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Addressing Bicyclist Safety through the Development of Crash Modification Factors for Bikeways

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16. Abstract

According to the Texas Department of Transportation Crash Record Information System database, there have been 26,148 crashes involving bicyclists (pedal cyclists) from 2010 to 2018 in Texas, resulting in 2,885 fatalities and suspected serious injuries and 22,937 non-incapacitating and possible injuries. Overall, bicycle crashes, as well as fatal and suspected serious injury crashes involving bicyclists, have been on the rise. Bicyclist safety concerns exist not only in cities and metropolitan areas but for the overall state highway network as well. In this project, the research team developed crash reduction factors for bikeway facilities implemented on Texas roadways to assess their safety and economic effectiveness. This research addressed the development of crash reduction factors for target crash types where sufficient bicycle facility information and crash information are available. To enable future cost-benefit assessments, the research included an estimate of the service life, installation, and maintenance costs of such facilities. The findings of this project indicate that installation of bikeway facilities can significantly improve safety for bicyclists. Implementing conventional bicycle lanes can help reduce total, fatal and injury, and property-damage-only crashes by 41–49 percent. Buffered bicycle lanes can improve safety by 20–65 percent, and separated bicycle lanes can improve safety by 41–53 percent. The economic benefits of these treatments were also found to be significantly higher than the estimated cost of installing them.

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LIST OF ACRONYMS AND ABBREVIATIONS.

A	Incapacitating (Suspected Serious) Injury Crashes
AACOG	Alamo Area Texas Coalition of Governments
AADB	Annual Average Daily Bicyclists
AADT	Average Annual Daily Traffic
AAMPO	Alamo Area Metropolitan Planning Organization
AASHTO	American Association of State Highway and Transportation Officials
ACS	U.S. Census Bureau's American Community Survey
ADA	Americans with Disabilities Act
AIC	Akaike Information Criterion
AV	Autonomous Vehicle
B	Non-incapacitating Crashes
BAC	Blood Alcohol Concentration
C	Possible Injury Crashes
CALTRANS	California Department of Transportation
CI	Confidence Interval
CMF	Crash Modification Factor
CORD	Central Okanagan Regional District
COSA	City of San Antonio
CRF	Crash Reduction Factors
CRIS	Crash Record Information System
CRIS	TxDOT Crash Record Information System
DES	TxDOT Design Division
DOT	Department of Transportation
EB	Eastbound
FARS	Fatality Analysis Reporting System
FHWA	Federal Highway Administration
ft	Feet
H-GAC	Houston-Galveston Area
HSM	Highway Safety Manual
K	Fatal Crashes
KABC	Fatal and Injury Crashes
LTS	Level of Traffic Stress
mi	Miles
MOD	Mobility on Demand
mph	Miles per Hour
MPO	Metropolitan Planning Organization
MSE	Mean Squared Error
NACTO	National Association of City Transportation Officials

NB	Negative Binomial
NCTCOG	North Central Texas Coalition of Governments
NHTSA	National Highway Traffic Safety Administration
NSBPAB	National Survey of Bicyclist and Pedestrian Attitudes and Behaviors
NTSB	National Transportation Safety Board
PBCAT	Pedestrian and Bicycle Crash Analysis Tool
PDO	Property Damage Only Crashes
PSM	Propensity Score Matching
RHiNo	TxDOT Roadway-Highway Inventory Network
RLV	Red-light Violation
RRD	TxDOT Rail Division
SAT	San Antonio District
SE	Safety Effectiveness
St. D.	Standard Deviation
TAZ	Traffic Analysis Zone
TM	Technical Memorandum
TPP	Transportation Planning and Programming
TRF	TxDOT Safety Division
TTI	Texas A&M Transportation Institute
TxDOT	Texas Department of Transportation
VMT	Vehicle miles traveled
WB	Westbound

CHAPTER 1. INTRODUCTION

BACKGROUND

According to the Texas Department of Transportation's (TxDOT's) Crash Record Information System (CRIS) database, there have been 26,582 crashes involving bicyclists (pedalcyclists) from 2010 to 2020 in Texas. These crashes have resulted in 3,989 fatalities and suspected serious injuries (KA), and 21,278 non-incapacitating and possible injuries (BC). Overall, bicycle crashes, as well as fatal and suspected serious injury crashes involving bicyclists, have been on the rise (Figure 1). This trend could continue increasing due in part to the increasing demographics of millennials and the active population in major metroplex areas and energy sector corridors.

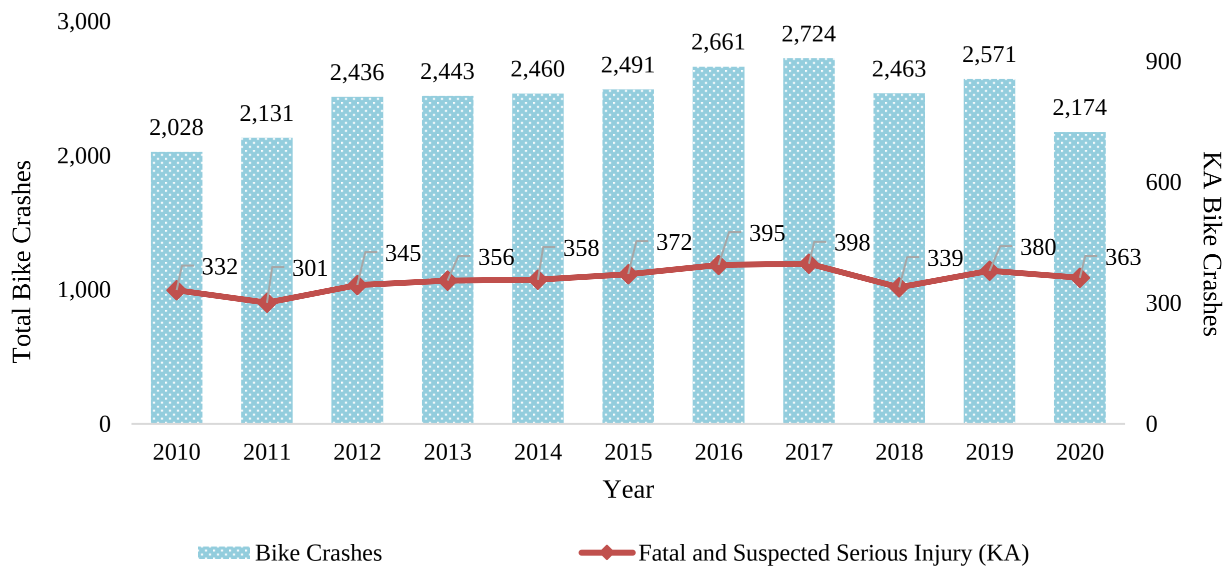


Figure 1. Bicycle Crash Trends in Texas.

Bicyclist safety concerns not only impact cities and metropolitan areas but the overall state highway network as well. On-system highways are usually in better conditions than local roads; hence, bicyclists more often use these roadways for training, recreational or commuting purposes. The use of state highways by bicyclists holds daunting safety implications: analysis of crashes on Texas roadways shows that 55 percent (371 out of 666) of overall bicyclist fatalities in 2010-2020 occurred on state highways. Table 1 presents the number of total and KA bicyclist crashes on on-system and off-system segments and intersections, together with the total death counts (i.e., number of bicyclists killed in crash).

Table 1. Distribution of Crashes Involving Bicyclists in Texas, 2010–2020.

Roadway Facility Type	On-System Bike Crashes			Off-System Bike Crashes			Total Bike Crashes		
	All	KA	Death Count	All	KA	Death Count	All	KA	Death Count
Segment*	3,618	1,011	320	9,073	1,342	210	12,691	2,353	530
Intersection	3,296	428	51	10,595	1,158	85	13,891	1,586	136
Total Roadway Network	6,914	1,439	371	19,668	2,500	295	26,582	3,939	666

**Segment refers to roadway segment that may or may not have a bicycle lane.*

To reduce bicycle-related crashes around the country, several U.S. jurisdictions are implementing a growing number of on-street bikeway designs. New on-street bikeway designs include (but are not limited to) protected bike lanes, two-way cycle tracks, buffered bicycle lanes, advisory bike lanes, through bike lanes, turn lanes, bike boxes, green pavements, etc. Existing studies indicate that drivers may be more cautious at roadways incorporating bikeway facilities since the facility design encourages them to expect to share the road with bicyclists. In a study by Sanders (2016), for example, both bicyclists and drivers reported greater comfort with more separation from bicycles. Moreover, bicycle lanes were found to be associated with greater predictability of cyclist behavior and, in general, were expected to alert drivers to expect cyclists on the roadway. Other studies have shown that intersections with bicycle-specific treatments can help decrease bicycle-related crashes in conflict zones. These treatments can improve visibility and slow traffic, which can help to reduce the number of crashes involving vulnerable road users and/or reduce the injury severity of such crashes.

The objective of the 0-7043 project is to develop crash modification factors (CMFs) for bikeway facilities implemented on Texas roadways, with the goal of assessing their safety and economic effectiveness. CMF is the ratio indicating the expected effect of the roadway engineering treatment on target crashes (i.e., crashes involving bicyclists).

Crash Modification Factors

There is very little research concerning the safety implications of on-street bikeway facilities. Although there are several studies that identify crash modification factors associated with bicycle facilities, many of these are low rated, which has contributed to the need for this research. The FHWA's CMF Clearinghouse (available at: https://www.cmfclearinghouse.org/) hosts the CMFs for the safety treatments that have been successfully implemented in the United States and abroad. The query on bicyclist safety yielded 168 CMFs; 32 of these were developed for all roadway functional systems, 9 were developed for principal arterials. The functional system for the remaining 126 CMFs was not specified (Figure 2). Also, as can be observed in the figure, most of the existing CMFs were developed for roadway segments (136 CMFs) as opposed to intersections (31 CMFs).

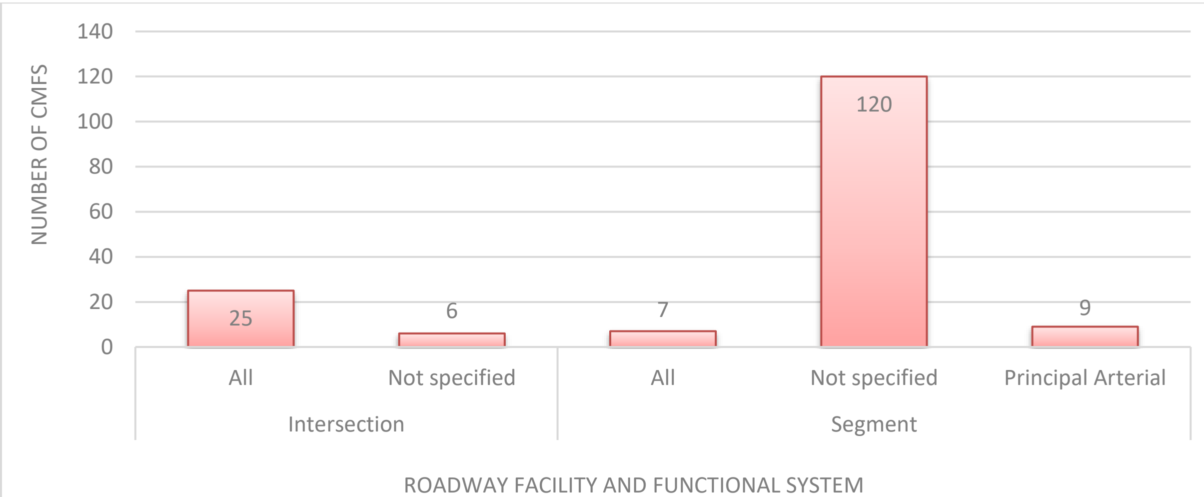


Figure 2. Number of CMFs Developed per Roadway Type.

Table 2 shows the name of the treatment along with the CMF for total crashes, fatal and injury crashes, and property damage only (PDO) crashes. Depending on the study, the fatal and injury crashes are defined as a combination of fatal (K), suspected serious injury (A), non-incapacitating injury (B), and possible injury (C) crashes; for example, KA crashes refer to a combination of fatal and suspected serious injury crashes.

All of the CMFs shown in this table were developed for vehicle-bicyclist crashes. Many of the treatments provide the CMFs for total crashes only. This is due to the fact that bicyclist crashes are very rare thus do not have enough sample size for conducting data-driven safety analysis, while the CMFs developed for the bicyclist crashes were not significant and had low-star rating. Moreover, due to police crash-reporting practices, many bicyclist crashes are not included in police reports, thus reducing the opportunities for developing high-quality CMFs. The list of all CMFs queried from the CMF Clearinghouse is presented in the appendix to this report. This table shows the name of the treatment (i.e., bikeway facility type), roadway facility types (i.e., intersection/segment), functional system, crash type, severity, and CMF. As observed, the CMF Clearinghouse mainly inventories the CMFs for total, KABC, and PDO bicyclist crashes.

Table 2. Name and Average CMF of Treatments (per Crash Type and Severity).

Name of Treatment	CMF		
	Total Crashes	KABC	PDO
Install bicycle boulevard	0.4		
Install bicycle lanes	0.9	1.0	1.0
Install bicycle tracks	1.4	1.1	1.1
Install cycle tracks, bike lanes, or on-street cycling	0.4		
Install separated bicycle lane	1.2		
Install shared path	0.8		
Install sidewalk barrier	1.6	2.3	
Install a cycle track 0–2m from the side of the main road with cyclist priority at intersections	1.0		
Install a cycle track 2–5m from the side of the main road with cyclist priority at intersections	0.6		
Install a cycle track over 5m from the side of the main road with cyclist priority at intersections	0.9		
Install a speed hump or other traffic calming measure for through motorized vehicles on the main road	1.3		
Install a two-way cycle path with cyclist priority at intersections	1.8		
Install additional travel lanes and a raised island	1.1		
Install additional travel lanes, a raised island, and left-turn lane	1.0		
Install bicycle lanes at signalized intersections	1.1		
Install bicycle lanes at signalized intersections with exclusive right-turn lanes	1.0		
Install bicycle lanes at signalized intersections with shared through/right turn lanes	1.0		
Install colored bicycle lanes at signalized intersections	0.6		
Install high-quality markings for bicycle crossings with cyclist priority at intersections	1.7		
Install of left-turn lane or left-turn section on the main road where cyclists have priority at the intersection	1.1		
Install raised bicycle crossing or other traffic calming measure for vehicles entering or leaving the side road	0.5		
Install raised island and left-turn lane	1.5		
Install raised island with a separate space for cyclists	1.4		
Install red color and high-quality markings for bicycle crossings with cyclist priority at intersections	2.5		
Install red color for bicycle crossings with cyclist priority at intersections	1.5		
Install vehicle travel lanes	1.7		
Introduction of restricted visibility from vehicles on a minor road to approaching bicyclists at intersections with cyclist priority	1.4		
Introduction of very poor visibility from vehicles on a minor road to approaching bicyclists at intersections with cyclist priority	0.5		
Moving a separate bicycle crossing to a four-legged intersection	1.3		
Moving a separate bicycle crossing to a three-legged intersection	0.8		

Name of Treatment	CMF		
	Total Crashes	KABC	PDO
Presence of crosswalk at signalized intersection (bike crashes)	8.8		
Provide bike lanes	0.7	0.7	
Raised bicycle crossings		1.1	
Replacement of traditional intersection with roundabout with a grade separated cycle path	0.6	1.3	
Replacement of traditional intersection with roundabout with separated cycle path	0.8	1.4	

REPORT STRUCTURE

This document is organized as follows:

- Chapter 2 presents the results of the literature review and state of the practice review
- In Chapter 3 presents the findings from the agency survey
- In Chapter 4 presents the safety database development process
- Chapter 5 presents the safety effectiveness evaluation method and crash modification factors
- Chapter 6 presents the guidelines for implementing the results of this project in TxDOT’s Highway Safety Improvement Program (HSIP).
- Chapter 7 presents the summary and conclusions of this project.

CHAPTER 2. LITERATURE REVIEW AND STATE OF THE PRACTICE

REVIEW OF BICYCLIST CRASH-CONTRIBUTING FACTORS

Numerous studies have been conducted to evaluate pedalcyclist safety based on hospital or police records, observations, and surveys. The majority of studies have identified road users' behavior and infrastructure characteristics as contributing factors to bicycle-motorized vehicle collisions. Other studies identified variables related to exposure, vehicles, and built environmental factors as contributing factors (Prati et al., 2018). In this chapter, a comprehensive literature review regarding bicyclist safety is performed based on five broad categories of crash-contributing factors (also known as contextual factors) as shown in Table 3.

Table 3. Bicyclist Crash Contributing Factors

Demographic & Socio-Economic Factors	Roadway & Bikeway Facility Type	Built Environment & Roadway Infrastructure
• Age • Gender • Race • Disability • Education • Household income	• Rural/Urban • Intersection/Segment • Bicycle facility	• Land use • Street parking • Bus stops • Street lighting • Driveway access • Street network density • Roadway design elements
Driver & Bicyclist Behavior	**Bicyclist Exposure & Operations**	**Temporal Factors**
• Distracted and impaired driving • Vehicle overtaking bicyclist • Use protective gear (e.g., helmet) • Cyclist-driver awareness/interaction	• Speed limit • Bicyclist volume (average annual daily bicyclists, AADB) • Vehicle volume (average annual daily traffic, AADT)	• Season • Weather • Time of day • Day of the week • Natural light

Roadway and Bikeway Facility Type

Regarding the geographic locations where fatal bicycle crashes are distributed, the National Highway Traffic Safety Administration (NHTSA) reports that, in 2017, the majority of pedalcyclist fatalities occurred in urban areas (75 percent) compared to rural areas (25 percent) (NHTSA, 2017). Meanwhile, pedalcyclist fatalities in urban areas increased by 48 percent in 2018 compared to 2009; rural areas decreased by 8.9 percent, a drop likely due to the lower exposure of bicyclists in rural areas. A route preference survey for adults conducted in Vancouver, Canada, found that rural roads and routes on major streets were least likely to be chosen for cycling (Winters and Teschke, 2010). And in the 2018 U.S. Department of

Transportation's (DOT) Mobility on Demand Initiative, rural communities were identified as a key issue related to equity and accessibility (Shaheen et al., 2018).

Research also suggests that more bicycle crashes occurred at intersections than non-intersection locations (Klassen et al., 2014). Some studies have noted the positive association between intersection density and bicycle crash frequency (Wei and Lovegrove, 2013; Siddiqui et al., 2012; Strauss et al., 2013), but high intersection density appears to be related to much lower crash severities (Marshall and Garrick, 2011). In addition, the more complex intersections are, the more likely they are to be the site for bicycle crashes (Wei and Lovegrove, 2013). Significant factors affecting the bicycle-motor vehicle intersection collision severity include, but are not limited to, the interaction between roadway and approach-control type; the existence of partial crosswalks and bike signs; motor vehicle speeds; the cyclist's gender; and the cyclist's age (Klassen et al., 2014; Harris et al., 2013).

Despite a higher percentage of bicycle-motor vehicle crashes at intersections, fatal and severe bicycle-motor vehicle crashes disproportionately occur at non-intersection locations. In 2017, over 60 percent of pedalcyclist fatalities occurred at mid-block locations in the United States (NHTSA, 2019). Motor vehicles tend to travel at faster speeds midblock compared to intersections (National Transportation Safety Board [NTSB], 2019). Downhill grades increased risks at both intersections and non-intersections (Harris et al., 2013). Other factors significantly affecting bicycling risk at midblock sites include, but are not limited to, the bike or pedestrian infrastructure; the presence of streetcar or train tracks; construction and route grade; on-street parking allocations; and the driver's age (Klassen et al., 2014). Bicycle-specific infrastructure was found to be associated with reduced injury risk at midblock locations (Klassen et al., 2014). Therefore, the National NTSB recommends improving public roadway infrastructure with separated bike lanes, intersection treatments, and road diets to reduce crashes at midblock and intersection locations (NTSB, 2019).

Numerous studies indicate that bike lanes appear to be somewhat beneficial for safety; however, findings about their effectiveness are rather inconclusive. According to Wei and Lovegrove (2013), as early as 1976, Lott et al. found that the on-bike lanes, the frequency of bicyclist crashes was reduced by 53 percent, and the frequency of all crash types was reduced by 31 percent in Davis, California. When evaluating the effectiveness of on-street bicycle lanes in Charlotte, North Carolina, Pulugurtha and Thakur (2015) discovered that bicyclists are at three to four times higher risk on segments without on-street bicycle lane compared to segments with on-street bicycle lanes. Behavioral studies also demonstrate the safety benefits of bike lanes. For instance, the observational studies of Duthie et al. (2010) in three large Texas cities concluded that bicycle lanes create a safer and more predictable riding environment relative to wide outside lanes.

Built Environment and Roadway Infrastructure

A rich body of literature has focused on the impact of the built environment and land use on bicycle safety. Results consistently indicate that the built environment and land use have a significant impact on bicyclist injury and crash risk. For example, research shows that higher rates and/or increased severity of bicycle crashes are associated with roads or areas with more road signals, street parking, automobile traffic, bus stops, sidewalk/bike lane barrier, etc. The opposite is true for roads or areas with improved street lighting, increased land use mixture, bicycle lanes, and lower speed limits. Selected research under this subject are presented below in chronological order:

Reynolds et al. (2009) reviewed studies prior to 2009 about the impact of transportation infrastructure on bicyclists' safety. The researchers divided infrastructure into two categories: intersections and segments. Intersection studies were found to focus mainly on roundabouts. Though roundabouts are a positive road safety treatment for cars, this review found that multi-lane roundabouts can significantly increase the risk to bicyclists unless a separated cycle track is included in the design. The studies of straightaways suggested that sidewalks and multi-use trails pose the highest risk, major roads are more hazardous than minor roads, and the presence of bicycle facilities (e.g., on-road bike routes, on-road marked bike lanes, and off-road bike paths) was associated with the lowest risk.

Ma et al. (2010) investigated the risk factors associated with severe crash occurrences on arterial roads in Beijing, China. Results show that arterial roads with heavier traffic volumes, more road lanes, and higher speed limits tended to have more severe crashes. Medians were helpful in reducing severe crash risk. Higher risks of severe crashes were generally associated with intersections having small angles and countdown signals and road segments having higher side-access densities and the presence of bus stops. Barriers that separated bikeways from roadways on minor roads were found effective in significantly reducing severe crash risk at intersections.

Wei and Lovegrove (2013) hypothesized a global model on the relationship between bicycle use and road safety levels in North America. Using urban data from the Central Okanagan Regional District (CORD) in Canada, they tested their hypothesis with collision prediction models. The model results revealed that bicycle-auto collisions were directly associated with total lane kilometers, bicycle lane kilometers, bus stops, signals, intersection density, and arterial-local intersections; however, bicycle-auto collisions were inversely associated with drive commuters and drive commuter percentage. The findings about drive commuters are somewhat counterintuitive. This could be attributed to the fact that these models were developed in a North American community with low bicycle use (less than 4 percent).

Chen (2015) conducted a spatial study — with the Traffic Analysis Zone (TAZ) in Seattle as the unit of analysis — to understand the relationship between built environment factors and bicycle crashes with motor vehicles involved. The results indicate that (1) safety improvements should focus on places with more mixed land use; (2) off-arterial bicycle routes are safer than on-arterial bicycle routes; (3) TAZ-based bicycle crashes are spatially correlated; (4) TAZs with more road signals and street parking signs are likely to have more bicycle crashes; and (5) TAZs with more automobile trips have more bicycle crashes. This study suggests that the local authorities should lower the driving speed limits, regulate cycling and driving behaviors in areas with mixed land use, and separate bike lanes from road traffic.

Chen et al. (2016) later performed another analysis with bicycle collision data in Seattle to estimate the effects of built environment factors on cyclist injury severity in automobile-involved bicycle crashes. Their findings show that employment density is negatively associated with cyclist injury severity, whereas increased land use mixture is correlated with lower likelihood of severe injury or fatality. The study also found that improving street lighting can decrease the likelihood of cyclist injuries and increasing speed limit is positively associated with the probability of evident injury and severe injury or fatality. Finally, the study concludes that cyclists are more likely to be severely injured when large vehicles are involved in crashes.

Mukoko et al. (2019) examined the influence of network, land use, and demographic characteristics on the number of bicycle-vehicle crashes in Mecklenburg County in North Carolina . The results suggest that bicyclists are more often involved in crashes while 1) traveling on segments with no bicycle lane, 2) when there is traffic light, 3) when speed limit is 45 mph, and 4) at residential (densely populated), and heavy industrial areas.

Raihan et.al (2019) developed crash modification factors (CMFs) for bicycle crashes for different roadway segment and intersection facility types in urban areas with four years (2011–2014) of crash data from Florida. The results reveal that, on segments, lane width, speed limit, grass in the median, and increased bicycle activity have positively contribute to reducing bicycle crashes. Also, the study finds, the presence of sidewalk and sidewalk barriers increased the bicycle crash probabilities. At intersections, increased bicycle activity and the presence of bus stops were found to correlate with a higher probability of bicycle crashes; whereas, protected signal control had a positive impact on bicycle safety.

Bicyclist Exposure and Operational Factors

Bicyclist exposure is a measure of the number of potential opportunities for a motor vehicle-involved crash to occur and is governed by two major factors: *bicyclist volume* and *motor vehicle volume*. Besides the number of trips, bicycle crash and exposure are affected by where and when rides occur, as well as the length of the rides; the skill, knowledge and application of safe behaviors by the cyclist; and the application of safe behaviors by drivers around the cyclist (NHTSA, 2011). The effect of bicyclist exposure on bicycle safety has been widely discussed.

Many studies report a negative relationship between bicyclist exposure and conflict rate. A study by Ekman (1996) determined that the conflict rate for an individual bicyclist is higher when the number of bicyclists is low, with this conflict rate decreasing as the flow of bicyclists increased. In another study conducted by Jensen in 2002, the results indicated a 40 percent increase in bicycle-kilometers traveled corresponded to a 50 percent decrease in seriously injured bicyclists in the City of Copenhagen. Later studies conducted by Jacobsen (2003), Nordback and Marshall (2011), Kaplan and Giacomo Prato (2015) and others support the conclusion that more bicyclists on the road can help reduce the crash risk for the individual bicyclist.

While studies generally attribute the bicyclist "safety in numbers" effect to changes in driver behavior and awareness, a recent study suggests that safety for all road users may result from reaching a threshold of bicyclist volumes that compels drivers to drive slower. In the attempt to better understand the phenomenon of lower fatality rates in bike-oriented cities, Marshall and Garrick (2016) examined 11 years of road safety data (1997–2007) from 24 California cities; they discovered that cities with a high bicycling population rate are associated with a much lower fatality risk for all road users when compared to other cities in this study. This strongly suggests that crashes occur at lower speeds in cities with a high bicycling rate. The conclusion states that while the bicycle infrastructure itself might help concerning traffic calming, it may be that the actual presence of a large number of bicyclists can change the dynamics of the street enough to lower vehicle speeds.

Demographic and Socio-economic Factors

Bicycle crash statistics show that bicyclists belonging to a certain age or gender were involved in more bicycle crashes than others. According to the National Highway Traffic Safety Administration (NHTSA), the average age of pedalcyclists killed in motor vehicle crashes has steadily increased from 41 to 47 over the past 10 years (2008–2017) (NHTSA, 2019). In 2017, the largest number of pedalcyclist fatalities were in the 50–54 age group. Children under the age of 15 account for seven percent of all pedalcyclist deaths. The majority of pedalcyclists killed (89 percent) were males. And the population-based pedalcyclist fatality rate was eight times higher for males than for females.

Similar findings were revealed in other studies. Vanparijs et al. (2015) reviewed 20 bicycle safety papers published prior to 2015. The results suggest higher incidence rates of bike accidents for men compared to women, and an increased risk of injury for cyclists aged 50 years or older. The study by Chen and Shen (2016) suggests that age is positively related to increasing crash severityOlder cyclists were found prone to severe injury or fatality crashes. The other study by Kröyer et al. (2015) states that senior cyclists have an elevated risk of serious or fatal injuries.

Besides age and gender, the impact of other demographic and socio-economic factors like race and income have also been discussed in bicycle safety and equity studies. After analyzing road fatalities in the United States that took place over the course of a 24-year period (1989–2012), Marshall et al. (2018) found disparities in road fatalities along racial and ethnic lines, particularly for pedestrians and bicyclists in predominantly black or Hispanic neighborhoods. Additionally, Rebentisch et al. (2019) analyzed pedestrian and cyclist crashes in New York City and found that higher income and gentrified areas had better access to protected bicycle infrastructure, while low-income communities and communities of color did not have access to such infrastructure; hence, they were overrepresented in severe injury and fatality rates among cyclists.

The demographic and socio-economic factors play a substantial role in bicycling safety perceptions, too. The survey results from over 3,000 bicyclists living in six large Canadian and U.S. cities reveal that bicyclists who were male, younger, lower-income, had young children, had a high-school education, and bicycled more frequently were more likely to perceive bicycling in their city as “safe” (Branion-Calles et al., 2018).

Though bicycling can benefit and improve the health of disabled people, disability is under-researched in cycling studies. Clayton et al. (2017) note that the health and wellbeing benefits of cycling for disabled people are evident, but that there are many issues to be resolved before cycling infrastructure is accessible to (and usable by) disabled people. There is a need to undertake further research in order to better understand, in greater detail, how this can happen.

Behavioral Factors

The behavior of bicyclists and drivers directly influence bicycling safety. A multi-year study of fatal and severe bicycle crashes in TxDOT’s Austin District between 2011 and 2018 shows that the top three crash scenarios involve motorists making a left turn/merge (20 percent), making a right turn/merge (13 percent), or overtaking bicyclist (10 percent) (Dai and Hudson, 2019). The top three contributing factors among drivers are driver inattention (22 percent), failed to yield right-of-way – turning left (21 percent), and failed to yield right-of-way – to bicyclist (8 percent). For bicyclists, they are other (17 percent), bicyclist inattention (13 percent), and bicyclist failing to yield the right-of-way to the vehicle (12 percent).

At the national level, the combined Fatality Analysis Reporting System (FARS) dataset for 2010 to 2015 shows that bicyclists failing to yield the right-of-way to vehicles is the most common bicyclist actions (35 percent) prior to bicyclist fatalities. The rest of the actions among the top five include no improper action (26 percent), not visible (12 percent), failure to obey traffic signs, no signals or officer present (12 percent), and wrong-way riding (8 percent). Inattentiveness only accounts for 3 percent of bicyclist actions prior to bicyclist fatalities in this dataset. Comparing to the findings in the TxDOT’s Austin district dataset, this result may suggest that inattentiveness could lead to more severe bicycle crashes.

The concerns about inattention and traffic violations were also highlighted in the reported result of the 2012 National Survey of Bicyclist and Pedestrian Attitudes and Behavior (NSBPAB) survey (NSBPAB, 2012). Two of the five most frequently reported reasons that made respondents consider it dangerous to bicycle in their neighborhoods relate to bicycling or driving behavior. The two reasons are distracted drivers/riders and drivers/riders not obeying traffic laws. The use of electronic devices was surveyed as a distraction for bicycling. One-fifth of the respondents who rode a bicycle within the year before the survey, reported using electronic devices during at least some of their bicycling trips during the time period. When it comes to compliance with traffic laws, almost all respondents were aware that the rules that apply to motor vehicles regarding traffic lights and stop signs also apply to bicyclists. However, awareness is not equal to compliance. Red-light violations (RLVs) are a frequent and typical bicyclist behavior (Pai and Jou, 2014). Guo et al. (2018) discovered that RLV is more likely to occur at signalized intersection crosswalks than road segment crosswalks. In the study conducted by Johnson et al. (2011), cyclists turning left were found to be 28.3 times more likely to run a red light at intersections as compared to those who travel straight through; and young bicyclists were more likely to run red lights.

The 2012 NSBPAB survey also assessed the awareness of helmet laws. Forty-three percent of the respondents believed their locality had such a law. However, nearly half of the respondents reported that they hadn’t worn a helmet when bicycling in the past year. In the study by MacAlister and Zuby (2015), only 14 percent of cyclists involved in a crash had worn a helmet; similarly, only 13 percent of fatally injured cyclists had worn a helmet. Kullgren et al. (2019) analyzed fatal cycling crashes that occurred between 2006 and 2016 in Sweden and estimated that almost half of non-helmeted bicyclists who died would have survived with a helmet. In addition to wearing a helmet, using bicycle lights and reflective clothes could also reduce the crash risk for bicyclists.

Driving or biking under the influence of alcohol is another serious risk factor for bicycle crashes, especially for fatal crashes. In 2017, alcohol involvement (BAC of 0.1+ g/dl) was reported in 37 percent of the fatal pedalcyclist crashes (NHTSA, 2017). After studying single bicycle–single vehicle crashes in Virginia from 2010 to 2014, Robartes and Chen (2017) found that automobile driver intoxication increases the probability of a cyclist fatality six-fold and doubles the risk of a severe injury; they also found that bicyclist intoxication increases the probability of a fatality by 36.7 percent and doubles the probability of severe injury. Additionally, bicycle and automobile speeds, obscured automobile driver vision, specific vehicle body types (SUV, truck and van), vertical roadway grades, and horizontal curves elevate the probability of more severe bicyclist injuries.

Temporal Factors

Temporal factors like daylight and weather are also studied in bicycle-crash analysis research. While more bicycle crashes occurred in daylight (Kullgren et al., 2019; Beck et al., 2016), more pedalcyclist fatalities occur at night (NHTSA, 2017).

When dividing the time of day into eight 3-hour intervals starting at midnight, NHTSA found that, during weekdays, the time period with the highest frequency of pedalcyclist fatalities was 6:00 p.m. to 8:59 p.m. (20 percent). Day of the week is defined as weekday (6:00 a.m. Monday to 5:59 p.m. Friday) and weekend (6:00 p.m. Friday to 5:59 a.m. Monday). The second-highest percentage (18 percent) of pedalcyclist fatalities occurred between 3:00 p.m. and 5:59 p.m. On weekends, the time period with the highest frequency of pedalcyclist fatalities was 9:00 p.m. to 11:59 p.m. (25 percent), followed by the period from 6:00 p.m. to 8:59 p.m. (22 percent).

Weather, especially in winter, is often discussed as a cycling barrier. Hoffman et al. (2010) found that December and January were the months with the highest bicycle incident rate. de Niska (2010) found that the majority of bicycle accidents were single bicycle incidents due to slippery surfaces, mainly caused by ice and snow. The participants in the focus groups of this study perceived a considerable increase in the incident risk during winter, mainly due to slipperiness and darkness. In addition, the study of de Vanparijs et al. (2012) found that the incident rate for cyclists, during weeks when the roads were snowy or icy, is twice as high as the incident rates for weeks with dry surface conditions.

STATE OF THE PRACTICE

In this section, the researchers present the list of on-street bikeway facility types (i.e., safety improvements targeting bicyclist safety) installed on the nation's roads, as well as the list of crash modification factors (CMFs) associated with some of these facilities. A list of on-street bikeway facility types is compiled based on the Bikeway Selection Guide by Federal Highway Administration (FHWA, 2019), the Guide for the Development of Bicycle Facilities by the American Association of State Highway Officials (AASHTO, 2012), and the Urban Bikeway Design Guide by the National Association of City Transportation Officials (NACTO, 2014). The list of on-street bikeway facilities is divided into segment treatments and intersection treatments. The following section summarizes selected types of on-street bikeway facilities and literature review outcomes.

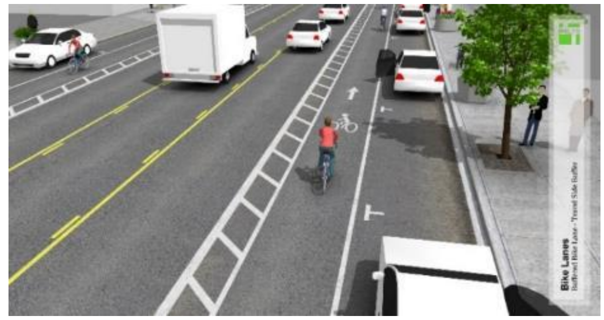
Segment Treatments

The list of bikeway facilities installed on roadway segments includes conventional bike lane, buffered bike lane, contra-flow bike lane, left-side bike lane, one-way protected cycle track, raised cycle track, two-way cycle track and shared lane marking (aka, sharrow). Figure 3 provides an example of bikeway facility types implemented on roadway segments.

Conventional Bicycle Lane

A bike lane (Figure 3 (a)) is defined by NACTO as a portion of the roadway designated by striping, signage, and pavement markings for the preferential or exclusive use of bicyclists. Conventional bike lanes are typically located on the right side of the street, between the adjacent travel lane and curb, road edge, or parking lane.

a) Bike lane



b) Buffered bike lane

c) Contra-flow bike lane

d) Green pavement

e) One-way cycle track (aka separated bike lane)

f) Two-way cycle track

Source: NACTO (2014)

Figure 3. Segment Treatments for Accommodating Bicyclists

Buffered Bike Lane

A buffered bike lane (Figure 3(b)) is defined by NACTO as a conventional bicycle lane paired with a designated buffer space separating the bicycle lane from the adjacent motor vehicle travel lane and/or parking lane by striping. It can be applied anywhere a standard bike lane is being considered, especially on streets with extra lanes or extra lane width. It is expected to provide more protection than conventional bicycle lanes on streets with high travel speeds, travel volumes and or truck traffic. Among the cities that have installed buffered bike lane, an evaluation survey in Portland, Oregon, showed that bicyclists chose to ride on the segment more often than before the buffered bike lanes were installed; both bicyclists and drivers favored the additional separation provide by the buffered bike lanes. However, the results also indicated confusion over when (or if) motor vehicles were allowed to use the buffered bike lane.

Contra-Flow Bike Lane

A contra-flow bike lane (Figure 3(c)) is defined by NACTO as a bicycle lane designed to allow bicyclists to ride in the opposite direction of motor vehicle traffic [58]. It converts a one-way traffic street into a two-way street: one direction for motor vehicles and bikes, and the other for bikes only. It is most applicable to low-speed, low volume streets, where large numbers of bicyclists are already riding the wrong way or the contra-flow lane can provide significant convenience and safety. An evaluation of the contra-flow bike lanes installed on New Hampshire Avenue in Washington, D.C., reported enthusiastic agreement from cyclists on the fact that the contra-flow bike lanes made cycling safer and easier (Dill, 2012).

Left-side Bike Lane

A left-side bike lane is defined by NACTO as a conventional bike lane placed on the left side of one-way streets or two-way median divided streets. Its major benefit is to avoid any potential right-side bike lane conflicts on streets with parking, transit stops, right-turn traffic, etc. However, the left-side bike lane is not commonly used, and the effectiveness is controversial. For instance, drivers who turn right may not see the cyclists coming from the right side because the drivers were focused on finding a gap in the traffic coming from the left (Johannsen and Jansch, 2017)

Colored Bike Lane

As NACTO explains it, the benefits of colored pavement (Figure 3 (d)) within a bicycle lane include increasing the visibility of the facility, identifying potential areas of conflict, and reinforcing priority to bicyclists in conflict areas and in areas with pressure for illegal parking. However, as was the case with many other bicycle facilities, the findings of colored bike lane effectiveness were mixed. While the colored bike lanes had a positive impact on bicyclist-motorist interactions and safety perceptions, they also have limits (Strauss et al., 2013; Sadek et al., 2007). For example, the evaluation of blue bike-lane treatments in Portland, Oregon, revealed that significantly higher numbers of motorists yielded to cyclists and slowed or stopped before entering the blue pavement areas; also, more cyclists followed the colored bike-lane path. However, the blue pavement also resulted in fewer cyclists turning their heads to scan for traffic or using hand signals, perhaps signifying an increased comfort level (Hunter et al., 2000).

Separated Bike Lanes (Cycle Tracks)

A cycle track or a separated bike lane (Figure 3 (e)-(f)) is defined by NACTO as an exclusive bike facility that combines the user experience of a separated path with the on-street infrastructure of a conventional bike lane. A cycle track is physically separated from motor traffic and distinct from the sidewalk. Based on the travel direction, separation type, and other design factors, cycle tracks have different forms.

One-Way Separated Bike Lane

A one-way separated bicycle lane (Figure 3 (e)) is defined by NACTO as a bikeway at street level that uses a variety of methods for physical protection from passing traffic. It improves the perceived comfort and safety of bicyclists, as well as reduces risks of bicyclist overtaking crashes. The 2008 study of Jensen on cycle tracks in Copenhagen, Denmark, was one of the first before-and-after studies to evaluate the effect of one-way cycle track installation on bicyclists' and other road users' safety (Jensen, 2008). It reports a 20 percent increase in bicycle and moped traffic and a 10 percent decrease in motor vehicle traffic. Surveys of Danish adults and German cyclists found that respondents rated cycle tracks higher than striped bike lanes based on their comfort and perceived safety (Underlien, 2007; Bohle and Verkehr, 2000).

Two-Way Separated Bike Lane

A two-way separated bicycle lane (Figure 3 (f)) is defined by NACTO as a physically separated cycle track that allows bicycle movement in both directions on one side of the road. Besides providing benefits as a one-way protected cycle track does, a two-way cycle track could also reduce out-of-direction travel by allowing contra-flow movement on one-way streets. However, bicycle users in a study conducted in Montreal, Quebec (Canada) claimed to perceive intersections with two-way cycle tracks twice as safe as painted bicycle lanes (Wexler and El-Geneidy, 2017). The study indicates that two-way cycle tracks require appropriate design at intersections.

Raised Cycle Track

A raised cycle track is defined by NACTO as a bicycle facility vertically separated from motor vehicle traffic. Many such facilities are paired with a furnishing zone between the cycle track and motor vehicle travel lane and/or pedestrian area. Though the raised cycle track has obvious safety benefits, it is neither commonly seen in the United States nor widely studied. The first raised cycle tracks in Ottawa, Canada, were installed in 2014 as part of the Complete Street approach to encourage active travel (City of Ottawa, 2015).

Intersection Treatments

Intersection treatments include bike boxes, intersection crossing markings, two-stage turn queue boxes, medium refuge islands, through bike lanes, combined bike lane/turn lanes, bicycle signals, and protected intersections. Figure 4 provides an example of bikeway facility types implemented at intersections.

a) Bike box

b) Two-stage turn queue box

c) Crossing markings

d) Through bike lane

e) Bike signal head

f) Protected intersection

Source: NACTO (2014)

Figure 4. Intersection Treatments for Accommodating Bicyclists

As discussed in the previous chapter, the majority of bicycle crashes occur at intersections. In general, it is recommended that a bikeway design be consistent and continuous from mid-block locations through intersections. To configure a safe intersection for bicyclists, elements should be taken into considerations include color, signage, medians, signal detection, and pavement markings. Different intersection treatments are summarized below.

Bike Box

A bike box (Figure 4 (a)) is defined by NACTO as a designated area at the head of a traffic lane at a signalized intersection that provides bicyclists with a safe, visible way to get ahead of queuing traffic during the red signal phase . It has a lot of benefits, including increasing visibility of bicyclists and helping to prevent conflicts with right-turn vehicles. However, research on its safety benefits reveals mixed results (DiGioia et al., 2017). While most studies showed a reduction in bicycle-motor vehicle conflicts (Dill et al., 2012), the City of Portland reported a doubling of bicycle right-hook crashes with motor vehicles at some intersections where bike boxes had been installed (Burchfield, 2012).

Two-Stage Turn Queue Box

A two-stage turn queue box (Figure 4 (b)) is a bike box that offer bicyclists a way to make left turns (or, in some cases, right turns) at multilane signalized intersections without the need to merge across traffic to enter the left-turn lane. It may also be used at unsignalized intersections to simplify turns from a bicycle lane or cycle track. There is an overall lack of research on the implementation of this treatment. A 2018 study evaluated the effects of two bike boxes and two turn boxes installed in 2014 at an intersection in Charlottesville, Virginia (Ohlms et al., 2019). It found high levels of improper (but not necessarily unsafe) uses of the turn boxes; before-and-after results regarding traffic infractions were mixed.

Crossing Markings

Intersection crossing markings (Figure 4(c)) indicate the intended path for bicyclists. They raise awareness of bicyclists to motorists and reduce potential conflicts with turning motorists. There are a number of different markings strategies. Raised bicycle crossings could provide continuations of raised cycle tracks or side paths across intersecting side streets and driveways without dropping the path to street level at each intersection (DiGioia et al., 2017).

Combined and Through Bike Lanes

A combined bike lane/turn lane (Figure 4(d)) places a suggested bike lane within the inside portion of a dedicated motor vehicle turn lane or to the left/right of the turn lanes to provide a path to bicyclists passing through the intersections. Its main purpose is to reduce the risk of right-hook collisions at intersections. It also helps with the situation when enough space exists to mark a dedicated bike lane to the left of the right-turn lane. In the comparison between shared narrow right-turn lanes and the combination of a bike lane and right turn lane in Eugene, Oregon, more than half of bicyclists felt no difference between these two configurations at intersections [66].

Bicycle Signal Head

A bicycle signal head (Figure 4(e)) is an electrically powered traffic control device used in combination with other conventional traffic signals or hybrid beacons. It is used to provide guidance to bicyclists at intersections with a high traffic volume of entering vehicles. Some of the benefits of bicycle signal heads include reducing conflicts between bicyclists and turning vehicles; providing priority to bicyclists; protecting bicyclists at intersections; improving operations; and improving bicyclist movements through complex intersections. A newly published National Cooperative Highway Research Program (NCHRP) Report 273 synthesizes the experience with bicycle signal face installations across the United States, assessing bicyclists' and drivers' understanding of bicycle signal heads. This study found that gaps exist in communicating the allowable, protected, or permissive movements to bicyclists at intersections. The study also found guidance gaps in size, placement, and orientation of bicycle signal faces, and guidance on visibility and detection of bicycle symbols.

Protected Intersections

Protected intersections are being implemented at an increasing rate (Figure 4(f)). The advantage of these facilities over conventional intersection treatments is that bicyclists are not forced to merge into mixed traffic; instead they are given a dedicated or protected path through intersections. Protected intersections help to reduce turning speeds, make bicycles visible, and give the bicyclists the right of way. NACTO's new guidance document on protected intersections presents the key features of such facilities (NACTO, 2019). These consist of no stopping zones, pedestrian islands, bikeway setbacks, crossing markings, motorist waiting zones bike queue area, corner island and bend-in/bend-outs to reduce the approaching bicycle speeds. The existing protected intersections use combinations of these features, rather than following a uniform guidance, which makes the safety assessment of this type of facilities more challenging.

CHAPTER 3. AGENCY SURVEY

INTRODUCTION

The decision to install a particular bicycle facility type is based on a number of elements, driven by industry design guidance and the context of the project. The agencies in Texas use various guidelines for implementing bicycle facilities. These include but are not limited to:

- TxDOT Guidelines for Emphasizing Bicycle and Pedestrian Accommodations
- TxDOT's Environmental Handbook
- 2011 Texas Manual on Uniform Traffic Control Devices (TMUTCD)
- Texas Accessibility Standards
- TxDOT's Roadway Design Manual
- Federal Highway Administration (FHWA) Bikeway Selection Guide
- FHWA Policy Guidance, 2019
- USDOT. Policy Statement on Bicycle and Pedestrian Accommodations. March 15, 2015
- Americans with Disabilities Act (ADA) Accessibility Guidelines
- American Association of Highway Transportation Official's (AASHTO) Guide for Development of Bikeway Facilities
- National Association of City Transportation Officials (NACTO) Urban Bikeway Design Guidelines

To learn about the state-of-the-practice in Texas, the research team conducted a survey. The objective of the survey was two-fold: 1) to identify the state of the practice and types of bicycle facilities implemented in jurisdictions, and 2) to identify a potential list of agencies who are collecting the data on bicycle counts and infrastructure cost and are willing to share the data with the research team. The questionnaire developed for this purpose was divided into three parts to gather information regarding:

1. Respondent Background
2. Bicycle Facility Information
3. Readily Available Data Information and the Contact Details

The questionnaire was then revised by the project panel members. After addressing the comments and feedback of the panel, the survey was published online. The outline of the survey is provided in Appendix A. Survey Instrument.

SURVEY INSTRUMENT AND IMPLEMENTATION

The research team compiled a list of approximately 300 contacts from previous activities and from a webinar series dedicated to topics on bicycle and pedestrian mobility. The research team shared the survey with these contacts via email. The survey was also disseminated through the social media channels of Texas A&M Transportation Institute (TTI) and TxDOT. The survey was activated on February 10, 2020, and closed on March 25, 2020. In this chapter, a summary of responses per survey question and a discussion of the next steps is provided.

List of Survey Questions

The survey questions were designed to gather information from the respondents about their agency and contact details, type of facilities installed in their jurisdiction, type of data being collected by their agency, and if they could share the readily available data with the research team. Figure 5 depicts the survey outline and a list of questions included in the survey. The questions were multiple choice. The full version of survey questions and response options are provided in Appendix A.

- Introduction
- Background Information:
  - Who do you work for?
  - What is your primary role?
- Bicycle Facility Information
  - Does your jurisdiction implement any of the following on-street or adjacent bikeway facilities?
  - Has your jurisdiction implemented any of the following intersection improvements?
- Readily Available Data Information
  - Please indicate if your agency has or plans to collect any of the data below and if you can share the data with the research team.
  - Bicycle count data
  - Bicycle Speed data
  - Bikeway facility data
  - Bikeway infrastructure cost
- End of Survey
  - Please provide the appropriate contact information to reach out to.

Figure 5. List of Survey Questions.

Summary of Responses to Survey

A total of 138 useable responses were obtained in the survey. Out of the usable responses, 101 of them had the associated city (34 cities total), and 45 of them had answered all the questions. Only 41 of the respondents agreed to share the information with the research team. Figure 6 shows the distribution of respondents across the state. The number of respondents per city is provided in Figure 6. As can be observed, Austin, Houston, and San Antonio had the greatest number of respondents answering the survey (9–16 respondents), followed by Arlington, Brownsville, and Dallas (4–8 respondents). The rest of the cities had one to three respondents taking the survey. The summary of responses is discussed in this section.

In the following sections, the number and percentage of responses per question are provided. Note that since the survey was multiple-choice, one respondent may select several answers. Therefore, the total numbers provided in summary figures do not represent the number of respondents.

