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Effects of Safe Bicycle Passing Laws on Drivers' Behavior and Bicyclists' Safety

FINAL REPORT

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This report identifies the effect of passing distance laws on drivers' behaviors and bicyclist's safety during an overtaking maneuver. Using an instrumented bicycle and driver survey, the study measured bicycle passing in a naturalistic field experiment using video recording, an ultrasonic distance measuring device, and a LiDAR. In order to evaluate the effect of passing distance laws, the study examined jurisdictions with a three-foot passing law, with a five-foot passing law, and without a passing law. The experiment required a bicyclist to ride the instrumented bicycle in two-lane and three-lane roads to capture the distance between the bicycle and the overtaking motor vehicle. Moreover, a new analysis algorithm is presented to assess the speed and distance transformation of the vehicles approaching and entering the passing zone of the bicycle in micro level transportation systems. The results demonstrated that drivers' overtaking distances were significantly greater in locations with the five-foot passing law than in other areas. The study also found that roads with paved shoulders, wider travel lanes, and a greater number of lanes were associated with greater passing distances. In contrast, we found that passing distance was shorter on roads with shared lane markings (i.e., sharrows) or higher truck composition. By comparing the surveys conducted in locations with different passing laws, the study illustrates that drivers usually overestimate the distance that they pass bicyclists. These results can be useful to transportation engineers, policymakers, and legislators who intend to provide efficient designs of road infrastructure to better accommodate bicycles.</td></tr>
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Chapter 1 Introduction

1.1 Background

The National Highway Traffic Safety Administration (NHTSA) has successfully demonstrated the benefits of the high visibility enforcement (HVE) approach for changing motorist behavior in a variety of situations. While *Click It or Ticket* is perhaps the most visible and widespread example of the success of the technique, it has also been successfully applied to many other situations. For example, Van Houten et al. (2013) used HVE to change the culture of drivers yielding to pedestrians at crosswalks in Gainesville, Florida.

As reported in a NHTSA Compendium (2017), grouping bicycle crashes (Cross & Fisher, 1977) into crash types has been fundamental to the success of NHTSA's research program. Crash typing has further evolved from the initial studies based on other work by NHTSA and FHWA (Knoblauch, 1977) on reexamining bicycle crash types in the late 1990s, and on creating an easy to use typing system for determining and maintaining databases of typed crashes (Hunter et al., 1995). The existence of bicycle/motor vehicle crash types is relevant to the proposed study both as an aid in selecting the target behavior and as a pedagogical device to facilitate the evaluation. Two classes of crash types identified by Cross and Fisher (1977)—Motorist Turns or Drives in Front of Bicyclist (Class C) and Motorist Overtakes Bicyclist (Class D) have particular relevance to the proposed study. In fact, one of the Class D types—Type 16: Motorist misjudges space required to pass bicyclist, is of key importance because it was also the type with the highest number of fatalities in the Cross and Fisher (1977) study.

In 2016, the National Highway Traffic Safety Administration (NHTSA) reported that there were 840 bicyclists killed in traffic crashes, which has steadily increased from 628 in 2009. This represents a 34 percent increase in fatalities from 2009. Seventy one percent of pedalcyclist fatalities occurred in urban areas; Additionally, more than 50 bicyclists were killed on shoulder/roadside and more than 33 of the bicyclists were killed while they were using a bicycle lane.

In recent years, states and municipalities have passed laws for passing distance as an attempt to increase the distance between drivers and bicycles (National Conference of State

Legislators, 2017). In 1973, Wisconsin became the first state to enact such a law. As of December of 2016, 27 states have enacted a three-foot passing laws.

At the time of this study, Michigan did not have a state passing law, but several cities had passed ordinances requiring motorists to pass bicycles at a safe minimum distance. The city of Grand Rapids was the first city to pass such an ordinance in September of 2015, which specifies a minimum passing distance of five feet. The cities of Ann Arbor, Kalamazoo and Portage subsequently passed five-foot passing ordinances. To date, there is no data on the efficacy of a five-foot bicycle passing ordinances and only limited evidence on the efficacy of a three-foot bicycle passing law. Therefore, there is a strong need for investigating effects of five-foot passing laws associated with bicycle infrastructure, cultural differences, and community education and outreach.

1.2 Research Objectives

The purpose of this research is to evaluate motorist-bicycle passing distances on arterial roads with/without a bike lane in cities with/without a five-foot bicycle passing law/ordinance. Although limited previous research has shown that there are a significant number of violations of a three-foot bicycle passing law, there is no data on the percentage of drivers violating a five-foot passing ordinance. Comparing passing distances in cities with a five-foot passing ordinance and cities without such an ordinance would make a valuable contribution. Data collected in jurisdictions with a five-foot passing ordinance would also help in establishing a benchmark or baseline to evaluate the efficacy of interventions designed to increase passing distance such as enforcement, driver education, signage, and bicycle infrastructure changes which are needed to influence compliance with bicycle passing laws. This research also measured cycling stability using an instrumented bicycle. The bicycle instrumentation can collect cyclists' maneuvers associated with motorist-bicycle passing distances and vehicle speeds. These data could contribute to understanding the relationship between laws or ordinances specifying a legal passing distance and the actual passing distance.

1.3 Research Scope and Overview

In order to investigate motorist-bicyclist passing distances, this study proposes to employ two types of data collection methods and three statistical analyses. Figure 1-1 depicts conceptual flow of the proposed research. This research will be conducted with following five tasks.

Task 1: Literature Review
Task 2: Selection of Test Sites
Task 3: Data Collection
Task 4: Modeling and Analysis
Task 5: Conclusion

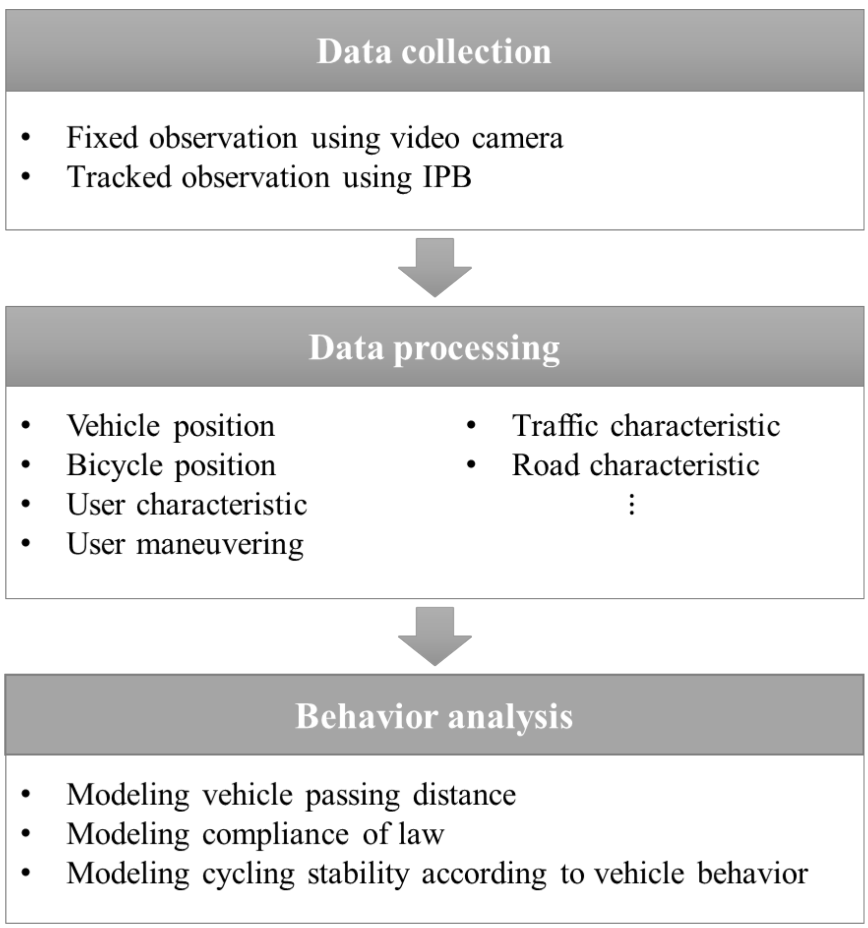


Figure 1-1: Conceptual Flowchart of the Research

Chapter 2 Literature Review

2.1 Overview

The interaction between motorists and bicyclists, specifically during passing maneuvers, is an area of concern to the bicycle safety community. There is also a general perception that motor vehicle drivers do not share the road effectively with bicyclists (Chapman & Noyce, 2012). Once a vehicle overtakes a bicycle in the same direction, the cyclist is pushed by lateral forces, which may influence the cyclist stability or path (Khan & Bacchus, 1995). The lateral forces from overtaking vehicle increase the risk of bicyclist's collision with traffic or parked vehicles. The risk will also be dependent on traffic volume, speed and motor vehicle composition (Parkin et al., 2007). Bicycle safety policy for Vehicle Passing Distance (VPD) usually is 3-foot or in some cases is dependent on speed or size of the passing vehicle. State legislatures have paid special attention on determining the appropriate VPD for bicyclists' safety.

2.2 Motor Vehicle-bicycle Interaction

Pedalcyclists are known as one of the major vulnerable road users. From 2010 to 2015 in the U.S., pedalcyclists' fatal crashes have increased by 31 percent (from 623 to 818). Additionally, the share of pedalcyclist deaths among traffic fatal crashes increased during the same period. Crash data from 2015 also indicate that 96 percent (783) of the pedalcyclists death were involved in single-vehicle crashes. It is also stated that the majority of pedalcyclist fatalities occurred in urban areas (70 percent) as opposed to rural areas (40 percent). Furthermore, 61 percent of pedalcyclist fatalities occurred at non-intersection locations (NHTSA, 2017). This raises the question about the factors influencing bicyclist's safety when a motor vehicle passing him/her at non-intersection locations.

There are several studies conducted on interaction between motor vehicles and bicyclists during overtaking maneuvers that indicated roadway and geometry design (Bella & Silvestri, 2017; Savolainen et al., 2012; Sando et al., 2011; and Shackel & Parkin, 2014), wearing a helmet (Walker, 2007), type of vehicle (De Ceunynck et al., 2017), traffic volume (Li et al., 2012), speed (Llorca et al., 2017; and Chuang et al., 2013), equity barriers (Chavis et al., 2018) and presence of Share the Road sign (Kay et al., 2014; Høye et al., 2016 and McCall, 2014) significantly affect the interaction.

2.2.1 Naturalistic Studies

Bella & Silvestri (2017) analyzed the overtaking maneuver of a cyclist under three different cross-sections on two-lane rural roads with the same lane width, but with and without a bicycle lane of different widths. They also measured the effect of geometric elements of the alignments by considering tangents with different lengths and curve types. Significantly, drivers in the condition of wider bicycle lanes adopted wider lateral clearance distance between bicyclists. The authors concluded that the driver travelled nearest to the centerline on the left curves and subsequently, the highest lateral clearance was recorded in this geometric condition. In another study, Savolainen et al. (2012) measured the lateral placement of motor vehicles as they passed bicyclists by using 4 mounted cameras. They evaluated the effect of presence of centerline rumble strips in a high-speed (55 mph speed limit) rural two-lane highway. Other considered variables included opposing traffic present and group bicycling. The results of the study indicated that the lateral position of the bicycle (on the left edge of shoulder, right edge of shoulder, or within the center of shoulder) significantly influenced the lateral position of motor vehicles. They also concluded that motor vehicles were more likely to ride over or across the centerline when encountering bicyclists. Furthermore, riding over or crossing the centerline occurred more frequently when motor vehicles encountered a group of bicyclists riding together.

Shackel & Parkin (2014) collected comprehensive data including lane width, road marking, time of day, speed limit (20 mph and 30 mph), bicycle speed, and platoon overtaking. They employed an instrumented bicycle equipped with ultrasonic sensor to evaluate the passing distance and perpendicular video camera to measure the motor vehicle speed. They found that closer passing distances occur when vehicles approach in a platoon from the opposite side of the roadway. Unsurprisingly, that number of lanes wes associated with greater passing distance even when the lane width was less than 3.10 meters.

Another factor reported by several studies is the relationship between the motor vehicle type and the passing distance. Walker (2007) investigated that professional drivers of large vehicles were likely to leave less passing distance. Likewise, De Ceunynck et al. (2017) determined the interaction between bicyclists and buses on shared bus lanes. They defined a close overtaking when a bus overtakes a bicyclist with a passing distance less than 1 meter and found that close overtaking maneuvers are common on bus lanes. Additionally, more close overtaking maneuvers took place on the narrower bus lane (3.1 meters), but the difference was not statistically significant.

