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16. Abstract

Because of the serious societal, environmental, economic, and public health problems associated with motorized transportation, there is increased interest in encouraging non-motorized modes of travel. The current study contributes toward this objective in two ways. First, it evaluates the operational impacts of bicycling adjacent to on-street parking. Second, it identifies the importance of attributes influencing bicyclists' route choice preferences. The importance of evaluating both operations and individual preferences at the same time is the interrelationship between the two; poorly designed roadways may encourage cyclists to leave designated bicycle routes.

Operationally, this study examines field data that was collected in Austin, Houston, and San Antonio and resulted in over 6,400 observations of motorists and/or cyclists adjacent to on-street parking. From the data, multivariate regression models were developed to predict the motorist's and cyclist's position on the roadway and the probability of motor vehicle encroachment. The models indicate that on-street parking has a significant impact on motorist and cyclist position; a bike lane combined with a buffer space is the only way to completely remove cyclists from the door zone, and operationally, a bicycle lane is more effective than a wide outside lane. As a result of the study, the *Texas Guide for Planned and Retrofit Bike Facilities* was updated to include on-street parking.

In evaluating route choice, the study specifically examines a comprehensive set of attributes that influence bicycle route choice, including: (1) bicyclists' characteristics, (2) on-street parking, (3) bicycle facility type and amenities, (4) roadway physical characteristics, (5) roadway functional characteristics, and (6) roadway operational characteristics. The data used in the analysis is drawn from a web-based stated preference survey of Texas bicyclists. The results of the study emphasize the importance of a comprehensive evaluation of both route-related attributes and bicyclists' demographics in bicycle route choice decisions. The empirical models indicate that travel time is the most important attribute for commuters in choosing their routes. These factors also impact bicyclists' route choice: traffic volume; speed limit; on-street parking characteristics; bicycle route continuity; number of stop signs, red lights, and cross streets; and roadway terrain.

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Chapter 1. Introduction

1.1 Purpose of Study

As state Departments of Transportation, cities, and county agencies continue to address traffic congestion, transportation funding deficiencies, and increased energy costs, they are challenged with providing adequate service. While suburbs continue to grow, a substantial portion of the population is choosing to move back into the city, causing a large diversity in transportation needs. In addition to single occupancy vehicles and trucks, there is an increase in demand for car/van share programs, as well as transit, rail, walking, and bicycling facilities.

The current federal highway bill entitled "Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users" (SAFETEA-LU) was signed August 10, 2005 and authorized $286.4 billion in spending for surface transportation projects over a 5-year period. This bill provides more resources for non-motorized transportation than ever before, with $4.5 billion in federal funds specifically for bicycling and pedestrian projects (according to Americabikes.org).

The Texas Department of Transportation (TxDOT) administers numerous federally funded programs for the Federal Highway Administration (FHWA) to ensure projects are developed in compliance with state and federal guidelines. To better evaluate on-street bicycle facilities and to supplement the American Association of State Highway and Transportation Officials' (AASHTO) *Guide for the Development of Bicycle Facilities* (1999 edition), TxDOT has initiated several research projects. These research projects have provided additional information and resources for determining the effective use of state and federal funds to promote bicycling as an alternative mode of transportation.

The scope of this research project includes two separate but complementary approaches to evaluating bikeways with on-street motor vehicle parking. The first approach addressed the operational elements of roadways, while the second considered roadway characteristics and the influence that on-street motor vehicle parking has on a cyclist's route choice through the use of a stated preference survey. The importance of evaluating roadway operations and individual preferences simultaneously was to identify any potential interrelationship between the two. Providing safer, more efficient bikeways on roadways with on-street parking is needed to address the hazards that parked vehicles present. When a cyclist chooses to ride on the sidewalk, they are more likely to be involved in a collision (according to Mortiz 1998 research). Alternatively, a bicyclist may choose a different route that is longer and/or more difficult to ride, which may make bicycling a less likely mode of transportation for commuting by bicycle in the future.

There are many ways that on-street parking can create dangerous conditions for bicycling. First, the space occupied by parked vehicles may be the same space designated for shared use by bicyclists. Second, parking turnover can be a hazard when vehicles pulling into or out of parking spaces do so without looking. The third and most common danger occurs when the door of a parked vehicle is opened into the path of a bicyclist. (This is known as a *dooring* collision.)

The issue of dooring was brought to public attention when a 36-year-old doctoral student at Tufts University, Dana Laird, died on July 2, 2002 when the door of a parked vehicle opened in her path (see Allen 2001). Laird either swerved abruptly or was thrown by the vehicle door and was crushed to death by a bus. This incident created concern because the bicycle facility she was riding on, a 5-ft bike lane adjacent to a 7.5-ft parking lane, was in compliance with AASHTO's bikeway recommendations, with 5 inches to spare. Furthermore, a study of motor vehicle–bicycle collisions in the Boston Metropolitan area by Dennerlein and Meeker (2002) identified a high incidence of bike-hitting-car-door crashes. The study collected data from cyclists and reported that doorings accounted for 16 percent of all injury-producing crashes. Additionally, in 1996 Pein completed a study of the 1995 crashes involving bicyclists in Santa Barbara, California. The Pein study verified that the most frequently occurring bicycle crash types were "Bicyclist Strikes Parked Vehicle" and "Motorist Right Turn." All of the "Bicyclist Strikes Parked Vehicle" crashes were dooring events.

The primary goal of this research project was to update the Bicycle Compatibility Index-Passenger Event Model (BCI-PEM) methodology presented in TxDOT's Research Project 0-5157, and to develop an on-line survey to measure the trade-offs among various roadway characteristics that cyclists are willing to make on their bicycle commute. By collecting empirical evidence of actual behaviors of cyclists and motorists traveling on roadways with on-street parking, and through a survey of bicyclists' personal preferences, this research project should provide planners and engineers with the ability to better evaluate the operational suitability of various bikeway designs, especially those adjacent to motor vehicle parking.

Chapter 2. Literature Review of Bicycle Operations

Improving roadway safety and operations for bicycling in urban areas has been a recent objective of many transportation researchers. Evidence has demonstrated that the most important way to promote bicycling is to provide appropriate bicycle facilities. Dill (2003) demonstrated that bicycle usage in urban areas is directly proportional to the percentage of arterial streets with bike lanes. Cities in the United States with high bicycling populations have more bike facilities per roadway mile and more bike lanes per arterial than those with low bicycling populations.

As bicycling becomes more accepted as an alternative mode of transportation many federal, state, and local governments have adopted bikeway design guidelines. Additional research may be needed to develop design and construction guidelines for more effective and safer facilities for on-street bicycling. Early research in this field concentrated specifically on evaluating different types of bicycle accommodations (Designated Bicycle Lanes, Wide Curb Lanes, Shared Lanes, and Paved Shoulders). More recent bikeway studies have looked at both the operational and safety issues associated with on-street bikeways; however, there is a lack of information about the effects that on-street vehicular parking has on bicycling.

2.1 Current Regulations and Design Guidelines

Most roadways are available to bicyclists; however, access may be denied by a local ordinance or when the roadway is a limited access highway. Appropriate bikeway design is dependent upon numerous roadway characteristics, including roadway classification, traffic volume, type of motor vehicle traffic, and posted speed limit/actual speed traveled. At minimum, designated bicycle lanes should conform to the recommendations in AASHTO's *Guide for the Development of Bicycle Facilities* or local standards, if the local standards are superior to AASHTOs. AASHTO's guidelines for parking adjacent to a bicycle lane are shown in Figure 2.1. These guidelines show a recommended minimum width of 8 to 10 feet for parked vehicles and a minimum width of 5 feet for the adjacent bicycle lane. For a signed shared lane adjacent to on-street parking, AASHTO recommends a lane width 15-foot or wider. In most of the published guidelines at the federal, state, and local levels, minimum and/or maximum widths for both the bike lane and on-street parking are written without specifications to determine when a specific width should be provided.

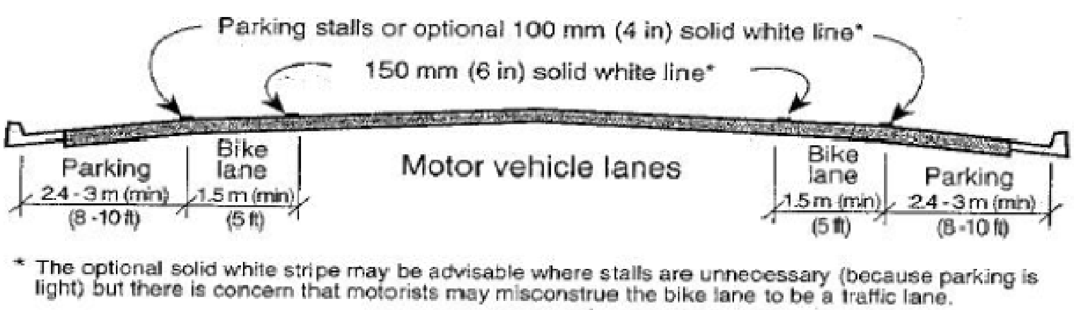


Figure 2.1: AASHTO Width Guidelines for Marked Parking and Bike Lanes

The FHWA conducts research to provide additional guidance on numerous transportation topics. Such as, *Implementing Bicycle Improvements at the Local Level (1997)*, which includes three options for modifying a typical 64-ft-wide, four-lane roadway to accommodate bicyclists. Two options include designated bicycle lanes and the third recommends a wide outside lane. These options were used in the development of the Lubbock Metropolitan Area Comprehensive Plan and supported by the Bicycle Federation of America. The cross sections for these designs are shown in Figure 2.2.

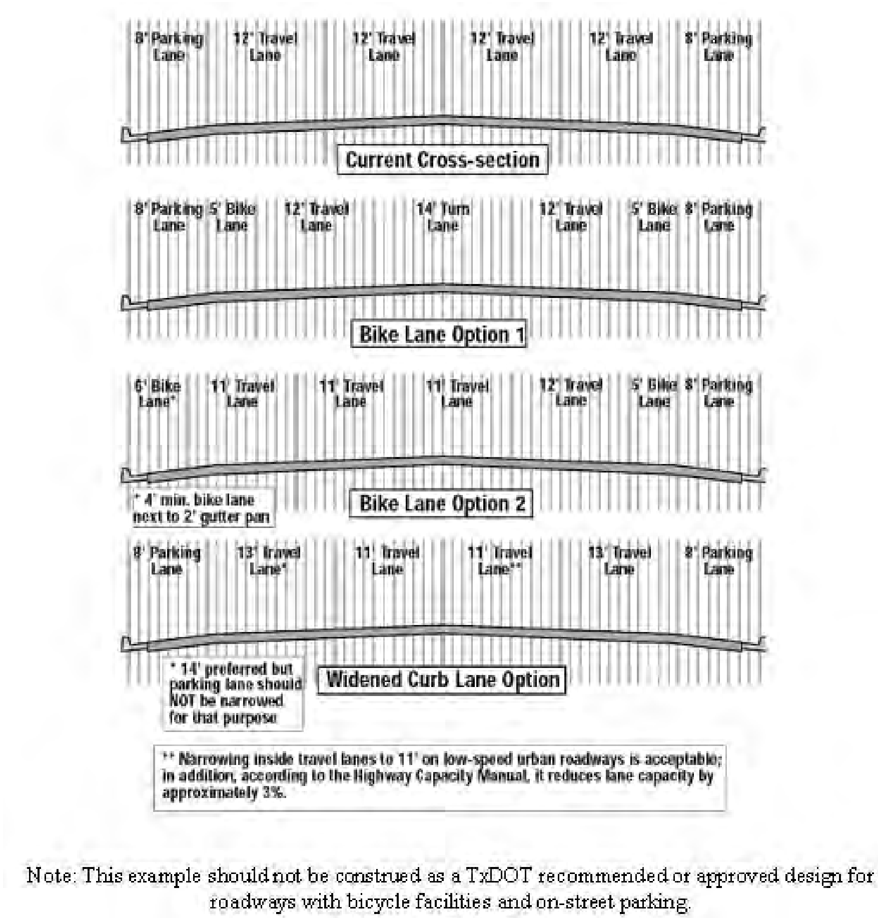
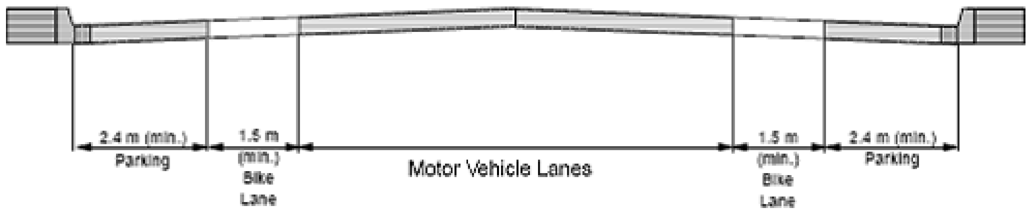


Figure 2.2: Lubbock Metropolitan Area Comprehensive Plan/Bicycle Federation of America Recommendations for Adding a Bicycle Facility

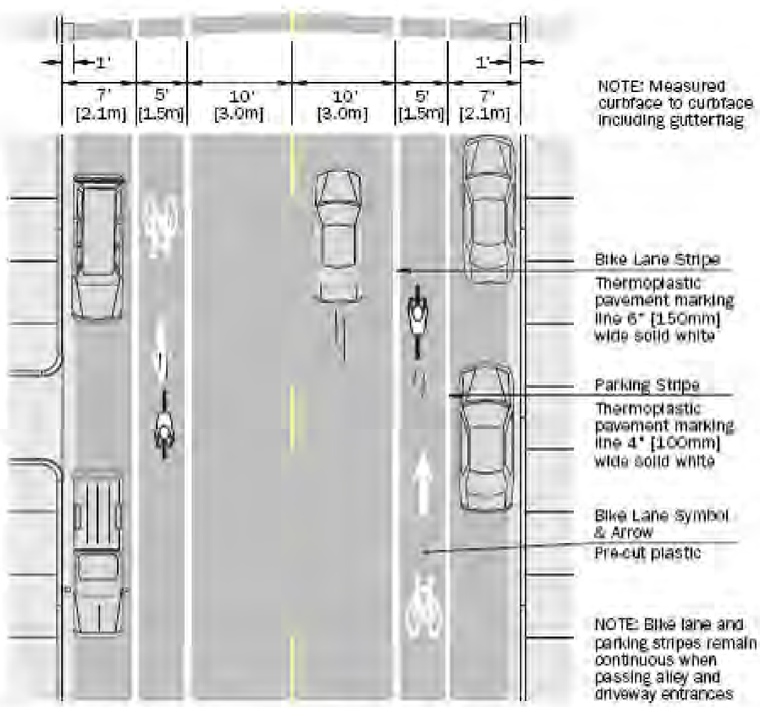
In addition to the federal recommendations and AASHTO's bikeway guide, many states, cities, and Metropolitan Planning Organizations (MPO) publish comprehensive bikeway plans. These plans generally describe the importance of walking and bicycling, discuss pedestrian and bicycle safety, identify various funding strategies, categorize the different bikeway types and offer locally or nationally recommended design guidelines. These guidelines should provide minimum and/or maximum recommended lane widths for shared wide outside lanes, designated bicycle lanes, bikeways on shoulders, off-road shared use paths, and designated bicycle lanes with on-street parking. For example, the State of Florida's statewide bikeway plan includes Figure 2.3, a recommendation consistent with AASHTO's 1999 *Guide for the Development of Bicycle Facilities.*



Note: This example should not be construed as a TxDOT recommended or approved design for roadways with bicycle facilities and on-street parking.

Figure 2.3: State of Florida Recommendations for Bike Lanes Adjacent to On-Street Parking

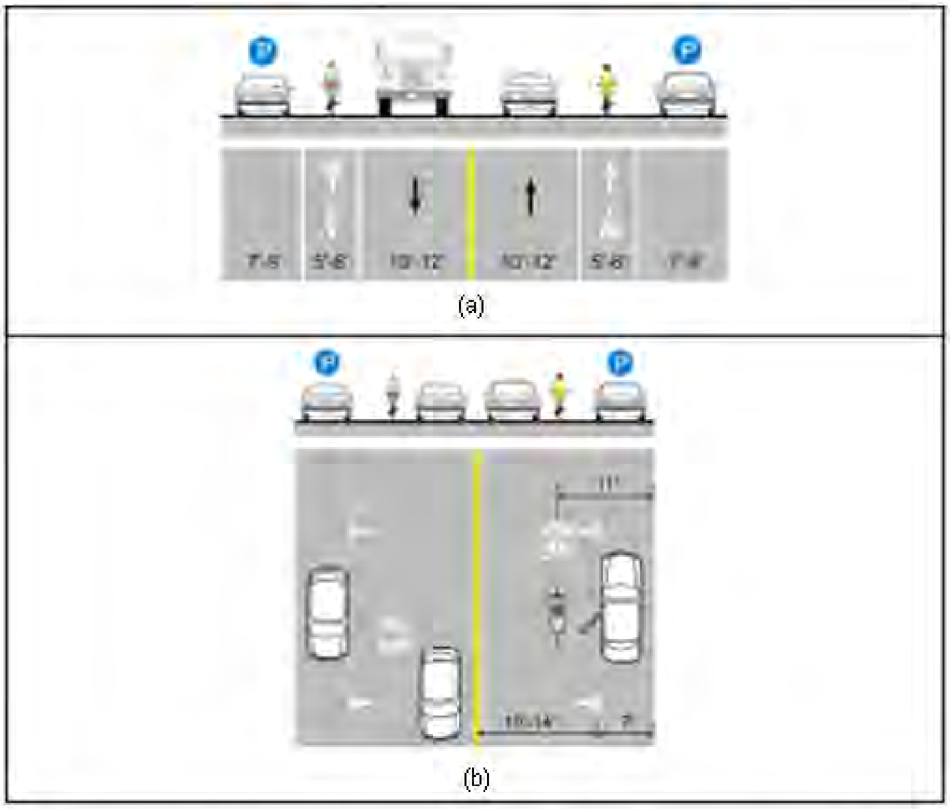
Some cities have provided bikeway guidelines that are either a supplement to or a replacement for AASHTO and FHWA guidelines. The most detailed design guide was written, in collaboration with the Pedestrian and Bicycle Information Center at the University of North Carolina-Chapel Hill, the Chicagoland Bicycle Federation, and the City of Chicago for use in the City of Chicago. Chicago's bikeway guide provides typical roadway sections of varying widths with standard road striping for mid-block crosswalks, parking, on-street bikeways, and traffic channelization techniques. An example of a 44-foot wide, 2-way street with parking on both sides and designated bike lanes can be seen in Figure 2.4.



Note: This example should not be construed as a TxDOT recommended or approved design for roadways with bicycle facilities and on-street parking.

Figure 2.4: City of Chicago Bicycle Design Guide's Standard Road Striping for a Bike Lane on 44' Wide Street

The City of San Francisco Bicycle Plan provides guidelines in less detail for both a designated bicycle lane and a designated shared use lane. As seen in Figure 2.5, the recommended minimum and maximum widths for motor vehicle lanes, designated bicycle lanes, and parking, are shown without sufficient information to determine the appropriate width for each.



Note: This example should not be construed as a TxDOT recommended or approved design for roadways with bicycle facilities and on-street parking.

Figure 2.5: San Francisco Bicycle Plan Guidelines for (a) Bike Lane Adjacent to On-Street Parking and (b) Shared Motor Vehicle and Bicycle Lane Adjacent to On-Street Parking

Some cities provide recommendations for bicycle facilities without consideration of on-street parking. Other cities base their designs on specific roadway data. For example, the Minnesota Bicycle Plan recommends the type of bicycle facility depending on the traffic volume and speed limit. (See Figure 2.6.)

Motor Vehicle ADT (2 Lane)		<500	500-1,000	1,000-2,000	2,000-5,000	5,000-10,000	>10,000
Motor Vehicle ADT (4 Lane)		N/A	N/A	2,000-4,000	4,000-10,000	10,000-20,000	>20,000
Motor Vehicle Speed	25 mph	SL	WOL	WOL	WOL	BL = 5 ft	Not Applicable
	30 mph	SL with sign	WOL	BL = 5 ft	BL = 5 ft	BL = 6 ft	BL = 6 ft
	35 - 40 mph	WOL	BL = 5 ft	BL = 5 ft	BL = 6 ft	BL = 6 ft	BL = 6 ft or PS = 8 ft
	45 mph and greater	BL = 5 ft	BL = 5 ft	BL = 6 ft	BL = 6 ft	BL = 6 ft or PS = 8 ft	SUP or PS= 10 ft

BL = Bicycle Lane, SL = Shared Lane, WOL = Wide Outside Lane, SUP = Shared-Use Path, PS = Paved Shoulder

Figure 2.6: Minnesota Bicycle Plan Recommendations for Bike Facilities Based on Speed limit and Average Daily Traffic (ADT)

As evidenced by the number of studies and guidelines described, the federal, state, and local governments have varying opinions on providing adequate bicycle facilities. Although safety and traffic operations remain large concerns, there appears to be a lack of attention to the implications that on-street parking may have on motorists and bicyclists, which leaves many uncertainties for planners and engineers considering on-street bikeways. As a result, additional bicycle research may be warranted.

2.2 Operational Impact of Bicycle Facilities

To determine if bicycle facilities are effective at improving traffic operations, many studies have looked specifically at bicycle lanes and wide curb lanes separately to see how they impact bicyclists and motorists. Kroll and Ramey (1977) analyzed the effects of bicycle lanes on motorist's and bicyclist's behavior by comparing their lateral positions before and after the installation of bicycle lanes on three urban streets. Kroll/Ramey showed that bicycle lanes increased the predictability of motorist's behavior when passing a bicyclist (fewer wide swerves and close passes). To reduce lane encroachments, wide swerves, and close motor vehicle-bicycle passes, the Kroll/Ramey study recommends bike lanes on streets when the lane width is less than 15 feet. Loop and Layton (1977) also evaluated the effect that bicycle lanes have on vehicles in the adjacent lane. By observing speeds at different traffic volumes, Loop and Layton showed that when a bicyclist was present, the mean speed of the motorist decreased 3 mph when average hourly volume (AHV) was 340 vehicles and decreased 1.5 mph when AHV was 900 vehicles. Loop and Layton also stated that the motorists' reduction in speed was less on wider streets because vehicles have more room to maneuver.

McHenry and Wallace (1985) looked specifically at wide curb lanes to determine if different widths were adequate for shared use by motor vehicles and bicycles. By collecting and analyzing lateral positioning data for motorists and bicyclists, it was shown that a 13.8-ft outside lane was not wide enough for lane sharing; as a result the bicyclist became a lateral obstruction. Additionally, a wide curb lane of 17.5 ft was excessive. McHenry and Wallace concluded that a lane width of approximately 15 ft was optimal when shared lanes (bicyclist and motorist) are designated on collector or minor arterial roads with a posted speed limit of 40 mph or less.

2.3 Safety Impact of Bicycle Facilities

In addition to studies that were concerned with the positioning of motorists and bicyclists during passing movements, several studies have focused on bikeway safety. Each year, more than 500,000 people in the U.S. are treated in emergency departments, and more than 700 people die as a result of bicycle-related injuries (National Center for Injury Prevention and Control). Providing safer bicycling facilities is needed to reduce injuries. Some safety benefits attributed to having bicycle lanes include a more orderly flow of mixed traffic, bicyclists riding in the correct direction (i.e., with the flow of traffic), having a separation between vehicle and bicycle traffic on-street, and motorists becoming more aware of cyclists while driving or parking (see Landis, 1998 and Harkey and Stewart, 1996).

Several studies have analyzed factors that influence bicycle crash severity (see Allen-Munley et al., 2006; Klop and Khattak, 1999; Hunter et al., 1996) on roads that have no bicycle considerations. These studies looked at operational and physical variables from bicycle crash records to determine the type, location, and severity of crashes that are most prevalent. These studies have shown that the vertical and horizontal grade of the roadway, natural lighting/darkness, time of day (shadows, sunrise, sunset), vehicular speed, and traffic volume are among some of the factors that influence automobile-bicycle crashes.

Some of these studies evaluate all automobile-bicycle crashes. Lott and Lott (1976) separated the data to analyze the accident types to determine how bicycle lanes contribute to overall safety. Police reports from 145 accidents in Davis, California were analyzed, and the frequency of accident types was compared for streets with and without bicycle lanes. Lott and Lott found that the rate of automobile-bicycle crashes was higher on streets without bicycle lanes, showing that bike lanes reduced bicycle-automobile crashes. In fact, bicycle lanes have been recognized to improved safety, in terms of the number and severity of automobile-bicycle crashes, in cities throughout the United States. Additionally, having designated bicycle lanes has reduced crash rates for all users (bicyclists, pedestrians, and motorists). Research has also shown that bicycle lanes have been associated with safer bicyclist behavior, including less wrong-way and sidewalk riding and more obedience to traffic controls (see Hunter et al., 1999).

2.4 Comparison of Different Types of Bicycle Facilities

Additional studies comparing operational characteristics of various on-street bikeways need to be disclosed. Hunter et al. (1999) compared bicycle lanes (BL) versus wide curb lanes (WCL) by videotaping approximately 4,600 incidents involving a bicyclist and a motorist from 48 sites to evaluate operational characteristics and conflicts bicyclists had with motorists, other bicyclists, and pedestrians. The conclusion was that wrong-way riding and sidewalk riding were more prevalent when a WCL design was used. In addition, motorist encroachment into the adjacent motor lane occurred more often when a WCL design was used. Ultimately, the research proved that both BL and WCL facilities can and should be used to improve riding conditions for bicyclists.

Harkey and Stewart (1997) analyzed the interaction between bicyclist and motorist on wide curb lanes, bike lanes, and paved shoulders. The study revealed that the type of bikeway has a significant effect on the separation distance between bicyclists and motor vehicles. Paved shoulders and bicycle lanes generally resulted in similar interactions between motorists and bicyclists. Motorists were less likely to encroach into the adjacent motor lane or show significant movement within their lane when a shoulder or bike lane was available versus when passing a bicyclist on a wide curb lane. Harkey and Stewart concluded that bike lane widths of 4 feet or greater optimize operational conditions and provide improved safety conditions for motorists and bicyclists.

Several research projects have been done to evaluate the operational and safety impacts of converting a wide curb lane into separate motorist and bicycle lanes. Hunter et al. (2005) examined the effect of converting a 14 foot-wide curb lane to an 11 foot-wide travel lane with a 3-ft-wide undesignated lane. They collected lateral positions of bicyclist and motorist before and after the conversion. For three of the newly striped sites, cyclists increased their distance from the curb by 7 to 9 inches. In motorist-passing-cyclist scenarios, motorists moved closer to cyclists by approximately 3 to 5 inches, and motorist encroachments into the adjacent motor lane were reduced 15–40 percent. Hunter el al concluded that striping separate lanes for motorists and bicyclists has the potential to improve safety and comfort for both cyclists and motorists. However, providing a designated bike lane that is less than 5 feet wide does not meet AASHTO recommendations.

2.5 Operational and Safety Impact of Bicycling Alongside Parked Cars

As evidenced by the studies discussed, there have been few studies that considered how on-street parking impacts motorist’s and bicyclist’s behavior. Only four studies have evaluated the operational and safety impacts of bicyclists using roadways with on-street parking, and each study has limitations in making generalizations about bikeways adjacent to on-street parking.

2.5.1 Bicycle Lanes and On-Street Parking

The first in-depth study including a bikeway with on-street parking evaluation was conducted by Hunter and Stewart (1999). Data was collected on two Florida roadways: A1A in Fort Lauderdale and Hollywood Boulevard in Hollywood. Both four-lane roads were re-striped to include designated bike lanes, adjacent to on-street parking. A1A was re-striped to include a 10.5-foot motor lane, adjacent to a 4.5-foot bike lane and next to parallel parking. Hollywood Boulevard was re-striped to include a 12-foot motor lane adjacent to a 5-foot bike lane and next to parallel parking. The re-striping of Hollywood Boulevard was in conformity with AASHTO’s recommended 5-foot bike lane width and A1A’s 4.5-foot bike lane width was considered acceptable. Over 300 cyclists from each road were observed as they passed the parked motor vehicle and the distance from the parked vehicle’s front driver side tire to the center of the bicycle tire to the outside tire of the moving motorist was measured. When a motorist passed the bicyclist and parked vehicle at the same time, the distance from the center of the bicycle tire to the outside tire of the moving motorist was also measured. From the observations, it was noted that the designated bike lanes generated fewer conflicts and no collisions with motorists. Comparing the lateral distances obtained by Hunter and Stewart to the results of Harkey and Stewart (1997), on-street parking did not appear to diminish the lateral clearance between motorists and cyclists. Hunter and Stewart concluded that despite the presence of on-street parking, both roadways were suitable for cycling. The limitation of this study is that the results are based on only two sites, which may not be generally applicable as both sites had similar characteristics. Additionally, in making conclusions, the researchers did not address how much lateral clearance between cyclists and parked vehicles is needed for safety.

In 2003, Houton and Seiderman considered the impact of on-street parking when they performed a study for the City of Cambridge, Massachusetts to evaluate how bike lanes and other bikeway pavement markings affect motorist's and bicyclist's positioning on the roadway when on-street parking is present. It focused particularly on how far away bicyclists travel from parked cars. This was completed by sequentially adding pavement markings to designate a bicycle lane from no pavement markings, to adding a lane line between the motoring traffic and bicyclist, then on-street bicycle symbols and directional arrows and lastly the lane line next to the parked motor vehicle to fully designate a bike lane on Hampshire Street, a two-lane road with parallel parking on-street (see Figure 2.7). The study collected approximately 4,500 observations of cyclists and found that when bicycle lanes or other pavement markings were added, bicyclists traveled farther away from parked cars.

Figure 2.7: Added Components of Bicycle Lane

Houton and Seiderman also conducted on-street surveys of bicyclists and motorists. Bicyclists overwhelmingly favored bike lanes, with 82 percent of them preferring designated bicycle lanes and another 5 percent preferring at minimum a line marking the separation between the motor vehicle lane and the parking/bicycle area. Cyclists stated that they recognized the change in pavement markings and felt that more motorists recognize the street as a bikeway when a designated bicycle lane is visible. Motorists were more likely to identify bike lanes as a reason why they noticed bicyclists. One constraint of this study was the limited width of the roadway; for cyclists to travel completely outside the dooring zone, the bicycle's left handle bar would encroach into the through motor lane. Although the study allowed researchers to conclude that the designated bike lane improved traffic operations and safety, additional test sites would have strengthened the validity of the results and allowed for generalizations to be made. In conclusion, additional studies using similar characteristics should be conducted to validate the initial findings and determine safer widths to reduce encroachments by both motorists and bicyclists.

2.5.2 Shared-Use Markings and On-Street Parking

In addition to evaluating designated bicycle lanes, Alta Planning & Design evaluated San Francisco's shared lane pavement markings in an effort to improve bicycle safety. They studied the effects that shared-lane pavement markings had on cyclists' and motorists' road position, cyclists' riding behavior, and bicycle-motorist conflicts on roadways with on-street parking. The first step was a stated-preference survey completed by 120 bicycling commuters and 120 motorist commuters, in which respondents were shown photographs of the three most common shared-lane pavement markings in the U.S (see Figure 2.8). Respondents were asked what they felt they should do in each scenario, why they would react that way, and what they thought the pavement marking indicated that they should do. Although the markings encouraged motorists to be aware of bicyclists, there was some confusion, with respondents understanding the bike-and-directional-arrow (center picture in Figure 2.8) to mean “bikes straight only at the intersection ahead.” Alta concluded that on-street pavement markings currently used to designate shared lanes (where bicyclists and motor vehicles are expected to share the same lane) need to be improved.

Bike-and-chevron marking | Bike-and-separate-arrow marking | Bike-in-house marking

Figure 2.8: Photographs of Pavement Markings Used in Stated Preference Survey

As a result of Alta’s stated-preference survey, and based on the opinions of the Technical Committee, the researchers chose two designs for a before and after field study; the modified “bike-in-house” marking and the “bike-and-chevron” marking as seen in Figure 2.9. The consultant team collected more than 140 hours of video at six locations. The pavement markings were placed 11 feet from the face of curb for the study. This was based on (1) the 85th percentile of cars with open doors extending to 9.5 feet from the curb, (2) an average bicycle width of 2 feet, and (3) 0.5 feet clearance from the opened car door to the bicycle handlebar. The *before* study included 1,100 cyclists and 1,000 motor vehicles, and the *after* study included 1,300 cyclists and 1,400 motor vehicles, noting lateral positions of each.

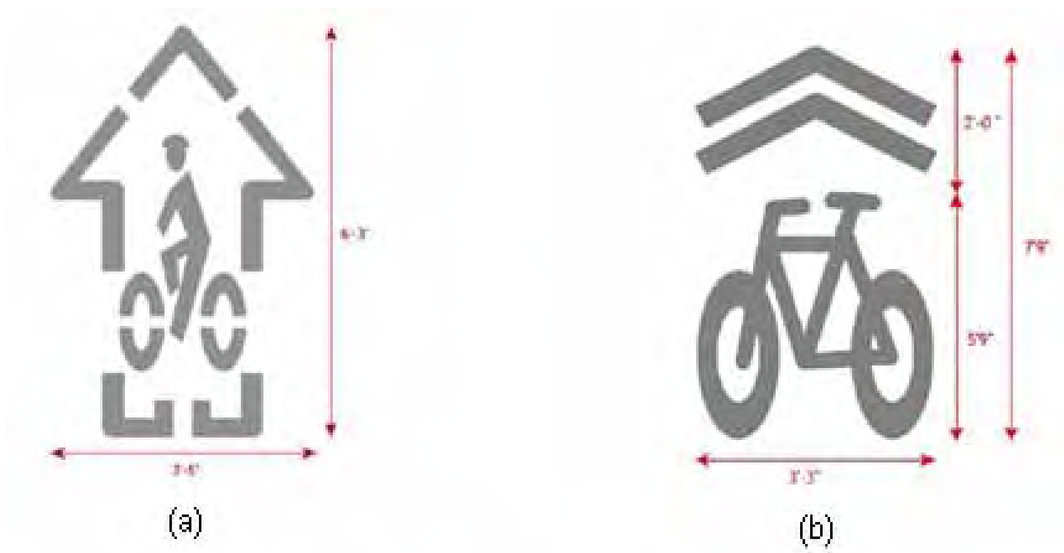


Figure 2.9: Examples of (a) bike-in-house marking and (b) bike-and-chevron marking

In conclusion, the placement of either pavement marking increased the distance between cyclists and parked cars by 8 inches. When motor vehicles and bicyclists passed the pavement markings together in the "after" test, the increased distance was 3 to 4 inches between cyclists and parked cars. The pavement markings produced a considerable increase in the distance between the bicyclists and passing motor vehicles by over 2 feet. In terms of reducing improper bicyclist behavior, the markings significantly reduced the number of sidewalk riders (bike-in-house by 25 percent and bike-and-chevron by 35 percent). The bike-and-chevron marking significantly reduced the number of wrong-way riders by 80 percent. As a result of this study, the researchers concluded that shared-lane pavement markings in San Francisco did have a positive impact on motorist and cyclist behavior, positions, and safety. The research team recommended the bike-and-chevron marking for the City of San Francisco. The limitations of this study are that only shared-lane options were considered.