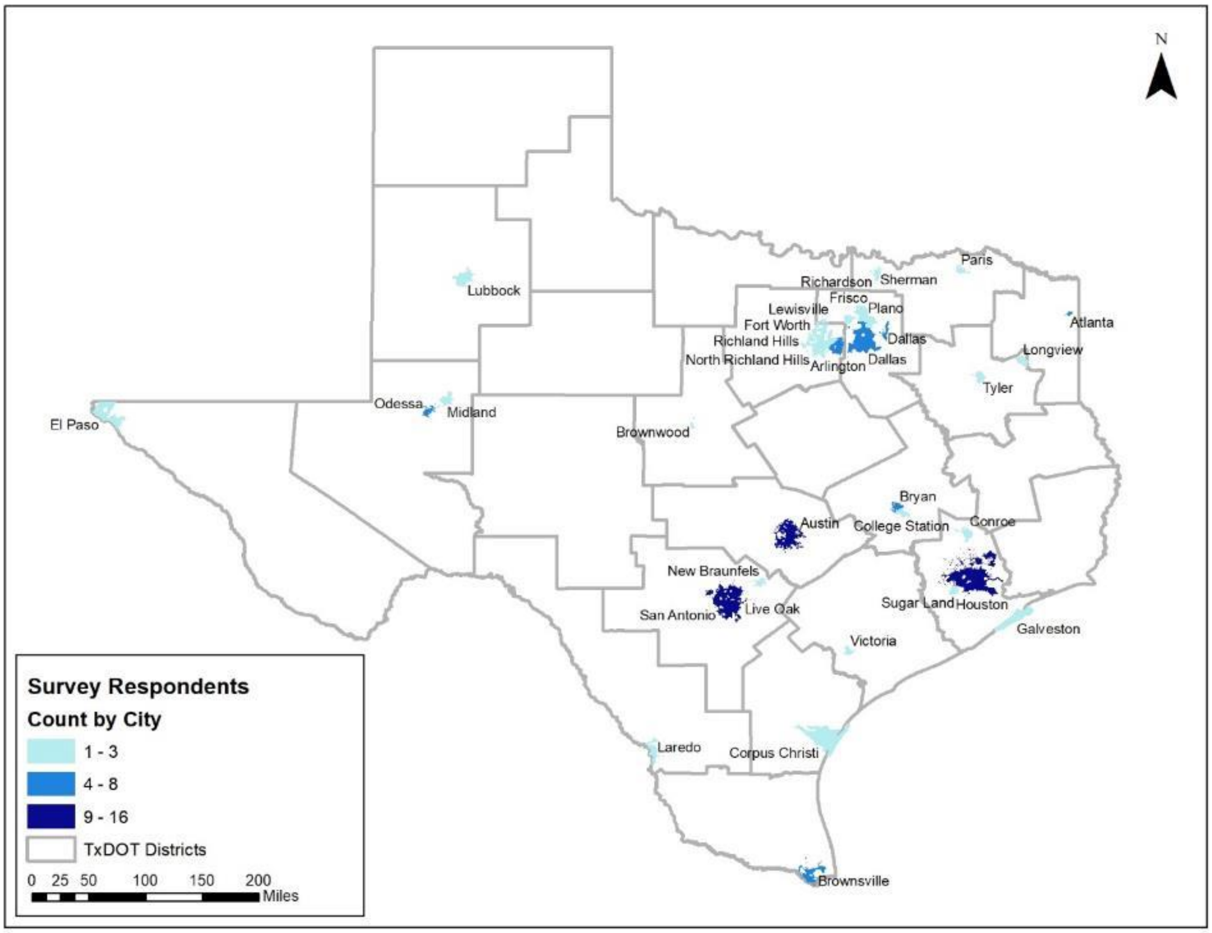
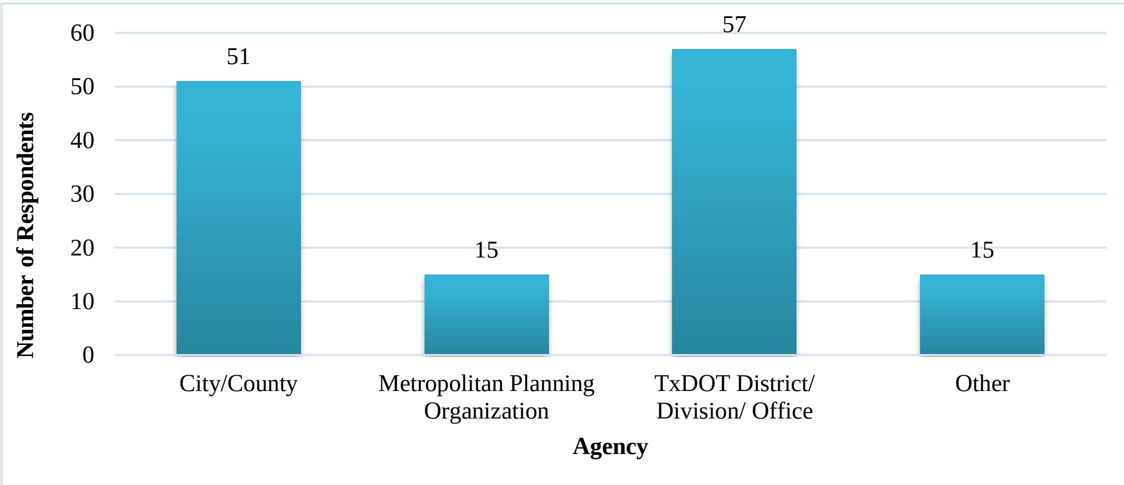


Figure 6. Number of Respondents per City.

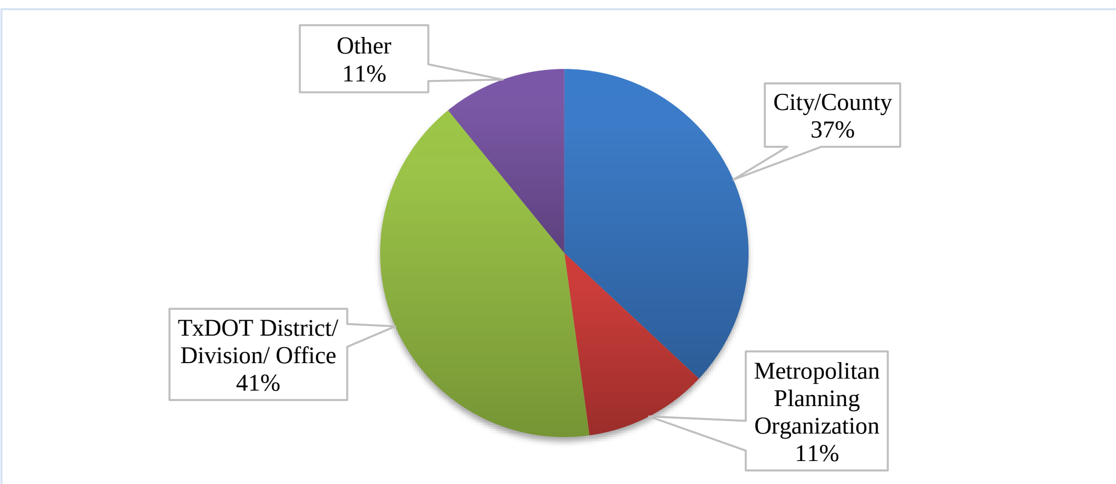
Background Information

Agency of the Respondent

In this question, the respondents were asked which agency they were working for. The available choices were TxDOT Division, District, and Office; City or County; and MPO. They were provided another choice if their agency did not belong to one of the former categories. Out of 138 respondents, 41 percent of them (57 respondents) indicated that they worked for a TxDOT division, district, or office. Thirty-seven percent of respondents (51) worked for a city or county, while 11 percent (15 respondents) worked for MPOs. The remaining 11 percent of respondents worked for other agencies such as universities and consulting firms (Figure 7).



a) Number of Respondents

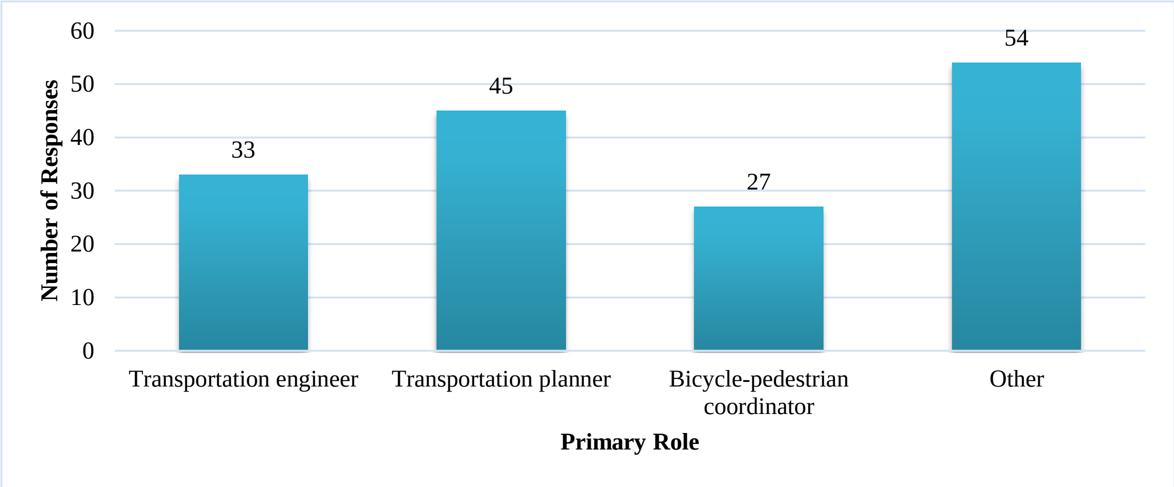


b) Percentage of Responses

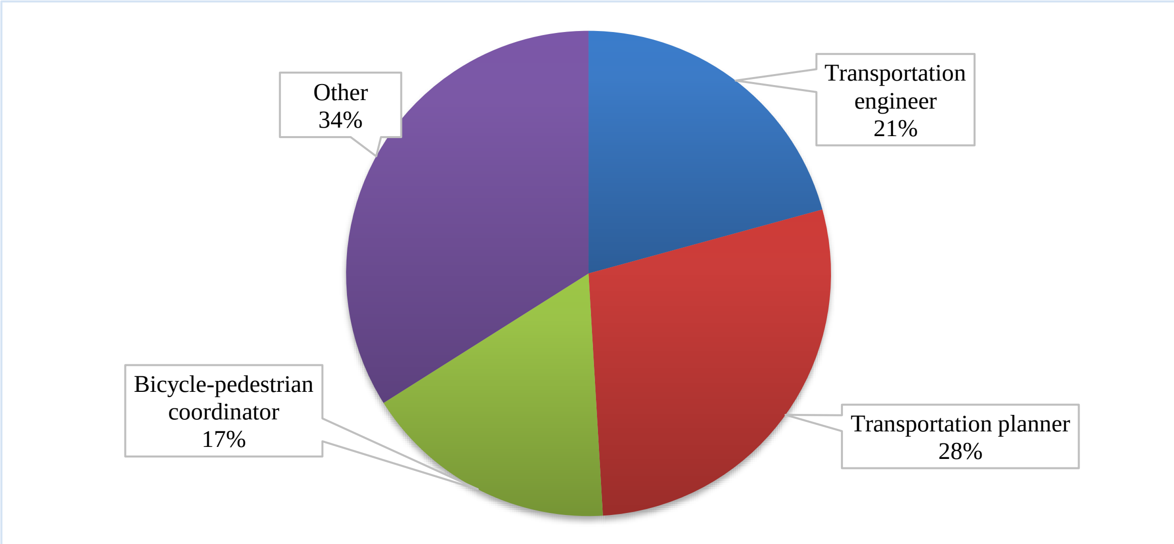
Figure 7. Agency of the Responses.

Primary Role

In this question, the respondents were asked to select their primary role within the agency. They could select multiple answers if applicable. Thirty-three (21 percent) of the responses indicated that respondents were transportation engineers, 45 responses (28 percent) indicated that the respondents were transportation planners, and 27 (17 percent) of responses indicated that the respondents were bicycle and pedestrian coordinators (Figure 8). Fifty-four responses belonged to other categories not defined in the survey. Note that the statistics indicated in this question and the remainder of questions represent the number of responses and not the respondents.



a) Number of Responses



b) Percentage of Responses

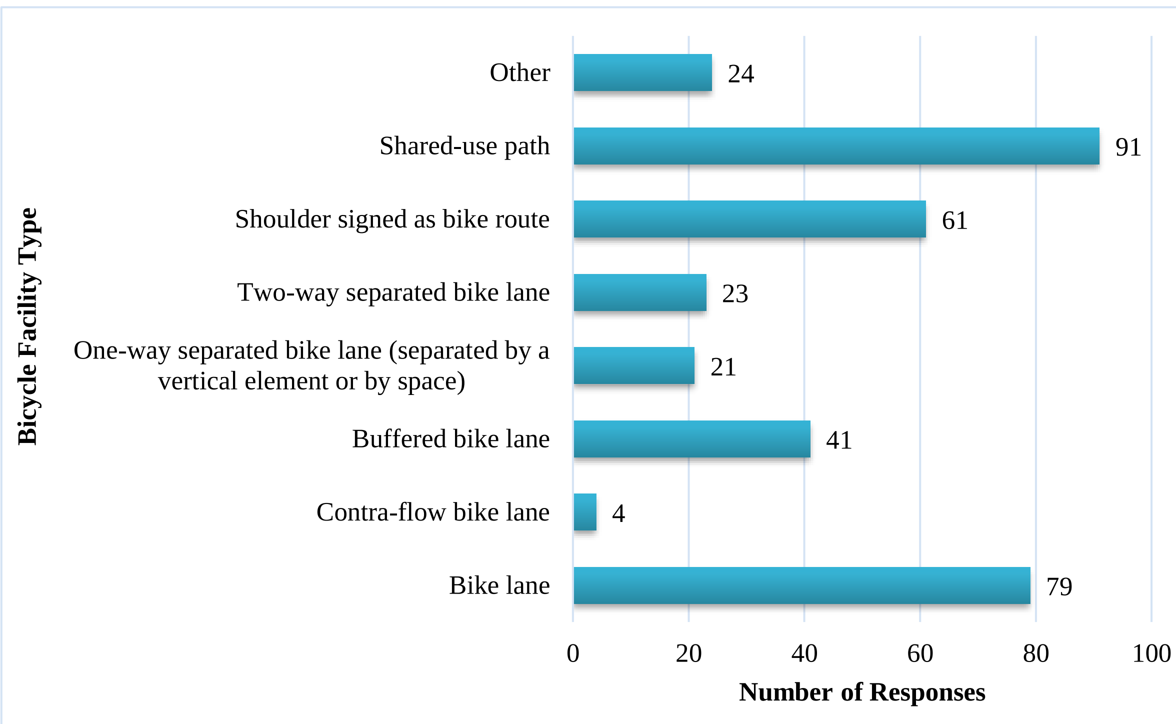
Figure 8. Primary Role of the Responses.

Bicycle Facility Information

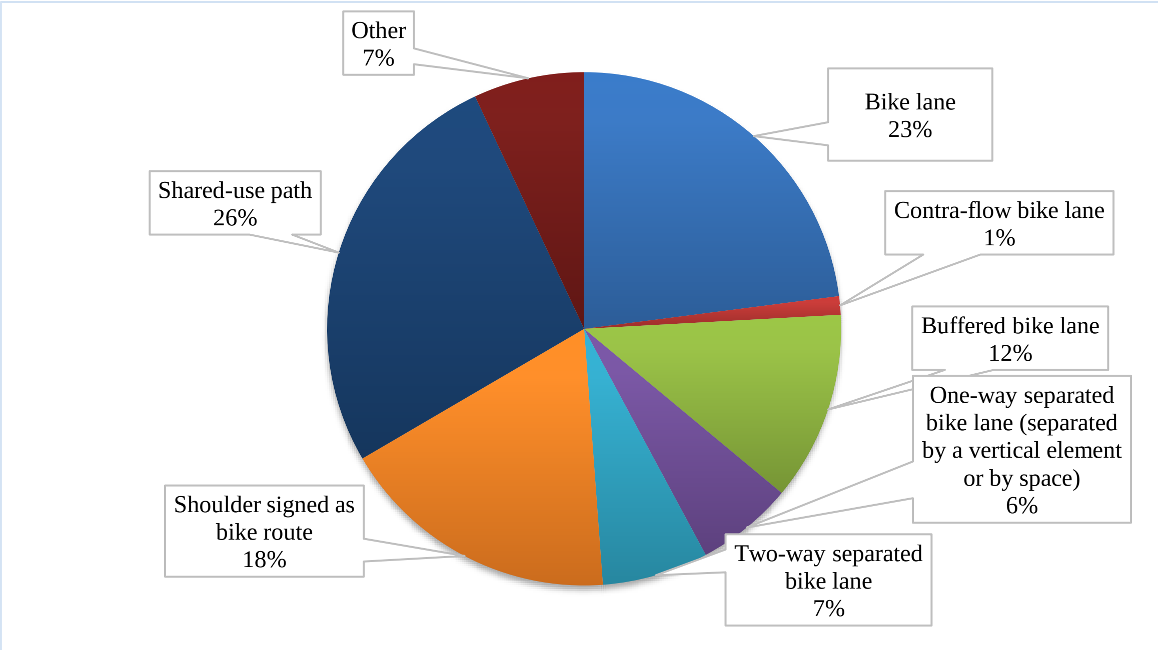
Segment Treatments Implemented

In this question, the respondents were shown images of on-street and adjacent bikeway facility designs and were asked if these facilities were installed in their respective jurisdictions. The respondents could select multiple options if applicable. The list of on-street bikeway facilities shown to the respondents is depicted in Figure 3. These include bicycle lanes, contra-flow bicycle lanes, buffered bicycle lanes, one-way and two-way separated bicycle lanes, shoulders signed as a bicycle lane, and shared-use paths. The respondents were also allowed to indicate additional types of bikeway facilities implemented in their jurisdiction that were not shown in this list.

According to the survey results, most jurisdictions have implemented shared-use paths and bike lanes; 91 of the responses (26 percent) indicated that the respondents' jurisdiction had implemented shared-use paths, and 70 respondents indicated that their jurisdiction had implemented bike lanes (Figure 9). The third and fourth most common bicycle facility was the shoulder signed as a bike route (61 responses) and buffered bike lane (41 responses). In addition to these, 23 and 21 of the responses indicated that the respondents' jurisdictions had installed two-way and one-way separated bike lanes, respectively. Only four of the responses indicated that the jurisdiction had implemented the contra-flow bike lane. The respondents also provided the list of other types of bicycle facilities implemented in their jurisdiction. Note that these responses have not been summarized per agency; hence it is possible that some of the responses were received from the same agency.



a) Number of Responses



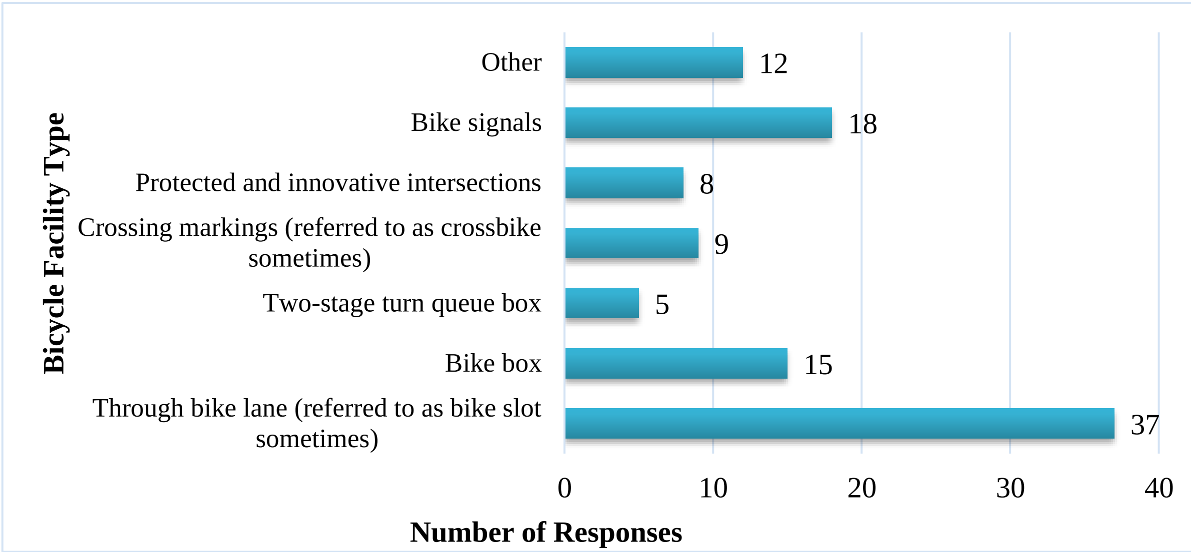
b) Percentage of Responses

Figure 9. Segment Treatments Implemented.

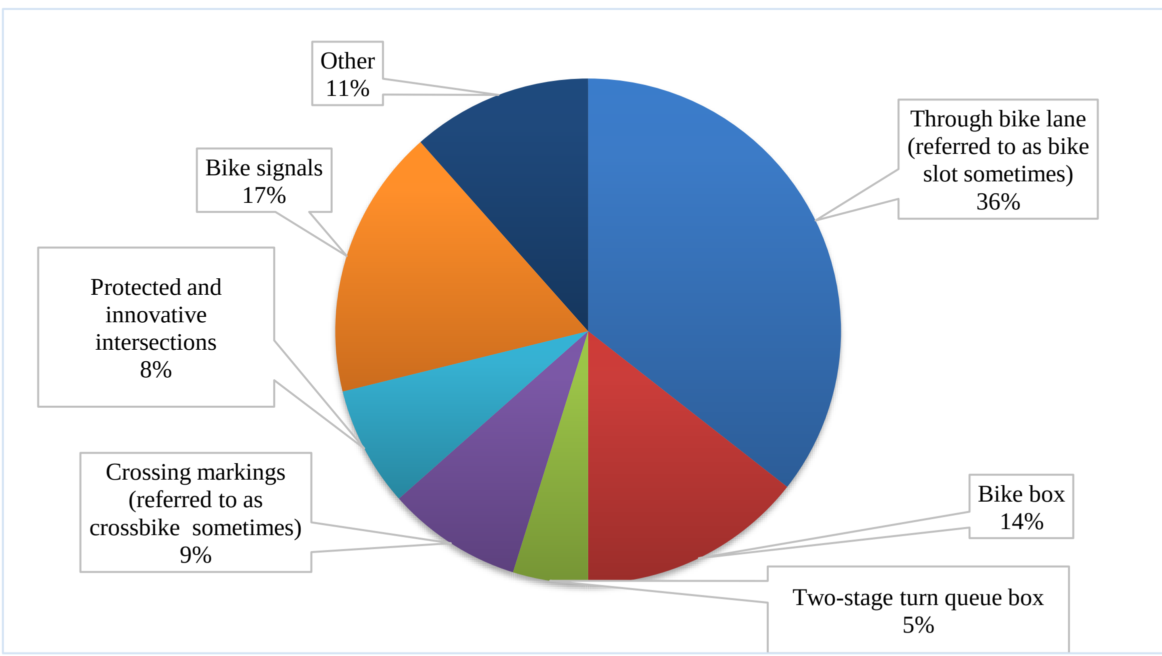
Intersection Treatments Implemented

In this question, the respondents were shown images of bikeway facility designs for accommodating bicyclists at intersections and were asked if these facilities were installed in their jurisdictions. The respondents could select multiple options if applicable. The list of on-street bikeway facilities shown to the respondents is depicted in Figure 3 and Figure 4. These include through bike lane (or bicycle slot), bike box, two-stage turn queue box, crossing markings, protected intersections, and bike signals. The respondents were also provided an option to list the facility types that were not included in the survey.

According to survey results, 37 of the responses (36 percent) indicated that the respondents' jurisdiction had implemented through bike lanes (Figure 10). Eighteen responses (17 percent) indicated that the jurisdiction had implemented bike signals, and 15 (14 percent) indicated that the jurisdiction had implemented a bike box. Other less frequently implemented facilities included crossing markings (9 responses), protected intersections (8 responses), and two-stage turn queue box (5 responses). Twelve of the responses indicated that the respondents' jurisdiction had implemented other types of facilities for accommodating bicyclists at intersections.



a) Number of Responses



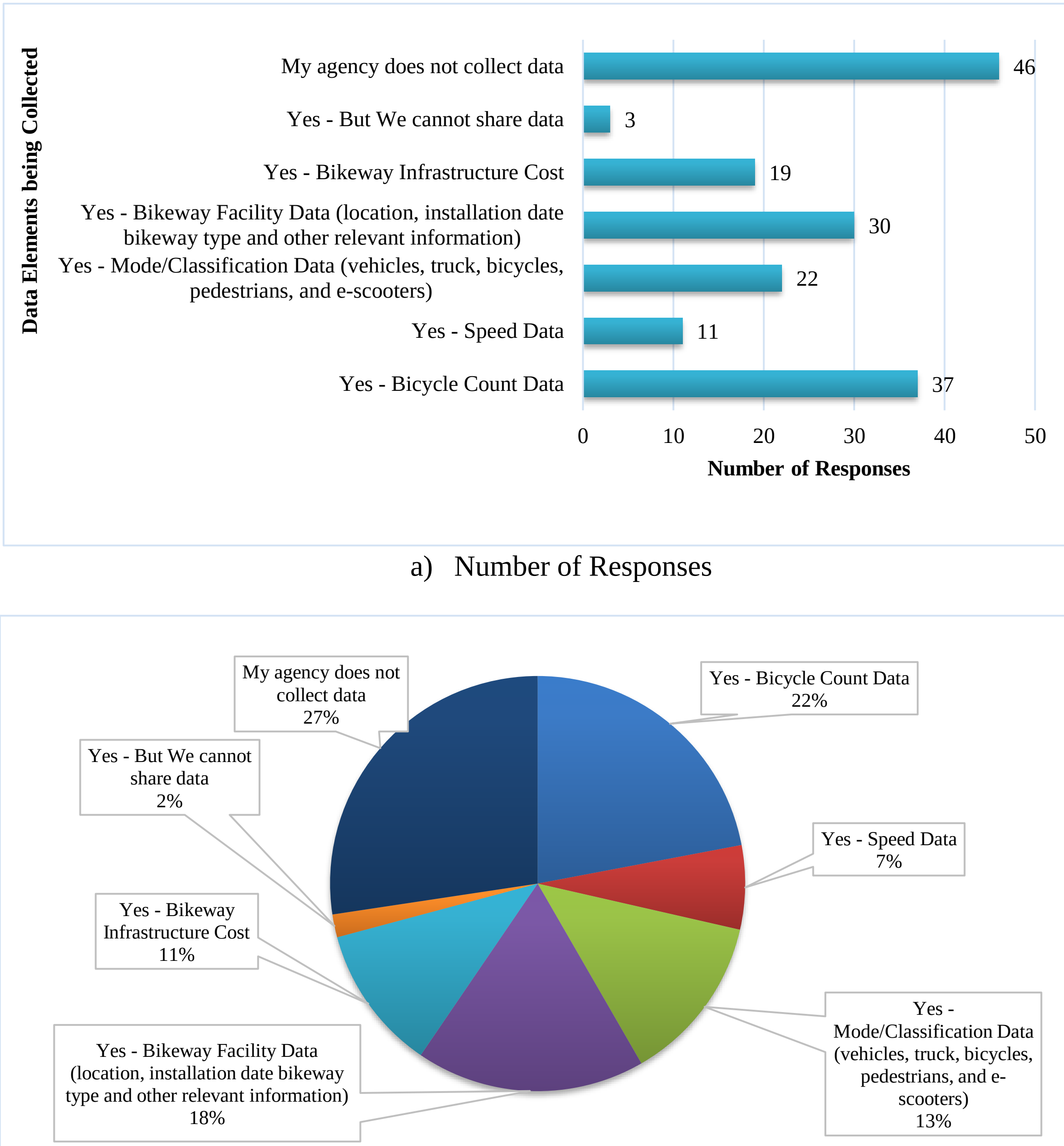
b) Percentage of Responses

Figure 10. Intersection Treatments Implemented.

Readily Available Data Information

Data Being or Planned to Be Collected

In this question, the respondents were asked if their agency was collecting data and were provided a list of options to select from. Figure 11 shows the list of data elements being or planned to be collected.



a) Number of Responses

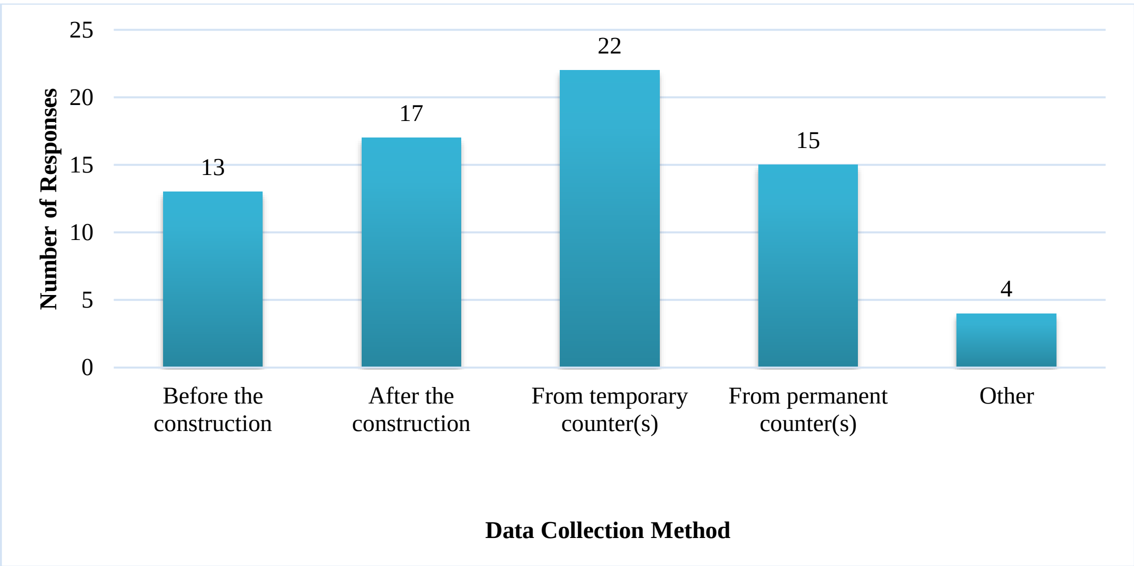
b) Percentage of Responses

Figure 11. Data Elements Collected.

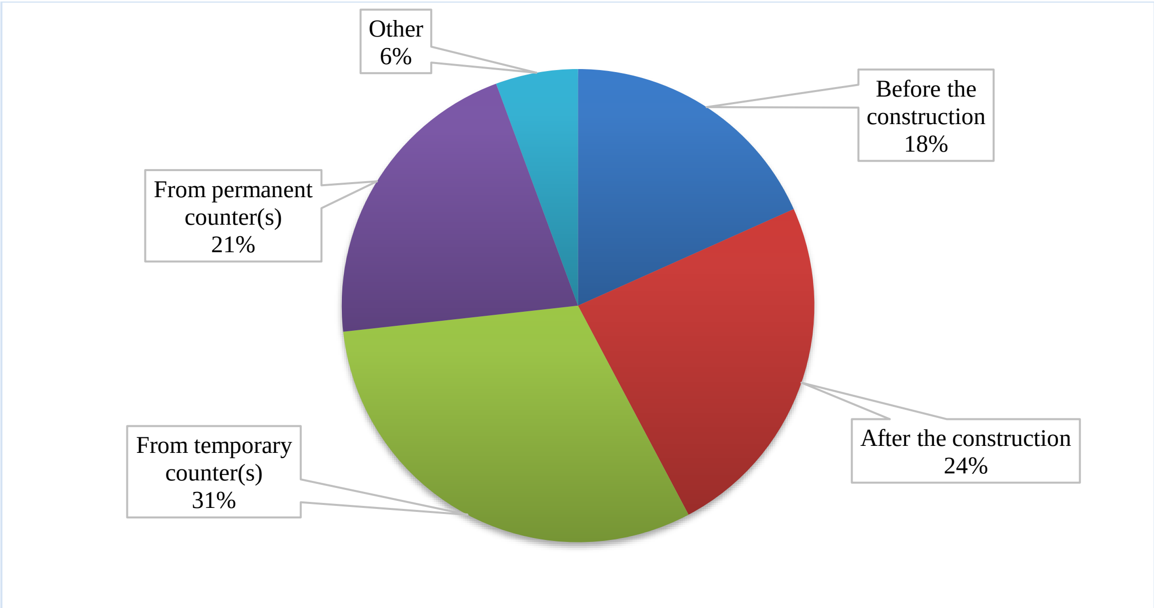
A total of 46 responses indicated that the agency of the respondent did not collect data, while 36 indicated that the agency was collecting bicycle counts. Thirty responses indicated that the respondents' agency was collecting bicycle facility data such as the location of the facility and the date of installation. Twenty-two responses indicated that the agency was collecting mode classification data such as bicycle, pedestrian, and vehicle information. Nineteen responses indicated that the agency was collecting bikeway infrastructure costs such as installation and maintenance costs, and finally, 11 of the responses indicated that the respondents' agency was collecting speed data. Only three responses indicated that despite collecting data, the agency was not able to share it.

Bicycle Count Data

In this question, the respondents were asked about the method their agency had used for collecting the bicycle counts and whether the data were collected before and/or after the installation of a bicycle facility. Figure 12 shows the method of data collection selected by the respondents.



a) Number of Responses



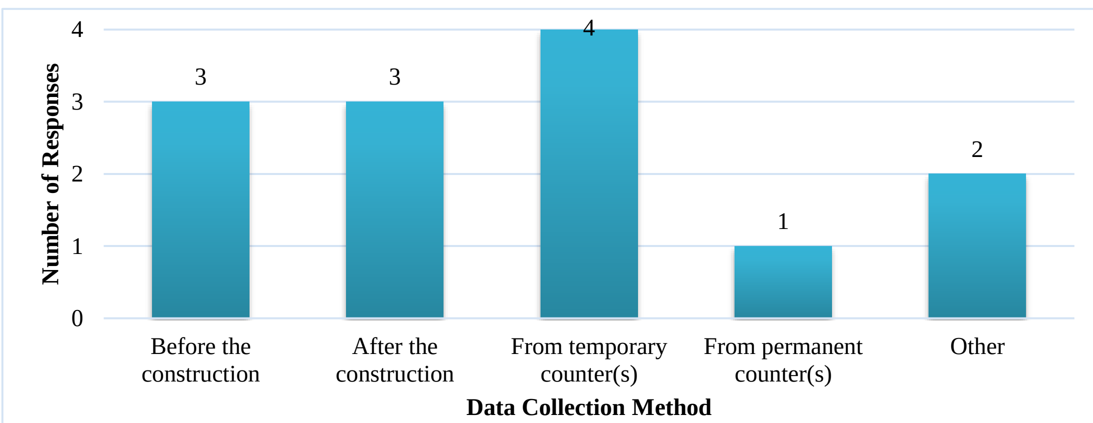
b) Percentage of Responses

Figure 12. Bicycle Count Data.

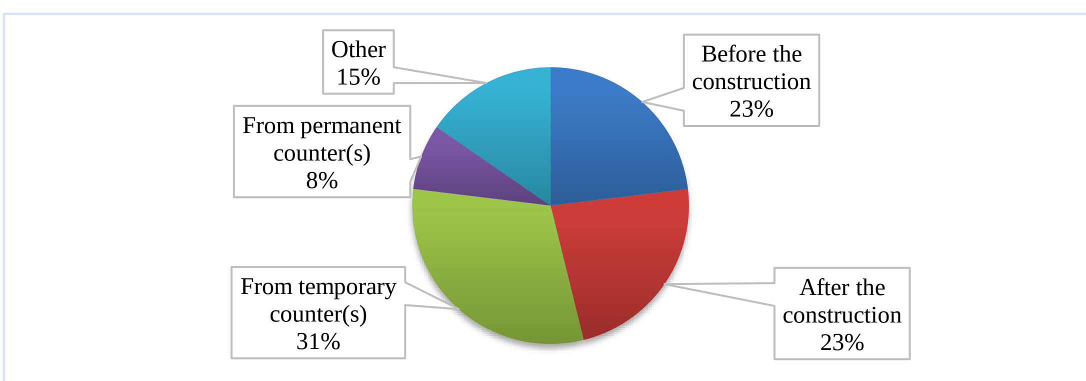
Thirteen and 17 responses indicated that the respondents' agency was collecting the bicycle counts before and after the installation, respectively. Twenty-two responses indicated that the agency was collecting data from temporary counters, while 15 responses indicated that the agency was collecting data from permanent counters. Four of the responses indicated that the agency was using other methods for data collection.

Bicycle Speed Data

In this question, the respondents were asked about the method their agency had used for collecting speed data, and whether the speed data were collected before and/or after the installation. Figure 13 shows the number and percentage of responses per answer. As can be observed, very few agencies are collecting speed data. Three responses indicated that the respondents' agency was collecting before and after speed data. Four responses indicated that the speed data was collected from temporary counters, while one response indicated that the speed data was collected from permanent counters. Two responses indicated that the respondents' agency was using other methods to collect the speed data.



a) Number of Responses

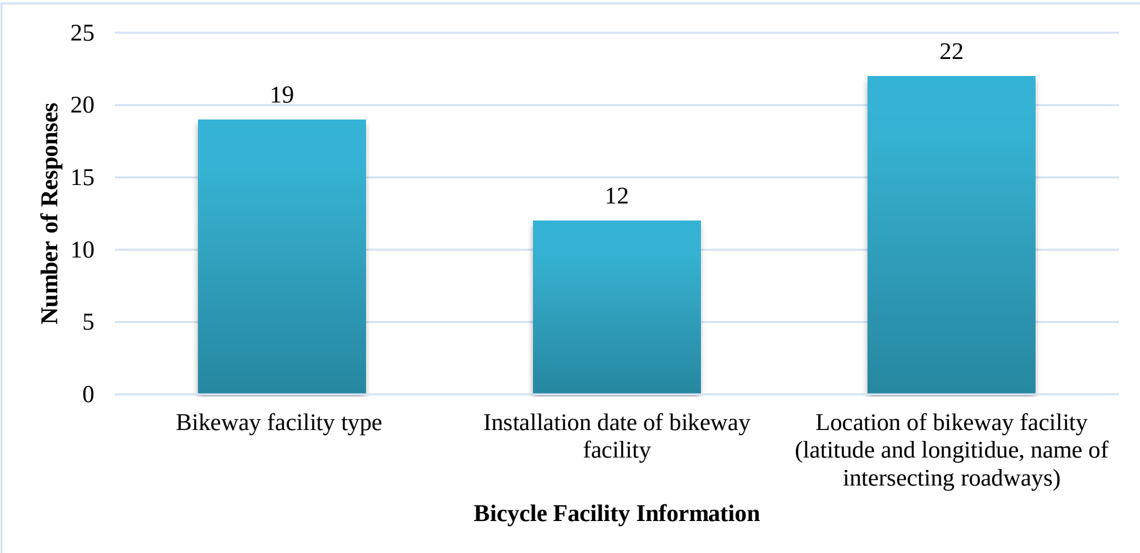


b) Percentage of Responses

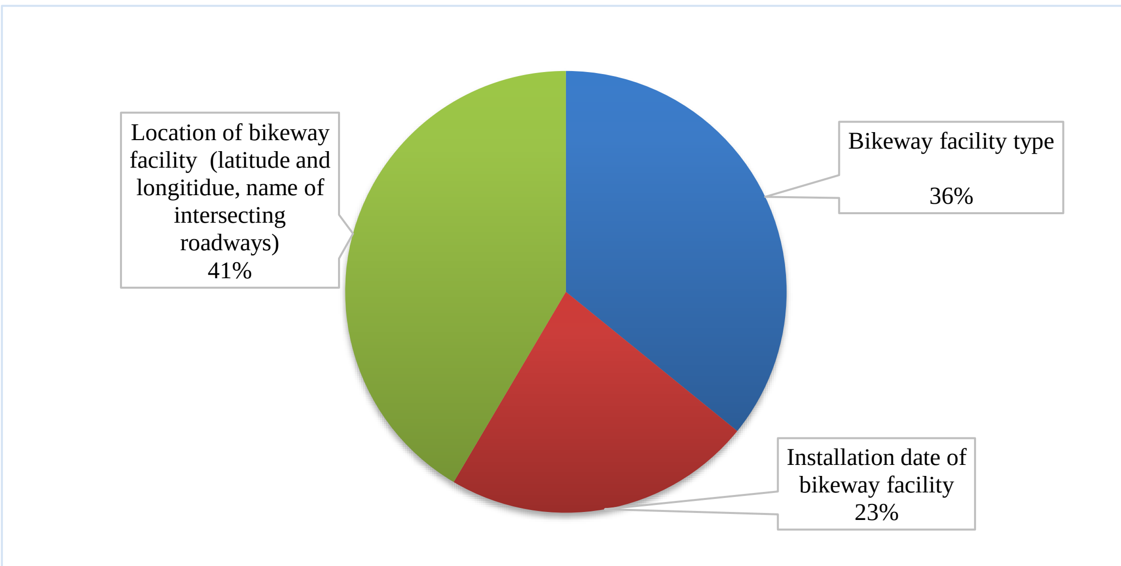
Figure 13. Bicycle Speed Data.

Bicycle Facility Data

In this question, the respondents were asked what type of bicycle facility data their agency had collected. The facility data of interest were bicycle facility type, installation date, and location of the facility (Figure 14). Twenty-two responses indicated that the respondents' agency was collecting the data about the location of the facility, 19 indicated that the agency was collecting facility type, and 12 indicated that the agency was collecting the date of installation.



a) Number of Responses

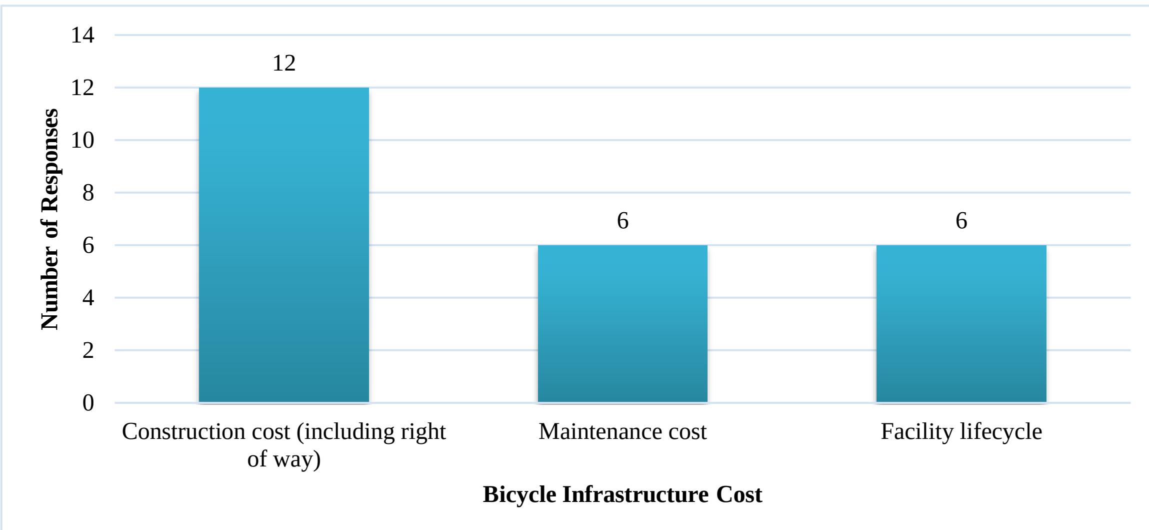


b) Percentage of Responses

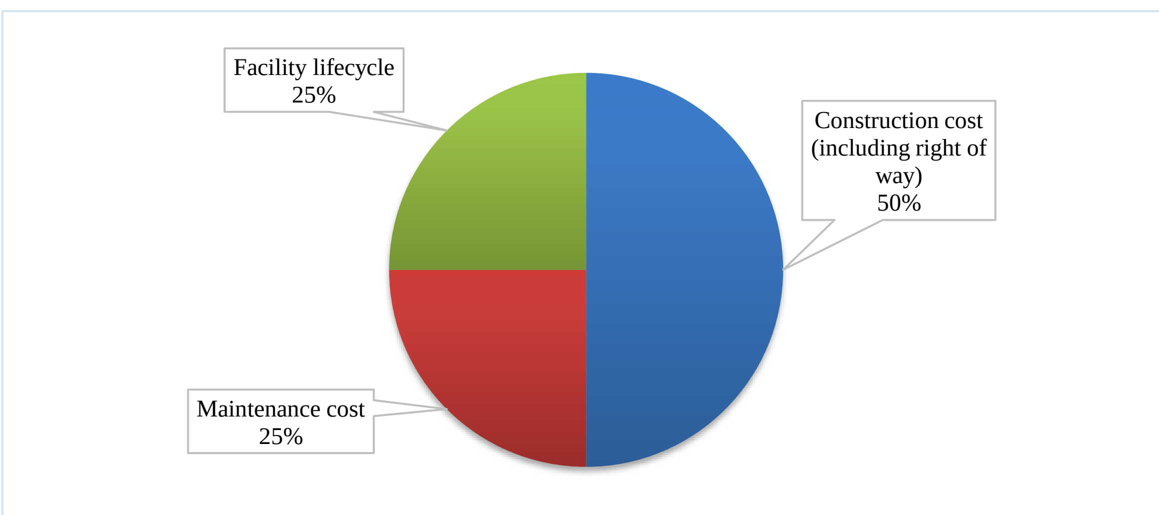
Figure 14. Bicycle Facility Data.

Bicycle Infrastructure Cost

In this question, the respondents were asked if their agency was collecting bicycle infrastructure cost information. The information of interest included construction and maintenance costs and the lifecycle of the facility (Figure 15). As can be observed, very few agencies have the infrastructure cost information; 12 responses indicated that the respondents' agency was collecting construction cost. Six responses indicated that the agency was collecting maintenance cost and the lifecycle of the facility.



a) Number of Responses



b) Percentage of Responses

Figure 15. Bicycle Infrastructure Cost.

RESPONSES AND DATA REQUEST

In mid-April of 2020, TTI researchers contacted each of the survey respondents who indicated that they had collected data on bicycle facilities and were willing to share that data. In total, 34 emails were sent to 37 respondents (some were from the same agency). Reminders were sent in mid-May and again in early June. All except seven jurisdictions responded to the request in some form. Some respondents pointed to the TxDOT Bicycle and Pedestrian Data Exchange or TTI studies to access data. Others forwarded the request to people within or outside of their agency. As of June 15, 2020, TTI has received information from 10 jurisdictions, including the following:

- Buffalo Bayou Partnership.
- City of Austin.
- City of College Station.
- City of North Richland Hills.
- City of Plano.
- City of Sugar Land.
- San Antonio River Authority.
- TxDOT Laredo District.
- TxDOT San Antonio District.
- TxDOT Design Division.

Others have indicated that they would make their bicycle data available. Researchers will continue to follow up with these jurisdictions. They include the following:

- City of El Paso.
- City of Brownsville.
- City of San Antonio.

A SharePoint site was created where agencies could upload their data. Several took advantage of this opportunity. Others emailed ArcGIS shape files, Excel files, or reports directly to TTI. Table 4 shows the list of agencies that shared the readily available data with the research team. For privacy purposes, the names of respondents are not included in this table.

Table 4. List of Agencies Providing Readily Available Data.

Respondent ID	Agency Name	Area Name	Type of Data Provided
8	TxDOT Design Division	Statewide	Statewide ped bike inventory on state roads
5	TxDOT Rail Division	Statewide	Did not respond

Respondent ID	Agency Name	Area Name	Type of Data Provided
114	TxDOT Austin District	Austin	Suggested others and then did not respond to request for contact info
40	TxDOT Bryan District	Bryan/College Station	Does not have data after all
100	TxDOT Dallas District	Dallas	Did not respond
87	TxDOT El Paso District	El Paso	Does not have data after all
17	TxDOT Fort Worth District	Fort Worth	Bike facility costs
16	TxDOT Houston District	Houston	Bike count data
11	TxDOT Laredo District	Laredo	Sent pdf files of TTI studies
13	TxDOT Lubbock District	Lubbock	Does not have data after all
7, 119	TxDOT San Antonio District	San Antonio	Sent pdf files of TTI studies
52	City of Austin	Austin	- Data exchange - Bike facility - Bike counts
102, 23	City of Brownsville	Brownsville	Bike counts
66	City of College Station	College Station	Bike facility
95	City of Dallas	Dallas	No contact info provided in survey
48	City of El Paso	El Paso	- Bike counts - Bike speed - Mode/classification - Bike facility - Bike infrastructure cost
6	City of Fort Worth	Fort Worth	Did not respond
65	City of Frisco	Frisco	Does not have data after all
25	City of Galveston	Galveston	Did not respond
118	City of New Braunfels	New Braunfels	Does not have data after all
26	City of North Richland Hills	North Richland Hills	Data exchange

Respondent ID	Agency Name	Area Name	Type of Data Provided
55	City of Odessa	Odessa	Does not have data after all
124, 97	City of Plano	Plano	- Bike counts
20, 83, 122	City of San Antonio	San Antonio	- Bike counts - Facility costs
98	City of Sugar Land	Sugar Land	- Bike counts
117	Alamo Area MPO	San Antonio	Did not respond
123	Corpus Christi MPO	Corpus Christi	Did not respond
19	North Central Texas Council of Governments (NCTCOG)	Dallas/Ft. Worth	Data Exchange
47	Buffalo Bayou Partnership	Houston	- Bike counts
90	San Antonio River Authority	San Antonio	- Bike counts
129	VIA Metropolitan Transit	San Antonio	Does not have data after all

Table 5 shows the summary of the answers to the survey question, "Does your jurisdiction implement any of the following on-street or adjacent bikeway facilities?" The top five most common bicycle facilities (based on frequency from high to low) include shared use path, bike lane, shoulder signed as bike route, through bike lane, other—bikeway. This information provides an overview of bicycle facility types in each city or district. It also identifies which city or district has installed the less common type of bicycle facilities.

Table 5. Bicycle Facilities by City/District/Agency.