Llorca et al. (2017) confirmed the impact of motor vehicle type on passing distance on two-lane rural roads. In addition to vehicle type, they developed instrumented bicycles (Figure 2-1) equipped with laser rangefinders, a GPS tracker and three cameras to analyze lateral passing distance and vehicle speed. Using Laser Technology Inc. T100 devices, they collected relative speed of the overtaking vehicle. However, measuring the passing distance to the overtaking vehicle by averaged value of two Laser Technology Inc. S200 rangefinders was not accurate enough for such a short passing duration. They adopted equations including passing distance and motor vehicle speed according to aerodynamic lateral force as a vehicle overtakes a bicycle. They found that a combination of vehicle speed and passing distance, which is proportional to aerodynamic forces between overtaking and overtaken vehicles, was correlated with bicyclist's risk perception.

Figure 2-1: The instrumented bicycle used in Liorca's study (Llorca et al., 2017)

Aside from vehicle speed, Chuang et al. (2013) considered the passing time as an essential factor. They implied that a longer passing time caused bicyclists to demonstrate cautious but less stable riding behaviors. They employed an instrumented bicycle, which was equipped with ultrasonic distance sensor, gyroscope, accelerometer, and variable resistor. The pairwise comparisons indicated that the mean lateral distance was significantly smaller when the passing time was 0.1–0.4 s as compared to a passing time longer than 0.4 s. Furthermore, the wheel angle variation was significantly smaller for passing times of 0.1–0.4 s than for passing times longer than 1.3 s and on roads with slow traffic separation as compared to roads without slow traffic separation. In addition, mean speed was significantly lower on roads with lane separation and slow traffic separation as compared to their counterparts without these features.

2.2.2 Simulation-based Studies

Aside from adopting instrumented bicycles, several studies attempted to analyze influential behavioral factors on motor vehicle-bicycle interaction in a simulated environment. Caird et al. (2008) carried out a simulated experiment with University of Calgary Driving Simulator (UCDS) to investigate the best bicycle lane treatment. They integrated white dashed, blue dashed, blue solid and sharrows treatment into three experimental drives in an advanced simulation environment. The simulation system included eye movement tracker, three screens, brake sensor, accelerometer, and base and surround speakers. The results revealed that sharrows had the highest level of comprehension and was preferred by the majority of participants.

Herrera (2015) pointed out that the three-foot passing law is the most common legislative actions to provide greater protection and comfort for the bicyclists on the US roadways. She controlled traffic and roadway related conditions (i.e. two-lane, undivided, without shoulder, rural, flat surface, 12 feet lane width, 45 mph posted limit, and daytime) within Louisiana State University driving simulation system (Figure 2-2). Opposing traffic volume was varied through three levels (high, medium, and low) during the simulation. The striking aspect of the study was the participants' awareness of the three-foot law. The result were contradictory to the intent of the law. Accordingly, the results did not support the influence of awareness of a three-foot law on drivers' keeping a safe lateral distances from bicyclists when passing. It was demonstrated that average passing distance and average speed of participants who were informed about the law were not significantly different from those who were unaware of the law. Nevertheless, the average tendency of participants was to provide more than three feet minimum requirement whether or not they were aware of the law.

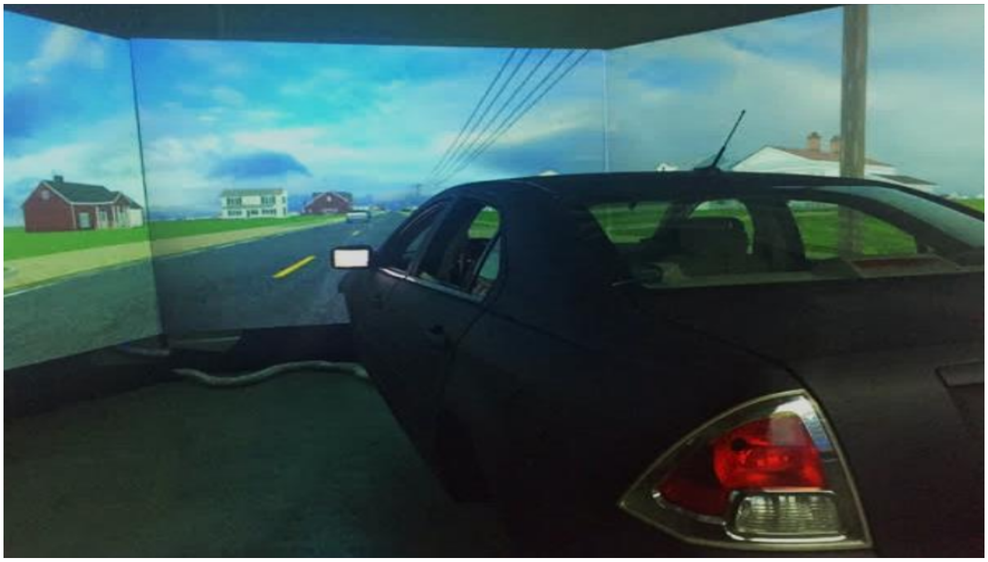


Figure 2-2: LSU Driving Simulator (Herrera, 2015)

2.3 Bicycle Safety Legislation

Legislative strategies, in addition to Education, Enforcement, and Engineering (known as 3 E's), aim at improving bicyclists' safety and comfort. Among legislation strategies for bicyclists' safety, the three-foot passing law gained significant interest and activity in the United States. In 1973, Wisconsin became the first state to enact a minimum of 3 ft. passing distance when overtaking bicyclists. They establish three-foot as lateral clearance required when passing the bicycle and required drivers to maintain the clearance until they pass the overtaken bicycle. North Carolina has a two-foot passing law that also allows drivers to pass a bicycle in a no-passing zone if they leave a 4-foot clearance. Pennsylvania has a four-foot passing law and South Dakota enacted a two-tiered passing law with a six-foot law on roads with a speed limit over 35 mph and a three-foot law on roads with a speed limit of 35 mph or less. Nine states have safe passing distance laws, which commonly declare that vehicles should pass bicyclists at a "safe distance and speed". For instance, Montana's law states that overtaking and passing a bicyclist will be allowed once motor vehicle operator can do so safely without endangering the bicyclists (National Conference of State Legislators, 2017). Figure 2-3 shows map of states with statutes regarding motorists passing bicyclists.

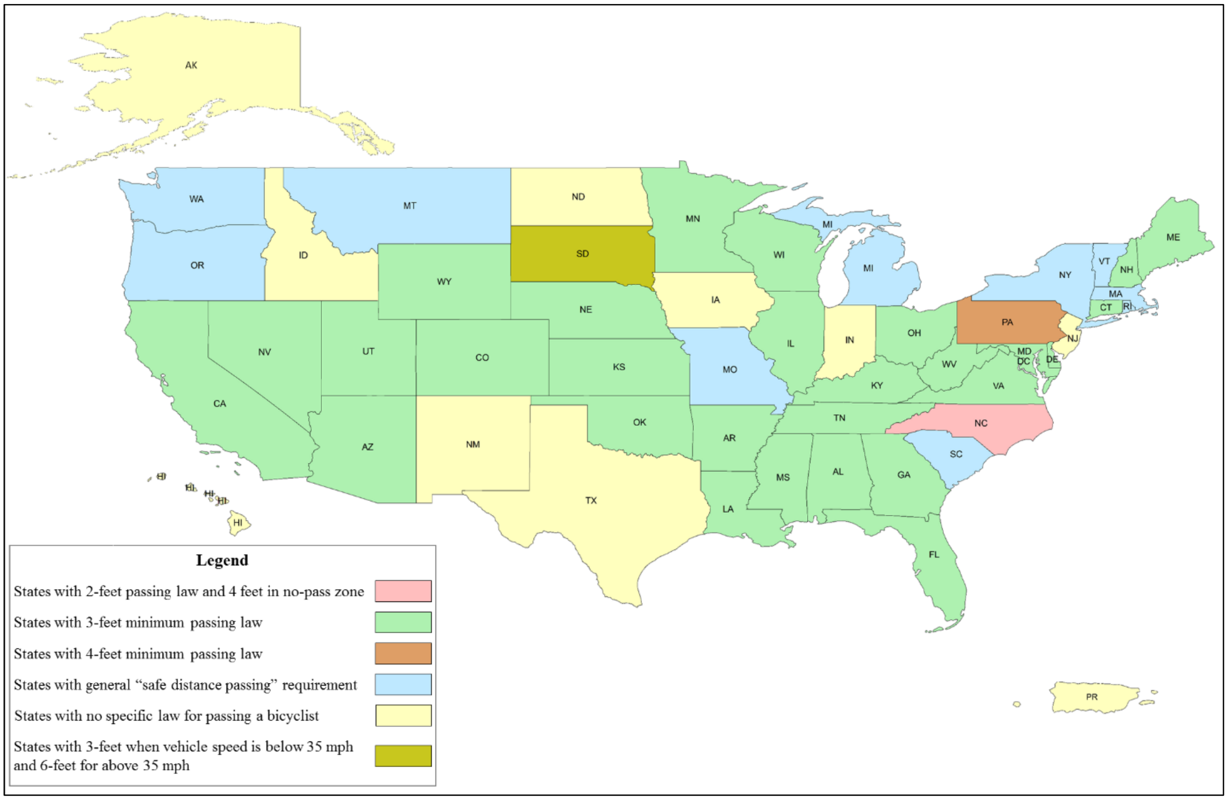


Figure 2-3: States with Statutes Regarding Motorists Passing Bicyclists

2.3.1 Michigan Passing Distance Law

Michigan is one of the only seven states that had not enacted a law requiring specific distance for motorists to pass bicyclists when this research was being carried out. The Michigan Vehicle Code at that time stated, *"The driver of a vehicle overtaking another vehicle proceeding in the same direction shall pass at a safe distance to the left of that vehicle, and when safely clear of the overtaken vehicle, shall take up a position as near the right-hand edge of the main traveled portion of the highway as is practicable*." This law left the "safe distance" to the judgement of the motorist. It was also open to interpretation for law enforcement (and therefore difficult to enforce). The "safe distance language" did not provide a clearly defined standard for patrol officers to use. Therefore, Michigan bicyclists faced significant risks from motorists overtaking too closely, even when riding "far to the far" in accordance with the state law.