2.5.3 Wider Parking and Parking "T's" Influence on Bicycle Operations

Lastly, at the 14th International Conference on Walking and Bicycling, Dustin White and the San Francisco Transportation Agency presented the topic *Bike Lanes and Car Doors: Details for Designers.* This presentation discussed the results of two different studies. The first study examined how the width of the parking lane impacts the distance the vehicle parks from the curb. With the door zone assumed to be 9.5 feet from the curb, Figure 2.10 shows three different parking configurations and the percentage of the bicycle lane that is in the door zone. At 11 different locations, 600 measurements were collected to quantify how far cars park from the face of curb (measured from the center of the hub cap to the face of the curb). Analysis of the data collected demonstrated that a wider parking lane may allow motorists to park slightly farther away from the curb. However, the mean distance from the curb increased only 2.5 inches when changing from a 7- to 9-foot parking lane.

Researchers concluded that the slight increase in parking distance from the curb is outweighed by the benefits of having more distance between the bike lane and opening car door. The limitation of this study is the assumption that if the bicycle lane is farther from the parked vehicle, the cyclist's lateral position will be farther from the parked vehicle. Unfortunately, there was no operational data collected to confirm how the width of the parking lane influenced the cyclist's position within the designated bike lane.

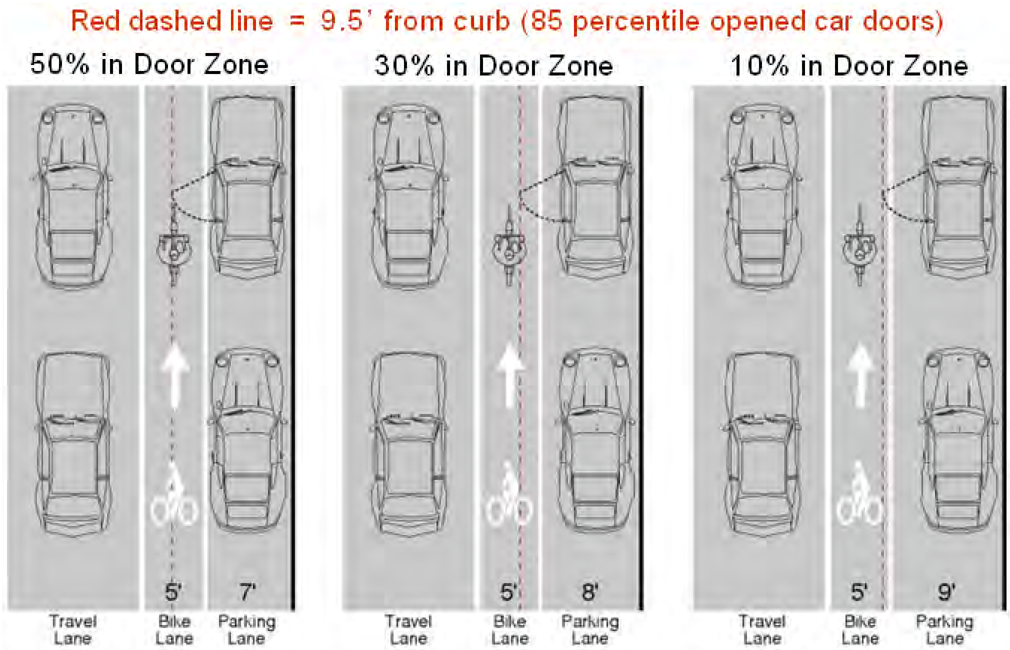


Figure 2.10: Changes in Parking Lane Width

Source: *Bike Lanes and Car Doors: Details for Designers* (White, 2006)

The second study evaluated the use of parking "Ts" as a pavement marking to delineate parking spaces on Howard Street, a key bicycle route in downtown San Francisco, with 150 cyclists per hour during peak periods (see Figure 2.6). Initially, the top of the "T" was placed 7 feet from the face of curb and the perpendicular leg extended to 9 feet from the face of curb. The perpendicular leg of the "T" was then extended an additional 2 feet (11 feet from the face of curb) to evaluate the effects this would have on a bicyclists' lateral position. These configurations are shown in Figure 2.11. Still photographs were taken of 178 cyclists passing parked vehicles with the "T" pavement markings having a 2-foot leg and 147 photographs were taken of cyclists after the perpendicular leg of the "T" was extended 2 feet. Tape was placed on the roadway at 6-inch intervals from the face of curb as reference points. Data collection was rounded to the nearest 3 inches. The researchers found that during the initial "T" placement, the average position of the cyclist's tire was 10 feet, 4 inches from the face of curb and that 24 percent of cyclists were in the door zone. After the "T" was extended 2 feet, the average position of the bicyclist increased from 10 feet, 4 inches to 10 feet, 11 inches from the face of curb, and the percent of cyclists in the door zone decreased from 24 percent to 10 percent.

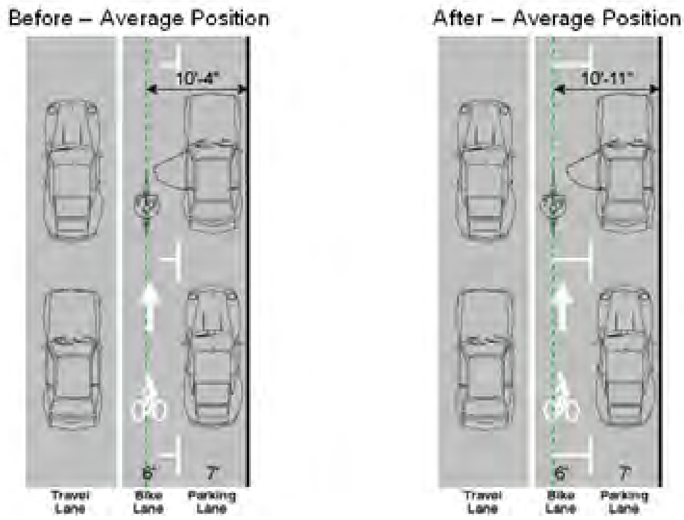


Figure 2.11: Analysis of Parking "T" Before and After Extension

Source: *Bike Lanes and Car Doors: Details for Designers* (White, 2006)

As a result of the parking "T" and Parking Lane Width Studies, researchers concluded that, wider parking lanes should be provided when placed adjacent to designated bike lanes or shared use lanes in order to give cyclists a buffer from opening car doors. Extending the parking "T" shows potential for encouraging cyclists to ride outside the door zone. Based on this analysis, the researchers believe that design standards should be revisited for bikeways with on-street parking.

2.6 Motivation for Current Field Research

Based on the research that has been completed, it is evident that many questions remain unanswered regarding both operational and safety impacts for bicyclists using roadways with on-street parking. The current study addresses the following issues:

1) Evaluation of intermittent residential parking: Study designated bike routes on residential streets with low traffic volumes and large gaps between parallel-parked vehicles where cyclists can use the space between parked vehicles to allow motoring traffic to pass. This study evaluated the lateral position of the bicyclist on residential streets, where the bicyclist is generally positioned, where the bicyclists is when passing parked vehicles and how moving motor traffic could impact a bicyclist's position when large gaps between parked cars exist.

2) Evaluation of angled parking: Observed bicyclists' lateral position and behavior on roadways with angled parking.

3) Large sample size: Previous studies have been based on a small number of sites (one to three sites per study) with similar characteristics, which has made it difficult to develop generalizations. In this study, eight sites were chosen from each of three cities including Austin, San Antonio, and Houston, Texas. Having 24 test sites that were identified as bike routes with varying roadway characteristics, traffic conditions, and parking configurations, provided the research team an opportunity to collect a significant amount of data and make logical scientific calculations and generalizations.

Chapter 3. Field Study of Motorist and Cyclist Behavior on Roadways with On-Street Parking and Bicycle Facilities

3.1 Project 0-5157

In January 2006, CTR's Hallett, Luskin, and Machemehl completed a research project (Project 0-5157) for TxDOT, in which they evaluated the operational and safety impacts of retrofitting designated bikeways onto existing roadways. The purpose of the study was to evaluate the design and operational characteristics of existing retrofit on-street bikeways (including designated bicycle lanes and wide outside lanes). The cities of Austin, Houston, and San Antonio were chosen to collect field data because each city has a large metropolitan area, with existing retrofit bikeways. These cities were assumed to be representative of other urban areas in Texas.

To collect data, the researchers hired thirty paid cyclists, with varying levels of cycling experience, who were videotaped riding laps consistently for a half-hour at six to nine different sites per city. The paid cyclists used their own bicycles and wore appropriate bicycling attire; however, they were not given any details about the research being conducted. Because retrofit bikeways generally result from *squeezing* a bicycle facility into an existing roadway right-of-way, the study focused on learning where bicyclists and motorists positioned themselves on a roadway with a retrofit bikeway. Therefore, the lateral position of the bicyclist and motorist were measured from the face of the curb along the pavement at two instances: 1) when a motorist was passing immediately adjacent to a cyclist, referred to as a "passing event" and 2) when a motorist passed the test section without the presence of a cyclist, referred to as a "non-passing event." During a passing event, it was also noted whether the motorist's driver-side wheels crossed onto or over the inside motor lane line or centerline stripe during the passing event (identified as an encroachment).

Using the data collected, regression models were developed to evaluate the lateral position of the bicyclist (LPB), the change in lateral position of the motorist (CLP), and the probability of encroachment occurring (ENC). As a result of the regressions, three important conclusions were formed. First, designated bicycle lanes of 4 feet or more are operationally superior to wide outside lanes for both cyclists and motorists. Second, the use of space adjacent to the wide outside lane (additional lanes in the same-direction, adjacent lane traveling in the opposite-direction or two-way-left-turn-lane adjacent) significantly impacts the behavior of a motorist during a passing event. Third, in residential areas, bicyclists' and motorists' behaviors were unpredictable when compared to all other areas.

As a result of Research Project 0-5157, and using other published research, *The Texas Guide for Retrofit and Planned Bicycle Facilities* was developed. Although this guide provides useful information for designing bicycle facilities for the State of Texas, it does not assess bicycle facilities on roadways with on-street parking. This limitation is the foundation for the current study, 0-5755, The Effects of On-Street Parking on Cyclist's Route Choice and the Operational Behavior of Cyclists and Motorists.

3.2 Current Project Study Sites

3.2.1 Determining Potential Field Sites

Three cities—Austin, Houston, and San Antonio—were selected to conduct field tests of bikeways with on-street motor vehicle parking. These cities were chosen due to local expertise of TxDOT representatives, concerns for efficient use of project time and travel resources for field data collection, and a belief that these three cities were diverse enough for test results to be applicable across all metropolitan areas within the state.

Because paid cyclists were used to conduct the field research, the potential sites had to be suitable for riding by an average adult cyclist. Unfortunately, there is an inconsistency in the way cities evaluate and describe bikeways; therefore, the potential study sites were chosen based on information provided in city bikeway maps with assistance from city employees and from TxDOT bicycle coordinators for that district. The cities' written guidelines are as follows:

Austin: Austin Bicycle Map (4^{th} edition, September 2003)

- Green Routes—described as "high ease of use; bike lanes or wide curb lanes on higher volume streets. Some low volume residential streets."
- Purple Routes—described as "moderate ease of use; generally low to moderate traffic volume; may have wide outer lane or shoulder."
- Any other street with a designated bicycle lane. (These streets are expected to be added to new editions of the Austin Bicycle Map.)

Houston: City of Houston Bikeway Program Map (October 2004)

- Blue Routes—described as "Bike lane; a designated, striped bicycle lane with special pavement markings and signs along the road. They are generally found to the right of a traffic lane and can be used only by bicyclists. There is no parking allowed on this lane unless otherwise indicated."
- Red Routes—described as a "Bike Route; a designated wide bike and motor vehicle shared roadway. Cars and bicycles ride side-by-side using this lane. Bike routes are generally found to the right of the traffic lane. There are special pavement markings and signs along this lane to remind both cyclists and motorists they are traveling on shared lanes." This category also includes a "Shared Lane; a shared lane is designated for bicycles OR motor vehicle use. The shared lane is not for simultaneous use of both vehicles. Motor vehicles traveling at a greater speed than cyclists can pass bikes as any other slow moving vehicle, using the left lane. There are special pavement markings and signs along this lane to remind both cyclists and motorists they are traveling on a shared lane."

San Antonio: San Antonio–Bexar County Bicycle Map (2nd edition, 2006)

- Green Routes—described as a high level of suitability; "street reasonably easy for all types of bicyclists (except children under 10)."
- Yellow Routes—described as a moderate level of suitability. "Street can accommodate experienced and casual bicyclists and/or may need altering to accommodate youth bicyclists."
- Any other street with signs and/or pavement markings designating it for use by cyclists. (These streets are expected to be added to new editions of the San Antonio–Bexar County Bicycle Map.)

The research team was charged with identifying potential test sites and choosing bikeways on sections of roadway with relatively uniform roadway design, parking, and traffic characteristics for comparability. Uniformity is critical in developing correct field data conclusions. Potential sites could be as short as 100 feet or over 1 mile in length. As such, multiple test sites could exist along the same roadway. This is often the case on arterials that traverse an entire city or on streets in the central business district that change purpose frequently (e.g., hotel reception, parking garage, bus lanes, etc.). The parking type, density, and turnover can vary along any given roadway, creating different riding environments for the cyclists. Selecting sites with limited horizontal curves and minor variations in vertical grades was also important, to reduce factors other than on-street parking that might impact the cyclist's or motorist's position on the roadway and to reduce the chance for error when extracting data from the videos.

Test site recommendations were taken from city bicycle coordinators, members of bicycle advocacy group and TxDOT Bicycle Coordinators. All bike routes with on-street parking were traveled by motor vehicle and considered for selection. The research team was able to identify approximately 128 sites in Austin, 72 in Houston, and 56 in San Antonio.

3.2.2 Categories of Sites

After identifying potential sites, it was evident that a variety of parking configurations existed along the various bike routes chosen; therefore, categories were derived for compiling data. They are described as follows:

Bicycle Lane (BL) Sites

Bicycle lane sites were selected based on AASHTO's definition: *a portion of the roadway that is designated by striping, signing, and/or pavement markings for preferential or exclusive use by bicycles*. For this study, the bicycle lane must be located adjacent to on-street motor vehicle parking with signage, striping, and pavement markings that clearly define the bike lane as separate from the motor lane (see Figure 3.1).

Figure 3.1: Example of a bicycle lane with adjacent on-street motor vehicle parking

Wide Outside Lane (WOL) Sites

A wide outside lane (recommended to be 14 feet wide or wider) may be signed for shared use by motor vehicles and bicyclists. Research supports having WOL widths 14 to 17 feet wide for ideal operational conditions (see McHenry and Wallace, 1985). As described in Section 2.1, AASHTO recommends a 15-ft minimum outside lane width on shared use roadways adjacent to on-street parking (see Figures 2.1 and Figure 3.2).

Figure 3.2: Example of a wide outside lane with adjacent motor vehicle parking

Angled Parking Sites

Angled parking sites shall be defined as any bikeway adjacent to angled motor vehicle parking. Although these sites overlap with other categories, angled parking is relatively rare and worthy of being evaluated separately because the actions associated with angled parking are different. It is possible that a motorist could back up into a bicycle lane without checking for cyclists. Angled parking next to a bike lane (BL) and wide outside lane (WOL) can be seen in Figure 3.3.

Figure 3.3: Examples of angled motor vehicle parking adjacent to a BL (right) and WOL (left)

One-Way Street Sites

A one-way street site shall be defined as any one-way street designated as a bikeway (BL or WOL) with motor vehicle parking on-street adjacent to the bikeway. In Texas, a bicyclist can ride on either side of the street on a one-way roadway. One-way sites are common in central business districts. Because these streets have different operational conditions and little research exists, it is important to include them in a separate category (see Figure 3.4).

Figure 3.4: Examples of one-way streets with BL (left) and WOL (right) and motor vehicle parking on-street

University Campus Sites

University campus sites include any street within the confines of a college or university campus available to bicyclists with angled or parallel motor parking (BL or WOL). These sites differ from other sites with similar roadway characteristics because they have extremely low motor vehicle speeds, more traffic violations, and high volumes of bicyclists and pedestrians. The posted speeds are usually 15 mph or less, which allows most cyclists to operate as a motor vehicle often utilizing the entire travel lanes. Heavy pedestrian traffic frequently restricts the movement of motorists and cyclists. Because cyclists act differently in this situation, these sites were not included in this study assuming that the results would not be applicable to non-university streets. An example of a university campus street with on-street motor parking can be seen in Figure 3.5.

Figure 3.5: Example of a university street with motor vehicle parking

Parking in the Outside Lane (POL) Sites

Parking in the outside lane (POL) sites have at least two motor vehicle lanes in the same direction and the outermost lane is available for motor vehicle parking. When there are no parked vehicles along a given segment, the outside lane functions as a normal motor vehicle lane. When there are parked motor vehicles in the outside lane, bicyclists tend to travel between the parked vehicles and the through motor lane. An example of a POL site can be seen in Figure 3.6.

Figure 3.6: Example of bicycle route with parking in the outside lane

Sub-21-Foot Sites

A sub-21-foot site is a roadway with 21 feet or less of pavement in each direction where a moving motor vehicle, a bicycle, and a parked motor vehicle share the pavement. Twenty-one feet represents an approximation of the minimum amount of space that these three vehicles can share: 10 feet for a moving motor vehicle, 4 feet for a bicycle, and 7 feet for a parallel-parked motor vehicle. The majority of these sites are residential streets where the parking density, motor vehicle speed, and/or traffic volume are low enough to avoid conflicts between cyclists and motorists. The position of the cyclist can vary dramatically depending on the traffic volume roadway classification, and adjacent land use (see Figure 3.7).

Figure 3.7: Examples of "sub-21-feet" streets identified as a bikeway with on-street parking, and low traffic volume (left) or high traffic volume (right)

Parking in the Bicycle Lane (PBL) Sites

Parking in the bicycle lane sites are roadways where motor vehicles park in the bicycle lane. These streets include a motor vehicle through lane(s) and a bicycle lane in each direction of travel. Although there is no marked on-street parking area, it is generally not illegal to park a motor vehicle in a bicycle lane. A no-parking zone is achieved when the local jurisdiction passes an ordinance and posts signs ("No Parking") to notify motorists. On-street parking can create dangerous conflicts for cyclists and motor vehicles when the cyclist can no longer travel in the designated bicycle lane. An example of motor vehicles parking in a bicycle lane can be seen in Figure 3.8.

Figure 3.8: Example of motor vehicles parking in the bicycle lane

Combination Parking and Bicycle Lane Sites

In this study, combination parking and bike lane sites have parking lanes that are 10-feet or wider where bicyclists often ride adjacent to the parked vehicle. Two sites in Austin were evaluated; neither site has bicycle lane pavement markings. In one case, warning signs were posted to notify motorists that bicycles use this roadway. The second site includes a bicycle route sign and parking markers segregating the space. These two sites are shown in Figure 3.9.

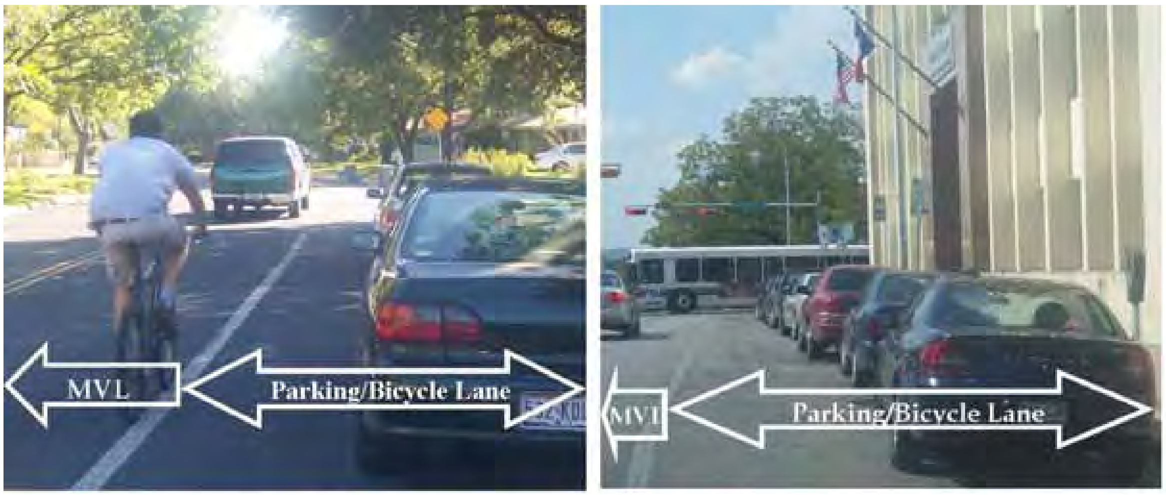


Figure 3.9: Examples of combined parking and bicycle lane

3.2.3 Final Site Choices

Based on the initial list of potential sites, each of the chosen sites was characterized according to width of motor vehicle lane, bicycle lane, and parking lane; lane configuration; type of parking (angled or parallel); parking density; parking turnover; and traffic volume. This was to ensure that sufficient variation exists in the final sites selected.

Based on preliminary tests and a sufficient variation in characteristics, twenty-five sites were selected for final analysis: nine from Austin, eight from Houston, and eight from San Antonio. Appendix A provides a complete description, including location, configuration, traffic volume, and characteristics of motor vehicle lanes, bicycle facilities, and parking for each of the sites. Additionally, Table 3.1 provides a summary of the sites analyzed.

Table 3.1: Characteristics of Bicycle Facilities at Final Sites

City	Total No. of Sites	No. of BL Sites	Range of BL Width (ft)	No. of WOL Sites	Range of WOL Width (ft)	No. of POL Sites	OL Width (ft)	No. of PBL Sites	Range of Motor Vehicle Lane Width (ft)[a]
Austin	9	8	3.79-6.08	0	N/A	0	N/A	1	13.38
Houston	8	1	5.52	6	11.93-16.9	1	14.22	0	N/A
San Antonio	8	0	N/A	3	14.15-20.2	1	15.93	4	13.18-15.59
Range/Total	25	9	3.79-6.08	9	11.93-20.2	2	14.22-15.93	5	13.18-15.59

[a] The motor vehicle lane width is the average distance from the edge of the car to the inside motor vehicle lane line (i.e., total width shared by cyclist and motorist).

3.3 Field Observation Methodology

3.3.1 Preliminary Tests

In order to determine the best method for collecting data, preliminary field testing was done at three separate locations. It was necessary for the research team to determine the best technique(s) to capture the lateral positions of both the motorist and cyclist passing a parked motor vehicle (PMV). Typically, the video camera and tripod were placed directly in front of the targeted PMV downstream. The camera was positioned to be out of the motorist's view until well after the passing event so that the camera did not influence the motorist's behavior.

In the second preliminary test researchers used a vehicle-mounted camera to capture passing events by following a motorist passing a cyclist and PMV. This method required close coordination between the cyclist and research vehicle. Although two-way radios were used, it was necessary for the driver to observe traffic control devices and avoid conflicts with motorists entering and exiting the roadway which made it too difficult to capture the passing events.

The third preliminary test involved two cyclists riding in a loop pattern past a parked motor vehicle with a fixed-location camera mounted on a tripod out of the motorist's view. At some sites an additional camera could be mounted on top of the parked research vehicle, to capture a better view of both the cyclist's and motorist's lateral positions. Based on travel time between sites, loading and unloading of bicycles, and the setup of cameras, it was determined that approximately six to eight sites, with half-hour laps at each, could be completed in 8 to 10 hours.

Lessons Learned

As a result of the preliminary tests, several important observations and decisions were made. First, a camera mounted on a tripod in a fixed location was the best method for collecting video data. By using two stationary cameras at a test site, one positioned on each side of the road, data could be collected in both directions at the same time. More observations of both passing events and non-passing events were gathered using the fixed-camera setup. In terms of safety, the vehicle-mounted cameras moving with the bicyclist increased hazards for both the cyclists and the research.

The second determining factor was that the quality of video images was dependent on the camera angle, zoom, and placement. To see more than one PMV, the camera had to be placed in line with the side of a PMV. Also, mounting a camera on top of the parked research vehicle could be used to improve the quality and quantity of the data collected. Unfortunately, this was not always a feasible option in cases where all on-street parking was occupied.

The third observation was that high occupancy and low occupancy parking could be found in both residential and commercial/retail parking environments. As a result, the research team chose to distinguish parking according to density type rather than purpose. The first type, *continuous* parking, is described as a location with nearly 100 percent parking occupancy. The second type, *discrete* parking, corresponds to sites with 80 feet or more between the targeted PMV and the next parked car along the test site. The research team hypothesized that cyclists might ride in the gaps between parked cars if there was enough space between them. The difference between *continuous* and *discrete* parking can be seen in Figure 3.10.

Figure 3.10: Examples of continuous (left) and discrete (right) parking

The fourth observation was that depth perception in the field videos was extremely poor: therefore, reference markers would be necessary to determine the location of a cyclist in relationship to a PMV. During preliminary tests, researchers determined that if cyclists adjust their lateral position, they tend to do so approximately 40 feet after passing a PMV in discrete situations. As a result, a reference marker 40 feet beyond a PMV should be made during field observations to determine the cyclists' lateral positions.

The last observation was that the rate of passing events was much lower than anticipated. In research project 0-5157, the researchers analyzed the operational and safety impacts when retrofitting bikeways; however, for the roadways selected, on-street parking was not permitted. In 0-5157, there were 30 to 50 passing events per hour. The preliminary tests revealed that only 10-25 percent as many passing events were observed at sites with on-street parking. Based on the results of the preliminary tests, the final methodology for data collection and analysis was developed.

3.3.2 Final Methodology

Cyclists

Although natural observations of cyclists would provide the most ideal and unbiased results, the volume of natural cyclists could not be guaranteed during the time frame allotted for data collection. As a result, cyclists of the different ages, fitness levels, and capabilities were hired to ensure that passing events occurred.

Paid cyclists were chosen to participate based on an effort to match the natural cycling population as closely as possible. The paid cyclists were expected to ride on-street and be in compliance with all traffic laws; therefore, cyclists were provided with the State of Texas bicycle statutes before the field work began. Although many cyclists formed assumptions about the purpose of the study, they were not given any information about the data collection or final objectives. The researchers believed that, by not informing the cyclists of the study's goals, the paid cyclists would react to both passing vehicles and parked vehicles in the same manner as an average cyclist would.

Data Collection

Data was collected in each city—Austin, Houston, and San Antonio—for five days, and on each day, two new paid cyclists rode at six to eight different sites. At each site, the cyclists were told where to ride, and where to cross the street in a safe and legal manner. On one-way streets, cyclists rode the length of the test site and then walked their bikes along the sidewalk back to the start of the test segment. Cyclists were instructed to ride as they normally would, and to ride approximately 75 feet apart to provide a gap between passing events. Cyclists rode for 30 minutes at each site. Based on Research Project 0-5157, 30 minutes was determined to be sufficient time to produce statistically significant results. After 30 minutes, cyclists tend to get bored and become less attentive.

Before the cyclists began riding, two video cameras on tripods were set up to capture passing events. Both cameras were placed so that they would be outside the view of the motorist until the motorist passed through the test site.

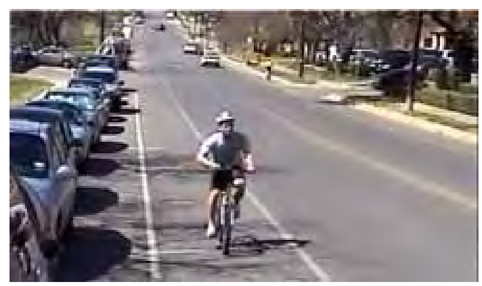
At each of the sites, field notes were taken to describe the width of the motor vehicle lane, the bikeway, the parking lane, and the distance between the parked vehicle and the bicyclist. Additional roadway information was needed to identify the parking type (discrete or continuous, parallel or angled), adjacent motor traffic lane width, median width, lack of median, continuous left turn lane, traffic control measures, and the separation from opposing traffic. If distinct striping was not present, reference markers were placed on the pavement for the purpose of extracting data.

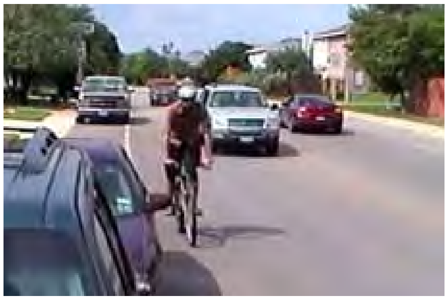
Data Reduction

Having 5 days of data collection, with eight sites each day, two cameras per site, and 30 minutes of tape per camera, there would be approximately 40 hours of data per city. However, the amount of actual data collected varied due to unforeseen conditions including insufficient PMVs, cyclist fatigue, available daylight, and inclement weather.

The videotapes were copied to DVDs and viewed on a flat-paneled television. Seven different aspects were considered and recorded from each passing event, as researchers stopped the video to measure the lateral position of the motorist and/or cyclist (see Table 3.2). The lateral position of the bicyclist (LPB) is measured from the face of curb or from the outside edge of drivers side front tire to the cyclist's front wheel, while the lateral position of the motorist (LPM) is measured from the face of curb or from the outside edge of drivers side front tire to the outermost edge of the moving motorist's passenger-side front wheel. Lines were drawn on the flat-paneled television using a dry-erase marker to establish measurements that could be converted from actual field measurements into lateral position values. For non-passing events, observations were gathered until 95 percent of motorists and cyclists were within three standard deviations of the iterative mean for the tape segment.

Table 3.2: Description of Each Event Recorded

Event Number	Description	Photographic Example
1	A passing event with a motorist, bicyclist, and parked motor vehicle (passing event)	
2	Only a bicyclist passing a parked motor vehicle (non-passing event)	
3	Only a motorist passing a parked motor vehicle (non-passing event)	

Event Number	Description	Photographic Example
4	Only the bicyclist 40 ft in front of the parked motor vehicle (non-passing event)	
5	A passing event with a motorist and bicyclist 40 ft. in front of the parked motor vehicle (passing event)	
6	Passing motor vehicle avoids confrontation with bicyclist (“yes” or “no” recorded)	
7	Bicyclist avoids confrontation with motorist (“yes” or “no” recorded)	

It was necessary to understanding the lateral position of the motorist and cyclist during passing events under different circumstances (see Table 3.2) to determine if and how the bicyclist’s and motorist’s position changed. The lateral position of the cyclist during non-passing events (Event 2) was recorded to measure the cyclist's change in position when passing only a parked vehicle. A bicyclist may feel constrained between a passing motor vehicle and a parked motor vehicle and move closer to the parked car, often placing the bicyclists in danger of dooring incidents. The lateral position of the motorist during non-passing events (Event 3) was compared with that of passing events (Event 5) to measure the change in the lateral position of the motorist who swerved or moved farther away from the parked vehicle when a cyclist was present.

The researchers hypothesized that during discrete parking scenarios, the bicyclist would tend to ride in the gap between parked vehicles. Event 4 established data to analyze the researcher's hypothesis about gaps between the parked vehicles, while Event 5 analyzed a motor vehicle passing a cyclist 40 feet in front of the targeted parked vehicle. These measurements, compared to their position when cycling next to the targeted PMV, would show if the cyclists and motorists changed position in the gaps between parked vehicles.

Event 6 recorded a motor vehicle avoiding a confrontation with a bicyclist. Event 7 recorded a cyclist avoiding a confrontation with a motorist. Events 6 and 7 are examples of the "wide outside Lane" where bicyclist and/or motorist were uncomfortable and/or the pavement width was insufficient for sharing. The analysis of these seven events did provide information to begin evaluating the operational and safety impacts of bicycling on roadways with on-street parking.

In addition to measuring the lateral position of motorist and/or cyclist, other important characteristics were recorded including the number of through motor vehicle lanes adjacent to the on-street parking, how motorists position themselves, the percentage of truck traffic (semi-trailers, delivery vehicles, buses, and pickups with utility beds), and whether the motor vehicle passing the bicyclist encroached into the adjacent motor vehicle lane.

Chapter 4. Results of Field Study

4.1 Final Results of Field Study

Data was collected from twenty-four sites in Austin, Houston, and San Antonio. Overall, thirty-nine cyclists were hired to generate passing events at the test sites. There were twenty-nine males and ten females between the ages of 19 and 64.

Individual cycling capabilities were categorized as “experienced commuter,” “experienced recreationalist,” and “casual recreationalist” using the Bicycle Compatibility Index terminology established in research completed by Harkey et al. in 1998. Experienced commuter bicyclists generally make the largest percentage of their bike trips for the purpose of commuting to/from school or work (approximately 60 percent). This group also rides more days per week, over longer distances, and makes more trips per week when compared to the other user groups. The experienced commuter bicyclists also tend to ride on major streets more often than the other two groups. By definition, experienced recreational bicyclists make approximately 80 percent of their bicycle trips for the purpose of recreation or exercise. They tend to ride fewer days and shorter distances per week than experienced commuter bicyclists but more days per week than casual recreational bicyclists. Experienced recreational riders are also less likely than experienced commuter bicyclists to ride on major streets, and more likely to ride off-road on shared use paths. By definition, casual recreational cyclists are similar to experienced recreational bicyclists in that they make the largest percentage of their trips (approximately 70 percent) for recreational/exercise purposes, but they ride the fewest days per week, make the fewest number of trips per week, and ride the least number of miles per week. Casual recreational cyclists seldom ride on major streets; they generally prefer off-road shared use paths.

Of the hired cyclists in the study, 53 percent were experienced commuters, 29 percent were experienced recreational cyclists, and 18 percent were casual recreational cyclists. A total of 6,414 passing were recorded during passing events 1-5. The numerical breakdown of these events is shown in Table 4.1.

Table 4.1: Number of Each Type of Observation

Observation	Number
Event 1- Motorist passing cyclist next to parked car	960
Event 2- Cyclist passing parked car (no motorist)	2238
Event 3- Motorist passing parked car (no cyclists)	2473
Event 4- Cyclist 40 feet in front of last parked car (no motorist)	579
Event 5- Cyclist 40 feet in front of last parked car with motorist passing	164
Total	**6414**

4.2 Site-to-Site Comparisons

Several site-to-site comparisons were completed on roadways with a shared outside lane or a designated bike lane adjacent to on-street parking in order to measure the lateral position of both the bicyclist(s) and motorist(s) and evaluate the differences during passing events. The lateral position of the bicyclist (LPB) is measured by the distance from the parked motor vehicle (PMV) driver's side tire to the cyclist's front tire. The lateral position of the motorist (LPM) is measured by the distance from the parked motor vehicle driver's side tire to the passing motorist's passenger-side front tire. Histograms have been used in this section to graphically display the LPB and LPM during passing events.

The door zone is the area where the bicyclist would be in danger of crashing into an opening car door, known as a *dooring* incident. In this section, a 2004 Honda Accord, 4-door model, was used to measure the distance of the open car door from the parked vehicle's rear tire to the first door catch (door half open); a distance of 2.17 feet was recorded. The average cyclist is assumed to have a width of 2.5 feet (see Figure 4.1). Since the lateral position of the bicyclist is measured from the cyclist's front tire, the door zone width, used in this analysis, is equal to the width of the open Honda Accord door at the first door catch (2.17 feet) plus one-half of the width of the average cyclist (1.25 feet), for a total width of 3.42 feet.

