed masses, and high speeds. This combined with an unprotected, vulnerable road user means that collisions are likely to occur on this street segment if the proper infrastructure, speed management techniques, or traffic flow is not homogenized for cyclists.

Therefore, this analysis recommends that Congress Avenue, north of the bridge, be turned into a homogenous roadway, like the east to west city streets in downtown Austin. South Congress Avenue at East Riverside Drive needs a road diet, however, instead of making this intersection and portion of the Congress Avenue Corridor a one-way road, road speed should be lowered to 20 miles per hour, and significant traffic calming for motorized vehicles need to be implemented. Additionally, physically separate cycle paths to create a buffer from different mass and speed vehicles should be implemented on this portion of the corridor.

Conclusion and Recommendations

Finally, this chapter concludes with recommendations to the Congress Avenue corridor. While policy changes and road design recommendations have been made throughout the entirety of this research, this portion will focus solely on Congress Avenue. For the portion of Congress Avenue that runs through Austin's downtown, a homogenous flow of traffic should be established, from the east to west city streets. Street parking should be limited to one side of the roadway to allow for a more walkable, pedestrian-friendly road, and cycle paths should be built along the roadway, extending out into the urban periphery. These adjustments would allow for a friendlier Congress Avenue in the urban core and establish a continuous pathway for cyclists out of Austin's downtown.

For South Congress Avenue, physically protected cycle lanes should be installed along both sides of the roadway and a designated bus lane assigned. Furthermore, the speed limit needs to be reduced to 20 miles per hour at least until West Stassney Lane, but ideally until West Slaughter Lane. These two recommendations would allow the corridor to keep its road width until the Congress Avenue bridge, until which the downtown corridor becomes a homogenous roadway by direction. This diversion of high-speed motorized traffic would match the social aspects of Congress Avenue and elevate mode share along this stretch.

Lastly, the proximity of this corridor to major tourist areas, like Zilker Park, Barton Springs Road, and the Texas Capitol means that reduced volume of traffic would only benefit this neighborhood. At the very least, physically protected cyclist lanes need to be implemented and two-sided street parking to be removed. These two actions would allow for a broad sidewalk along the corridor and physically protect cyclists from high-speed, bi- directional traffic, promising a reduction in the density of collisions in this corridor.

Table 9		**Street Interview Tool (SIT)**
Principal		Question
Functionality		What is the function or purpose of this road? Is it a social space or a functional space or a mix?
Homogeneity		Does the speed of the road match the function and purpose of the road? For instance, if the area is social in function, are speeds higher than 30 mph?
Predictability		Do road users behaviors support the road design and purposes of the space?
Forgiveness		Given the function and "feel" of the road, does the road segment provide a forgiving, that is appropriate for all road users?
Awareness		Does the roadway provide adequate signage and road design to prepare the road user for the road function?

Table 10	**Collected Mode Share Data**		
Time of Collection	Automobiles	Cyclists	Pedestrians
8am- 9am	1,264	19	31
3:30-4:30pm	1,604	4	8

Table 11	**Sustainably Safe Bicycle Audit Tool (SSBAT)**
5	Sustainable Safety
4	Targeted Improvement Needed
3	Multiple Improvements Needed
2	
1	Speed/Volume/Infrastructure Changes
0	
-1	

Table 11 Continued

-2	
-3	Potentially Unsafe to Hostile Conditions
-4	
-5	

Table 12 **Sustainably Safe Bicycle Audit Tool Congress Avenue**

Safe, Slow Mixed Street		Evaluation Criteria	Score
1.1: ADT 2,000 and below	Is a. the posted speed below 40km (32mph) and b. is there significant traffic calming?	If yes, to both "a" and "b," add 5. If no to both or a or b, score 0	0
1.2: ADT 2,001-4,000	Is a. the posted speed below 31km (20mph) and b. is there significant traffic calming?	If yes, to both "a" and "b," add 5. If no to both "a or" b," score 0	0
If you scored "5" on 1.1 or 1.2, STOP. You are done. If you answered "0," continue to #2			
Bike Facility Availability on Higher Speed/Volume Street			
2	Is there a bike facility present on the block?	If yes, add 5 and circle bike facility type below. If no, score 0.	5
Bike Facility Quality			
4	Is facility continuous for the entire block (excluding intersection)?	If no, subtract 1	-1
5	Is there a facility through the intersection?	If no, subtract 1	-1

Table 12 Continued			
5	Are there obstructions/debris or road surface hazards on the facility?	If yes, subtract 1	
6	Speed and Road Intensity	Is the bike facility appropriate for speed and traffic volume? (Find posted road speed in the chart below and check if bike facility on roadway matches. If no match, subtract 2)	-1
		Sum all rows together for the final score	1

Table 13	**Sustainably Safe Bicycle Audit Tool South Congress Avenue**		
Safe, Slow Mixed Street		Evaluation Criteria	Score
1.1: ADT 2,000 and below	Is a. the posted speed below 40km (32mph) and b. is there significant traffic calming?	If yes, to both "a" and "b," add 5. If no to both or a or b, score 0	0
1.2: ADT 2,001-4,000	Is a. the posted speed below 31km (20mph) and b. is there significant traffic calming?	If yes, to both "a" and "b," add 5. If no to both "a or" b," score 0	0
If you scored "5" on 1.1 or 1.2, STOP. You are done. If you answered "0," continue to #2			
Bike Facility Availability on Higher Speed/Volume Street			
2	Is there a bike facility present on the block?	If yes, add 5 and circle bike facility type below. If no, score 0.	5
Bike Facility Quality			
4	Is facility continuous for the entire block (excluding intersection)?	If no, subtract 1	-1
5	Is there a facility through the intersection?	If no, subtract 1	-1