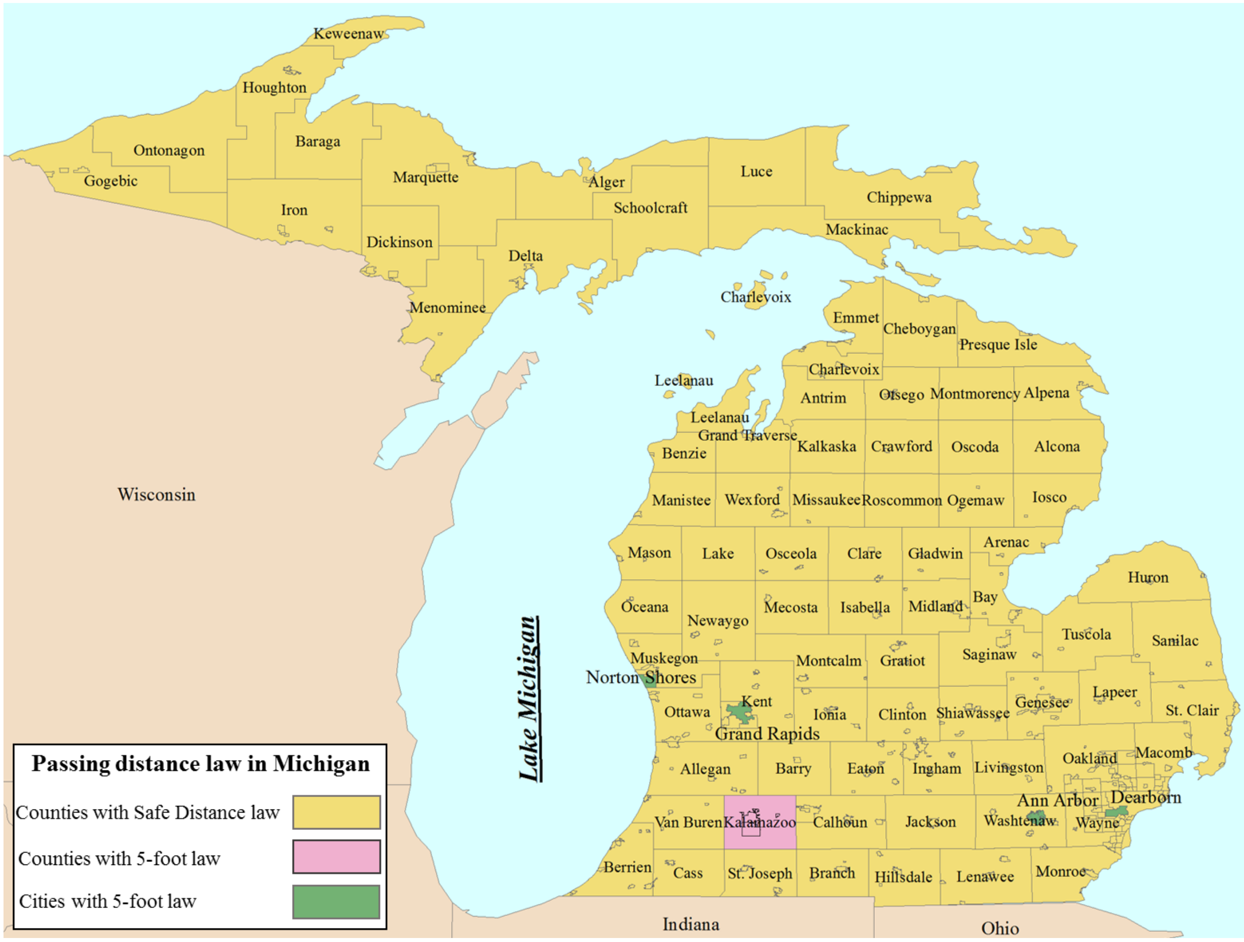


Figure 2-4: Passing Distance Law in Michigan

Despite the lack of the state law, several cities have passed ordinances requiring motorists to pass bicycles at a safe minimum distance. Grand Rapids was the first city to pass such the ordinance in September 2015, specifying a minimum passing distance of five feet. The cities of Ann Arbor, Kalamazoo and Portage subsequently passed five-foot passing ordinances. As it is shown in Figure 2-4, Kalamazoo County has enacted five-foot law for passing distance clearance. Other Michigan counties did not specify any ordinances. (Note: In September 2018, the three-foot passing law went onto effect in Michigan. The three-foot state law was not in effect at the time the current study was conducted. After the effective date of the Michigan State law, all the cities with the five-foot law still required a passing distance of five-foot. Cities cannot enforce distances less than the state law).

Despite the expectation that a bicycle passing law will improve the safety and comfort of bicyclists, there is little evidence of how much effective the three-foot or five-foot law is. Therefore, there is a strong need to study the effects of five-foot passing laws associated with bicycle infrastructure, cultural differences, and community education and outreach.

2.3.2 Effectiveness of Three-foot Passing Law

No research has been conducted to evaluate the effect of road users' awareness about such a law. One study obtained measurements on motorist passing distances after the implementation of three-foot passing law in Baltimore, MD (Love et al., 2012). The research team measured passing distance using a video recording methodology developed by Parkin and Meyers (2010). The results illustrated that cyclists in Maryland passed at a distance of three feet or less while cycling in standard lanes (i.e. without a bike lane or sharrow). On the other hand, no passes of three feet or less occurred in bicycle lanes. They developed a multiple linear regression model, which indicated lane width, bicycle infrastructure, cyclist identity, and street identity are significant on passing motor vehicle distance to cyclists.

Nehiba (2017) tested the effectiveness of a 3 ft. law on bicyclists' on fatal crashes. By employing 18,534 bicyclist fatalities from the Fatality Analysis Reporting System (FARS), the research adopted a negative binomial model. The model indicated that a state with a passing law is saving one life every 20.41 months compared to a state without a passing law. This equates to a slim reduction implying that passing laws are not an effective way to reduce bicyclist fatalities. The results, however, failed to find a statistically significant effect of passing distance law on bicyclists' fatalities. Consequently, the author suggested that the passing law is ineffective in reducing bicyclist fatalities. Despite of ineffectiveness on bicyclist fatalities, the only benefit passing law generates is possible increase in bicycle miles traveled.

One study conducted in Queensland, Australia, included interviews and focused groups with police agencies, road user surveys, observational study by video recording analysis, and crash data analysis (Schramm et al., 2016). In terms of practical implementation of a 3-foot passing law, the study asserted that it is difficult for police to enforce and drivers have stated concern about the ease of compliance on narrow roads and windy weather conditions. The drivers surveyed had expressed that is hard to estimate lateral distance to bicyclists accurately. Despite the problems of practical implementation, drivers have become more aware of bicyclists and give them more room, but their attitudes towards bicyclists have not necessarily changed. Unlike Nehiba (2017), the result revealed that bicycle-related crashes in the post-commencement period of three-foot law showed a statistically significant decreasing trend.

Another study examined the effectiveness of a trial Minimum Overtaking Gap (MOG) law in New Zealand (Balanovic et al., 2016). Three main challenges associated with MOG law were introduced in the study, including enforcement, education and awareness, and ability to uphold the law. As a conclusion, they recommended two different passing distances according to road classification and speed zone, namely 1m. at 60km/h or less, and 1.5m. at over 60 km/h.

2.4 Moving Objects Detection Using Remote Sensing Technique

Transportation agencies are experimenting with using remote sensing to detect and analyze trajectory of moving objects such as cars and bicycles to generate the bicyclist's perceived level of clearance. It is desirable to have an automated platform that could detect vehicles and bicycle maneuver to measure passing characteristics based on high-resolution datasets in the complex urban environment. Furthermore, high-resolution data could be a primary solution for many complex dynamic urban environments. A high-resolution dataset can be used to extract and assess passing maneuvers automatically. Remote sensing sensors such as light detection and ranging (LiDAR) and laser scanners can be used as an integral part of the accurate measurement and assessment process. LiDAR technology supplies a high-resolution data.

In 2003, the U.S. Department of Transportation (USDOT) introduced the vehicle-infrastructure integration (VII) systems such as remote sensing in vehicle and infrastructure communication systems to improve mobility and safety (Farradyne, 2005). Most recent remote sensing instruments can be employed to detect objects, make a classification, and provide tracking data. Data collection of advanced remote sensing instruments have been developing over time. LiDAR is classified as a high-resolution sensor that can achieve the defined research goals (Rufo, 2017). For instance, A Velodyne V16 LIDAR can generate up to 600,000 coordinate positions of the surrounding conditions. In addition, LIDAR has a 360-degree horizontal and a 15-degree vertical field of view (Velodyne LIDAR, 2018). However, in the way of contrast individuals have an approximate front horizontal field of view of 210-degrees (Traquair, 1949).

Kidono et al. (2011) defined light detection and ranging as a horizontally scanning laser scanner that generates the point cloud data. The dataset generated by LIDAR provides high-resolution environmental perception opportunities. Remote sensing sensors such as LIDAR and laser scanner which are usually set up in the stationary or mobile mode can supply a three-dimension dataset to use in the object detection procedure. LIDAR produces an accurate measurement of object characteristics in the Point Cloud Data (PCD) environment. The point cloud data can be used to extract different surfaces of the motor vehicle and bicycle during overtaking maneuver detections. There are many ways to detect and measure objects in point cloud data, such as grouping methods or segmentation methods which were used in the first stage of this research. In a three-dimension trajectory detection method, data directly retrieved from LIDAR are converted to PCD. However, processing of large sets of data such as point cloud data is time-consuming and may require automated algorithms. Integrating LIDAR data with machine learning techniques have brought many benefits to the users in reducing time consumption and while increasing the accuracy of data processing.

Many powerful algorithms have been developed for classification and regression of the data such as the k-Nearest Neighbors (KNN) at least squares, k-Nearest Neighbors, and Support Vector Machine (SVM). Vehicle and bicycle feature detection is the priority goals of this investigation. In object detection, determining a smooth and reasonable boundary are required to track moving objects.

Object detection technology offers an integrated solution to implement complex issues in a sustainable way in megacities which are called "smart cities." Smart cities use different types of technology to integrate all the data and platforms to provide a higher quality of life (van der Hoeven, 2017). Smart cities need to develop a bicyclist infrastructures monitoring system to provide safe and comfortable bicycle facilities in order to increase the bicyclist's perceived level of comfort. Real-time data processing facilitated the use of big data (Malik & Ali Shah, 2017). Smart algorithms play an important role in improving service quality while accelerating and coordinating data processing in smart cities.

2.5 Conclusion

Overall, no specific distance has been validated to be the cut-off point for bicyclists' safety, drivers' recognition, and police enforcement. Also, which type of passing law among different states, regions, and countries definitions is more effective in terms of implementation, safety and execution, has not yet been investigated. For instance, one might suspect a law which considered speed limit and road hierarchy would be more effective in terms of bicyclists' safety. On the other hand, implementation of such a law would be difficult because of lack of driver's education and awareness as well as the police enforcement. The current investigation therefore sought to overcome the limitations of the existing research and represent the overall effectiveness of different passing distance laws (without law, three-foot law, and five-foot law) in Michigan.

Chapter 3 Methodology

3.1 Overview

In order to evaluate motorist-bicyclist passing distances in cities with different passing laws, it was initially necessary to choose specific existing locations in the field for data collection. This process started with identification of cities, which possess different passing laws, but with similar population characteristics, cycling roadway and infrastructure in addition to considerable range of bicycle commuters. After the selection of appropriate cities, specific sites in each city were chosen. In order to assess bicycle-driver interactions and passing distances in cities with different laws, the site selection process should conform to a framework to facilitate accessible city-level comparison.

After selecting analogous sites with various roadway characteristics in cities with different passing laws, it is necessary to design and construct an instrumented bicycle to study passing distances in each of the sites. This chapter will also address how the instrumented bicycle was built.

3.2 Site Selection

3.2.1 Cities Identification

To meet the specific needs of this study, specific study areas including cities, and counties needed to be selected. The study areas had to provide a diversity among existing passing laws and roadway characteristics, along with a range of population and bicycle commuters. In Michigan, there are six cities (including Kalamazoo, Portage, Ann Arbor, Dearborn, Grand Rapids, and Norton Shores) that have passed five-foot ordinance at the start of this study. The study aims were to compare cities with five-foot law with those with a three-foot law, and those without a passing law.

City identification process started with picking a city among a total of 176 Michigan cities. To ensure adequate vehicle-bicycle interaction, the cities were selected had a population greater than 50,000. The mode share of the selected city should also be at least 0.1% bicycle commuters. To assure that motor-vehicle drivers and bicycle riders' behavior are not affected by different laws, a criteria for affected area was defined. In this study, we assumed that presence of a city with different passing law within less than 50 miles from the selected city could produce biased results of bicyclists or drivers behavior. For instance, drivers in Dearborn have to maintain 5 feet or more from bicyclists during an overtaking interaction; however, this city is surrounded by areas (e.g. Warren and Livonia) without the same law. Therefore, most of the drivers using the roadway would not necessarily be residents of Dearborn. To avoid getting these type of errors in behavior evaluation, site selection process was designed to reject such cases. Figure 3-1 illustrates the city identification process for site selection.