City/District/Agency	Bicycle Facility Type
Alamo Area MPO	Bike box, Bike lane, Shared-use path, Shoulder signed as bike route
Arlington City	Bike lane, Protected and innovative intersection, Shared-use path, Through bike lane, Other—bikeway
Atlanta District	Bike lane, Shared-use path, Shoulder signed as bike route
Austin City	Bike box, Bike lane, Bike signals, Contra-flow bike lane, Crossing marking, One-way separated bike lane, Protected and innovative intersection, Shared-use path, Shoulder signed as bike route, Through bike lane, Two-stage turn queue box, Other—bikeway
Austin District	Bike lane, Shared-use path, Through bike lane
Brownsville City	Bike lane, One-way separated bike lane, Shared-use path, Shoulder signed as bike route

City/District/Agency	Bicycle Facility Type
Brownwood City	Other—intersection treatment
Bryan City	Bike lane, Shared-use path, Through bike lane, Other—bikeway
Bryan District	Bike lane, Protected and innovative intersection, Shared-use path, Shoulder signed as bike route, Through bike lane, Other—intersection treatment
Burditt Consultants	Shared-use path, Shoulder signed as bike route, Other—bikeway
College Station City	Bike lane, One-way separated bike lane, Shared-use path, Through bike lane
Corpus Christi City	Bike lane, Shared-use path, Shoulder signed as bike route, Through bike lane, Other—bikeway
Dallas City	Bike box, Bike lane, Bike signals, Crossing marking, One-way separated bike lane, Shared-use path, Shoulder signed as bike route, Two-stage turn queue box
Dallas District	Bike lane, One-way separated bike lane, Shoulder signed as bike route
El Paso City	Bike box, Bike lane, Bike signals, Crossing marking, One-way separated bike lane, Shared-use path, Shoulder signed as bike route, Through bike lane
El Paso District	Bike box, Bike lane, Bike signals, Crossing marking, Shared-use path, Shoulder signed as bike route, Through bike lane
Fort Worth City	Bike lane, One-way separated bike lane, Shared-use path, Through bike lane, Two-stage turn queue box
Fort Worth District	Bike box, Bike lane, Bike signals, Shared-use path, Shoulder signed as bike route
Frisco City	Bike lane, Shared-use path
Galveston City	Bike lane, Shared-use path, Shoulder signed as bike route, Other—bikeway
Houston City	Bike box, Bike lane, Bike signals, One-way separated bike lane, Shared-use path, Shoulder signed as bike route, Through bike lane, Two-stage turn queue box
Houston District	Bike lane, One-way separated bike lane, Protected and innovative intersection, Shared-use path, Shoulder signed as bike route, Through bike lane, Other—intersection treatment
Laredo District	Bike lane, Contra-flow bike lane, One-way separated bike lane, Shared-use path, Shoulder signed as bike route, Through bike lane
Lewisville City	Bike lane, crossing marking, Shared-use path, Shoulder signed as bike route
Live Oak City	Shared-use path
Longview MPO	Bike lane, Shared-use path
Lubbock District	Contra-flow bike lane, Shoulder signed as bike route
Lubbock MPO	Bike lane, Shared-use path
Midland City	Bike lane, Shoulder signed as bike route, Other—intersection treatment
NCTCOG	Bike box, Bike lane, Bike signals, Contra-flow bike lane, Crossing marking, One-way separated bike lane, Protected and innovative intersection, Shared-use path, Shoulder signed as bike route, Through bike lane, Two-stage turn queue box, Other—bikeway

City/District/Agency	Bicycle Facility Type
North Richland Hills City	Bike lane, Shared-use path, Shoulder signed as bike route
Odessa City	Bike lane, Shared-use path, Shoulder signed as bike route, Through bike lane
Odessa District	Crossing marking, Shared-use path, Shoulder signed as bike route, Other—bikeway, Other—intersection treatment
Paris District	Shared-use path, Shoulder signed as bike route
Plano City	Shared-use path, Shoulder signed as bike route, Other—bikeway
Port Authority	One-way separated bike lane, Shared-use path, Other—intersection treatment
Richardson City	Bike lane, Shared-use path, Through bike lane, Other—bikeway
Richland Hills City	Bike lane, Shared-use path
San Antonio City	Bike box, Bike lane, Bike signals, Crossing marking, One-way separated bike lane, Shared-use path, Shoulder signed as bike route, Through bike lane
San Antonio District	Bike lane, Shared-use path, Shoulder signed as bike route, Through bike lane, Other—bikeway
San Antonio River Authority	Shared-use path
Sherman-Denison MPO	Shared-use path, Other—bikeway
Sugar Land City	Bike lane, Shared-use path, Through bike lane, Other—bikeway
TxDOT Division	Bike lane, Bike signals, Protected and innovative intersection, Shared-use path, Shoulder signed as bike route, Through bike lane, Other—bikeway, Other—intersection treatment
Tyler Area MPO	Bike lane, Shared-use path, Shoulder signed as bike route
Tyler District	Bike lane, Shoulder signed as bike route, Through bike lane
Unknown	Bike lane, Bike signals, One-way separated bike lane, Protected and innovative intersection, Shared-use path, Shoulder signed as bike route, Through bike lane, Other—bikeway, Other—intersection treatment
VIA Metropolitan Transit	Bike box, Bike lane, One-way separated bike lane, Shared-use path, Shoulder signed as bike route, Through bike lane
Victoria City	Shoulder signed as bike route

As mentioned before, TTI received information from ten jurisdictions during the follow-ups. Besides that, researchers also tried to gather information from other complementary sources and the Texas Bicycle and Pedestrian Count Exchange (BP|CX). Table 6 shows a list of data files collected from this effort. The information includes bicycle facility types and locations, bicycle counter locations and number of bicycle counts, and the average low bid unit prices.

Table 6. Data Files Received from Agencies by City/Agency.

Cities/Agencies	File Name	Type of Data	File Type
Austin	ATD_CompletedProjects_2020_04	Bike Facility	Geodatabase
	Austin Two-way Protected Before After Crash Analysis	Bike Facility	PDF
	Austin_BikeLane	Bike Facility	Shapefile
	BicycleCountbyYearforGISJoin-2018.11.09	Count	Excel
	CityofAustin_BicycleCountLocations	Count	Shapefile
	Austin Eco Tube In and Out. Data	Count	Excel
	CityofAustin_CTN_Shapefile	Count	Shapefile
College Station	COCS_BikePlan	Bike Facility	Shapefile
Houston Buffalo Bayou	e.g., "1.2016" (series of files named by month and year)	Count	Excel
	Buffalo Bayou Partnership City of Houston Buffalo Bayou Trail Pedestrian Counts Fall 2016 Report	Count	PDF
	City of Houston Buffalo Bayou Trail Pedestrian Counts Winter 2016 Report	Count	PDF
Laredo	Bicycle Workshop Addendum	Bike Facility	PDF
	FM 1472 Bike Lane Addendum	Bike Facility	PDF
	FM 1472 Bike Lane in Median Addendum	Bike Facility	PDF
	high level review	Bike Facility	Word
	Feasibility of Bike Facilities on Five Rural Corridors	Count, Bike Facility	PDF
League	081817 tube data	Count	Excel
NCTCOG	ActiveTransportation	Bike Facility	Geodatabase
	County Geodatabase File Metadata	Bike Facility	PDF
	Mobility 2040 Active Transportation Chapter	Bike Facility	PDF
	Mobility 2040 Active Transportation Network Overview	Bike Facility	PDF
North Richland Hills	2020-02_Cotton Belt Trail (E of Holiday Lane)	Count	PDF
	2020-03_Cotton Belt Trail (E of Holiday Lane)	Count	PDF
San Antonio	2014 Bikeway Inventory By Area Office	Bike Facility	PDF

Cities/Agencies	File Name	Type of Data	File Type
	TxDOT_TTI_PAI_Export	Bike Facility	Geodatabase
	AAMPO Bike LTS 2016_TTI Bike LTS 2017_LTS1&2 Only_Trails_Sidewalk	Bike Facility	JEPG
	AAMPO_Bicycle Facilities	Bike Facility	PDF
	BikewayInventory_Bexar	Bike Facility	PDF
	SA Bike Routes	Bike Facility	PDF
	San Antonio Pedestrian and Bike Accommodations Guidance Draft 10312019	Bike Facility	PDF
	SATRuralBikePlan Aug22_2016	Bike Facility	PDF
	Bike_Routes_SA_District	Bike Facility	Shapefile
	Wurzbach files	Count	Excel, PDF, Word
	Count Data FM 471 Hourly Totals spring 2016	Count	Excel
	Utopia TX daily bicycle counts FM 1050 857_2016-06-30-15-12-10	Count	Excel
San Antonio River Authority	EcoCounterBicycleCountsfrom2010toPresentbyLocation	Bike Facility	PDF
	ConfluenceBike	Count	Excel
	LockDamBikes	Count	Excel
	MissionTheoAveBike	Count	Excel
	SanJuanPumpBikes	Count	Excel
	VFWWestBankBikes	Count	Excel
Sugar Land	2014-2019_FBISD Pedestrian Counts for Parks Bond Trail Projects	Count	Excel
	2016_City of Sugar Land Pedestrian Counts June Analysis	Count	Excel
	2016_City of Sugar Land Pedestrian Counts Spring Analysis	Count	Excel
	2017_March Sugarland Pedestrian Counter Analysis	Count	Excel
	2016_City of Sugar Land Pedestrian Counts June Report	Count	PDF
	2016_City of Sugar Land Pedestrian Counts Spring Report	Count	PDF
	2017_March PedBike-Monitoring-Report-SugarLand	Count	PDF
TxDOT Bike Ped Database	bpcx_stations_043020	Bike Facility	Excel

Cities/Agencies	File Name	Type of Data	File Type
	e.g., "count_method_lookup"	Bike Facility	Excel
TxDOT	Average Low Bid Unit Prices	Cost	Excel
	IntersectionsTX	Other	KMZ
	TxDOT Bike Inventory (13 districts)	Bike Facility	Geodatabase
	BikePed (6 districts)	Bike Facility	Geodatabase

CHAPTER 4. DEVELOPING SAFETY DATABASE

Safety database was developed by combining the readily-available data obtained from the agencies and online sources and filed data collection as described in this chapter.

SUMMARY OF DATA OBTAINED FROM AGENCIES

In this section, we have summarized the data and reports obtained from the districts. Note that not all of these reports have been published, and were provided to the research team at the discretion of the agency.

City of Austin

Bicycle Count by Year

The data received for Austin included a shapefile with locations of 217 counters in the city. The dataset also included 24-hour bike counts in 79 of the locations mentioned above. The 24-hour count data is separated by road direction and was collected on different days at different locations between May 2017 and October 2017. The 24-hour counts have a range of zero (at three locations) to 2,211 (at San Jacinto Boulevard north of 21st street), with a mean of 195 bikes and a median of 110 bikes.

In addition to bike count locations, the research team obtained the shapefiles indicating the bicycle facilities in the City of Austin. Figure 16 shows the bicycle facilities together with the count locations.

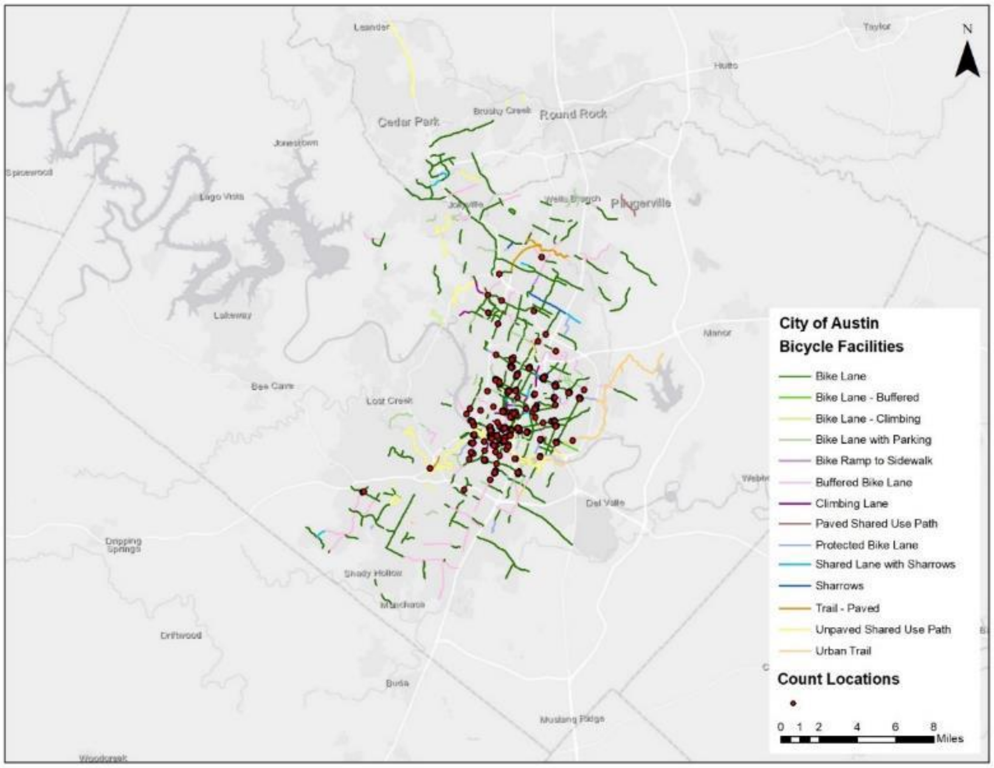


Figure 16. Bicycle Facilities and Count Locations, City of Austin.

Before-and-After Crash Data

A report on the results of a before-and-after study about crashes on roadway segments with a two-way protected bike lane in Austin provides the crash data for all modes on nine streets (Figure 17). The crash data for the nine study locations were retrieved from the TxDOT CRIS for the years 2010–2018. The study duration for each location varies with the project installation date and availability of crash data for the location between 2010 and 2018. The report aimed to maintain equal "before installation" and "after installation" duration. The study duration for the segments varied from 1.4 years to 8.7 years, with an average of 5.1 years. The change in crashes per mile per year after the installation of the two-way protected bike lane on the roadway segment was also studied. The number of crashes in six of the nine roadway segments decreased after installation of the two-way protected bike lane.

Figure 17. Before-and-After Crash Data, Austin.

Lakeshore Boulevard from Riverside Drive to Pleasant Valley Road experienced the highest number of crashes per mile per year. The number of crashes after installation of the two-way protected bike lane at this segment reduced by 60 percent. The report does not include a study on the change in the number of crashes per vehicle miles traveled, which would give a more accurate understanding of the impact of the bikeway facility on crash reduction.

City of College Station

The research team received the shapefile indicating the bicycle facilities in the City of College Station (Figure 18). As observed, the bike facilities include existing, funded, and proposed bike facilities in the city, as well as the location of multi-use paths (i.e., shared-use paths). The research team did not receive the count data from these locations.

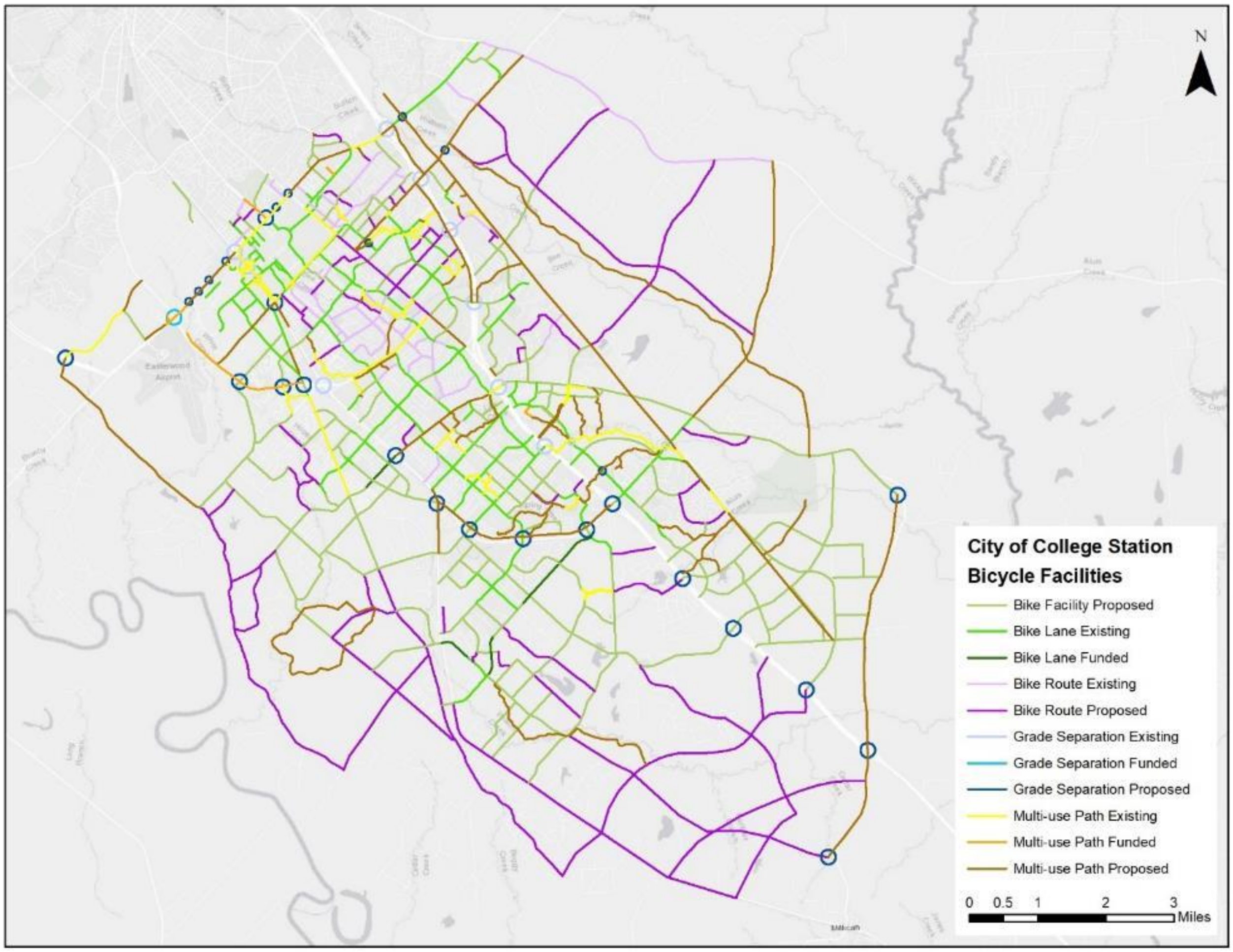
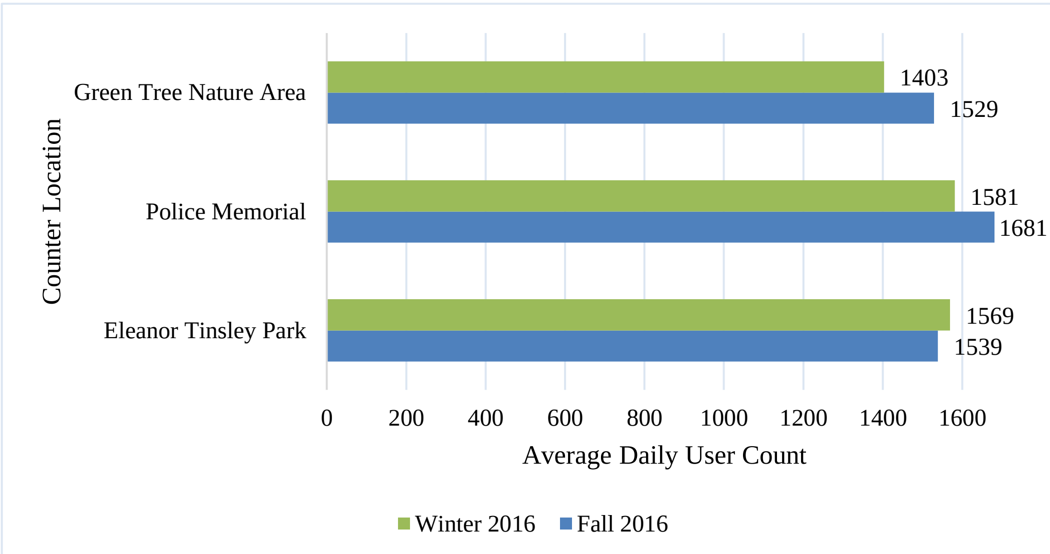


Figure 18. Bicycle Routes Map, College Station.

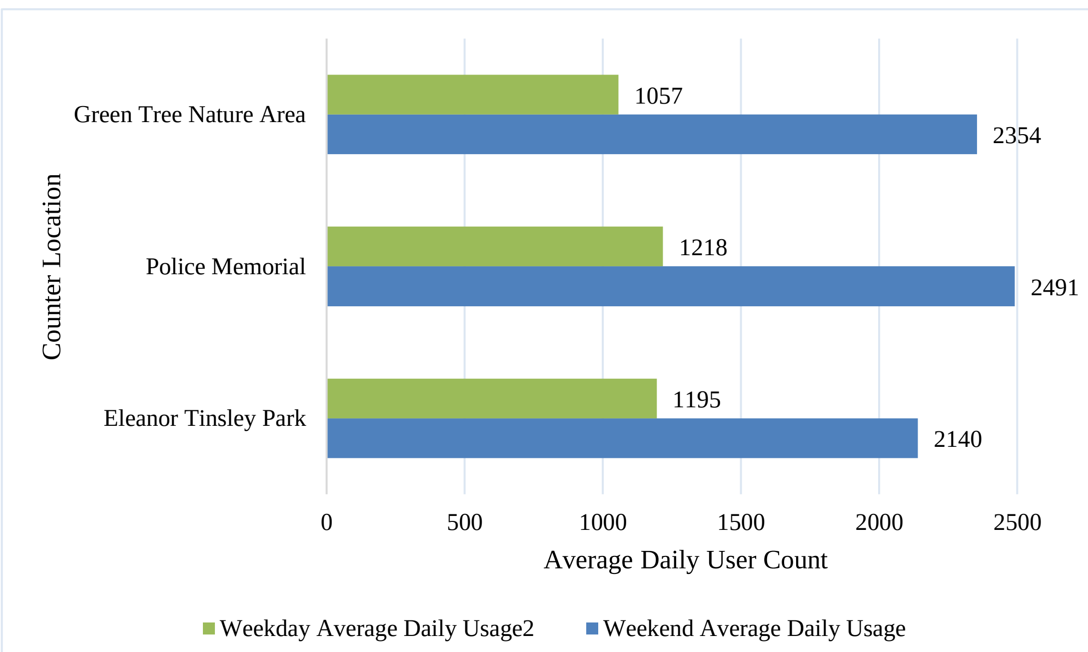
Houston

Buffalo Bayou Trail

The Buffalo Bayou Partnership, in collaboration with the Houston-Galveston Area Council (H-GAC) and TTI, collected pedestrian/bicycle counts at 20 locations along Buffalo Bayou (Houston-Galveston Area Council, 2016a, 2016b) H-GAC and TTI deployed seven and thirteen temporary counters, respectively. TRAFx (Infrared Trail Counters: Generation III) counters were used to count the number of people using trails and sidewalks; these counters do not differentiate between bicyclists and pedestrians but count the total number of users. The counters were placed on shared-use paths, pedestrian-only pathways, and sidewalks along the major thoroughfares near the Buffalo Bayou Park. The data was collected in two periods during 2016, with 13 counters deployed during the winter study and 20 counters during the fall. The study was conducted from February 19, 2016, to March 1, 2016 (12 days) and from September 30, 2016, to October 10, 2016 (11 days). Hourly user counts were collected at all the selected locations. More than a hundred thousand users—109,510 in winter and 117,030 in fall—were recorded in the study period with an average of 9,147 users daily in winter and 10,640 in fall. The counters at the Green Tree Nature Area, Police Memorial, and Eleanor Tinsley Park were the most used facilities along the bayou with an average of more than 1,500 users traveling along the routes daily (Figure 19).



a) Seasonal bike counts



a) Weekend and weekday bike counts

Figure 19. Average Daily User Count along Buffalo Bayou, Houston.

At all locations, the average daily usage was higher during weekends. Figure 19, with the average daily user count over weekdays and weekends at the three busiest locations along

Buffalo Bayou, exemplifies this statement. This trend suggests that the users are mostly recreational. At most locations, where the temporary counters have been deployed multiple times, the average daily usage has seen an increase every time. The counter at Eleanor Tinsley Park recorded a 118.8 percent higher average daily usage in fall 2016 than in October 2014.

The study also recorded and compared the average daily usage on shared-use paths, pedestrian-only paths, and roadside shared-use paths, where all three options were available to the users. The locations at which this study was possible included Buffalo Bayou North Bank at St. Thomas High School, Buffalo Bayou South Bank near Johnny Steele Dog Park, and Buffalo Bayou North Bank near the Nature Play Area. These locations provided better estimates of bicycle usage as pedestrians would likely use the pedestrian-only paths. To compare the usage of these different facilities, temporary counters were placed on shared-use paths and pedestrian pathways near each other to create a screen-line. The results vary with the study location. However, the variations were found to be consistent over time.

Lastly, the weather conditions had a consistent impact on the user count during the two study periods. The usage of the bike facilities was the lowest on days with significant rainfall (Monday, February 22nd and Tuesday, February 23rd). Similarly, all counters during the fall study had the lowest user counts on the days with the highest temperature readings of the twelve days (Wednesday, October 5th and Friday, October 7th).

Houston BCycle Program

The data includes BCycle usage data from September 2015 to August 2016 under the Houston BCycle program, a bike-sharing service (available at https://www.houstonbcycle.com/). The datasheets include checkout and return information along with other user-related and trip-related information like user ID, trip ID, trip duration, trip length, bike type, trip type (one-way or round trip), and program name. The data was collected from the bicycle tags after transactions by the users. The Houston BCycle program is a continually growing program that started with just three stations in May 2012 and now has more than 90 stations. Out of these stations, the data includes bicycle usage for checkouts from three locations only—Sabine Bridge, Jackson Hill & Memorial Drive, and Spotts Park. The average travel distance for these trips was 7.7 miles, with a median of 7.2 miles, and the average duration of these trips was 62 minutes, with a median of 49 minutes. The BCycle members get unlimited 60-minute rides, which might lead to the high average duration.

Table 7 shows the distribution of trips from the three stations. These trips end at 36 different destinations. An origin-destination matrix is needed to estimate the bike count along different routes. Similar data from all BCycle stations across Houston can be used to create an origin-destination matrix to understand the BCycle usage along all bike routes in Houston.

Table 7. Distribution of Trips.

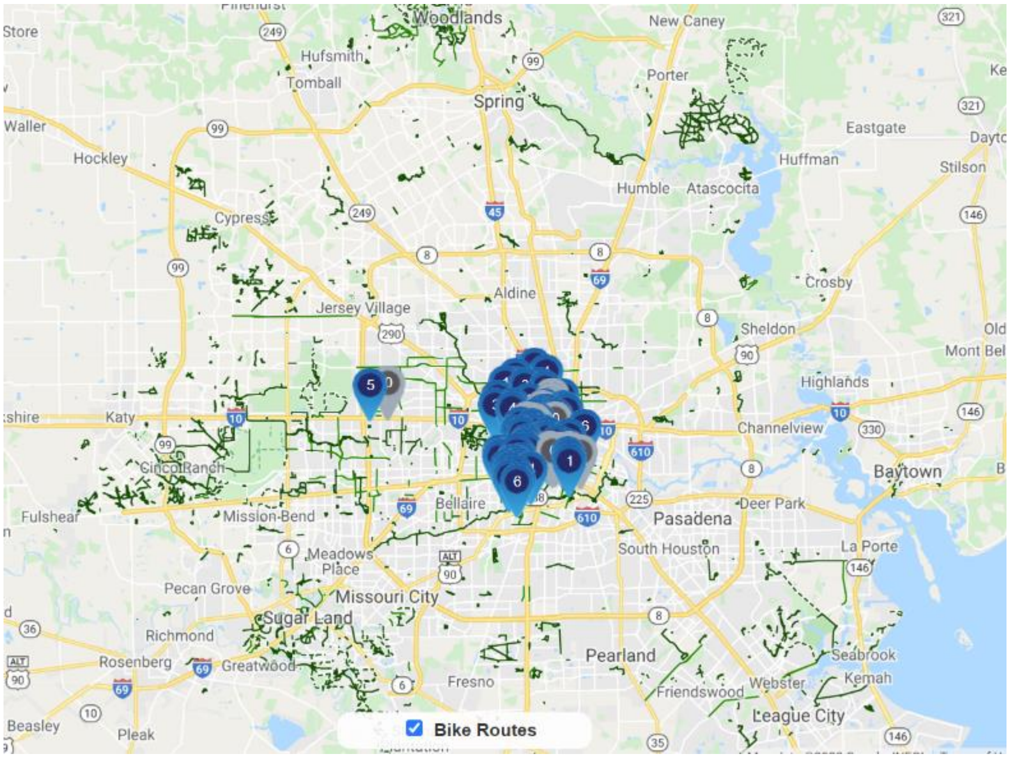
Origin	One-way Trips	Return Trips	Total Trips	Study Period
Spotts Park	2868	5986	8854	Sept '15–Aug '16
Sabine Bridge	4563	10293	14856	Sept '15–Aug '16
Jackson Hill & Memorial Drive	1621	2390	4011	Dec '15–Aug '16

Table 8 lists the popular routes in the Houston BCycle program that should be targeted since limited data is available.

Table 8. Popular BCycle Program Routes.

Downtown Routes	Rice University Routes
Hermann Park to Rice Village	Rec Center to Rice Village
Downtown to the Heights	Cambridge to Med Center
Montrose to Washington Avenue	Meditate to Rothko Chapel
Midtown Barhop	
EaDo to Emancipation Park	
Museum District Jaunt	
Ensemble/Row Houses/MFA	

Figure 20 below shows all the bicycle routes in Houston that are currently not included in the data received for the BCycle program and can be used to get facility type data. Lastly, the Houston BCycle program has also recently introduced e-bikes. These are not present in the datasheet available since the data dates back to 2015–2016.



Source: Houston BCycle

Figure 20. Houston Bike Routes and BCycle Stations.

TxDOT Laredo District

Bicycle Workshop Addendum

The TTI worked on a project with a focus on improving FM 1472 (Mines Road) in Laredo District (Kraus et al., 2017). The existing physical and traffic conditions that affect bicyclist safety were accessed and mapped for this project. TTI gathered this information from various sources like the TxDOT Roadway-Highway Inventory Network (RHiNo), the United States Census Bureau, the TxDOT Crash Records Information System (CRIS), and the City of Laredo. The number of bike trips originating in or destined to an area was estimated using travel demand forecasting. The U.S. Census Bureau's American Community Survey (ACS) was used to gather the information on workers who use bicycles to commute to other regions and was divided by the corresponding number of workers originating from that region to get a mode share for bicyclists. This data was then mapped to locate areas with a higher percentage of bike mode share in Laredo (>1%). The addendum also included information on potential locations that could attract bicyclists in Laredo and mapped the information to help predict bicycle demand. TxDOT's crash records in CRIS for the years 2012-2017 reported 129 crashes involving bicyclists in the Laredo area. These included one fatal crash and 15 serious injury crashes. The document mapped all the crashes by severity. The addendum included information on current roadway facilities in Laredo and had various maps that classified the roads in the Laredo area by outside shoulder width, posted speed limit, motor vehicle volumes, and heavy vehicle volumes. Lastly, the document included bikeway facility data of the Laredo area which was published by the City of Laredo online.

Feasibility of Bike Facilities on Five Rural Corridors

The TTI analyzed five rural highways within the Laredo area to study the feasibility of bicycle facilities on the study corridors (Ding and Kraus, 2017a). The analysis included case studies on current practices to accommodate bicyclists on rural highways in Texas. The 28-mile Loop 375 (El Paso) (Woodrow Bean/Transmountain Road) extending from IH-10 to east of the Franklin Mountains State Park entrance has a wide-shoulder bicycle facility, which continues outside the city limits for another 20.6 miles. The four-lane highway, divided by a wide median, experiences an Average Annual Daily Traffic of 20,000 to 22,000 in the trans-mountain region, and 18,000 in the section outside the city. Data collected from the crowd-sourced bicycle application Strava, which is primarily used to track cycling and running for exercise using GPS, recorded 1500 and 2500 bicycle trips on the roadway for the years of 2016 and 2017, respectively. Loop 360 in Austin is the other case studied and is a similar four-lane roadway divided by a median. Strava recorded 14,000 bicycle trips on this roadway for both directions combined between July 2016 and July 2017.

The analysis included the Strava heat map and Strava cluster map along with approximate bike counts and shoulder-width inventory for the five facilities in the study (July 2016–July 2017). However, a more detailed calibration effort is needed to determine the true bicycle trip count. Table 9 provides the approximate bicycle counts as observed using the Strava application.

Table 9. Bike Counts from the Feasibility Study of Five Rural Corridors (Jul 16–Jul 17).

City	**Roadway**	**Study Limits**	**AADT**	**Approximate Bike Count**
Eagle Pass	SL 480	International Bridge II to SH 57	903–3,401	1,000
Del Rio	SL 79	US 277 to US 377/US 277	1,126–2,691	40
Laredo	Loop 20	SH 359 to Mangana Hein Road	4,183–23,181	60
Laredo	FM 3338	FM 1472 to SH 255	823–2,084	180–300
Laredo	SH 255	Mexico Border to US 83	2,345–5,046	400

FM 1472 Bike Lane Addendum

The report followed the TxDOT guidance for bicycle facilities, which includes guidance for new construction projects, full construction projects, and construction projects using existing right-of-way (Kraus, 2016). The report also included zoning information for the City of Laredo as collected from the GIS Division of the City of Laredo Building Development Services, updated in 2016, as well as data on various speed limits along FM 1472 and the AADT volume on the roadway. The study compared the forecasted AADT with the actual AADT for 2015 along FM 1472. Lastly, the report included maps highlighting the existing and planned bikeway facilities as updated in the Laredo Metropolitan Transportation Plan update of 2015–2040 under the Laredo Urban Transportation Study by the Laredo MPO.

FM 1472 Bike Lane in Median Addendum

In the analysis conducted by TTI along FM 1472 to evaluate a possible bike facility in the median, researchers included national and Texas guidance on left-side bike lanes and bike lanes in medians (Ding and Kraus, 2017b). The researchers focused on the AASHTO *Guide for the Development of Bike Facilities* and stated that the projects must meet the minimum design requirement or appeal for a waiver. FHWA's *Separated Bike Lane Planning and Design Guide* includes guidance solely on separated bike lane facilities. It highlighted studies on bike facilities entirely separated from other modes of transportation, including mid-block crossings, transit stops, and loading zones. NACTO's *Urban Bikeway Design Guide* was also studied to understand the typical situations in which a left-side bike lane is preferred. Apart from this, the report also included other state design manuals. The New York Department of Transportation's 2015 *Highway Design Manual* provides some criteria for left-side bike lanes and bike paths in the median. It also references the California Department of Transportation manual, which prohibits the use of bike paths in the median since it requires travel contrary to normal rules of the road. Table 10 highlights the different bikeway facilities across the country studied in the report.

Table 10. Bikeway Facilities Case Studies.

Location	**Facility Type**
Heights Boulevard, Houston, Texas	Shared Use Trail in Median
Pennsylvania Avenue, Washington, DC	Center Median Bike Lanes
Queen Plaza N at Crescent St., New York City, New York	Bike Boulevard
Allen Street, New York City, New York	Left Side Bike Lane
Culver Boulevard, Los Angeles, California	Bike Path in Median

High-Level Review of Bike Lane Striping

The high-level review of bike lane striping was conducted along a major arterial in Laredo (City of Laredo, 2015). The document includes a review of the accommodation of bicyclists along the north and south sections of San Bernardo Avenue—from Chicago Street to Alamo Street and from Constantinople Street to Bruni Street. A conventional road diet was applied in the northern section, where a 5-foot bike lane was provided, and a 5-foot lane with a buffer of two feet was provided in the south section, which includes a school zone. The report also includes data on

AADT volumes in 2008, 2013, 2014, and 2015 for the northern section, along with AADT in 2008 and 2013 for the southern section.

Laredo Metropolitan Transportation Plan 2015–2040

The Laredo Metropolitan Transportation Plan 2015–2040 used TxDOT's CRIS to access crash records in the MPO region (Laredo MPO, 2015). There was a total of 96 bicycle-related crashes that occurred within the Laredo MPO area between 2010 and 2012. While no fatal bicycle-related crashes were recorded, the report includes a map that highlights the locations and frequency of bicycle- and pedestrian-related crashes. A high number of bicycle or pedestrian crashes occurred in the downtown area. The document also includes information on the current and planned bikeway facilities in the Laredo MPO region (see Table 11).

Table 11. Laredo MPO Bikeway Facilities (2015).

Bike Route Name	Limits	Status	Type
Loop 20	Shiloh Dr to South of Sinatra Pkwy	Existing	Cycle Track
Spur 400	N Arkansas Ave to Loop 20	Existing	Bike Lane
Zacate Creek Greenway Trail	Canal St to Rio Grande River	Existing	Shared Path
Manadas Creek Trail	At North Central Park and San Isidro Park S	Existing	Shared Path
Chacon Creek Trail	Rio Grande River to SH 359	Existing	Shared Path
Chacon Creel	Rio Grande River to Lake Casa Blanca	Planned	Shared Path

North Richland Hills

Cotton Belt Trail

NCTCOG set up a counter on the Cotton Belt Trail to the east of Holiday Lane in the city of North Richland Hills (North Central Texas Council of Governments [NCTCOG], 2020a, 2020b). Bicyclist and pedestrian data were collected during February 2020 and March 2020, and the results were presented in the report. The bikeway facility type is a shared-use path. A total of 1,500 bicyclists were counted in February and 3,395 in March, with a daily average of 52 and 110, respectively. The data was also divided by the direction of travel and day of the week. Analysis results of hourly data were provided to get the temporal bike flow distribution on weekdays and weekends. In both the studies, the highest number of bicyclists recorded using the trail occurred around 5 p.m. on weekdays. The usage of the trail over weekends was distributed evenly between 6 a.m. and 7 p.m. During February, 67.2 percent of total bicyclists used the trail on weekends, which reduced to 38.2 percent in March.

City of Plano

Plano Bike Count Data

Trail counters were installed at various locations along the trails in Plano. Bicycle counts from seven of of these counters were provided to TTI for this study in an Excel spreadsheet for periods between December 1, 2013, and December 31, 2019. A combined dataset of more than six years was uploaded to TTI's SharePoint with more than 1,273,700 bicyclists counted over the period. The available data is in raw form and must be cleaned and sorted for use. There are more than 900 null counts so a filtered dataset will provide a better analysis of the counters. Table 12 gives the aggregate bike count records for the seven locations.

Table 12. Plano Trails Bike Count.

Trail	No. of Days Studied	Daily Average Bike Count	Study Period
Chisholm Trail (Jack Carter Park)	1,889	218	06/03/2014–12/31/2019
Chisholm Trail (Orlando Drive)	2,035	153	06/03/2014–12/31/2019
Plano Bluebonnet Trail at US 75	1,718	52	06/05/2014–09/15/2019
Plano Legacy Trail	2,011	25	06/14/2014–12/31/2019
Plano OPP & NP Trail	2,027	142	06/14/2014–12/31/2019
Rowlett Trail	1,430	5	02/02/2016–12/31/2019
Russell Creek Counter	2,193	52	12/20/2013–09/15/2019

San Antonio

Alamo Area MPO Bike Level of Traffic Stress

The level of traffic stress (LTS) is an approach that quantifies how stressful it is to ride a bike close to cars, buses, and other traffic. The Alamo Area MPO (AAMPO) and the City of San Antonio worked together on this project by Hudson and Dai (2019) to evaluate the LTS in the MPO's study area in 2017. The report included maps of all the roadways in the study area and divided them according to two categories—TxDOT On-System LTS (2017) and AAMPO Bike LTS (2016). Under TxDOT On-System LTS, roadways were categorized as Level 1 (suitable for children cyclists) and Level 2 (LTS most adults can tolerate with lower stress). The AAMPO Bike LTS categorized the roadways as Green (almost everyone will feel comfortable bicycling on these segments), Comfortable (most adults will feel comfortable bicycling on these segments), COSA Park Trails, and Sidewalks. The Green Bike LTS segments include trails, shared-use paths, roads with less traffic, bike lanes, bike lanes with buffer, and protected bike lanes. The Comfortable category may or may not have a striped bike lane and would have posted speed limits between 30–35 MPH. TTI has the source data for this map.

AAMPO Bicycle Facilities

The AAMPO map highlights the existing bicycle facilities throughout the MPO area in 2016 (Figure 21). The bike facilities were categorized as bike lanes, bike paths, and bike routes. TTI has the source data for this map.

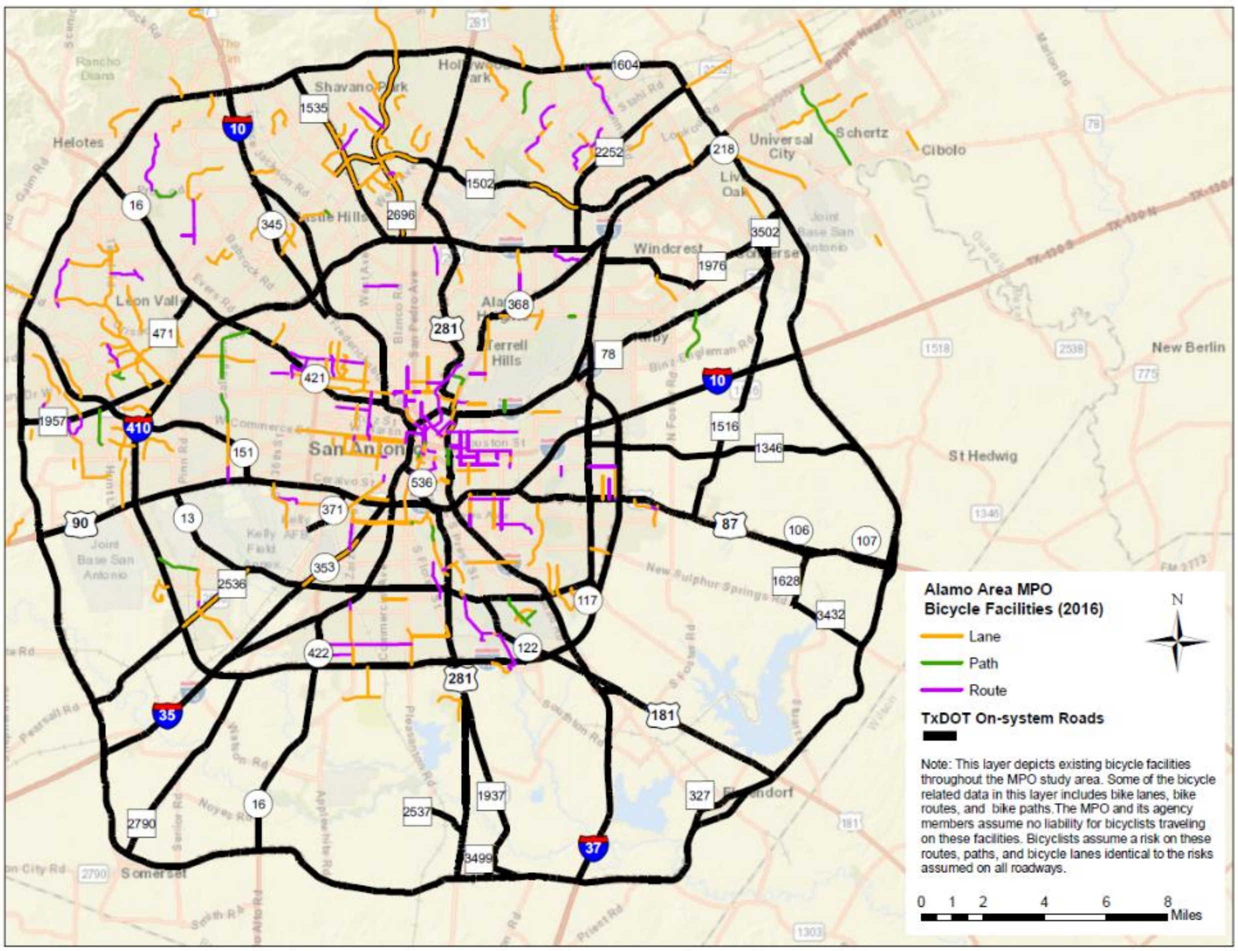


Figure 21. AAMPO Bicycle Facilities.

Bexar Bikeway Inventory

The inventory report includes bicycle facility type information on 20 roadways in Bexar County in 2014 (Bexar County, 2014). The list includes 19 bike lanes and one shared roadway (sharrow). Physical information of the bicycle facility like the bikeway length and bikeway width was also provided. In some cases, the type of material used for the roadway surface was also provided. The data lacks GIS coordinates to pinpoint the location. However, the start and end locations of the bicycle facility type are mentioned.

Bicycle Count—FM 471

Hourly bicycle counts for FM 471 in Medina County were collected during spring 2016 from Thursday, March 24th to Wednesday, April 6th. The bicycle counters were deployed at two locations and bicyclists were recorded for each direction of travel. The dataset included GIS coordinates for both locations. A total of 213 bikes were counted traveling northbound, and 165 bikes were counted traveling southbound on FM 471 between FM 1957 and Private Road 376 with an average of 15 and 12 bikes daily, respectively. The bicycle count recorded on FM 471 for two weeks on the north side of Castroville was 211 bicyclists northbound and 146 bicyclists southbound, with an average of 15 and 10 bicyclists daily. At this location north of Castroville, the data showed a spike on April 2, 2016, between 9–10 a.m. This spike was likely due to the fact that the location falls along the route of the Tour de Castroville Walk/Run/Ride event. This spike accounted for more than 50 percent of all bicyclists recorded at this location.

Bicycle Count—FM 1050

Hourly bicycle counts for FM 1050 in Uvalde County were collected during spring 2016 from Thursday, March 24th to Wednesday, April 6th. The bicycle counters were deployed to two locations and were divided according to the direction of travel. The dataset includes GIS coordinates for both locations. According to the Strava data mentioned in the San Antonio Rural Bike Plan (described below), the roadway had higher levels of bicycling. However, data results in spring 2016 showed very few bicyclists. The weather information included in the data is likely to have been a contributing factor.

San Antonio Bike Routes

San Antonio bike routes were provided in a map as a PDF document with popular bicycle routes in the city of San Antonio (Figure 22). These bike routes were identified using data from various sources like Cycle Texas, Hill County Bicycle Touring Club, San Antonio Riding Club, San Antonio Wheelmen, and the internet. The bikeway facility types were not categorized.

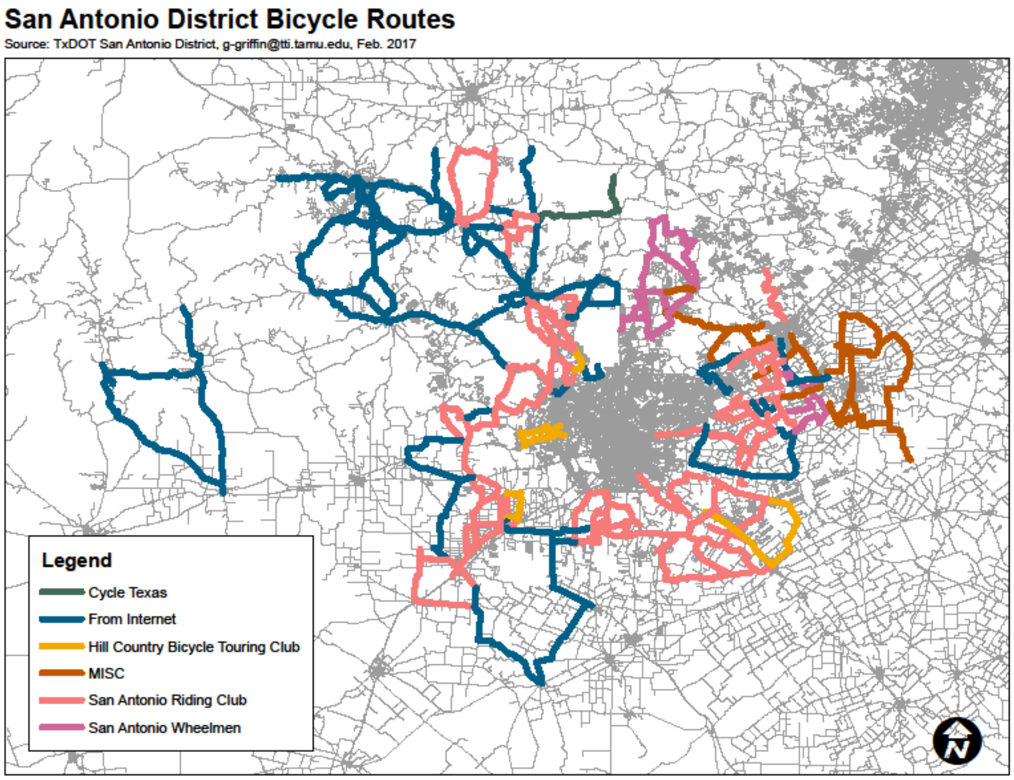


Figure 22. Bicycle Facilities, San Antonio.

Pedestrian and Bike Accommodations Guidance Technical Memo

TTI assisted the TxDOT San Antonio District in the development of a guidance system to accommodate pedestrians and bicyclists on state roadways in the San Antonio urban area within Loop 1604 (Hudson and Dai, 2019). Data from various sources were collected and integrated for this project (Table 13). The TxDOT Roadway Inventory provided important physical properties of the roadways such as shoulder width, motor vehicle traffic volume, and posted speed limit. The railroad data showed the railroad crossings at the state roadways. The bicycle heatmap developed by Strava gave an understanding of the bicycle volumes on San Antonio roadways. The report also included existing and proposed bikeway facility data, which was acquired from the Open Data Site of the City of San Antonio and the draft ADA Inventory prepared by Pape-Dawson Engineers for the TxDOT San Antonio District. The bikeway facilities were categorized as bike lane, buffered lane, cycle track, multi-use path, bike route, separated lane, shoulder, and park trails. The report used the data to evaluate the LTS for bicyclists on target roadways.

Table 13. Data Sources for Pedestrian and Bike Accommodation Guidance Tech Memo.

Data	**Source**	**Year**
Total Population	American Community Survey 5-Year Estimates	2013–2017
Texas Railroads	TxDOT	2016
Roadway Inventory	TxDOT	2017

Bike Facility	City of San Antonio	2019
Park Trails	City of San Antonio	2019
ADA Inventory	Pape-Dawson Engineers	2019
Bike Heatmap	Strava	2019

The report also provided an overview of crash data on 22 roadways in San Antonio over the three years between 2015–2017. The crash data were retrieved from the TxDOT CRIS database. However, as CRIS does not provide the level of detail needed for bike and pedestrian crash analysis, the researchers obtained crash narratives from police reports (CR-3s). The Pedestrian and Bicycle Crash Analysis Tool (PBCAT) was then used as a way to categorize the crash types. PBCAT is a software tool recommended by many agencies. A total of 78 KAB (fatal, suspected serious injury, and non-incapacitating injury) bike crashes occurred on the target roadways in the period, and each crash involved at least one motorist and one injured bicyclist. The report further provided an analysis of crashes by roadways, injury severity, location on the roadway (intersection and non-intersection), and place the person was riding (bike lane, sidewalk, and travel lanes). Fifty-eight percent of the KAB bike crashes occurred at intersections, and 13 percent were intersection related. About 42 percent of the crashes occurred on the sidewalk or a crosswalk, 39 percent occurred in travel lanes, and 14 percent occurred in the bike lane or on a paved shoulder. The data also included crashes involving pedestrians segregated in a similar format. The report also mentioned the bike facility separators, sometimes called zebras, armadillos, or turtles, with various locations that have these separators installed.

San Antonio District Rural Bike Plan

The San Antonio Rural Bike Plan report was prepared by TTI in cooperation with the TxDOT San Antonio District (Hudson et al., 2016). The rural bike plan covered the following seven counties: Atascosa, Bandera, Frio, Kendall, Kerr, McMullen, Medina, Uvalde, and Wilson. The data for this study included important roadway characteristics obtained from the TxDOT 2014 RHiNo. The report included maps and information on shoulder widths, posted speed limits, motor vehicle traffic volume, and truck traffic volume.

Bicycle trip data was acquired from the ACS which asked respondents how they got to work in the prior week. The answer had to be a single travel mode that the respondent used for the longest distance. This ACS data provided the bike mode share in all the counties studied. The 2010–2014 ACS 5-year estimates of bike mode share for commuting (journey to work) on a block group level were provided in the report. As expected, Bexar County had the highest percentage of bike commuter mode share. The report also included maps to highlight the prominent attractions for bicyclists throughout the counties. Lastly, the report included crash data for the seven counties from 2013–2015 collected from TxDOT's CRIS. The two bike count studies from San Antonio mentioned earlier were also included in this report.