Table 13 Continued			
5	Are there obstructions/debris or road surface hazards on the facility?	If yes, subtract 1	
6	Speed and Road Intensity	Is the bike facility appropriate for speed and traffic volume? (Find posted road speed in the chart below and check if bike facility on roadway matches. If no match, subtract 2)	-1
		Sum all rows together for the final score	1

7. CONCLUSION

This research looked at Austin, Texas, and their rates of collisions between cyclists and pedestrians. Beginning with a literature review on the causes of collisions, the importance of the vulnerable road user, the importance of the built environment in urban transportation, and possible framework to be adopted by Austin to create a safe road space for the city. The purpose which was to prepare for the analysis of Austin's densest active transportation clusters. The crash collision analysis conducted highlights dense clusters of pedestrian and cyclist collisions in Austin, Texas from 2014 to 2016. These dense clusters of collisions were discovered across Austin, Texas, but mainly located in the urban core and South Austin. Both pedestrians and cyclists' collisions had statistically significant clusters and both returned confidence intervals for collisions across the city. The spatial analysis, allowed this research to pinpoint areas or neighborhoods in Austin that have a high incidence of collisions and the descriptive and demographic analysis of Austin demonstrate that active transportation collisions are likely to increase in South Austin and its downtown.

Following the spatial and descriptive analysis of collisions, the research looked at mode share data and conducted its collection and site analysis review of the Congress Avenue corridor. The data collected confirmed the spatial and descriptive analysis suggestion that high speeds and wide road designs contribute to the high incidence of collisions within the urban core. Additionally, the growth Austin has experienced within the last decade only exacerbates the network, especially as IH 35 is continuously under construction and Austin lacks a real east to west corridor for its urban core.

Recommendation for Future Austin, Texas

For both cyclist and pedestrian clusters, Congress Avenue and North Lamar Boulevard present potential problems to active transportation users. As mentioned earlier, Congress Avenue has no protected bike lanes for cyclists and high-speed roads present potential problems even for pedestrians in Austin's urban core based upon average speed limit. Additionally, North Lamar Boulevard is the main north to south connector to and from the urban periphery. With it wide roadways and speeds of up to 40 miles per hour, being a pedestrian or cyclist becomes a hazard.

The analysis highlighted in the pedestrian hot spot analysis that bus stops in Austin, Texas are dangerous for pedestrians. To mitigate the hazards of bus stops in the area, pedestrian crosswalks with lights to stop crossing traffic should be considered at these locations, as well as significant traffic calming. For cyclists, the analysis showed that the urban core, particularly The Drag and around the University of Texas at Austin, is a dense area for cyclist collisions. Due to the high amount of university students in this area and the latent demand of Guadalupe Street, this trend is likely to continue unless significant road safety measures are undertaken. Currently, new plans are underway to improve the Guadalupe Street corridor and encourage walking and biking as a safer, more desirable mode in this area. However, as mentioned in the earlier chapter, cyclist hot spots in the urban core are distributed along corridors running north and south. Meaning the projects being implemented near West Campus and on The Drag should be applied to the Congress Avenue corridor, as well. The goal is to create equity amongst transit, meaning, one corridor or one neighborhood cannot be updated at a time, especially given the length of time it takes Austin to complete a road project. To mitigate the lack of equity in available transportation infrastructure available, low-speeds in dense pedestrian and cyclist corridors need to be implemented, at the very least.

Limitations of the Study

This research contributes to a growing trend in safe and sustainable transportation by looking for significant crash collision clusters for pedestrians and cyclists in Austin, Texas for 2014 to 2016. There were limitations to this study, first cyclist and pedestrian collisions often are underreported. Therefore, the data in this research are only a portion of the actual frequency of collisions that occurred over the last three years in Austin. Second, the data analyzed was not complete, there were missing ages of active transportation users, missing latitude, and longitude data, and missing speed limits, block ranges, etc. While this is to be expected, lack of consistent data makes identifying significant crash clusters difficult. The collection of mode share data was limited, at best, and in the future should not be conducted over spring break so that accurate numbers can be gathered. Last, this analysis only looked at collisions for three years in Austin. For a better picture of dense pedestrian and cyclist collisions in Austin, the study should look at a more extended period of record to indeed establish dense active transportation clusters.

Conclusion

In conclusion, this research looked for active transportation collisions in Austin, Texas for a three-year period. The findings of the GIS spatial analysis for the density of pedestrian and cyclist collision clusters discovered that those collisions are densest in Austin's downtown, moving north to south for cyclists, but more dispersed than pedestrian clusters. Pedestrian clusters appeared to move in an east to west fashion, suggesting that the barrier of IH 35 could continue to be a dividing line for Austin, Texas.

The research then visited a major north to south corridor, Congress Avenue, and analyzed the roadway. The findings supported the spatial and descriptive analysis that clusters occur in these areas due to a combination of road design, high-speeds, and other complex factors associated with collisions. Finally, this paper provided recommendations based on the findings of this research. In the future, further research should look at collision rates for a more extended period so that a more accurate portrait of Austin's collision rates and densities can be gathered.

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