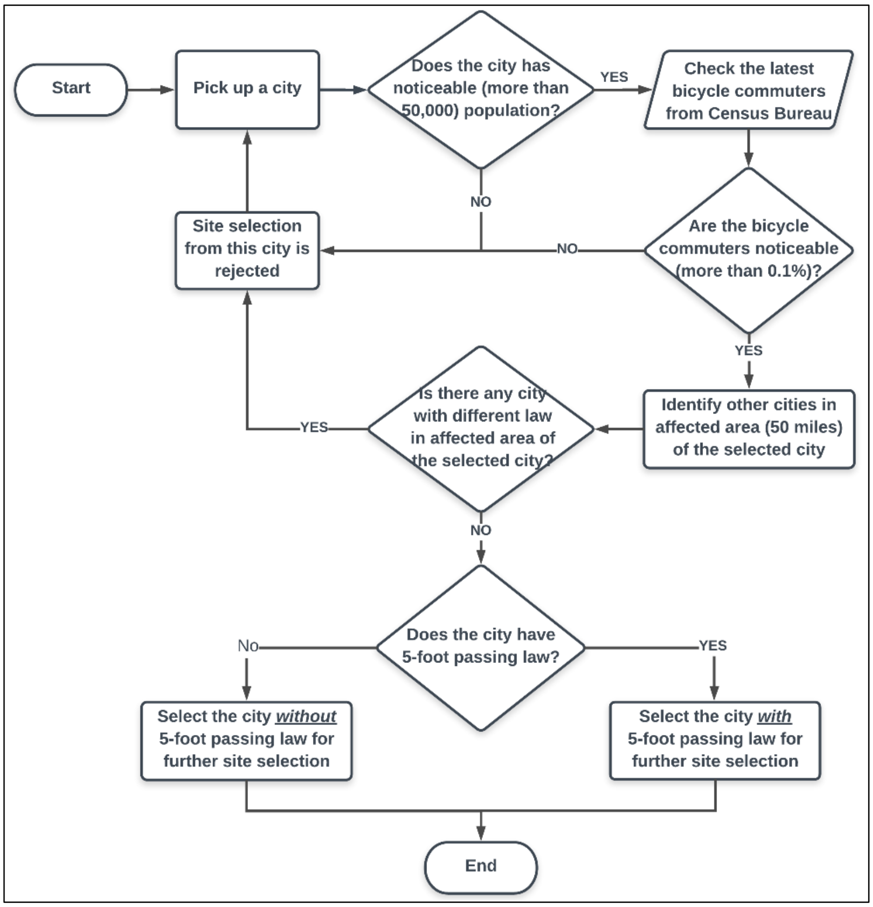


Figure 3-1: City Identification Process for Site Selection

The city identification process led three Michigan cities to be selected. Grand Rapids and Kalamazoo were selected as study cities that had introduced and adopted an ordinance for drivers requiring 5 feet away while passing bicycles. Furthermore, Lansing was chosen as a city that had not yet enacted legislation specifying a minimum passing distance. To involve a site with the most dominant passing distance law in the US (three-foot) and make a comparison with the selected cities, selecting additional city was required. Among several cities around Michigan that already had minimum three-foot passing distance law, South Bend, a city in the county of St. Joseph, Indiana, was selected. South Bend is located in the northernmost part of Indiana that borders Michigan. Indiana - like Michigan - had not yet enacted the minimum requirement for vehicle-bicycle passing distance during this study. However, South Bend had an ordinance requiring motor vehicle drivers to provide at least 3 feet of distance when passing bicycle users on the city's roadways since March 2013. Therefore, South Bend was selected as a city with a three-foot passing law. Table 3-1 and Figure 3-2 indicate selected cities' characteristics and geographical locations respectively.

Table 3-1: Selected cities' characteristics for data collection (U.S. Census Bureau, 2016)

City	County	State	Passing distance law	Population (2016)	Area (mi^2)	Population density ($/mi^2$)	Bicycle commuters (%)
Grand Rapids	Kent	Michigan	5 feet	196,458	45.27	4,200	1.5
Kalamazoo	Kalamazoo	Michigan	5 feet	75,988	24.11	3,000	0.8
Portage	Kalamazoo	Michigan	5 feet	46,262	35.17	1,300	0.2
Lansing	Ingham, Eaton	Michigan	No specified distance	117,400	36.68	3,100	1.2
South Bend	St. Joseph	Indiana	3 feet	102,442	41.82	2,457	1.5

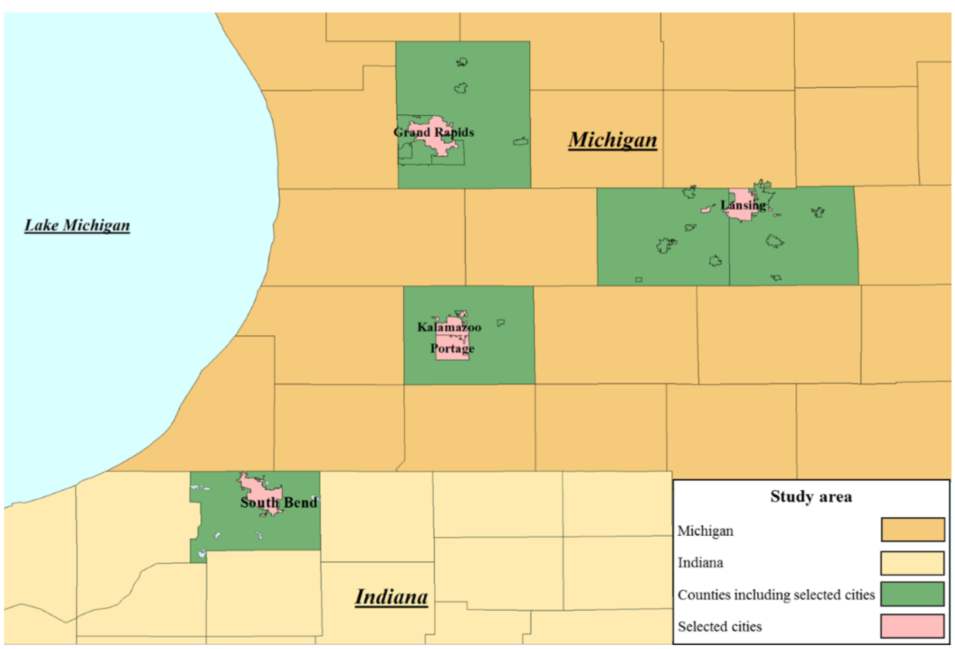


Figure 3-2: Geographical locations of selected cities

3.2.2 Site Selection Procedure

In order to assess drivers' passing distance while passing bicyclists in different study areas, specific locations in each city are required. According to roadway characteristics, eight types of roadway configurations, which are called clusters, were proposed to facilitate the comparison purposes among different sites. Creating clusters based on roadway characteristics enabled us to achieve inter-cluster comparison among areas with different passing distance laws as well as intra-cluster comparison. The eight clusters used in this study were:

- 2-lane roadway with separated bike lane
- 2-lane roadway with shoulder lane
- 2-lane roadway with sharrow
- 2-lane roadway with none of the above
- 3-lane roadway with separated bike lane
- 3-lane roadway with shoulder bike lane
- 3-lane roadway with sharrow
- 3-lane roadway with none of the above

Table 3-2: Roadway characteristics to filter similar sites

Factor	Range	Source
Number of lanes	2 3	Observation
Bike-way availability	Bike lane Sharrow Shoulder No bike-way	Observation
Segment length (mi)	Group1: 0.2-1 Group2: 1-3 Group3: >3	Measured from available online maps
Traffic count AADT (veh/day)	Group1: 3,000-10,000 Group2: 10,000-20,000 Group3: >20,000	MS2 Online services (www.ms2soft.com)
Access density (/mi)	Group1: 5-10 Group2: 10-20 Group3: >20	Calculated from available online maps
Speed limit (mph)	Group1: 25-35 Group2: 35-45 Group3: >45	Posted speed signs

A site selection procedure was required to find the specific locations required for each cluster. For instance, passing distance captured in a 2-lane rural highway with bike-lane cluster in high volume traffic may not be comparable with another site with lower average traffic volume. Therefore, to establish the site selection procedure, a set of roadway characteristics needed to be developed. In this study, in addition to traffic volume (AADT), we also selected site length, access density and speed limit to filter out different sites from the site selection process. Factors were classified into different groups to facilitate site selection process (i.e. access density was divided into three groups including 5-10, 10-20, and more than 20 /mi). In addition to factors discussed above, the researchers were aware that additional characteristics can influence passing distance. To address this problem, we assumed that all uncovered characteristics are constant. For instance, lane width is an important factor of passing distance, so we selected sites with a lane width of 11 feet and roadways without this characteristic were eliminated from site selection process. The factors used to select study sites are presented in Table 3-2.

As stated earlier, the purpose of site selection process was to find similar sites in identified cities for each cluster. The length of segment, traffic counts, access density and speed limit were used to filter out dissimilar sites from the process. The site selection was conducted for each cluster as a separate and independent process. To start the selection process an initial site for every cluster was required as a benchmark for making comparison between further sites. The benchmark was assumed as first input to the process that can be changed over iterations and replaced with another site. After benchmark selection, a new site was entered that was compatible with the cluster characteristics consist of number of lanes and type of bicycle service. Unfitting sites were stored for further clusters; and compatible sites proceeded to the next step. At this step, similarity between sites in the same clusters were examined. To exemplify, consider a site with traffic volume 22,000 veh/day (Group3) that cannot be assigned in a cluster that already possesses a site with 8,000 AADT (Group1). In like manner, all other factors were examined to find similar sites that fit into a clusters. The process was pursued for each cluster to ensure that all the sites from different cities were entered and the best-fitted sites were selected for data collection. Figure 3-3 illustrates the site selection procedure for a given cluster and benchmark.

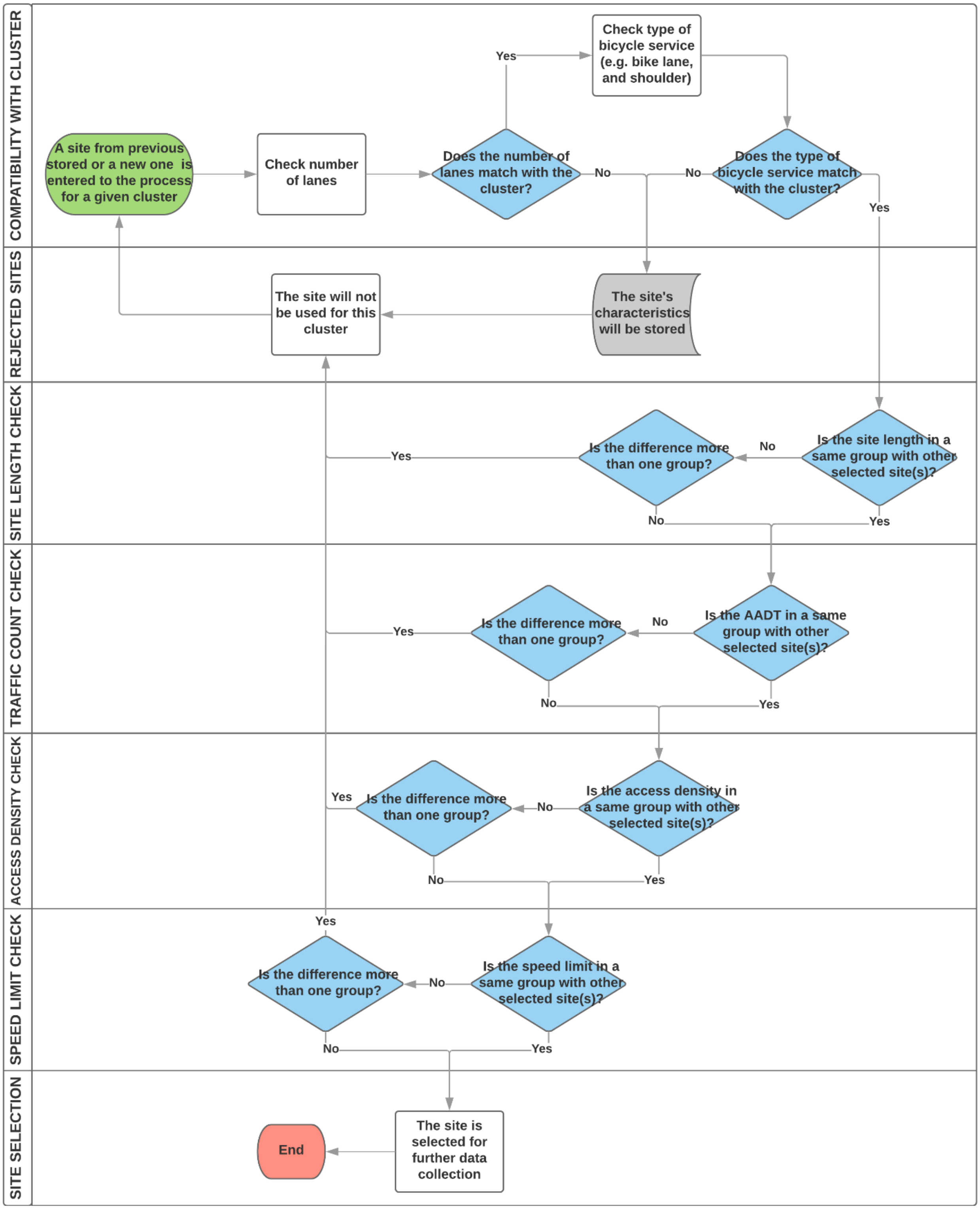


Figure 3-3: Site selection procedure for each cluster

Although the site selection process provided a procedure to get similar sites for specific clusters, no suitable sites were found in some locations. For instance, no 2- or 3-lane roadway with sharrow were found in Lansing. Selected sites in study areas are shown Figure 3-4 as well as the sites' information in Table 3-3.