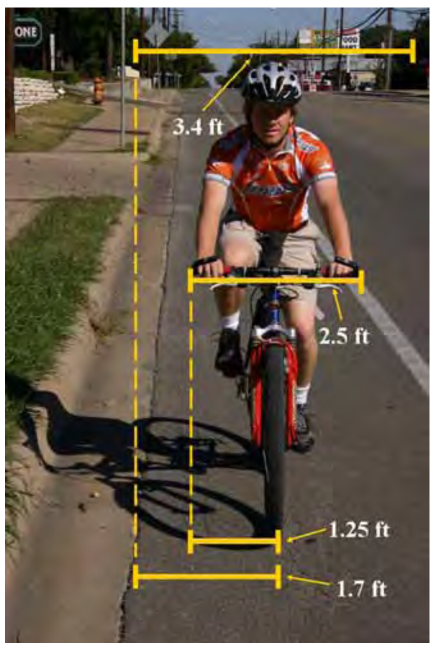


Figure 4.1: Operating space of a cyclist (Hallett et al., 2006)

4.2.1 Bicycle Lane versus Wide Outside Lane with Similar Total Pavement Widths (TPW)

The lateral position of the cyclist and motorist were analyzed to compare the operational difference between a designated bicycle lane and a shared wide outside lane (see Figure 4.2), both having similar pavement widths between the driver-side tire of the parked motor vehicle and the center line of the roadway. Parkfield Drive North in Austin, Texas, is a two-lane roadway with on-street parking, a 7.25-foot wide designated bike lane, and an 11.42-foot wide outside motor vehicle lane, for a total pavement width of 19.26 feet. Cincinnati Avenue in San Antonio is a two-lane shared roadway (cyclist and motorist share the outside lane) with a wide outside lane of 20.20 feet wide in each direction. The available pavement width was similar in this comparison (motor lane plus designed bike lane and the shared wide outside lane); however, the overall width is more generous than usual.

Although the example sites in Figure 4.2 have liberal pavement widths, the bicyclist and motorist were recorded traveling with approximately the same distance between them; however, most bicyclists ride outside of the door zone in the bike lane. This is likely the result of the bicyclist and motorist having separate lanes that are clearly designated. In Figure 4.2 the lateral position of the bicyclist in the shared outside lane is typical. As seen in the example, the cyclist(s) and motorist(s) are forced to compete for the same pavement. The cyclist will tend to shift as far from the moving vehicle as possible, often traveling within the dooring zone.

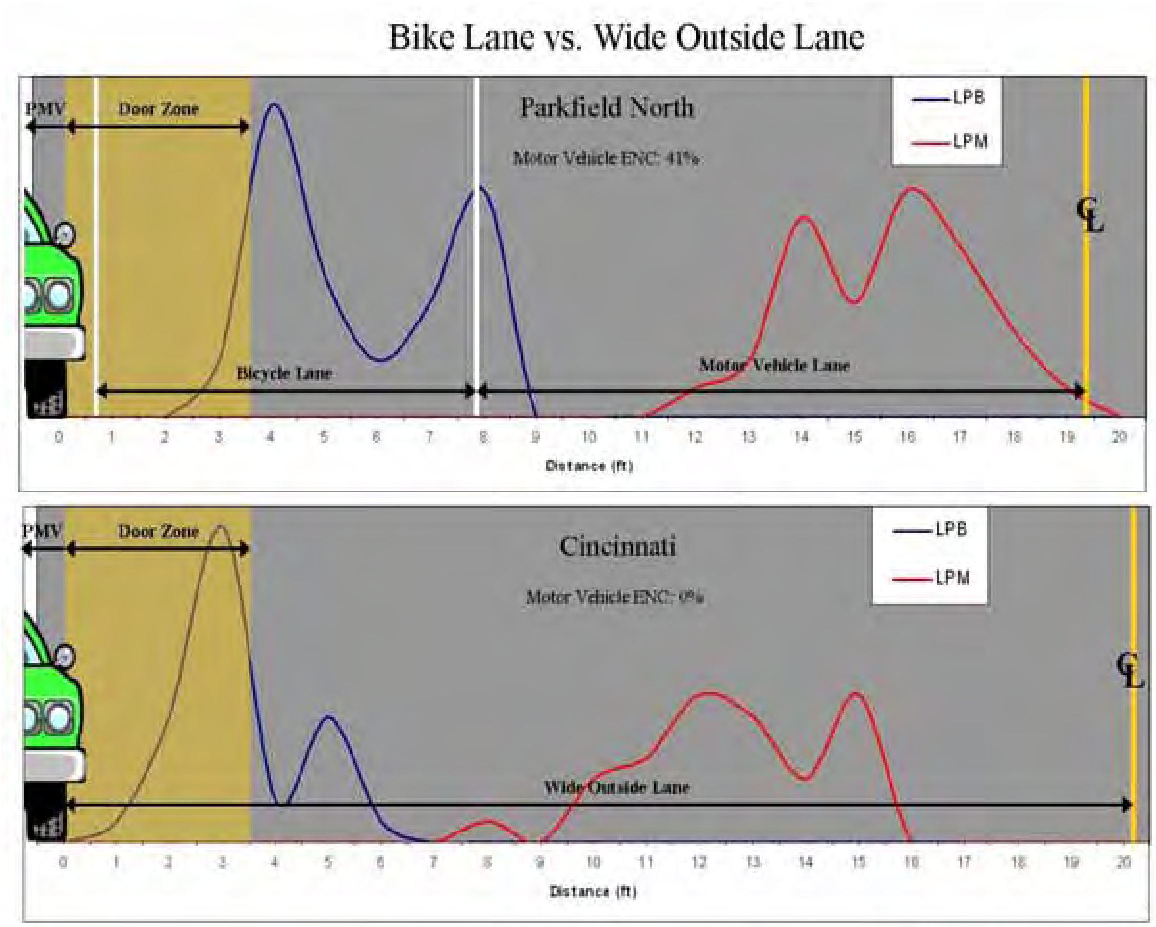


Figure 4.2: Comparison of Bicycle Lane vs. Wide Outside Lane (Same TLW)

4.2.2 Bicycle Lane versus Parking in Outside Lane with Similar Total Pavement Widths (TPW)

When a vehicle was parked in the outside lane of a roadway with four or more lanes, the space adjacent to the parked vehicle could be navigated similar to a bicycle lane. As seen in Figure 4.3 Georgian Road, in Austin, is a two-lane roadway with a 4.17 foot designated bike lane and a motor vehicle lane 11.50 feet wide for a total pavement width of 16.25 feet. However on-street parking is permitted in the designated bike lane on Georgian Street. Alamo Street, in San Antonio, is a four-lane roadway with on-street parking in the 16.45-foot wide outside motor lane. The two sites operated similar. The cyclists rode approximately the same distance from the parked vehicle, and the distances between the cyclist and passing motorist were alike. Unfortunately, the majority of cyclists in both examples were observed riding in the dooring zone. The motor vehicle encroachment rates were also similar.

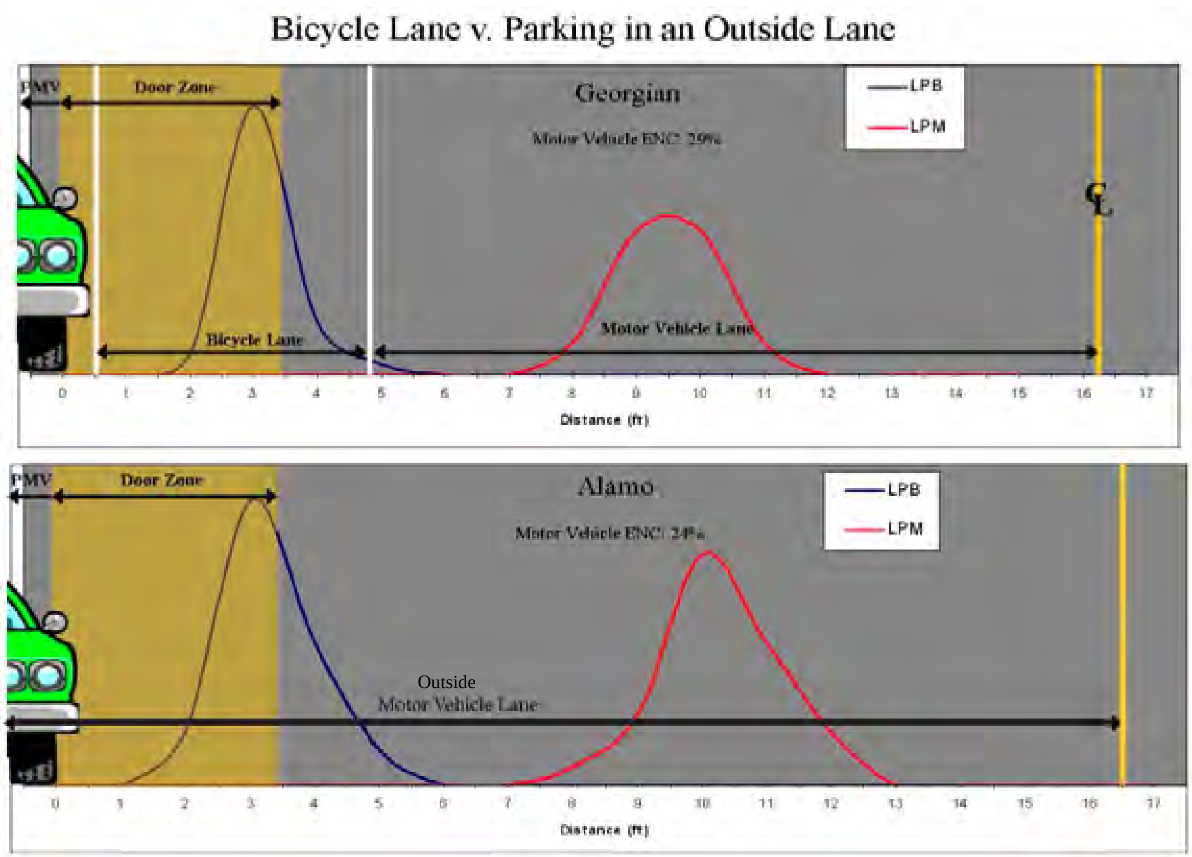


Figure 4.3: Comparison of Bicycle Lane vs. Parking in an Outside Lane (Same TLW)

4.2.3 Wide Outside Lane versus Parking in a Bicycle Lane Where Cyclist(s) and Motorist(s) Share Similar Total Pavement Width (TPW)

Figure 4.4 compares the operations of a wide outside lane versus a narrow motor vehicle lane plus bike lane where motorists are permitted to park in both the wide outside lane and the bike lane. Guadalupe Street in Austin, Texas, is identified for shared use by bicyclists and motorists with an outside lane width equal to 14.15 feet. Timber Path in Austin, Texas includes a designated bike lane of approximately 5 feet and an adjacent motor vehicle lane approximately 10.59 feet wide for a total of 15.59 feet. When motor vehicles are parked in the bike lane on Timber Path, bicyclists share the outside motor lane. A majority of the cyclists are riding within the dooring zone on both roadways.

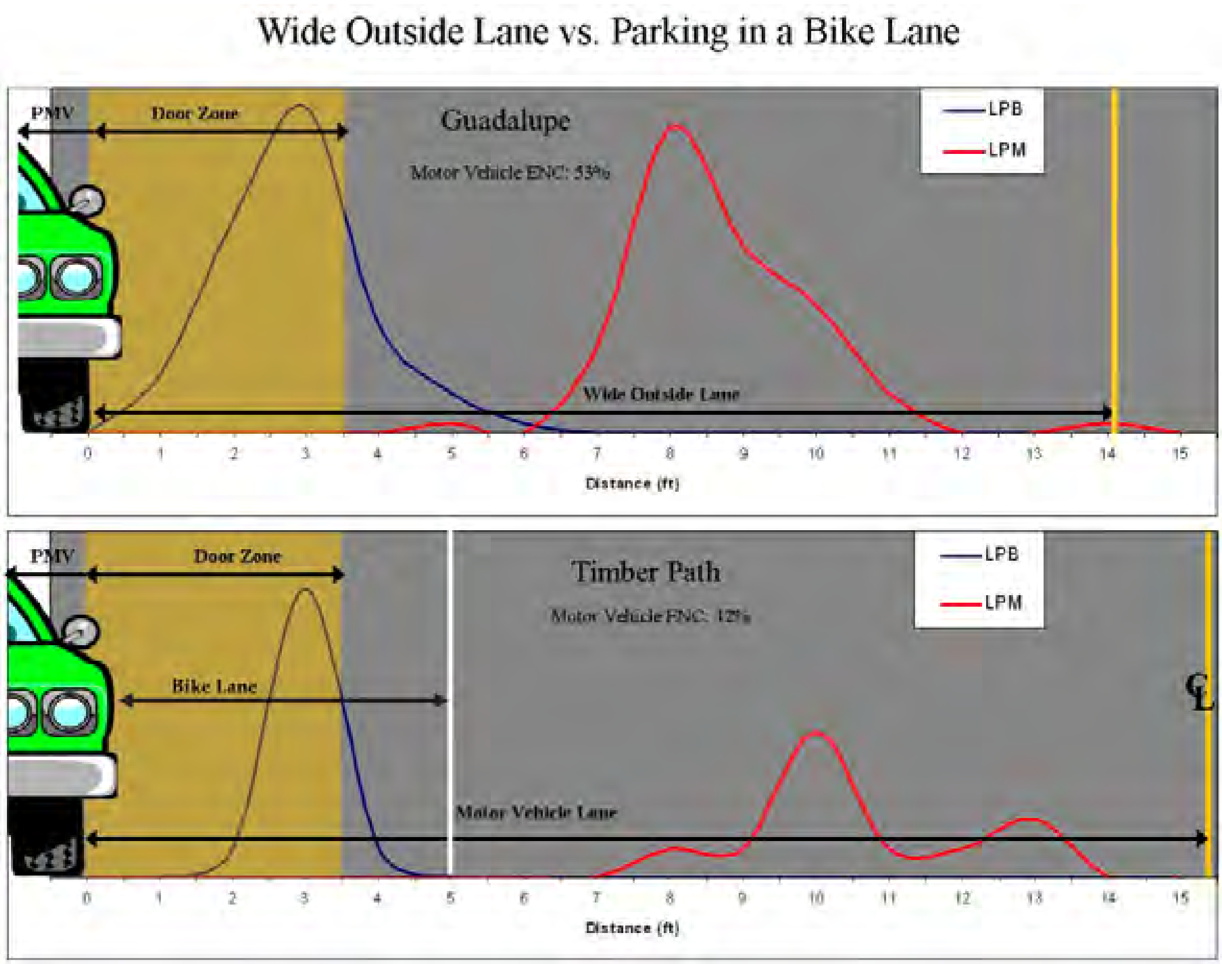


Figure 4.4: Example of Wide Outside Lane vs. Parking in a Bike Lane

4.2.4 Bicycle Lane Buffers with Similar Total Pavement Widths (TPW)

In Figure 4.5, Parkfield Drive North has on-street parking, a 5.08-foot designated bike lane, and a 12.17-foot wide motor vehicle lane. The average total pavement width from the parked vehicle's driver side tire to the roadway center line is 17.51 feet. San Jacinto Street in Austin, Texas, has on-street parking, a 3.76-foot buffer zone for opening a car door, a 5.79-foot designated bike lane, and an 11.25-foot motor vehicle lane. The average total pavement width from the parked vehicle's driver side tire to the roadway center line averaged 20.80 feet. When a buffer zone exists between the parked vehicle and the designated bike lane cyclists are able to maintain a consistent lateral position within the bike lane outside the dooring zone. As a result, motor vehicle encroachments rates on San Jacinto Street were 33 percent compared to 16 percent at Parkfield Drive North.

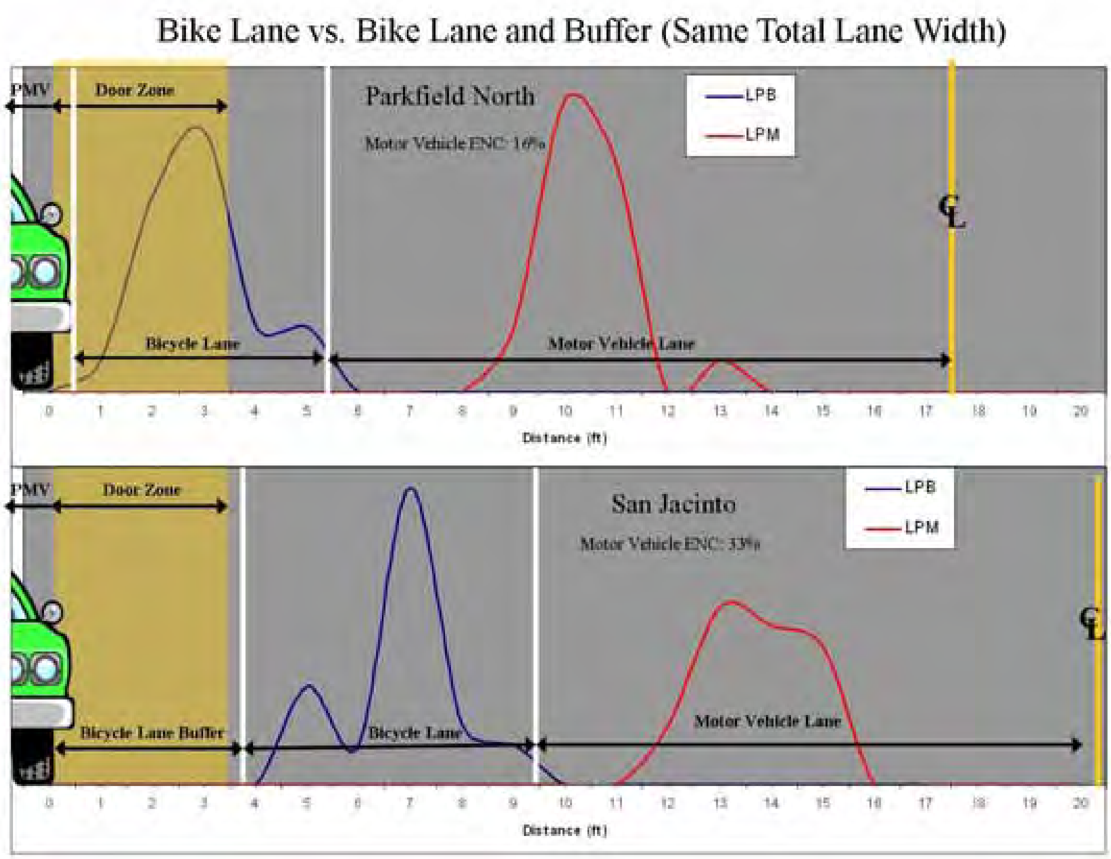


Figure 4.5: Example of Bike Lane vs. Bike Lane with Bike Lane Buffer

4.2.5 Bicycle Lanes of Similar Width with Varying Width Motor Vehicle Lanes

In Figure 4.6, Georgian Street includes on-street parking, a 3.92-foot bike lane, and a 10.81-foot motor vehicle lane for a total pavement width of 14.73 feet adjacent to the parking zone. 30th Street includes on-street parking, a 3.27-foot buffer zone, a 6.08-foot bike lane, and an 11.75-foot motor vehicle lane for a total pavement width equal to 21.10-feet adjacent to the parking zone. If on-street parking is permitted along with a designated bike lane and at least some of the roadway is designated as a bike lane buffer (to accommodate the opening of parked car doors) cyclists are generally able to ride outside the dooring zone. Additionally, roadways with designated bike lanes and buffer zones significantly reduce motor lane encroachments and improve traffic operations and safety (both motorists and cyclists have more space to operate).

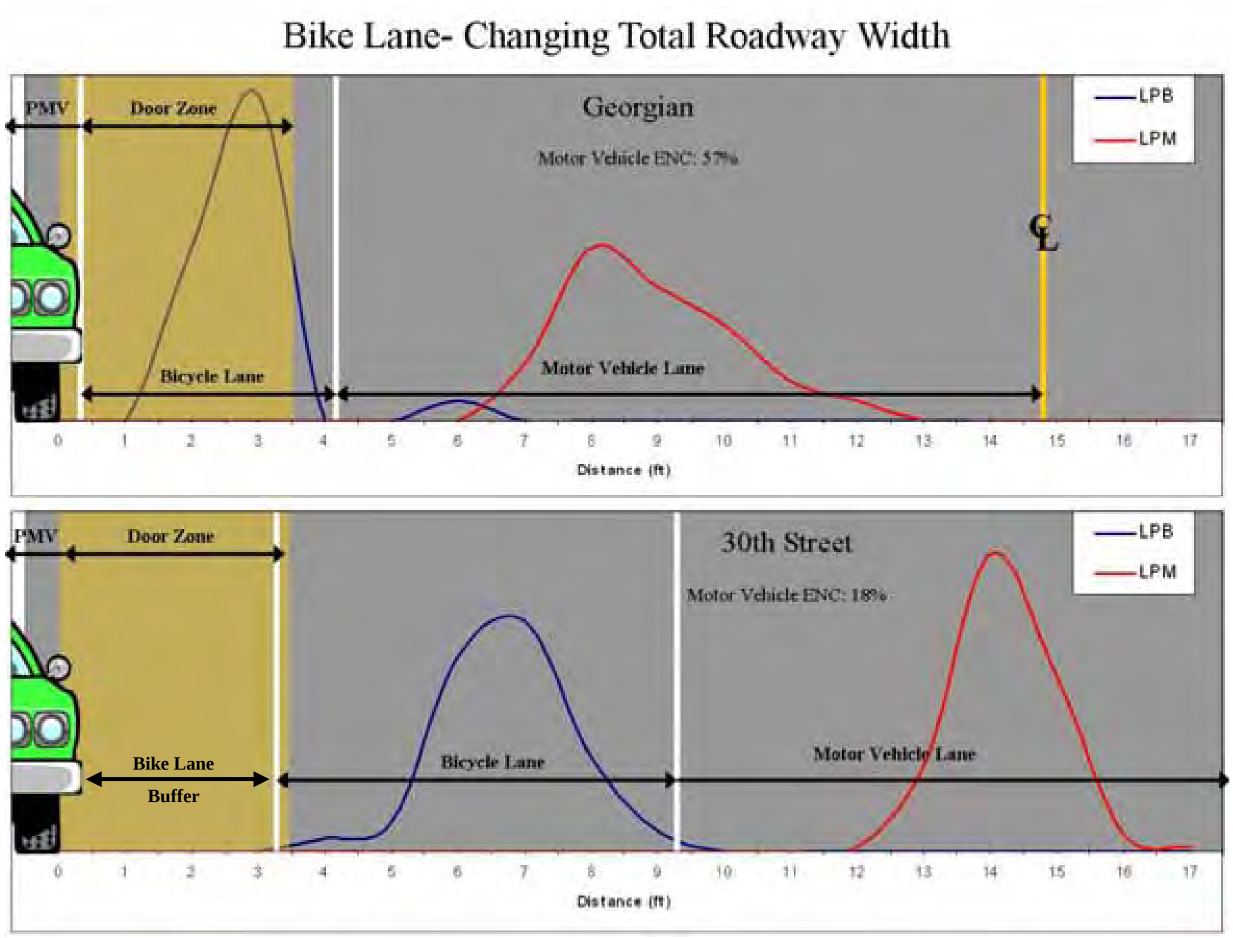


Figure 4.6: Example of Bike Lanes vs. Bike Lane with Bike Lane Buffer

4.2.6 Wide Outside Lanes (WOL) with Varying Widths

Figure 4.7 analyzed two shared roadways with on-street parking and significantly different wide outside lane widths. Meadow Glen has a shared outside lane width of 13.42 feet versus Cincinnati Avenue with a 20.20-foot shared outside lane width. Although Cincinnati Avenue has a much wider outside lane width, cyclists generally ride dangerously close to the parked motor vehicle. This behavior was typical for bicyclists traveling on shared roadways. In conclusion, the wide outside lane design is not as effective as a designated bike lane at increasing the lateral position of the bicyclists. This is likely due to the fact that a bike lane clearly identifies space within the roadway for bicycling. In this study, bike lanes were determined to be operationally safer for both cyclists and motorists when compared to a wide outside lane where cyclists must choose where to ride to avoid conflicts with both motorists and parked motor vehicles. In addition, having a wider roadway with designated bike lanes did reduce motor vehicle encroachment rates into an adjacent motor lane and incidents where motorists had to avoid cyclist events.

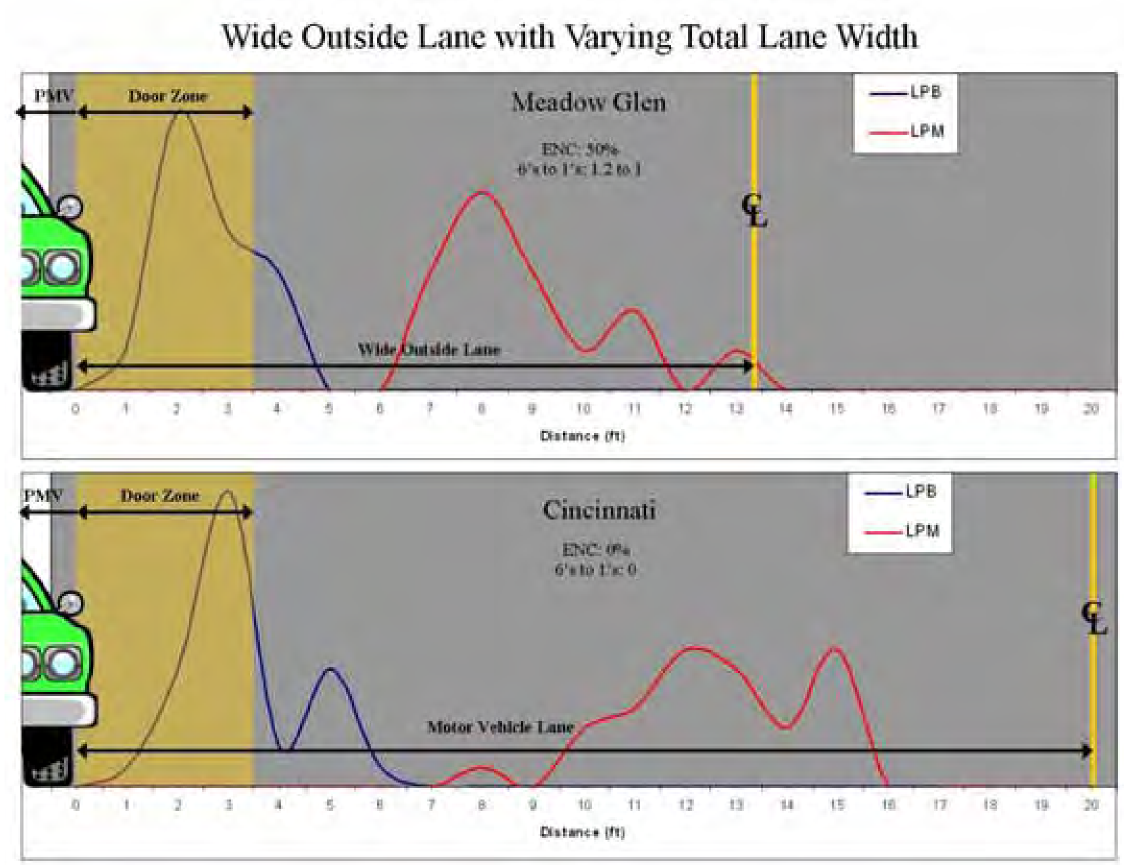


Figure 4.7: Example of Wide Outside Lane with Varying Roadway Width

4.2.7 Discrete versus. Continuous Parking

In Figure 4.8, the researchers compared the lateral position of the bicyclist and the motorist during different parking scenarios (discrete and continuous) when the total pavement width from the rear tire of the parked motor vehicle to the adjacent motor lane line is similar. Guadalupe Street is a shared roadway with continuous on-street parking and a 14.15-foot pavement width adjacent to the parked motor vehicle. While Meadow Glen Lane is a shared roadway with discrete on-street parking and a 13.42-foot shared motor lane adjacent to the parked motor vehicle. Figure 4.8 illustrates that when continuous parking is present, the lateral position of the bicyclist increases. This happens because the cyclist is constantly concerned with the parked motor vehicle and travels a distance further away from the continuous parked motor vehicles. When there is discrete parking, the cyclist is often willing to maneuver in and out of the parked vehicles often passing a parked motor vehicle dangerously close.

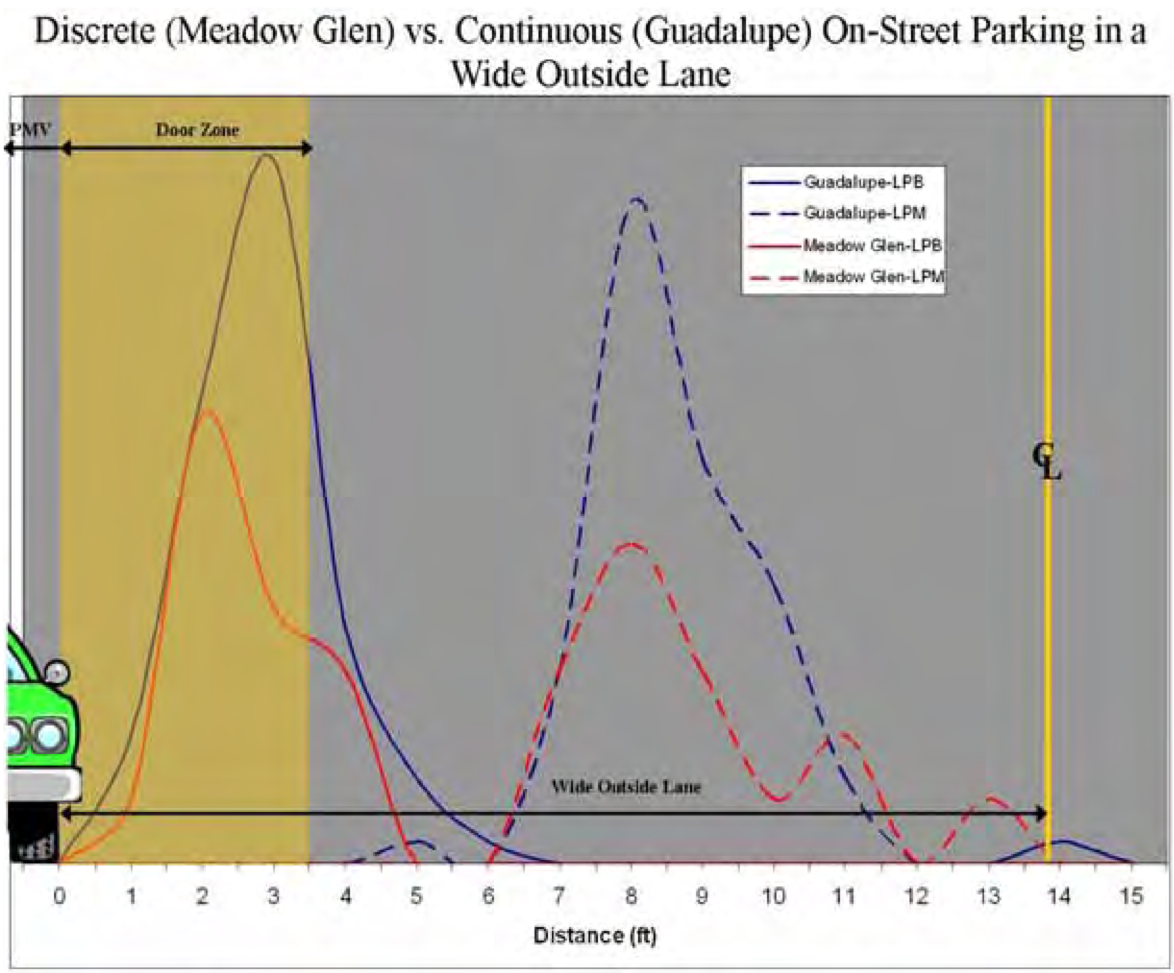


Figure 4.8: Example of Discrete vs. Continuous On-Street Parking in a Wide Outside Lane

4.2.8 Bicycle Lane – Parking versus No Parking

The lateral position of the bicyclists and the lateral position of the motorist were compared at sites with bicycle lanes and similar total pavement widths and where on-street parking was permitted on only one of the roadways. Georgian Street has on-street parking, a

3.92-foot bike lane width, a 10.61-foot motor lane for a total pavement width of 14.73 feet adjacent to the on-street parking. Hancock Avenue has no on-street parking, a bike lane width of 4.25 feet and a 10.33-foot motor lane for a total pavement width of 14.58 feet. It was expected that the lateral position of the bicyclist would increase with on-street parking because cyclists have an additional danger and must decide where to position themselves between two obstacles. Figure 4.9 confirmed that when on-street parking was present, the lateral position of the bicyclist increased as the cyclists moved farther away from the parked motor vehicle to avoid conflicts.

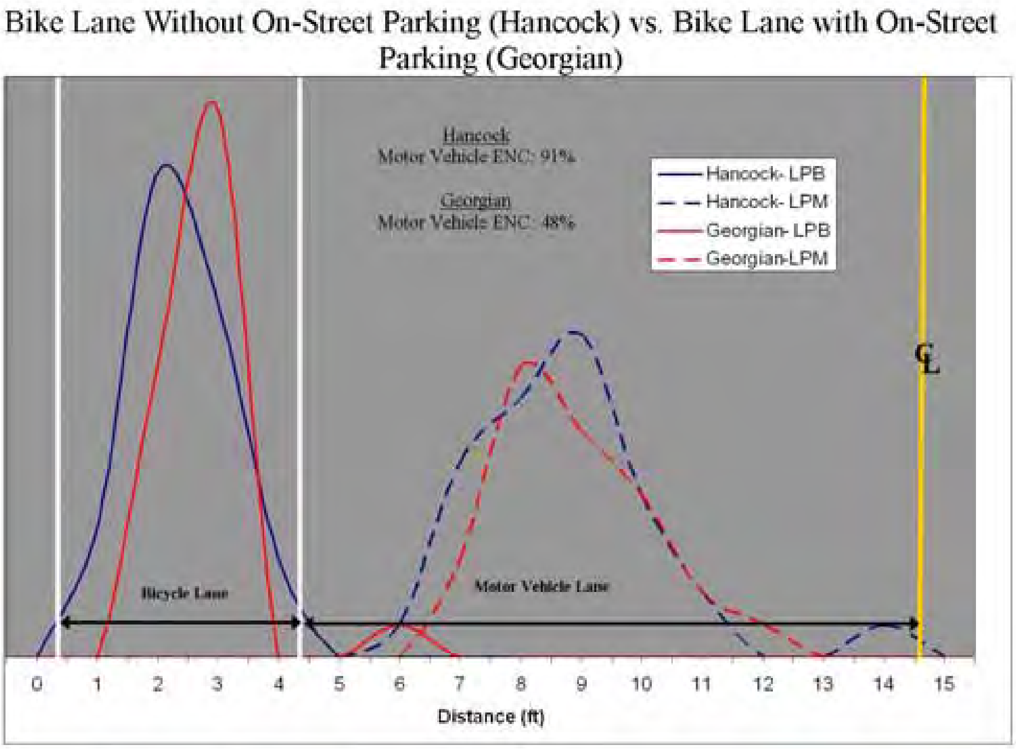


Figure 4.9: Example of Bike Lane with and without On-Street Parking

4.2.9 Wide Outside Lane – On-Street Parking versus No On-Street Parking

The differences between a wide outside lane with and without on-street parking were analyzed. Guadalupe Street has on-street parallel parking with a 14.15-foot lane width, while Westview Avenue has no on-street parking and a 13.75–foot lane width. Figure 4.10 illustrates that the lateral position of the bicyclist increases when on-street parking is present and the cyclist avoids conflicts with parked vehicles. The motor vehicle encroachment rates at the two sites were similar (53 percent for Guadalupe versus 58 percent for Westview), which is intuitive because the bicyclist(s) and motorist(s) share similar pavement widths.