Wurzbach Files

Hourly bicycle counts were collected on Wurzbach Parkway in San Antonio during summer 2016 from Thursday, May 5th to Monday, June 6th. Eco-Counter's bicycle tubes were deployed at four locations. The count data were divided according to the direction of travel. On Wurzbach Parkway near the Bitters Recycling Center, a total of 4,909 bikes were counted, with an average of 149 bikes every day. The counter located east of US 281 on the Wurzbach Parkway shared use path recorded 2,788 bikes, with an average of 111 bikes daily. This counter was under water due to heavy rains on May 29th and did not have accurate readings after this date. The total bicycle count recorded at Wurzbach Parkway near West Avenue was 2,890, with an average of 88 bikes per day. However, the counts at this location might be inaccurate for the last six days as the tube was dislodged on May 31st. The bike count at the last location on the Wurzbach Parkway bike lane and sidewalk west of Wetmore Road was extremely low, with a total count of 12 bikes recorded in 33 days and an average of fewer than one bike per day. The files also included location information for the four counters and recommendations for roadway improvements.

San Antonio River Authority

Permanent Eco-Counters were installed at various locations in San Antonio. Hourly bicycle counts from five of these counters collected by the San Antonio River Authority were provided in the datasheet for various periods from February 2, 2012, to April 26, 2020. The datasets were divided by locations, and the GIS coordinates for each location were provided in a separate document. The available data was in raw form. Table 14 gives the aggregate bike count records for the five locations.

Table 14. San Antonio River Authority Bike Counts.

Trail	**No. of Days Studied**	**Daily Average Bike Count**	**Study Period**
Confluence Park	502	67	12/12/2018–04/26/2020
Lock and Dam	2,147	66	11/06/2014–04/26/2020
Mission Theo Avenue	2,730	253	02/02/2012–07/25/2019
San Juan Pump Station	2,148	66	06/10/2014–04/26/2020
VFW West Bank	2,148	186	06/10/2014–04/26/2020

Sugar Land

H-GAC, in collaboration with the City of Sugar Land and TTI, collected pedestrian/bicycle counts at 39 locations in Sugar Land (HGAC, 2017). H-GAC and TTI issued a total of 19 and 20 counters in 2016 and 2017, respectively. All 39 locations were unique, and there were no locations counted more than once. There are plans to recount some locations to measure changes in use from previous years. TRAFx Infrared Trail Counters were used to count the number of people using trails and sidewalks. These counters use infrared technology to count the number of people who pass by the counter and do not differentiate between pedestrians and bicyclists or direction of travel. The counters were placed on shared-use paths and sidewalks along the major thoroughfares in the Sugar Land area. H-GAC and TTI deployed temporary counters in Sugar Land three times: eight in April 2016, eleven in June 2016, and twenty in March 2017. Hourly user counts were collected at all the selected locations. The counters at the Streetwater Boulevard at Austin Parkway, Austin Parkway at Mesquite Park Trail, and S. Woodstream Trail at Sweetwater Boulevard were the locations with the highest counts, with an average of more than 80 users traveling along the routes daily. The count totals decreased at some locations due to a school holiday during the spring study. The volumes were typically higher in the morning and evening hours. The average daily use was higher on weekdays than weekends at most locations, suggesting that the locations studied were prominently used for commuting to work or school. The effects of weather were also visible as many locations had the lowest usage on days with the highest precipitation.

BIKEWAY FACILITY DATA COLLECTION

The bikeway facility shapefiles provided by the transportation agency stakeholders used different categorizations of bikeway facilities. To enhance data quality and consistency, the researchers verified the type of bike facilities in these shapefiles that were implemented on roadway segments by converting the shapefiles into KMZ files and then importing them into Google Earth. Each bike facility in the file was checked against the Google Earth aerial image and Google Street View. New fields were added into the shapefiles to record the verified type of bikeway facility on each side of the roadway segments in the following categories: bike lane, contra-flow bike lane, buffered bike lane, two-way buffered bike lane, separated bike lane, two-way separated bike lane, sharrow, bike facility sign, shared bus–bike lane, advisory bike lane, shared-use path/trail, and two-way shared-use path. The development of the bicycle facility database was time intensive as each facility was verified and confirmed before including it in the ArcGIS file. The graph in Figure 23 shows the type and number of on-street facilities in each city. The maps in Figure 24 depict the bike facilities in the following cities: Austin, College Station, Dallas, Fort Worth, El Paso, Houston, and San Antonio.

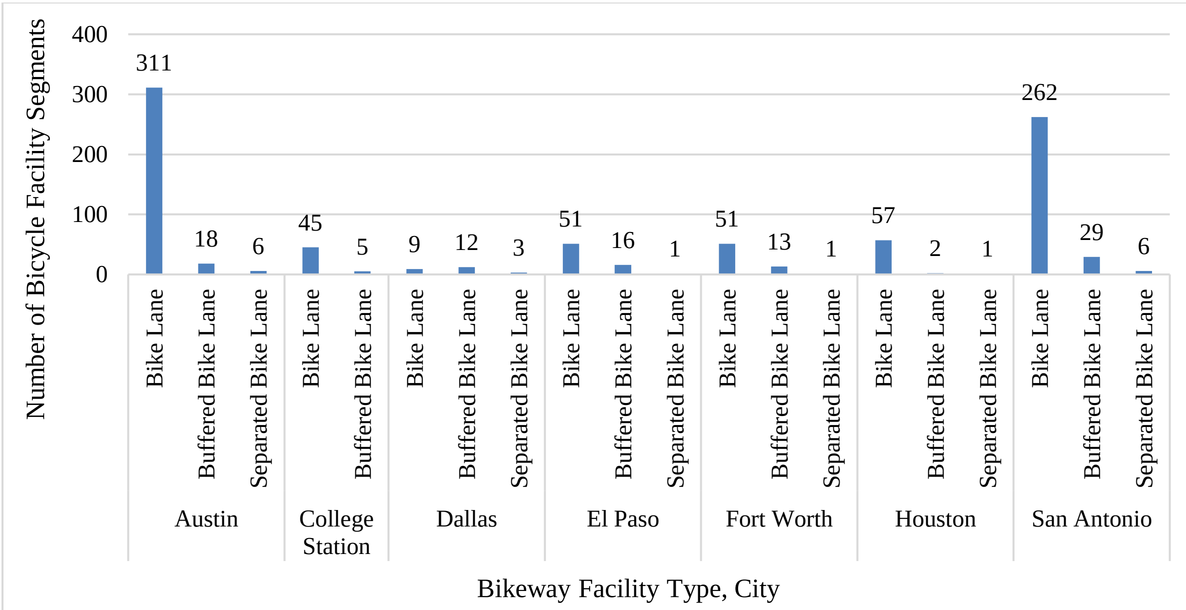
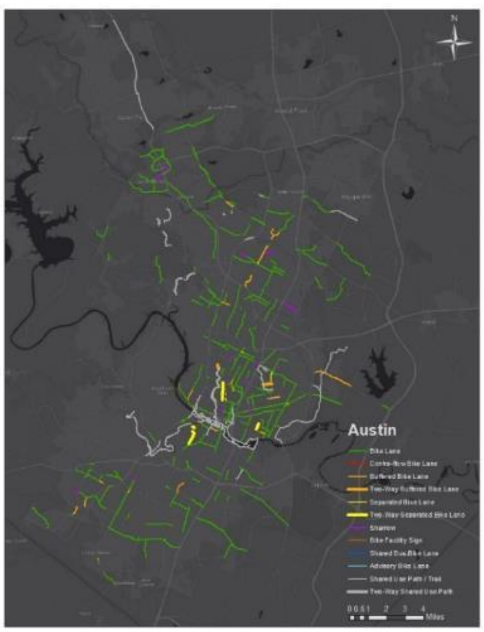
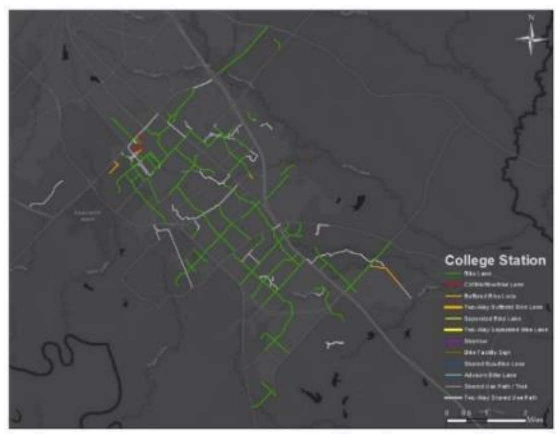


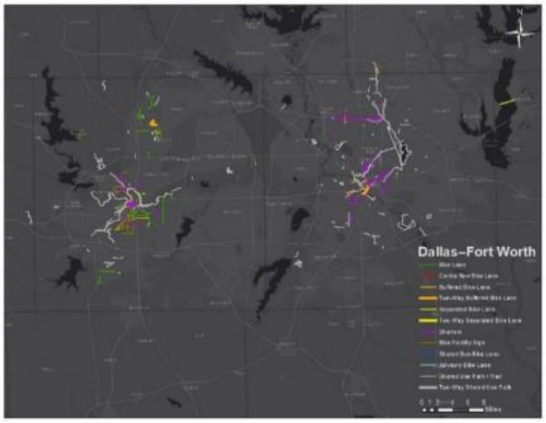
Figure 23. Total Number of On-Street Bicycle Facility Segments per City.



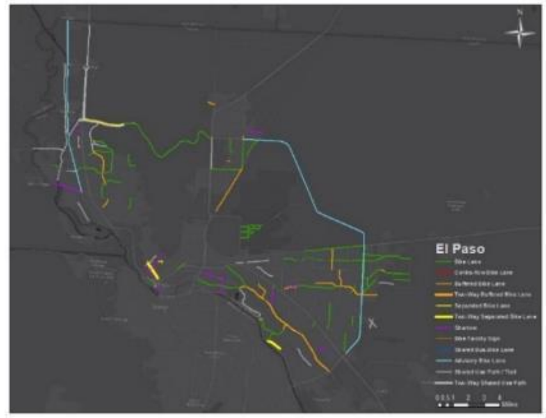
a) Austin



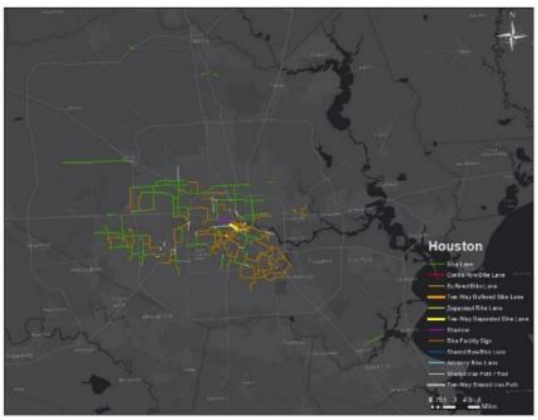
b) College Station



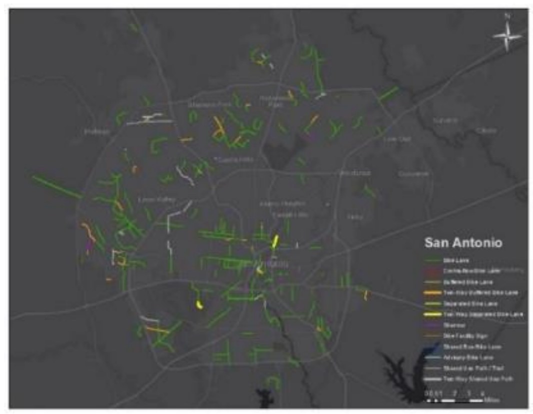
c) Dallas–Fort Worth



d) El Paso



e) Houston



f) San Antonio

Figure 24. Bicycle Facility Maps.

After validating the bicycle facility data, the research team conflated this database with the 2019 TxDOT RHiNo data. There were some typographic errors in the bicycle facility shapefiles. For example, some bike lanes were mistakenly digitized as a "circle" covering two roadway features (Figure 25). In some cases, distinct bike lane types were wrongly dissolved as one-line features. These errors were found and corrected during the conflation process.

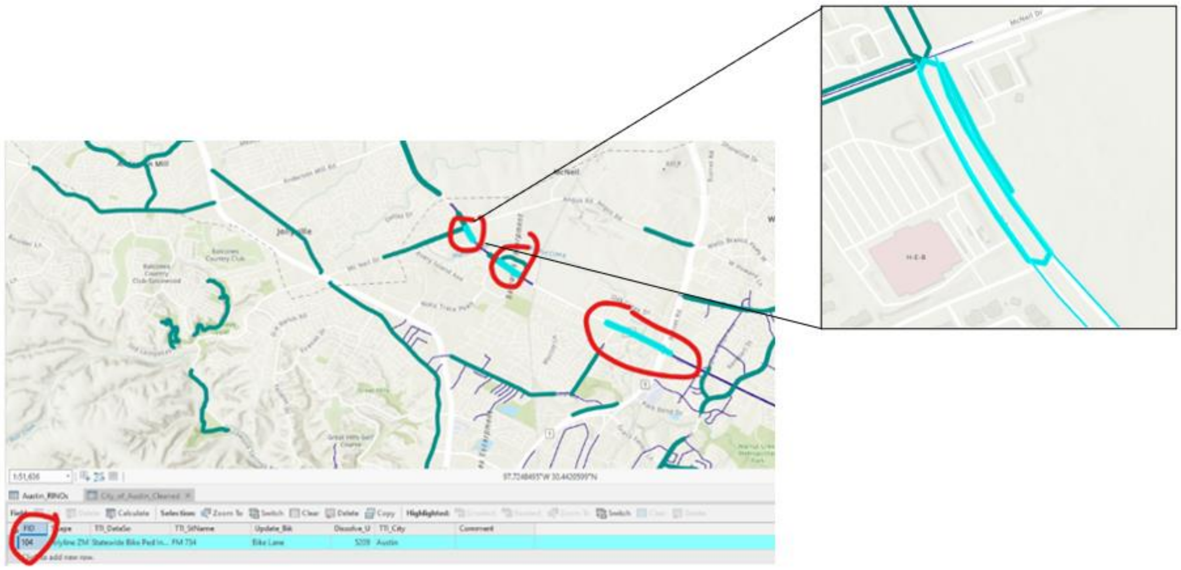


Figure 25. Errors Found in Bicycle Facility Shapefiles.

Since the bicycle facility files were not developed using the RHiNo segments (or links) the two shapefiles did not match. The RHiNo shapefile does not have a unique segment ID. Thus, the research team first created a new RHiNo segment ID by combining the unique roadway segment identifier (RIA_RTE_ID) and the beginning milepost (i.e., distance from the origin variable [Frm_DFO]). Moreover, some of the RHiNo segments can have more than one link indicating the centerline, right side, and left side of the same segment. The researchers used the RDBD_ID to select the Centerline/Single Roadbed. They then applied a 10-meter buffer to each bicycle lane to select the RHiNo segment nearest to it. Because the bike lane segments were longer than the RHiNo segments (in urban areas), the researchers generated a start, middle, and end point for each bike lane segment. They then used the Snap Tool in ArcGIS Pro to move these points to the edge of the nearest RHiNo segments (within 10 meters). They then performed the Spatial Join function to join the generated RHiNo ID to these points. Finally, the Join function was used to aggregate the RHiNo ID of the start, middle, and end points to their corresponding bike path. Some of the bike lanes were matched with up to six RHiNo segments. Therefore, the researchers added six new columns to the bike facility shapefile, which contained the IDs of matched RHiNo segments. Later they used R software to: (1) add new data points to the bicycle facility shapefile, where each observation involved a new RHiNo segment ID (wide-to-long data format), and (2) merge the bicycle facility shapefile with the matching RHiNo segment. The resulting data included the bicycle facility type on each RHiNo segment. If the RHiNo segment did not match, then the research team assumed that the segment did not have a bicycle facility.

FIELD DATA COLLECTION

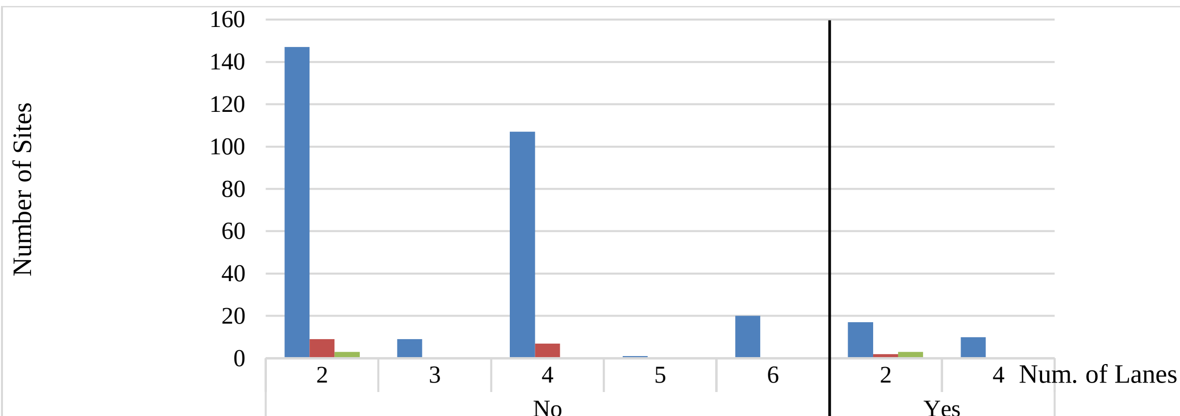
After validating the bicycle facility data and conflating with RHiNo, the research team conducted a stratified sampling to select the sites for data collection. Stratified sampling was conducted per facility type for each deployment. Since the researchers had 20 counters, 10 sites were selected per deployment. The researchers conducted one deployment per city, except for Austin, where they conducted two deployments (hence 20 sites). Described below is the stratified sampling process for Austin sites. A similar approach was used for selecting sites in other cities; however, each one is not described for the sake of simplicity. The list of sites selected for each deployment is presented in the next chapter.

Stratified Sampling: Austin

The research team identified 361 bicycle facilities in Austin, including:

- 311 bicycle lanes.
- 18 buffered bicycle lanes (one and two way).
- 6 separated bicycle lanes (one and two way).

The research team first combined the identified sites with the existing bicycle count data that were obtained from BP|CX. Figure 26 depicts the number of Austin sites with on-street bicycle facilities. The figure also shows the number of lanes and the availability of bicycle counts (Yes, No).



	2	3	4	5	6	2	4
	No					Yes	
Bike Lane	147	9	107	1	20	17	10
Buffered Bike Lane	9		7			2	
Separated Bike Lane	3					3	

Figure 26. Number of Bicycle Facility Types in Austin.

Out of 311 roadway segments with bike lanes, 27 had bike count data. The research team selected 12 bike lanes with no count data for filed data collection. Figure 27 shows the histograms of total and selected sites. Histograms provide a visual representation of the distribution of selected sites for each type of bicycle facility compared to all locations with that bicycle facility. As observed, the selected sites have similar characteristics to the total sites. For example, similar to the total sites, the majority of selected bike facilities were located on urban major collectors (U5). However, the researchers adjusted the sampling such that most locations selected for data collection were on four-lane roadways because BP|CX already had bike count data for 17 locations with two-lane roadways.

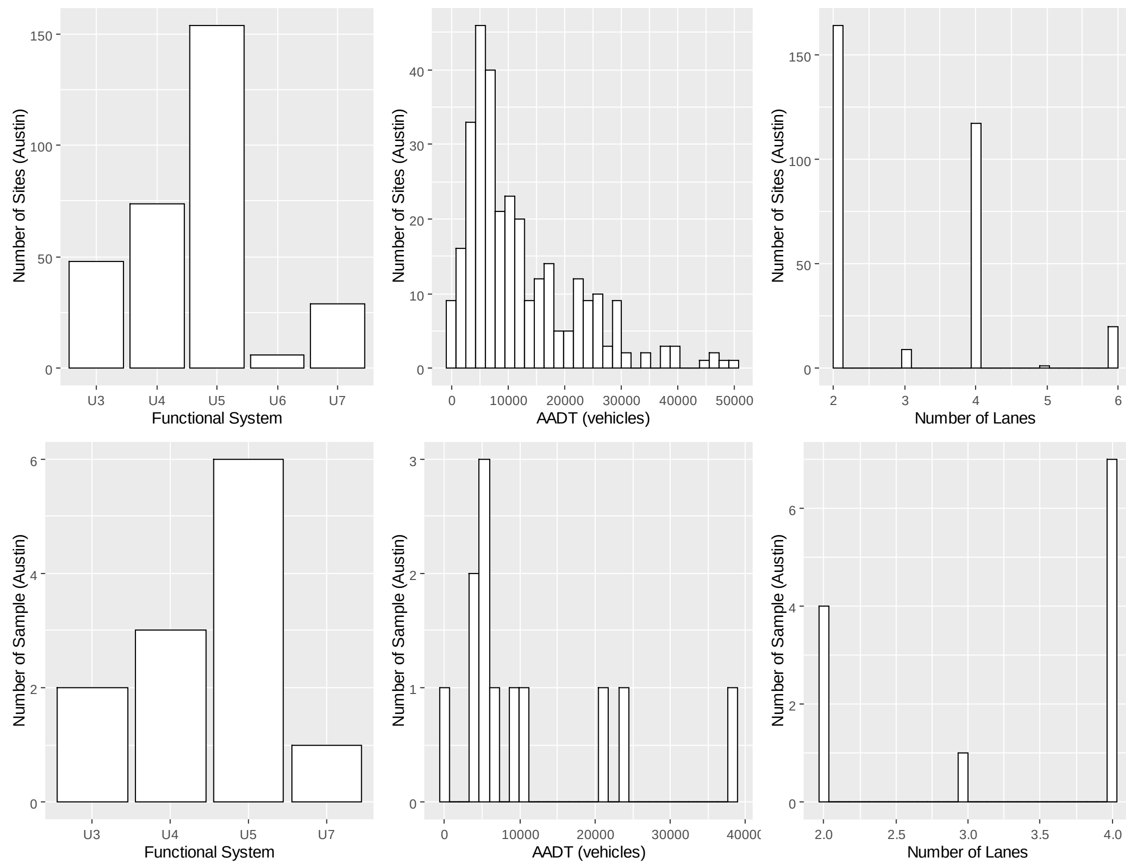


Figure 27. Histograms of Sites with Bike Lanes (Austin).

Out of 18 buffered bike lanes, two had bike counts (2017). Out of the remaining 16 with no count data, eight were randomly selected by accounting for the functional system, the AADT, and the number of travel lanes. Figure 28 shows the histogram of total and sample data for some of the important roadway characteristics at these sites.

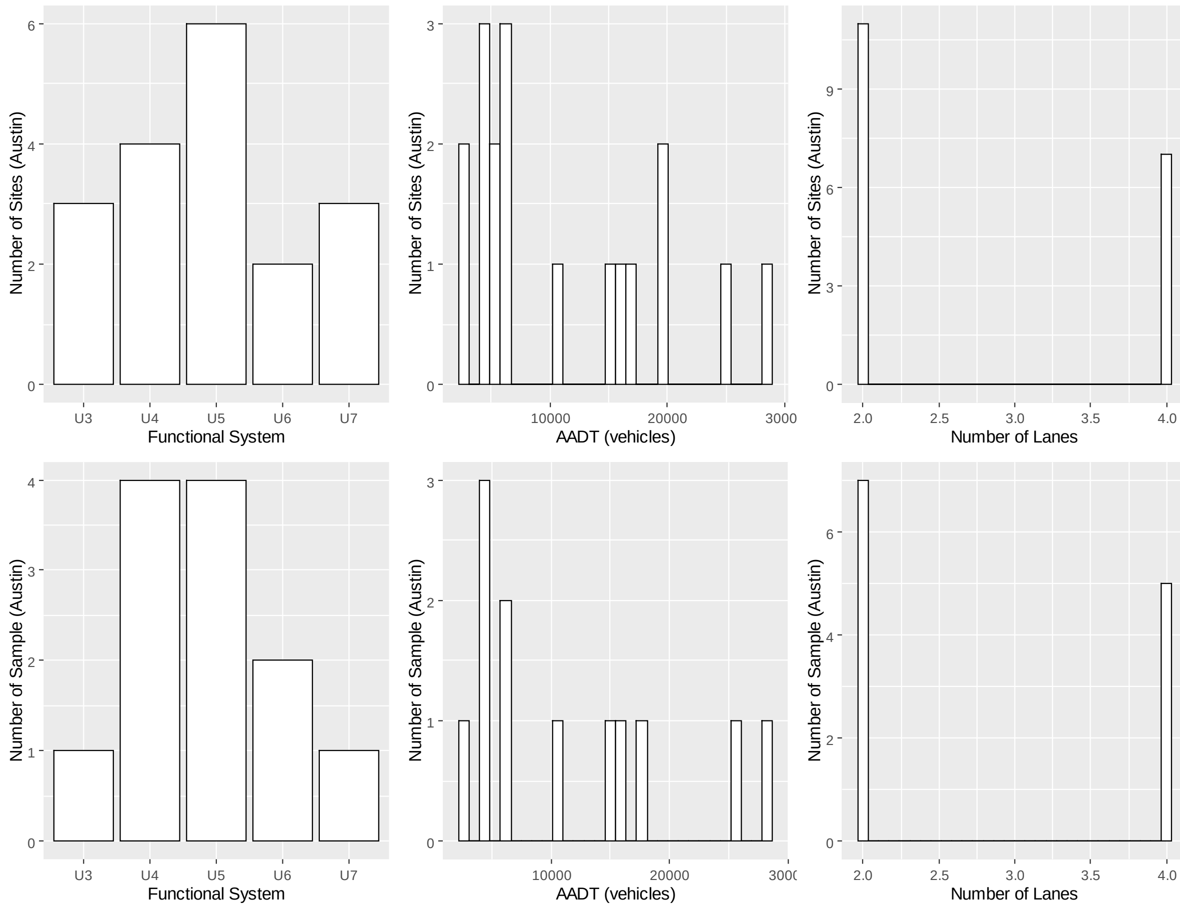


Figure 28. Histograms of Sites with a Buffered Bike Lane (Austin).

Out of six separated bike lanes, three already had count data. The remaining three were on Melridge Place, West 3rd Street, and Guadalupe Street. The separated bike lane on Guadalupe Street was installed only on one side of the road. Hence this site was not included. The remaining two were included in data collection. Histograms were not created for separated bike lanes because very few of them were in the Austin District.

Final List of Sites Selected

Although sampling is the preferred method, this was not possible for sites with a limited number of bicycle facilities. For example, in the Houston bicycle facility data, a handful of locations had on-street bicycle facilities. Therefore, applying the sampling method described above was not feasible.

After conducting the site selection using the database, one of the team members reviewed the selected sites to determine whether they were suitable for data collection (to be explained in the next chapter). Thus, the final list of selected sites was not always the same as the sampling process results.

Table 15 shows the final number of sites and bicycle facilities selected for field data collection.

Table 15. Number of Count Station Bicycle Facilities per City.

City Name	Bike Lane	Buffered Bike Lane	Separated Bike Lane	Through Bike Lane	Grand Total
Austin	9	9	2	1	**21**
College Station	8	2	0	0	**10**
Dallas–Fort Worth	3	5	2	0	**10**
El Paso	3	6	1	0	**10**
Houston	10	0	1	0	**11**
San Antonio	4	4	1	2	**11**
Grand Total	**37**	**26**	**7**	**3**	**73**

Figure 29 depicts the distribution of selected sites across various functional systems. As observed, most of the sites selected for data collection were on urban major collectors and minor arterials. The next chapter describes the field data collection process and results.

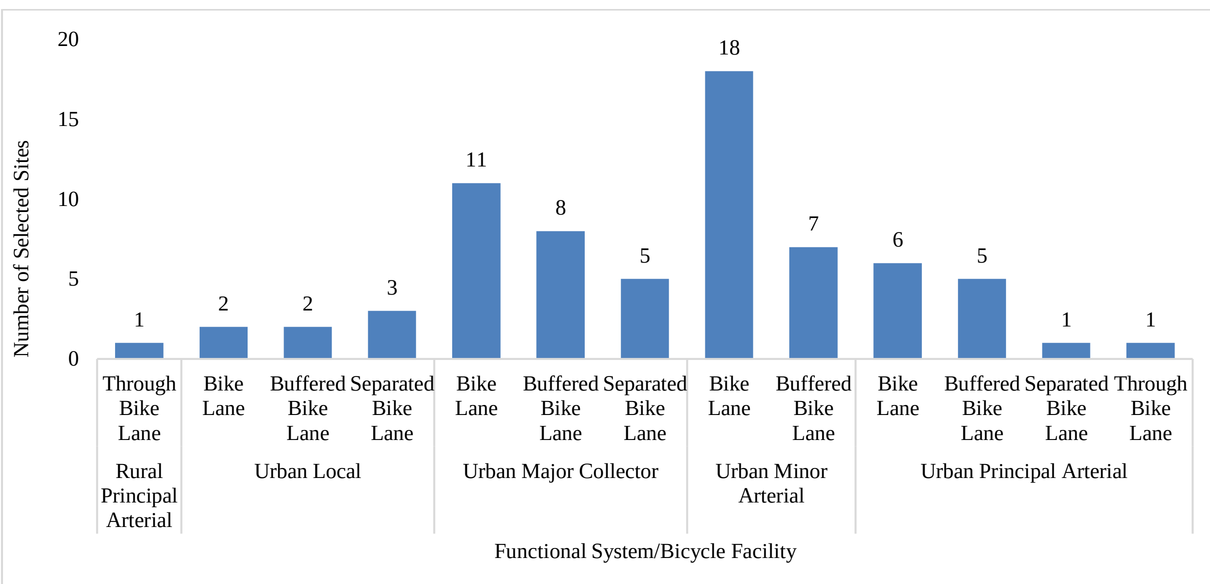


Figure 29. Number of Selected Sites per Roadway Functional System.

Counter Deployment

After identifying sites, the research team collected complementary short-term field data from locations of interest that did not have sufficient bicycle exposure data. The researchers followed the recommendations of FHWA's *Traffic Monitoring Guide* (*5*) and *TxDOT 6927 Project Report* (*6*) to collect the bicycle count data. The *TxDOT 6927 Project Report* provides a detailed description of equipment for collecting bicycle and pedestrian data and a methodology for collecting and adjusting non-motorized traffic count data.

To gather the short-term on-street bicycle count data, the team used Eco-Counter tube counters. The two tubes, connected to the counter, can collect data on bicyclists traveling in each direction separately and can distinguish bicycles from motor vehicles. Eight new tube counters were purchased from Eco-Counter to supplement the twelve counters already in TTI's possession. Additional tubes were borrowed from TxDOT and accessory items, including chains, locks, nails, and other items, were purchased in order to deploy and secure the counters.

The tube counter deployment involved a significant amount of time to plan, organize, and implement. With seven different deployment periods (including two in Austin), each lasting three to four weeks, the team was tasked with identifying specific locations along the roadway to place the counter. Usually, two counters were used for each site, one in each direction to gather counts in the bicycle facility located on each side of the roadway. For a two-way facility or a one-way roadway with a bicycle facility on one side, only one counter was required. The specific location to set the counter had to be a specific distance from intersections and driveways and have a signpost, utility pole, or tree in order to lock the counter. The tubes were only placed across the bicycle facility and did not extend into the motor vehicle travel lane (Figure 30). It took approximately one full workday for two to three researchers to set all of the counters and about half of a day for the researchers to retrieve the counters at the end of the counting period. Regular visits were made to each count site to ensure that the tubes were in place and the counter was functioning correctly.

The deployment periods are specified in

Figure 30. Photo of Deployment Process.

Table 16 and included six cities beginning with Houston and ending with El Paso. With 20 counters and 40 tubes, approximately 10 locations were counted per deployment. The locations included a mixture of downtown and university areas, single-family and multi-family residential, industrial arterials, and arterials with retail and restaurant establishments. In addition, suburban arterials and highway shoulders signed for bicyclists were included.

Figure 30. Photo of Deployment Process.

Table 16. Deployment Cities and Dates.

Deployment	Area	Deployment Date	Retrieval Date	Weather Conditions
Deployment 1	Houston	Tuesday, November 3, 2020	Monday, November 23, 2020	Usual conditions
Deployment 2	Austin	Thursday, December 3, 2020	Monday, December 21, 2020	Usual conditions
Deployment 3	Austin	Monday, January 11, 2021	Monday, February 1, 2021	Usual conditions
Deployment 4	San Antonio	Tuesday, February 2, 2021	Monday, March 22, 2021	Unusual ice storm
Deployment 5	Dallas–Fort Worth	Saturday, April 10, 2021	Sunday, May 2, 2021	Usual conditions
Deployment 6	College Station	Wednesday, May 5, 2021	Tuesday, May 25, 2021	Unusually high precipitations
Deployment 7	El Paso	Monday, June 7, 2021	Tuesday, June 29, 2021	Unusually high precipitations

Table 17 shows the total observed average weekend and weekday counts per facility type and per city. The average was calculated by summing the total counts observed during weekdays and weekends and dividing by the number of days. As observed among the facility types, the separated bike lanes had the most counts. Among the cities included in the data collection was

Houston with the highest number of observed bicyclists. However, since the data were collected during different dates, this conclusion may be biased.

Table 17. Average Bicycle Counts Observed per City and Facility Type.

City	Bike Lane		Buffered Bike Lane		Separated Bike Lane		Through Bike Lane		Grand Total	
	Weekday	*Weekend*	*Weekday*	*Weekend*	*Weekday*	*Weekend*	*Weekday*	*Weekend*	*Weekday*	*Weekend*
Austin	27.72	31.61	26.14	29.65	112.05	136.86	0.26	0.56	34.23	39.90
College Station	16.08	12.70	17.60	21.60	—	—	—	—	16.24	13.69
Dallas–Fort Worth	21.15	45.50	10.53	14.78	25.37	52.00	—	—	16.68	31.44
El Paso	6.13	5.95	6.10	5.91	18.42	5.54	—	—	8.57	5.85
Houston	27.36	37.07	—	—	268.24	428.40	—	—	51.45	76.20
San Antonio	12.68	23.10	9.24	18.20	2.89	4.27	5.97	9.40	9.04	16.65
Grand Total	**21.21**	**26.98**	**14.58**	**18.43**	**65.08**	**91.75**	**3.12**	**4.98**	**24.25**	**31.99**

Note: — means not applicable.

In the following subsections, the deployment process per city, observations during the data collection process, and a summary of the data collection results are presented. The count data are currently being quality-checked to be included in the BP|CX. The research team will use the quality-checked data for the CMF development. Therefore, the average numbers shown in the following tables may change.

Houston Sites

Ten locations were selected for the Houston deployment. Houston data were collected from October 21, 2020, to November 23, 2020. A few of the tubes were misplaced (road tubes instead of bike tubes); these tubes were identified and replaced at a later date. No major weather events were encountered during the Houston deployment. Figure 31 shows some of the images taken from the deployment sites in Houston.

a) Lamar Street b) Tanglewood

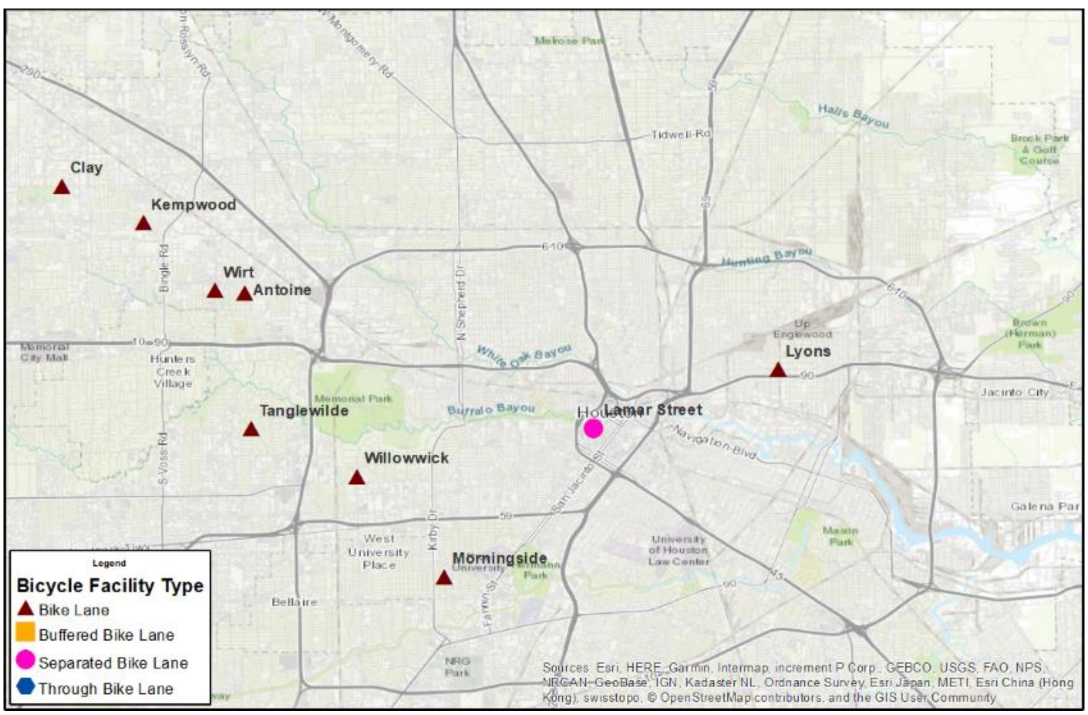
Figure 31. Photos from Houston Deployment Sites.

Table 18 shows the list of sites, bicycle facility type, roadway functional system, and average counts in Houston. Count data were mostly collected from bike lanes, with one exception on Lamar Street, which had a separated bike lane. Most of the bike facilities were located at two- and four-lane urban major collector and urban minor arterials. The observed average bike counts for the separated bike lane on Lamar Street were the highest with 268 and 428 average bike counts on weekdays and weekends, respectively. There were three counters on Tanglewood, two placed on the on-street facility, and one placed on the trail that ran between the two facilities. On the rest of the sites, two counters were placed one on each direction of travel.

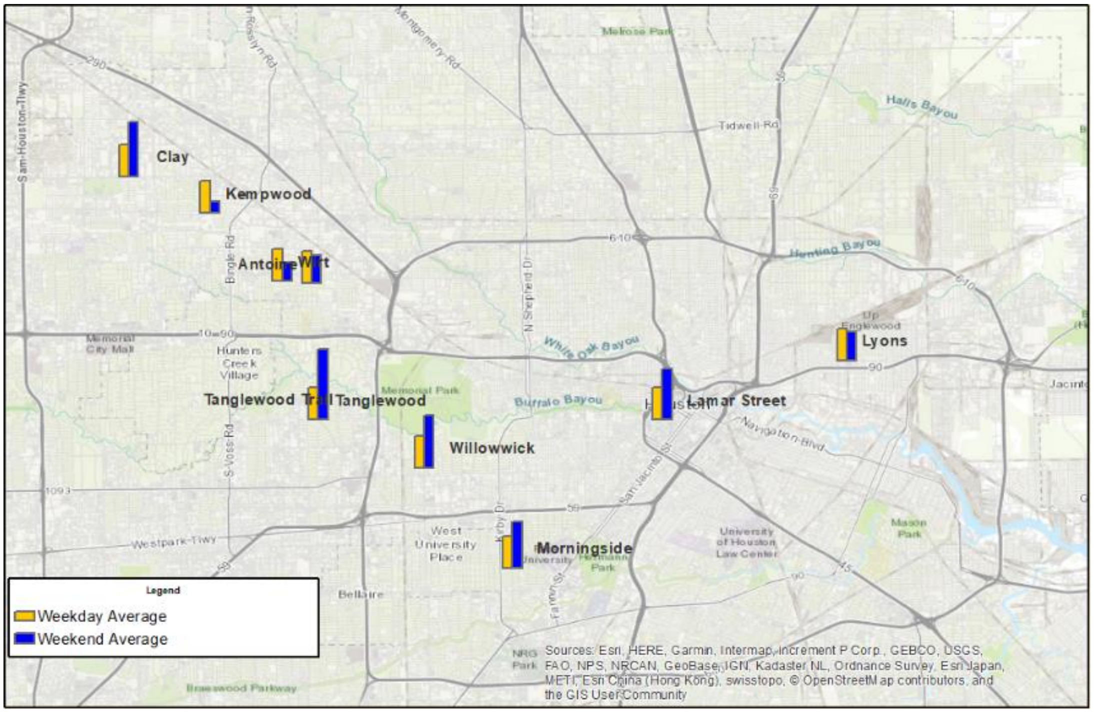
Figure 32 shows the map of count deployment locations and counts in Houston. As observed, the sites selected for deployment were mostly located on the west side of the city (Figure 32a). This part of the city had a better bicycle facility infrastructure making them suitable for data collection. There were very few facilities on the east side, and the existing bicycle facilities did not have a good quality (worn pavement markings, tree branches and shrubs on the street, etc.). Figure 32b shows the distribution of weekend and weekday averages; as observed on Clay, Tanglewood, Willowick, Morningside, and Lamar streets, there were more bicycle users during the weekends. On Kempwood, Wirt, Antoine, and Lyons, there were more bicyclists during the weekdays. In the next chapter, the site characteristics (e.g., land use type, socioeconomic factors, bicycle facility and roadway design characteristics, etc.) will be explored to assess how these factors may affect the bicyclist demand.

Table 18. Houston Area Locations and Counts.

Street Name	Bicycle Facility Type	Roadway Functional System	Number of Lanes	AADT	Weekday Average	Weekend Average
Antoine	Bike Lane	Urban Minor Arterial	4	15,895	4.59	4
Clay	Bike Lane	Urban Principal Arterial	4	26,545	74.41	126.4
Kempwood	Bike Lane	Urban Minor Arterial	4	15,567	11.12	4
Lamar Street	Separated Bike Lane	Urban Major Collector	4	5,746	268.24	428.4
Lyons	Bike Lane	Urban Minor Arterial	2	6,877	35.41	31.6
Morningside	Bike Lane	Urban Local	2	2,187	45.94	67.4
Tanglewood	Bike Lane	Urban Major Collector	2	2,148	50.47	66.8
Tanglewood Trail	Bike Lane	Urban Major Collector	2	2,148	1	2.2
Willowick	Bike Lane	Urban Minor Arterial	4	15,238	16.94	27.6
Wirt	Bike Lane	Urban Minor Arterial	4	20,071	6.35	3.6



a) Facility Types



b) Bike Count Averages

Figure 32. Map of Houston Deployment Locations.

Austin Sites

Twenty locations were chosen for the Austin area for bicycle count data collection. Data were collected in two deployments—one from December 2–3, 2020, to December 21, 2020, and the other from January 5, 2021, to February 1, 2021. Several issues were discovered during the weekly checks of counters mostly surrounding tube disconnections and damages (some due to vandalism), but also one counter was not counting. All concerns were addressed. Days with heavy rain and freezing temperatures occurred. Figure 33 shows some of the images taken from the deployment sites in Austin.

a) 3rd Street

b) Anderson Lane (looking west)

Figure 33. Photos from Austin Deployment Sites.

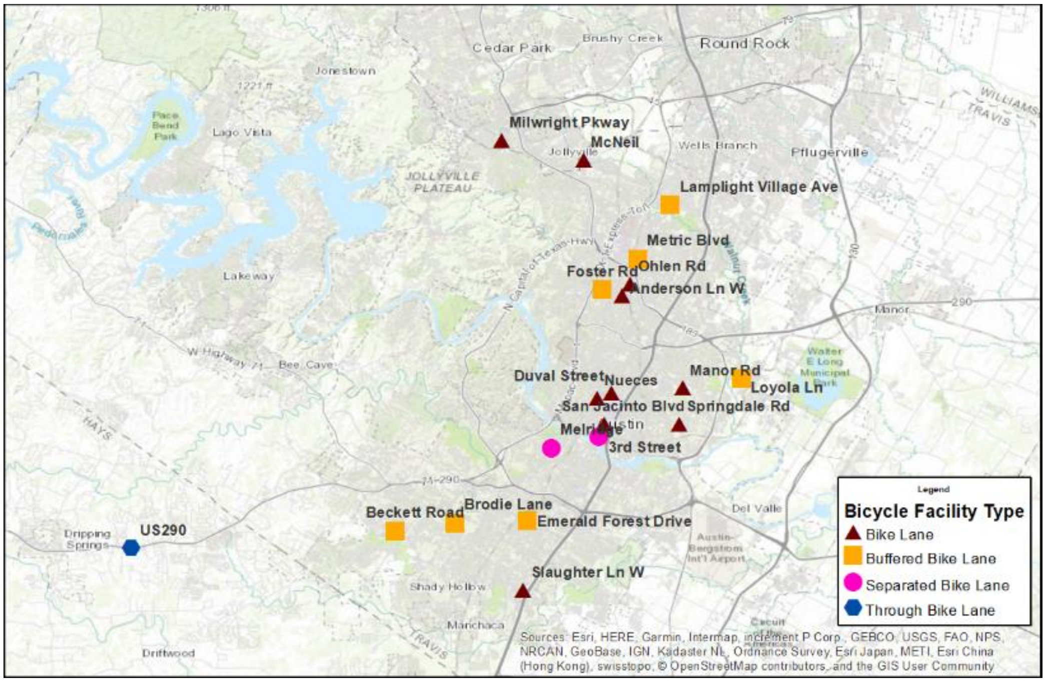
Table 19 shows the sites included in the Austin data collection deployment efforts and average counts. As observed, a wide variety of bicycle facilities were included in the Austin data collection. The facilities were located mostly on two- and four-lane urban major collectors and minor arterials, with a few exceptions including urban locals and one site on a rural highway. There was no striking difference between the facility types in terms of bicyclist counts.

Table 19. Austin Area Locations and Counts.

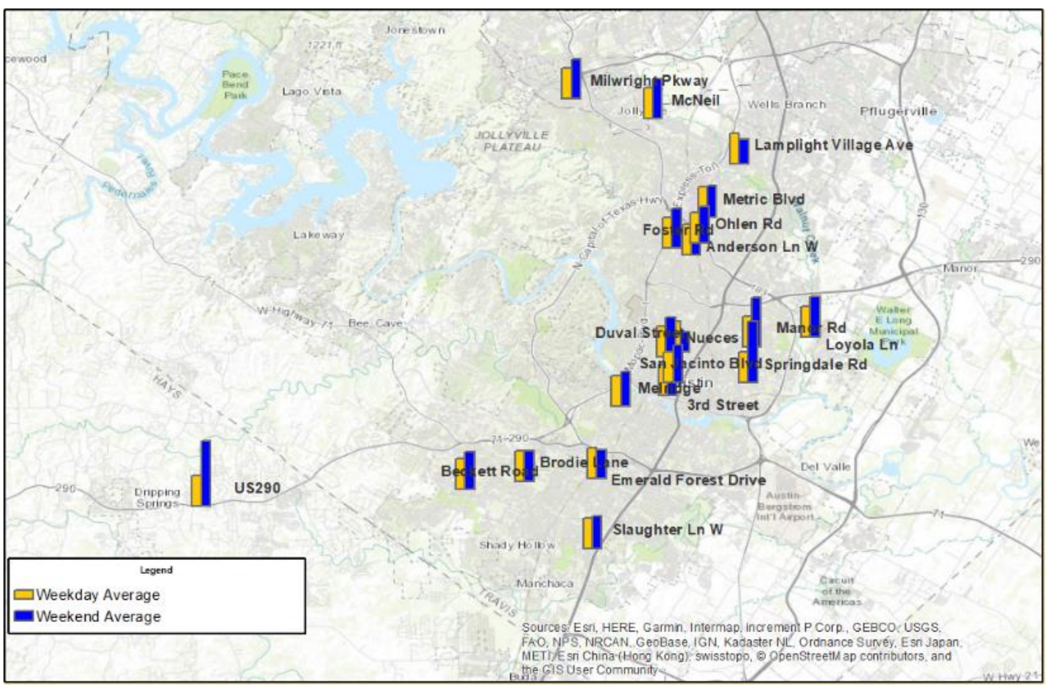
Street Name	Bicycle Facility Type	Roadway Functional System	Number of Lanes	AADT	Weekday Average	Weekend Average
3rd Street	Separated Bike Lane	Urban Local	2	413	196.48	242.22
Anderson Lane West	Bike Lane	Urban Principal Arterial	4	24,089	13.88	7.33
Beckett Road	Buffered Bike Lane	Urban Major Collector	2	4,255	17.85	22.11
Brodie Lane	Buffered Bike Lane	Urban Principal Arterial	4	21,610	19.91	19.89
Duval Street	Bike Lane	Urban Major Collector	4	4,855	41	26.33
Emerald Forest Drive	Buffered Bike Lane	Urban Major Collector	2	4,553	14.91	13.89
Foster Road	Buffered Bike Lane	Urban Local	2	6,398	92.31	120.83
Lamplight Village Avenue	Buffered Bike Lane	Urban Major Collector	4	8,664	11.13	8.83
Loyola Lane	Buffered Bike Lane	Urban Minor Arterial	4	17,651	8.81	11.5
Manor Road	Bike Lane	Urban Minor Arterial	4	7,053	33.25	52.83

Street Name	Bicycle Facility Type	Roadway Functional System	Number of Lanes	AADT	Weekday Average	Weekend Average
McNeil	Bike Lane	Urban Minor Arterial	4	21,609	18.25	23.5
Melridge	Separated Bike Lane	Urban Major Collector	2	2,848	27.63	31.5
Metric Boulevard	Buffered Bike Lane	Urban Minor Arterial	4	16,763	18.09	10.5
Milwright Parkway	Bike Lane	Urban Local	2	265	23.31	30.67
Nueces	Bike Lane	Urban Major Collector	2	5,384	16.89	21.61
Ohlen Road	Bike Lane	Urban Major Collector	2	7,028	23.19	27.33
San Jacinto Boulevard	Bike Lane	Urban Major Collector	3	5,117	39.88	49.06
Slaughter Lane West	Bike Lane	Urban Principal Arterial	6	39,058	6.22	6.56
Springdale Road	Bike Lane	Urban Minor Arterial	2	9,090	61.33	70.9
US 290	Through Bike Lane	Rural Principal Arterial	4	31,884	0.26	0.56

Figure 34 shows the map of Austin deployment sites and counts. The December 2020 deployment included sites mainly on the north and east parts of the region, while the January 2021 deployment sites were in the central, south, and west regions (Figure 34a). As observed in Figure 34b, in most of the sites, the weekend average counts were higher than the weekday counts.



a) Facility Types



b) Bike Count Averages

Figure 34. Map of Austin Deployment Locations.

San Antonio Sites

Eleven sites were selected in San Antonio for data collection. Deployment in San Antonio began on Wednesday, February 3, 2021, and continued on February 4th and 5th when the remaining counters were deployed. A field check was made on February 8th. An unusual ice storm occurred on February 14th and continued for that entire week across the region and Texas. On February 25th, the counters were checked again. It was discovered that one set of tubes was gone from the northbound direction on Main Street in downtown San Antonio. The tubes were replaced. On March 6th, TTI staff checked the counters again and found that the northbound and southbound tubes on Main Street were disconnected. They were reconnected. Another location (Avenue B) had a tube that was loose (inbound direction), so it was repaired as well. Spring break for most San Antonio area schools occurred March 8–12. Some school holidays continued through the week of March 15–19. All counters were retrieved on Monday, March 22, 2021. Figure 35 shows some of the images taken from the deployment sites in San Antonio.

a) Paul Wagner b) Timber Path

Figure 35. Photos from San Antonio Deployment Sites.