3.3 Sample Size Computation

In this study, distance from a passing vehicle to a moving bicycle captured by the C3FT device was defined as one observation. Since C3FT can capture passing distances up to 10 feet, distances with more than 10 ft. (unobserved distances), would not be considered as an observation in this study. Decision on total number of observations needed for data collection should be based on available resources, such as time frame and manpower as well as cost associated with conducting the experiment. In order to determine minimum time required for bicycle riding data collection in each site, a weighting factor was used. Since the expectation for sites with higher traffic volume contributes to more number of observations, a weighting factor for a site has an inverse relationship with the site's traffic volume. The formula to compute the weighting factor for specific site is suggested below:

$$W_i = \frac{\frac{1}{V_i}}{\sum_i \frac{1}{V_i}}$$

$$T_i = W_i * T$$

Whereby,

W_i = Weighted factor for site i,

V_i = Traffic volume for site i,

T_i = Minimum required time for data collection in site i, and

T = Minimum total time required for all sites.

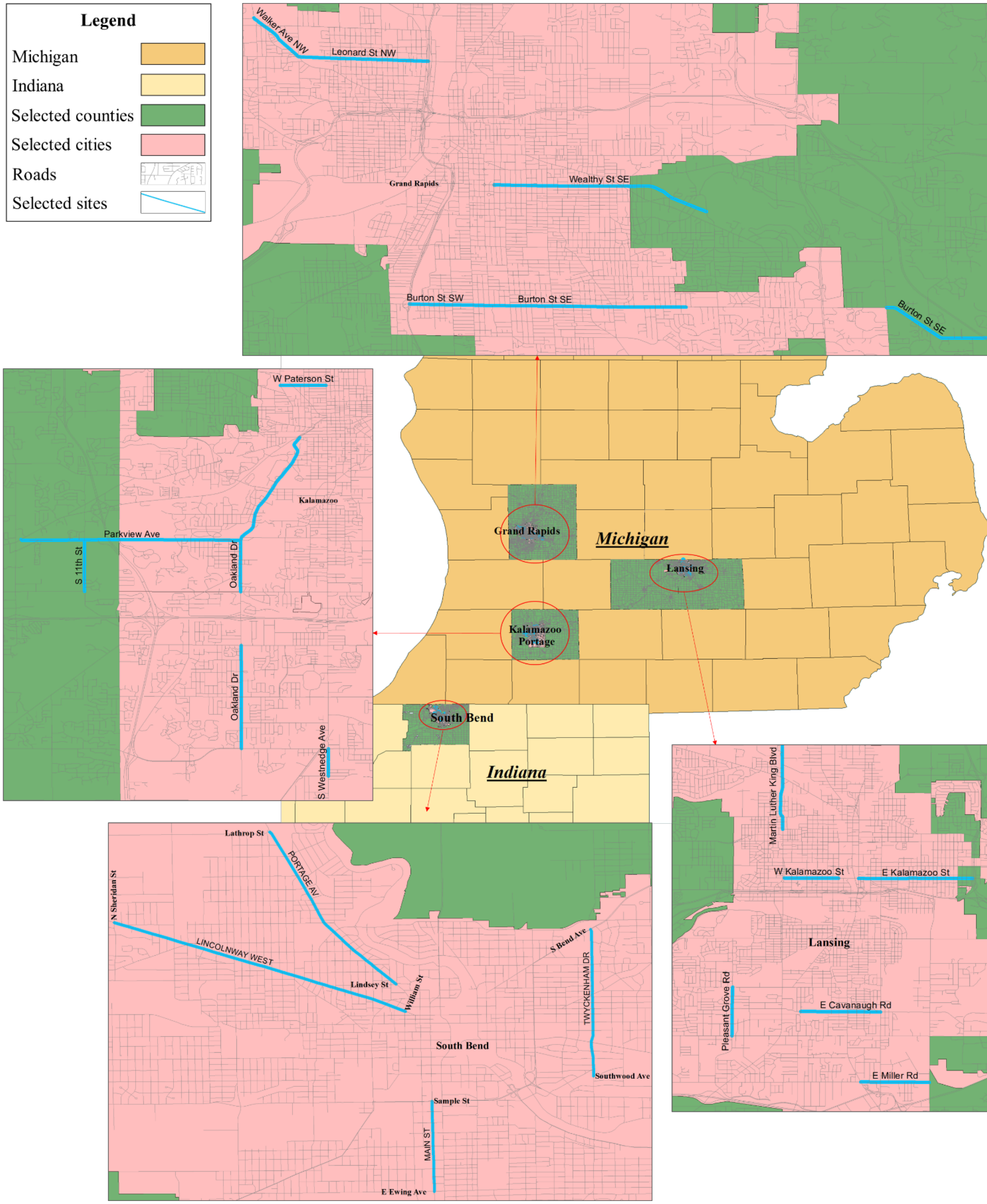


Figure 3-4: Selected sites in study area

Table 3-3: Selected sites in clusters

	Type of available bicycle service											
	Bike Lane						Sharrow					
#Lanes	Site	Cross streets	Length	AADT	Access	Speed	Site	Cross streets	Length	AADT	Access	Speed
2	Parkview	Drake Rd - Greenleaf Blvd	0.9	13288	8	45	11th St.	W N Ave - Parkview Ave	1	5200	8.2	35
	Leonard St	Walker Ave - Garfield Ave	0.5	11000	10	30	Wealthy St.	Lafayette Ave - Lake Dr	1.5	12462	14.7	30
	Pleasant Grove Rd	W Jolly Rd - Holmes Rd	1	9300	9	35	NA					
	Twyckenham Dr	S Bend Ave - McKinley Ave	0.9	7000	16.7	30	Portage Ave	Lathrop St - Queen St	0.9	9500	11.8	30
3	Parkview Ave.	Greenleaf Blvd - Oakland Dr	0.8	17376	15	35	NA					
	Oakland Dr.	Lovell - Kilgore	3.2	16786	12	30						
	Oakland Dr.	Milham - Center	2	18111	6.8	35						
	Burton St.	Division Ave - Concord Ave	2.5	18668	15	30	Leonard St	Garfield Ave - Seward	1	13000	13	30
	Martin Luther King	Daleford - Grand River	0.9	16401	10.3	35	NA					
	Kalamazoo St.	Larch - 127	1.5	9508	15	30						
	Lincoln Way	Harisson Ave - Sheridan St	2	17385	20	30	Lincoln Way	William St - Harrison Ave	0.5	13257	13.3	30

Kalamazoo Grand Rapids Lansing South Bend

Table 3 3: Selected sites in clusters (Continue)

	Type of available bicycle service											
	Shoulder						No bike road					
#Lanes	Site	Cross streets	Length	AADT	Access	Speed	Site	Cross streets	Length	AADT	Access	Speed
2	Parkview Ave.	Stadium Dr - 11th St	1	3900	10.3	35	W Paterson St	N Westnedge Ave - Doughlas Ave	0.65	5679	11	25
	Walker Ave	Leonar St - Bluberry Dr	0.8	6055	10.2	25	Wealthy St.	Lake Dr - Lakeside Dr	1.1	5500	10.8	25
	Kalamazoo St.	Martin Luther King - Grand Ave	0.8	4692	10.3	30	Cavanaugh	Pennsylvania - Lowcroft Ave	1.3	5000	10	25
	Twyckenham Dr	McKinley Ave - Southwood Ave	0.8	7500	13.9	30	Portage Ave	Queen St - Lindsey St	1	8000	16.7	25
3	Parkview Ave.	11th St - Drake Rd	0.5	10178	6.8	45	S Westnedge Ave	E Melody Ave - W Centre Ave	0.5	10400	12	35
	Burton St.	Paris Ave - I96	1.3	13362	6	45	Leonard St	Seward St - 296	0.3	15000	16.7	30
	Burton St.	Clyde Park Ave - Division Ave	0.7	17156	12.3	40						
	Miller Rd	S Cedar St - N Aurelius	1	8923	9	35	Martin Luther King	Grand River - Sheridan Rd	0.9	7769	13.4	30
	Main St	W Sample St - W Ewing Ave	1	12072	12.5	30	Main St	W Ewing Ave - W Sample St	1	12072	12.5	30

Kalamazoo | Grand Rapids | Lansing | South Bend

According to the total cost associated with data collection, the minimum total time required for riding the bicycle through selected sites was decided to be 24 hours. Then, using the equations gives the minimum time to provide sample size required for each site. Table 3-4 shows minimum time for data collection.

Table 3-4: Minimum time for data collection to provide sample size in each site

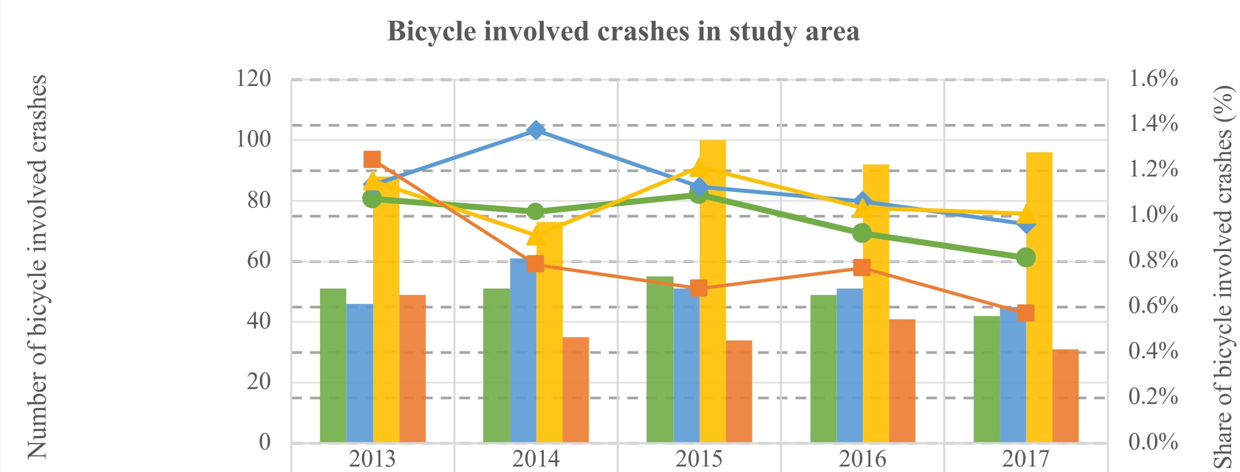
#Lanes	Bike Lane					Sharrow				
	Site	AADT	$1/V_i$	W_i	T_i (min)	Site	AADT	$1/V_i$	W_i	T_i (min)
2	Parkview	13288	8.E-05	2.1E-02	30	11th.	5200	2.E-04	5.3E-02	76
	Leonard	11000	9.E-05	2.5E-02	36	Wealthy	12462	8.E-05	2.2E-02	32
	Pleasant Grove	9300	1.E-04	2.9E-02	42	NA				
	Twyckenham	7000	1.E-04	3.9E-02	56	Portage	9500	1.E-04	2.9E-02	42
3	Parkview	17376	6.E-05	1.6E-02	23	NA				
	Oakland	16786	6.E-05	1.6E-02	24					
	Oakland	18111	6.E-05	1.5E-02	22					
	Burton St	18668	5.E-05	1.5E-02	21	Leonard	13000	8.E-05	2.1E-02	30
	M L King	16401	6.E-05	1.7E-02	24	NA				
	Kalamazoo	9508	1.E-04	2.9E-02	42					
	Lincoln W.	17385	6.E-05	1.6E-02	23	Lincoln W.	13257	8.E-05	2.1E-02	30
Total			9.E-04	0.24	342			5.E-04	0.15	209
#Lanes	Shoulder					No bike road				
	Site	AADT	$1/V_i$	W_i	T_i (min)	Site	AADT	$1/V_i$	W_i	T_i (min)
2	Parkview	3900	3.E-04	7.0E-02	101	W Paterson	5679	2.E-04	4.8E-02	70
	Walker	6055	2.E-04	4.5E-02	65	Wealthy.	5500	2.E-04	5.0E-02	72
	Kalamazoo	4692	2.E-04	5.8E-02	84	Cavanaugh	5000	2.E-04	5.5E-02	79
	Twyckenham	7500	1.E-04	3.7E-02	53	Portage	8000	1.E-04	3.4E-02	49
3	Parkview	10178	1.E-04	2.7E-02	39	S Westnedge	10400	1.E-04	2.6E-02	38
	Burton	13362	7.E-05	2.1E-02	30	Leonard	15000	7.E-05	1.8E-02	26
	Burton	17156	6.E-05	1.6E-02	23					
	Miller	8923	1.E-04	3.1E-02	44	M L King	7769	1.E-04	3.5E-02	51
	Main	12072	8.E-05	2.3E-02	33	Main St	12072	8.E-05	2.3E-02	33
Total			1.E-03	0.33	471			1.E-03	0.29	417

Kalamazoo Grand Rapids Lansing South Bend

3.4 Crash Data in Study Area

3.4.1 Trend of Bicycle-involved Crashes

Bicycle-involved crashes in study area for the past 5 years were analyzed. Figure 3-5 depicts the number of bicycle involved crashes and share of bicycle involved crashes among total crashes in four cities. Note that since some sites have been extended to the city of Portage (immediately adjacent to Kalamazoo) crash data for this city is included in Kalamazoo city statistics. Analysis also revealed that Grand Rapids has the highest number of bicycle-involved crashes. However, the overall rate of bicycle-involved crashes in this city is not more than other cities. Moreover, the rate of bicycle-involved crashes in the study area has been decreasing since 2015.