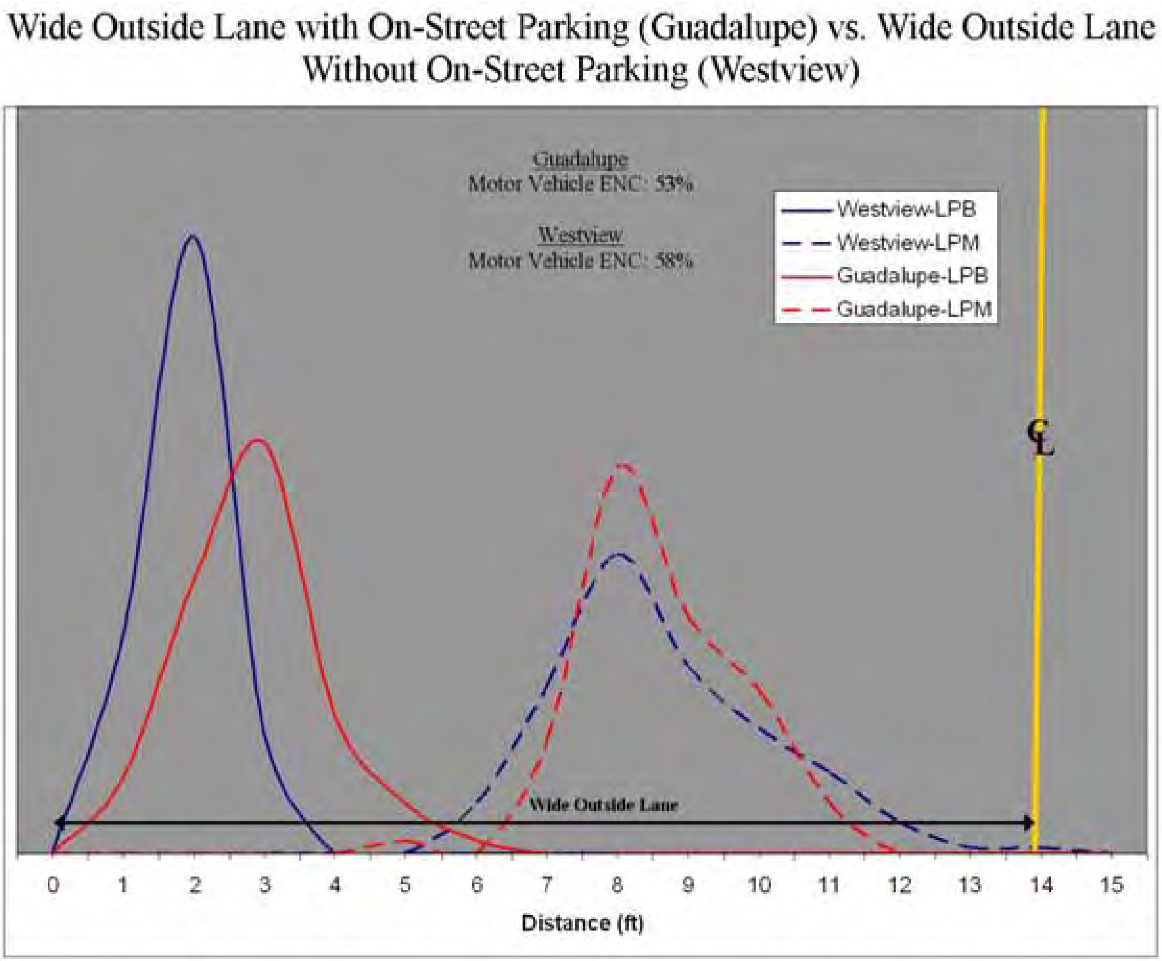


Figure 4.10: Example of Wide Outside Lane with and without On-Street Parking

4.3 Regression Analysis

Because the independent variables varied among the sites, it was not possible to perform a direct comparison of the average lateral positions among all the sites. As a result, regression models were developed to describe the effect of different geometric and traffic characteristics on the lateral position of the bicyclist, the lateral position of the motorist, and motorist encroachments. The models represent the general tendencies of the data set, therefore they can be used to describe, and predict data set implications.

Several independent variables were considered, including the following:

- Seven Events (passing and non-passing events)
- Presence of on-street parking
- Presence of bicycle lane
- Bicycle lane width
- Total lane width (distance from the parked car's passenger tire to the inside motor vehicle line)
- Type of parking (continuous or discrete)
- Presence of gap between parked car and outside motor vehicle lane line
- Width of gap between parked car and outside motor vehicle lane line (if present)
- Presence of different types of adjacent traffic lanes (opposing, same-direction, or two-way, left-turn)
- Presence of central business district
- Presence of residential development (characterized by non-arterial roads, low traffic volumes, and strictly residential land-use)
- Cyclist experience level (casual recreational, experienced recreational, experienced commuter)
- Parking turnover (high, medium, low)
- Presence of parallel or angled parking

Random effects were incorporated into these models to account for the influence of test sites or cyclists not accounted for by the independent variables. Many iterations were performed to develop the most statistically significant and intuitive models. For each of the models, the data was combined with the previous project (Project 0-5157) to provide a better understanding of how the presence of on-street parking influences the cyclist's and motorist's positions on the roadway. In each regression output, the *p*-value indicates the probability that the coefficient estimate generated is the result of random variation. For this analysis, variables with coefficient estimates where $p>.05$ were eliminated.

4.3.1 Lateral Position of Bicyclist

Using the data from the current research project (0-5755), with on-street parking, combined with research data from project 0-5157, without on-street parking, an analysis could be completed to examine how the cyclist's lateral position changed when roadway configurations differed. A total of 6,651 observations were collected including both passing and non-passing events (3,453 passing events from Project 0-5157, 960 passing events from 0-5755, and 2,338 non-passing events from 0-5755), and used to develop the regression model. Many of the independent variables were found to have a statistically significant effect on the lateral position of the bicyclist. These variables included whether it was a passing or non-passing event, the presence of a bike lane, the bike lane width, presence of a bike lane buffer, a gap between the parked vehicle and the outside motor vehicle lane line, presence of continuous parking, presence of residential development, and presence of a central business district. The magnitudes of these effects and their statistical significance are provided in Table 4.2.

Table 4.2: Multivariate Regression Results for LPB

Variable	Coefficient Estimate	p-value
Intercept	1.7	<0.01
Event 2	0.6	<0.01
Presence of Parking	0.5	0.05
Presence of Bike Lane (no on-street parking)	-0.9	0.12
Bike Lane Width (no on-street parking)	0.3	<0.01
Presence of Bike Lane (w/ on-stree parking)	-1.9	<0.01
Bike Lane Width (w/ on-street parking)	0.4	<0.01
Presence of Bike Lane and Buffer	0.8	<0.01
Presence of Gap between parked car and OMVLL	-1.4	0.01
Width of Gap between parked car and OMVLL	0.4	<0.01
Presence of Continuous Parking	0.9	<0.01
Presence of CBD	1.3	<0.01
Presence of Residential Development	0.4	<0.01

This model displays how on-street parking impacts the lateral position of the bicyclist on different bikeways. When on-street parking is present, the lateral position of the bicyclist will increase by approximately 0.5 ft, meaning that if all other variables were constant, the cyclist's tire would be 2.2 ft from the parked vehicle. However, it is evident that the cyclist must deal with two different obstacles: the passing motorist and the parked motor vehicle. Because the passing motorist might appear to be more of a danger to the cyclist, the cyclist will generally ride closer to the parked car when a passing motorist is present. This was supported by the model, where the average lateral position of the bicyclist increased by an additional 0.6 ft when there was no passing motorist adjacent to the bicyclist (this occurred only in an on-street parking scenario).

The type of bicycle facility also influences a cyclist's lateral position. Similar results to those found in Project 0-5157 were obtained for a bicycle lane with no on-street parking. The presence of a bike lane and the bike lane width both yield an increase in lateral position of the bicyclist(s): approximately 0.2 feet on a 4-foot bike lane and 0.9 feet on a 6-foot bike lane. Additionally, if there is motor vehicle parking adjacent to a designated bike lane, the cyclist will move even farther away from the parked vehicle. In this study, bike lane widths ranged from 3.8 to 6.1 feet (the lateral position of the bicyclist changed from -0.38 to 0.54 feet when compared to a wide outside lane. This demonstrates the importance of a wider bike lane to move cyclists farther away from parked vehicles and the dooring zone. Providing a bike lane buffer also proved to be effective at moving the cyclist father away from the dooring zone. For every additional foot of buffer, the cyclist's position increased approximately0.8 foot.

Having a gap between the parked vehicle and the outside motor vehicle lane line (OMVLL) acts similarly to having a bicycle lane because cyclists tend to ride in the gap, this is supported by the model. Having a gap that is 4 feet or greater will increase the lateral position of the bicyclist by at least 0.2 foot (based on a synthesis of the data collected).

Land uses and roadway classification also had an influence on the cyclist's lateral position. When riding in residential areas, cyclists tend to ride an average of 0.4 feet farther from the parked car. This could be a result of a more leisurely riding environment with lower traffic volumes and less frequent on-street parking. When in the central business district, cyclists ride 1.3 feet farther from the parked car. This separation also occurs when intersections are closer together and traffic speeds are reduced allowing cyclist and motorists to travel at similar speeds. The type of parking is also important. When continuous parking is present, cyclists tend to ride an average of 0.9 foot farther from the parked car because there is a greater chance of collisions with opening doors.

In addition, there were some independent variables worth noting that were not statistically significant. The parking turnover rate (high, medium, or low) was not significant. This research showed that parking turnover could impact a rider's comfort level and/or their route choice, but the parking turnover did not influence where riders position themselves on the roadway. In a survey conducted after the completion of the day, the hired cyclists were asked what was the most important factor in determining how far away they rode past the parked car. According to the surveys, 50 percent of the bicyclists responded *whether a person was inside the parked car*, 15 percent responded that they *anticipated width of car door*, 4 percent responded *seeing other cars leave*, and 0 percent responded to the turnover of parking. Therefore, it is evident that turnover is not as important as other factors in determining a bicyclist's lateral position on the roadway. Additionally, in this study the presence of angled versus parallel parking was not significant. However, parking type may influence a bicyclist's comfort or route choice, but not where cyclists generally position themselves on the roadway when parking was present. The roadways chosen for analysis were designated bikeways, they were assumed to be safer for the average adult cyclist than a roadway that was not designated as a bikeway and that cyclists with varying levels of experience could ride similarly on signed shared roadways.

4.4 Lateral Position of Motorist (LPM)

Several roadway and traffic variables also impact the lateral position of the motorist during both passing and non-passing events. Using the data from the current study (research project 0-5755, with on-street parking) combined with data from the previous study (research project 0-5157, without on-street parking) allowed researchers to analyze how motorists change position on the roadway during passing and non-passing events. A total of 7,108 observations were collected of motorist position during non-passing events (2,473 from 0-5755 and 4,635 from 0-5157) and 4,413 observations during passing events (960 from 0-5157 and 3,453 from 0-5755), were used to develop the regression models. The independent variables that influenced the lateral position of the motorist during non-passing events included the presence of a bike lane, the bike lane width, total lane width, the presence of a gap between the parked vehicle and the outside motor vehicle lane line. Similarly, the independent variables that influenced the lateral position of the motorist during passing events included the lateral position of the bicyclist, adjacent land uses, whether a bike lane was designated, the total lane widths for motorists and bicyclists, the number of through motor lanes, and the direction of traffic in the adjacent lane. The magnitudes of these effects and their statistical significance are provided in Table 4.3.

Table 4.3: Multivariate Regression Results for LPM

	Non-Passing Events		Passing Events	
Variable	Coefficient Estimate (ft)	*p-value*	Coefficient Estimate (ft)	*p-value*
Intercept	4.38	<0.01	-0.7	0.12
TLW (no on-street parking)	0.1	<0.01	0.6	<0.01
TLW (on-street parking)	0.2	<0.01	0.6	<.01
Presence of Adjacent Lane- Opposing Traffic	-1.4	<0.01	-0.4	<0.01
Presence of Bicycle Lane	-3.6	<0.01	-0.4	<0.01
Bicycle Lane Width	1.1	<0.01	N/A	N/A
Presence of Gap Between Parked Car and OMVLL	-2.6	<0.01	N/A	N/A
Width of Gap Between Car and OMVLL	0.7	<0.01	N/A	N/A
LPB	N/A	N/A	0.5	<0.01
Presence of Residential Land Use	N/A	N/A	0.5	0.02

For both passing and non-passing events, several of the same variables were statistically significant. There is one primary difference between the two models; for passing events, the intercept is not statistically significant, meaning that the absolute position of a passing motor vehicle is not certain. In Table 4.3, the other coefficients represent relative changes between non-passing and passing events with a high degree of certainty The overall change in the lateral position of the motorist increased an average of 1.0 foot during a passing event when the adjacent motor lane was opposing traffic (see "Presence of Adjacent Lane – Opposing Traffic;" -0.4 minus -1.4).

The roadway characteristics that influence the lateral position of the motorist are the total outside lane width and the direction of traffic in the adjacent lane. The lateral position of the motorist in all cases is measured from the rear wheel of the parked vehicle or face of curb to the passenger-side front tire of the motorist. As the total roadway width widens, the motorist's position generally increases. The lateral position of the motorist will also increase when on-street parking is present. The motorists, like the cyclists, position their vehicle to avoid open car doors and vehicles entering/exiting parking spaces. If the adjacent lane has traffic in the opposite direction, the average lateral position of the motorist will decrease based on available space and the danger of a head-on collision. During a passing event the motorist will try to avoid both opposing traffic in the adjacent motor lane on the left and the cyclist on the right.

The type of bikeway also has an impact on the motorist's position on the roadway. When a bicycle lane was available (with no parking in the bike lane), the overall change in lateral position of the motorist during a non-passing and passing event increased approximately 3.2 feet, see "Presence of Bicycle Lane" row in Table 4.3 (-0.4 minus -3.6). This means that the lateral position of the motorist will be greater during passing events than non-passing events as motorists attempt to avoid a crash with a cyclist. In this study, bike lane widths ranged from 3.8 to 6.1 feet. The lateral position of the motorist changed from 0.6 feet to 3.1 feet. The bike lane clearly described where the cyclist and motorist should operate. In addition, when a gap between the parked motor vehicle and the outside motor vehicle lane line was 4-feet wide or greater the lateral position of the motorist increased by at least 0.2 foot during non-passing events. This is approximately the same increase measured in the lateral position of the bicyclist. As the cyclist moves farther from the parked car, the motorist generally moves about the same distance to avoid a conflict with the cyclist.

In conclusion, during passing events two factors were significant. First, when the lateral position of the bicyclist increases, the lateral position of the motorist increases approximately the same distance in order to maintain the same distance between them. Second, the lateral position of the motorist increases in areas with residential development where traffic volumes and speeds are reduced.

4.5 Encroachments (ENC)

A logistic regression model was used to predict the probability of a motorist encroaching into an adjacent motor vehicle lane to move away from a cyclist. Encroachment is defined as any time both driver-side wheels come in contact with the adjacent lane stripe (this lane could have traffic traveling in the same or opposite direction). A total of 4,413 observations were collected of passing events (960 from Project 0-5755 and 3,454 from Project 0-5157) and used to develop the regression model for encroachments. Table 4.4 represents the likelihood of an encroachment resulting from a one unit increase in a given variable determined to be statistically significant. Although estimates of these changes do not have a direct interpretation, their magnitude give an indication of the effect and importance of that roadway design and traffic characteristics have on the probability of encroachment.

Table 4.4: Multivariate regression results for ENC

Variable	Coefficient Estimate (log-likelihood)	p-value
Intercept	3.9	<0.01
LPB	0.3	<0.01
Bike Lane	-0.9	<0.01
Adjacent Lane is Two-Way Left-Turn Lane	0.7	0.03
Total Lane Width (No on-street parking)	-0.2	<0.01
Total Lane Width (On-street parking)	-0.3	<0.01

In Table 4.4, the regression results provide values to describe the lateral position of the bicyclist, the total outside lane width, whether a bike lane is designated, and when a two-way left-turn lane will impact the probability of encroachment. The results of this regression model are intuitive. As the lateral position of the bicyclist increases, motorists are more likely to encroach into the adjacent lane to avoid conflict with the cyclist. If the adjacent lane was a two-way left-turn lane, the probability of encroachment increased. This occurs because the two-way left-turn lane usually has lower traffic volumes and fewer conflicts with other motorists allowing the motorist to move into the two-way left-turn lane and out of the way of the cyclist.

The important factors that reduce the probability of a motorist encroaching are: total pavement width, if a bicycle lane is designated and whether on-street parking is permitted. If the motor lane is wide, motorists may be able to move out of the way of a cyclist without encroaching into the adjacent motor lane. The presence of a bike lane has the greatest impact on the probability and magnitude of the motor vehicle encroachment. Bike lanes reduce encroachment because they delineate space on the roadway for both the cyclists and motorists to operate.

4.6 Implications of Results

As a result of the site-to-site comparisons and the regression models that were developed as part of this research, engineers and planners have additional tools to evaluate bikeways adjacent to on-street parking. It is evident that on-street parking can cause hazards for both cyclists and motorists.

Bicycle lanes are superior to wide outside lines at increasing the lateral position of the bicyclist. As shown in Figure 4.2, when a bicycle lane is present, cyclists tend to move farther away from the parked motor vehicle and ride outside the door zone. This behavior was not evident when compared with a wide outside lane. This comparison was supported by the results of the regression analysis. The operating space of a cyclist is 3.3 feet (AASHTO 1999), which includes 2.5 feet for the width of the bicycle and an average of 9 inches for the natural meandering that occurs while cycling. Half of this distance is approximately 1.7 feet. In non-residential or non-central business districts, cyclists generally ride 2.2 feet from the parked motor vehicle's front driver side tire, a separation distance of only 0.5 feet from the parked car. As a result, cyclists are usually in danger of dooring incident when on-street parking exists. AASHTO recommends a bike lane width of 5 feet or wider when placed adjacent to motor-vehicle parking (see Figure 4.1). Providing wider bike lanes can be an effective measure taken to increase the lateral position of the bicyclist. Bicycle lanes also help to define the motorist's path. Affording cyclists and motorist designated space within the roadway significantly reduces motor vehicle encroachments. When multiple lanes in the same direction exist and parking is permitted in the outside lane the gap between the parked car and the adjacent motor vehicle lane may act similar to a bike lane when at least 4 feet or more exists. If parking in that outside lane is continuous, the space adjacent to the parked vehicles may be designated as a bike lane or added to the motor vehicle lane to provide a wide outside lane shared by motorists and bicyclists.

When a buffer zone exists between on-street parking and the bike lane cyclists are able to ride outside of the dooring zone. For each additional 1 foot of buffer, the cyclist's lateral position increased by an average of 0.8 foot. Additionally, as illustrated by both the site comparisons and regression analysis, increasing the motor lane width and/or the bike lane width will help reduce the rate of motor vehicle encroachments.

When the threat of a head-on collision exists the motorist will move away from the opposing traffic. In comparison the motorist's lateral change in position was approximately 1.4 feet during a non-passing event (Event 3 - motorist passing a parked vehicle without a bicyclist present) and 0.4 feet during a passing event (Event 1 - motorist and bicyclist passing a parked motor vehicle at the same time). The site-to-site comparisons demonstrated that when the total roadway width was the same, cyclists and motorists travel a similar distance between them and when the motorist drives closer to the parked vehicle, the cyclist rode closer to the parked vehicle and possibly within the dooring zone. The differences between passing and non-passing events suggest that when no cyclist is present, the motorist feels more comfortable driving closer to the parked vehicle than the opposing traffic. When passing a cyclist, the motorist must negotiate between two moving obstacles (cyclist and opposing traffic); the motorist will generally move farther from the opposing-traffic lane, but not as far as when no cyclist is present. Alternatively, if the adjacent lane is a two-way left turn lane (TWLTL), the motorist’s probability of encroachment will increase approximately 70 percent. This occurs because a TWLTL is often void of traffic and the motorist is more likely to move into the two-way left turn lane away from the cyclist.

The type of development (land use) in the area will influence both the cyclist’s and motorist’s position on the roadway. For example, when riding in a residential area, the cyclist and motorist will move farther away from the on-street parked motor vehicle (an average of 0.4 feet and 0.5 foot respectively).

Chapter 5. Field Research Conclusions

5.1 Conclusions on Operational Results

As a result of the field study evaluating the operational impact of bicycling adjacent to on-street motor vehicle parking, five primary conclusions were formed:

1) The total roadway width is critical to the safety and operational behaviors of both cyclists and motorists. A wider roadway will increase the lateral positions of both the cyclist and motorist and decrease the probability of motor vehicle encroachments.

2) Operationally, bicycle lanes are superior to wide outside lanes. The lateral position of the bicyclist increased and the change in lateral position of the motorist decreased during non-passing and passing events. As a result in having a designated bike lane the probability of motor vehicle encroachments were reduced.

3) A 5-foot bicycle lane combined with a buffer zone between the bike lane and the on-street parking is the only way to ensure that cyclists have sufficient space to safely ride outside the dooring zone.

4) The behavior of motorists and cyclists is significantly different when on-street parking exists. Several variables, in addition to on-street parking, significantly impacted the lateral position of the bicyclist: the width of the gap between a parked motor vehicle and adjacent motor vehicle lane line, continuous or intermittent on-street parking, and adjacent land uses. Additionally, the lateral position of the bicyclist will have a significant impact on the change in lateral position of the motorist and motor vehicle encroachments.

5) As a result of this study, additional data has been incorporated into a revised edition of the *Texas Guide for Planned and Retrofit Bike Facilities* and associated Excel Workbook.

Chapter 6. Introduction to Bike Route Choice Preference Study

In the U.S., the increasing dependence on the automobile has contributed to growing traffic congestion, a decline in air quality, increased energy consumption, and a greater dependency on foreign fuel supplies (see Schrank and Lomax, 2005; EPA, 1999; Litman and Laube, 2002; Jeff et al., 1997; Schipper, 2004). This increased dependence on the automobile was made evident by Pucher and Renne in 2003 when they revealed that 92 percent of U.S. households owned at least one motor vehicle in 2001 compared to approximately 80 percent in the early 1970s. Furthermore, household motorized vehicle miles of travel increased 300 percent between 1977 and 2001 (relative to a population increase of 30 percent during the same period; see Polzin and Chu, 2004). The dependence of U.S. households on the automobile has far-reaching impacts including but not limited to public health, the regional ecosystem's health, global climate change, urban life styles, economic stability, and energy security (Boyle, 2005; TRB, 2002; U.S. Congress, 1994).

The negative consequences of increasing auto dependency have led regional, state, and federal planning agencies to consider transportation demand management strategies that encourage public transportation, car and van pools, as well as non-motorized modes of transportation. In this context, bicycling has drawn considerable attention due to its wide array of societal and environmental benefits. For instance, bicycling presents an inexpensive mode of transportation that may increase funds available for non-transportation expenditures, reduce the number of automobiles on the road, and contribute to air quality/energy consumption benefits. However, the benefits of bicycling are not confined to transportation. Bicycling has the potential to enhance bicyclists' physical fitness and public health at large by promoting active lifestyles, an issue that has captured the attention of public health researchers (Lawrence and Engelke, 2007). Indeed, an earlier study has indicated that physical inactivity has more serious public health repercussions (such as obesity) than automobile-related health problems (including deaths caused by traffic accidents and air pollution), demanding the attention of both transportation and public health researchers (Sallis et al., 2004).

In spite of the benefits from bicycling, and the efforts of planning agencies to encourage bicycling, only 27.3 percent of the driving age public (aged 16 and older) in the U.S. rode a bicycle even once during the summer period (2002 National Survey of Pedestrian and Bicyclist Attitudes and Behaviors). Clearly, the percentage of regular bicyclists is much smaller. For instance, a study of the 2001 National Household Travel Survey (NHTS) done by Polzin and Chu in 2005 revealed that 0.4 percent of individuals used bicycling as their usual mode of transportation. The low percentage of bicycling for transportation is despite the fact that a significant percentage of trips in U.S. urban areas are short-distance trips. Based on the 2001 NHTS, 41 percent of all trips made in 2001 were less than 2 miles, and 28 percent were less than 1 mile. However, Americans used automobiles for about 74 percent of trips less than 2 miles, and about 66 percent for trips less than 1 mile. While a number of reasons exist to cause automobile use for short distance trips, it is safe to say that there is a lack of good bicycling facilities, bikeways are often disconnected, and individual safety considerations may contribute to create barriers to bicycling. In 2003, Pucher and Dijkstra compared fatality rates per mile of travel by different modes in the U.S., and concluded that bicyclists were 12 times more likely to get killed than car occupants which should raise questions about the safety to which bikeways are currently being designed.

6.1 Approaches to Assess Impact of Route Design Attributes

There are at least two broad approaches to examine the impacts of bicycling route design attributes. The first approach is to elicit information from a large sample of individuals from the general population who are interested in bikeways and are willing to identify current barriers to bicycling. The second approach is to elicit similar information like the first approach, but from a sample of actual bicyclists. The first approach has the advantage that it provides useful information to understand why current non-bicyclists stay away from bicycling, how they are different from current bicyclists, and what can be done to entice the non-bicyclists to take up bicycling. Based on a cursory evaluation of the current bicycling infrastructure, non-bicyclists may be staying away from bicycling due to overall lifestyle considerations in general and pre-conceived notions about safety on bicycles. To the extent that they choose not to expose themselves to bicycle routes, current non-bicyclists will not be able to provide as much objective information as bicyclists for developing recommendations to improve bicycle route planning and design guidelines. The second approach has the limitation that it is confined to bicycle users, the group that is obviously bicycling-oriented in lifestyle in the first place. This approach does not permit a clear evaluation of the lifestyle factors and safety-related perceptions/factors that determine bicycling use. However, it has the advantage that it provides information on route design attributes that are considered favorable and those not considered favorable, as well as the relative valuations of different route design attributes, from a group of individuals who actually ride on existing bikeways and make conscious choices about bicycling routes. The second approach is generally more efficient because the amount of information related to bicycle route design per individual is higher. In short, current bicyclists are more *tuned in* to bikeway design attributes, and should provide useful information for making objective recommendations to improve bikeway planning and design.

In an ideal setting, it would be useful to obtain information from both bicyclists and non-bicyclists. The current study adopted the second approach because of efficiency and because it is easier to target actual bicyclists (see Section 8.1). *One preference elicitation* approach is to ask respondents to state which design factors they consider important and which ones they do not. This approach does not provide the relative and absolute quantitative values of different route design attributes (for example, how much more time a bicyclist is willing to travel to avoid a route that has parallel parking, or how much less likely they are willing to continue using a route if parallel parking is introduced?).[1] *A second preference elicitation* approach is to collect data on the actual (or revealed) route choices of bicyclists and compare the design attributes of the chosen route with those of the route not chosen. The revealed preference data collection method is problematic. The analyst would need to construct all alternative routes between the origin and destination for each bicycle trip (or trips if multiple bicycle trips are recorded) and determine if the respondent considered alternative routes. It would be very time-consuming to identify all the route possibilities and those considered by the respondent. (See Stinson and Bhat, 2003, Ben-Akiva and Morikawa, 1990, and Bhat and Sardesai, 2006 for related discussions.) Overall, developing a good set of alternatives that could be considered by the bicyclist is a daunting task.

[1] One could argue that such questions could be posed directly to respondents. However, with the multitude of route design attributes that need to be considered, the number of such questions would lead to a questionnaire whose length would turn away all but the most ardent of bicyclist enthusiasts. Besides, survey research studies have shown that responses to such direct questions are not consistent with the actual choices of individuals, suggesting that individuals are not very good at responding to such direct trade-offs (see, for instance, Zaller and Feldman, 1992, Chaudhuri and Mukherjee, 1988, Duffy and Waterton, 1988, and Fox and Tracy, 1986).

A third preference elicitation approach is to present alternative routes to a respondent, each with a pre-determined set of attribute factors, and ask the respondent to select the route they would choose. The factors that characterize each route can be controlled and generated in an efficient choice experimental design, so that researchers can assign the magnitudes and relative trade-offs among all route attributes based on the choices made by respondents. This can be the most efficient way to collect data for determining magnitude effects and trade-offs across a multitude of route attributes. One limitation often cited of stated preference-based analyses is that respondents may not respond to the *hypothetical questions* in ways that they would in the actual field. While one can never completely ignore these limitations, the issues can be alleviated by presenting route attributes that pivot off the attributes chosen by the bicyclist for a recent trip. To the extent that the respondents are bicyclists, they should be more able to identify the various attributes in the choice experiment (compared to individuals who have not bicycled before). Finally, to the extent that the routes are generated in a careful experimental design, the respondents will be asked to make some difficult trade-offs and decisions in their choices. It would be difficult for them to *play a game* in a way that exaggerates the importance of specific route attributes with a view to bias the results toward recommendations that may benefit their own bicycling habits and needs.

6.2 The Current Study and Paper Structure

The current study identifies the route design attributes that affect bicycle route choice and evaluates the absolute and relative importance of these attributes. The study's objective is to provide information, to develop guidelines for improving existing and planned bikeways. Demographic characteristics were considered in the study as determinants of bicyclist route choice. The factors considered to explain bicyclist route choice include: (1) bicyclist characteristics such as age, gender, employment characteristics, bicycling experience, reason for bicycling; (2) on-street parking factors, such as parking type (angled/parallel), parking turnover rate, length of parking area, and parking occupancy rate; (3) bikeway type such as bicycle lane, shared wide-outside lane, etc.; (4) bikeway amenities such as access to showers and lockers; (5) bikeway continuity; (6) roadway physical characteristics such as roadway grade, number of stop signs, red lights and cross streets; (7) roadway functional characteristics such as traffic volume and roadway speed limit; and (8) roadway operational characteristics such as travel time. A stated preference approach was adopted, and the survey targeted Texas bicyclists in the spring of 2007.

The remainder of the paper is organized as follows. Section 7 discusses earlier studies undertaken to evaluate bicycle facilities, and positions the current study within this broader context. Section 8 discusses the survey data collection procedures. Section 9 outlines the modeling methodology employed for data analysis. Section 10 describes the sample used in the analysis, and presents basic descriptive statistics. Section 11 presents the empirical results. Section 12 summarizes the findings from this study, and the researchers' recommendations.

Chapter 7. Earlier Research on Bicycle Route Choice

There is a substantial body of literature directly or indirectly examining the effects of bike route design attributes and route preferences. These studies may be classified into two broad categories: (1) Aggregate-level studies and (2) Disaggregate-level studies. The aggregate-level studies focus on analyzing the relationship between bicycle route characteristics and aggregate bicycle user measures (such as changes in the number of bicyclists using a bikeway after improvements are made), or by drawing inferences from cross-comparing bicycle use levels among cities investing in bicycle infrastructure. Examples of such aggregate-level studies include Clarke, 1992, Nelson and Allen, 1997, Wynne 1992, Denver, 1993, Forester, 1996, Moritz, 1997, Treadgold, 1996, and Copley and Pelz, 1995. The disaggregate-level studies analyze the ability of individual bicyclists, rather than using aggregate-level dependent variables. An advantage of using a disaggregate-level analysis is that it better captures the fundamental behavioral relationship between bicyclist route preferences and the determinants (see Kassoff and Deutschman, 1969 for an extensive discussion). In this section, researchers focused on the disaggregate-level studies, since these are most relevant for quantifying the relationship between route design attributes and bicyclist route preferences.

Table 7.1 provides a summary of earlier studies that examined the relationship between bicycle route attributes and bicycle route preferences. This summary table provides information regarding the data source (specifically respondents targeted, date of data collection, and data elicitation approach), the specific bicycling purpose considered (commuting, non-commuting, or all purposes), the focus of the analysis (and dependent variables considered), the analysis framework employed (descriptive analysis, regression techniques, or discrete choice methods), and the bicyclist characteristics and route attributes identified as determinants of bicycle route choice. Several observations can be drawn from this summary table. *First,* most of the studies have adopted either a revealed preference or stated preference survey technique to obtain information on route choices. *Second*, none of the earlier studies considered all six categories of variables identified in this study. The studies in the table have identified bikeway type (whether a designated bicycle lane, shared wide outside lane, or an off-road shared-use path) and bikeway continuity as determinants of bicycle route choice. *Third*, many earlier studies employed descriptive analysis techniques to evaluate the attributes influencing bicycle route choice. However, few studies have employed regression and multinomial logit models to evaluate the trade-offs among route attributes. *Fourth*, very few studies consider on-street parking as a determinant of bicycle route choice preferences. Those studies that considered on-street parking as a determinant did so in the context of whether on-street parking was permitted and did not consider important attributes, such as parking type (angled or parallel), parking turnover rate, length of parking area, and parking occupancy rate. *Fifth*, few studies consider the impact of directness or travel time to the destination. Travel time has been found to be an important factor in bicycle route choice for utilitarian travel (see Bovy and Bradley 1984, Hunt and Abraham 2006, and Tilahun et al., 2007). *Sixth*, none of the previous studies considered the potential that taste (sensitivity) variation has among individuals to route attributes. For instance, some bicyclists may be very safety conscious while others may be less safety conscious. This can get manifested in the form of differential sensitivity to motorized traffic volumes in route preferences. Similarly, some commuting bicyclists may be time-conscious; while others may be more time-relaxed (this may hold even after controlling for work flexibility). Ignoring the moderating effect of such unobserved individual characteristics can, and in general will, result in inconsistent estimates in nonlinear models (see Chamberlain, 1980 and Bhat, 2001).

The focus of the current work is to contribute to the existing literature on bicycle route choice analysis by (1) providing a set of route attributes in bicyclist route choice analysis, and evaluating the trade-offs among route attributes, (2) identifying on-street parking characteristics as they impact bicyclist route choice, and (3) employing a multivariate analysis framework for route choice analysis that considers taste (sensitivity) variations among bicyclists to include observed and unobserved individual characteristics.