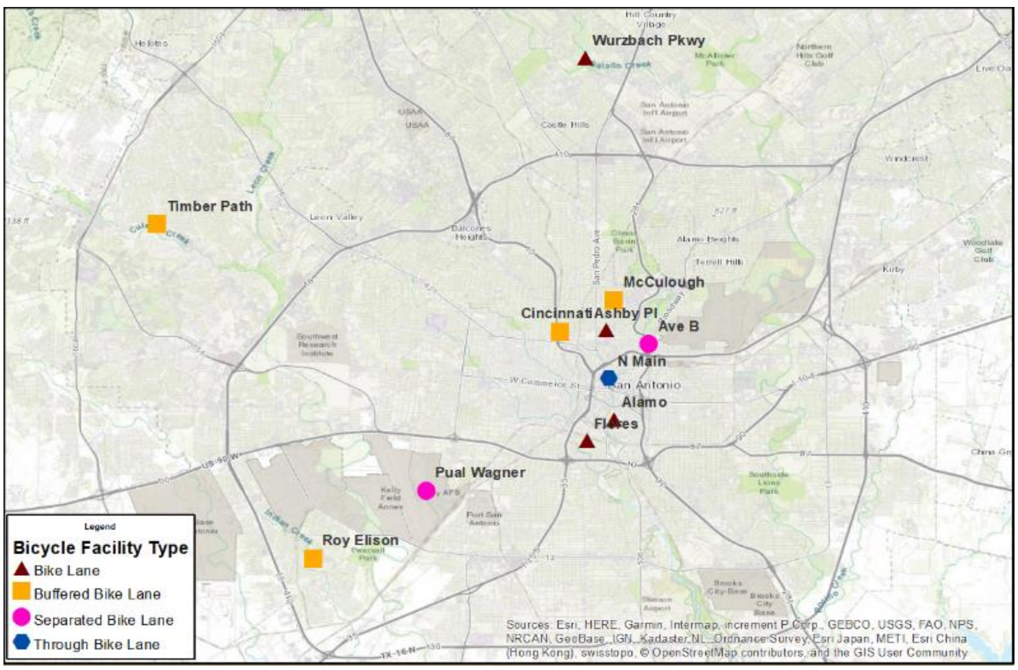
Table 20 shows the sites included in the San Antonio data collection deployment efforts. Most of the bicycle facilities selected for the data collection were located on two-lane urban major collectors and minor arterials. In general, these types of roadways seem to be the preferred locations for installing bike facilities in the city. As observed, the counts in San Antonio were significantly lower than the previous deployments, which could be due to the winter storm.

Table 20. San Antonio Area Locations and Counts.

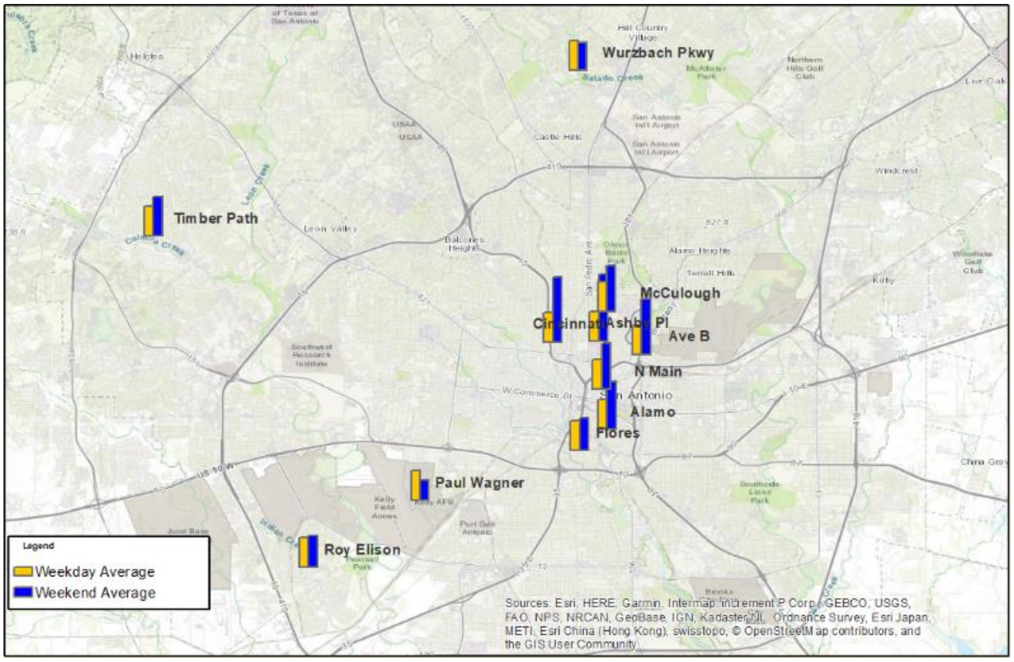
Street Name	Bicycle Facility Type	Roadway Functional System	Number of Lanes	AADT	Weekday Average	Weekend Average
Alamo	Bike Lane	Urban Minor Arterial	2	9,185	14.44	23.4
Ashby Place	Bike Lane	Urban Major Collector	2	6,088	25.81	57.67
Avenue B	Separated Bike Lane	Urban Major Collector	2	1,554	3.84	7.2
Cincinnati	Buffered Bike Lane	Urban Minor Arterial	2	6,317	26.5	58.33
Flores	Bike Lane	Urban Minor Arterial	2	10,580	9.97	10.87
McCullough	Buffered Bike Lane	Urban Minor Arterial	2	9,881	4.78	7.33
North Main	Through Bike Lane	Urban Principal Arterial	2	12,510	5.97	9.4

Paul Wagner	Separated Bike Lane	Urban Local	2	1,985	1.94	1.33
Roy Elison	Buffered Bike Lane	Urban Minor Arterial	2	8,157	1.19	1.27
Timber Path	Buffered Bike Lane	Urban Major Collector	2	5,774	4.47	5.87
Wurzbach Parkway	Bike Lane	Urban Principal Arterial	3	52,790	0.5	0.47

Figure 36 depicts the deployment sites and counts in San Antonio. As observed, a diverse range of facility types was selected from San Antonio (Figure 36a), and the majority of the selected sites were located mostly around the downtown areas. In most sites, the average weekend counts were higher than the average weekday counts (Figure 36b).



a) Facility Types



b) Bike Count Averages

Figure 36. Map of San Antonio Deployment Locations.

Dallas–Fort Worth Sites

Ten sites were selected for the Dallas–Fort Worth area deployment. The deployment took place on April 10, 2021, and the tubes were picked up on May 2, 2021. The tubes were deployed on weekends due to weekday availability issues. Field checks were conducted on April 15th and 24th. Tubes had to be replaced at some locations, and the plugged ends had problems that were resolved on site. There was a good amount of rain while the counters were deployed.

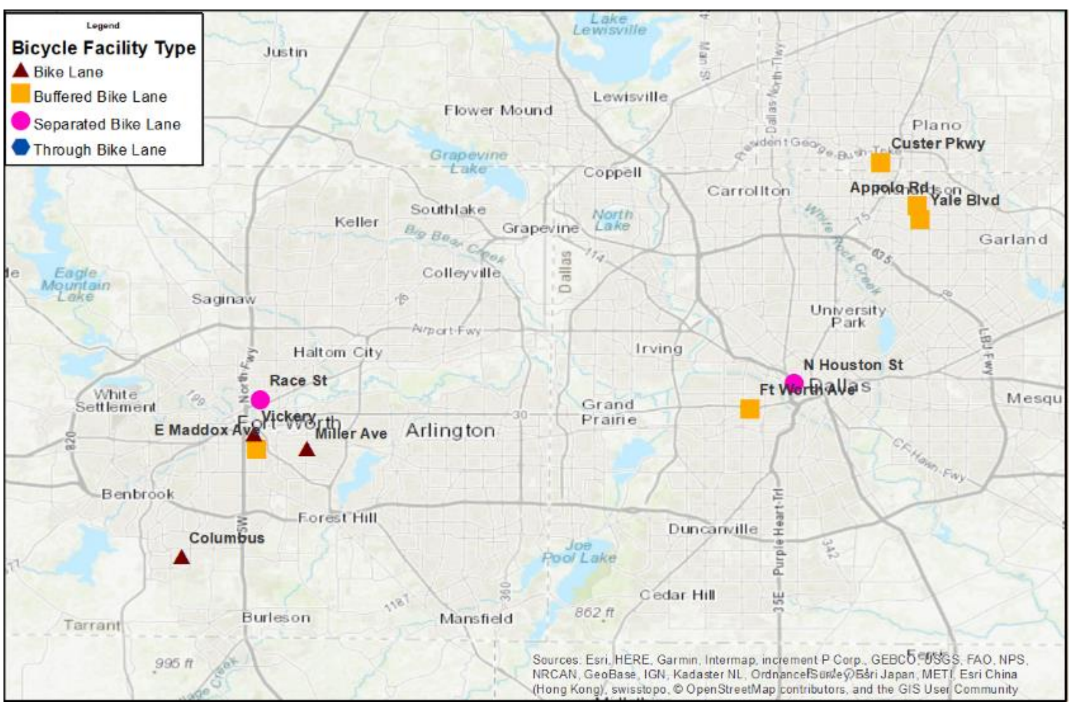
Table 21 shows the list of sites together with the bike facility types and average bike counts observed in the Dallas–Fort Worth area. Bike facilities selected for data collection were located on two- and four-lane urban major collectors and arterials. One location (Fort Worth Avenue) was a six-lane principal arterial with a buffered bicycle lane. The average number of bicyclists observed on these locations did not have a lot of variation.

Table 21. Dallas–Fort Worth Area Locations and Counts.

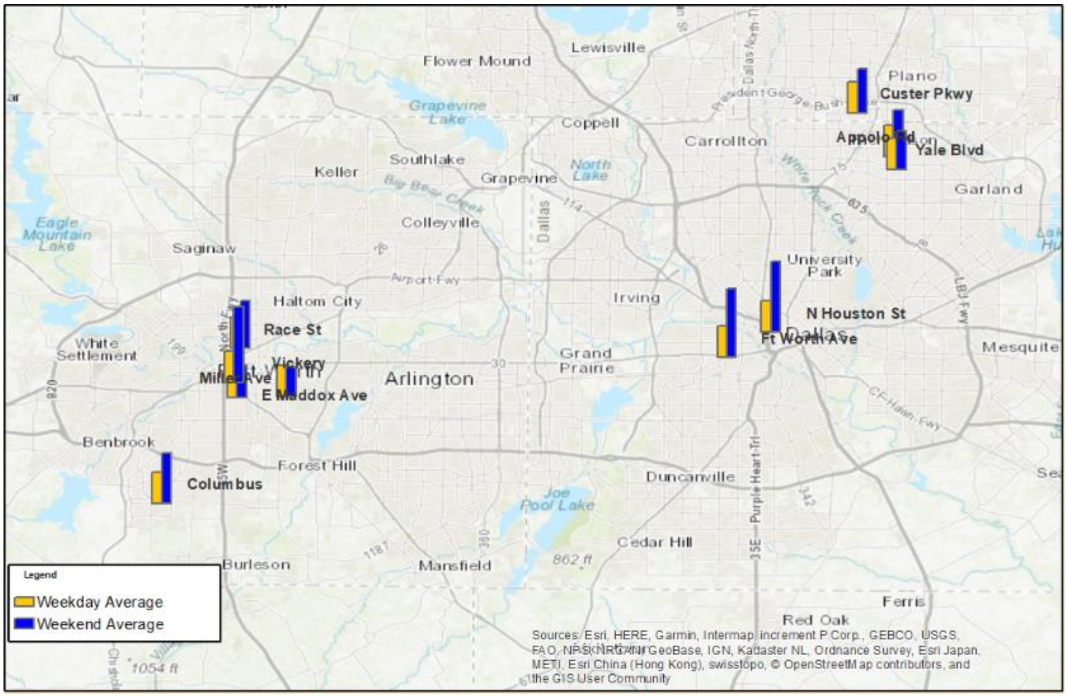
Street Name	Bicycle Facility Type	Roadway Functional System	Number of Lanes	AADT	Weekday Average	Weekend Average
Appolo Road	Buffered Bike Lane	Urban Major Collector	2	1,241	4.53	6.67
Columbus	Bike Lane	Urban Major Collector	2	5,521	12.13	19.67
Custer Parkway	Buffered Bike Lane	Urban Minor Arterial	4	5,073	5.27	7.5

East Maddox Avenue	Buffered Bike Lane	Urban Major Collector	2	6,176	17.73	18.33
Fort Worth Avenue	Buffered Bike Lane	Urban Principal Arterial	6	15,333	11.13	24.5
Miller Avenue	Bike Lane	Urban Minor Arterial	4	12,058	4.93	4.67
North Houston Street	Separated Bike Lane	Urban Principal Arterial	4	6,091	36.13	81.5
Race Street	Separated Bike Lane	Urban Local	2	288	14.6	22.5
Vickery	Bike Lane	Urban Minor Arterial	2	1,849	46.4	112.17
Yale Boulevard	Buffered Bike Lane	Urban Major Collector	2	4,177	2.6	3.17

Figure 37 shows the map of deployment sites and counts in the Dallas–Fort Worth area. As observed, sites were selected from both Dallas and Fort Worth, therefore the deployment in this area was the most complex and time-consuming (Figure 37a). The average bicycle counts were higher during the weekends than the weekdays (Figure 37b).



a) Facility Types



b) Bike Count Averages

Figure 37. Map of Dallas–Fort Worth Deployment Locations.

College Station Sites

Ten sites were selected for the College Station deployment. The deployment took place on May 5, 2021, and the tubes were picked up on May 25, 2021. As before, the counters were checked every 10 days to ensure the data collection was being performed by the counters. This time period overlapped with the Gulf storms—particularly the last week of the data collection period when the city experienced a higher precipitation rate than usual. Repairs to the tubes were made during the field checks (one was disconnected and two were damaged). Figure 38 shows some of the images taken from the deployment sites in College Station.

a) Anderson b) Pebble Creek Parkway

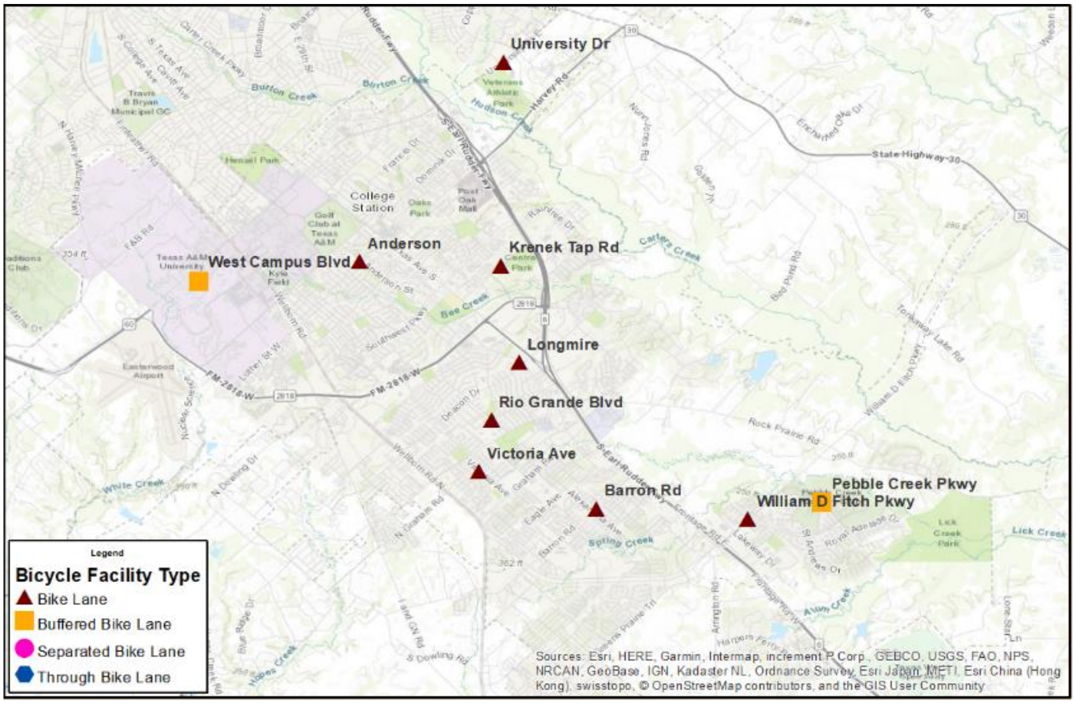
Figure 38. Photos from College Station Deployment Sites.

Table 22 shows the list of sites in College Station. Bicycle facilities selected for this deployment were located mostly on two-lane urban major collectors and minor arterials. The average weekend and weekday bicyclist counts were relatively higher compared to the San Antonio and Dallas–Fort Worth sites; however, there was no significant variation between the locations.

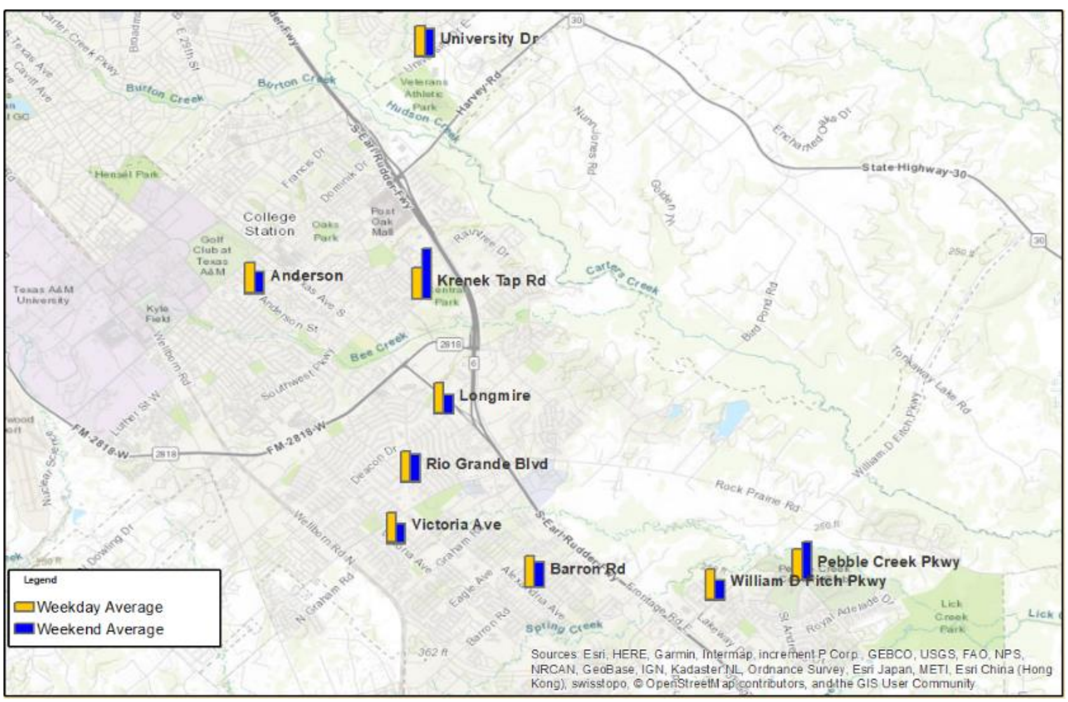
Table 22. College Station Area Locations and Counts.

Street Name	Bicycle Facility Type	Roadway Functional System	Number of Lanes	AADT	Weekday Average	Weekend Average
Anderson	Bike Lane	Urban Minor Arterial	2	7,720	25.6	18.7
Barron Road	Bike Lane	Urban Minor Arterial	2	13,319	13.1	10.7
Krenek Tap Road	Bike Lane	Urban Major Collector	2	991	5.4	8.7
Longmire	Bike Lane	Urban Major Collector	2	11,609	12.9	7.7
Pebble Creek Parkway	Buffered Bike Lane	Urban Major Collector	4	5,760	17.6	21.6
Rio Grande Boulevard	Bike Lane	Urban Major Collector	2	4,539	15.6	13.8
University Drive	Bike Lane	Urban Minor Arterial	2	17,111	21.3	19.8
Victoria Avenue	Bike Lane	Urban Minor Arterial	2	5,750	25.1	16
William D. Fitch Parkway	Bike Lane	Urban Minor Arterial	4	18,668	9.6	6.2

Figure 39 shows the map of deployment sites and counts in College Station. As observed, most of the sites had bike lanes and two sites had buffered bike lanes (Figure 39a). The selected sites were well-distributed across the city. In contrast to the previous deployments, the average bicyclist counts on weekdays seemed to be higher than the weekends (Figure 39b). This could have been due to the bike users being associated with the college (students or staff).



a) Facility Types



b) Bike Count Averages

Figure 39. Map of College Station Deployment Locations.

El Paso Sites

The final deployment took place in El Paso. Again, 10 sites were selected for data collection. The data collection started on June 7, 2021, and was concluded on June 29, 2021. This time period was also accompanied by a higher precipitation rate in El Paso. During regular checks, the researchers addressed issues mostly related to nails dislodging and tubes being disconnected due at least in part to extreme heat and vandalism. Figure 40 shows some of the images taken from the deployment sites in El Paso.

a) Delta Drive

b) Pebble Hills

Figure 40. Photos from El Paso Deployment Sites.

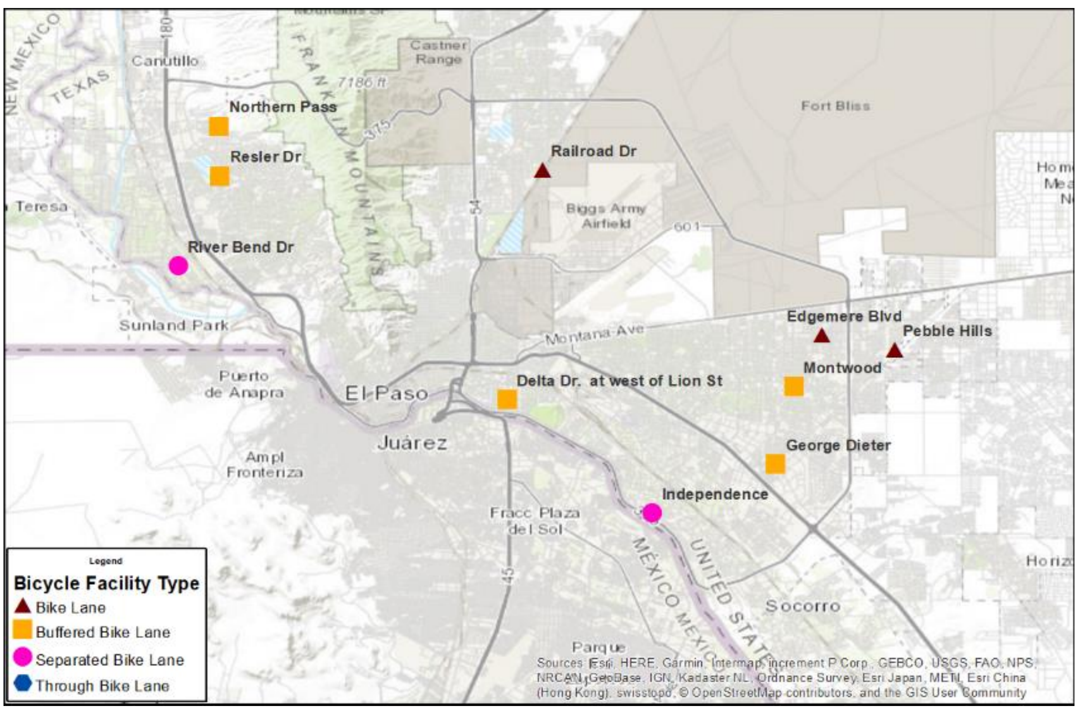
Table 23 depicts the list of sites and average counts in El Paso. Most of the bicycle facilities selected for data collection in El Paso were buffered bike lanes located on four-lane principal and minor arterials. These roadways observed higher AADT. The bike counts observed in El Paso were relatively lower than the previous counts. However, the lower numbers could have been due to the higher temperatures and higher precipitation rate observed during the data collection time frame.

Table 23. El Paso Area Locations and Counts.

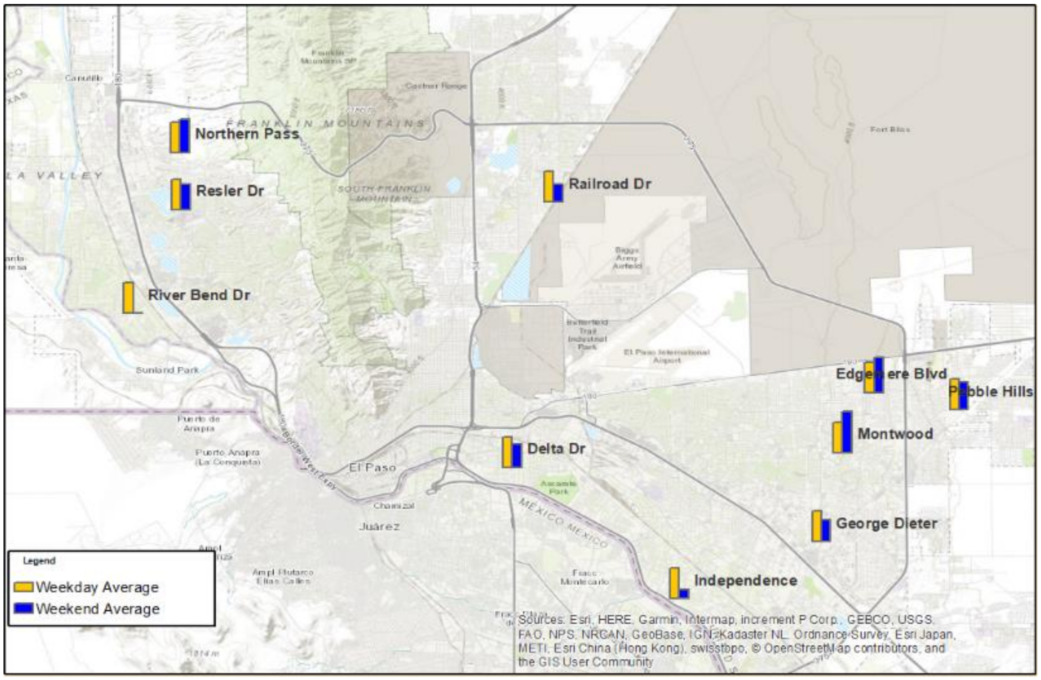
Street Name	Bicycle Facility Type	Roadway Functional System	Number of Lanes	AADT	Weekday Average	Weekend Average
Delta Drive to the West of Lion Street	Buffered Bike Lane	Urban Minor Arterial	4	8,460	6.82	5.09
Edgemere Boulevard	Bike Lane	Urban Principal Arterial	4	27,930	8.96	10.23
George Dieter	Buffered Bike Lane	Urban Principal Arterial	4	25,467	1.25	0.92
Independence	Separated Bike Lane	Urban Major Collector	2	5,840	36.71	11.08
Montwood	Buffered Bike Lane	Urban Principal Arterial	4	28,082	3.58	4.85

Northern Pass	Buffered Bike Lane	Urban Local	2	271	11.75	12.85
Pebble Hills	Bike Lane	Urban Minor Arterial	4	30,872	6.63	6
Railroad Drive	Bike Lane	Urban Principal Arterial	4	23,401	2.79	1.62
Resler Drive	Buffered Bike Lane	Urban Principal Arterial	6	25,458	7.08	5.85
River Bend Drive	Separated Bike Lane	Urban Major Collector	2	2,862	0.13	0

Figure 41 shows the map of deployment sites in El Paso. As observed, the locations are well-distributed across the city (Figure 41a). Similar to College Station, the average bike counts during the weekdays were observed to be higher than the weekends, particularly on the northwest side of the city, where The University of Texas at El Paso Campus is located (Figure 41b). As indicated earlier, this type of contextual factor will be considered when developing the exposure models for estimating the bicycle counts.



a) Facility Types



b) Bike Count Averages

Figure 41. Map of El Paso Deployment Locations.

CHAPTER 5. CRASH REDUCTION FACTORS FOR BIKEWAY FACILITIES

The research team developed CMFs for bicyclist crashes observed on bikeway facilities implemented on Texas roadways to assess their safety effectiveness. To accomplish this goal, the research team used the approach recommended in the Highway Safety Manual (HSM) (*1*) to develop the CMFs for bikeway facilities identified in Task 4 technical memorandum (TM4): bicycle lanes, buffered bicycle lanes, and separated bicycle lanes. The CMFs are developed for bicyclist crashes (both at midblock locations and intersections). The researchers used the observed field data and crowdsourced data to estimate the bicyclist counts for periods and sites with no count data.

SAFETY EFFECTIVENESS EVALUATION METHODOLOGY

Safety effectiveness (SE) of treatment (i.e., bikeway facility) refers to the percentage change in the crash data as the result of the treatment:

$$CRF_{Treatment} = (1 - CMF_{Treatment}) \times 100\% \qquad (1)$$

where, $CRF_{Treatment}$ is the crash reduction factor (CRF) of the treatment, and $CMF_{Treatment}$ is the CMF, i.e., the ratio indicating the expected effect of the treatment. CMF of the treatment can be calculated using before-and-after crash data or the crash data from comparison (i.e., control) sites (referred to as a cross-sectional analysis):

Before and After:

$$CMF_{Treatment} = \frac{Crash_{observed,after\ treatment}}{Crash_{observed,before\ treatment}} \qquad (2)$$

Cross-sectional:

$$CMF_{Treatment} = \frac{Crash_{observed,treatment}}{Crash_{observed,comparison}} \qquad (3)$$

Because the installation dates of facilities considered in this study are not readily available, the researchers used a cross-sectional approach to assess the SE of bikeway facilities. Cross-sectional studies use statistical modeling techniques that consider the crash experience of sites with and without a particular treatment of interest (bikeway facility in this case). In cross-sectional studies, analysts develop CMF using the crash frequency of the treated and the comparison sites. The main drawback of cross-sectional analysis is selection bias. The treated sites tend to experience a high number of crashes compared to the comparison sites. This implies that even if the crash frequency at the treated site may reduce after the treatment, the number of crashes continue to be higher compared to the crashes at the comparison sites. Therefore, comparing the crash frequency at the two sites might yield biased results.

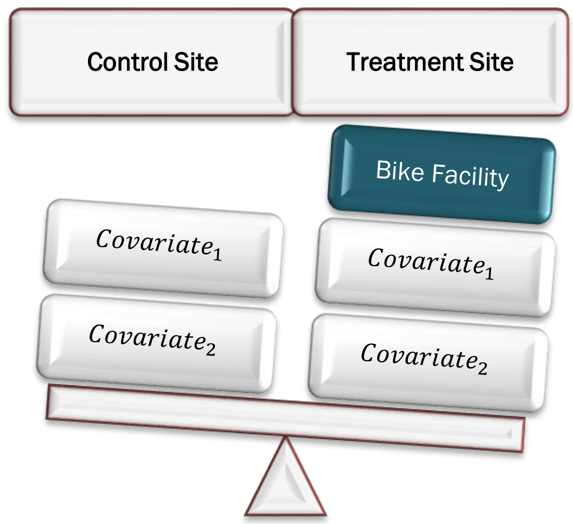


Figure 42. Data Matching Principle.

One of the methods used to overcome the selection bias in cross-sectional studies is the propensity score matching (PSM) method (*3*). The PSM uses the propensity score to mimic the random selection method. A propensity score represents a conditional probability of a facility receiving a treatment given the covariates and the outcomes. It shows the relationship between treatment status (1-Treated; 0-Control) and covariates (i.e., variables that completely or partially account for the apparent association between an outcome and risk factor) (see Figure 42). The propensity score can be estimated using several parametric and non-parametric tools. In this project the researchers used logistic regression models to select the covariates and estimate the propensity score. After matching the data based on the selected covariates the researchers conducted a quality check and implemented negative binomial (NB) models to estimate the CMFs (Figure 43).

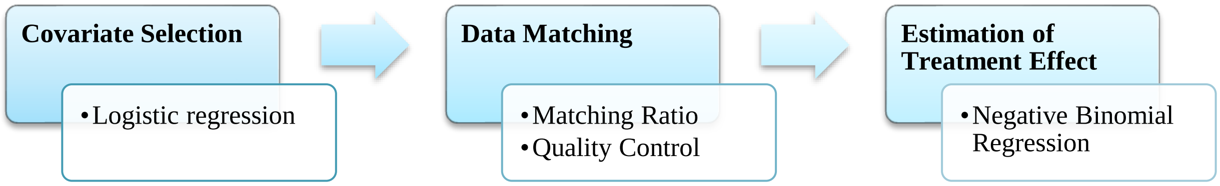


Figure 43. Propensity Score Matching Framework.

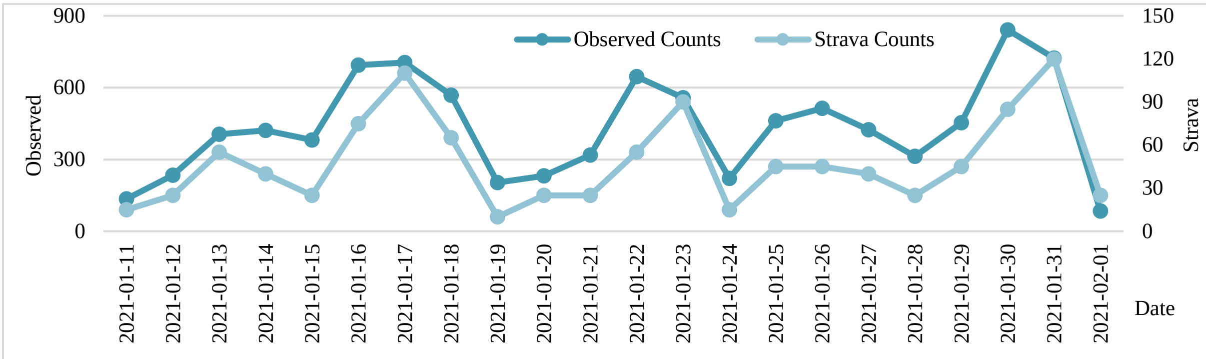
After developing the safety database, the researchers identified the list of bikeway treatments for developing CMFs. Although previously included in the agency surveys, due to the limited number of sites with bicycle boxes, bicycle signals, and through bicycle lanes, the researchers did not consider these treatments in CMF development. For the purposes of this project the researchers developed CMFs for installing the bikeway facility on a roadway segments without any bicycle facilities. In this project the researchers developed CMFs for total, KABC, and PDO bicyclist crashes. The CMFs were not developed for the segment and intersection crashes since the treatments evaluated in this study normally extended till the intersection (like number of lanes that do not have separate CMFs for intersection and segment crashes). Moreover, dividing crashes into these groups may further reduce the number of crashes and affect the CMF quality.

EXPLORATORY DATA ANALYSIS

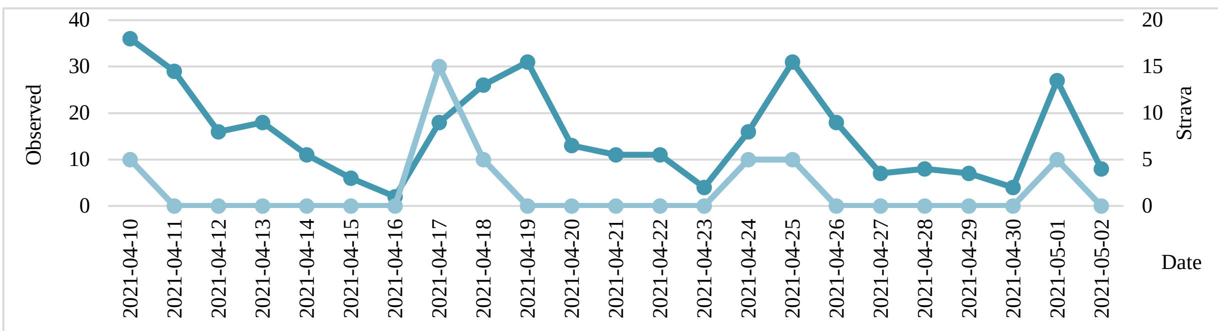
Bicyclist Exposure

The researchers used the count data collected from the counters that were deployed during 2020–2021 to develop exposure models for estimating bicyclist counts on bikeway facilities. After revising the existing data in the BP|CX (available at https://mobility.tamu.edu/bikepeddata/) and discussing with the researchers behind the project, the research team could not identify permanent counter data that could be used in this project. This was because the majority of permanent counters were placed at shared use paths, and the permanent counters on the on-street facilities had stopped working prior to the count data collection.

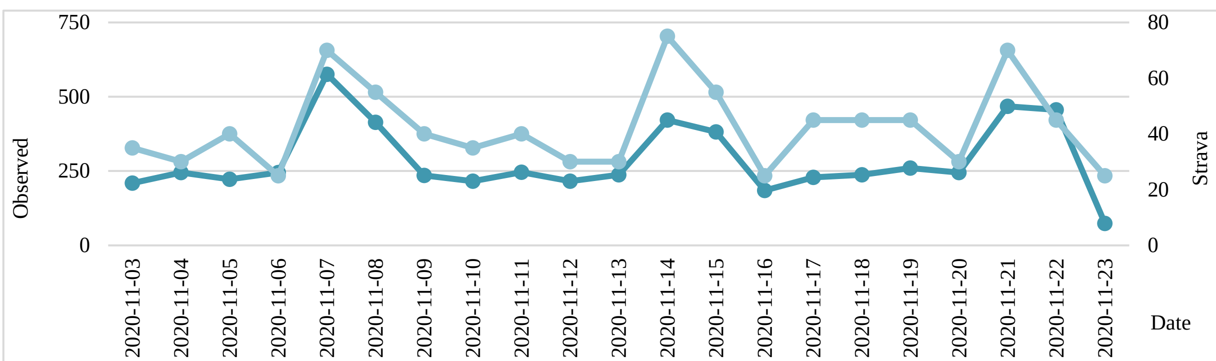
The researchers used the Strava data (available since 2017 at https://metroview.strava.com) to estimate the number of bicyclists for prior years and sites with no count data. For most of the counters, the seasonal variation between the Strava and observed counts seemed to be similar. Figure 44 depicts a sample of four sites in four different cities where the seasonal similarity between the bicyclist counts and Strava sample counts can be observed. Therefore, the seasonal adjustment using the daily data was not required, and the annual average data were used.



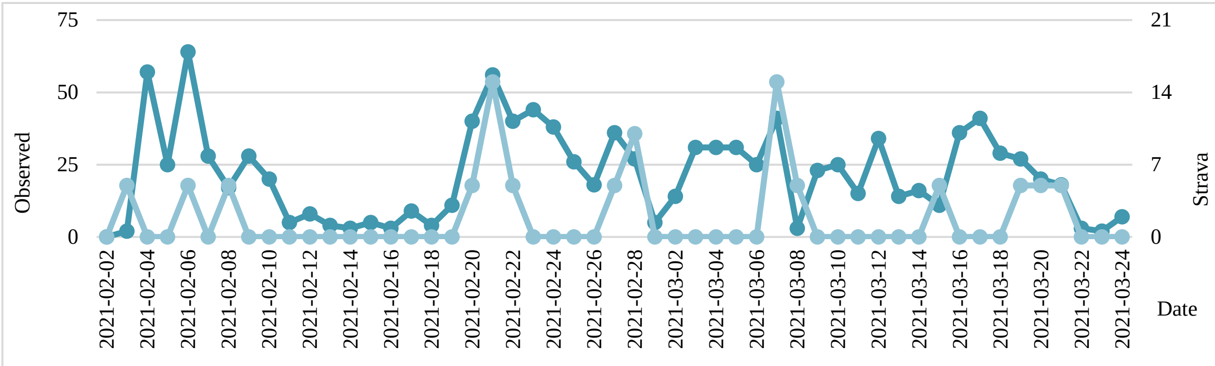
a) 3rd Street, Austin



b) Fort Worth Ave., Dallas–Fort Worth



c) Lamar Street, Houston



d) Ave B., San Antonio

Figure 44. Observed vs Strava Counts.

However, there were some abnormally high bike counts (significantly higher than the normal range of bike counters' readings) observed from a few bike counters in Austin for a couple of days. Although these numbers might be correct (observed during December 2021), for the purposes of crash data analysis, these outliers needed to be adjusted. To adjust these values, the researchers first grouped the bike counts for each counter by the days of the week. They then replaced the abnormally high values with the averaged bike counts collected from the same counters on the same day of the week.

Table 24 presents the average (daily) observed and Strava counts per bicycle facility and number of travel lanes on urban street. As observed, separated bike lanes experienced highest number of bicyclists, followed by bike lanes and buffered bike lanes. The number of bicyclists observed on buffered bike lanes was less than the bike lane users. This could be due to the land use characteristics of sites where buffered bike lanes are installed, since there does not seem to be major difference between the roadway and traffic exposure characteristics of the sites where the bike lane and buffered bike lanes were installed (see Table 26 and Table 27 in the next section). Also, as observed the bicycle counts on the reverse direction of the separated bike lanes on an urban four-lane segment are very small. There was only one site with these characteristics which was a two-way separated bike lane (Lamar Street in Houston) thus the reverse count in this case refers to the number of users going in the wrong-direction, and not on the reverse direction of travel lane. However, there is an inconsistency in the number of Strava users since the average Strava users seem to be higher than the observed bicyclists. This may be due to the fact that the Strava counts are usually rounded up to the nearest 5 increments. For example, if there is one Strava user on the road this will be rounded up to 5, and so on. Since the average daily bicyclist and average Strava users are estimated by summing up all the bicyclists and dividing by the number of deployment days, overestimation of Strava users can lead to higher averages than the observed bicyclists.

Table 24. Expansion Factors for Estimating Bicycle Counts Based on Strava Samples.

Number of Lanes (Urban)	Bicycle Facility	Average Total Daily Counts			Average Total Daily Counts, Forward Direction			Average Total Daily Counts, Reverse Direction		
		Obs. Counts	*Strava Counts*	*Expan-sion Factor*	*Obs. Counts*	*Strava Counts*	*Expan-sion Factor*	*Obs. Counts*	*Strava Counts*	*Expan-sion Factor*
2	Bike Lane	35.48	7.82	4.53	17.58	4.09	4.30	17.90	3.73	4.80
2	Buffered Bike Lane	17.36	8.65	2.01	8.54	4.39	1.94	8.82	4.25	2.08
2	Separated Bike Lane	62.71	7.81	8.03	36.37	3.93	9.25	26.34	3.88	6.78
4	Bike Lane	22.41	5.83	3.84	12.29	4.35	2.83	10.12	1.48	6.82
4	Buffered Bike Lane	11.36	3.58	3.17	5.88	2.75	2.14	5.48	0.83	6.61
4	Separated Bike Lane	162.39	34.09	4.76	161.48	19.77	8.17	0.91	14.32	0.06

In this project, the researchers have used the Strava data to develop relatively simple and practical exposure models to estimate the annual average daily bicyclist counts (AADB). These models were developed for conducting safety analyses, therefore the researchers used the recommendations from the upcoming edition of the *Highway Safety Manua*[1] to develop the exposure models for following roadway and bikeway facilities:

1. Urban two-lane undivided segment with a bicycle lane.
2. Urban two-lane undivided segment with a buffered bicycle lane.
3. Urban two-lane undivided segment with a separated bicycle lane.
4. Urban four-lane undivided and divided segment with a bicycle lane.
5. Urban four-lane undivided and divided segment with a buffered bicycle lane.
6. Urban four-lane undivided and divided segment with a separated bicycle lane.

[1] NCHRP Project 17-84 Pedestrian and Bicycle Safety Performance Functions, available at https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4203

Table 25 depicts the functional form (negative binomial model) of the exposure models per roadway and bikeway facility types. Although not presented in this report, the Strava coefficients in all of these models were significant, and the overdispersion parameter was relatively small. These formulae can be used to estimate the average daily bicyclist counts on indicated roadway and bikeway facilities for conducting safety analyses. To learn more about how to implement these models, please refer to TxDOT Project 0-6927 report.

Table 25. Strava-based Exposure Models to Estimate AADB for Safety Analysis.

Roadway Facility	Bikeway Facility		
	Bike Lane	***Buffered Bike Lane***	***Separated Bike Lane***
Urban, Two-lane Undivided	$16 \times (\exp(Strava))^{0.07}$	$8 \times (\exp(Strava))^{0.05}$	$17 \times (\exp(Strava))^{0.06}$
Urban, Four-lane Divided and Undivided	$11 \times (\exp(Strava))^{0.07}$	$7 \times (\exp(Strava))^{0.05}$	$12 \times (\exp(Strava))^{0.06}$

The researchers estimated bicyclist exposure through AADT and AADB. They estimated the AADB using the exposure models presented in Table 25. Since the observed field counts were collected from on-street facilities, the researchers only applied the exposure models to estimate the AADB at sites with a bikeway facility. For the sites with no bikeways the researchers used the raw Strava number, since there was no reliable observed data to use as a reference. The researchers also used posted speed limits (PSL), obtained from the TxDOT Speed Limits (available at https://gis-txdot.opendata.arcgis.com/datasets/txdot-speed-limits/explore?location=31.121687%2C-100.055172%2C6.76), as another exposure variable. After mapping the speed limit shapefile to the roadway inventory, many sites, particularly in low-traffic areas, were found to have missing speed data. To address this limitation, the researchers used the speed limit on similar facilities to fill in the missing values in the data.

Table 26 presents the descriptive statistics of exposure variables. The AADT, AADB, and Strava were averaged across 2017–2020. On average, there were an estimated number of 22, 11, and 31 bicyclists per day on bike lanes, buffered bike lanes, and separated bike lanes, respectively. Moreover, some sites with bike lanes, buffered bike lanes, and separated bike lanes observed 532, 324, and 207 bicyclists per day (maximum). A closer inspection of these sites showed that these facilities were near recreational parks and university campuses such as Mopac Blvd in Austin and UTSA Blvd. in San Antonio. Therefore the researchers assumed that these numbers were acceptable and were not inflated due to the exposure models. The researchers also observed some unusually high speed limits on roadways with bikeway facilities, such as 65, 55, and 60 mph speed limit on bike lanes, buffered bike lanes, and separated bike lanes, respectively. After closer inspection, it was found that most of these bikeway facilities were indeed installed near the high-speed roadways (e.g., Joe Battle Blvd. in El Paso and Wurzbach in San Antonio).

Table 26. Descriptive Statistics of Average Bicyclist Exposure (2017–2020).

Bicyclist Exposure	Descriptive Stats	Bike Lane	Buffered Bike Lane	Separated Bike Lane	No Bike Lane
	Number of Sites (n)	***1,091***	***167***	***38***	***15,683***
AADB (bicycles)	Mean	22.12	10.71	31.18	0.89
	St. D.	36.39	24.69	37.63	5.14
	Min	11	7	12	0
	Max	532	324	207	358
Average Daily Strava (bicycles)	Mean	3.32	2.69	5.97	0.89
	St. D.	8.01	6.69	9.68	5.14
	Min	0	0	0	0
	Max	118	67	39	358
AADT (vehicles)	Mean	12,055.89	9,247.50	24,265.10	10,624.13
	St. D.	10,842.51	8,541.80	48,255.25	17,631.78
	Min	37	62	203	3
	Max	69,119	33,070	160,645	234,371
Speed Limit (mph)	Mean	35	30	35	35
	St. D.	7.88	6.37	10.96	12.24
	Min	20	20	30	20
	Max	65	55	60	75

Roadway and Bikeway Design

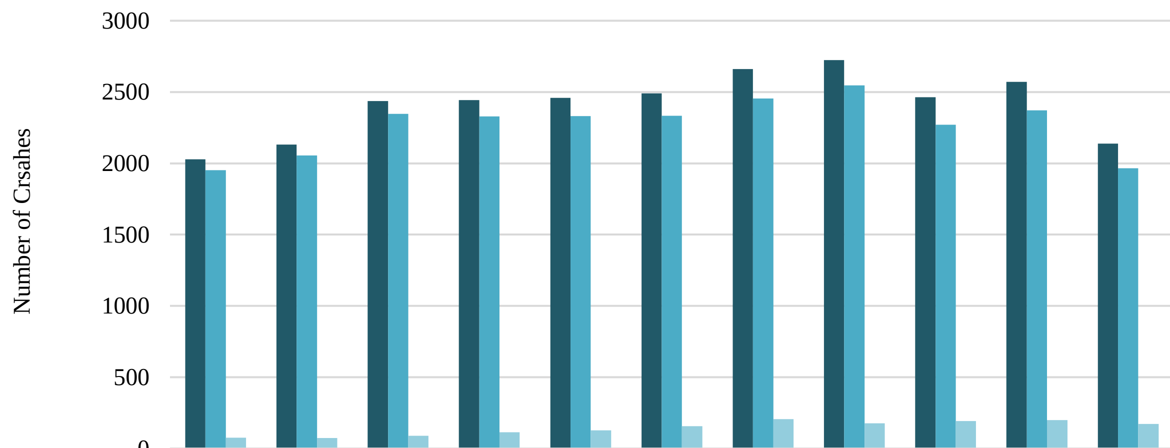
Roadway design elements were obtained from TxDOT's RHiNo website (available at https://www.txdot.gov/inside-txdot/division/transportation-planning/roadway-inventory.html). As indicated in the previous report, the research team collected and compiled the bikeway data from various agencies across Texas (reported in TM4 and TM5 and compiled at: https://storymaps.arcgis.com/stories/628ba9f7dc1e4f18b643204b13385115). The research team conflated the two shapefiles using the RHiNo as the basemap. Table 27 presents the descriptive statistics of roadway segments included in the study.

Table 27. Descriptive Statistics of Roadway Design Elements.