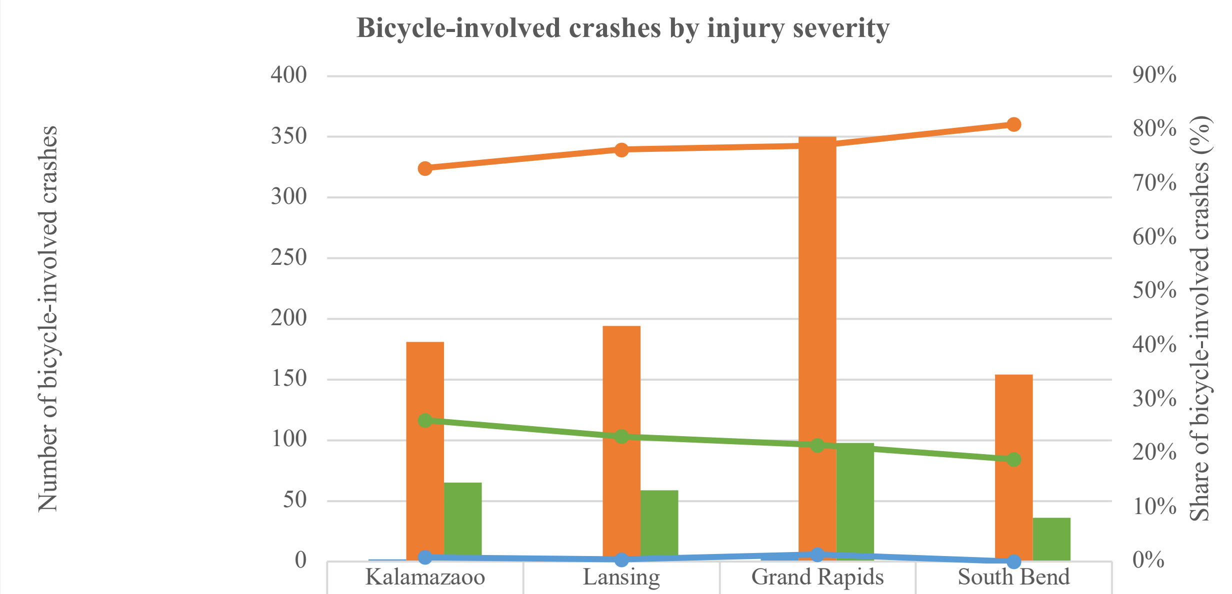


	2013	2014	2015	2016	2017
Kalamazaoo	51	51	55	49	42
Lansing	46	61	51	51	45
Grand Rapids	88	73	100	92	96
South Bend	49	35	34	41	31
Kalamazaoo (%)	1.07%	1.02%	1.09%	0.92%	0.82%
Lansing (%)	1.14%	1.38%	1.13%	1.06%	0.96%
Grand Rapids (%)	1.16%	0.91%	1.22%	1.04%	1.01%
South Bend (%)	1.25%	0.79%	0.68%	0.77%	0.57%

Figure 3-5: Number of bicycle involved crashes in study area

3.4.2 Bicycle-involved Crashes by Injury Severity Level

In order to determine crash severity in the study area, bicycle-involved crashes from 2013 to 2017 were categorized into three levels including fatal, injury, and property damage only. The analysis showed that at least 70 percent of bicycle-related crashes in study areas caused injuries. Also, a total of 9 fatal bicycle-crashes occurred in last 5 years in the study area that the majority of them (6 out of 9) has occurred in Grand Rapids. Figure 3-6 reflects total number of bicycle-involved crashes in last 5 years by injury severity.



	Kalamazaoo	Lansing	Grand Rapids	South Bend
fatality	2	1	6	0
injury	181	194	350	154
property damage only	65	59	98	36
fatality	0.8%	0.4%	1.3%	0.0%
injury	73.0%	76.4%	77.1%	81.1%
property damage only	26.2%	23.2%	21.6%	18.9%

Figure 3-6: Bicycle-involved crashes by injury severity (2013-2017)

3.5 LiDAR Data Extraction

In this study, Lidar was used to detect vehicles and extract trajectories for overtaking maneuvers. The data were collected in the two and three lanes road with or without shoulder with the bicycle. One of the significant limitations of the moving vehicle and bicycle feature analysis is accessing the comprehensive database to use for analyzing the data. The general concept of LiDAR object detection can be used to generate object features for the motor vehicle and bicycle trajectories after data processing.

In this research, a new analysis algorithm was developed to assess the potential advanced technologies that could be added to the field of measuring the bicycle-vehicle maneuver, which included speed and distance transformation in micro level transportation systems. Data are collected in X, Y and Z coordinates that were referred to as PCD to represent the surface which preserves flexibility and accuracy within the objects in the transportation facilities. For the purpose of this research, the definition of data gathering, and post-processing were involved in the complex calculation challenges. The entire recognition process was implemented by a single algorithm - from the normalized data through the final clustering information.

The literature review shows that data processing methods and corresponding algorithms have been developed to detect vehicles automatically. Most of the publications used data obtained in the controlled environments and did not consider the relation between distance and speed measurements as overtaking's related parameters, however, our data collection method represents the real vehicle and bicycle maneuvers. In our study, two significant steps were made to accurately evaluate and assess vehicles overtaking a bicycle: (1) detecting of vehicles by preprocessing and processing raw data; and (2) extracting and evaluating vehicles overtaking bicycle's characteristics data. The following steps were followed in the automated evaluation and extraction of vehicles overtaking a bicycle (Figure 3-7):

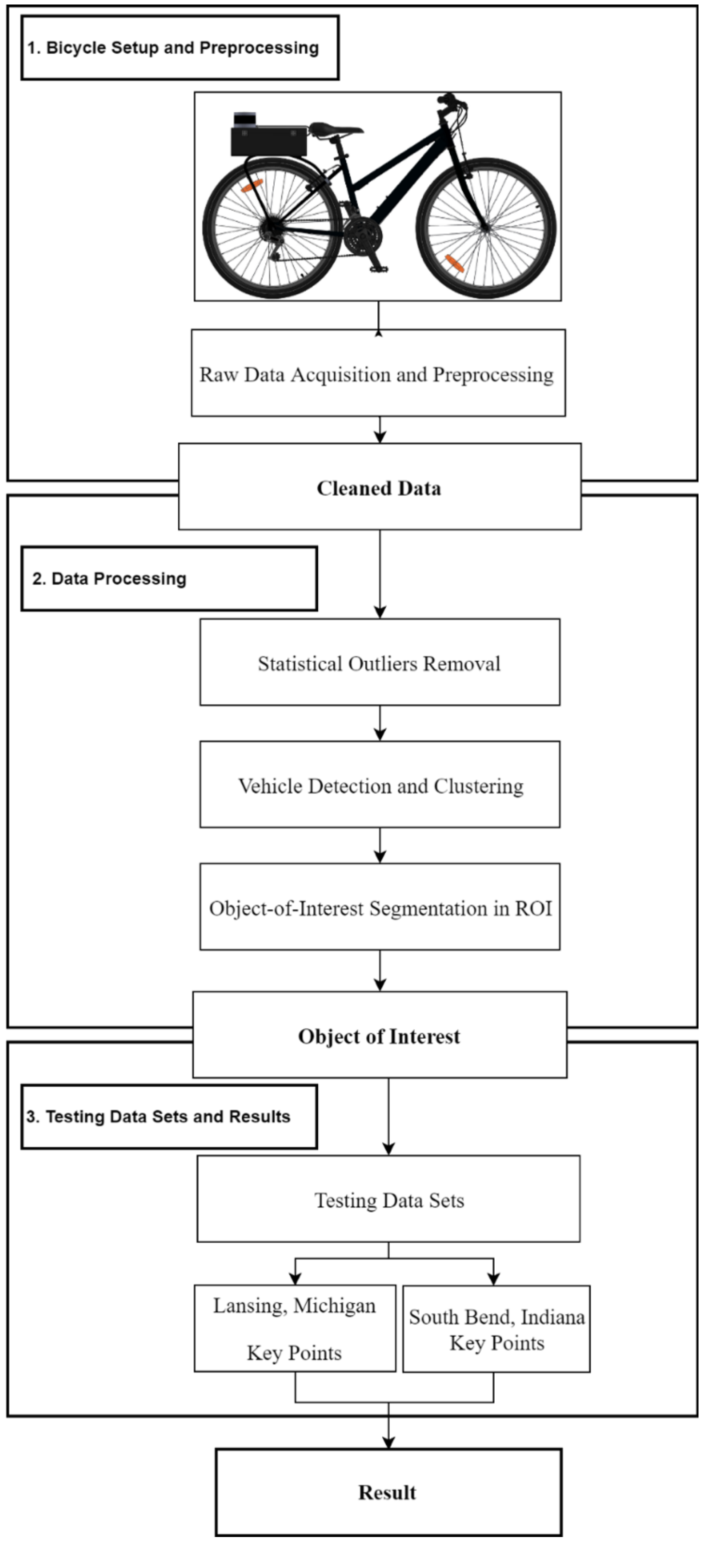


Figure 3-7: Proposed methodology flow-chart of automated evaluating of vehicles overtaking a bicycle

3.5.1 Raw data acquisition and preprocessing

The LIDAR is a sensor which is able to generate up to 30,000 of points with their coordination information in every data frame (Figure 3-8). The LIDAR sensor used in this research was Velodyne's VLP-16 model.

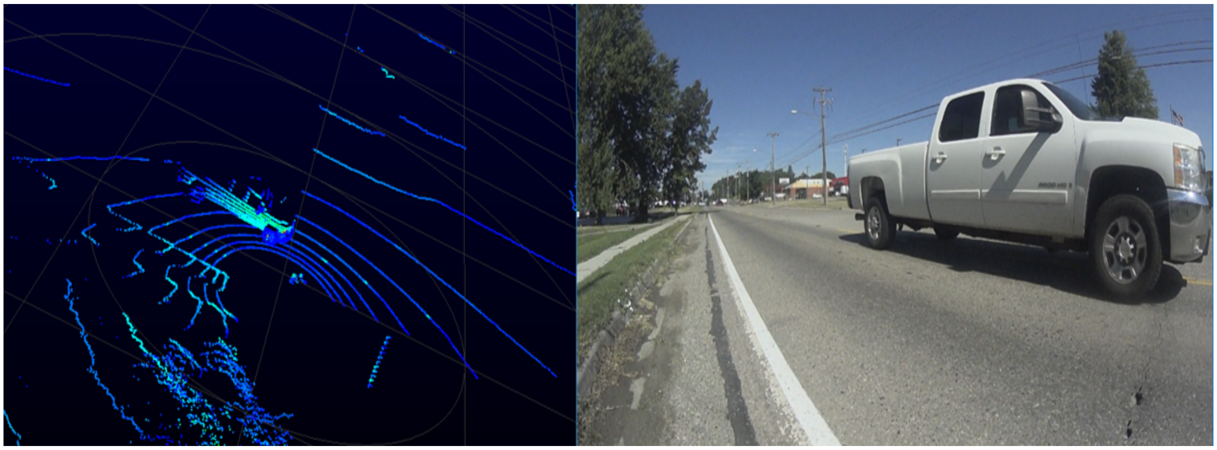


Figure 3-8: A raw data view of a vehicle (left) and a camera view of the same vehicle (right)

The primary objective of vehicle and bicycle trajectory detection was to define the Region Of Interest (ROI), which is a portion of a data-limited based on the roads and vehicles geometry. In this investigation, the data analysis was executed for the study area. Based on Dozza et al. (2016), vehicles maneuvers that are more than 12 feet on the side of bicycle and 16 feet before and after leaving the bicycle are not very important in determining the overtaking trajectory of the overtaking vehicle. In our research, the ROI defined was within 16 feet which means all points with ranges higher than 16 feet distance from the LiDAR were deleted (Figure 3-9).