Table 7.1: Earlier Studies of Bicycle Route Choice

Study	Data Source			Bicyclists purpose considered	Focus of the analysis (dependent variable)	Analysis framework employed	Attributes considered					
	Respondents targeted	Date of data collection	Data elicitation approach				Individual and Household	On-Street parking	Bicycle facility type and amenities	Roadway physical characteristics	Roadway functional characteristics	Roadway operational characteristics
Antonakos 1994	Questionnaire distributed to cyclists in Michigan in	1992	Revealed preference survey (based on an overall perception of bicyclists)	Leisure travel	Environmental and travel preferences of bicyclists (bicycling facilities and on-road facility characteristics)	Descriptive analysis	Age, gender, auto availability, bicycle availability, cycling experience	---	Bike facility type and continuity	Pavement surface, terrain, scenery, traffic stops, road signs	Traffic volume and speed	Distance, travel time
Aultman-Hall 1996	Bicyclists in Ontario, Canada	1993	GIS database of 397 commuter bicycle routes; a Revealed Preference survey	Commuting	Bicycle route characteristics of commute routes (proportion of bicycle routes with different route attributes)	Descriptive analysis	Age, gender	---	Facility type	Intersection spacing and configuration	---	---
Axhausen and Smith 1986	2 civil engineering classes and Bombay bicycle club members	1984	Stated Preference survey	All purposes	Bicycle route choice (bicycle route)	Descriptive analysis and linear regression	Cycling experience	---	Facility type	Pavement surface, route surrounding land-use characteristics	Traffic volume	---
Bovy and Bradley 1984	Employees of Delft University, The Netherlands	---	Stated Preference survey	Commuting	Bicycle route choice (bicycle route)	Ordinary least squares, multinomial logit	---	---	Facility type	Pavement surface	Traffic volume	Travel time
Calgary 1993	Bicyclists in Calgary	1992	Revealed preference survey	Commuting	To obtain a better understanding of bicycle facility needs (bicycle route characteristics)	Descriptive analysis	---	---	Facility type, Bicycle parking facilities	---	Traffic volume, weather	---
Davis 1995	Bicyclists in 8 test segments in Atlanta, Georgia	1995	Revealed preference questionnaires	All purposes	Evaluate the effect of roadway conditions on bicycling (route suitability for bicycling based on preferences of bicyclists)	Descriptive analysis	---	Presence of on-street parking	Facility type	Pavement surface, Intersection spacing and configuration, route surrounding land-use characteristics, grades	Traffic speed	---
Guttenplan and Patten 1995	Bicyclists near Pinellas Trail, Florida	1993	Revealed preference survey	All purposes	Use of bicycle trail for bicycling (factors influencing trail use)	Descriptive analysis	---	---	Facility type, Bicycle parking facilities, showers	---	---	Travel time

TABLE 7.1 (Continued): Earlier Studies of Bicycle Route Choice

Study	Data Source			Bicyclists purposes considered	Focus of the analysis (dependent variable)	Analysis framework employed	Attributes considered					
	Respondents targeted	Date of data collection	Data elicitation approach				Individual and Household	On-Street parking	Bicycle facility type and amenities	Roadway physical characteristics	Roadway functional characteristics	Roadway operational characteristics
Harris and Associates 1991	Nationwide survey	1991	Revealed preference survey	All purposes	Bicycle facilities and bicyclist characteristics (bicycle use information for last year, month and bicycle facility characteristics)	Descriptive analysis	---	---	Facility type	---	---	---
Hunt and Abraham 2006	Bicyclists in Edmonton, Canada	1994	Stated preference survey	Non-recreational travel purpose	Factors influencing bicycle use (bicycle route choice)	Multinomial logit model	Age, bicycling experience	---	Facility type, bicycle parking, showers	---	Traffic volume	Travel time
Landis et al. 1997	A test course located in Tampa, Florida	1997	Experimental data from test course	Experiment study with all participants of varied cycling experience	Develop a bicycle level of service variable (quality of service)	Regression analysis	---	---	Facility type	Pavement surface, route surrounding land-use characteristics	Traffic speed, traffic volume	---
Lott et al., 1978	Bicyclists in Davis, California	1974	Revealed preference data before and after the new facility construction	All purposes	Attitudes of bicyclists toward a new bicycle facility (bicycle route choice)	Descriptive analysis	---	---	Facility type	---	---	Safety concerns
Sacks 1994	Bicyclists on greenways in Baltimore	1993	Revealed preference questionnaires	All purposes	Examining the use of greenways for bicycling (bicyclist and bicycle facility characteristics)	Descriptive analysis	Age, gender, vehicle ownership, work flexibility, personal security	---	Facility type, continuity, bicycle parking, showers	---	---	---
Stinson and Bhat 2003	Commuter bicyclists in the US	2002	Web based stated preference survey	Commuting	Factors affecting commuter bicyclist route choice (bicycle route choice)	Multinomial logit model	Age, gender and income	Presence of parallel parking	Facility type, continuity	Roadway class, pavement surface, bridge type, terrain grade, traffic stops, red lights and cross streets	---	---
Tilahun, Levinson, and Krizek 2007	Employees of the University of Minnesota, excluding students and faculty	2004	Adaptive Stated Preference Survey	Commuting	To understand the tradeoffs between different bicycling facility features (bicycle route choice)	Binomial logit and linear utility models	Age, gender, bicycling season; household size, household income	Presence of side-street parking	Facility type	---	---	Travel time

Chapter 8. Data Source

The web-based stated preference survey was created by the research team to obtain data from Texas bicyclists. In this section, we discuss the web-based survey, survey administration details, and the survey experimental design.

8.1 Web-based Bicycle Survey

We adopted a web-based survey approach for several reasons. First, the web-based survey is relatively inexpensive in terms of distribution and accessibility and it is environmentally friendly. Second, a web-based survey has a quick turn-around time (in terms of receiving responses). Third, survey question branching was possible because additional questions are based on an individual's response to previous questions within the survey. That is, only relevant questions are presented to a respondent as they continue answering questions. Fourth, the analyst can implement a stated preference experiments in which the attribute levels are pivoted off the bicyclists' Revealed Preference (RP) values.

8.2 Survey Administration

The survey was administered through a website hosted by The University of Texas at Austin. The survey was created by the research team and made available through the internet, using a combination of HTML, JavaScript and Java programs. Once the initial web survey design was completed, the research team conducted test surveys to provided valuable feedback that lead to changes in design, content, attribute definitions, and presentation of the survey. The final version was made available at: http://bicyclesurvey.ce.utexas.edu.

The research team introduced the survey to various bicycle groups and several Texas cities (including Austin, Dallas, Houston, El Paso, Waco, Lubbock, Tyler, and College Station), and requested that they forward the survey to other organizations and individuals. The web link was e-mailed to student groups in Texas universities. Further, we disseminated information about the survey to media outlets in Austin (including newspapers and television channels). The survey information was also circulated with the help of metropolitan planning organizations and the Texas Department of Transportation offices.

8.3 Stated Preference Experimental Design

The focus of the stated preference experimental design was to estimate the trade-offs that influence bikeway route choices. Based on a review of earlier studies, intuitive judgment, and input from the project advisors and others, the research team identified a set of potential determinants that could affect a bicyclists' route choice with on-street parking-related attributes of particular emphasis. The focus of our analysis was narrowed to bikeway route attributes that are more likely to influence City Planning Organizations and State Departments of Transportation in designing and planning bikeways. The final attributes chosen include (by category):

- Bicyclist characteristics: Demographics (age and gender), employment-related characteristics (commute distance, work schedule flexibility), and bicycle use characteristics (reason of bicycling and experience in bicycling). Additional consideration is needed regarding individual bicyclist characteristics.

- On-street parking: Parking type (none, angled, or parallel), parking turnover rate (time), length of parking area (longitudinally), and parking occupancy rate (percentage). Additional consideration is needed regarding parking dimensions and length, adjacent land uses, bikeway type adjacent to the parking area, and traffic data.
- Bicycle facility characteristics: On-road bicycle lane (a portion of the roadway which has been designated by striping, signing and pavement markings for the preferential or exclusive use of bicyclists) versus shared roadway (a roadway which is open to both bicycle and motor vehicle travel. This may be an existing roadway, street with wide curb lanes, or road with paved shoulders). The overall width of the roadway, the bikeway type, and bikeway continuity are critical factors.[2] Additional consideration is needed regarding roadway conditions and bikeway.
- Roadway physical characteristics: Roadway grade, and number of stop signs, red lights and cross streets.
- Roadway functional characteristics: Motorized traffic volume and speed limit.
- Roadway operational characteristics: Travel time.

Note: Additional research is recommended regarding the characteristics and attributes of roadway design, traffic data, on-street parking, and adjacent land use as they relate to bikeway accommodations.

Among the attributes identified above, the bicyclists' characteristics are not part of the stated preference experiments. Rather, they are used in the empirical analysis to identify variations in sensitivity to the route attributes captured in the remaining five attribute sets listed above. Separate experimental designs were developed for commuter bicyclists (those who bicycle for commuting purposes, some of whom may also bicycle for non-commuting reasons) and non-commuter bicyclists (those who bicycle only for non-commuting purposes). The identification of respondents into these two bicyclist groups is based on questions before the stated preference experiments were presented. For commuter bicyclists, the stated preference experiments were designed to elicit information regarding commuting route choice, while, for non-commuting bicyclists, the stated preference experiments were designed to elicit information on non-commute purpose route choice. It is important to know that travel time was included in the stated preference experiments for commuter bicyclists only since travel time is generally not an issue for non-commuting bicycling.

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[2]The focus of this research was on a bicycle lane or a shared roadway (which may or may not be signed as a bike route) to better understand bike route choice behavior when sharing pavement with motorized traffic. A wide curb lane (or a wide outside lane) may be signed as a bike route. Shared-use path are physically separated from the motorized traffic either by space or barrier and were not considered. In addition, AASHTO's guide for the development of bicycle facilities (1999) discourages shared-use paths alongside roads. Within the context of bicycle lanes, we consider the case of a wide curb lane (or a wide outside lane) and not paved shoulders. We also do not distinguish between signed and unsigned shared roadways in this analysis.

Overall, there are eleven route attributes in the commuter-related stated preference experiments, and ten route attributes for non-commuting-related experiments (see Table 8.1 for a description of the attributes). Because incorporating all these route attributes to characterize routes in the stated preference experiments is overwhelming for respondents to absorb and respond to, we used an innovative partitioning scheme where only five attributes were used to characterize routes for any single respondent. At the same time, the selection of the five attributes for any individual was undertaken in a carefully designed rotating and overlapping fashion to capture the effects of all variables when the responses from the different stated preference choice scenarios were brought together. For each (and all) individual scenario, parking type (i.e., whether parking is permitted, and whether the parking type is parallel or angled), and a route attribute was included. This achieved two purposes. First it placed emphasis on how parking effects route choice. Second the survey maintained one common attribute for all stated preference choice scenarios, along with a careful overlapping for other attributes, to develop a model that incorporates the effects of all route attributes simultaneously.

Each respondent was presented with four choice questions (or choice experiments) in the survey. Within each choice question, three alternative routes (with different attributes) were available to select, and the respondent was asked to make a route choice. The route attribute levels were carefully developed to be distinct to affect bicyclist perception (see Table 8.1). The attribute levels for all the attributes except travel time are predetermined. In the stated preference experiments for commuting bicyclists the travel time levels were designed to pivot off the actual bicycle commute times reported by the respondent. This was done to preserve some quantity of realism. For example, an individual who takes 5 minutes to get to work by bicycle would find it difficult to evaluate a bike route that would take an hour.

All the levels for each of the attributes were tested for reasonability in pilot surveys, and several changes were made before arriving at the final version. The characteristics of each route in each choice scenario were developed using a balanced, orthogonal, and blocked fractional factorial design comprised of four stated preference questions for each respondent. The design is intended to extract the maximum amount of information regarding the effects of route attributes on route choice decisions. The design was checked to ensure that there was not a clear dominant alternative in any stated preference choice question. Further, researchers placed an explicit constraint in the stated preference design to ensure that, when the parking type attribute takes a level of "none" for any route in a choice question, none of the other parking attributes (parking turnover rate, length of parking area, and parking occupancy rate) appear for that choice question scenario.

Table 8.1: Bicycle Route Attribute Levels Selected for the SP Experiments

Attribute Category	Attribute	Attribute	Attribute levels
On-street parking	Parking type	The parking configuration on a shared roadway (for instance, parallel parking)	1. None 2. Parallel 3. Angle
	Parking turnover rate	The likelihood of a cyclist encountering a car leaving a parking spot along the route	1. Low (A cyclist very occasionally encounters a car leaving a parking spot) 2. Moderate (A cyclist sometimes encounters a car leaving a parking spot) 3. High (A cyclist usually encounters a vehicle leaving a parking spot)
	Length of parking area	The length of the motor vehicle parking facility on the bicycle route	1. Short (½ – 1 city block) 2. Moderate (2-4 city blocks) 3. Long (5-7 city blocks)
	Parking occupancy rate	The percentage of parking spots occupied in a motor vehicle parking facility	1. Low (0- 25%) 2. Moderate (26- 75%) 3. High (76-100%)
Bikeway facility	Bikeway continuity	A bicycle route is considered to be *continuous* if the whole route has a bicycle facility (a bike lane or wide outside lane) and *discontinuous* otherwise	1. continuous – the whole route has a bicycle facility 2. discontinuous -the whole route does not have a bicycle facility
	Bikeway facility type and width	The width of the bike lane when it is present; otherwise the roadway width	1. A bicycle lane 1.5 bicycle width wide (or 3.75 feet wide) 2. A bicycle lane 2.5 bicycle width wide (or 6.25 feet wide) 3. No bicycle lane and a 1.5 car width (10.5 feet) wide outside lane 4. No bicycle lane and a 2.0 car width (14.0 feet) wide outside lane 5. No bicycle lane and a 2.5 car width (17.5 feet) wide outside lane
Roadway physical characteristics	Roadway grade	The terrain grade of the bicycle route (for instance, moderate hills)	1. Flat – no hills 2. Some moderate hills 3. Some steep hills
	Number of stop signs, red lights and cross streets	Number of stop signs and red lights encountered on the bicycle route	1. 1-2 2. 3-5 3. More than 5
Roadway functional characteristics	Traffic volume	Traffic volume on the roadways encountered on the bicycle route	1. Light 2. Moderate 3. Heavy
	Speed limit	Speed limit of the roadways encountered on the bicycle route	1. Less than 20 mph 2. 20-35 mph 3. More than 35 mph
Roadway operational characteristics	Travel time	Travel time to destination (for commuting bicyclists only)	1. Stated travel time for commute – y 2. Stated travel time for commute – x 3. Stated travel time for commute 4. Stated travel time for commute + x 5. Stated travel time for commute + y If stated travel time ≤ 25 minutes x = 5, y = 10; If stated travel time > 25 and ≤ 45 minutes x = 5, y = 15; If stated travel time > 45 minutes x = 10, y = 20; The travel time obtained after the operations is rounded off to the nearest multiple of 5

Chapter 9. Econometric Modeling Framework

The research team formulated a panel mixed multinomial logit (or MMNL) model for the bicycle route choice analysis. The panel MMNL model formulation accommodates heterogeneity among individuals for both observed and unobserved individual attributes. In the following discussion of the model structure, we will use the index q (q = 1, 2, …, Q) for the decision-makers, i for the route alternative (i = 1, 2, …, I) and k for the choice occasion (k = 1, 2, …, K). In the current study I = 3 and K = 4, for all q.

In the usual tradition of utility maximizing models of choice, we write the utility U_{qik} that an individual q associates with the alternative i on choice occasion k as follows:

$$U_{qik} = (\beta' + v'_q)\ \ x_{qik} + \varepsilon_{qik}\ , \tag{1}$$

where x_{qik} is a $(M \times 1)$-column vector of route attributes, and the interactions of route attributes among themselves and with bicyclist characteristics, affecting the utility of individual q for alternative i at the k^{th} choice occasion. β is a corresponding $(M \times 1)$-column vector of the mean effects of the coefficients of x_{qik} on route choice tendencies, and v_q is another $(M \times 1)$-column vector with its m^{th} element representing unobserved factors specific to individual q and her/his trip environment that moderate the influence of the corresponding m^{th} element of the vector x_{qik}. A natural assumption is to consider the elements of the v_q vector to be independent realizations from a normal population distribution; $v_{qm} \sim N(0, \sigma_m^2)$. ε_{qik} represents a choice-occasion specific idiosyncratic random error term assumed to be identically and independently standard Gumbel distributed. ε_{qik} is assumed to be independent of x_{qk}. In the current context, we do not have any alternative specific variables since the route alternatives are "unlabeled" and characterized by route attributes.

For a given value of the vector v_q, the probability that individual q will choose route i at the k^{th} choice occasion can be written in the usual multinomial logit form (McFadden, 1978):

$$P_{qik} \mid v_q = \frac{e^{\beta' x_{qik} + v'_q x_{qik}}}{\sum_{j=1}^{I} e^{\beta' x_{qjk} + v'_q x_{qjk}}} \tag{2}$$

The unconditional probability can then be computed as:

$$P_{qik} = \int_{v_q} (P_{qik} \mid v_q) d\boldsymbol{F}(v_q \mid \sigma) \tag{3}$$

where $\boldsymbol{F}$ is the multivariate cumulative normal distribution and σ is a vector that stacks up the σ_m elements across all m (we assume independence of the elements of v_q). The reader will note that the dimensionality in the integration above is dependent on the number of elements in the v_q vector.

The parameters to be estimated in the model of Equation (3) are the β and σ vectors. To develop the likelihood function for parameter estimation, we need the probability of each individual's sequence of observed stated preference choices. Conditional on v_q, the likelihood function for individual q's observed sequence of choices is:

$$L_q(\beta \mid v_q) = \prod_{k=1}^{K} \left[\prod_{i=1}^{I} \{P_{qik} \mid v_q\}^{\delta_{qik}} \right], \tag{4}$$

where δ_{qik} is a dummy variable taking the value of 1 if the q^{th} individual chooses the i^{th} route in the k^{th} occasion, and 0 otherwise. The unconditional likelihood function for individual q's observed set of choices is:

$$L_q(\beta,\sigma) = \int_{v_q} L_q(\beta \mid v_q) dF(v_q \mid \sigma) \tag{5}$$

The log-likelihood function is $L(\beta,\sigma) = \Sigma_q \ln L_q(\beta,\sigma)$. We apply quasi-Monte Carlo simulation techniques to approximate the integrals in the likelihood function and maximize the logarithm of the resulting simulated likelihood function across all individuals with respect to the parameters β and σ. Under rather weak regularity conditions, the maximum (log) simulated likelihood (MSL) estimator is consistent, asymptotically efficient, and asymptotically normal (see Hajivassiliou and Ruud, 1994; Lee, 1992; McFadden and Train, 2000).

In this research, we use Halton sequences to draw realizations for v_q from its population normal distributions. Details of the Halton sequence and the procedure to generate this sequence are available in Bhat (Bhat, 2003). Bhat demonstrated that the Halton simulation method out-performs the traditional pseudo-Monte Carlo (PMC) methods for mixed logit model estimation. Researchers tested the sensitivity of parameters estimated with different numbers of Halton draws per observation; as a consequence researchers were able to obtain stable results with as few as 150 draws. In this analysis, researchers used 200 draws per observation to establish estimation.

Chapter 10. Sample Formation and Description

The data from the web survey was downloaded in ASCII format, and then imported into SPSS (Statistical Package for the Social Sciences). Respondents who provided incomplete information were removed from the dataset. Several screenings were undertaken to validate the information provided in the respondent's survey, including checking the reported commute distance traveled, reported bicycle travel times, and the ratios of the reported bicycle travel times versus the reported auto travel times for commute.

The final sample used in the descriptive analysis of the survey respondents included 1,863 respondents. Of the 1,863 respondents, 863 (46.3 percent) use their bicycle for commuting and were designated as commuter bicyclists (855 of these 863 commuter bicyclists also bicycle for non-commuting purposes such as running errands, exercising, visiting friends or family, recreation, and racing/stunt-riding). The remaining 1,000 individuals (53.7 percent) bicycle only for non-commuting purposes, and are designated as non-commuting bicyclists. The following sections present demographic and bicycling characteristics of the survey respondents.

10.1 Demographic Characteristics

In the sample, 72 percent of respondents were male and 28 percent were female (these gender shares are similar to the national bicycling shares estimated to be 63 percent and 37 percent for males and females, respectively; see National Survey of Pedestrian and Bicyclist Attitudes and Behaviors, 2002). Among the male respondents, 53 percent are commuter bicyclists and for female respondents 45 percent are commuter bicyclists.

For all the respondents who commute to work by bicycle, the average one-way commute distance is 6.88 miles. Twenty-two percent of the commuter bicyclists live within 2 miles of their work place. The majority of commuter bicyclists (78 percent) live within 10 miles of their work place and a sizeable percentage of the commuters (28 percent) live more than 10 miles from their work place (see Figure 10.1).

The work start time and work end time distributions of commuter bicyclists are shown in Figure 10.2 and Figure 10.3, respectively. 80 percent of the commuter bicyclists start work between 8 and 10 a.m., with 75 percent of them starting their work day between 9 and 10 a.m. Interestingly, a non-insignificant percentage of commuter bicyclists (14 percent) start work after 11 a.m. Figure 10.3 shows that 62 percent of bicyclists end their work day between 4 and 7 p.m., with 33 percent of them having work end times between 5 and 6 p.m. Also, a good fraction of bicyclists (21 percent) end their work day before 3 p.m. In addition to examining the work start and end time distribution for commuter bicyclists, the work schedule flexibility was measured in terms of whether the respondent believes it would be easy for her/him to arrive at work 30 minutes late and/or leave 30 minutes early from work schedule. By this definition, 51 percent of commuter bicyclists have flexible arrival times, 49 percent of them have flexible departure times, and 35 percent have flexibility in both arrival and departure times.

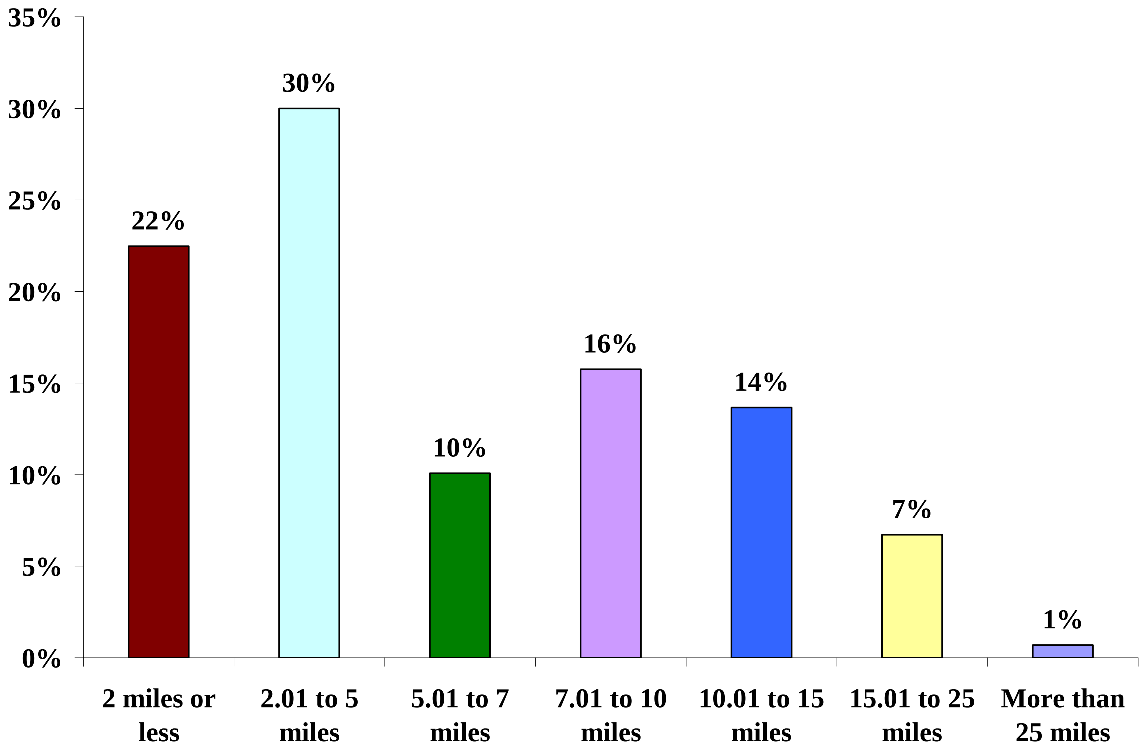

Figure 10.1: Distribution of commute distance for commuter bicyclists

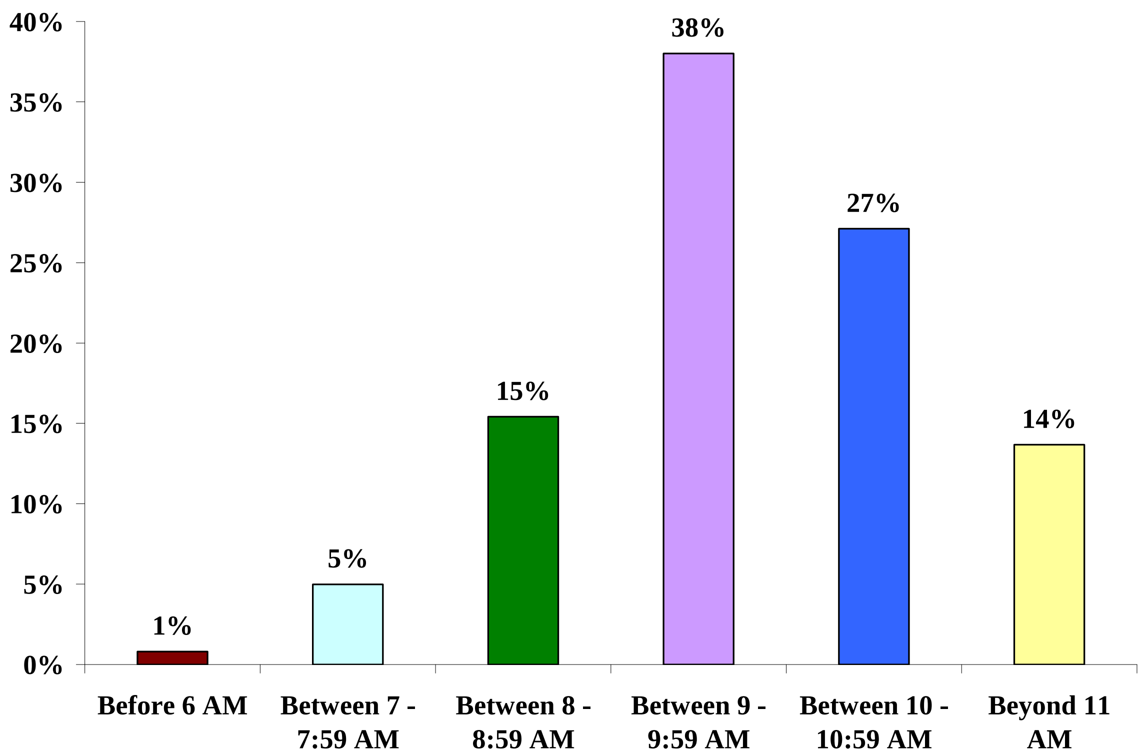

Figure 10.2: Work start time distribution of commuter bicyclists

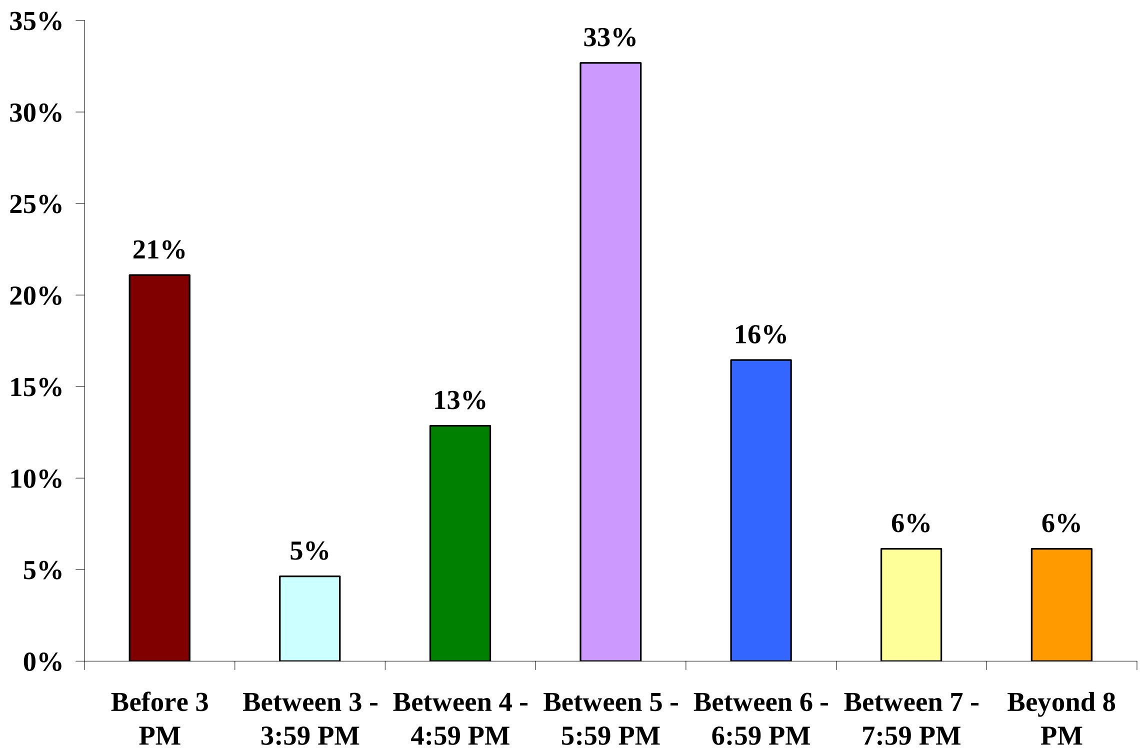

Figure 10.3: Work end time distribution of commuter bicyclists

The age distribution of respondents (commuter and non-commuter bicyclists) of the survey is provided in Figure 10.4. About two-thirds of the respondents are between the ages of 35 and 64, suggesting that bicyclists tend to be in the middle age group. The descriptive analysis of education level of respondents indicates a bias towards individuals with a higher education level (see Figure 10.5). Among the respondents, 42 percent had completed Bachelors degrees, and 33 percent had completed graduate degrees or higher. Previous research has indicated that bicyclists tend to be in the higher education and income groups (Bolen et al., 1998). However, a web-based survey is likely to contribute to the bias toward affluent/educated individuals.

The residential location distribution of respondents is presented in Figure 10.6. The figure shows that of the respondents 49 percent live in the Austin area, 17 percent were from Houston, 12 percent were from San Antonio, and 6 percent were from the Dallas-Fort Worth-Arlington area.

In terms of motorized vehicle ownership, 98 percent of the bicyclists' households own at least one automobile, with 73 percent owning two or more vehicles (Figure 10.7). All bicyclists who participated in the survey own at least one bicycle, with 88 percent having at least two bicycles in their households (Figure 10.8). The distribution of household size (Figure 10.9) shows that 81 percent of the bicyclists' households have two or more residents. The vast majority of bicyclists (71 percent) do not have any children in their household (see Figure 10.10).