Roadway Design Elements	Descriptive Stats	Bike Lane	Buffered Bike Lane	Separated Bike Lane	No Bike Lane
	Number of Sites (n)	***1,091***	***167***	***38***	***15,683***
Lane Width (ft)	Mean	12.46	12.31	12.32	11.23
	St. D.	3.58	3.98	3.39	2.51
	Min	4	8	10	0
	Max	<12	<12	<12	<12
Length (mi)	Mean	0.62	0.63	0.57	0.62
	St. D.	0.54	0.58	0.44	0.59
	Min	0.1	0.1	0.1	0.1
	Max	3.52	3.06	2.17	3
Median Width (ft)	Mean	2.02	2.02	0.63	2.8
	St. D.	7.49	5.61	1.36	15.76
	Min	0	0	0	0
	Max	72	35	4	770
Number of Lanes	Mean	3.12	3.08	3.05	2.92
	St. D.	1.24	1.33	1.59	1.33
	Min	2	2	2	1
	Max	8	6	8	12
Roadbed Width (ft)	Mean	42.29	41.2	41.53	37.11
	St. D.	20.7	20.49	27.55	23.1
	Min	18	20	20	0
	Max	124	100	128	318
Shoulder Width, Inside (ft)	Mean	0.84	0.72	1.26	1.09
	St. D.	2.66	2.64	3.43	3.41
	Min	0	0	0	0
	Max	<6	<6	<6	<6
Shoulder Width, Outside (ft)	Mean	1.38	0.99	2.42	1.43
	St. D.	3.91	3.75	5.79	4.22
	Min	0	0	0	0
	Max	<6	<6	<6	<6
Surface Width (ft)	Mean	40.06	39.49	37.84	34.62
	St. D.	17.8	18.43	20.11	19.43
	Min	12	20	20	0
	Max	124	96	96	318

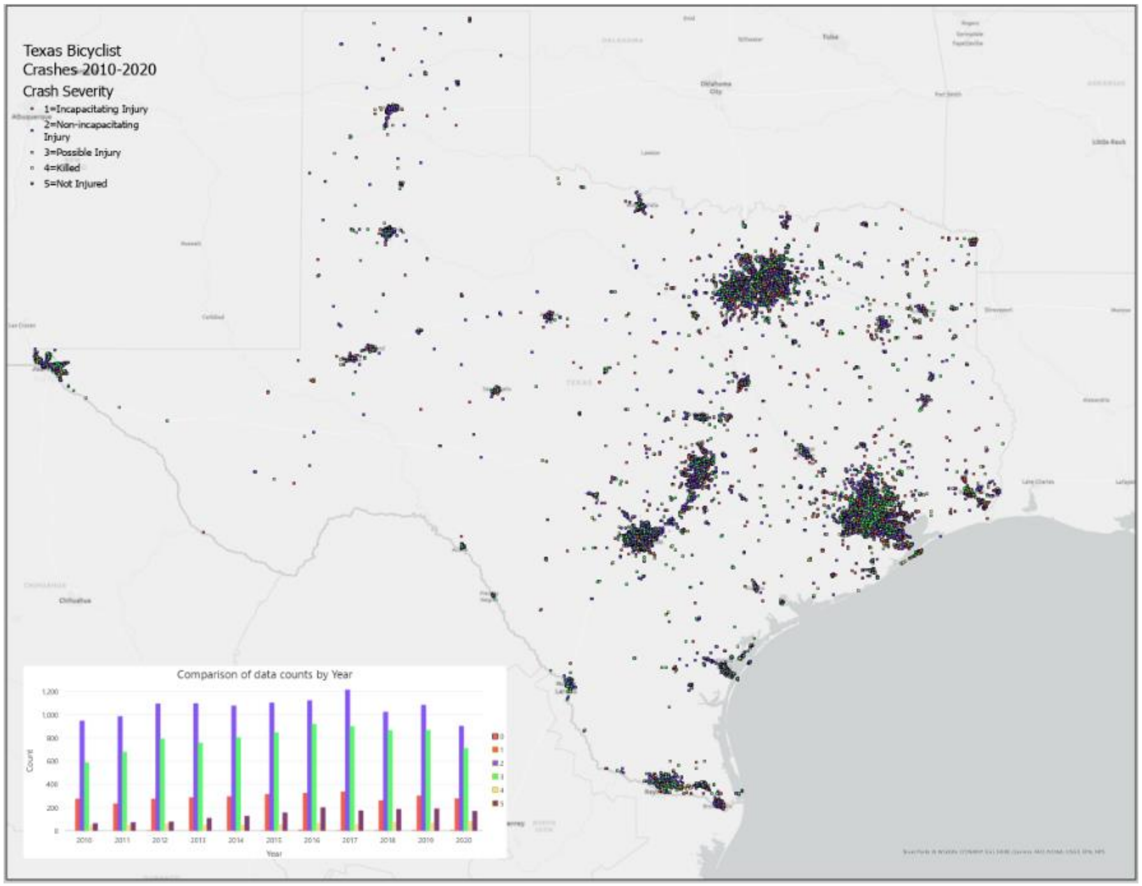
Crash Data

The researchers obtained the bicyclist crash data from TxDOT's CRIS database (available at https://cris.dot.state.tx.us/). The researchers initially obtained the crash data from 2010 to 2020 to identify the roadway segments where crashes had occurred historically. Figure 45 depicts the total number of bicyclist crashes per year. Interestingly, the number of crashes did not observe significant reduction during 2020 (only 16 percent reduction compared to 2019) despite the pandemic.



	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Total Crashes	2028	2131	2436	2443	2460	2491	2661	2724	2463	2571	2139
KABC Crashes	1952	2056	2346	2329	2331	2334	2454	2546	2271	2371	1966
PDO Crashes	76	75	90	114	129	157	207	178	192	200	173

a) Historical Crash Trends



c) Geographic Extent of Crashes

Figure 45. Number and Location of Bicyclist Crashes per Year.

For the purposes of this project the researchers used the crash data from 2017 to 2020 to develop the CMFs. This decision was made based on three factors: (a) the installation date of bicycle facilities is not readily available, however it can be safely assumed that they were in place by 2017 since most of the data compiled by the research team were available since this date, (b) Strava data is available since 2017, (c) at least three years of crash data are required for safety analysis. Another advantage of using the crash data since 2017 is avoiding the potential bias in the selected sites because if the sample data was used (i.e., 2017–2020) instead of the entire crash data (i.e., 2010–2020), there would be many sites (with and without bikeway facilities) with zero crashes, thus making the sites with and without bikeway facilities similar in terms of their crash history. Additionally, the researchers removed rural segments and all the urban and rural interstate and freeway crashes.

Table 28 depicts the aggregated KABC, PDO, and total bicyclist crashes at selected facilities from 2017 to 2020. As discussed earlier, in order to create the safety database, we first conflated the bicycle facility data with the TxDOT RHiNo database in order to create a consistent

Roadway-Bikeway segment shapefile. As the result of this conflation, a single bike lane (or corridor) was either divided into several smaller segments, or was combined with contiguous bike lanes in order to create a RHiNo segment. After this, we mapped the bicyclist crashes to the RHiNo shapefile using the latitude and longitude of the crash, and aggregated crashes per RHiNo segment. Finally, the aggregated crash data was combined with the Roadway-Bikeway segment shapefile by using the RHiNo segment IDs. In our safety database, we were able to identify 1,091 RHiNo segments (i.e., sites) with bicycle lanes, 167 RHiNo segments with buffered bicycle lanes and 38 RHiNo segments with separated bicycle lanes, where the segment lengths were between 0.01 and 2 miles (mi). Additionally, over 15,683 RHiNo segments with no bikeway facility observed at least one bicyclist crash between 2010 and 2020. However, since the researchers only used 2017–2020 crash data some of these sites had zero crashes. Of all these sites, the sites with no bikeway facility experienced the highest number of KABC (maximum of 17 crashes) and total (maximum of 19 crashes) bicyclist crashes, while bicycle lanes seemed to have the highest PDO crashes (maximum of three crashes). In terms of average crashes per bikeway facility types, the separated bike lanes experienced the highest number of PDO, KABC, and total crashes.

Table 28. Descriptive Statistics of Total Bicyclist Crashes per Bicycle Facility Type (2017–2020).

Bicyclist Crashes per Severity Type	**Descriptive Stats**	**Bike Lane**	**Buffered Bike Lane**	**Separated Bike Lane**	**No Bike Lane**
	Number of Sites (n)	***1,091***	***167***	***38***	***15,683***
Property Damage Only (PDO)	Mean	0.02	0.03	0.08	0.05
	St. D.	0.17	0.17	0.36	0.22
	Min	0	0	0	0
	Max	3	1	2	2
Fatal and Injury (KABC)	Mean	0.34	0.19	0.89	0.49
	St. D.	0.96	0.51	2.1	0.69
	Min	0	0	0	0
	Max	13	3	9	17
Total Crashes	Mean	0.36	0.22	0.97	0.54
	St. D.	1	0.57	2.16	0.72
	Min	0	0	0	0
	Max	14	3	9	19

Crash Severity

A total of 24,834 bicyclist crashes from 2010 to 2020 were matched with the existing roadway segment. The rest of the crashes involving bicyclists (1,748 out of 26,582) did not have a latitude and longitude information and were therefore removed from the database. Figure 46 shows the distribution of crashes by Crash Severity. As observed, almost all the crashes involving bicyclists (95.86%) involve some kind of injury with a total of 630 crashes out of those leading to fatalities, while only 1,028 crashes are limited to property damage.

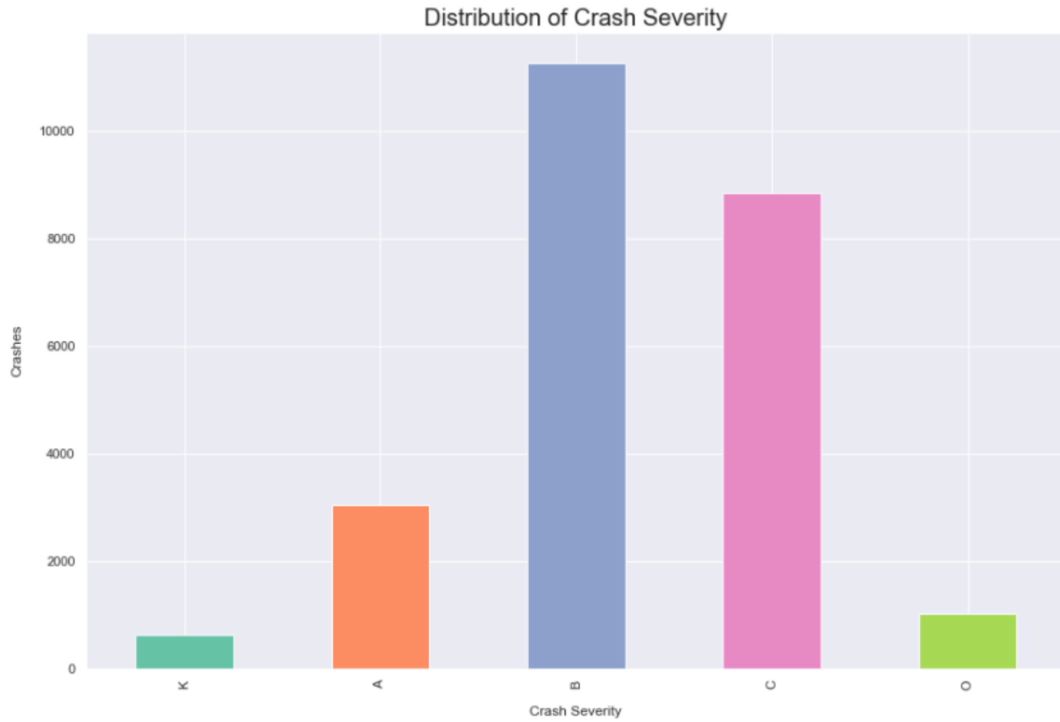


Figure 46. Distribution of Crashes by Severity

Temporal Distribution of Crashes

Further analysis of the temporal distribution of crashes involving bicyclists and the corresponding crash severity shows that the year 2017 experienced the highest number of crashes (Figure 47). One peculiar observation in this analysis is for the year 2020, which experiences a sudden dip in the total number of crashes while having the highest number of fatal crashes. The year 2020 experiences a dip of approximately 10% in the number of crashes when compared to the yearly average, and an increase of 40% in the number of average yearly fatal crashes.

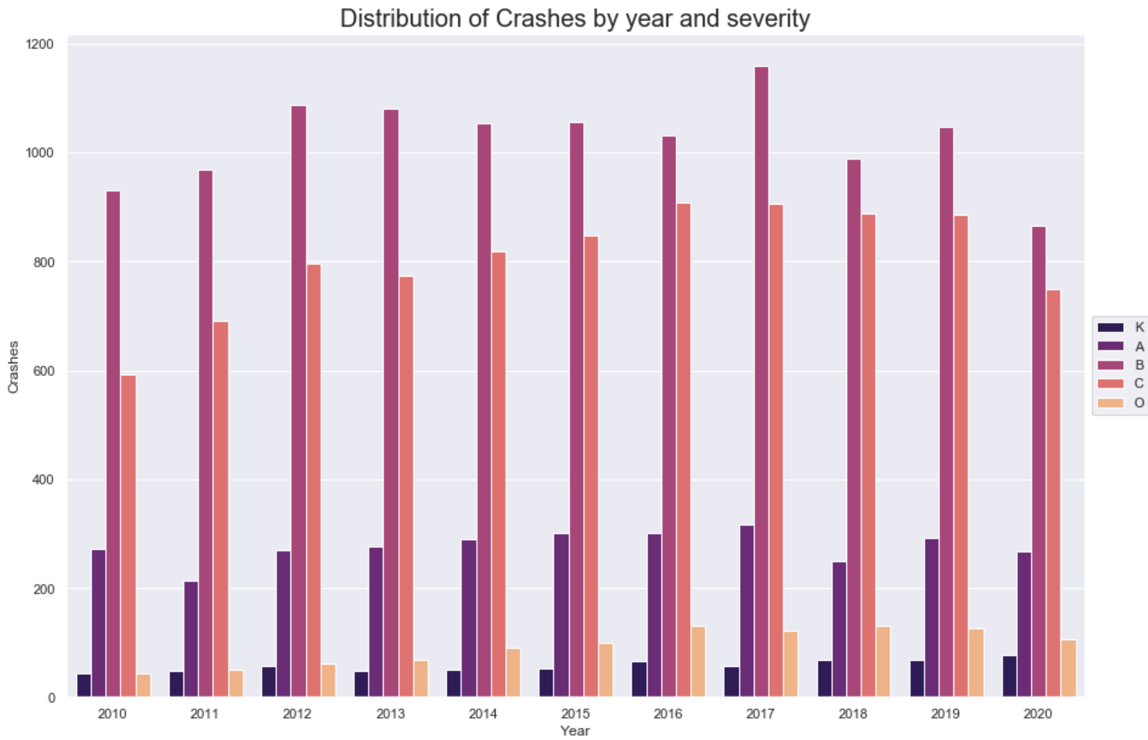


Figure 47. Distribution of Crashes by Year

A similar analysis of the distribution of crashes over months (Figure 48) and days of the week (Figure 49) show that the holiday months of November, December, and January and the weekend with presumably reduced work-related commute experience a dip in the number of crashes. The crashes are distributed almost evenly across other months and across the weekdays, with an unusual spike in the month of October. The effect of temperature on crashes should also be studied as February also has less than the average number of crashes, and the frequency of crashes then increases as the temperature in the state starts going up.

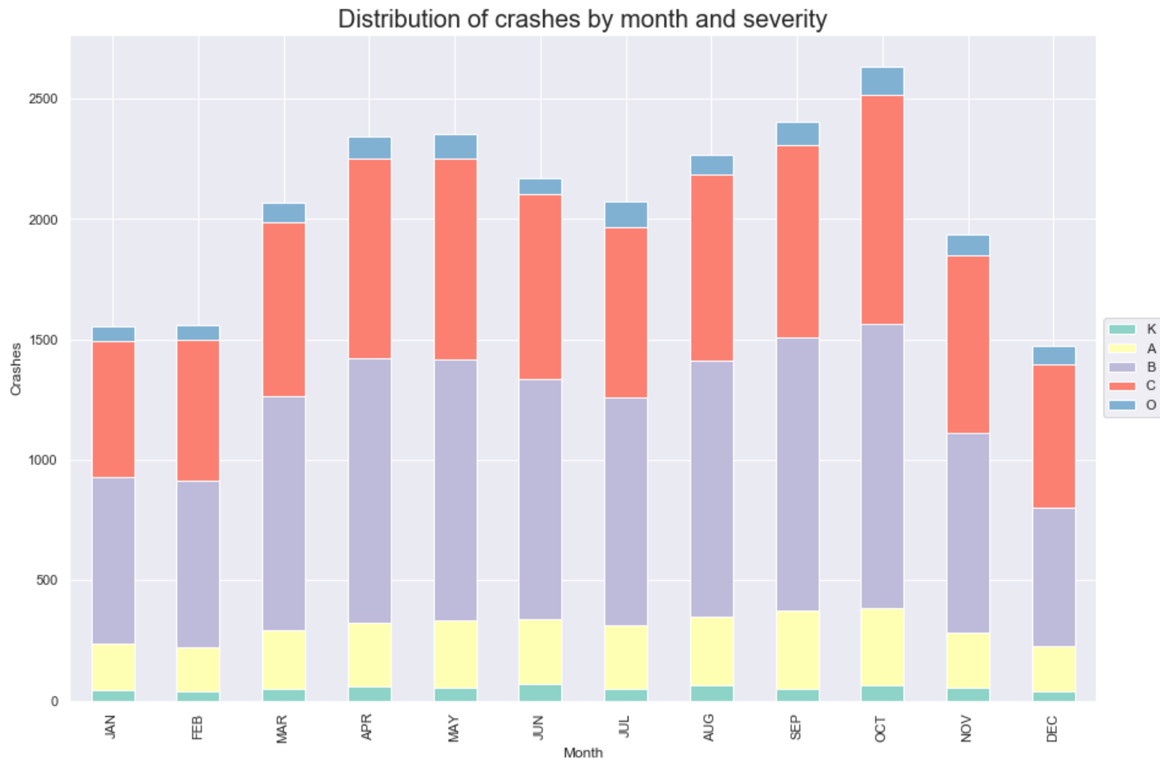


Figure 48. Distribution of Crashes by Month

Figure 49. Distribution of Crashes by Day of Week

Figure 50 shows all the crashes in the year 2017 distributed by the number of crashes per day. The line chart is visualized to understand the variation in the number of crashes on a daily basis.

A scatter plot of the count of crashes on Sunday is added to amplify the number of times the reduction in crashes/day occurs on Sunday. The crashes happening on Sundays are highlighted in the graph to give an even more accurate representation of the temporal distribution and the dip in the number of crashes on the weekend.

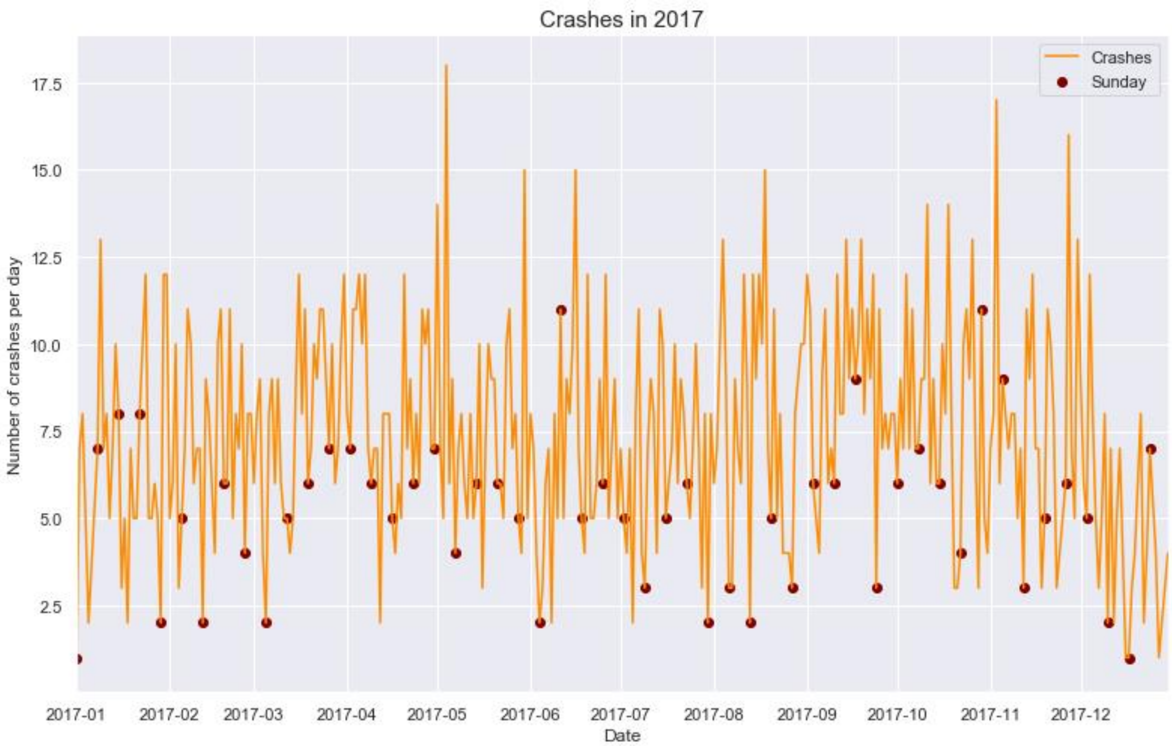


Figure 50. Daily Variation of Crashes (2017)

Analyzing the temporal distribution of crashes across the day (Figure 51) shows a pattern similar to the general traffic movement over a usual workday. The number of crashes spike during the morning and evening peak hours, with the evening peak hour outweighing the morning peak hour.

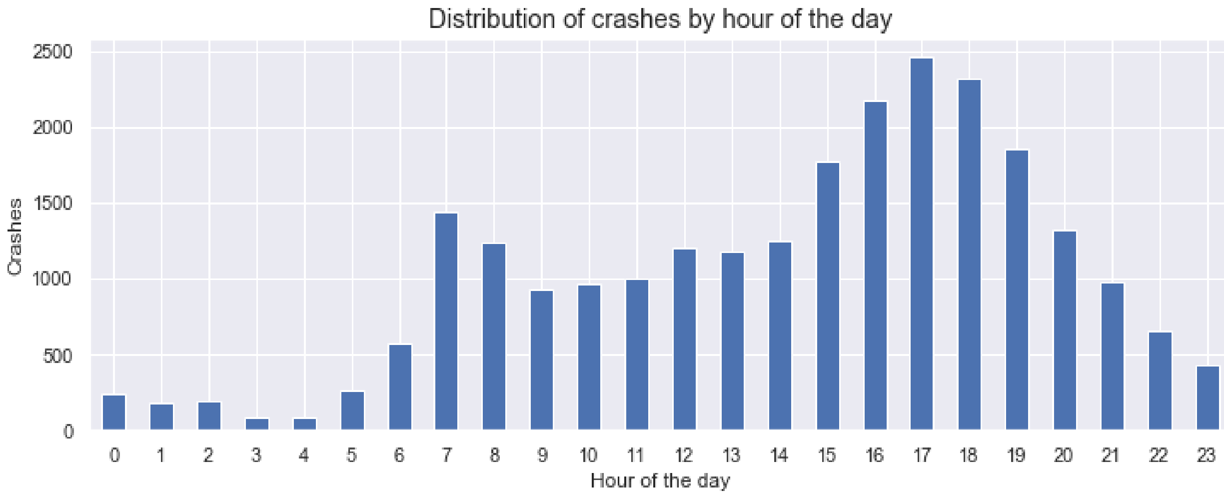


Figure 51. Distribution of Crashes by Hour

However, as seen in Figure 52, while night-time crashes (8 PM to 5 AM) are the least in count, they also highlight the highest number of fatalities. A further analysis into the time period based on the lighting conditions during the crash shows that crashes in locations without streetlights are most exposed to fatalities.

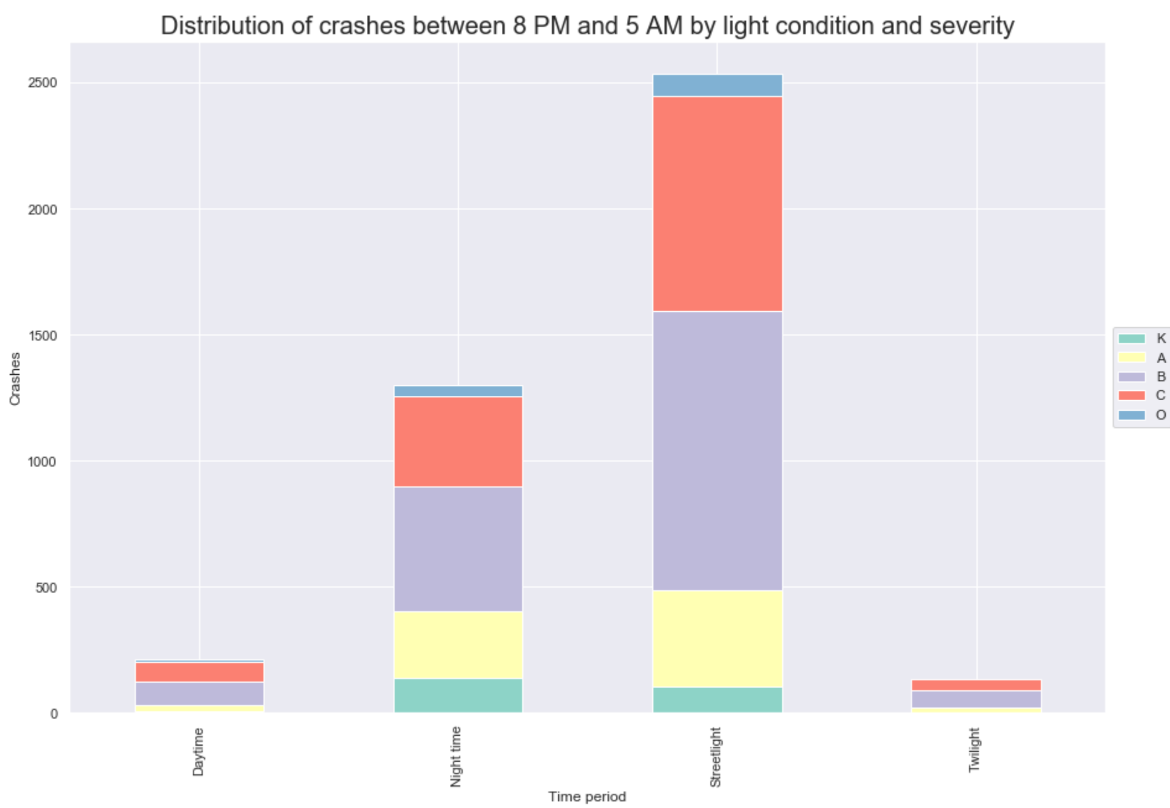


Figure 52. Distribution of Crashes by Night and Daytime

A similar analysis into this distribution of all the crashes while considering the type of light condition available to the driver is shown below in Figure 53. The sunburst chart gives a clearer understanding of how light conditions affect crash frequency through the day. The classifications of the light condition is done as:

- Daytime – Regular daily light conditions during daytime when the sun is above driver's head
- Twilight – Lighting conditions when the during dawn and dusk when the sun is parallel to driver eyesight
- Night time – Minimal or no natural lighting conditions after the sunset, with no artificial source of lighting available for the roadway
- Streetlight – Minimal or no lighting conditions after the sunset, with street-lights being the main source of illumination on the roadway

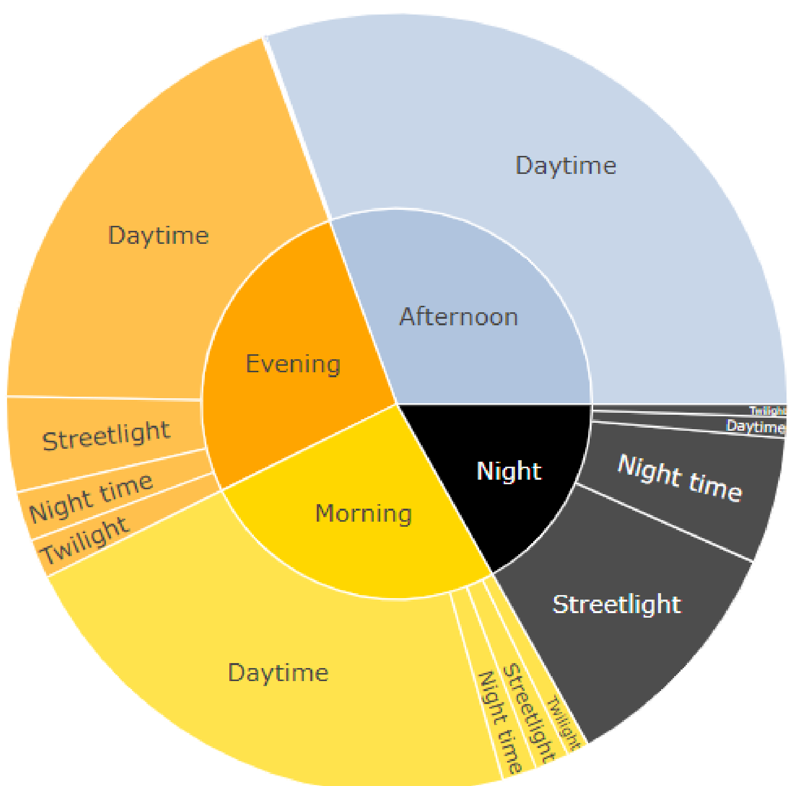


Figure 53. Distribution of Lighting Conditions Throughout the Day

Roadway Characteristics

The following charts show the distribution of crashes by roadway characteristics. As seen in Figure 54, it is understandable that most crashes are located at Local, Collector, or Arterial roadways as these are the routes generally used by bicyclists. There are still some crashes seen on the Freeway and Interstate, which might be due to inconsistent reporting of the crashes in police report, since these reports assign the crash on frontage or feeder roads to the nearest freeway. Note that in this project, we had removed the interstate and freeway crashes from the data analysis.

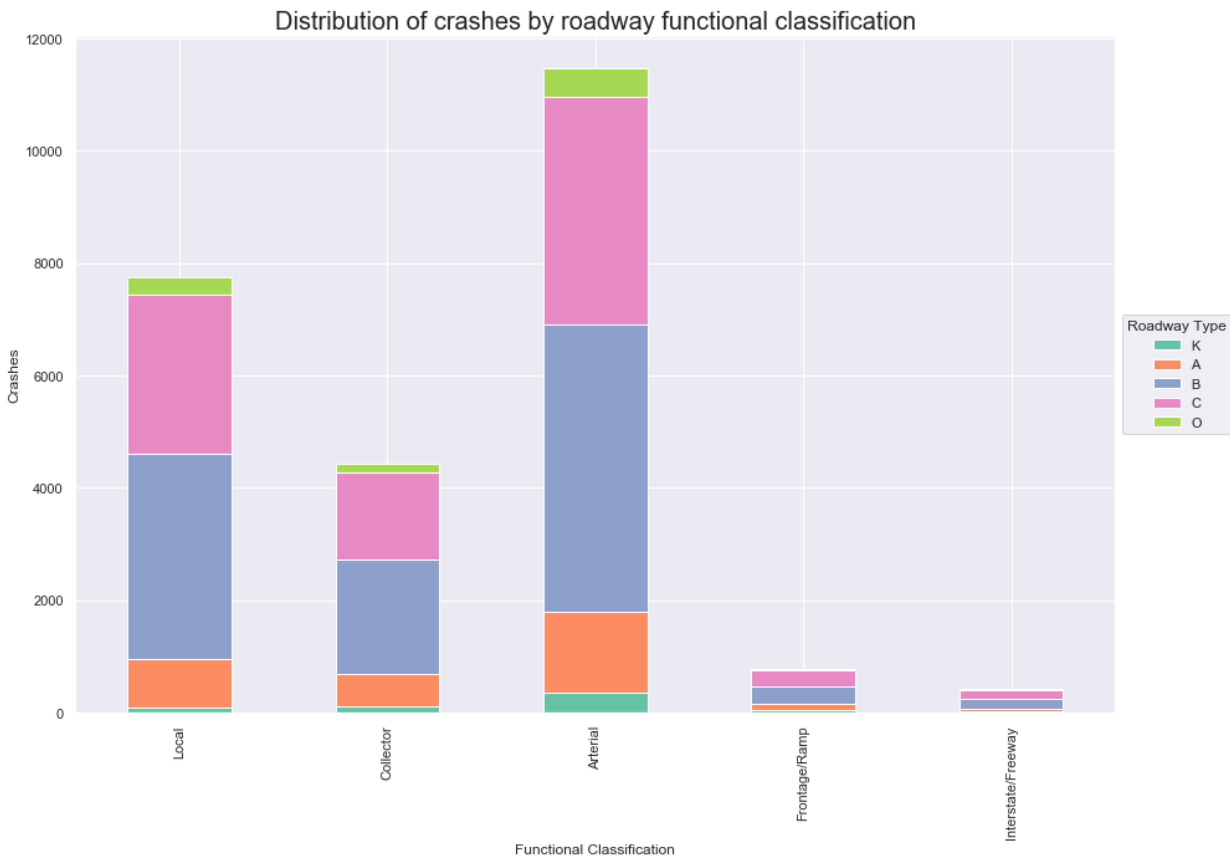


Figure 54. Distribution of Crashes by Functional Classification

To better understand the distribution of crashes across roadways and the reasoning behind it, another chart depicting the relationship between posted speed limits is also included (Figure 55). This chart also shows the stark difference in the KABC and PDO crash counts related to bicyclists.

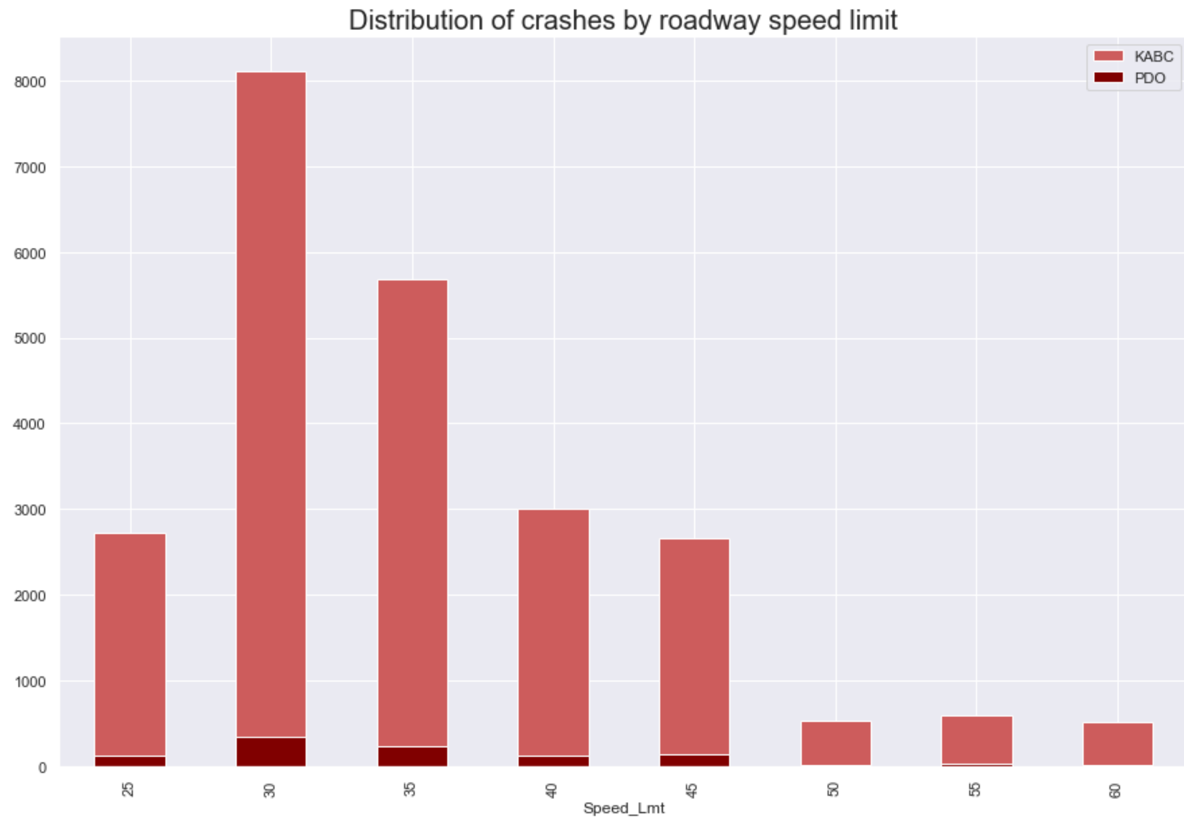


Figure 55. Distribution of Crashes by Posted Speed Limit

Figure 56 depicts the distribution of crashes per number of travel lanes. The findings of the this chart are also consistent with the general understanding, as more crashes are seen on two-lane roadways which generally welcome cyclists as the vehicular population is lower. It can also be seen that the proportion of fatalities to injuries on four-lane roadways is more than the other counterparts.

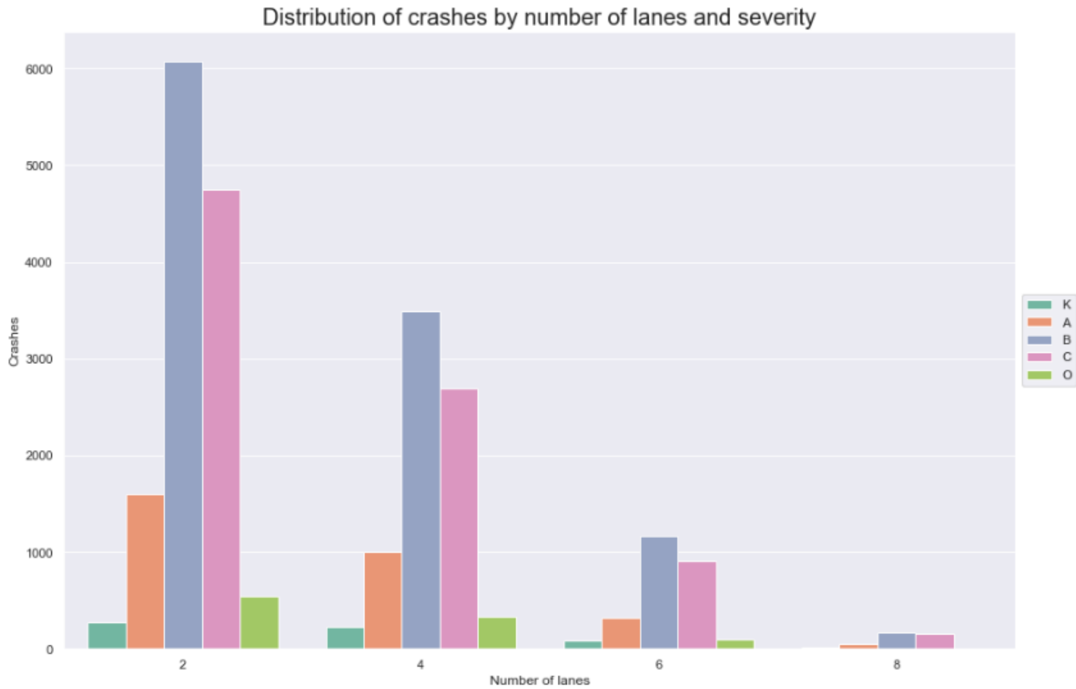


Figure 56. Distribution of Crash Severity by Number of Travel Lanes

Figure 57 depicts the distribution of crashes by lane width, where the lane width was categorized as: narrow (< 10ft), medium (10-12 ft) and wide (> 12 ft). As observed, narrow lane roadways have the highest number of crashes while wide lane roadways have the lowest crashes. This might be because wide lane roadways are generally used for the interstates, freeways, and state highways where bicyclists are not commonly seen. However, it should be noted that moderate width lane roadways experience more fatalities than any other lane width type.

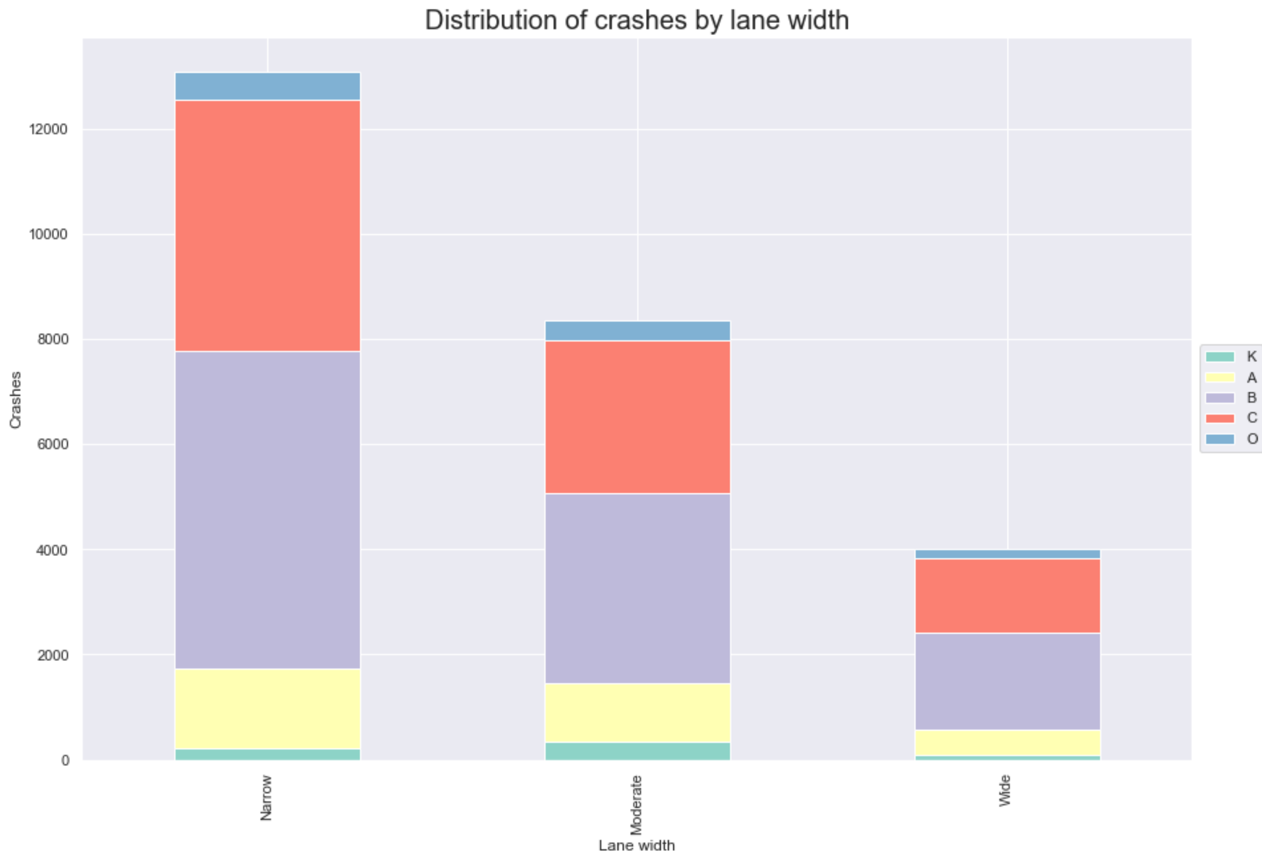


Figure 57. Distribution of Crash Severity by Travel Lane Width

Bike Facility

As the research is limited to crashes involving bicyclists, it was also checked if there was any bicycle facility in the vicinity of the crash location. This data was collected and compiled from different state and city agencies, along with various open data sources. However, different agencies tend to follow differing nomenclatures, and the bicycle facilities also ranged from a simple 'Sharrow' to 'Protected bike lanes with concrete pavements. For consistency, the bicycle facilities were narrowed down to the following categories:

- Bike Lane (Bike lanes, Through bike lanes, Bike lanes with green paint, Two-way bike lanes)
- Buffered Bike Lane (Buffered bike lanes, Two-way buffered bike lanes)
- Separated Bike Lane (Protected bike lane with Flexi-post/ vegetation/ barrier/ parking/ curb)
- Other (Sharrows, Bike route signs, Share the road signs, Trails, Shared use paths)

Figure 58 presents the distribution of crash data per roadway and bikeway segments included in the study.

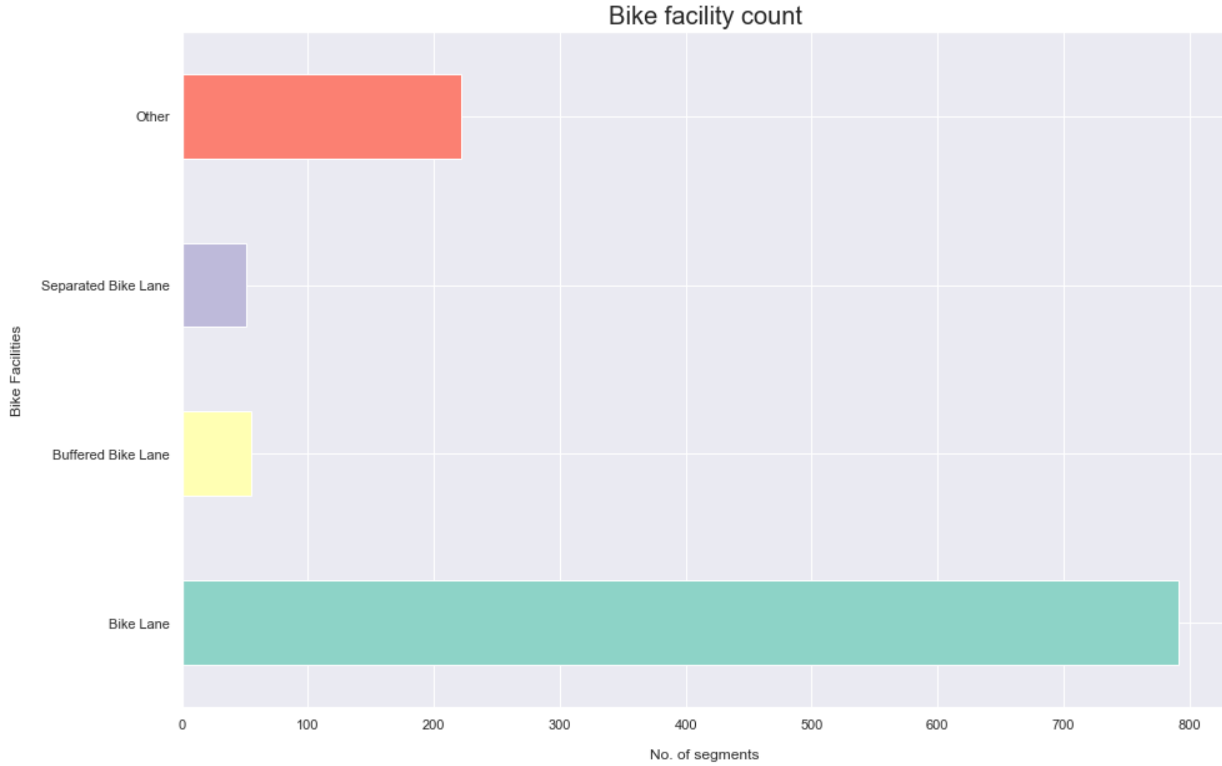


Figure 58. Distribution of Bikeway Facilities Studied

While most crashes occurred on roadways without any bike facilities (23,715), the counts for crashes happening on roadways with bike facilities are as follows: 791 crashes on bike lanes, 55 crashes on buffered bike lanes, 51 crashes on separated bike lanes and 222 crashes on other bikeway facilities. The number of crashes should not be considered as an independent indicator of protection provided by different types of bike facilities, as the proportion of these facilities is also not equal.

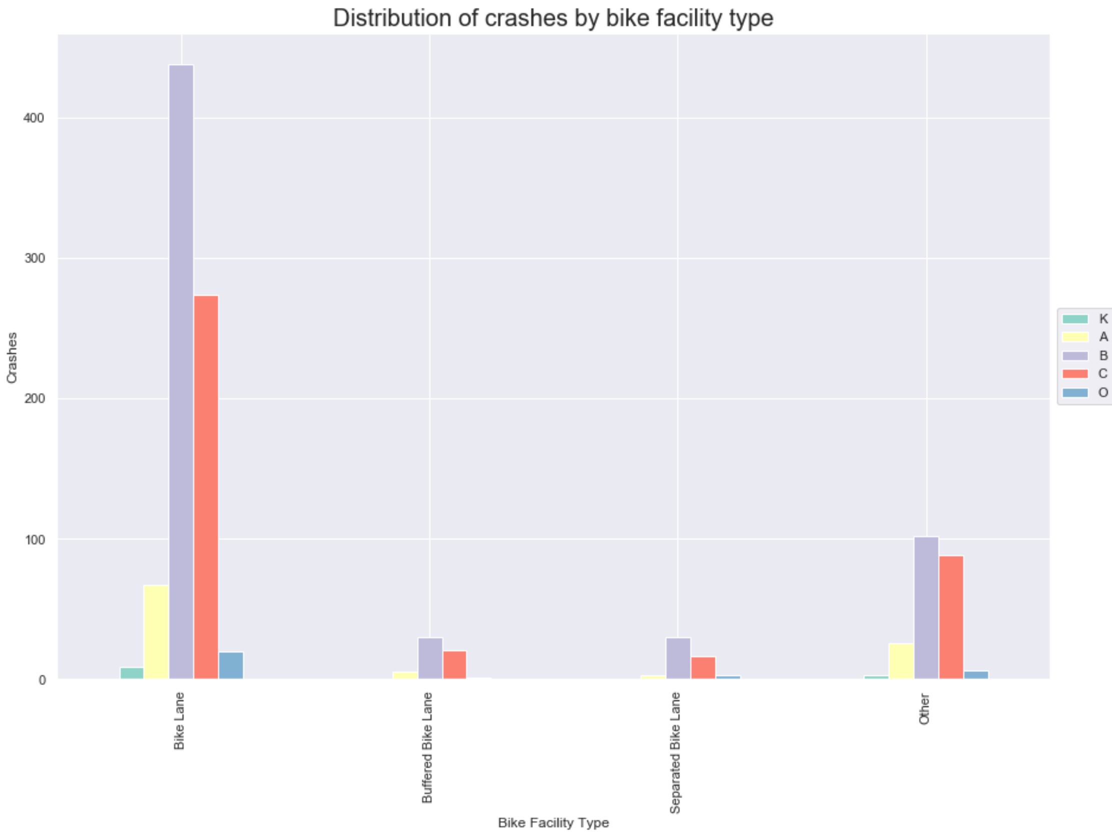


Figure 59. Distribution of Crashes by Bicycle Facility Type

However, one very interesting analysis of the division of crashes by severity is exemplified in the chart below. The percentage of crashes leading to fatalities (K) or serious injuries (A) for roadways with each facility type, gradually decrease as shown in Table 29. The percentage of crashes resulting in minor injuries are generally consistent across the different bike facility types, including the roadways with no bike facilities, and account to around 30% - 40% of the crashes. The crashes resulting in property damage only are the most in roadways with separated bike facilities, and account for almost 6% of the total crashes occurring on that facility type.

Table 29. Crash Severity per Bicycle Facility Type

Bike Facility	Total Crashes	Fatalities (K)	Serious Injuries (A)	Fatalities or Serious Injuries (KA)
None (Not shown in figures)	23,715	2.62%	12.45%	15.07%
Other	791	1.35% ⇩	11.26% ⇩	12.61% ⇩
Bike Lane	222	0.88% ⇩	8.22% ⇩	9.10% ⇩
Buffered Bike Lane	55	- ⇩	9.09% ⇧	9.09% ⇩
Separated Bike Lane	51	- ⇩	5.89% ⇩	5.89% ⇩

PROPENSITY SCORE MATCHING

Bicycle Lane Treatment

The researchers matched treated sites (i.e., site with the bicycle facility being studied) with the control sites (i.e., comparison site with no facility or with a different type of facility) based on other roadway design and exposure factors to evaluate the safety effectiveness of conventional bicycle lanes. For this purpose the researchers used AADT and speed limits as the exposure variables and number of lanes and lane width as the roadway design characteristics. Because the number of bicyclists is significantly related to the bicycle facility type, the researchers did not use this variable for matching the treated and control sites. Other design variables such as shoulder and median width were not found to be significant factors for installing bicycle facilities. Moreover, the data matching based on the roadway functional class did not yield desirable outcome in terms of propensity scores, therefore this variable was not included in the list of covariates for identifying the control sites.

Table 30 shows the results of logistic regression where the impact of roadway design features and exposure variables on the installation of bicycle facilities were assessed. Note that this table does not indicate the impact of these factors on the crashes, but rather is used to ensure that the treatment and control sites are relatively identical. As observed, all the selected variables for matching the treatment and control sites are statistically significant (p-values are very small), thus indicating that these variables are highly associated with the existence of the treatment.