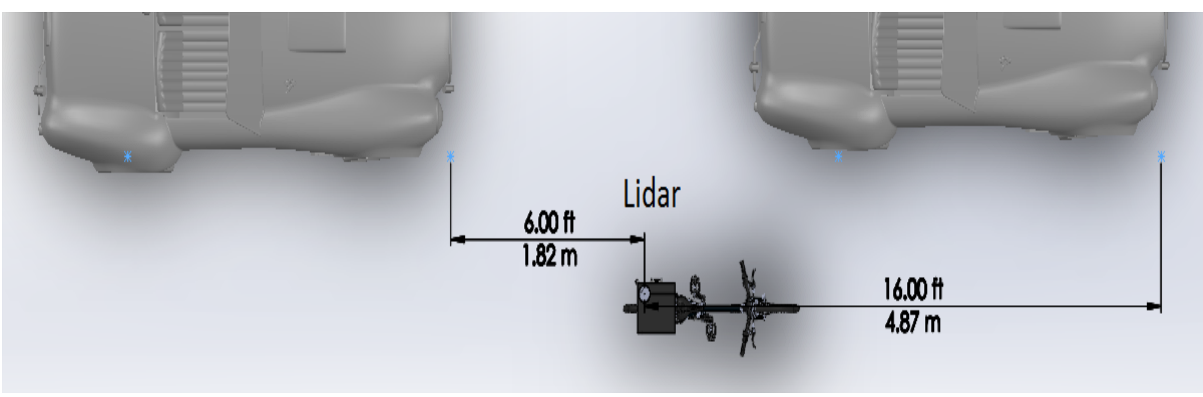


Figure 3-9: ROI schematic for a vehicle trajectory detection

The LIDAR data has been used to acquire data points of object's surface such as the vehicle, trees, building surfaces, etc. Once outrange data are removed, it is necessary to filter out objects that are noise in our dataset such as traffic signs, trees, etc. within the 16 feet range.

3.6 Building an Instrumented Bicycle

The bicycle used in this study was a regular bicycle (Jamis Coda Sport) with 17-inch frame size. An ultrasonic detector was mounted on the handlebar of the bicycle to measure overtaking distances. On the back of the bicycle, a LiDAR was installed on the top of a case to capture vehicle speed, vehicle trajectory, and passing distances.

3.6.1 Ultrasonic Detector

A sensitive ultrasonic detector was also utilized to measure passing distance. The device is a bicycle-mounted electronic hardware system designed to detect, capture, and display the lateral proximity of passing motor vehicles (Codaxus, 2017). The device was mounted on the bicycle's handlebar by means of an adjustable arm. The sensor unit ended at the left edge of the handlebar. In order to measure an accurate distance from the bicycle to passing motor vehicles, the sensor was installed perpendicularly to the traffic flow. The sensor could not automatically store the captured distances. Therefore, a camera was set up at the top of the sensor's screen to record all the measurements during the experiment. Figure 3-10 provides more details about mounting the device and the camera on the handlebar.

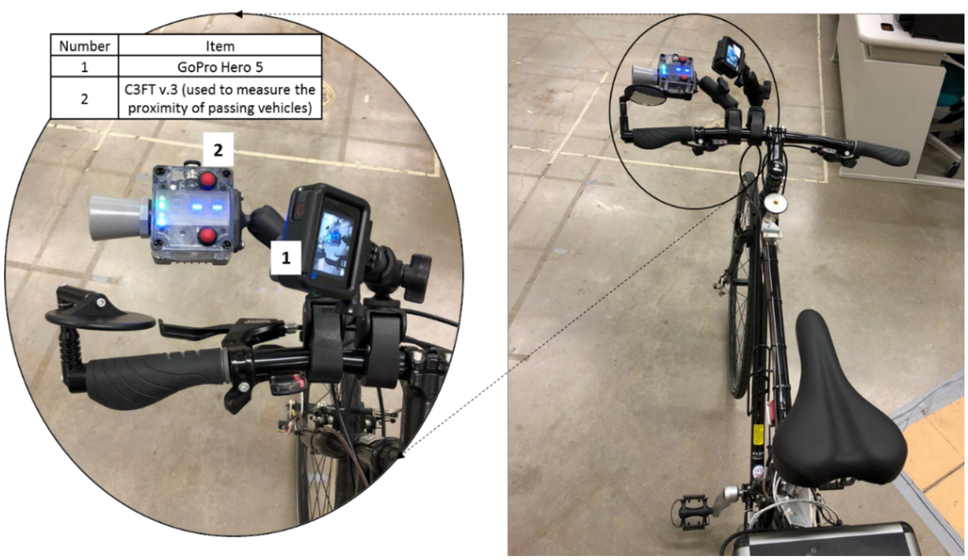


Figure 3-10: Positioning of C3FT and the camera on the bicycle's handlebar

3.6.2 LiDAR Set Up

A Velodyne Lidar system was installed on the top of a case, which was attached at the back of the bicycle. A Sony X3000 4K camera was installed on the left corner of the case viewed passing motorists from it is concealed location within the case. The configuration of the system was not likely to attract the attention of passing vehicles as it was within the typical outline of the bicyclist. A pair on onboard batteries (Figure 3-11) located in the case powered the Lidar, Sony camera, Garmin GPS receiver, and accelerometer equipment (SBG sensor). The overall weight of the system was not an impedance to the rider and never influenced the normal bicycle operation. Table 3-5 presents characteristics of the devices installed on the case at the back of the bicycle.

Figure 3-11: Lidar and bicycle set up

Table 3-5: Devices installed on the case back of the bicycle

Sensor type	Sensor Name	Data Provided	Resolution	Sample frequency
LIDAR	Velodyne V-16	Point Cloud	Angular resolution (vertical): 2°	5 – 20 Hz
Camera	Sony X3000	Video Frames	1920*1080 Pixel	30 fps
GPS	Garmin 18x LVC	Latitude and Longitude	1 MS	1 Hz

Chapter 4 Data Collection

4.1 Overview

In order to identify drivers' behavior in areas with different passing distance regulations, two types of data were collected. First, a questionnaire was designed and distributed to a random sample of licensed drivers. The main purpose of the survey was to determine the awareness of drivers of the passing distance regulation in their area. It also examined whether the different regulations could affect the drivers perspective about minimum bicycle passing distance. The survey started with general personal questions (i.e. age, gender and race), then asked about existing passing distance regulation and enforcement policy in the city in which the participant lived. At the end, the survey participant was asked what distance they usually keep when passing a bicyclist. The survey can be found in Appendix 1.

The second approach for data collection was to obtain field data by riding the instrumented bicycle through selected sites and recording passing vehicles distances to the bicycle. The field experiment was carried out by an experienced bicycle rider who was familiar with the locations.

This chapter presents descriptive analysis of the conducted survey and the field experiment results on passing distances, as well as speed when a vehicle overtakes a bicyclist.

4.2 Survey

The survey was implemented to determine drivers' perception about existing passing law and enforcement in each city. There were several questions in the survey, which were designed to identify drivers' perception on their distances while overtaking a bicyclist in areas with different laws. People in four cities (including Kalamazoo, Grand Rapids, Lansing, and South Bend) were asked to participate in a quick interview by the survey team. We distributed the questionnaires in three parking locations (including grocery stores, gas stations, and shopping malls) to obtain participants who were drivers. Since we intended to focus on drivers' behavior, the first question was asked from participants whether they have driver license. The surveyor proceeded with asking further questions if the participant was a licensed driver. Six hundred licensed drivers (150 in each city) agreed to complete the survey. The descriptive analysis for every question asked are presented below:

4.2.1 City Criteria

According to aforementioned assumption in city identification, the city criteria was defined as the area within 50 miles distance. Thus, the responses from participants who live more than 50 miles away from the city should be eliminated from existing data set. Comprehensively, 21 surveys were removed from data set due to exceeding the city criteria. Figure 4-1 points out the living location of respondents in each city.

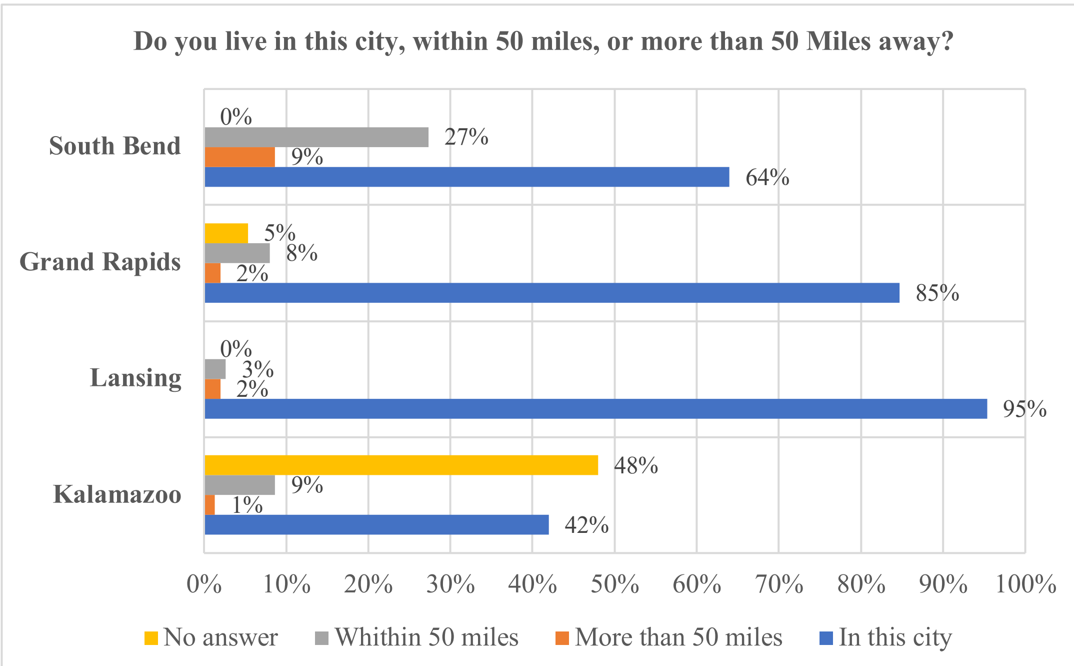


Figure 4-1: Participants living location

4.2.2 Survey Location

Three general locations, which have a high percentage of drivers, were selected to conducting the survey. The survey locations included gas stations, grocery stores, and shopping malls. In Lansing, the number of participants in each location were equally distributed, however in the three remaining cities there were no survey from gas station. Figure 4-2 shows distribution of survey locations in each city.

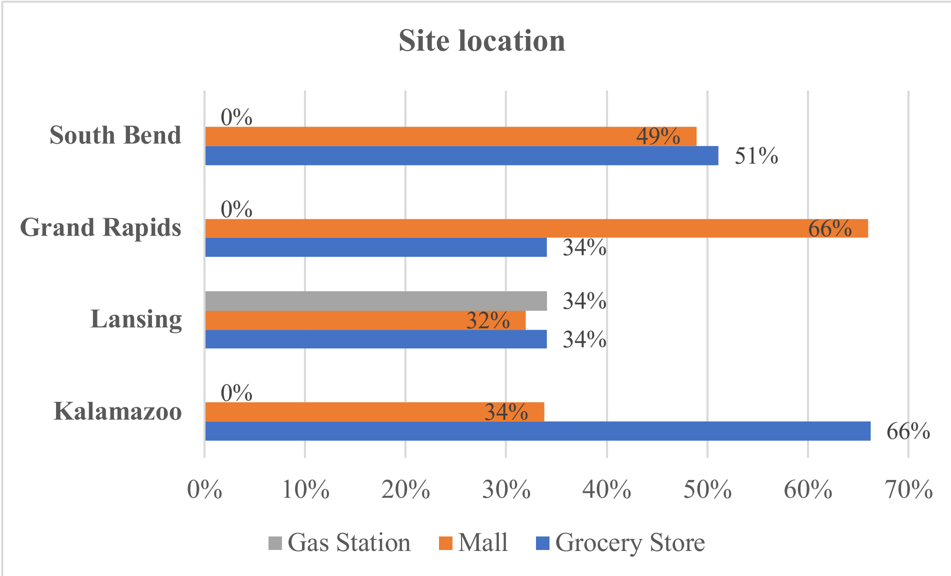


Figure 4-2: Survey location distribution

4.2.3 Driving License Duration

In order to have a better understanding of participants' driving skill, driving license duration was asked. The question was open-ended and the answers varied in range of 1 to 73 years. Kalamazoo had the highest average driving license time among participants. Figure 4-3 shows the average and standard deviation of driving license time in study area.