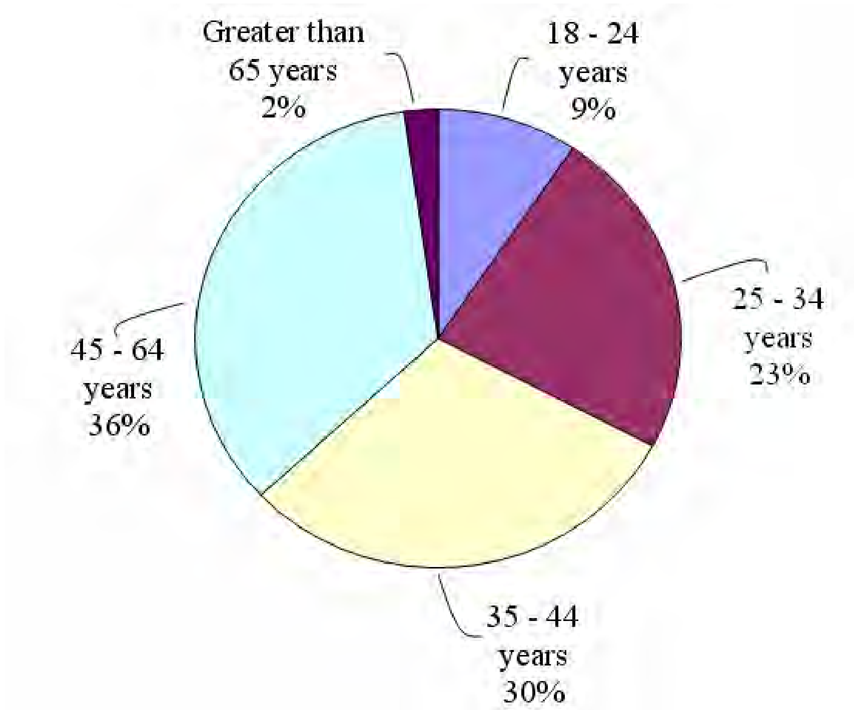

Figure 10.4: Age distribution of respondents

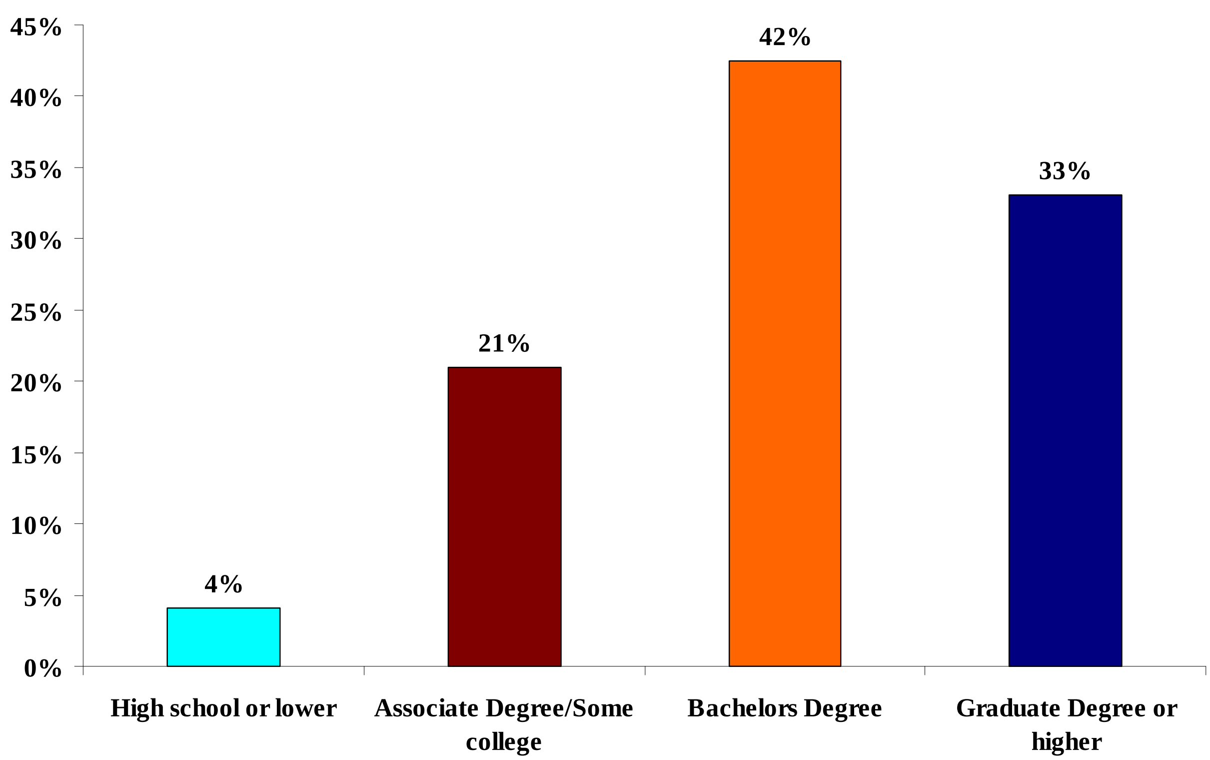

Figure 10.5: Distribution of highest level of education

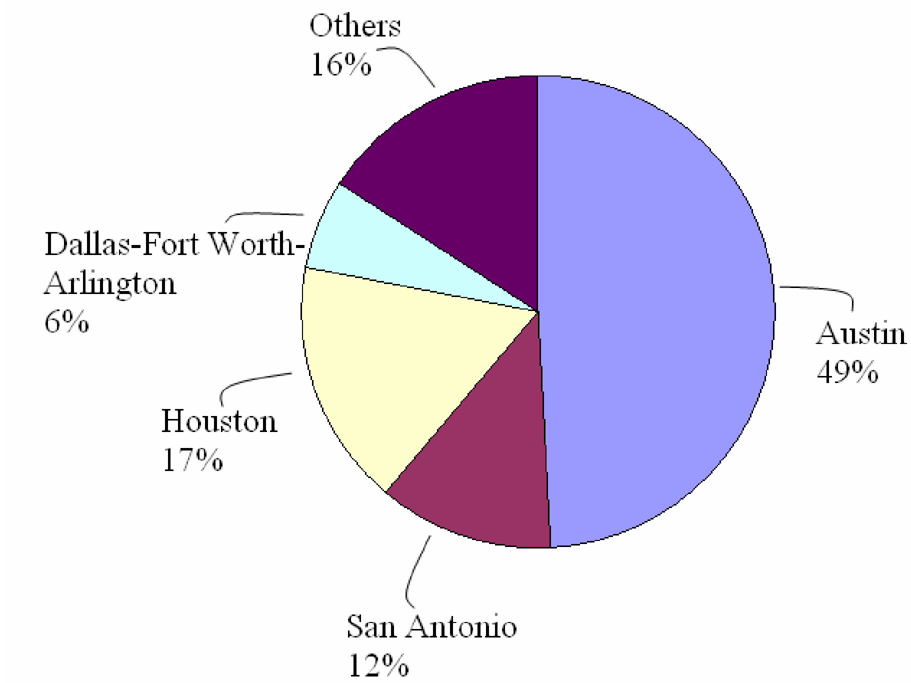

Figure 10.6: Residential location of survey respondents

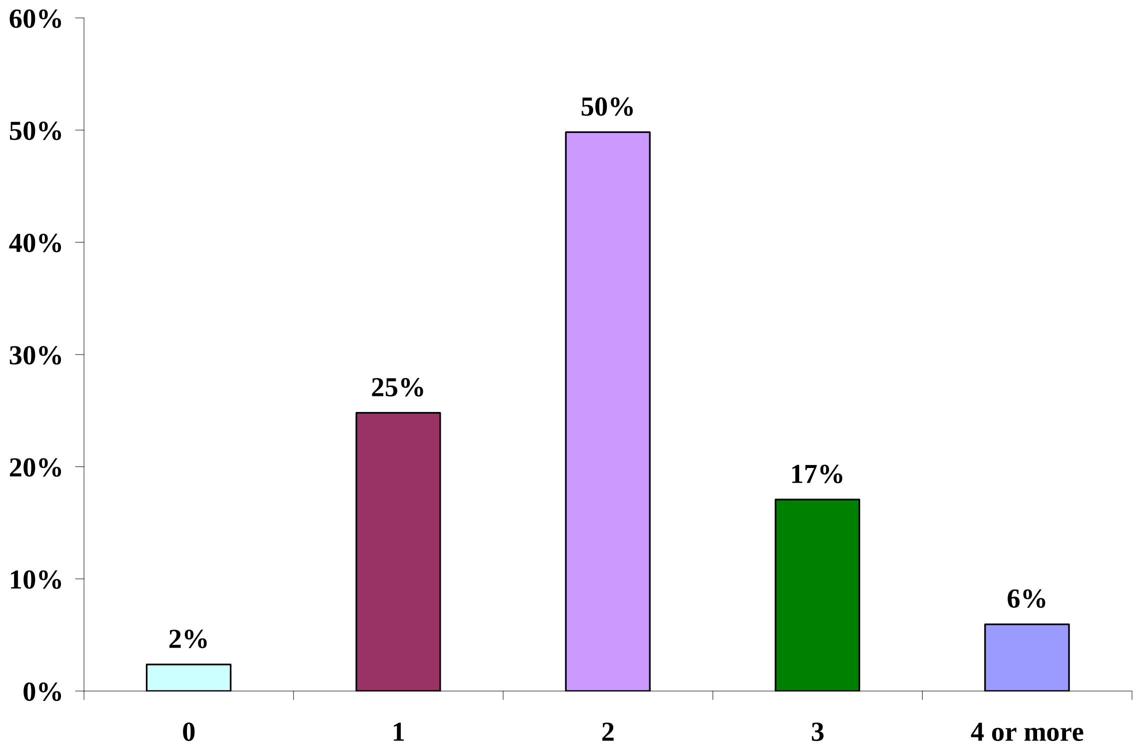

Figure 10.7: Distribution of auto ownership

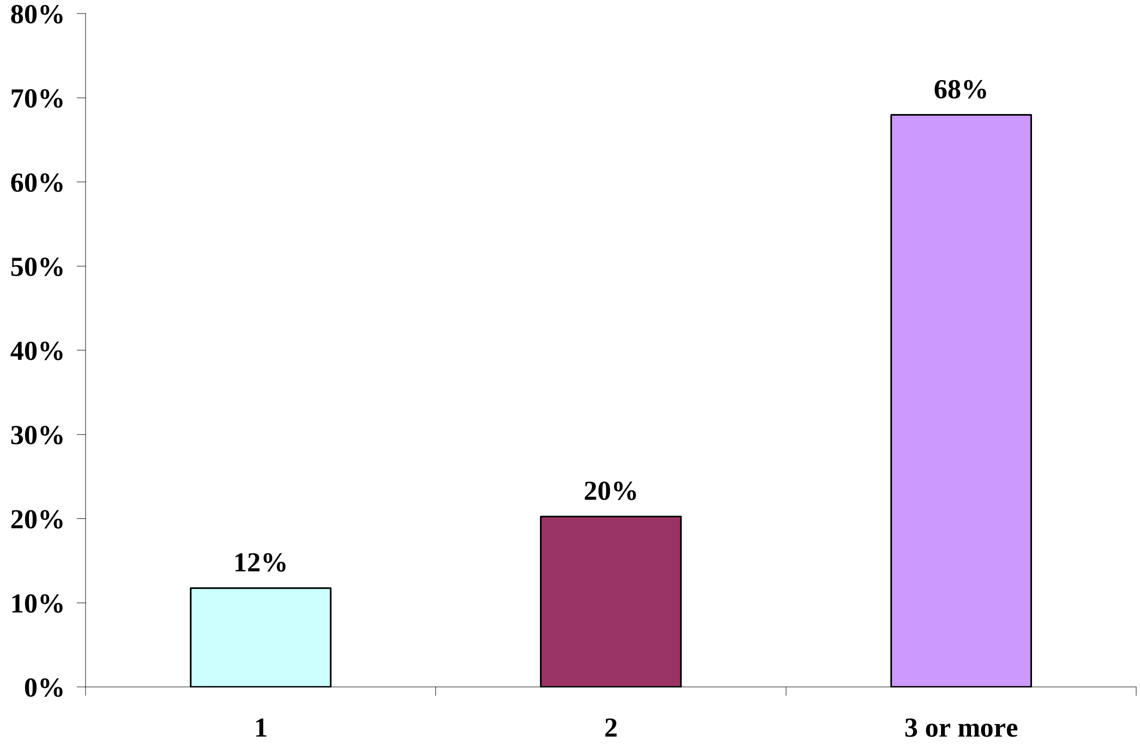

Figure 10.8: Distribution of bicycle ownership

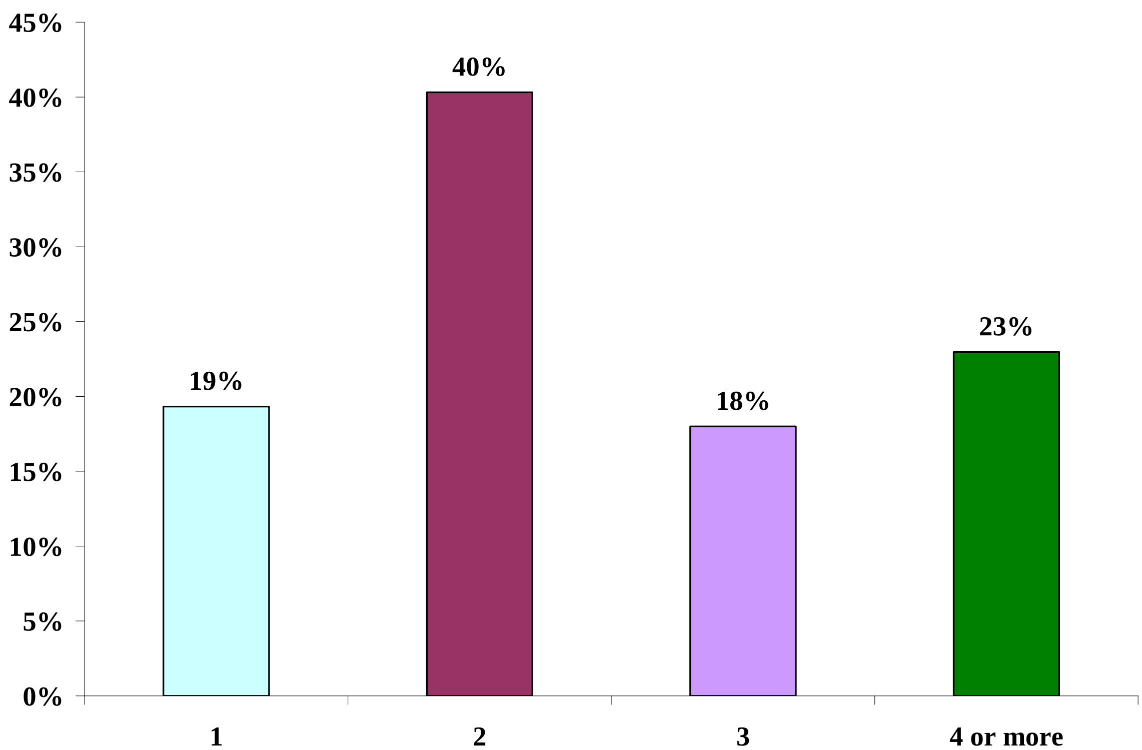

Figure 10.9: Distribution of household size

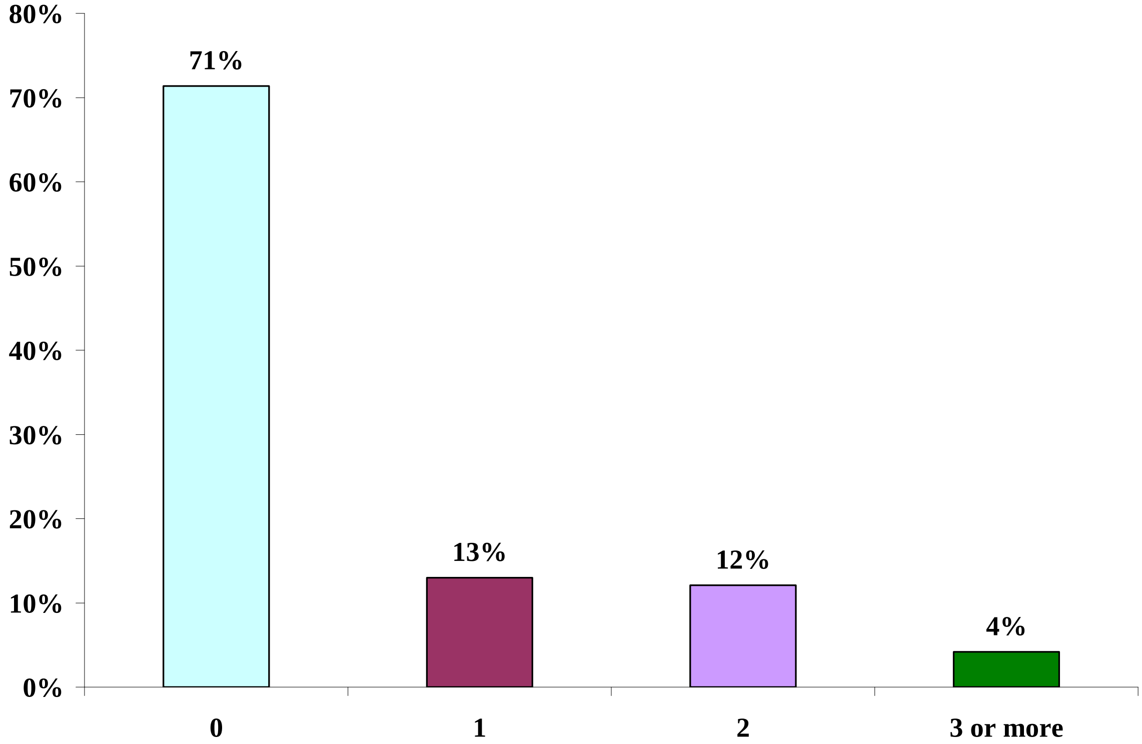

Figure 10.10: Distribution of number of children in bicyclists' households

10.2 Bicycling Characteristics

The bicycling characteristics elicited in the survey may be categorized into three groups: (1) Bicyclists' travel perceptions, (2) Bicycle use characteristics, and (3) Bicycle commute-related characteristics.

10.2.1 Bicyclists' travel perceptions

The bicyclists' travel perceptions indicate that about 70 percent of respondents feel that bicycling is "somewhat dangerous" or "very dangerous" from the standpoint of traffic crashes (Figure 10.11). In contrast, only 20 percent of respondents feel that bicycling is "somewhat dangerous" or "very dangerous" in the context of crime (Figure 10.12). Clearly, safety from traffic crashes appears to be more of a concern than safety from crime. Further, 78 percent of the respondents indicated that the overall quality of bicycle facilities in their respective communities is "inadequate" or "very inadequate" (see Figure 10.13). These results highlight the need to improve bicycling infrastructure.

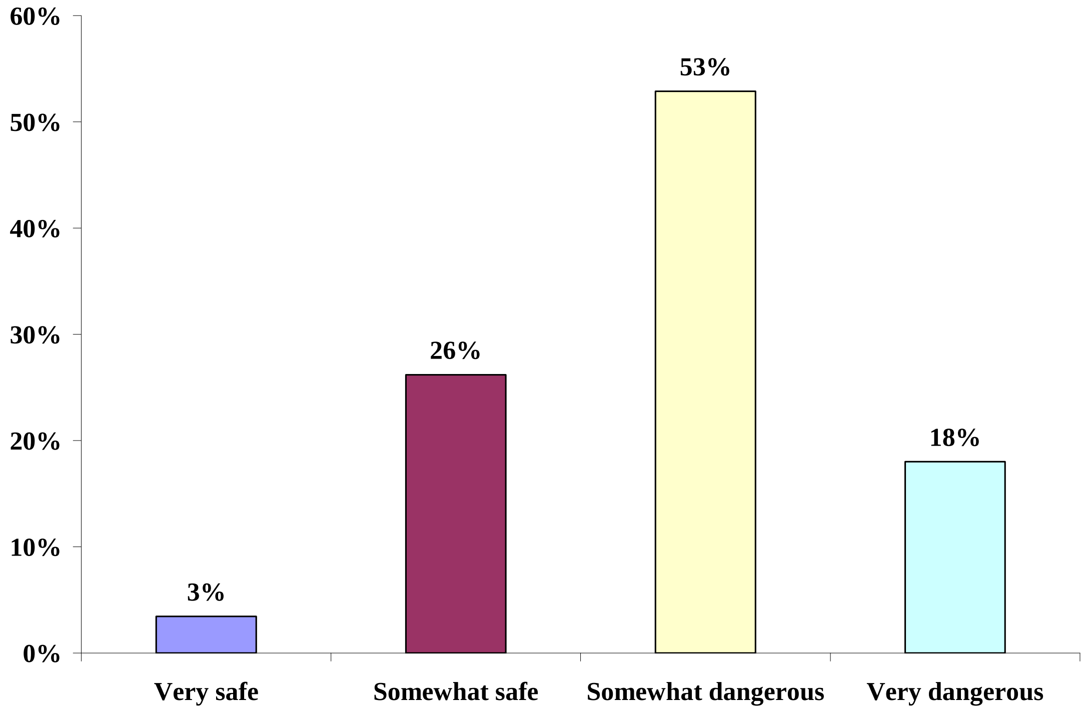

Figure 10.11: Bicyclists' perception of safety from traffic crashes

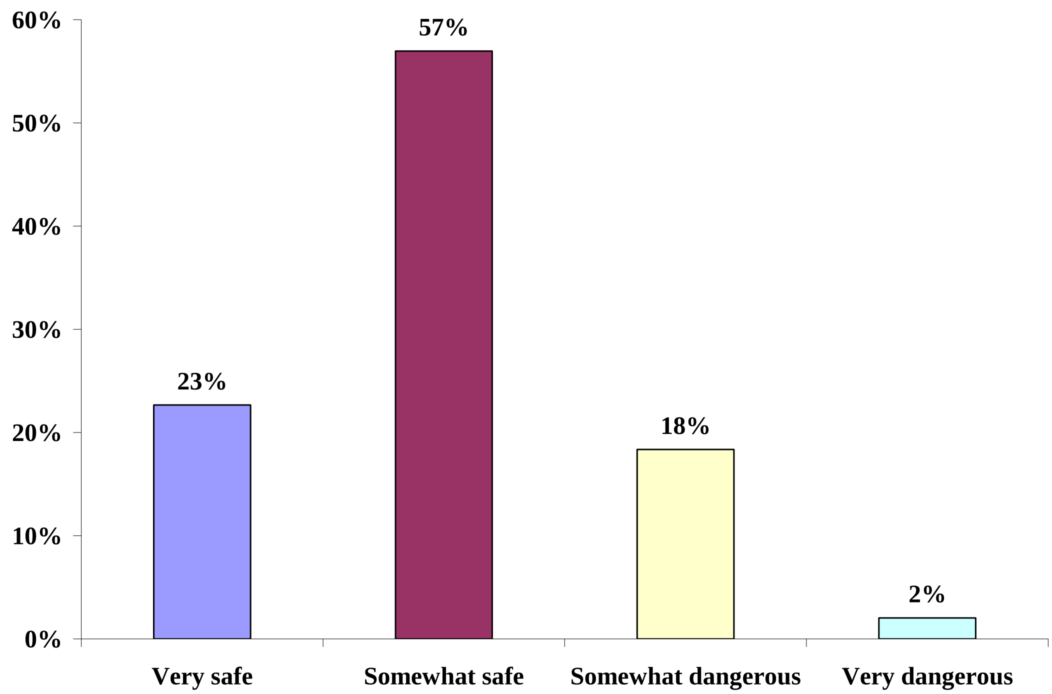

Figure 10.12: Bicyclists' perception of safety from crime

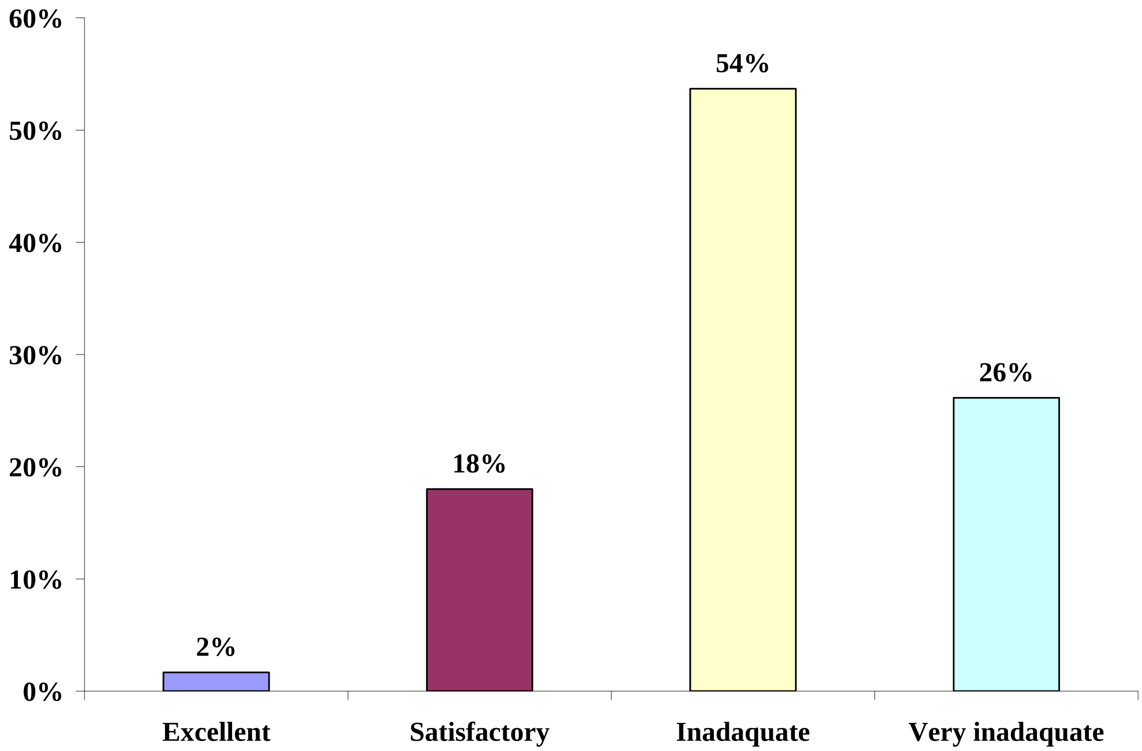

Figure 10.13: Overall quality of bicycle facilities in the community

10.2.2 Bicycle use characteristics

The survey results indicate that exercising is the most common reason for bicycling, followed by recreational activities (such as parades, riding with family around the block, etc.), and running errands (see Figure 10.14)[3]. The results indicate that bicyclists do value health-related issues, and perceive bicycling as a physical activity. Figures 10.15(a) and Figure 10.15(b) provide information regarding the time period of the year for non-commuting and commuting activities, respectively. Figure 10.15(a) shows that 69 percent of commuter bicyclists are experienced bicyclists (bicycling for a year or more), while Figure 10.15(b) illustrates a much higher percentage of the respondents are experienced non-commuting bicyclists (89 percent).

Figure 10.16 shows the seasons of the year the bicycle is used for commuting by commuter bicyclists and Figure 10.17 for non-commuter bicyclists. Figure 10.16 indicates that most of the commuter bicyclists bicycle from March to April (88 percent) and September to November (85 percent), while a slightly lower percentage (76 percent) bicycle from May to August. The least attractive time period for bicycling by commuter bicyclists in Texas appears to be from December to February, probably because of cooler weather conditions. The share of commuter bicyclists who bicycle during all the time periods is 48 percent. Figure 10.17 indicates that March to November is the most attractive time period for bicycling for non-commuting reasons, while December to February is again less attractive. The share of non-commuter bicyclists who bicycle during all time periods is 87 percent.

[3] The percentages in Figure 10.14 are greater than 100 percent because respondents can choose multiple reasons for bicycling.

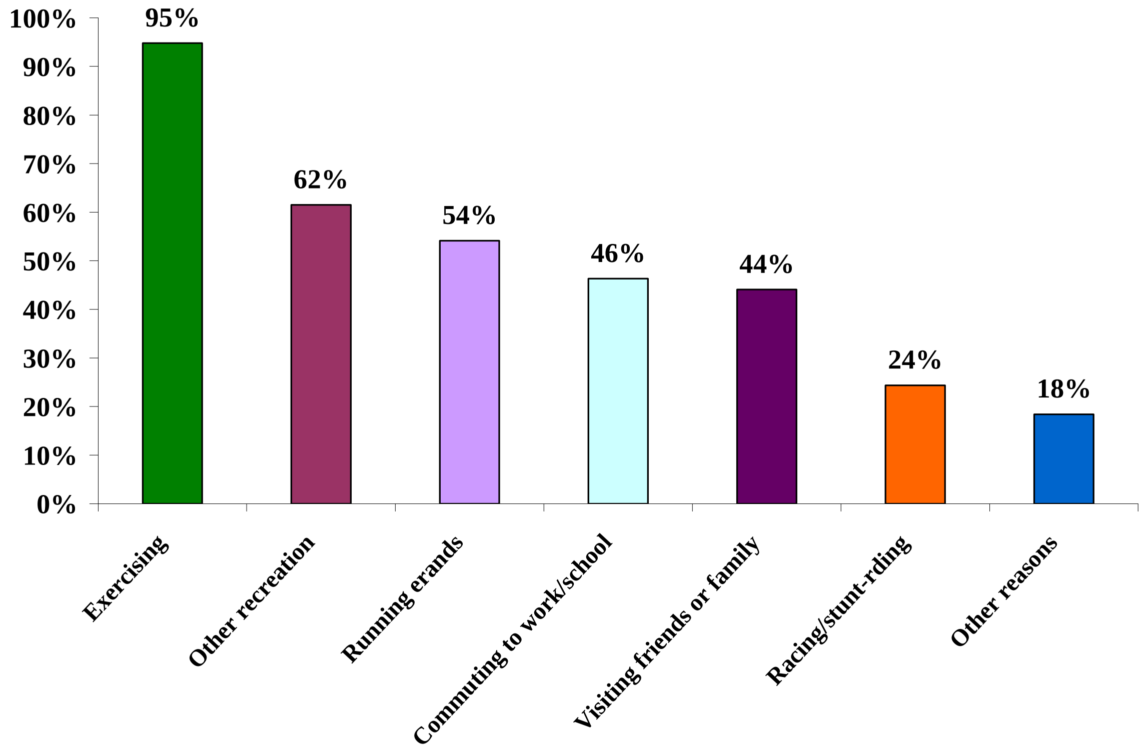

Figure 10.14: Distribution of the purpose for bicycling

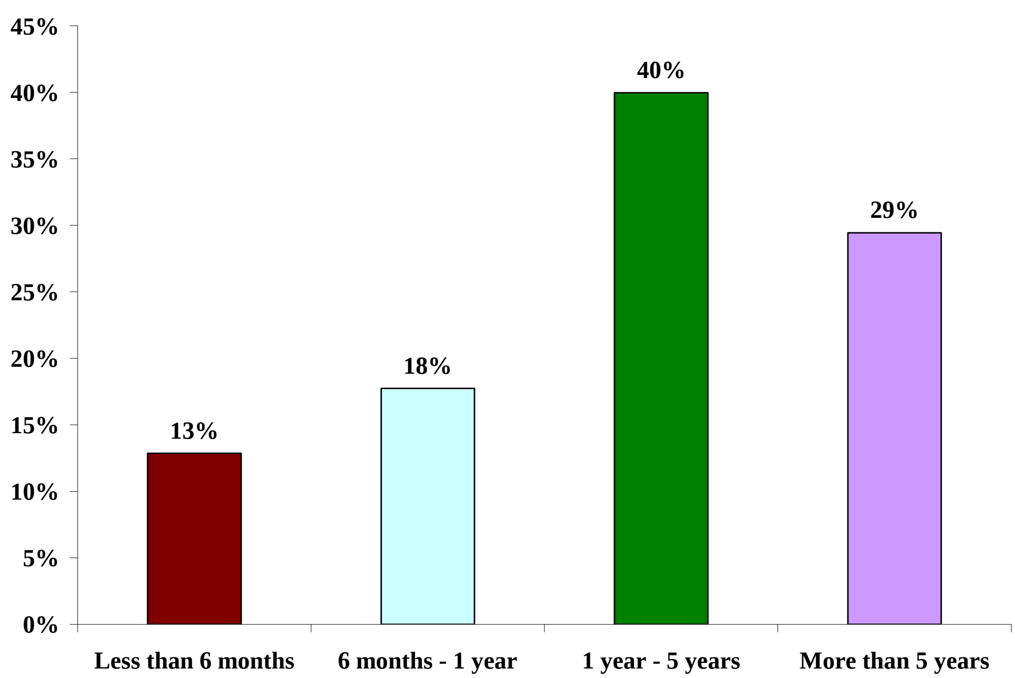

Figure 10.15: (a) Duration of bicycling for commuting

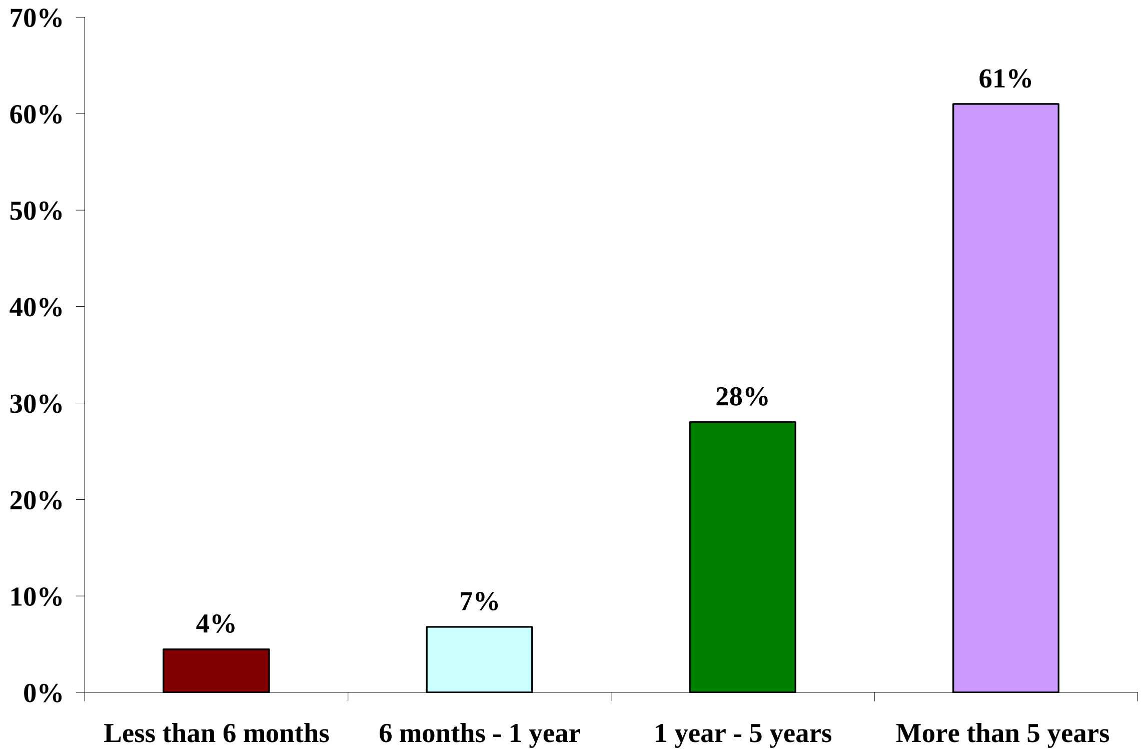

Figure 10.15: (b) Duration of bicycling for non-commuting

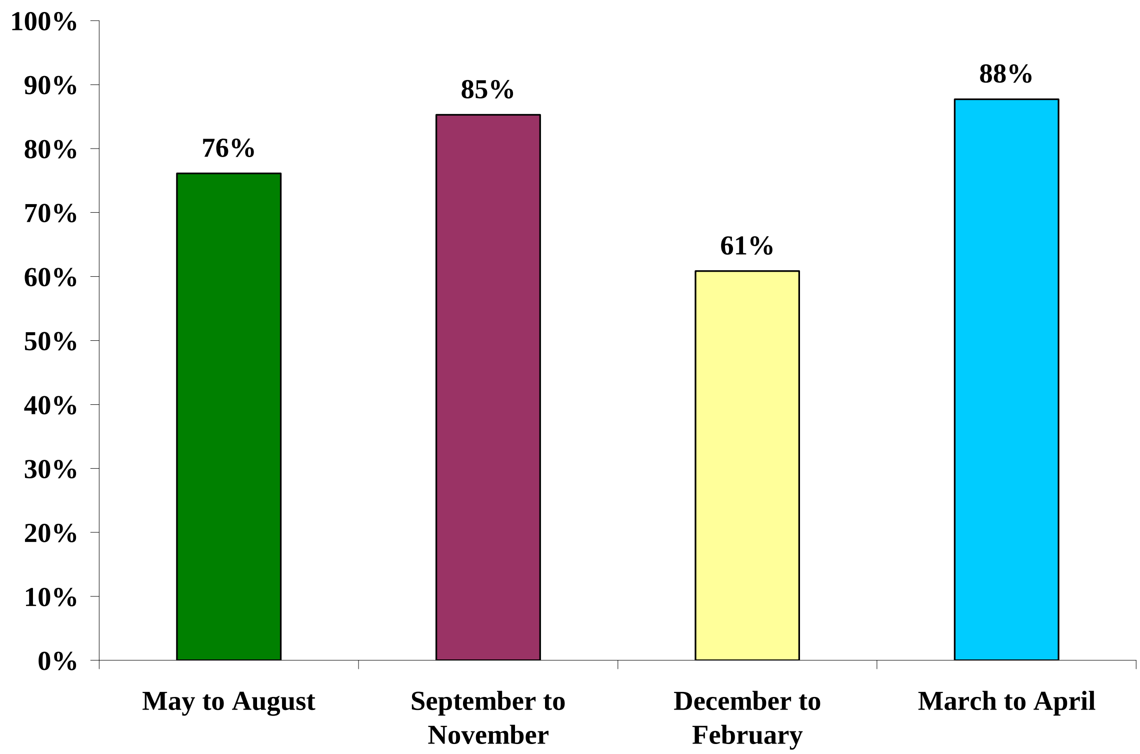

Figure 10.16: Time period of the year for bicycling for commuting

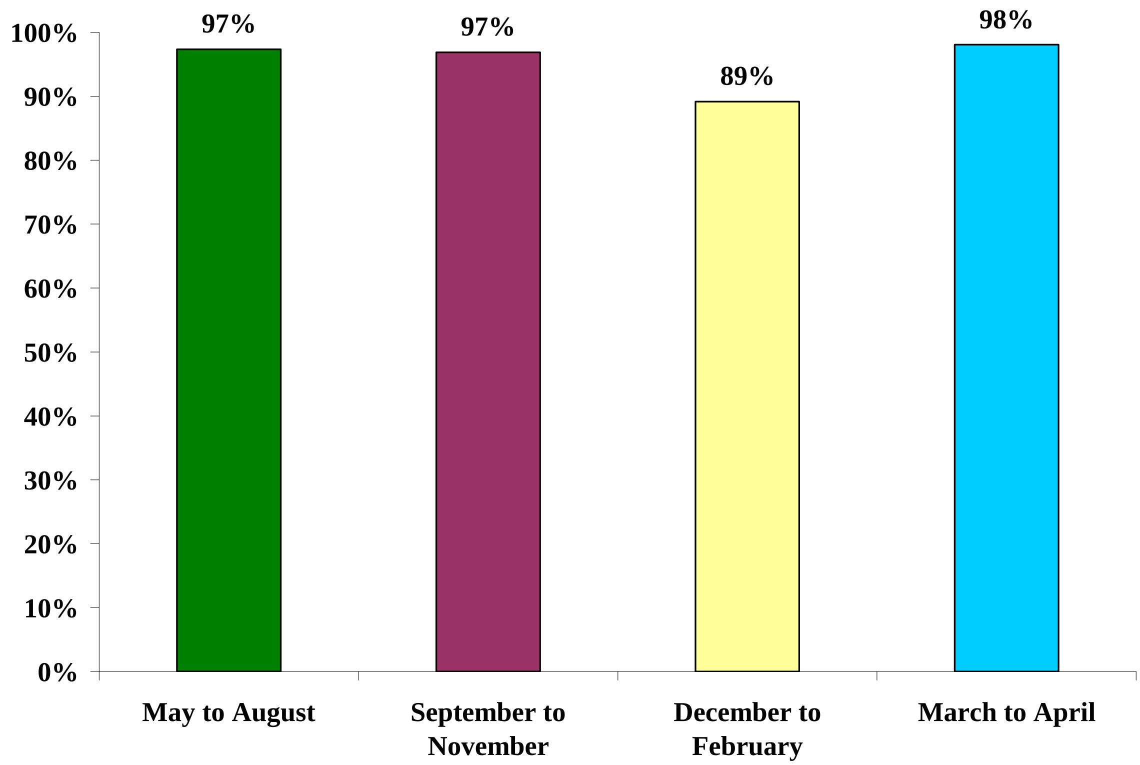

Figure 10.17: Time period of the year for bicycling for non-commuting

Figures 10.18(a) and 10.18(b) suggest that bicycling frequency during all of the time periods (i.e., May to August, September to November, December to February and March to April) follows a similar trend for both commuter and non-commuter bicyclists. According to these figures, approximately 41 percent of commuter bicyclists use bicycles to travel to work about 4-5 (or more) days a week, while 46 percent of non-commuting bicyclists use their bicycles about 2-3 days a week.