Table 30. Estimation Results for Calculating Propensity Scores, Bicycle Lanes.

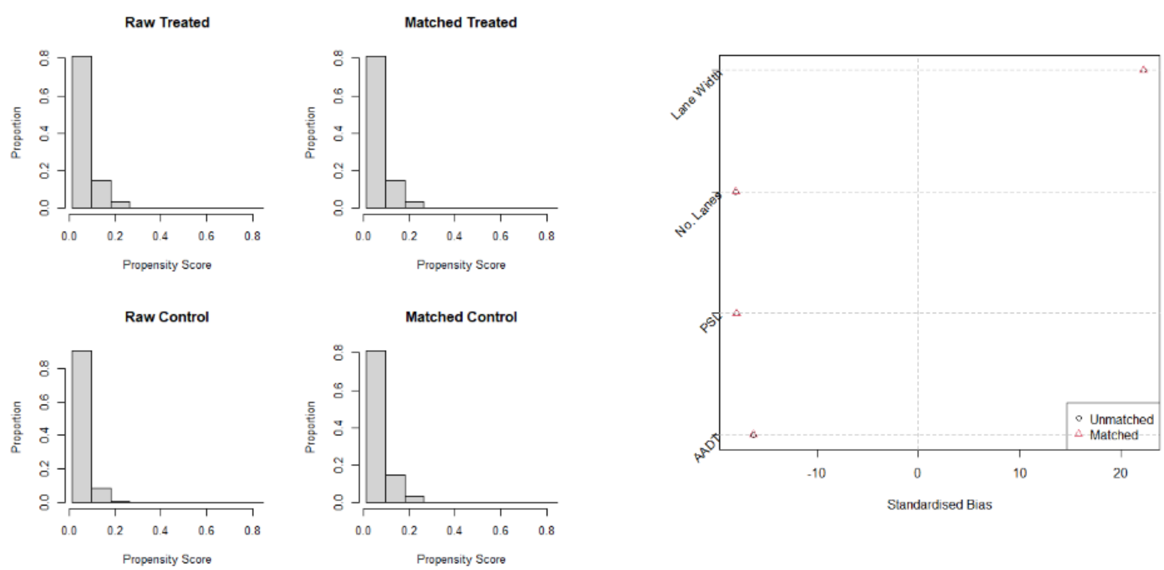
Covariates	Bicycle Lane vs No Facility		
	Estimate	***Std. Err.***	***p-value***
(Intercept)	−3.975	0.156	<0.0001
AADT	0.001	0.001	<0.0001
Posted Speed Limit	−0.018	0.003	<0.0001
Num. of Lanes	0.139	0.029	<0.0001
Lane Width	0.127	0.009	<0.0001

Table 31 shows the number of treated and control sites selected based on the propensity scores. The recommended ratio of 1:4 (Treated:Control) was used to identify the number of treated and control sites. As observed, all the bicycle lanes (1,091) were included in the total sample, and 4,347 of 15,683 no bicycle facility sites were included in the sample. For developing the CMFs, the researchers used the "Matched" sample (n = 5,438).

Table 31. Sample Size of Matched Data, Bicycle Lanes.

Sample Size	Bicycle Lane vs No Facility		
	Control	***Treat.***	***Total***
All (Raw)	15,683	1,091	16,774
Matched	*4,347*	*1,091*	*5,438*
Unmatched	11,336	0	11,336
Discarded	0	0	0

Prior to the count data modeling, the quality of the matched data needed to be tested and validated. To validate the quality of the matched data, the propensity score distributions and standardized biases were inspected. It was expected that when overlaid, the propensity score distributions of treated and control groups would overlap, which was the case in the matched data (Figure 60a). The second quality control test was data balancing. It was expected that the covariate means in both treatment and control groups would be very similar, which was again achieved in the matched data (Figure 60b). Hence the researchers concluded that the treatment and control sites were nearly identical in terms of roadway design and exposure.

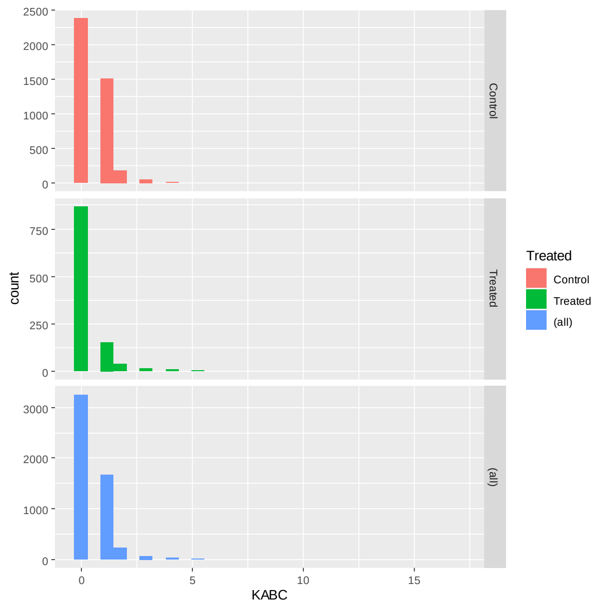


a) Propensity Score Distribution

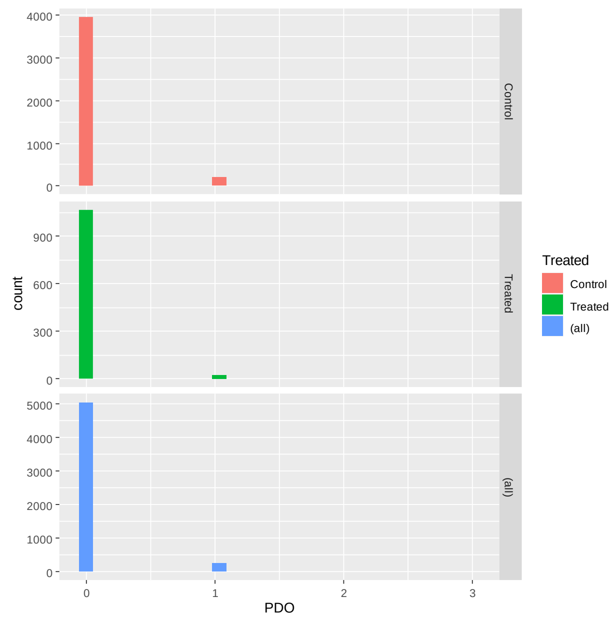
b) Standardized Bias

Figure 60. Propensity Score Distribution and Standardized Bias, Bicycle Lanes.

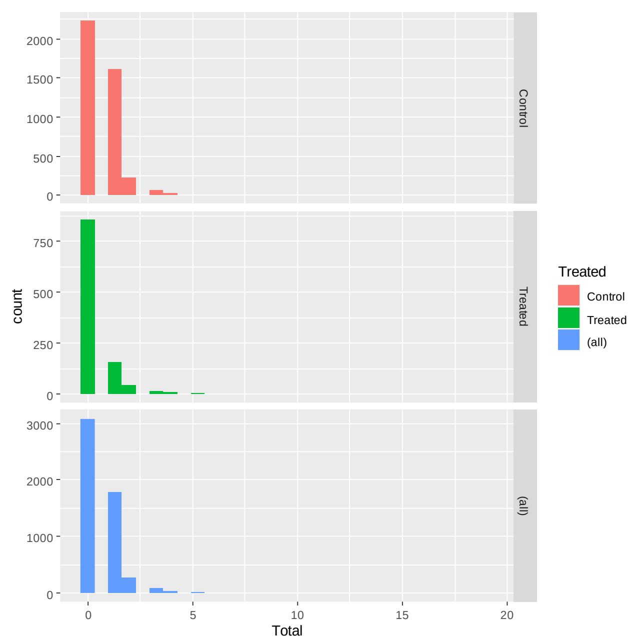
Figure 61 depicts the distribution of KABC, PDO, and total bicyclist crashes in the matched data. At first glance, for all three crash types, the bicyclist crashes seemed to be lower in treatment sites. However, to assess whether this was due to the treatment, the researchers needed to conduct regression analysis.



a) KABC Crashes



b) PDO Crashes



c) Total Crashes

Figure 61. Distribution of KABC, PDO, and Total Bicyclist Crashes at Bicycle Lanes vs No Bikeways.

The researchers used negative binomial models to estimate the impact of bike lanes and other roadway and exposure factors on KABC, PDO, and total bicyclist crashes. As discussed earlier, the researchers used the aggregated crashes across four years (2017–2020). Since bicyclist crashes are extremely rare events, using the average annual crashes could affect the model performance. For the sake of consistency the researchers also used the aggregated AADT and AADB across four years. Because the AADT number was extremely high compared to the crashes, the researchers log-transformed the AADT. Log transformation for the AADB was not feasible due to some segments having zero AADB values.

Table 32 depicts the final estimation results for the bicycle lane treatments. Overall model performance was acceptable, in that the standard error and overdispersion parameters were quite small, indicating that the model was an adequate fit for the data. The researchers also calculated the mean squared error (MSE) which is the mean square of the difference between the observed and predicted values. As observed, this value is also very small.

Table 32. Estimation Results, Bicycle Lane Treatment.

Variables	KABC			PDO			Total		
	Est.	*St. D.*	*p-value*	*Est.*	*St. D.*	*p-value*	*Est.*	*St. D.*	*p-value*
Intercept	−2.158	0.171	<0.0001	−3.943	0.528	<0.0001	−2.021	0.163	<0.0001
Bike Lane (Yes = 1, No = 0)	−0.577	0.064	<0.0001	−0.667	0.247	<0.001	−0.590	0.062	<0.0001
Segment Length	0.246	0.022	<0.0001	0.267	0.060	<0.0001	0.250	0.021	<0.0001
log (AADT)	0.164	0.022	<0.0001	0.122	0.067	0.069	0.160	0.021	<0.0001
AADB	0.005	0.001	<0.0001	−0.003	0.007	0.640	0.005	0.001	<0.0001
Posted Speed Limit	−0.004	0.003	0.113	−0.010	0.009	0.227	−0.005	0.003	0.066
Number of Lanes (2 vs 4 lane)	0.049	0.051	0.336	0.049	0.162	0.764	0.049	0.049	0.317
Goodness of Fit									
AIC	9,999			2,020			10,454		
Overdisp.	3.9			1.4			4.4		
St. Err.	0.5			1.1			0.6		
MSE	0.822			0.051			0.884		

The variable estimates indicate that the existence of a bicycle lane has a significantly positive impact on reducing bicyclist crashes; the estimated impact of this variable on KABC, PDO, and total bicyclist crashes is -0.6, -0.7 and -0.6 respectively. The standard deviation of estimates is very low and statistically significant (small p-values), indicating that they have "high star rating" in terms of the CMF Clearinghouse[2]. According to the estimation results, AADT and AADB have an increasing impact on bicyclist crashes. Posted speed limits on the other hand have a negative impact, which may be counterintuitive. However, this estimate is not significant. The number of lanes also has a positive coefficient, indicating that bike lanes installed at four-lane roadways may observe relatively less reduction in crashes compared to that of two-lane segments. However, again this variable is not very significant.

Buffered Bicycle Lane Treatment

Table 33 shows the results of logistic regression where the impact of roadway design features and exposure variables on the installation of buffered bicycle facilities were assessed. Again all the variables seem to be significantly associated with the installation of this particular treatment.

Table 33. Estimation Results for Calculating Propensity Scores, Buffered Bicycle Lanes.

Covariates	Buffered Bicycle Lane vs No Facility		
	Estimate	***Std. Err.***	***p-value***
(Intercept)	−5.606	0.356	<0.0001
AADT	0.000	0.000	<0.05
Posted Speed Limit	−0.029	0.007	<0.0001
Num. of Lanes	0.284	0.079	<0.0001
Lane Width	0.117	0.019	<0.0001

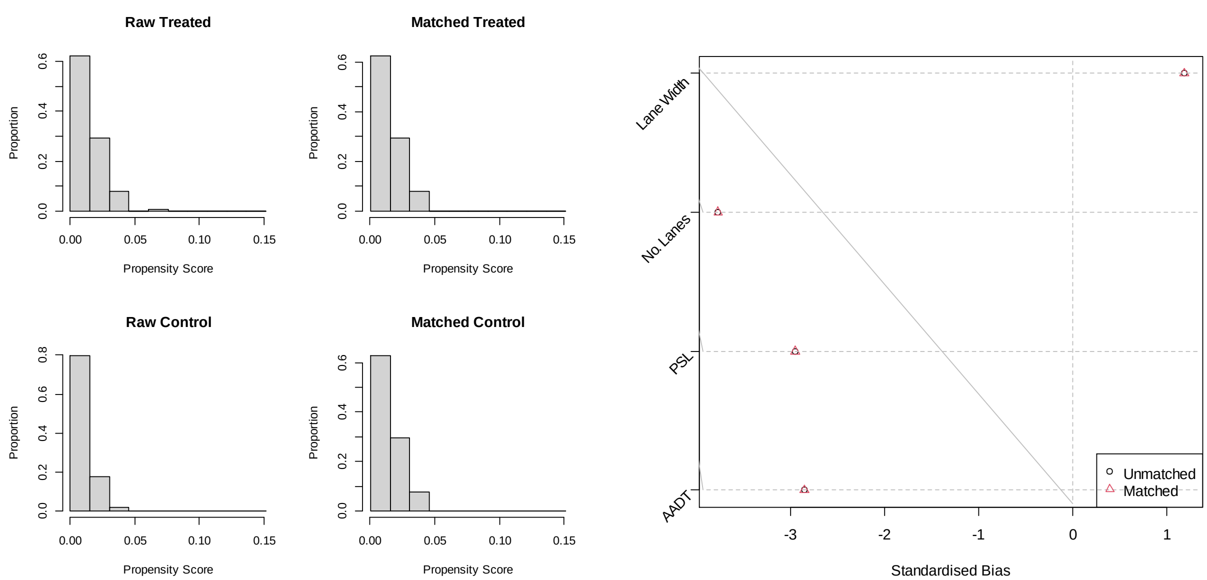
Table 34 shows the number of treated and control sites selected based on the propensity scores. For this treatment, the ratio of 1:3 (Treated:Control) was found to yield better matching results. As observed, all the bicycle lanes were included in the total sample, and 498 of 15,683 no bicycle facility sites were included in the sample. For developing the CMFs, the researchers used the "Matched" sample.

[2] FHWA. CMF Clearinghouse, available at http://www.cmfclearinghouse.org/

Table 34. Sample Size of Matched Data, Buffered Bicycle Lanes.

Sample Size	Buffered Bicycle Lane vs No Facility		
	Control	***Treat.***	***Total***
All (Raw)	15,683	167	15,850
Matched	498	166	664
Unmatched	15,185	1	15,186
Discarded	0	0	0

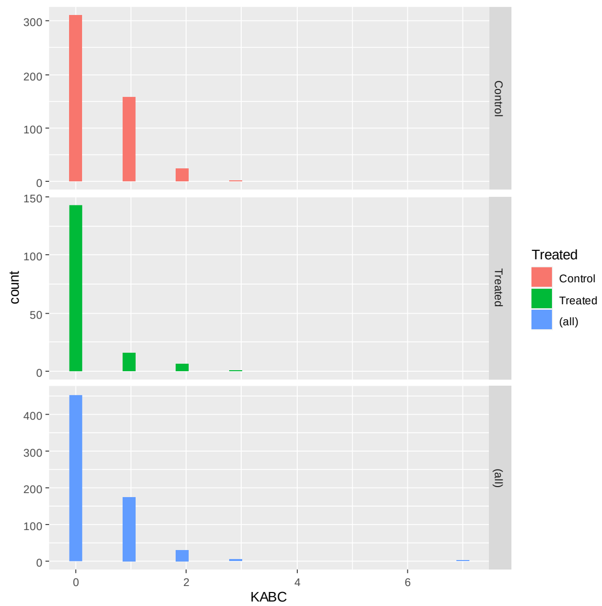
Figure 62 shows the propensity score distribution and standardized bias in the matched data. As observed, the propensity score distributions of treated and control sites in the matched data are very similar (Figure 62a) and the standardized biases of covariates in the matched data are very small (−3 to 1), thus indicating that the roadway and exposure characteristics of treatment and control sites in the matched data are nearly identical.



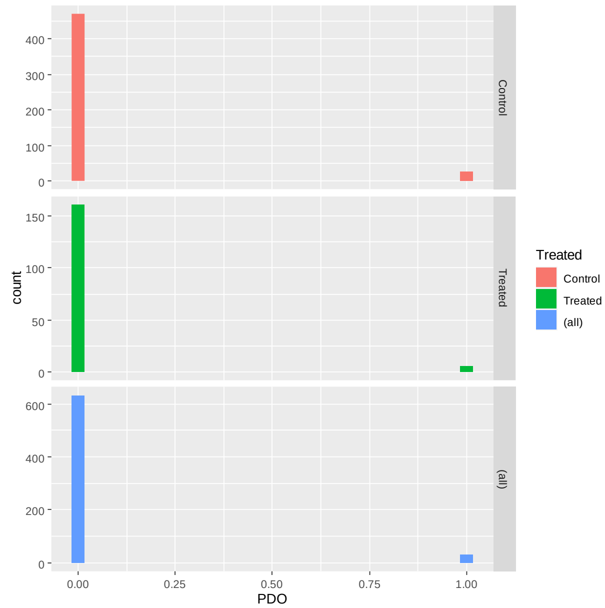
a) Propensity Score Distribution b) Standardized Bias

Figure 62. Propensity Score Distribution and Standardized Bias, Buffered Bicycle Lanes.

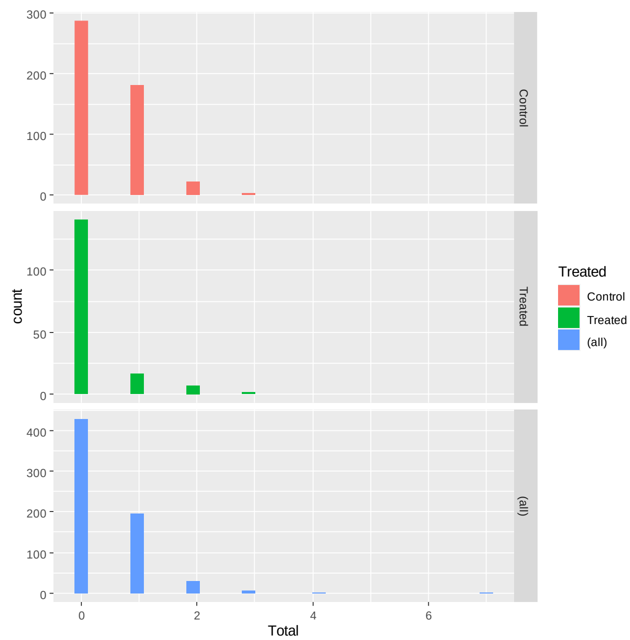
Figure 63 shows the distribution of crashes in the matched data. As observed, the number of KABC, PDO, and total bicyclist crashes at sites with buffered bike lanes are much smaller when compared to similar sites with no buffered bike lanes.



a) KABC Crashes



b) PDO Crashes



c) Total Crashes

Figure 63. Distribution of KABC, PDO, and Total Bicyclist Crashes at Buffered Bicycle Lanes vs No Bikeways.

The estimation results for the buffered bicycle treatments are presented in Table 35. The model goodness of fit statistics (AIC, overdispersion, standard error, and MSE) seemed to be acceptable, indicating that the model was an adequate fit for the matched data. As in the case of bike lanes, the buffered bike lanes had a significant impact on reducing KABC, PDO, and total bicyclist crashes (−0.9, −0.3 and −0.9). The exposure variables (i.e., AADB, AADT, and PSL) on the other hand had an increasing impact on the number of KABC, PDO, and total bicyclist crashes. However, these estimates were not statistically significant. Results indicate that the crash reduction on four-lane roadways with bikeways was higher than that of two-lane roadways with buffered bike lanes, indicating that installing buffered bike lanes on four-lane roadways may be more effective in reducing bicyclist crashes.

Table 35. Estimation Results, Buffered Bicycle Lane Treatment.

Variables	KABC			PDO			Total		
	Est.	*St. D.*	*p-value*	*Est.*	*St. D.*	*p-value*	*Est.*	*St. D.*	*p-value*
Intercept	−1.675	0.498	<0.0001	−4.541	1.302	<0.0001	−1.656	0.463	<0.0001
Buffered Bike Lane (Yes = 1, No = 0)	−0.899	0.203	<0.0001	−0.217	0.843	0.797	−0.856	0.188	<0.0001
Segment Length	0.321	0.091	<0.0001	0.278	0.261	0.288	0.316	0.085	<0.0001
log (AADT)	0.080	0.054	0.139	0.081	0.153	0.596	0.079	0.051	0.119
AADB	0.002	0.005	0.658	−0.047	0.089	0.593	0.002	0.005	0.773
Posted Speed Limit	0.001	0.012	0.937	0.027	0.030	0.359	0.004	0.011	0.686
Number of Lanes (2 vs 4 lane)	−0.141	0.165	0.391	−0.215	0.457	0.638	−0.147	0.154	0.342
Goodness of Fit									
AIC	1,043			269			1,112		
Overdisp.	11.1			10.9			18.5		
St. Err.	14.6			15.4			34.1		
MSE	0.544			0.048			0.601		

Separated Bicycle Lane Treatment

Table 36 shows the results of logistic regression where the impact of roadway design features and exposure variables on the installation of separated bicycle lanes were assessed. Among these factors, only AADT seems to have had a significant association with the installation of a separated bicycle lane. The researchers assumed that this was because the sample size of separated bike lanes in the dataset was very small (38 sites). Therefore the researchers decided to use the same covariates as the other two treatments for data matching purposes.

Table 36. Estimation Results for Calculating Propensity Scores, Separated Bicycle Lanes.

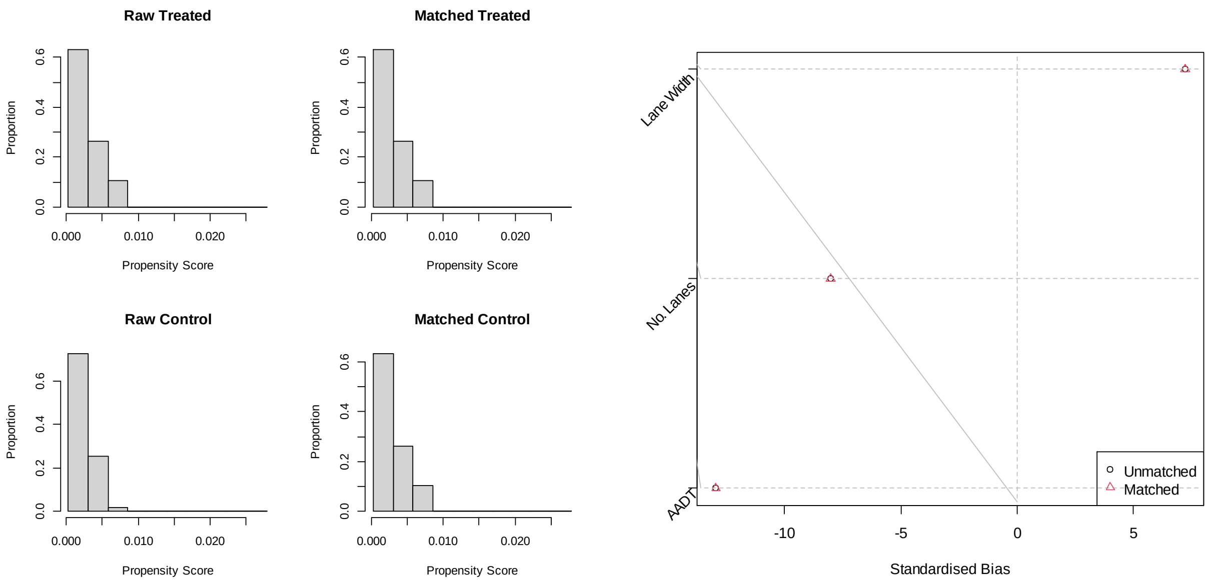
Covariates	Separated Bicycle Lane vs No Facility		
	Estimate	***Std. Err.***	***p-value***
(Intercept)	−8.884	1.026	<0.0001
AADT	0.294	0.129	<0.01
Posted Speed Limit	−0.005	0.014	0.729
Num. of Lanes	−0.201	0.164	0.218
Lane Width	0.069	0.045	0.122

Table 37 shows the number of treated and control sites selected based on the propensity scores. All of the 38 separated bicycle lanes were included in the total sample, and 152 of 15,683 no bicycle facility sites were included in the sample. For developing the CMFs, the researchers used the “Matched” sample.

Table 37. Sample Size of Matched Data, Separated Bicycle Lanes.

Sample Size	Separated Bicycle Lane vs No Facility		
	Control	***Treat.***	***Total***
All (Raw)	15,683	38	15,721
Matched	*114*	*38*	*152*
Unmatched	15,569	0	15,569
Discarded	0	0	0

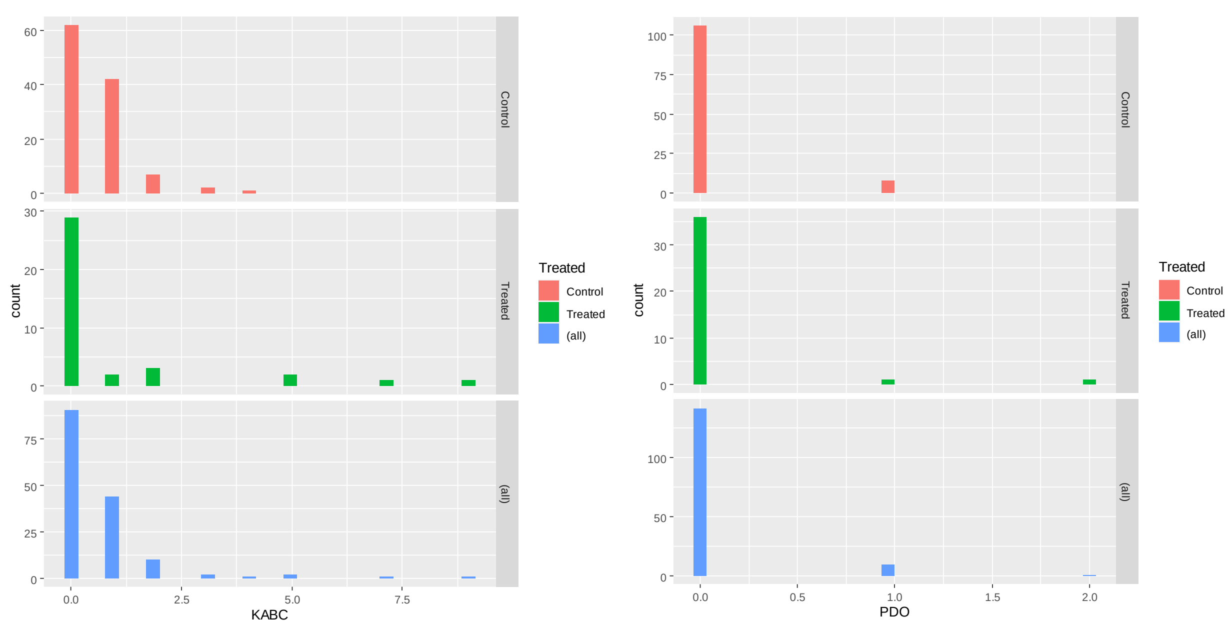
As before, according to the propensity score distribution and standardized bias (Figure 64) the treatment and control sites in the matched data seem to have nearly identical characteristics, except for the presence of the treatment.



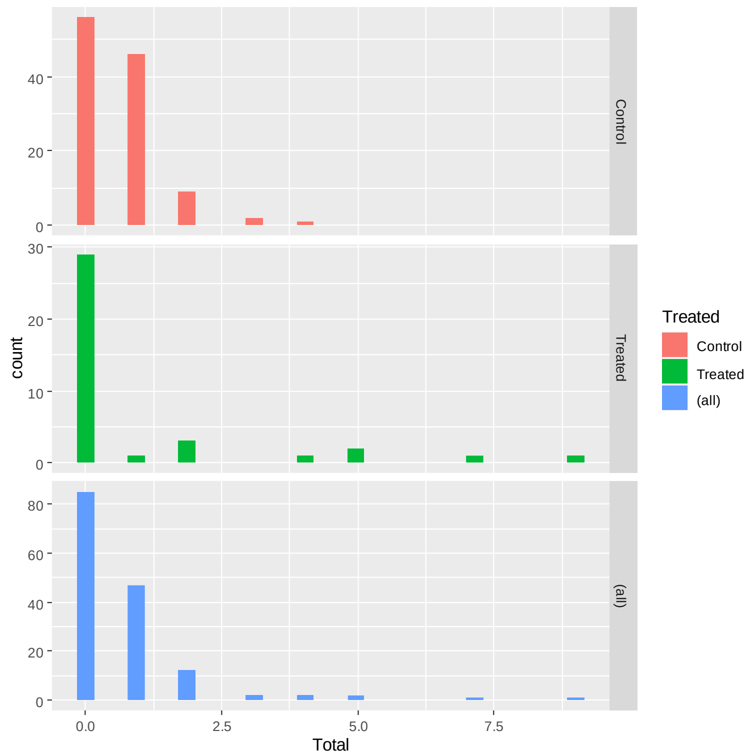
a) Propensity Score Distribution b) Standardized Bias

Figure 64. Propensity Score Distribution and Standardized Bias, Separated Bicycle Lanes.

Figure 65 presents the number of crashes in the matched data. As observed, in this dataset there were only 11 PDO crashes, three of which occurred at separated bike lanes. Due to such a small sample of crashes, PDO crashes were not included in the safety effectiveness evaluation of separated bicycle lanes.



a) KABC Crashes b) PDO Crashes



c) Total Crashes

Figure 65. Distribution of KABC, PDO, and Total Bicyclist Crashes at Separated Bicycle Lanes vs No Bikeways.

Table 38 presents the estimation results. As before, the model goodness of fit statistics (AIC, overdispersion, standard error, and MSE) indicate that the model was an adequate fit for the matched data. The estimation results indicate that the installation of separated bike lanes was significantly associated with the reduction in KABC and total bicyclist crashes. AADB and AADT were found to have a significant impact on increasing crash frequency at these sites, while posted speed limits had a decreasing impact. However, this variable was not significant. In general, in all three models the posted speed limits had a non-significant and somewhat counterintuitive impact on crash frequency. The researchers assumed that this could have been due to the data quality; as discussed earlier, the researchers had to make some assumptions to fill in the missing speed limits data which may have contributed to this outcome. Therefore, the researchers would urge caution when trying to interpret these results.

Table 38. Estimation Results, Separated Bicycle Lane Treatment.

Variables	KABC			Total		
	Est.	***St. D.***	***p-value***	***Est.***	***St. D.***	***p-value***
Intercept	−2.249	0.893	<0.01	−2.065	0.829	<0.01
Separated Bike Lane (Yes = 1, No = 0)	−0.755	0.352	<0.01	−0.641	0.323	<0.01
Segment Length	0.368	0.189	<0.05	0.380	0.179	<0.01
log (AADT)	0.222	0.110	<0.01	0.181	0.103	<0.05
AADB	0.023	0.004	<0.0001	0.022	0.003	<0.0001
Posted Speed Limit	−0.016	0.015	0.275	−0.009	0.013	0.499
Number of Lanes (from 2 to 4)	0.011	0.301	0.971	0.109	0.286	0.705
AIC	316			338		
Overdisp.	3.3			3.6		
St. Err.	2.3			2.5		
MSE	1.086			1.191		

CHAPTER 6. IMPLEMENTATION GUIDELINES

CRASH MODIFICATION AND CRASH REDUCTION FACTORS

After estimating the CMFs the researchers calculated the CRFs to estimate the potential number of bicyclist crashes that could be reduced due to each treatment. CMF is calculated using the exponentiated value of the estimates. For example, the CMF of bicycle lanes for KABC bicyclist crashes ($CMF_{Bike\ Lane,KABC}$) is calculated as:

$$CMF_{Bike\ Lane,KABC,2-lanes} = \exp(-0.577) = 0.562 \quad (4)$$

Because the base model is developed for two-lane segments, this CMF is applicable to two-lane roadways. To estimate the CMF for four-lane roadway, the coefficients of bike lanes and the number of lanes must be summed:

$$CMF_{Bike\ Lane,KABC,4-lanes} = \exp(-0.577 + 0.049) = 0.59 \quad (5)$$

After estimating the CMF, we use equation (1), to estimate the crash reduction factor:

$$CRF_{Bike\ Lane,KABC,2-lanes} = \left(1 - CMF_{CMF_{Bike\ Lane,KABC,2-lanes}}\right) \times 100\% \quad (6)$$

$$CRF_{Bike\ Lane,KABC,2-lanes} = (1 - 0.562) \times 100\% = 44\%$$

Hence we expect to observe a 44 percent reduction in KABC bicyclist crashes when installing a bike lane on an urban two-lane segment. For the sake of consistency with the HSM, the CMFs developed for two-lane segments can be applied to one, two, and three-lane segments, while CMFs for four-lane segments can be applied to roadway segments with <4 lanes.

Table 39 presents the list of CMFs and CRFs developed in this project. As observed all the CMFs have low standard error and are statistically significant, indicating that the estimates are not biased. In terms of the CMF Clearinghouse they can be considered having high star rating. Overall, installing a bicycle lane, buffered bicycle lane and separated bicycle lane on an urban two-lane segment is expected to decrease the fatal and injury bicyclist crashes by 44, 59 and 53 percent respectively, and total bicyclist crashes by 45, 58 and 47 percent respectively. By installing bicycle lane, buffered bicycle lane and separated bicycle lanes on a four (or more)-lane urban roadway segment we expect to see a 41 (bicycle lanes), 65 (buffered bicycle lanes) and 52 (separated bicycle lanes) percent reduction in fatal and injury bicyclist crashes, and 42, 63 and 41 percent reduction in total bicyclist crashes. As observed, installing the buffered and separated bicycle lanes are expected to be more beneficial in terms of lives saved. However, the decision to install the particular facility will depend on the needs of the population and the availability of the resources. For example, installing a separated bicycle lane at sites with higher usage (hence higher exposure) may be a lot more beneficial than installing a bicycle lane. On the other hand, if the city or district does not have enough resources, a simple restriping of roadway segment for installing a bicycle lane may have a merit. Overall, the findings of this study implies that any type of treatment of a roadway for accommodating bicyclists will have significant impacts on reducing the crashes involving bicyclists.

Table 39. Crash Modification and Crash Reduction Factors per Bikeway Treatment.

Treatment Type	Number of Roadway Lanes	KABC Bicyclist Crashes			PDO Bicyclist Crashes			Total Bicyclist Crashes		
		CMF	*CRF*	*St. D.*	*CMF*	*CRF*	*St. D.*	*CMF*	*CRF*	*St. D.*
Bicycle Lane	2 lanes	0.562	44%	0.171	0.513	49%	0.528	0.554	45%	0.163
	4 lanes	0.590	41%	0.051	0.539	46%	0.162	0.582	42%	0.049
Buffered Bicycle Lane	2 lanes	0.407	59%	0.203	0.805	20%	0.843	0.425	58%	0.188
	4 lanes	0.353	65%	0.165	0.649	35%	0.457	0.367	63%	0.154
Separated Bicycle Lane	2 lanes	0.470	53%	0.352	NA	NA	NA	0.527	47%	0.323
	4 lanes	0.475	52%	0.301	NA	NA	NA	0.587	41%	0.286

BENEFIT COST ASSESSMENT

After evaluating the safety effectiveness of bikeway facilities, the research team conducted benefit-cost (B/C) analysis to assess the economic effectiveness of bikeway facilities. In the HSM B/C analysis, the CRF (i.e., the percentage change in crash frequency) is converted to a monetary value, summed, and then compared to the countermeasure cost. The expected reduction in crash frequency and severity can be converted into monetary values using societal comprehensive crash costs. Table 40 shows the steps and data needs for conducting the HSM B/C analysis.

Table 40. Calculation Steps and Data Needs in the HSM B/C Analysis.

Step	Data Needs
• Calculate the change in the number of crashes by severity	○ Crash frequency by severity ○ Before and after AADT volumes ○ Implementation start and end dates ○ CMFs (work codes) for all countermeasures under consideration
• Convert change in crash frequency to monetary value	○ The monetary value of crashes by severity
• Calculate construction and other implementation costs	○ Subject to standards for the jurisdiction
Calculate the ratio of benefits (monetary value) to total project cost	

The expected reduction in crash frequency and severity can be converted into monetary values using societal comprehensive crash costs. Table 41 depicts the national societal costs published by the National Safety Council (NSC), TxDOT Highway Safety Improvement Program (HSIP) and the FHWA project (Harmon et al., 2018).

Table 41. Average Comprehensive Crash Costs

Crash Severity	NSC Estimates	TxDOT's Crash Cost	FHWA Estimates
Fatal (K)	$10,080,000	$3,300,000	$11,295,400
Suspected Serious Injury (A)	$1,100,000	$3,300,000	$655,000
Non-Incapacitating Injury (B)	$304,000	$475,000	$198,500
Possible Injury (C)	$140,000	Not Applicable in HSIP	$125,600
Property Damage Only (PDO)	$8,500	Not Applicable in HSIP	$11,900

The cost of the treatment, on the other hand, include right-of-way acquisition, construction, operational and maintenance costs, and lifecycle of the treatment. The construction of bikeway facilities differ significantly, and generally includes elements such as restriping, widening concrete roadway for bikeway facilities, modifications to the right of way, etc. The research team referred to the TxDOT's Bicycle Tourism Trails Study (2018) to obtain the estimated construction and maintenance per mile costs for several bikeway types (see Table 42 and Table 43). In addition to the proposed construction costs and comprehensive crash costs the length of treated segment in miles, and service life of treatment (SLT), present value of investment (PVI) and the CRF of the treatment are required to estimate the benefit-cost ratio of the treatment. These cost estimates were used to conduct the benefit-cost assessment using the CRFs for the bicycle lanes as presented in the Case Study below.

Table 42. Bikeway Construction Cost

Table 1: Per Mile Bikeway Construction Cost Estimate Ranges

Bikeway Improvement Project	Initial Construction Costs[a,b]	
	Low-end	High-end
Construct Shared Use Path	$480,000	$570,000
Restripe roadway for Buffered Bike Lane	$140,000	$160,000
Widen *concrete* roadway for Buffered Bicycle Lane	$1,190,000	$1,430,000
Widen *asphalt* roadway for Buffered Bicycle Lane	$1,080,000	$1,300,000
Restripe roadway for Bicycle Lane	$80,000	$100,000
Widen *concrete* roadway for Bicycle Lane	$1,000,000	$1,200,000
Widen *asphalt* roadway for Bicycle Lane	$980,000	$1,180,000
Widen *concrete* Shoulder	$1,040,000	$1,250,000
Widen *asphalt* Shoulder	$950,000	$1,130,000

Source: TxDOT Bicycle Tourism Trails Study (2018), Table 1.

Table 43. Bikeway Operations and Maintenance Cost

Table 2: Bikeway Operation and Maintenance Activities

O&M Category	Maintenance Activities (TxDOT bid item#)	Annualized Per Mile Unit/Activity Cost*
Routine Maintenance *Multiple times each year*	Grass mowing (730 6002)	$216
	Cleaning/brushing (738 2006)	$5,600
	Tree trimming (752 6001)	$1,500
	Vandalism repair	$3,000
	Litter control (751 6005)	$672
Periodic Maintenance *Every 1 to 5 years*	Clearance pruning (751 6011)	$1,500
	Major tree trimming (752 6001)	$1,500
	Brush cutback (752 6002)	$1,500
	Roadway edging (751 6007)	$2,112
	Crack sealing (713 6005)	$5,280
	Re-striping (713 6005)	$1,584
	Permanent counter modem, batteries, etc	$92

* Periodic maintenance activities do not occur every year. To derive annual maintenance costs for these items, routine maintenance costs were divided by 5 to represent an annualized cost.

Source: TxDOT Bicycle Tourism Trails Study (2018), Table 2.

Case Study: Benefit-Cost Assessment of Installing Bicycle Lane

The research team conducted a benefit and cost analysis (BCA) to assess the economic effectiveness of installing a *bicycle lane* on a two-lane urban roadway by *restriping*.

For this case study, we assume that the treatment site is a 10-mi long, urban two-lane roadway segment, that has experienced four KABC bicyclist annually. Note that the average bicyclist crashes on a 0.1 – 2 mi segment was found to be 0.69, therefore this assumption may not be far-fetched. Additionally, we will assume that the service life of the treatment is three years.

To assess the economic benefit-cost of installing bicycle lane on this site, we will first estimate the expected reduction in crashes after installing the bicycle lane during the service life of the treatment. The average KABC bicyclist crash on this segment is expected to be 12 $(4 \text{ KABC crashes} \times 3 \text{ Years} = 12 \text{ KABC crashes})$ without the treatment. After installing the bicycle lane, we estimate that the KABC crashes will reduce by 44 percent (Table 39), hence leading to six crashes instead of 12:

$$Estimated_{KABC} = Observed_{KABC} \times CRF_{Bike\ Lane,KABC,2-lanes} \tag{CS.1}$$
$$Estimated_{KABC} = 12 \times 44\% = 6$$

Where $Observed_{KABC}$ is the total number of KABC bicyclist crashes without treatment, $Estimated_{KABC}$ is the total number of KABC bicyclist crashes with the treatment.

This implies that potentially there will be six less dead or injured victims, i.e., six lives will be saved: $12 \text{ KABC crashes} - 6 \text{ Estimated KABC Crashes} = 6 \text{ Lives Saved}$. To translate this reduction in crashes to societal costs, we first estimate the crash cost – ECC of a single KABC bicyclist crash using TxDOT's HSIP estimates (Table 41):

$$ECC_{KABC} = \frac{K + A + B + C}{4} \tag{CS.2}$$
$$ECC_{KABC} = \frac{\$3{,}300{,}000.00 + \$3{,}300{,}000.00 + \$475{,}000.00 + 0}{4} = \$1{,}768{,}750.00$$

Where ECC_{KABC} is the estimated crash cost of a KABC bicyclist crashes. Note that in this formula we are using the cost of K, A and B crash, while the cost of C crash is assumed to be zero. To estimate the crash cost (hence the benefit) of reduced crashes after the treatment, we will multiply this number by the number of Lives Saved:

$$ECC_{Lives\ Saved} = \$1{,}768{,}750 \times 6\ Lives\ Saved = \$10{,}612{,}500.00 \tag{CS.3}$$

This implies that the societal and economic benefit of installing a bicycle lane on a two-lane, urban roadway in the three years of service life of the treatment will be $\$10{,}612{,}500.00$.

After estimating the potential benefits, the cost of the treatment is estimated using the construction and maintenance cost, service life of treatment and present value of investment as follows:

$$Project\ Cost = Construciton\ Cost + Maintenance\ Cost \times PVI \qquad (CS.4)$$

$$PVI = \frac{1}{0.01}(1 - \frac{1}{(1 + 0.01)} \times SLT \qquad (CS.5)$$

Where PVI is the present value of investment and SLT is the service life of treatment. As observed in Table 42 the construction cost of restriping the segment for installing a bicycle lane is between \$80,000.00 and \$100,000.00 (\$90,000.00 on average). Meanwhile the annual maintenance cost is estimated to be \$10,988.00 (Table 43). Therefore the total cost of constructing and maintaining the bicycle lane during the three-year service life of the treatment will be:

$$PVI = \frac{1}{0.01}(1 - \frac{1}{(1 + 0.01)} \times 3 = 2.94 \qquad (CS.6)$$

$$Project\ Cost = \$90{,}000 \times 10\ miles + \$10{,}988 \times 2.94 = \$932{,}304.00$$

To estimate the benefit-cost ratio (BCR) of installing a bicycle lane on a two-lane urban segment is therefore equal to:

$$BCR_{Bicycle\ Lane} = \frac{ECC_{Lives\ Saved}}{Project\ Cost} = \frac{\$10{,}612{,}500.00}{\$932{,}304.00} = 1.9 \qquad (CS.7)$$

As observed, in this particular example, the estimated benefit of installing the bikeway facility by restriping a two-lane urban segment is almost twice higher than the associated costs.

CHAPTER 7. SUMMARY AND CONCLUSIONS

PROJECT SUMMARY

In this project, the research team conducted a safety effectiveness evaluation of bikeway facilities implemented on Texas roadways. The research team reviewed the literature and state of the practice to (a) identify the list of crash-contributing factors affecting bicyclist safety and (b) identify the list of safety improvements and implemented practices for preventing bicyclist crashes. The findings of the literature review indicate that the following factors impact the safety of bicyclists on roadways: socio-economic and demographic characteristics, roadway and bikeway facility type, built environment and roadway infrastructure, bicyclist exposure, behavioral factors, and temporal factors. With the goals of reducing bicyclist-vehicle crashes and improving bicyclist safety, state, regional, and city transportation agencies have implemented on-street bikeway facilities. Overall findings indicate that these facilities may improve bicyclist safety; however, there is still a lack of a more comprehensive, data-driven safety analysis that needs to be addressed.

The research team then conducted an online survey to gather information regarding the state of the practice in Texas. The survey was shared with more than 300 participants. A total of 138 valid responses were obtained, and 45 of the respondents had answered all the survey questions. The respondents were from 34 cities across the state. The agencies responding to the survey were TxDOT districts and divisions, city and county transportation agencies, and MPOs. Other agencies such as AACOG and NCTCOG also responded to the survey. According to the survey results, the transportation agencies have installed various types of bicycle facilities to accommodate bicyclists on roadway segments and intersections in Texas. These facilities include but are not limited to bicycle lanes, contra-flow bicycle lanes, buffered bicycle lanes, one-way and two-way separated bicycle lanes, shoulder signed as a bicycle lane, shared-use paths, through bike lane (or bicycle slot), bike box, two-stage turn queue box, crossing markings, protected intersections, and bike signals.

Forty-one of the survey respondents agreed to share readily available data gathered by their respective agencies with the research team. The readily available data collected from the agencies included bicycle counts, bicycle speed, bicycle facility types, and bicycle infrastructure cost. The information provided by the agencies was mostly used for building the bikeway inventory database. In addition to this, the research team conducted field data collection. The field data collection consisted of seven deployments in the following cities: Austin, College Station, Dallas, El Paso, Fort Worth, Houston, and San Antonio. The researchers selected 10 sites per city, except for Austin where they conducted two deployments. During the field data collection, a major weather event occurred, which undoubtedly affected the number of observed bicyclists. The field data collection results were later combined with the crowdsourced Strava data to develop bicycle exposure models.

The research team obtained the bicycle crash data from TTI's Center for Transportation Safety. These data were later combined with the roadway inventory, bikeway inventory, and bicyclist exposure to develop the safety database.

Using the comprehensive safety database, the research team developed the crash modification factors. The CMFs were developed for bicycle lanes, buffered bicycle lanes, and separated bicycle lanes installed at urban two- and four-lane segments, for KABC, PDO, and total bicyclist crashes. The CMFs for two-lane segments can be applied to one-, two-, and three-lane roadways, while CMFs for four-lane segments are applicable to roadways with four and more lanes. Modeling results indicate that installation of bicycle facilities on Texas roadways have led to statistically significant reduction in bicyclist crashes.

The findings of this study suggests that installation of bicycle lanes, buffered bicycle lanes and separated bicycle lanes can potentially lead to significant reduction in bicyclist crashes. Installation of buffered and separated bicycle facilities will lead to higher reductions in crashes, however the crash reductions due to installation of conventional bicycle lanes are also noteworthy and should be implemented at sites with relatively lower usage.

Finally, the research team provided guidance and a case study for assessing the benefit-cost of installing a bicycle facility. The case study covered the benefit-cost assessment of installing a bicycle lane on an urban roadway segment that has experienced bicyclist crashes. For this example, we used restriping or a roadway segment as a treatment. The results of the case study suggested that the expected benefit of this simple treatment is twice as much as the associated costs.

CONCLUSIONS AND IMPLICATIONS

As indicated earlier in the Introduction, one of the major limitations in the existing bicyclist safety studies is the limited availability of required exposure and bikeway inventory data. These limitations have negatively impacted on the safety studies and have contributed to mixed findings regarding the safety effectiveness of on-street bicycle facilities. In this study, the research dedicated considerable effort in developing a comprehensive safety database addressing these limitations. In addition to evaluating the safety effectiveness of bicycle facilities in Texas, the research team has also developed a comprehensive bikeway inventory map and developed exposure models for estimating bicycle counts. As the result of this effort, in this project we were able to develop statistically significant CMFs that clearly indicate that installing bicycle facilities are beneficial for improving safety of bicyclists. These facilities are also economically cost effective, in that the estimated number of lives saved and crash costs outweigh the costs associated with the implementation of such facilities. The findings of this data-driven safety study can be readily implemented to estimate the potential reductions and economic benefits of installing bicycle facilities on Texas roadways. Moreover, the findings of the data-driven safety analysis is expected to significantly contribute to the bicycle safety literature and implementation practices.

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APPENDIX

APPENDIX A. SURVEY INSTRUMENT

Introduction

Texas A&M Transportation Institute

TxDOT has sponsored a research project 0-7043 to evaluate the safety impacts of on-street bikeway facilities and develop crash modification factors, with the goal of reducing fatalities and injuries involving bicyclists. As part of this research, Texas A&M Transportation Institute is conducting a survey to gather relevant information about the current state of the practice implemented by agencies in Texas and to identify data that could be used to assess safety benefits of bicycle infrastructure. Your input is critical for conducting this research and for developing crash reduction factors.

Do you work for an agency in Texas?

Yes

No

→

Q2. Who do you work for?

Texas A&M Transportation Institute

Who do you work for?

City/County

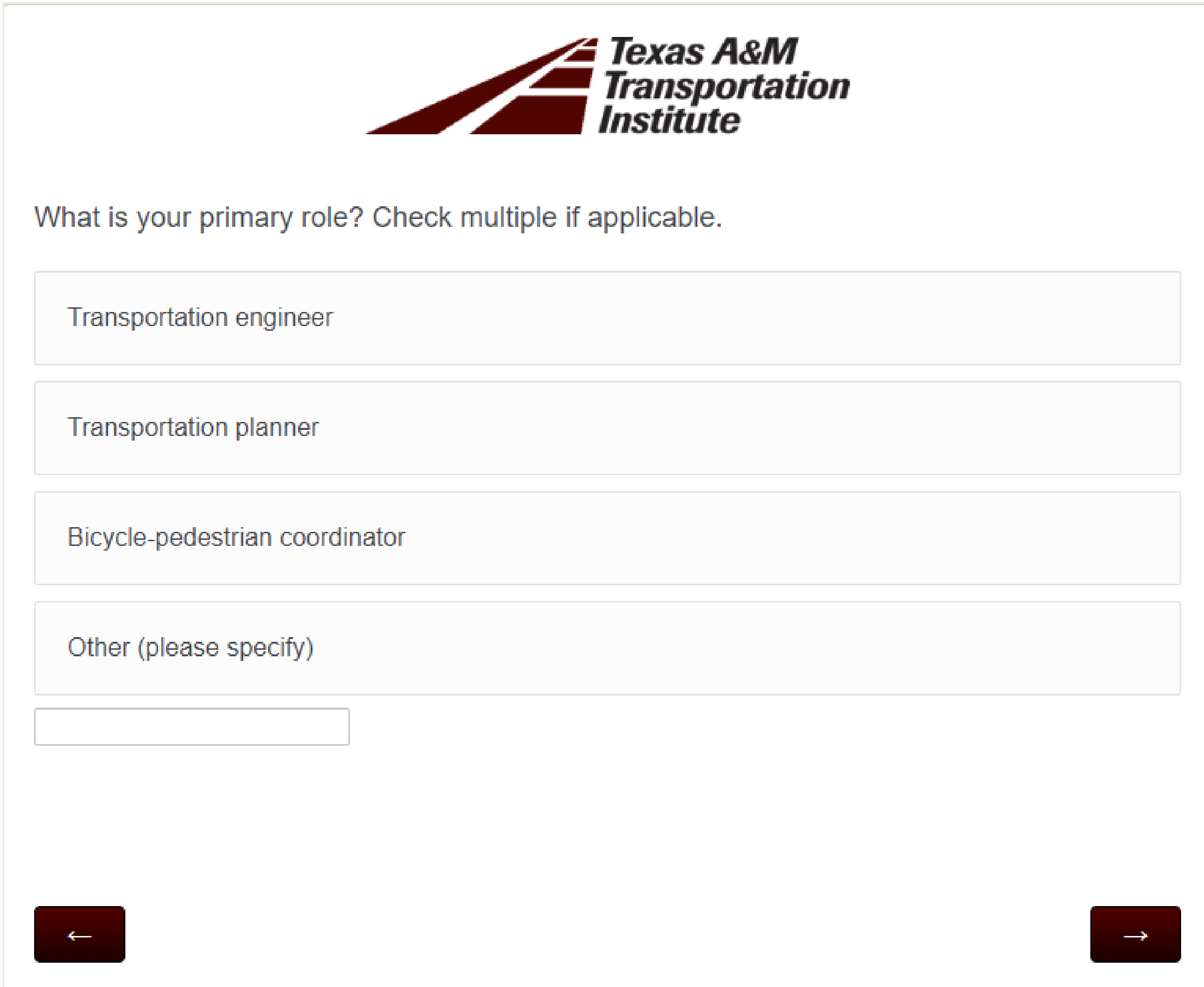
Metropolitan Planning Organization (MPO)

TxDOT District/Division/Office

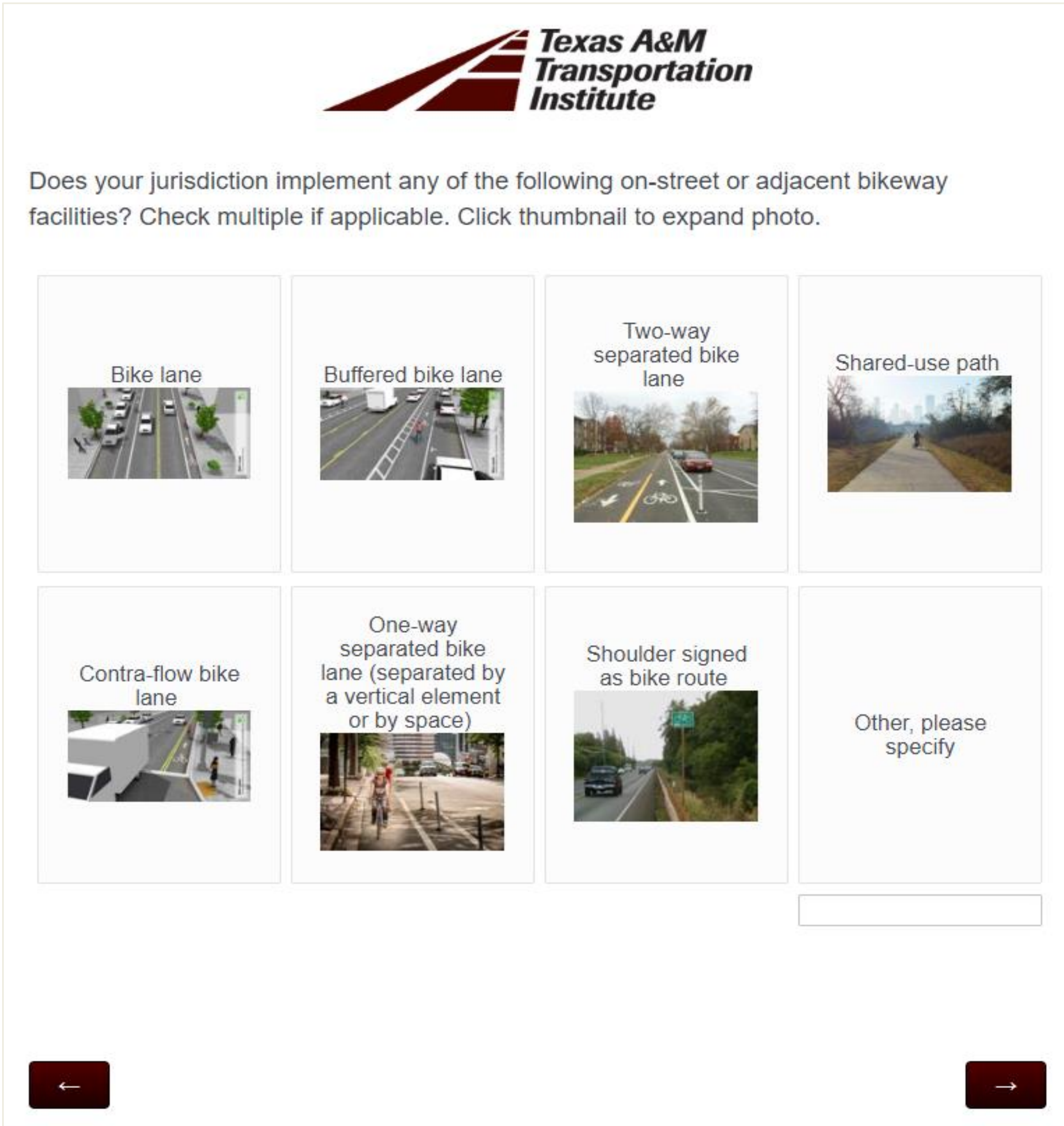
Other

← →

Q3. What is your primary role? Check multiple if applicable.



Q4. Does your jurisdiction implement any of the following on-street or adjacent bikeway facilities? Check multiple if applicable. (*Note: For every option presented, there is a corresponding picture, and if the participant clicks on the picture, they will see it in full size.*).



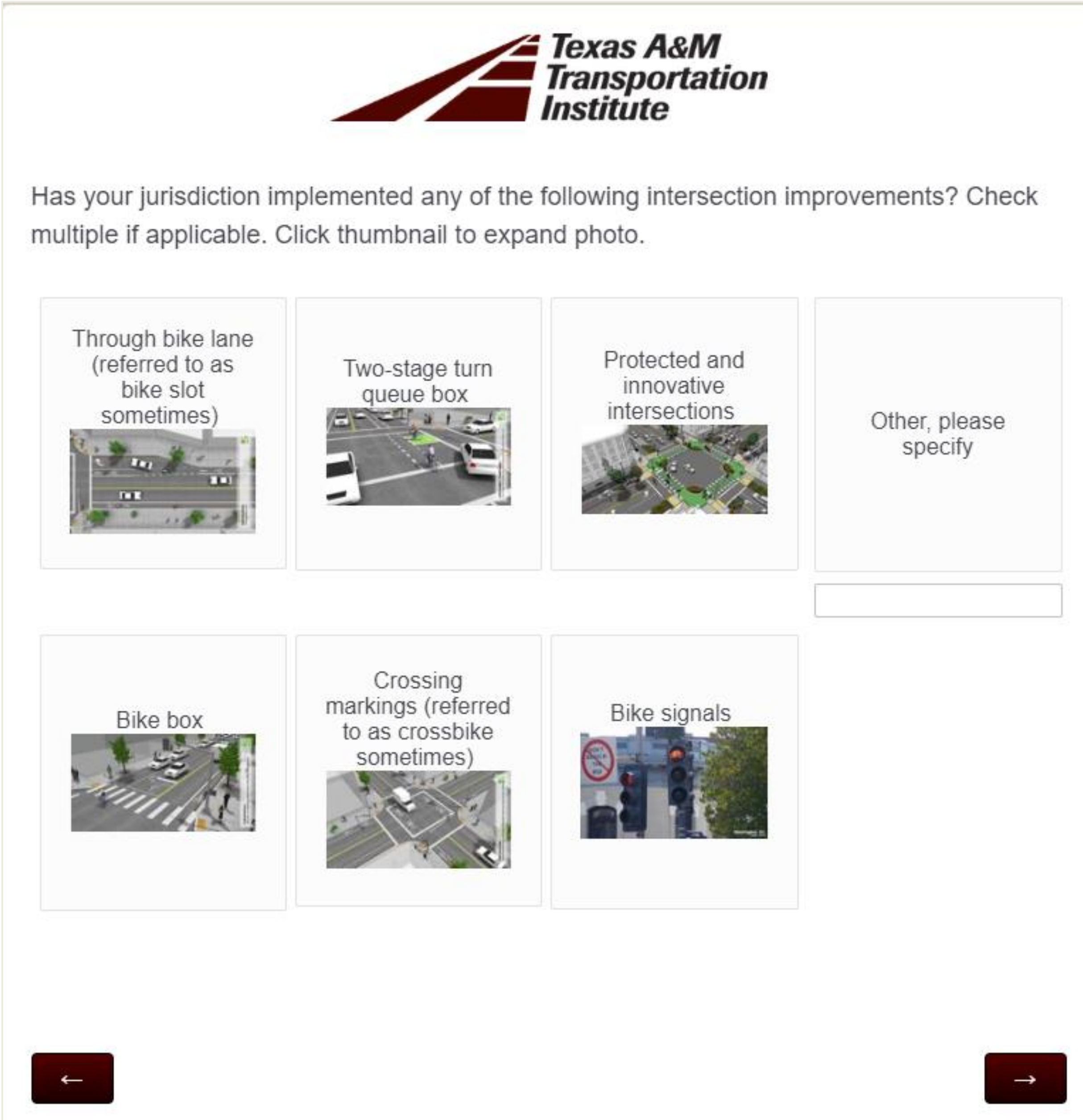
Texas A&M Transportation Institute

Does your jurisdiction implement any of the following on-street or adjacent bikeway facilities? Check multiple if applicable. Click thumbnail to expand photo.

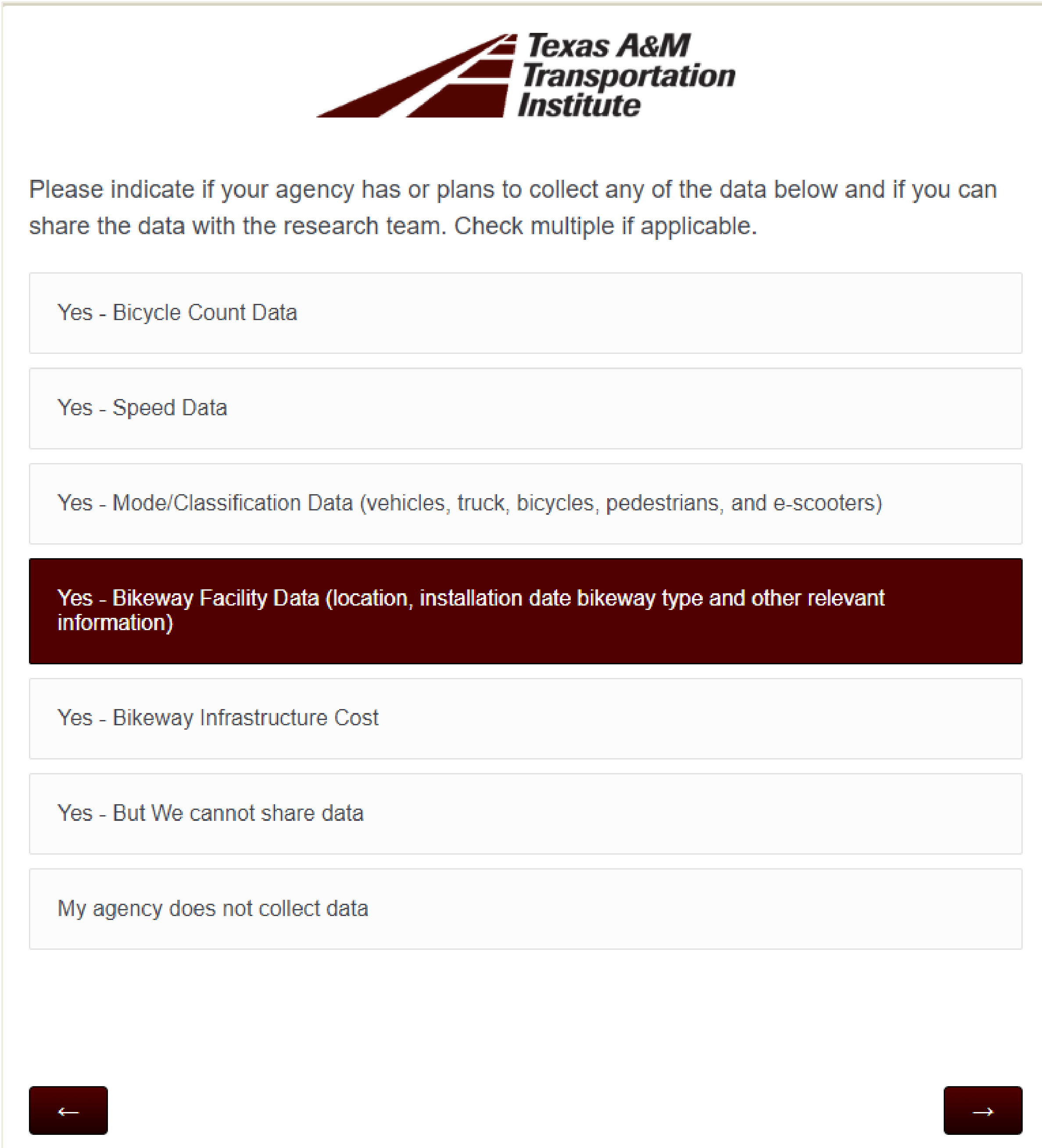
Bike lane	Buffered bike lane	Two-way separated bike lane	Shared-use path
Contra-flow bike lane	One-way separated bike lane (separated by a vertical element or by space)	Shoulder signed as bike route	Other, please specify

← →

Q5. Has your jurisdiction implemented any of the following intersection improvements? Check multiple if applicable (*Note: For every option presented, there is a corresponding picture, and if the participant clicks on the picture, they will see it in full size*).



Q6. Please indicate if your agency has or plans to collect any of the data below and if you can share the data with the research team. Check multiple if applicable.


Texas A&M Transportation Institute

Please indicate if your agency has or plans to collect any of the data below and if you can share the data with the research team. Check multiple if applicable.

- Yes - Bicycle Count Data
- Yes - Speed Data
- Yes - Mode/Classification Data (vehicles, truck, bicycles, pedestrians, and e-scooters)
- Yes - Bikeway Facility Data (location, installation date bikeway type and other relevant information)
- Yes - Bikeway Infrastructure Cost
- Yes - But We cannot share data
- My agency does not collect data

← →

Q7. Bicycle count data (*Display if Q6 = Yes, Bicycle count data***):**

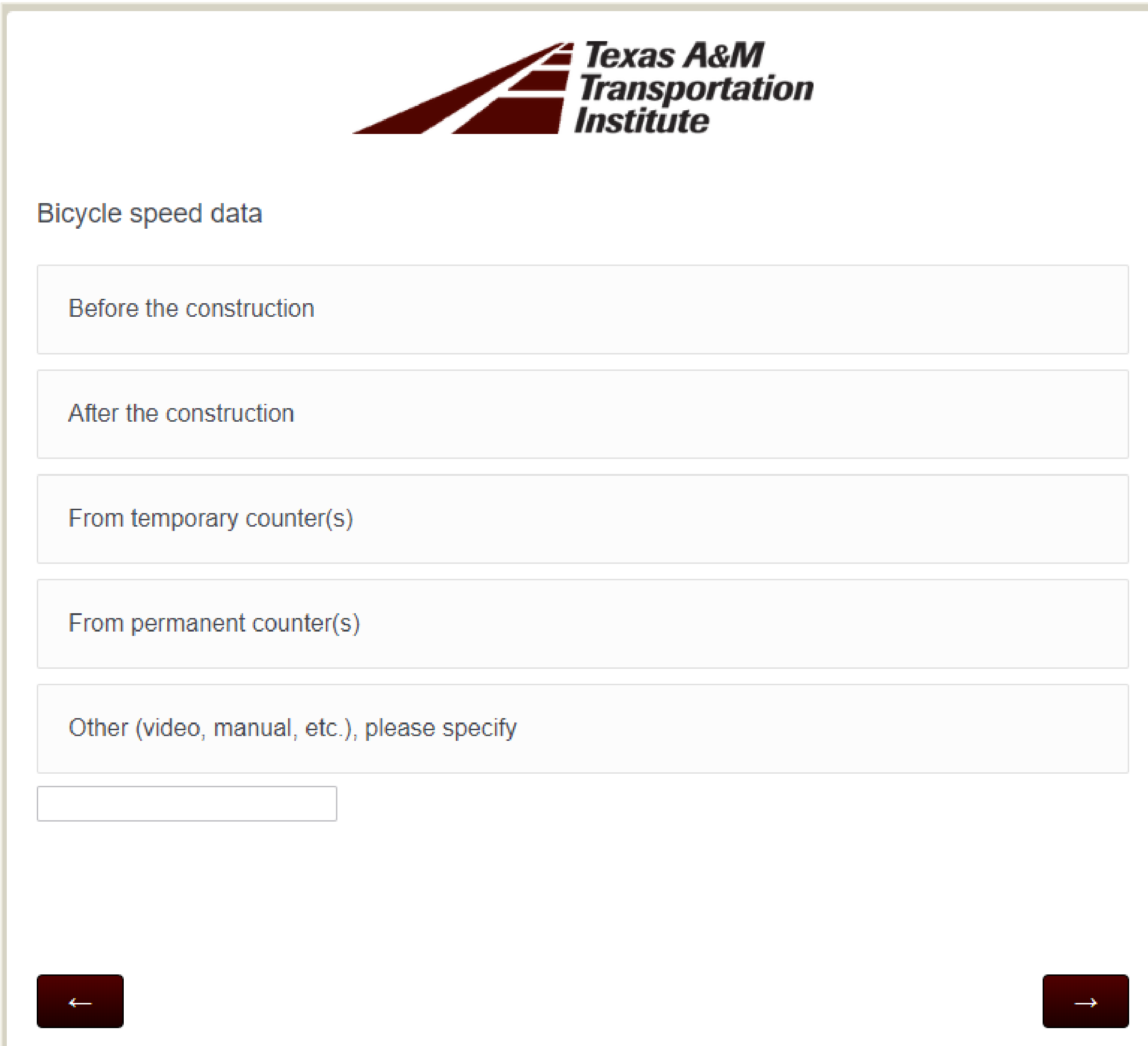
Texas A&M Transportation Institute

Bicycle count data:

- Before the construction
- After the construction
- From temporary counter(s)
- From permanent counter(s)
- Other (video, manual, etc.), please specify

← →

Q8. Speed data (*Display if Q6 = Yes, Speed data*)::



Texas A&M Transportation Institute

Bicycle speed data

Before the construction

After the construction

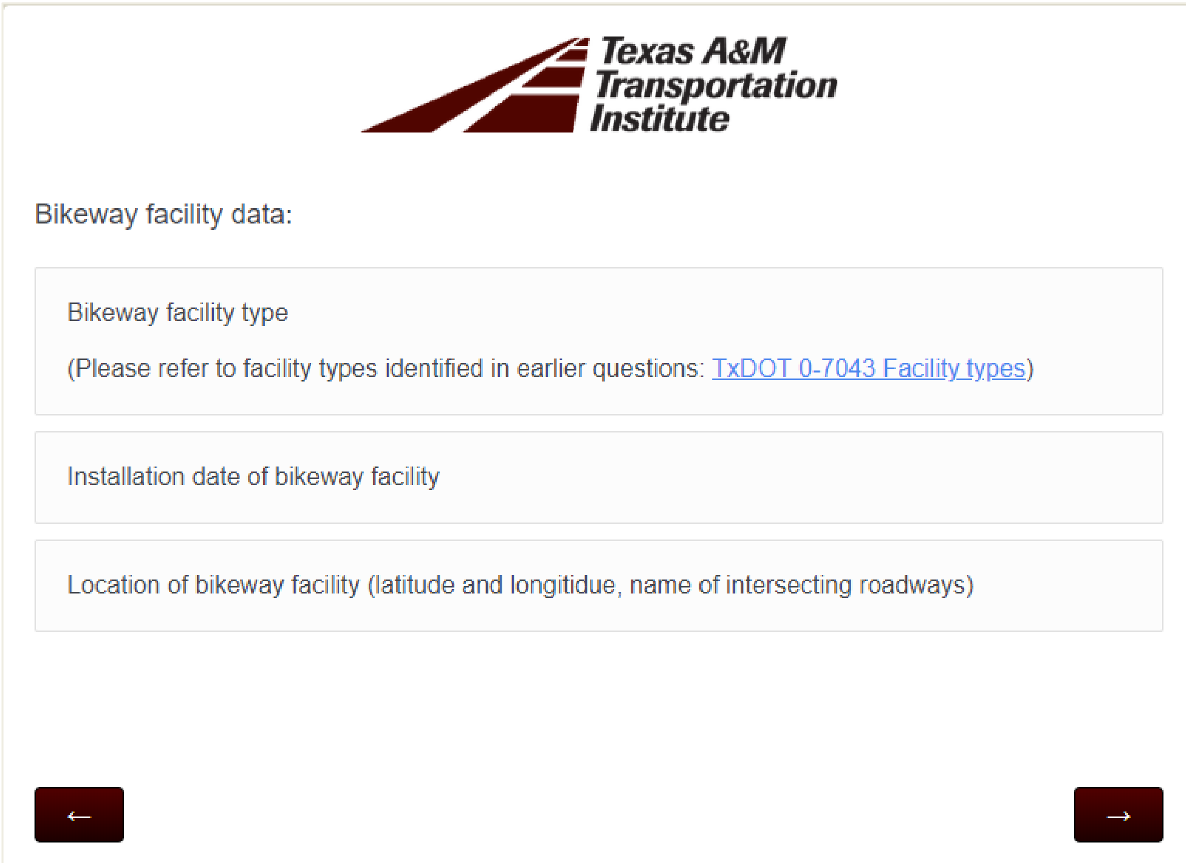
From temporary counter(s)

From permanent counter(s)

Other (video, manual, etc.), please specify

← →

Q9. Bikeway facility data (*Display if Q6 = Yes, Bikeway facility data***):**



Texas A&M Transportation Institute

Bikeway facility data:

Bikeway facility type

(Please refer to facility types identified in earlier questions: TxDOT 0-7043 Facility types)

Installation date of bikeway facility

Location of bikeway facility (latitude and longitidue, name of intersecting roadways)

←

→

Q10. Bikeway infrastructure cost (*Display if Q6 = Yes, Bikeway infrastructure cost***):**

Texas A&M Transportation Institute

Bikeway infrastructure cost:

- Construction cost (including right of way)
- Maintenance cost
- Facility lifecycle

← →

Q11. Please provide the appropriate contact information to reach out to (*Display if Q6 = Yes, Bicycle count data, or Bikeway facility data, or Bikeway Infrastructure cost***).**

Texas A&M Transportation Institute

Please provide the appropriate contact information to reach out to you.

Agency Name and Address	
Name	
Phone Number	
Email address	

← →

APPENDIX B. PILOT STUDY FOR ASSESSING SAFETY OF SHARED USE PATHS

Document Overview and Objective

Per panel recommendation, the Texas Department of Transportation (TxDOT) Project 0-7043 research team has prepared this pilot study for assessing the safety impacts of shared-use paths in Texas. The project team selected four sites for the pilot study. The sites were selected according to the established criteria, as explained in the next section, for conducting the before-and-after safety analysis. Since the shared-use paths are not comparable to other types of facilities, the project team did not consider conducting a cross-sectional analysis.

In this document, the project team uses the definition of shared-use paths (SUPs) established by the Federal Highway Administration, which indicates that "shared use paths (SUPs) are facilities on the exclusive right-of-way and with the minimal cross flow by motor vehicles" (1). The width of the facility is expected to be at least 10 ft and does not include sidewalks and shoulders.

Site Selection and Data Collection

For the pilot study, the project team implemented a before-and-after (B/A) safety-effectiveness evaluation approach to assess the potential safety impacts of SUPs on parallel streets (side paths). A B/A analysis typically requires at least three years of before and after periods from the construction completion date of the bike facilities. Changes were made to the crash data collection methods around 2010 that were related to variable consistency and the addition of business rules to make TxDOT's crash database (the Crash Records Information System [CRIS]) more accurate. With that being said, the number of 2010 bike crashes in CRIS should be accurate, but if the analysis tries to get into specific details about the bicyclists, there may or may not be usable data. Considering these changes, the installation date of SUPs considered in this study should be between 2013 and 2017 to guarantee at least three years of before and after periods. In addition to the installation date, the project team also decided to only consider sites with existing bicycle count data. Finally, due to the requirements of data-driven safety analysis, the roadway segments considered for the study should be longer than 0.1 miles and shorter than 2 miles (2). Therefore, the following criteria were established for selecting the SUPs:

1. The SUP is adjacent to the right of way or runs parallel to adjacent streets for at least 2 miles.
2. The SUP is not on a low-traffic-volume neighborhood street.
3. The SUP installation date ranges from 2013 to 2017.
4. Continuous bicycle count data are available.

Shared-Use Paths Selected

The project team used the information received from the Austin Transportation Department and the expertise of the research team to select the SUPs matching the established criteria. The project team identified seven potential sites for conducting the pilot study. However, after the assessment of the readily available data, only four sites were found to be relevant to the objectives of the study, and the remaining three were dropped. Table 44 shows a list of the four sites selected for safety assessment. These include one SUP in Houston, two SUPs in Austin, and one SUP in San Antonio. The SUPs were installed between 2015 and 2017. All the sites were two-way paths, and the total widths were between 10 ft and 12 ft. For the sake of simplicity, the exact locations of these sites are presented in the next section, together with the counter and crash data. (see Figure 68-Figure 71).

Table 44. SUP Information.

City	Shared Use Path			
	Name	Date Installed	Total Width (ft)	Type
Houston	I-610 and Woodway	4/1/2016	10	Two-way
Austin	Mopac Expressway	9/1/2016	12	Two-way
Austin	Shoal Creek Trail near 24th Street	7/2/2017	12	Two-way
San Antonio	Wurzbach Parkway	1/1/2015	10	Two-way

Parallel Street Data

After identifying the sites, the project team collected roadway information about the parallel streets from TxDOT's Roadway Inventory (RHiNO). As discussed previously, 2-mile segments adjacent the SUPs were selected for conducting the safety assessment. A roadway segment is defined as part of the roadway between two intersections (2). To select the beginning and ending of the 2-mile segments, the project team identified the nearest intersections 1 mile upstream and downstream of the counter. Table 45 shows the functional system of the sites and the roadway design elements such as the number of lanes, roadbed, median, shoulder, and lane widths. The exact start and end of parallel street segments selected for this study are shown in the next section. The SUPs selected in this study were installed parallel to urban freeways, principal major and minor arterials, and collectors. For one of the sites, the project team also considered the intersecting street due to the location of the counter (it was installed at the intersection of two streets).

Table 45. Roadway Information.

City	Site Name	Street Name	Functional System	Number of Lanes	Roadbed Width (ft)	Median Width (ft)	Average Shoulder Width (ft)	Lane Width (ft)
Houston	I-610 and Woodway	I-610 Frontage Road	Urban, major collector	3	36	0	0	12
		Woodway Drive	Urban, principal arterial	4	60	12	0	12
Austin	Mopac Expressway	East Frontage Road	Urban, major collector	3	52	0	8	12
Austin	Shoal Creek Trail near 24th Street	Lamar Street	Urban, principal arterial	4	54	0	0	11
San Antonio	Wurzbach Parkway	Wurzbach Parkway	Urban, principal arterial	6	85	5	0	14

Bicycle Exposure Data

Researchers obtained bicycle counts from the Texas Bicycle and Pedestrian Count Exchange (https://mobility.tamu.edu/bikepeddata/). Table 46 shows the total, weekend, and weekday bicycle counts (i.e., average annual daily bicycles [AADB]) per direction of travel on the SUPs, together with traffic volume data (i.e., annual average daily traffic [AADT] and posted speed limits [PSLs]). Bicycle counts represent the daily averages for all the years that had data available. AADT data represent the average AADT from 2010 to 2018 (the latest data available).

Table 46. Bicycle Exposure.

Site Name	Count Data Collected		SUP AADB on Travel Direction 1 (2016–2020)			SUP AADB on Travel Direction 2 (2017–2020)			Parallel Street Traffic Volume	
	Start	End	Total	Week-end	Week-day	Total	Week-end	Week-day	AADT (2010–2018)	PSL (mph)
I-610 and Woodway	8/19/2017	5/31/2020	67	100	54	64	94	52	23,372	45
Mopac Expressway	8/17/2017	1/7/2020	41	60	34	55	83	43	14,978	65
Shoal Creek Trail near 24th Street	5/1/2017	12/2/2018	42	41	43	59	61	58	31,341	35
Wurzbach Parkway	5/5/2016	6/6/2016	75	119	54	78	123	58	44,542	45

Bicycle Crash Data

To assess the safety impacts of SUPs, the project team identified the historical bicyclist crashes from 2010 to 2019 that occurred at the parallel side street. The SUPs do not generally affect the cross-sectional design of the parallel street; therefore, they are not expected to affect the vehicle crashes unless that crash involves a bicyclist. This is different for on-street bicycle facilities. The on-street bicycle facilities such as bicycle lanes also affect the overall design of the street (e.g., changing the lane width, removing the shoulder, and adding two-way left-turn lanes), which can affect other types of crashes that do not involve bicyclists. Therefore, for the safety assessment of the on-street bicycle facilities, the project team also considered the motor vehicle crashes.

Table 47 shows the number of segment and intersection crashes involving bicyclists for four sites considered for the B/A analysis. As observed, six crashes occurred from 2010 to 2018, all of which occurred at intersections where the parallel side street intersected either the SUP or another street. No bicyclist crashes occurred on the parallel street segments either before or after the installation of the SUP.

Table 47. B/A Crash Data.

Site Name	Installation Date	Segment Crashes (2010–2018)		Intersection Crashes (2010–2018)	
		Before	After	Before	After
I-610 and Woodway	4/1/2016	0	0	0	3*
Mopac Expressway	9/1/2016	0	0	0	0
Shoal Creek Trail near 24th Street	7/2/2017	0	0	3	0
Wurzbach Parkway	1/1/2015	0	0	0	0

*All crashes were in the intersection and on the northwest corner where there is no SUP.

Safety Assessment—Exploratory Analysis

The project team assessed the safety impacts of each site separately. The following subsections present the satellite and street view images of each site, together with the summary of crash narratives and bicycle exposure data.

Site 1: I-610 and Woodway

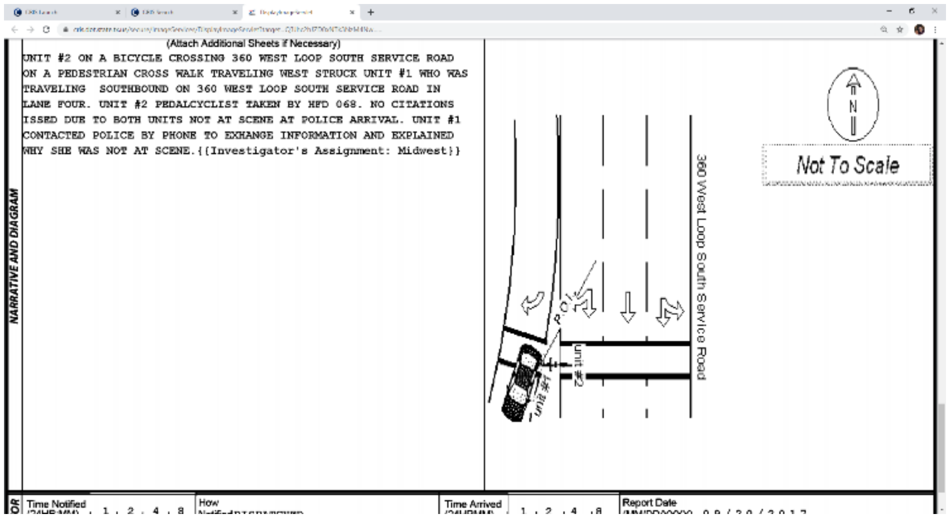
Figure 66 shows the site information and the location of the counter and crashes at the I-610 and Woodway site. The SUP at this site was installed in April 2016. The SUP runs along the I-610 frontage road and Woodway Avenue (a principal arterial). The AADT and PSL of the frontage road are 22,265 and 45 mph, respectively. The AADT and PSL of the principal arterial are 19,949 and 40 mph, respectively. The average number of daily bicyclists (all days of the week) using the facility between 2017 and 2020 was 131 in both directions of travel, with the weekend averages reaching 194 bicyclists per day.

Because the counter was placed near the intersection of both streets, the project team obtained the crash data from the frontage road and principal arterial. As observed, three reported crashes at this site occurred after the installation of the SUP. Figure 67 shows the police narratives collected from the crash sites. All three crashes took place at the intersection of the two streets where the SUP merges onto the main street. According to the police investigation, the drivers failed to yield to the bicyclists crossing the street. The crashes did not result in a fatality or serious injury. In all three cases, the bicyclist crossing the road from the sidewalk was hit by a right-turning vehicle.

a) Satellite View

b) Street View

Figure 66. Site and Crash Data for I-610 and Woodway.



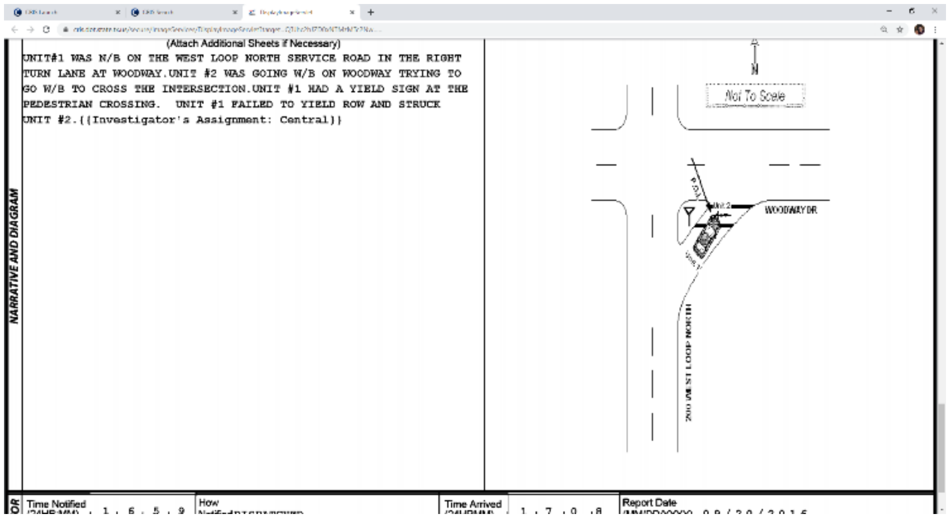
NARRATIVE AND DIAGRAM

(Attach Additional Sheets if Necessary)

UNIT #2 ON A BICYCLE CROSSING 360 WEST LOOP SOUTH SERVICE ROAD ON A PEDESTRIAN CROSS WALK TRAVELING WEST STRUCK UNIT #1 WHO WAS TRAVELING SOUTHBOUND ON 360 WEST LOOP SOUTH SERVICE ROAD IN LANE FOUR. UNIT #2 PEDALCYCLIST TAKEN BY HFD 068. NO CITATIONS ISSED DUE TO BOTH UNITS NOT AT SCENE AT POLICE ARRIVAL. UNIT #1 CONTACTED POLICE BY PHONE TO EXHANGE INFORMATION AND EXPLAINED WHY SHE WAS NOT AT SCENE.{(Investigator's Assignment: Midwest}}

Time Notified | 1 2 4 8 | How Notified | Time Arrived | 1 2 4 8 | Report Date

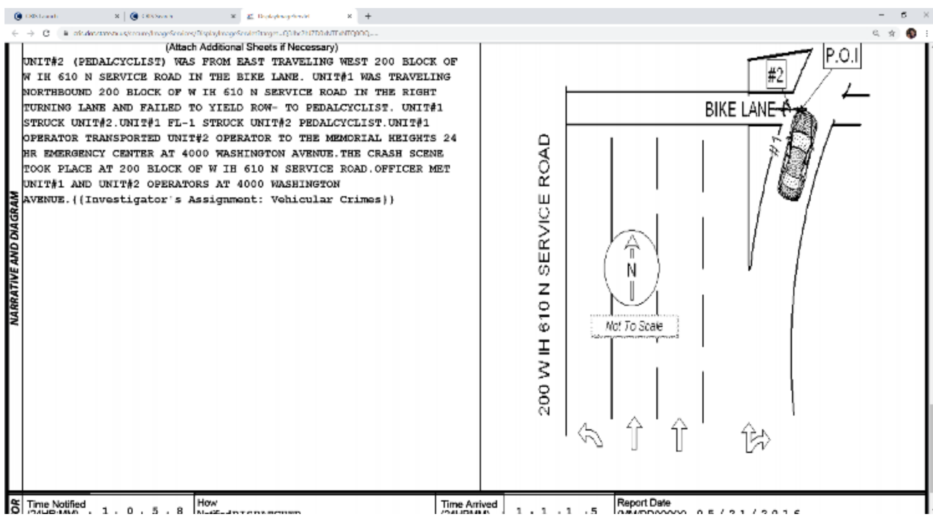
a) Crash #1



(Attach Additional Sheets if Necessary)

UNIT#1 WAS N/B ON THE WEST LOOP NORTH SERVICE ROAD IN THE RIGHT TURN LANE AT WOODWAY.UNIT #2 WAS GOING W/B ON WOODWAY TRYING TO GO W/B TO CROSS THE INTERSECTION.UNIT #1 HAD A YIELD SIGN AT THE PEDESTRIAN CROSSING. UNIT #1 FAILED TO YIELD ROW AND STRUCK UNIT #2.((Investigator's Assignment: Central))

c) Crash #2



(Attach Additional Sheets if Necessary)

UNIT#2 (PEDALCYCLIST) WAS FROM EAST TRAVELING WEST 200 BLOCK OF W IH 610 N SERVICE ROAD IN THE BIKE LANE. UNIT#1 WAS TRAVELING NORTHBOUND 200 BLOCK OF W IH 610 N SERVICE ROAD IN THE RIGHT TURNING LANE AND FAILED TO YIELD ROW- TO PEDALCYCLIST. UNIT#1 STRUCK UNIT#2.UNIT#1 FL-1 STRUCK UNIT#2 PEDALCYCLIST.UNIT#1 OPERATOR TRANSPORTED UNIT#2 OPERATOR TO THE MEMORIAL HEIGHTS 24 HR EMERGENCY CENTER AT 4000 WASHINGTON AVENUE.THE CRASH SCENE TOOK PLACE AT 200 BLOCK OF W IH 610 N SERVICE ROAD.OFFICER MET UNIT#1 AND UNIT#2 OPERATORS AT 4000 WASHINGTON AVENUE.((Investigator's Assignment: Vehicular Crimes))

d) Crash #3

Figure 67. Crash Narratives of Bike Crashes at I-610 and Woodway.

Site 2: Mopac Expressway

Figure 68 depicts the satellite and street views of the SUP at Mopac Expressway. The street view shows the location of the counter at this site. The SUP was installed in September 2016. A daily average of 96 bicyclists have used the facility since August 2017. It runs along the Mopac Expressway East Frontage Road, which had an average AADT of 27,750 from 2010 to 2018. The PSL of the segment is 55 mph. No bicyclist crashes occurred at this site or along the frontage road before and after the installation of the SUP. This may indicate that no bicyclists used the frontage road before the installation of the SUP.

a) Satellite View

b) Street View

Figure 68. Site and Crash Data for Mopac Expressway.

Site 3: Shoal Creek

Figure 69 depicts the satellite and street views and the counter and crash location for the Shoal Creek site.

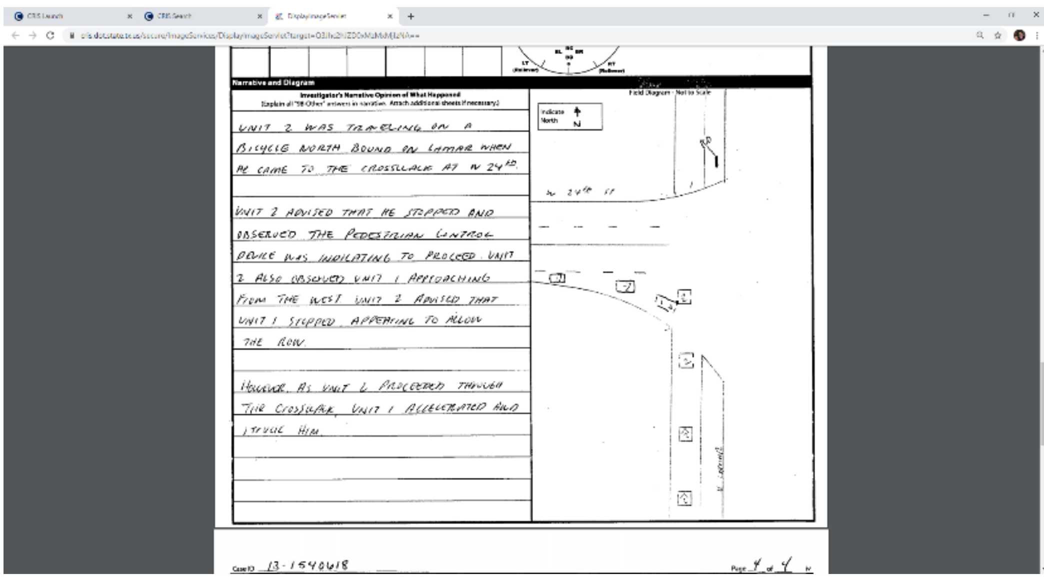
a) Satellite View

b) Street View

Figure 69. Site and Crash Data for Shoal Creek.

The SUP at this site was installed in July 2017. The average daily bicyclist volume on this facility was 101 from 2017 to 2018. The SUP runs along Lamar Boulevard, which has an AADT of 31,341 and a PSL of 35 mph.

Three bicyclist crashes were reported on Lamar Boulevard before the installation of the SUP (Figure 70). They were all intersection related and did not result in fatality or serious injury. In all three cases, the bicyclist crossing the road from the sidewalk was hit by a right-turning vehicle.


Narrative and Diagram

Investigator's Narrative Opinion of What Happened
(Explain all "98-Other" answers in narrative. Attach additional sheets if necessary.)

UNIT 2 WAS TRAVELING ON A BICYCLE NORTH BOUND ON LAMAR WHEN HE CAME TO THE CROSSWALK AT N 24TH.

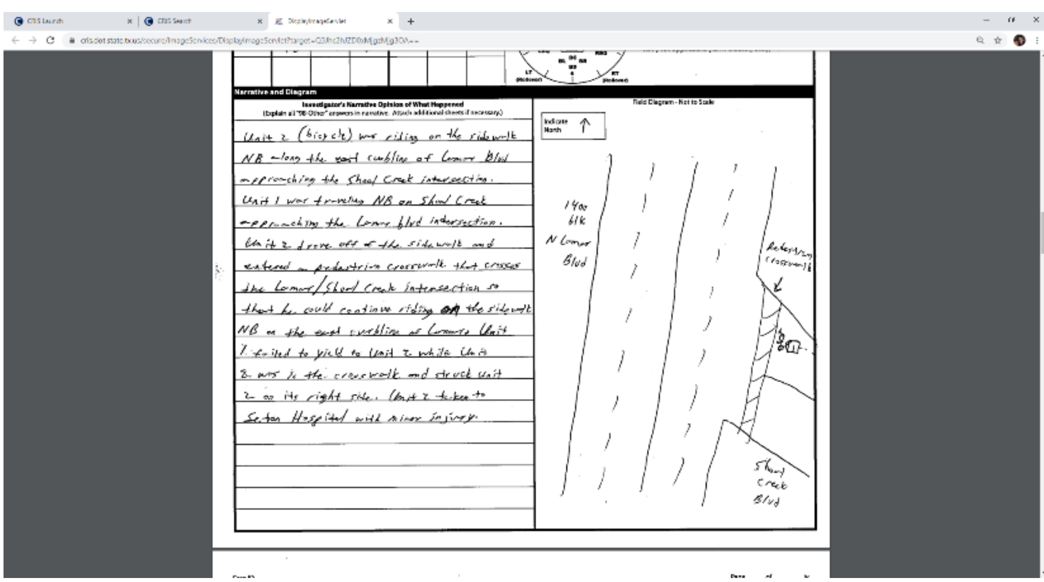
UNIT 2 ADVISED THAT HE STOPPED AND OBSERVED THE PEDESTRIAN CONTROL DEVICE WAS INDICATING TO PROCEED. UNIT 2 ALSO OBSERVED UNIT 1 APPROACHING FROM THE WEST. UNIT 2 ADVISED THAT UNIT 1 STOPPED, APPEARING TO ALLOW THE ROW.

HOWEVER, AS UNIT 2 PROCEEDED THROUGH THE CROSSWALK, UNIT 1 ACCELERATED AND STRUCK HIM.

Field Diagram - Not to Scale

Case ID 13-1540618

a) Crash #1

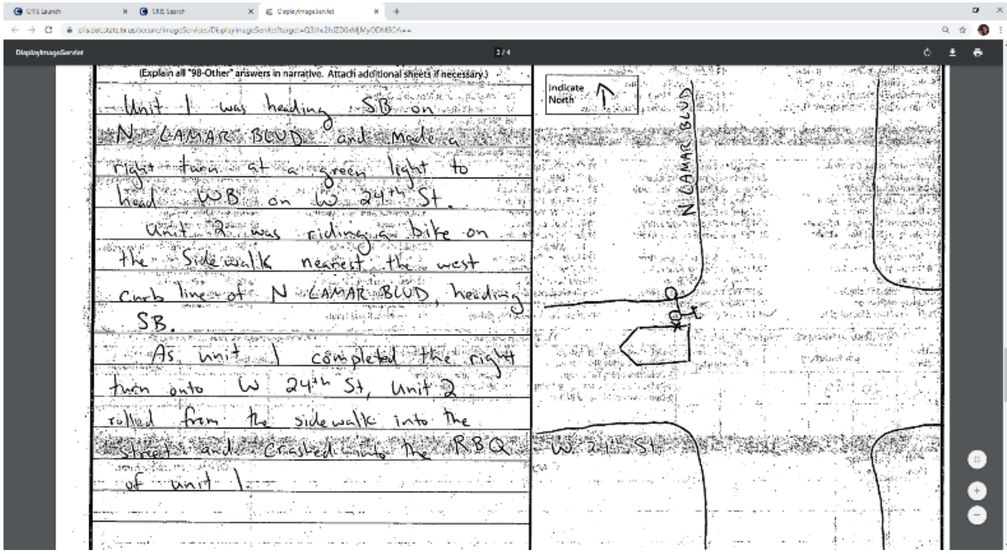

Narrative and Diagram

Investigator's Narrative Opinion of What Happened
(Explain all "98-Other" answers in narrative. Attach additional sheets if necessary.)

Unit 2 (bicycle) was riding on the sidewalk NB along the east curbline of Lamar Blvd approaching the Shoal Creek intersection. Unit 1 was traveling NB on Shoal Creek approaching the Lamar Blvd intersection. Unit 2 drove off of the sidewalk and entered a pedestrian crosswalk that crosses the Lamar/Shoal Creek intersection so that he could continue riding on the sidewalk NB on the east curbline of Lamar. Unit 1 failed to yield to Unit 2 while Unit 2 was in the crosswalk and struck Unit 2 on its right side. Unit 2 taken to Seton Hospital with minor injury.

Field Diagram - Not to Scale

b) Crash #2



(Explain all "98-Other" answers in narrative. Attach additional sheets if necessary.)

Unit 1 was heading SB on N LAMAR BLVD and made a right turn at a green light to head WB on W 24th St.
Unit 2 was riding a bike on the side walk nearest the west curb line of N LAMAR BLVD, heading SB.
As unit 1 completed the right turn onto W 24th St, Unit 2 rolled from the side walk into the street and crashed into the RBQ of unit 1.

c) Crash #3

Figure 70. Crash Narratives of Bike Crashes at Lamar Boulevard (Shoal Creek Site).

Site 4: Wurzbach Parkway

Figure 71 shows the satellite and street views of the SUP installed at Wurzbach Parkway. The SUP at this site was installed in January 2015 and has a high volume of bicyclists; an average daily number of 149 bicyclists used the facility in 2016. The SUP runs parallel to a principal urban arterial, with more than 44,542 AADT. The PSL of the parallel street is 60 mph. No bicyclist crashes occurred along this roadway segment either before or after the installation of the SUP. As observed, the starting point of the roadway segment is place.

a) Satellite View

b) Street View

Figure 71. Site and Crash Data for Wurzbach Parkway.

Conclusions and Future Research

The project team conducted a safety assessment of SUPs and faced several challenges while conducting this study. First, the installation date of the SUPs was not readily available. In this pilot study, the project team hoped to use exact dates obtained from the agencies; however, these data were not always readily available and required manual data collection using Google Earth historical imagery. The second major challenge was the availability of the count data. Although most of the count data identified in the previous tasks were collected from SUPs, due to the placement of these counters (e.g., far away from the parallel street), very few of them were found to be suitable for the purposes of this study. Finally, the project team identified very few bicyclist crashes for conducting B/A safety analysis, which could be due to the fact that not many bicyclists were using the parallel street either before or after the installation of the SUPs. As observed, the SUPs used in this study were installed parallel to high-speed, high-volume roadways, which could explain the lack of bicyclist crashes on these streets. The project team did not identify the sites with counters installed at both the SUP and the parallel street; therefore, they could not make an assumption about the number of bicyclists on the parallel street before the installation of the SUP.

Despite these challenges, the pilot study yielded a few important findings. Although very few crashes occurred, all were observed to be intersection related and involved right-turning vehicles. All of the crash scenarios indicated that the bicyclists riding along the SUP or the sidewalk were involved in crashes with motor vehicle drivers who failed to yield at the intersections when they were turning right. Therefore, the project team suggests considering the locations where the SUPs intersect with the roadway segments for a future safety assessment analysis. This approach will also impact the data collection methodology. Currently, almost no permanent or short-term counters are placed at the intersection of the SUPs with the roadway segment. If the project panel agrees to conduct the safety analysis of the intersections with SUPs, the project team will adjust the data collection plan to include these sites in data collection efforts.

An alternative approach is to conduct an observational B/A study where the bicyclist counts, and conflicts are observed before and after the installation of the SUP. However, this effort was outside the scope of Project 0-7043 and could be best addressed as a separate effort.