Fitness and health, pleasure/enjoyment (or leisure), and being environmentally friendly are the most compelling reasons for bicycling for both commuting (Figure 10.19) and non-commuting (Figure 10.20). A higher percentage of commuter bicyclists identify environmental concerns as a reason for bicycling to work relative to the percentage of non-commuter bicyclists who identify environmental concerns as a reason to bicycle. The leading factors discouraging respondents from bicycling for commuting and non-commuting purposes are provided in Figures 10.21 and 10.22. These figures suggest that, regardless of the reason for bicycling (i.e., commuting or non-commuting), the biggest deterrent to bicycling is inclement weather.

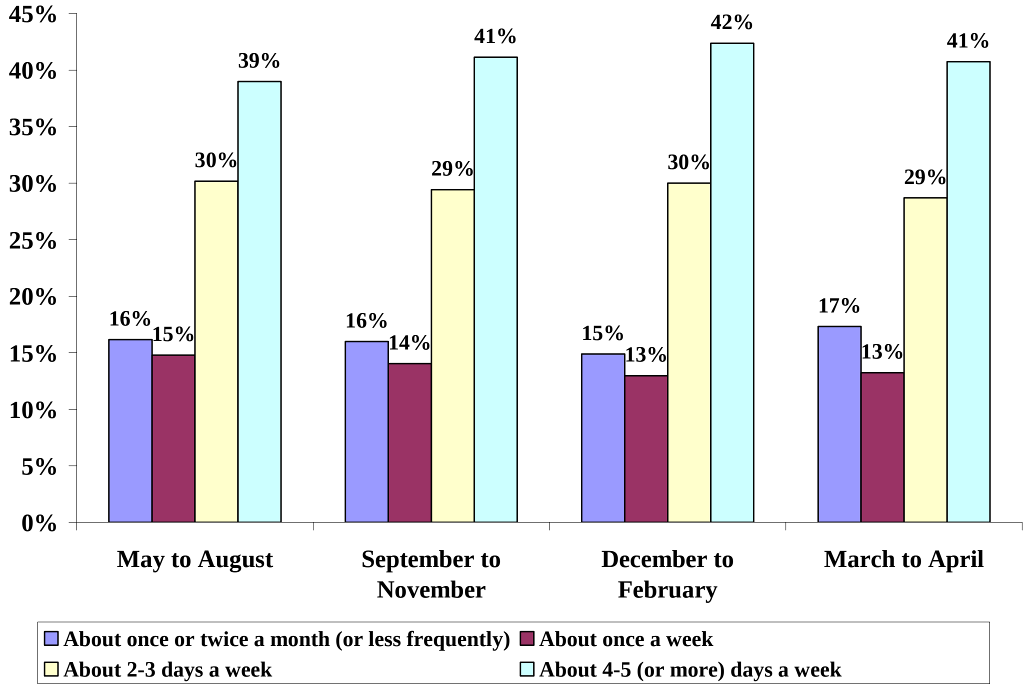

Figure 10.18: (a) Bicycling frequency for commuting during different time periods of the year

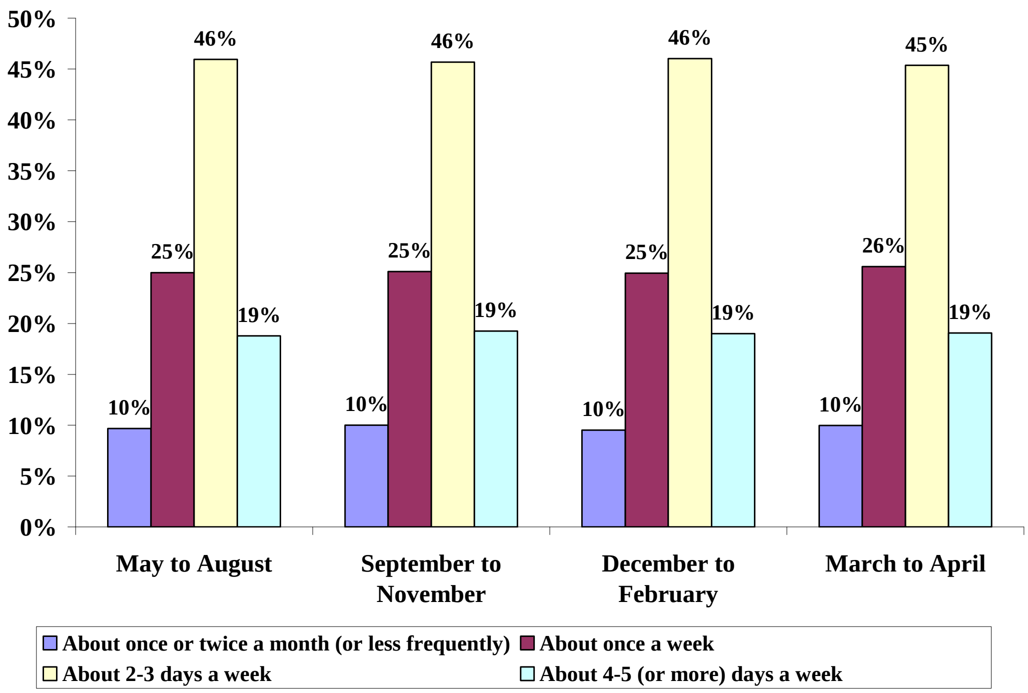

Figure 10.18: (b) Bicycling frequency for non-commuting during different time periods of the year

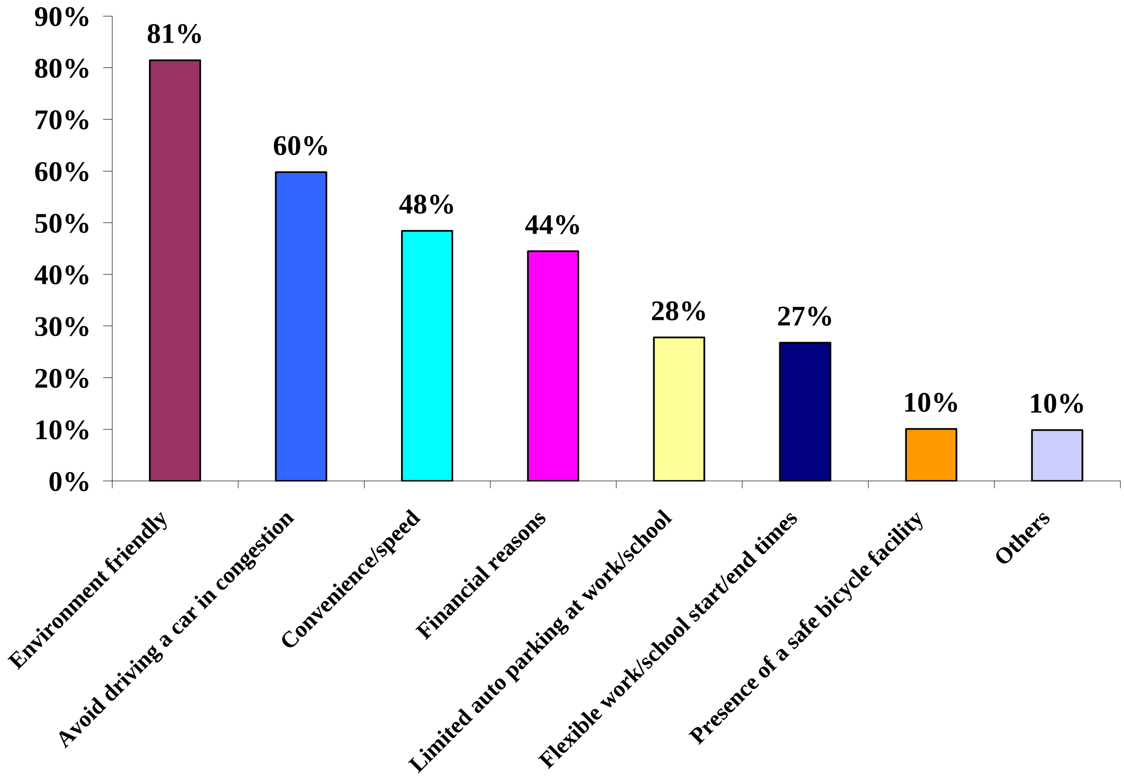

Figure 10.19: Reasons for bicycling for commuting

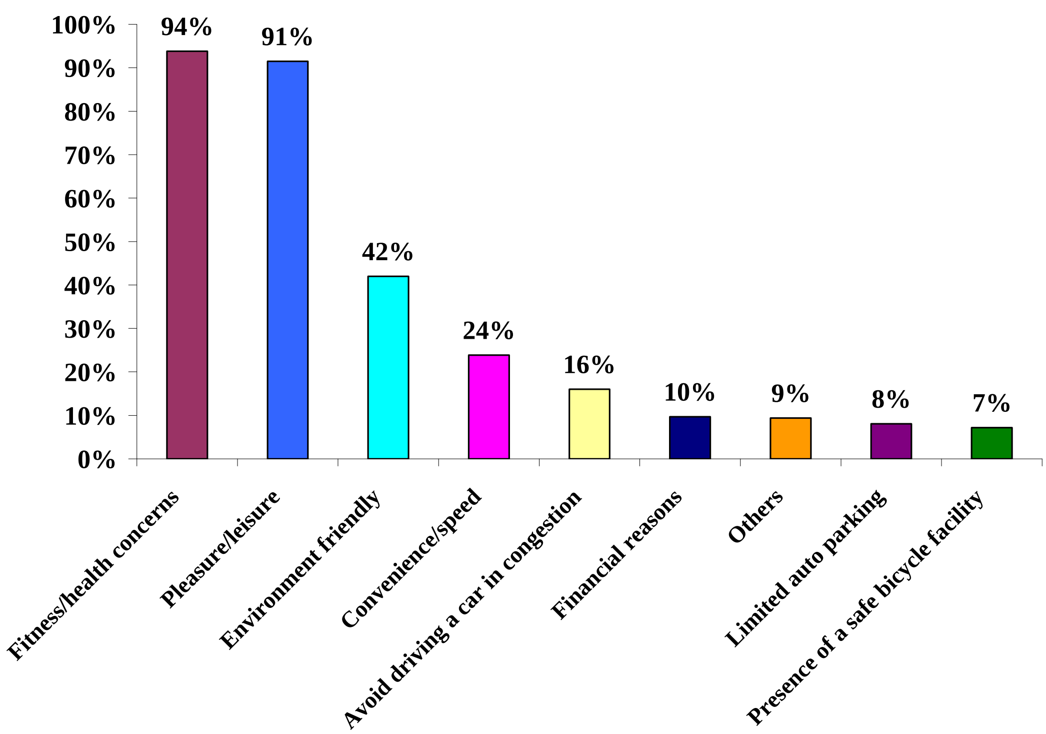

Figure 10.20: Reasons for bicycling for non-commuting

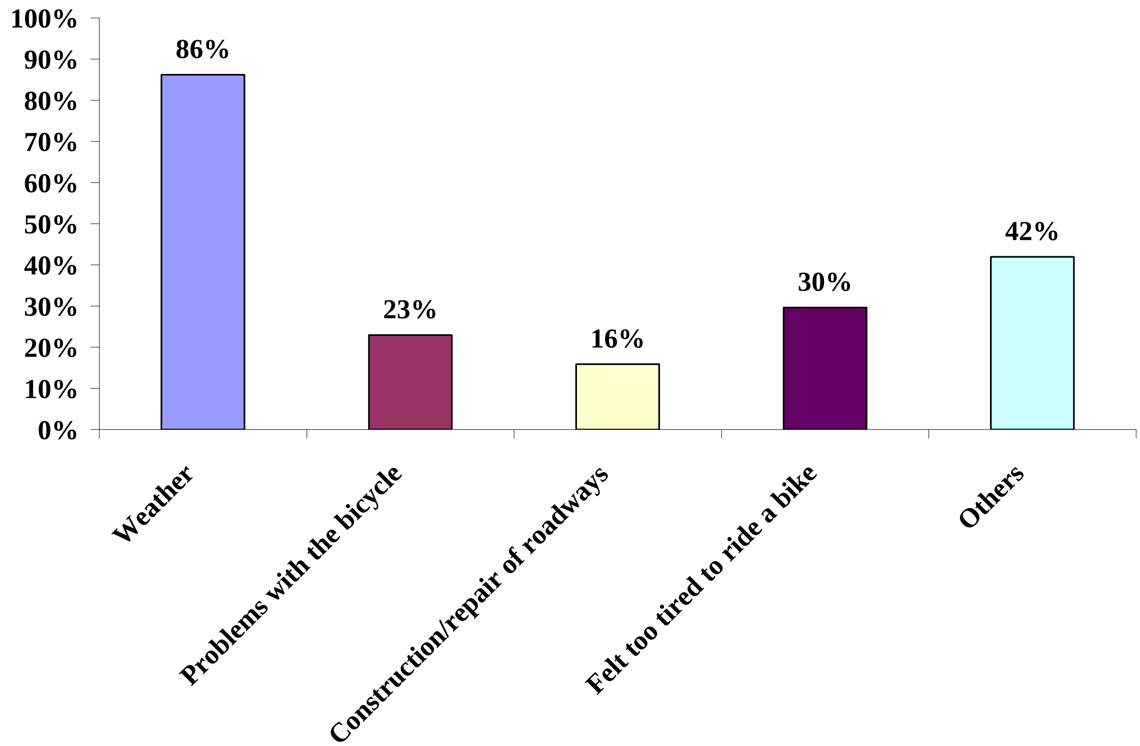

Figure 10.21: Reasons for not bicycling for commuting

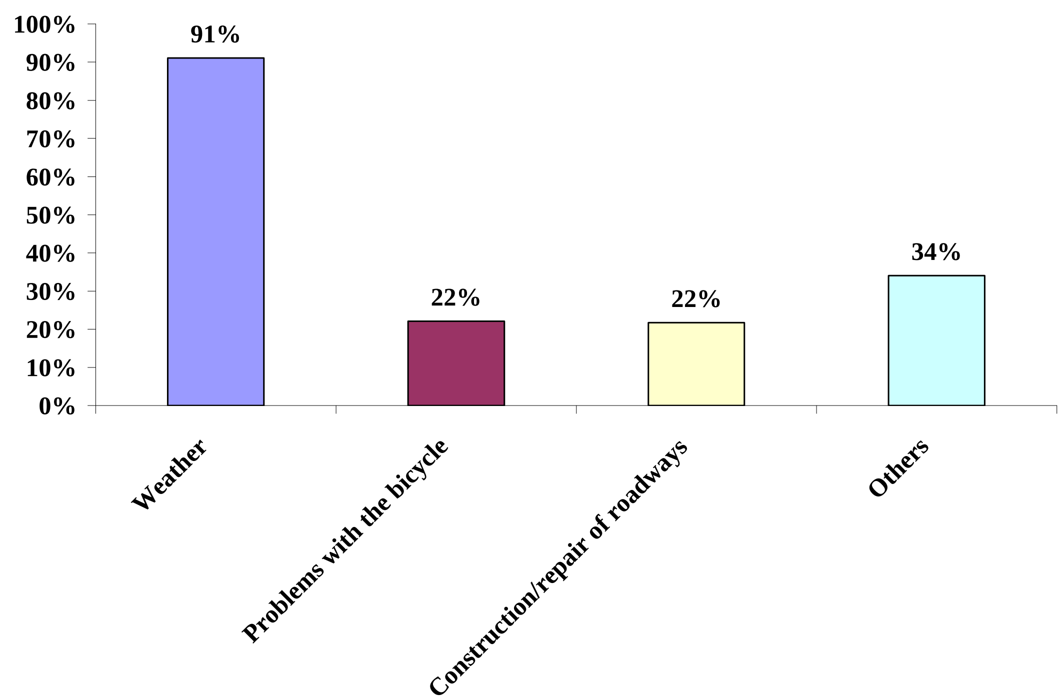

Figure 10.22: Reasons for not bicycling for non-commuting

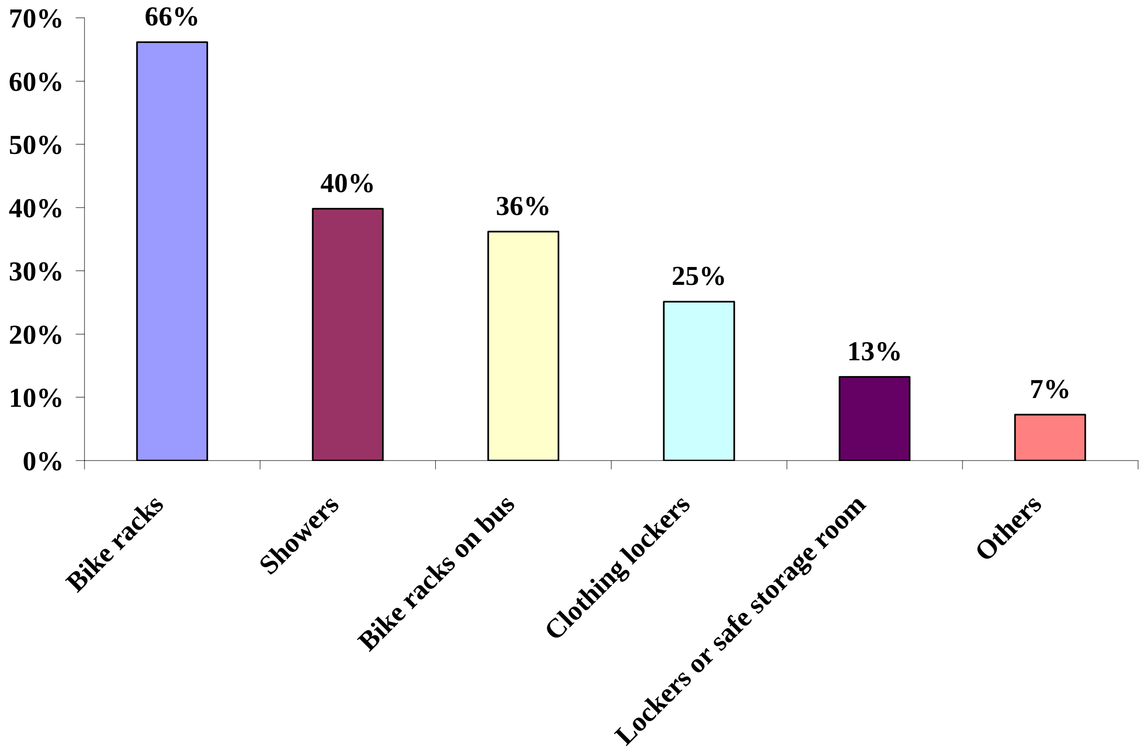

Figure 10.23: Existing bicycle amenities

10.2.3 Bicycle commute-related characteristics

As illustrated in Figure 10.23, a relatively sizeable fraction of commuter bicyclists (66 percent) indicate that there exist bike racks at their work place/school or along the routes that they take. Unfortunately, the presence of other amenities on the bicyclists' routes is less common. In terms of bicycle facilities on the commute route, most commuter bicyclists (72 percent) commute on roadways with the motorized traffic that are not designated as a bike route (Figure 10.24). However, a significant percentage of commuters use bicycle lanes exclusively while others use a combination of designated bicycle lanes and shared roadways not signed as bike routes.

The survey data revealed that about 8 percent of the respondents have been involved in a crash with a parked vehicle or vehicle in the process of parking. Among those, 68 percent defined the parking configuration as parallel and 32 percent as angled parking. About half of the crashes reported occurred because the driver of the parked vehicle was moving the car into or out of a parking spot and about one fourth of the crashes occurred when the driver of the parked vehicle opened their car door (Figure 10.25).

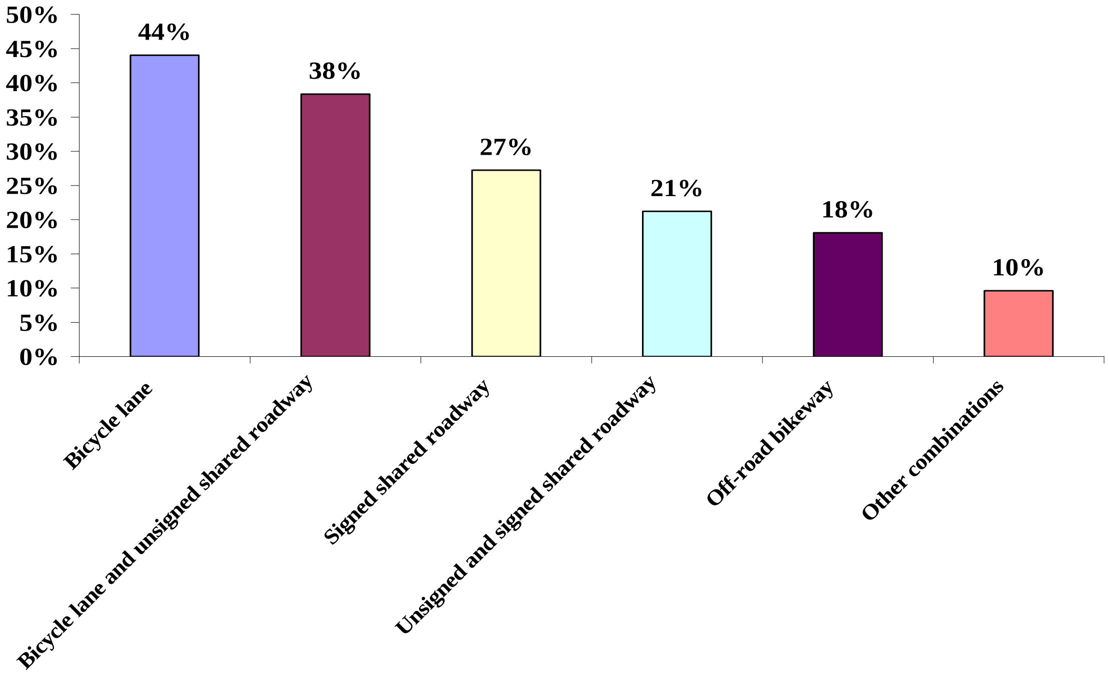

Figure 10.24: Existing bicycle facilities on the commute route

Figure 10.25: Characteristics of the crash involving parked vehicle or vehicle being parked

Chapter 11. Empirical Analysis

The records of respondents who provided incomplete information on the experimental design questions were removed from the dataset. The final estimation sample used in the empirical modeling of bicycle route choice included 6,684 choice occasions from 1,621 individuals.

The route choice model was used to consider the five sets of route attributes identified in Table 8.1, to evaluate the interaction effects among the route attributes and the interaction effects of route attributes with bicyclist characteristics. The bicyclist characteristics included age, gender, employment characteristics (whether or not the commute distance is longer than 5 miles), bicycling experience (bicycling for more than a year or less than a year), and whether the bicyclist was presented with commute-related questions or non-commute related questions.

The final variable specification was based on a systematic process of eliminating variables found to be statistically insignificant. Although several interaction variables that may have an impact on bicycle route choice were examined, only the statistically significant effects are presented as part of this report.

In the following presentation of the empirical results, the discussion begins with the model parameter estimates for the effects of variables (Section 11.1) followed by the likelihood-based measures of data fit (Section 11.2) and the elasticity effects of variables (Section 11.3). Then, researchers presented the trade-offs relative to time of the route attributes (Section 11.4). Section 11.5 illustrates some useful applications of the model.

11.1 Empirical Results

The effects of route attributes and related interaction effects are presented in Table 11.1 and discussed in the following sections by route attribute category. The parameters provide the effect of variables on the propensity to use a route. Interaction effects of route attributes with any bicyclist characteristics are shown in Table 11.1 by indenting the labels for bicyclist characteristics under the route attributes. Interestingly, while researchers attempted several interactions among route attributes, none of these turned out to be statistically significant, except two: the interaction effect of heavy motorized traffic and whether a continuous bicycle facility was available.

11.1.1 On-street parking characteristics

In the group of on-street parking characteristics, the effect of parking type is introduced by including variables associated with angled parking and parallel parking, and their interactions with other variables (the absence of parking serves as the base category). With regard to the respondents personal and trip circumstances, all bicyclists prefer no parking when compared to having any form of parking on their route. This is intuitive, since parking reduces sight distance, presents a hindrance to bicycle movement, and poses a safety threat.

Table 11.1: Bicycle Route Choice Model Results with Interaction Effects

	Attribute	Attribute Level and Interactions	Coefficient	t-statistics
On-street Parking Characteristics	Parking type (base: absence of parking)	*Parallel parking permitted*	-0.422	-4.35
		Male	-0.125	-1.77
		Age		
		18-24 years	0.281	2.60
		Long commute distance		
		5 miles or longer	-0.230	-2.45
		Angle parking permitted	-0.190	-2.98
		Male	-0.125	-1.77
		Long commute distance		
		5 miles or longer	-0.230	-2.45
	Parking turnover rate (base: low parking turnover)	*Moderate*	-0.264	-3.15
		High	-0.490	-3.09
		Female	-0.401	-2.22
	Length of parking area (base: short -1/2-1 city block)	*Moderate (2-4 city blocks)*	-0.564	-4.37
		Long (5-7 city blocks)	-0.631	-5.30
	Parking occupancy rate (base: low -0-25%)	*Moderate (26-75%)*	-0.290	-2.29
		High (76-100%)	-0.959	-7.04
Bicycle Facility Characteristics	Bikeway width/type (base: bicycle lane "3.75 ft-6.25 ft")	No bicycle lane and a 10.5 feet wide outside lane	0.089	1.56
		No bicycle lane and a ≥ 14 feet wide outside lane	0.097	2.23
	Continuous bicycle facility (base: discontinuous)	*Continuous facility*	0.859	9.72
		Long commute distance		
		5 miles or longer	0.322	2.44
		Parallel parking permitted	-0.249	-3.08
Roadway Physical Characteristics	Terrain grade (base: flat-no hills)	*Moderate Hills*	0.226	1.68
		Non-commuting bicycling	0.376	2.59
		Standard deviation	0.683	7.06
		Steep Hills	-0.353	-2.37
		Male	0.447	5.01
		Non-commuting bicycling	0.376	2.59
		Standard deviation	0.683	7.06

TABLE 11.1 (Continued). Bicycle Route Choice Model Results with Interaction Effects

	Attribute	Attribute Level and Interactions	Coefficient	t-statistics
Roadway Physical Characteristics	# Stop signs, red lights and cross streets (base: low- 1-2)	*Moderate (3-5)*	-0.513	-6.22
		Male	0.202	2.04
		High (more than 5)	-1.702	-6.46
		Male	0.190	1.83
		Experience in bicycling	0.869	3.43
Roadway Functional Characteristics	Traffic volume (base: light)	*Moderate*	-0.726	-5.99
		Male	-0.239	-2.15
		Non-commuting bicycling	0.390	3.73
		Standard deviation	1.041	15.58
		Heavy	-2.128	-16.58
		Male	-0.239	-2.15
		Non-commuting bicycling	0.390	3.73
		Long commute distance 5 miles or longer	-0.493	-3.08
		Discontinuous bicycle facility	-0.512	-2.93
		Standard deviation	1.041	15.58
	Speed limit (base: low- less than 20 mph)	*Moderate (20-35 mph)*	-0.742	-3.00
		Experience in bicycling	0.605	2.36
		Long commute distance 5 miles or longer	0.455	3.29
		High (more than 35 mph)	-1.559	-6.65
		Experience in bicycling	0.642	2.65
		Long commute distance 5 miles or longer	0.423	3.05
Roadway Operational Characteristics	Travel time	*Travel time (minutes)*	-0.068	-7.21
		Age 18-34 years	-0.052	-4.07
		Standard deviation	0.081	10.66

In this research all bicyclists, except young adults (18-24 years of age); prefer angled parking to parallel parking. In the case of angled parking, the angled configuration provides a little more maneuvering room for bicyclists and provides more time to react because bicyclists are generally more prepared and more able to see vehicles backing out from an angled parking space. In a parallel parking configuration there is higher duration of *conflict exposure* when motorists are backing into and pulling out from a parallel parking spot. In addition, bicyclists are particularly vulnerable to *dooring* incidents as motorists get into/out of their parked vehicles. Third, young adult bicyclists, surprisingly, have a slightly higher preference for parallel parking over angled parking, though this effect is statistically insignificant[4]. A better articulation of this result would be that young adult bicyclists do not see parallel parking as any more threatening than angled parking, perhaps because they have better reflexes than their older peers. Fourth, male bicyclists are more likely to stay away from routes on which parking is allowed than are female bicyclists. This may be a manifestation of male bicyclists traveling at higher speeds (see Helgerud et al.). Finally, the parking type effects also indicate that parking is more of a deterrent in route choice for long commute trips (distance > 5 miles) relative to shorter commute trips and non-commute trips. This is possibly related to the duration of constant (and draining) alertness that is needed for long distance commute routes.

The remaining on-street parking variables *switch on* the parking type being parallel or angled parking. Parking turnover is introduced with the case of low parking turnover (a cyclist will occasionally encounter a car leaving a parking spot) as the base category. The results in Table 11.1 show that bicyclists are less likely to use routes with moderate turnover (a cyclist sometimes encounters a car leaving a parking spot) and high turnover (a cyclist usually encounters a car leaving a parking spot) when compared to low turnover rates. Female bicyclists are especially sensitive to high turnover rates. Overall, bicyclists (and especially female bicyclists) shy away from routes where they are likely to encounter vehicles leaving parking spots. This suggests that some consideration should be given to relax or remove time-restricted parking limits (such as 30-minute parking or 1-hour parking) on roadways designated as bike routes.

The results of the last two on-street parking-related variables reinforce the general notion that bicyclists prefer routes with less parking activity (if they have to choose among routes with or without parking). Specifically, when parking is present, bicyclists prefer shorter lengths of parking, as can be observed from the negative sign on the coefficient of "moderate length (2-4 city blocks)" and the even higher negative sign on "long length (5-7 city blocks)". Similarly, among alternative routes with parking, bicyclists prefer those with lower parking occupancy rates. It is also interesting to note that bicyclists preferred routes with long parking lengths that have moderate parking occupancy rates (latent propensity reduction of $-0.631-0.290=-0.921$ compared to short parking areas and low occupancy rate) relative to routes that have moderate parking lengths and high parking occupancy rates (latent propensity reduction of $-0.564-0.959=-1.523$ compared to short parking areas and low occupancy rate).

Interaction effects of parking characteristics with bicyclist experience, bicycle facility characteristics, and roadway physical/functional characteristics were also considered, but surprisingly none of these other interaction effects came out to be statistically significant. The

[4] The difference in the coefficient between parallel parking and angled parking for young adults is (-0.422+0.281-(-0.190) = 0.042, which shows a slight preference for parallel parking relative to angled parking. However, the t-statistic corresponding to this difference is only 0.26.

implication is that parking characteristics do not differentially impact bicyclist route choice based on bicyclist experience and bicycle facility/roadway characteristics.

11.1.2 Bicycle facility characteristics

The variables in Table 11.1 represent the bikeway characteristics of the bicycle route choice model results with interaction effects. Two attributes are used to capture the characteristics. The first is whether the bikeway is a bicycle lane (a portion of the roadway which has been designated by striping, signing and pavement markings for the preferential or exclusive use of bicyclists) or a shared roadway (a roadway which is open to both bicycle and motor vehicle travel), and corresponding bike lane and roadway widths. This attribute is captured in the form of four dummy variables, with the base category being the presence of a 3.75 ft bicycle lane (equivalent to a bicycle "width" of 2.5 ft and a half). The four dummy variables are: (1) presence of a 6.25 ft bicycle lane (equivalent to 2.5 bicycle widths), (2) no bicycle lane and a 10.5 ft wide outside lane (equivalent to 1.5 car widths), (3) no bicycle lane and a 14.0 ft wide outside lane (equivalent to 2 car widths), and (4) no bicycle lane and a 17.5 ft wide outside lane (equivalent to 2.5 car widths). The second attribute is whether the bicycle lane or roadway is a continuous bike route.

The findings in Table 11.1 show no statistically significant differences in preferences between a 3.75 ft bicycle lane and a 6.25 ft bicycle lane (and so both of these levels form the base category). The bicyclists in this survey prefer a shared roadway to a designated bicycle lane. While this result may seem counterintuitive, the respondents in this survey may have perceived that the shared roadway provides more maneuvering room (or the respondents have the perception of more maneuvering room) by not *boxing* cyclists into a bicycle lane, giving the psychological freedom to go around vehicles/objects as needed. In addition, many on-street bikeways have been retrofitted on existing roadways by reducing motor lane widths and providing minimal width bike lanes. When a bikeway is a retrofit facility, a wide outside lane may be more desirable. However, when the motor lane width is not compromised and the bike lane width is 5 feet or greater, cyclists tend to prefer the designated bike lane.

Another concept is vehicular bicycling (Forester, 1993, 1994), which is based on the notion that motorists should be educated to treat bicyclists as lawful users of roadways. Proponents of vehicular bicycling oppose bicycle lanes on the grounds that it "promotes the belief that bicyclists are not legitimate users of ordinary roads" (see Pucher et al., 1999). However, this result may also be related to the fact that many respondents in the survey are experienced bicyclists and may be bicycle enthusiasts with a *road warrior* mentality. Also, it should be noted that the result here is confined to current bicyclists. It is possible that non-bicyclists would be more willing to bicycle if there were a designated bicycle lane designed to meet AASHTO-recommended widths without compromising the adjacent motor lane, rather than a wide outside lane (see Wilkinson et al., 1994).

The other variable in the bicycle facility characteristics category is bikeway continuity, which indicates whether the bikeway is a continuous bike route (bicycle lane or shared roadway). The positive coefficient corresponding to the continuity dummy variable clearly underscores the preference among bicyclists for a continuous bike route; especially for long commute trips (see Stinson and Bhat, 2003, and Antonakos, 1994 for a similar result). The presence of parallel parking effectively leads to a "discontinuous-like" path due to the intrusion of vehicles into the bicyclist's path.

11.1.3 Roadway physical characteristics

Among the group of roadway physical characteristics, the positive sign on "moderate hills" indicates a mean preference for slightly hilly terrain (compared to flat terrain), especially for non-commuting bicycling. This trend may be attributed to the preference for a bicycle route that is not monotonous in landscape or physical effort, especially for bicyclists undertaking bicycling for recreation/leisure (see Stinson and Bhat, 2003 for similar results). Bicyclist may prefer an occasional uphill effort followed by a period of rest on the downhill side when compared to a more constant level of effort on flat ground. The standard deviation estimate suggests that, among commuting bicyclists, 63 percent prefer moderate hills to a flat riding surface, while 37 percent prefer a flat riding surface to a moderate hill surface. The corresponding estimates for non-commuting bicyclists are 81 percent and 19 percent, respectively.

The coefficients on "steep hills" and its interaction terms indicate the following general route choice trends (the interpretations are based on combining the estimates on the "steep hills" variables and its interaction effects. Female bicyclists commuting to work avoid routes with steep hills. Male bicyclists commuting to work marginally prefer routes with steep hills to those with flat terrains, but prefer routes with moderate hills to steep hills. Female bicyclists riding a bicycle for non-commuting purposes are indifferent between routes with steep hills and flat terrains, but prefer routes with moderate hills to both the flat and steep hill extremes. Male bicyclists riding a bicycle for non-commuting purposes have a statistically significant preference for routes with steep hills over moderate hills, and for moderate hills over flat terrains. Overall, these gender differences in preference for terrain grade may be associated with the higher inclination for physical activity among men relative to women (see, for instance, Bhat and Lockwood, 2004 and Lawrence and Engelke, 2007). Of course, the statistically significant estimate on the standard deviation corresponding to the "steep hills" variable also indicates substantial unobserved heterogeneity in preferences among bicyclists for steep hills.

The final variable in the category of roadway physical characteristics corresponds to the number of stop signs, red lights and cross streets on bicycle routes. The results clearly reflect the reduced likelihood of bicyclists using routes with a higher number of traffic controls and cross-streets. However, males and experienced bicyclists are not as bothered by traffic controls and cross-street traffic as are females and inexperienced bicyclists.

11.1.4 Roadway functional characteristics

The motorized traffic volume and speed limit are used to represent roadway functional characteristics. As expected, bicyclists, in general, prefer a bike route with less traffic. This is particularly so for men (relative to women) and bicyclists commuting to work. Bicyclists commuting long distances are especially sensitive to heavy traffic. Bike routes that are discontinuous with heavy traffic increase the conflict points and accident hazards for bicyclists and are not favorably evaluated by bicyclists, as evidenced by the negative interaction term corresponding to "discontinuous facility" and "heavy traffic volume." The statistically significant standard deviation on the moderate and high volume dummy variables show that there is substantial variation in how bicyclists respond to traffic volume conditions, depending on unobserved personality traits (for example, some bicyclists may be less concerned about riding with traffic, while others may be paranoid and claustrophobic traveling with traffic).

The results corresponding to the speed limit variables show a preference for roadways with lower speed limits. However, this preference is tempered for individuals experienced in bicycling and for long distance commuting. The study results show that experienced bicyclists commuting long distances (prefer moderate speed limit routes to low speed limit routes, perhaps because they are more experienced bicyclists. However, even experienced bicyclists avoid high speed roadways with increased safety hazards.

11.1.5 Roadway operational characteristics

The final set of variables in Table 11.1 corresponds to travel time effects. These variables are relevant only for commute-related route choice. The coefficient on the travel time variable is negative and highly significant, reflecting a preference for shorter commute travel times. The results also show that young bicyclists (18-34 years) are more sensitive to travel time than are older bicyclists (35 years or over). Finally, there is a relatively high variation in the sensitivity to travel time due to unobserved factors (for example, some individuals may be dynamic *go-getters* who value time substantially, while others may be peaceful *bigger-life* picture-oriented individuals who enjoy their time bicycling to work). The magnitude of the travel time coefficients relative to the standard deviation estimate implies a negative effect of travel time for 80 percent of bicyclists who are 35 years or older. This percentage increases to 93 percent for individuals who are younger than 35 years.

11.2 Likelihood-Based Measures of Fit

The log-likelihood value at convergence of the final mixed multinomial logit (MMNL) model with interactions is -5277.85. The corresponding log-likelihood value at convergence of the simple multinomial logit (MNL) model without the unobserved individual heterogeneity terms is -5403.75. The likelihood ratio test value for comparing the MMNL model with the MNL model is 251.80, which is much higher than the critical chi-square value with 3 degrees of freedom (corresponding to the unobserved heterogeneity terms related to the sensitivity to roadway terrain, traffic volume, and travel time) at any reasonable level of significance. This clearly indicates the presence of unobserved individual factors that influence the sensitivity to roadway terrain, traffic volumes, and speed limits in bicyclist route choice decisions. Additionally, the log-likelihood value at convergence for the model without any explanatory variables or unobserved heterogeneity is -5488.33. A likelihood ratio test between our final specification and the model without any explanatory variables or unobserved heterogeneity is 420.96, which is again much higher than the critical chi-squared value with 23 degrees of freedom at any reasonable level of significance. This clearly underscores the value of the model to explain route choice as a function of route attributes and their interactions with bicyclist characteristics

11.3 Elasticity Effects of Bicycle Route Attributes

The parameters on the exogenous variables in Table 11.1 do not directly provide the magnitude of the effects of variables on route choice probabilities. To address this issue, we compute the aggregate-level “elasticity effects” of bicycle route attributes.

The aggregate-level elasticity effect of a continuous exogenous variable *x* (such as travel time) on the expected likelihood of choosing a route $(\overline{P}_i)$ may be computed from the choice probability expression in Equation (2) as:

$$\eta_x^{\bar{P}_h} = \frac{\sum_q \sum_k \left[\int_{v_q} \beta_h (P_{qik} \mid v_q) \left[1 - (P_{qik} \mid v_q) \right] dF(v_q \mid \sigma) \right] x_{qik}}{\sum_q \sum_k \left[\int_{v_q} (P_{qik} \mid v_q) dF(v_q \mid \sigma) \right]}, \qquad (6)$$

where β_h is the coefficient specific to the continuous variable *h* and x_{qik} is the value of the continuous variable for individual *q* for the i^{th} alternative for her or his k^{th} choice occasion.

Finally, to compute an aggregate-level "elasticity" of a dummy exogenous variable (such as heavy traffic volume), we change the value of the variable to one for the subsample of observations for which the variable takes a value of zero and to zero for the subsample of observations for which the variable takes a value of one. We then sum the shifts in expected aggregate shares in the two subsamples after reversing the sign of the shifts in the second subsample, and compute an effective percentage change in expected aggregate shares in the entire sample due to change in the dummy variable from 0 to 1.

The elasticity effects are evaluated for different segments of the population. Specifically, the elasticity effects are evaluated for non-commuting bicyclists, short distance commuting bicyclists and long distance commuting bicyclists. The results are presented in Table 11.2 by attribute category and by bicycling purpose.[5] The final column summarizes the elasticity effects across all purposes and all individuals. The elasticity effects for on-street parking are presented for each combination of parking turnover rate, length of parking area, and parking occupancy rate. The numbers in the table may be interpreted as the percentage change in the probability of bicyclists choosing a route due to an increase in continuous variables (such as travel time) or due to a change in the dummy variables (such as heavy traffic volume) from 0 to 1. For instance, the first numerical cell value of -10.15 percent in Table 11.2 indicates that the share of non-commuting bicyclists choosing a route will drop by about 10 percent if parallel parking with low parking turnover rate, short parking area length (1/2-1 city blocks), and low parking occupancy rate (0-25 percent) is permitted when compared to when no parking is permitted. Equivalently, the first numerical cell value on the second page of Table 10.2 indicates that the share of non-commuting bicyclists will be 4 percent less on a route with angled parking and low parking turnover rate, short parking area length (1/2-1 city blocks), and low parking occupancy rate (0-25 percent) when compared with a route with no parking.

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[5] While the sensitivity to some route attributes is also a function of gender and age, we do not provide the elasticity effects by these sociodemographic categories to reduce clutter.

Table 11.2: Elasticity Effect of Route Attributes

	Attribute	Attribute Level			Elasticity Effects (%)			
					Non-commuting	Commuting		All purposes
						Short-commute distance	Long-commute distance	
On-street Parking	Parking type	Parking turnover rate	Length of parking	Parking occupancy rate				
	Parallel	Low	short	low	-10.15	-5.65	-4.62	-7.79
		Low	short	moderate	-21.83	-16.1	-14.88	-18.8
		Low	short	high	-45.55	-38.14	-36.15	-41.5
		Low	moderate	low	-32.13	-25.51	-24.05	-28.58
		Low	moderate	moderate	-42.15	-34.51	-32.89	-38.05
		Low	moderate	high	-61.59	-53.11	-50.74	-56.9
		Low	long	low	-34.52	-27.81	-26.29	-30.93
		Low	long	moderate	-44.32	-36.65	-34.94	-40.2
		Low	long	high	-63.25	-54.91	-52.42	-58.61
		moderate	short	low	-20.83	-13.91	-12.19	-17.11
		moderate	short	moderate	-31.78	-23.84	-21.99	-27.5
		moderate	short	high	-53.54	-44.67	-42.15	-48.63
		moderate	moderate	low	-41.3	-32.7	-30.68	-36.64
		moderate	moderate	moderate	-50.39	-41.16	-39.01	-45.38
		moderate	moderate	high	-67.78	-58.51	-55.72	-62.61
		moderate	long	low	-43.5	-34.88	-32.79	-38.83
		moderate	long	moderate	-52.36	-43.19	-40.94	-47.37
		moderate	long	high	-69.24	-60.21	-57.31	-64.16
		High	short	low	-33.98	-23.47	-19.75	-27.99
		High	short	moderate	-43.85	-32.76	-29.17	-37.58
		High	short	high	-62.78	-51.95	-48.07	-56.57
		High	moderate	low	-52.2	-40.86	-37.25	-45.8
		High	moderate	moderate	-60.08	-48.62	-45.06	-53.62
		High	moderate	high	-74.76	-64.35	-60.58	-68.78
		High	long	low	-54.12	-42.91	-39.24	-47.78
		High	long	moderate	-61.77	-50.51	-46.88	-55.41
		High	long	high	-75.96	-65.91	-62.08	-70.15

TABLE 11.2 (Continued): Elasticity Effect of Route Attributes

					Elasticity Effects (%)			
						Commuting		
	Attribute	Attribute Level			Non-commuting	Short-commute distance	Long-commute distance	All purposes
On-street Parking	Parking type	Parking turnover rate	Length of parking	Parking occupancy rate				
	Angle	Low	short	low	-3.99	-2.53	-0.96	-2.93
		Low	short	moderate	-15.89	-13.15	-11.23	-14.13
		Low	short	high	-40.36	-35.94	-33.41	-37.66
		Low	moderate	low	-26.45	-22.58	-20.34	-24.06
		Low	moderate	moderate	-36.81	-31.83	-29.32	-33.83
		Low	moderate	high	-57.24	-51.18	-48.2	-53.64
		Low	long	low	-28.91	-24.89	-22.52	-26.44
		Low	long	moderate	-39.08	-34.04	-31.43	-36.05
		Low	long	high	-59	-53.12	-50.08	-55.48
		moderate	short	low	-14.87	-11.01	-8.49	-12.41
		moderate	short	moderate	-26.09	-21.21	-18.42	-23.07
		moderate	short	high	-48.72	-42.83	-39.64	-45.14
		moderate	moderate	low	-35.93	-30.13	-27.13	-32.42
		moderate	moderate	moderate	-45.43	-38.87	-35.69	-41.52
		moderate	moderate	high	-63.88	-56.92	-53.47	-59.74
		moderate	long	low	-38.22	-32.38	-29.29	-34.68
		moderate	long	moderate	-47.5	-41.02	-37.77	-43.62
		moderate	long	high	-65.44	-58.76	-55.29	-61.43
		High	short	low	-28.36	-20.67	-16.55	-23.63
		High	short	moderate	-38.54	-30.18	-25.99	-33.47
		High	short	high	-58.54	-50.09	-45.86	-53.45
		High	moderate	low	-47.34	-38.37	-34.17	-41.97
		High	moderate	moderate	-55.68	-46.4	-42.17	-50.17
		High	moderate	high	-71.45	-62.77	-58.54	-66.27
		High	long	low	-49.36	-40.53	-36.3	-44.06
		High	long	moderate	-57.48	-48.43	-44.2	-52.09
		High	long	high	-72.76	-64.47	-60.28	-67.78

TABLE 11.2 (Continued): Elasticity Effect of Route Attributes

			Elasticity Effects (%)			
				Commuting		
	Attribute	**Attribute Level**	**Non-commuting**	**Short-commute distance**	**Long-commute distance**	**All purposes**
Bicycle Facility	Bikeway width/type	No bicycle lane and a 10.5 feet wide outside lane	3.81	3.96	3.65	3.81
		No bicycle lane and a ≥ 14 feet wide outside lane	4.15	4.31	3.98	4.16
	Continuous bicycle facility	Continuous	34.63	34.56	43.59	36.56
Roadway Physical Characteristics	Terrain grade	Moderate hills	15.57	10.23	9.51	12.62
		Steep hills	3.20	-1.74	0.50	1.11
	# Stop signs, red lights and cross streets	Moderate (3-5)	-15.96	-16.02	-14.00	-15.54
		High (more than 5)	-30.07	-33.18	-28.58	-30.62
Roadway Functional Characteristics	Traffic volume	Moderate	-28.22	-32.13	-29.70	-29.69
		Heavy	-88.08	-75.23	-82.66	-83.07
	Speed limit	Moderate (20-35 mph)	-5.81	-9.05	11.81	-2.93
		High (more than 35 mph)	-35.67	-41.57	-21.39	-34.27
Roadway Operational Characteristics	Travel time	Travel time (minutes)	-	-63.89	-129.68	-91.41

The results presented in Table 11.2 are insightful. First, the impact of on-street parking attributes has more of a negative impact on non-commuter bicyclist route choice than commuter bicyclist route choice. The variables on route choice preferences are similar for the non-commuting and short-distance commuting for the attributes identified on the third page of Table 11.2 with two exceptions, terrain and traffic volume. Non-commuting bicyclists prefer non-flat terrains more than short distance commuting bicyclists and non-commuting bicyclists are less sensitive to traffic volume than are short distance commuting bicyclists. Regardless of the bicycling purpose, individuals have different sensitivities to parking types. Overall, bicyclists tend to prefer angled parking to parallel parking on their bike routes.

Bicyclists' route preferences exhibit considerably different sensitivities with respect to different attribute levels. For example, in this study non-commuting bicyclists choosing a route will drop by 22 percent if parallel parking with low parking turnover rate, short parking area length (one-half to one city block), and moderate parking occupancy rate (26-75 percent) exists on a route compared to a route without parking. The corresponding drop was 32 percent for parallel parking with low parking turnover rate, moderate parking area length (2-4 city blocks), and low parking occupancy rate (0-25 percent). These numbers allow us to understand the trade-offs of length of parking area versus parking occupancy rate. The elasticity values allow us to rank the attributes in the order of their significance. Travel time is the most important attribute in bicycle route choice (for commuters), followed by heavy traffic volume, high parking occupancy rate, whether the bike route is continuous, the speed limit (whether the speed limit is greater than 35 mph), the number of stop signs, red light, and cross-streets, and roadway grade. To summarize, the results clearly suggest that bicyclists prefer routes with shorter travel time, light traffic, no parking or low activity levels of parking, and continuous bicycle facilities.

11.4 Time-Based Trade-offs of Route Attributes for Commuting Bicyclists

Table 11.3 provides the result of the time and money-based trade-off analysis by commute distance.[6] The positive time (or money) values in the table indicate how much additional travel time (money) bicyclists would be willing to travel (pay) to *avoid* the corresponding attribute on their route, while negative values indicate how much additional travel time (or money) bicyclists would be willing to travel (pay) to *have* the corresponding attribute on their route. For instance, the first numerical cell value of 6.21 minutes indicates that short commute distance bicyclists would be willing to bicycle about 6.21 more minutes to avoid parallel parking on their bicycle commute route. Similarly, short commute distance bicyclists would be willing to pay $1.26 to travel on a route on which parallel parking is not available. At the same time, the value of -12.63 minutes associated with the continuous bicycle facility attribute indicates that short commute distance bicyclists would be willing to bicycle 12.63 minutes more if the bicycle facility on their route is continuous. Equivalently, the value of $-2.57 indicates the amount of money short commute distance bicyclists would be willing to pay for having a continuous bicycle facility along their route.

[6] Strictly speaking, these trade-offs with respect to time (and money) are a function of age and gender too, but we aggregate over age and gender for the trade-off computations in Table 5 by assuming the age split and gender split as obtained in our sample. The reader will also note that we are only providing the trade-offs for commuter bicyclists, because travel time is a relevant factor only for such bicyclists.

Table 11.3: Time and Money-Based Trade-offs of Route Attributes

	Attribute	Attribute Level	Time Value (in min.)		Money Value (in $)[7]	
			Short-commute distance	Long-commute distance	Short-commute distance	Long-commute distance
On-street Parking	Parking type	Parallel parking permitted	6.21	9.59	1.26	1.95
		Angle parking permitted	2.79	6.18	0.57	1.25
	Parking turnover rate	Moderate	3.88	3.88	0.79	0.79
		High	13.10	13.10	2.66	2.66
	Length of parking area	Moderate (2-4 city blocks)	8.29	8.29	1.69	1.69
		Long (5-7 city blocks)	9.28	9.28	1.89	1.89
	Parking occupancy rate	Moderate (26-75%)	4.26	4.26	0.87	0.87
		High (76-100%)	14.10	14.10	2.87	2.87
Bicycle Facility	Bikeway width/type	No bicycle lane and a 10.5 feet wide outside lanewidths	-1.31	-1.31	-0.27	-0.27
		No bicycle lane and a ≥ 14 feet wide outside lanewidths	-1.43	-1.43	-0.29	-0.29
	Continuous bicycle facility	Continuous	-12.63	-17.37	-2.57	-3.53
Roadway Physical Characteristics	Terrain grade	Moderate hills	-3.32	-3.32	-0.68	-0.68
		Steep hills	5.19	5.19	1.05	1.05
	# Stop signs, red lights and cross streets	Moderate (3-5)	7.54	7.54	1.53	1.53
		High (more than 5)	25.03	25.03	5.09	5.09
Roadway Functional Characteristics	Traffic volume	Moderate	10.68	10.68	2.17	2.17
		Heavy	31.29	38.54	6.36	7.83
	Speed limit	Moderate (20-35 mph)	10.91	4.22	2.22	0.86
		High (more than 35 mph)	22.93	16.71	4.66	3.39

[7] The money value of time, which is 12.19 $/hr, was obtained from a research conducted by Bhat and Sardesai (2006).

The results in Table 11.3 indicate that the time and money values of attributes are very similar for long and short commute distance bicyclists. The exceptions are for parking type (long distance commuting bicyclists are more sensitive to both parallel and angle parking than short distance commuting bicyclists are), continuous bicycle facility (long distance commuting bicyclists are willing to pay more for a route with no parking than short distance commuting bicyclists), traffic volume (long distance commuting bicyclists are willing to pay more to travel on a route with less heavy motorized traffic than short distance commuting bicyclists), and speed limit (short distance commuting bicyclists are willing to pay more for a route with lower speed limit on the roadway than short distance commuting bicyclists). Further, traffic volume corresponds to the attribute for which commuting bicyclists are willing to pay the highest time and/or money for an improvement. Specifically, short distance commuting bicyclists are willing to travel (pay) about 31 minutes (or $6) more for a route with light or moderate traffic, while the corresponding time and money values for long distance commuting bicyclists are even higher (i.e., about 39 minutes or $8). In addition, bicyclists would be willing to travel (pay) a considerable amount of time (money) for improvements in other attributes, such as a reduction in the number of stop signs, red lights and cross streets on the route, parking occupancy rate, and length of parking area.

11.5 Applications of the Model

The proposed model in this study can be used to support policy making decisions and design applications. These applications may be broadly summarized into four major categories: (1) The model can be used as an evaluation tool for planners to examine potential bicycle route alternatives, (2) to evaluate the potential for an increase in bicycling demand based on measurable improvements, (3) to assess the trade-offs between various attributes to make changes to existing routes, and (4) to identify specific demographic groups, such as commuting and non-commuting bicyclists, to develop more efficient policies and/or local design guidelines. In this section, we demonstrate the applications of the proposed model by providing some examples based on the results of the survey.

First, the excel spread sheet provides a useful tool to input data, evaluate various bike route alternatives, assess existing bicycle routes, and plan future bike routes. Table 11.4 and Table 11.6 provide a comparison of attributes between the two bike routes to determine the preferred bike route (or the most attractive route). First, the coefficient associated each route attribute is identified, followed by the computation of the total utility for each route. For instance, in Table 11.4 the parking attributes have zero value. The bikeway width/type is a shared roadway with a 14 ft outside lane, and the corresponding coefficient for a ≥14-foot wide outside lane is 0.097 (see Table 11.1). Similarly, the coefficients of other attributes are computed. Overall, Table 11.4 clearly shows that the utility of the second route is higher than the utility of the first route, i.e., the second route is preferred.

This model can also be applied to evaluate the potential increase in demand based on measureable improvements. Table 11.5 shows that the probability of choosing the first route increases to 18.5 percent with a 5 minutes travel time improvement, while the corresponding probability for the second route decreases to 81.5 percent. These results reveal that an increase in demand can be attained by reducing the travel time.

Another important application of the proposed model is the ability to identify trade-offs among attributes to make improvements to existing bike routes. In Table 11.6 In Table 11.6 parking was introduce with a 30 percent parking turnover rate, two to four city blocks long, and

26-75 percent parking occupancy rate. Our results indicate that the on-street parking significantly discourage bicyclists to choose this route. The trade-offs of route attributes can be assessed as a function of travel time and traffic speed.

Finally, the estimation results of this study may be used to develop effective policy initiatives targeting specific demographic groups. It is important to provide specific suggestions for various groups since different demographic groups such as commuter and non-commuter bicyclists generally have different preferences and priorities when choosing bicycle routes. Our results indicate that, while commuter bicyclists can be attracted by reducing travel time, non-commuter bicyclists can be encouraged by providing routes along roadways that have moderate to steep hills. Furthermore, providing connectivity between bicycle routes could encourage new commuter bicyclists.

Table 11.4: Comparison of different route alternatives (first application)

	Route 1				Route 2			
Attribute	**Attribute level**	**Independent Variable (x)**	**Coefficient (β)**	**Utility (β*x)**	**Attribute level**	**Independent Variable (x)**	**Coefficient (β)**	**Utility (β*x)**
Parking Type	No parking	0	0	0	Parallel parking	1	-0.422	-0.422
Parking turnover rate	-	0	0	0	60%	1	-0.264	-0.264
Length of parking area	-	0	0	0	2-4 city blocks long	1	-0.564	-0.564
Parking occupancy rate		0	0	0	26-75%	1	-0.29	-0.29
Bikeway width/type	Shared roadway with 14 feet wide outside lane	1	0.097	0.097	Shared roadway with 16 feet wide outside lane	1	0.097	0.097
Terrain grade	Moderate hills	1	0.226	0.226	Steep hills	1	-0.353	-0.353
# Stop signs, red lights and cross streets	More than 5 stop signs, red lights, and cross streets	1	-1.702	-1.702	1-2 stop signs, red lights, and cross streets	1	0	0
Speed limit	More than 35 mph	1	-1.559	-1.559	Less than 20 mph	1	0	0
Travel time	25 minutes	25	-0.068	-1.7	15 minutes	15	-0.068	-1.02
Total Utility	TRUE				TRUE			
Probability of choosing the route	FALSE 0.139				FALSE 0.861			
Total Utility_Route 2 > Total Utility_Route 1								

Table 11.5: Comparison of different route alternatives (second application)

	Improved Route 1				Route 2			
Attribute	**Attribute level**	**Independent Variable (x)**	**Coefficient (β)**	**Utility (β*x)**	**Attribute level**	**Independent Variable (x)**	**Coefficient (β)**	**Utility (β*x)**
Parking Type	No parking	0	0.000	0.000	Parallel parking	1	-0.422	-0.422
Parking turnover rate	-	0	0.000	0.000	60%	1	-0.264	-0.264
Length of parking area	-	0	0.000	0.000	2-4 city blocks long	1	-0.564	-0.564
Parking occupancy rate		0	0.000	0.000	26-75%	1	-0.290	-0.290
Bikeway width/type	Shared roadway with 14 feet wide outside lane	1	0.097	0.097	Shared roadway with 16 feet wide outside lane	1	0.097	0.097
Terrain grade	Moderate hills	1	0.226	0.226	Steep hills	1	-0.353	-0.353
# Stop signs, red lights and cross streets	More than 5 stop signs, red lights, and cross streets	1	-1.702	-1.702	1-2 stop signs, red lights, and cross streets	1	0.000	0.000
Speed limit	More than 35 mph	1	-1.559	-1.559	Less than 20 mph	1	0.000	0.000
Travel time	20 minutes	20	-0.068	-1.360	15 minutes	15	-0.068	-1.020
Total Utility	= 0.000+0.000+0.000+0.000+0.097+0.226-1.702-1.559-1.360 = -4.298				= -0.422-0.264-0.564-0.290+0.097-0.353+0.000+0.000-1.020 = -2.816			
Probability of choosing the route	=exp(-4.298)/(exp(-4.298)+exp(-2.816)) =0.185 = 18.5%				=exp(-2.816)/(exp(-4.298)+exp(-2.816))= 0.815 =81.5%			
Total Utility Route 2 > Total Utility Improved Route 1								

Table 11.6: Comparison of different route alternatives (third application)

	Route 1_with new parking facilities				Improved Route 1_with new parking facilities			
Attribute	**Attribute level**	**Independent Variable (x)**	**Coefficient (β)**	**Utility (β*x)**	**Attribute level**	**Independent Variable (x)**	**Coefficient (β)**	**Utility (β*x)**
Parking Type	Angled parking	1	-0.190	-0.190	Angled parking	1	-0.190	-0.190
Parking turnover rate	30%	1	0.000	0.000	30%	1	0.000	0.000
Length of parking area	2-4 city blocks long	1	-0.564	-0.564	2-4 city blocks long	1	-0.564	-0.564
Parking occupancy rate	26-75%	1	-0.290	-0.290	26-75%	1	-0.290	-0.290
Bikeway width/type	Shared roadway with 14 feet wide outside lane	1	0.097	0.097	Shared roadway with 14 feet wide outside lane	1	0.097	0.097
Terrain grade	Moderate hills	1	0.226	0.226	Moderate hills	1	0.226	0.226
# Stop signs, red lights and cross streets	More than 5 stop signs, red lights, and cross streets	1	-1.702	-1.702	More than 5 stop signs, red lights, and cross streets	1	-1.702	-1.702
Speed limit	More than 35 mph	1	-1.559	-1.559	20-35 mph	1	-0.742	-0.742
Travel time	25 minutes	25	-0.068	-1.700	20 minutes	20	-0.068	-1.360
Total Utility	= 0.190+0.000-0.564-0.290+0.097+0.226-1.702-1.559-1.700 = -5.302				= 0.190+0.000-0.564-0.290+0.097+0.226-1.702-0.742-1.360 = -4.145			
Probability of choosing the route	=exp(-5.302)/(exp(-5.302)+exp(-2.816)) =0.077 = 7.7%				=exp(-4.145)/(exp(-4.145)+exp(-2.816))= 0.209 =20.9%			
Total Utility Improved Route 1 with new parking facilities > Total Utility_ Route 1 >Total Utility Route 1 with new parking facilities								

Chapter 12. Conclusion of the Study on the Effects of On-Street Parking on Cyclists Route Choice and the Operational Behavior of Cyclists and Motorists

This research paper and deliverables provide additional information and tools for evaluating bikeways. The study results contribute to the existing literature on bicycling in three ways. *First*, unlike any other study, it presents an analysis of attributes impacting bicyclist route preferences by examining all bikeway attributes in a single framework. *Second*, a number of earlier studies have employed descriptive analysis to evaluate the influence of attributes on bicycle route choice. The current study employs a multivariate analysis of the attributes that influence bicycle route choice. *Third*, on-street parking attributes are often not considered in bicycle route choice analysis. In this research, the consideration of parking related attributes, including parking turnover rate, length of parking area, and parking occupancy rate, was the focus and how various other attributes and conditions effect a bicyclist route choice.

It is clear that evaluating the influence of numerous attributes through revealed preference data alone does not provide sufficient results. Thus, a stated preference methodology was undertaken to develop a web-based survey to gather additional data from bicyclists in Texas. The data from the survey was collected and cleaned prior to estimation. After checking the consistency of the data, a panel mixed multinomial logit formulation was employed to evaluate the trade-offs of the attributes.

The results of the empirical analysis offer several important insights. The study results underscore the influence that on-street parking has on bicycle route choice. Specifically, the results indicate that bicyclists prefer routes without on-street parking. Among the routes with parking, bicyclists prefer routes with angle parking. The study also highlights the preference for continuous bicycle facilities, lower traffic volume, and lower roadway speeds as well as fewer stop signs, red lights, and cross streets. Another interesting fact revealed by the analysis was that bicyclists generally prefer moderate hills over flat terrain. Finally, the analysis clearly emphasizes the sensitivity of bicyclists to travel time, and the need to consider both route-related attributes and bicyclists' demographics when selecting and designing bikeways.

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Appendix A

Table A.1 Characteristics of Final Sites

City	Site	Limits			Site Length (miles)	Street Class[a]	Type of Bike Facility[b]	Motor Vehicle Lane Width (feet)[c]	Bike Lane Width (feet)	Parking Type	Parking Density	Parking Turnover Rate[d]	Number of Lanes in One Direction	One Way?	Traffic Volume[e]
Austin	Barton Springs Rd.	Robert E. Lee Rd.	east to	Kinney Ave.	0.3	A	BL	10.00	3.79	Parallel	25% or less	high	2	No	Heavy
Austin	Parkfield Dr. (South)	Peyton Gin Rd.	north to	Norseman Ter.	0.1	C	BL	10.33	5.00	Parallel	25-75%	low	1	No	Moderate
Austin	San Jacinto Blvd.	Duval St.	north to	E. 30th St.	0.2	A	BL	10.33	4.50	Angled	75% or more	high	2	No	Moderate
Austin	San Jacinto Blvd.	Duval St.	north to	E. 30th St.	0.2	A	BL	11.25	5.79	Parallel	75% or more	med	1	No	Moderate
Austin	Georgian Dr.	E. Rundberg Ln.	south to	Fawnridge Dr. E.	0.2	C	BL	11.50	4.17	Parallel	25-75%	low	1	No	Moderate
Austin	E. 30th St.	East Dr.	east to	University Ave.	0.2	C	BL	11.75	6.08	Parallel	75% or more	low	1	No	Moderate
Austin	Lake Austin Blvd.	Redbud Tr.	west to	Enfield Rd.	0.3	A	BL	12.08	4.92	Parallel	100%	low	1	No	Light
Austin	Parkfield Dr. (North)	Norseman Ter.	north to	W. Rundberg Ln.	0.3	C	BL	12.25	4.92	Parallel	25-75%	low	1	No	Moderate
Austin	Shoal Creek Blvd.	White Rock Dr.	south to	Allandale Rd.	0.2	C	PBL	13.38*		Parallel	25-75%	low	1	No	Moderate
Houston	Heights Blvd.	15th St.	north to	17th St.	0.2	A	BL	14.69	5.52	Parallel	25-75%	low	1	Divided	Heavy
Houston	Clay St.	Milam St.	east to	Main St.	0.1	PA	POL	14.22*		Parallel	75% or more	med	3	Yes	Moderate
Houston	Sunset Blvd.	Cherokee St.	west to	Hazard St.	0.4	C	WOL	11.93*		Parallel	25-75%	low	1	Divided	Heavy
Houston	High Star Dr.	Wilcrest Dr.	west to	Boone Rd.	0.3	C	WOL	12.87*		Parallel	25% or less	low	1	No	Light
Houston	Meadowglen Ln.	Briarpark Dr.	east to	Elmside Dr.	0.4	C	WOL	13.42*		Parallel	25-75%	low	1	No	Moderate
Houston	Preston St.	San Jancinto	east to	Austin St.	0.1	PA	WOL	13.59*		Ang/Para	25-75%	med	2	Yes	Moderate
Houston	Caroline St.	Congress	south to	Prairie St.	0.1	PA	WOL	14.44*		Angled	75% or more	med	2	Yes	Moderate
Houston	Commerce St.	Elysian St.	west to	San Jacinto St.	0.1	PA	WOL	16.9*		Angled	75% or more	med	3	Yes	Heavy
San Antonio	Steves Ave.	Roosevelt Ave.	east to	S. Presa St.	0.3	PA	PBL	13.18*		Parallel	25-75%	low	2	No	Light
San Antonio	Bowens Crossing	Grace Point	south to	Lands Point St.	0.3	C	PBL	15.19*		Parallel	25% or less	low	1	No	Moderate
San Antonio	Les Harrison Dr.	Village Arbor	north to	Woodtrail	0.2	C	PBL	15.19*		Parallel	25-75%	low	1	No	Moderate
San Antonio	Timber Path Rd.	Les Harrison Dr.	east to	Hidden Dale St.	0.2	C	PBL	15.59*		Parallel	25% or less	low	1	No	Light
San Antonio	S. Alamo St.	S. St. Marys St.	south to	E. Sheridan St.	0.3	PA	POL	15.93*		Parallel	75% or more	med	2	No	Moderate
San Antonio	Guadelupe St.	S. San Jancinto St.	east to	S. Brazos St.	0.1	PA	WOL	14.15*		Parallel	5-100%	high	1	No	Heavy
San Antonio	Avenue E	4th St.	south to	3rd St.	0.1	A	WOL	19.84*		Parallel	25-100%	med	1	No	Light
San Antonio	Cincinnati Ave.	Wilson Blvd.	west to	Germania Ave.	0.2	C	WOL	20.2*		Parallel	25% or less	low	1	No	Moderate

[a] The street class abbreviations have the following meanings: C = collector, A = arterial, PA = principal arterial

[b] The type of bike facility abbreviations have the following meanings: BL = bicycle lane, WOL = wide outside lane, POL = parking in outside lane, PBL = parking in bicycle lane

[c] An asterisk (*) at the end of a specific motor vehicle lane width means that the width is the average distance from the edge of the car to the inside motor vehicle lane line (i.e., total width shared by cyclist and motorist)

[d] The parking turnover rates have the following meanings: Low- all cyclists unlikely to encounter a parker car exiting; often associated with residential and employee parking, High- cyclist likely to encounter a parked car exiting along the segment; associated with short duration retail (e.g., convenient store, restaurant, etc), Med- turnover rate that is not considered low or high

[e] The traffic volumes have the following meanings: Heavy- vehicles are in platoons with little time between separate platoons, Light- there are periods of several seconds or more where a traveling vehicle is not in sight, Moderate- traffic volumes between heavy and light