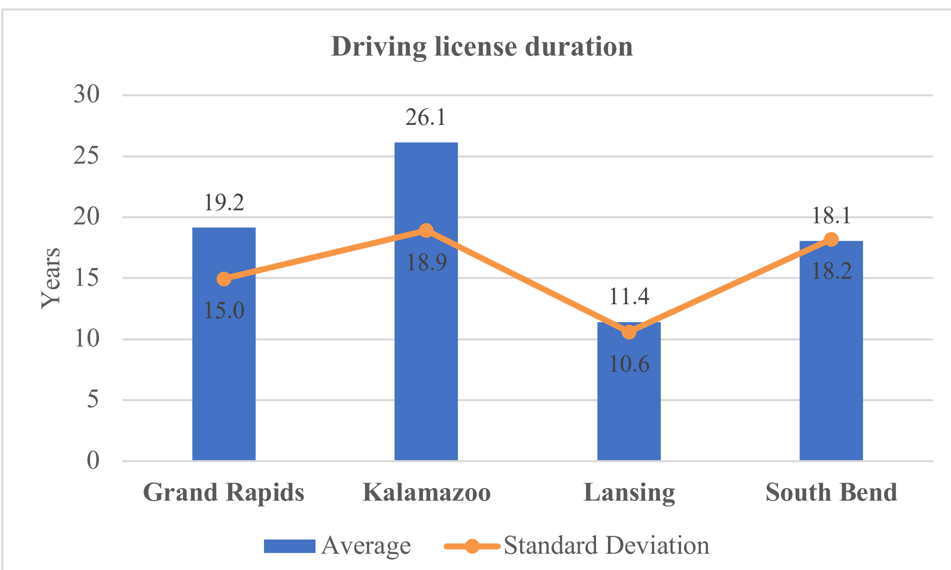


Figure 4-3: Driving license duration in study area

4.2.4 Demographic Information

To identify the probable effects of demographic information on drivers' behavior, three factors were considered. Those demographic factors were determined based on the surveyor's observation. Since age is usually difficult to determine, four age groups were defined for the questionnaire to make age estimation easy. The age groups were: under 25, 25 to 44, 44 to 65, and more than 65. Figure 4-4 demonstrates age variation as well as the average in study area. Furthermore, participants' gender distributions in cities are shown in Figure 4-5, which indicates that total gender distribution is almost equal for male and female.

Race recognition was based on four common races (White, Hispanic, African-American, and Asian) plus a choice for those who could not be determined (unable to determine). As it is shown in Figure 4-6, the white race is the dominant race in all study areas.

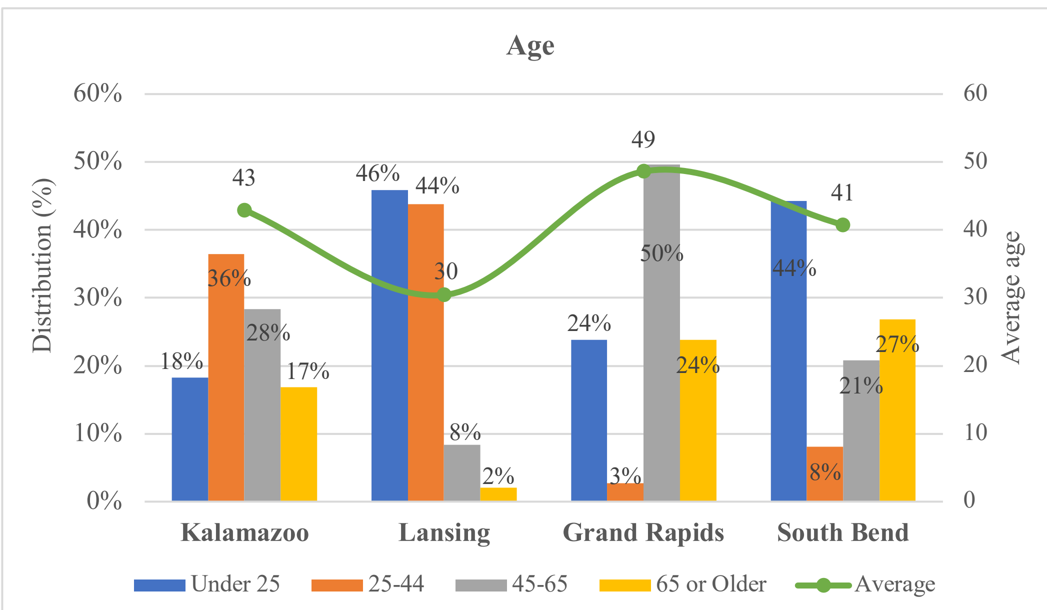


Figure 4-4: Participants' age variation

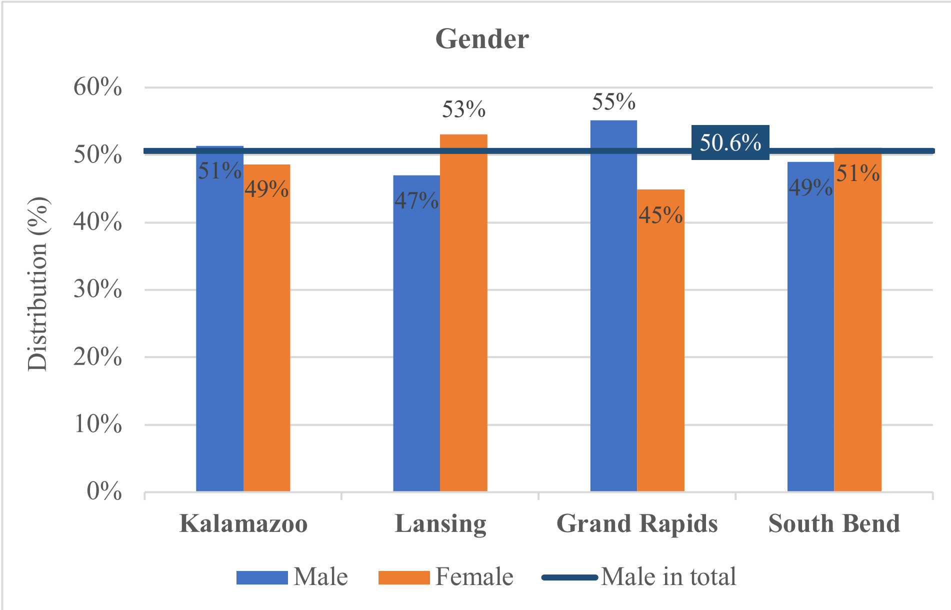


Figure 4-5: Participants' gender distribution

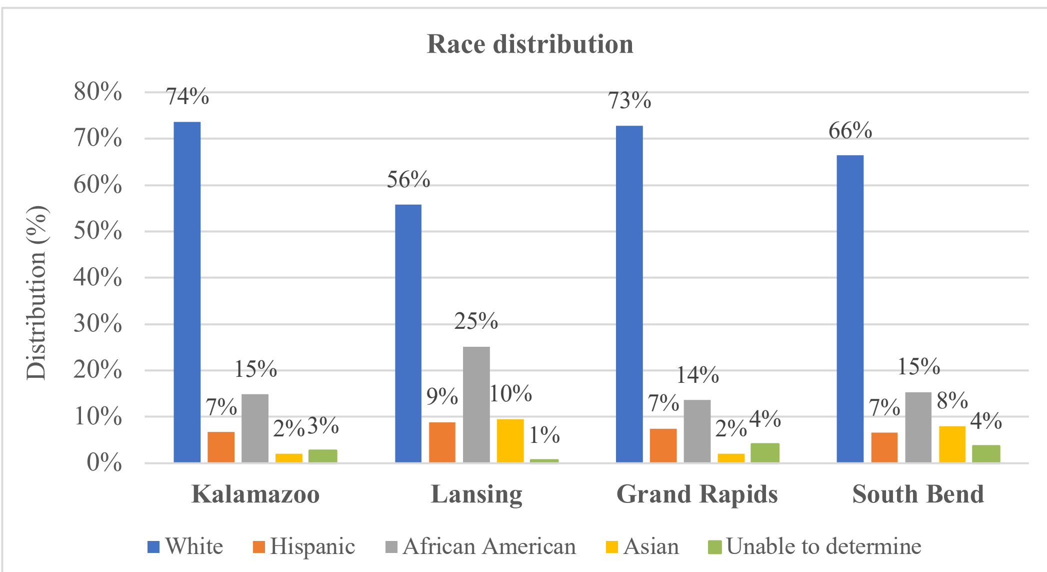


Figure 4-6: Participants' race distribution

4.2.5 Type of Vehicle

Type of vehicle that participants mostly drive was the passenger car. There was also an extra choice for fleet vehicle that no one selected. Additionally, the choice of "other" in the questionnaire was designed for wagons, taxis, and no vehicles. Figure 4-7 describes the types of vehicle that participants usually drive.

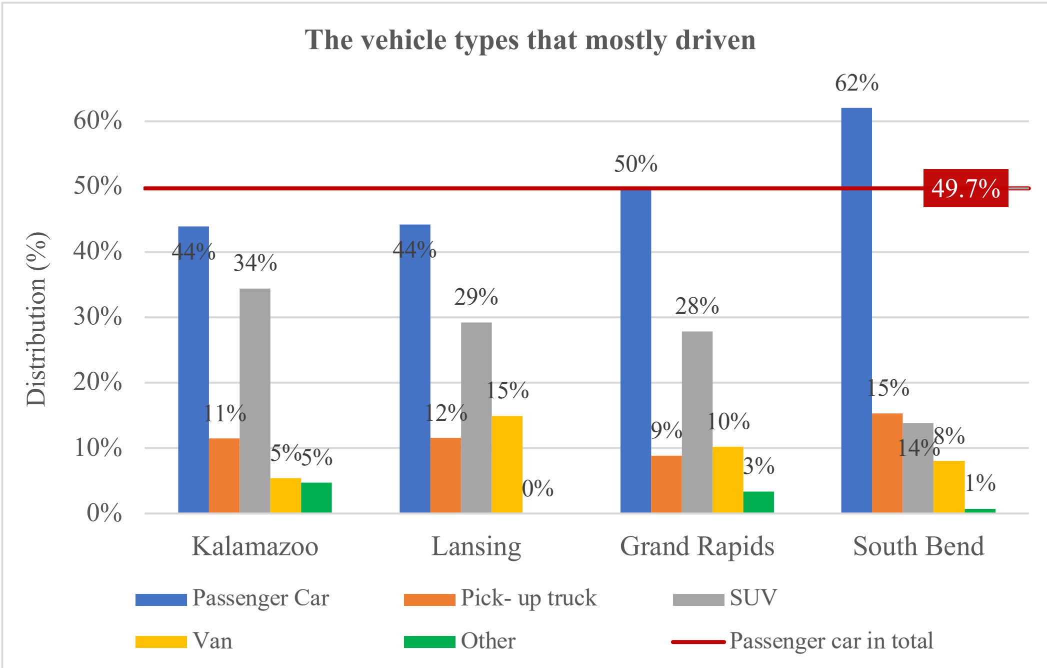


Figure 4-7: Types of vehicle that participants drive most often

4.2.6 Awareness of Local Passing Distance Law

In order to meet one of the objectives of this study, identifying public awareness of existence of a local regulation on passing distance between overtaking vehicle and a bicycle was required. A two-part conditional question was designed. While, Lansing experiences the lack of passing distance law, only 20 percent of people in this city were aware of this and 69 percent were uncertain about whether a law existed in their location. Moreover, the major part of answers (54 percent) in South Bend reveals that people are mostly uninformed about the three-foot passing law. This indicates that it is important to publicize such a local regulation. Figure 4-8 displays responses to the existence local law on passing distance in chosen cities.

Among those who answered yes to the previous question, an additional question was asked to determine what that law says from their understanding. Surprisingly, the responses varied from 3 to 25 feet. The majority of answers (76 percent) were almost correct in Kalamazoo, while the average of answers in other studied areas was around 6 feet. In addition, half of respondents in South Bend who know there is a law for passing distance were unsure of the specified distance requirement. More details on answers to this question associated with the average distance described in each city are presented in Figure 4-9.

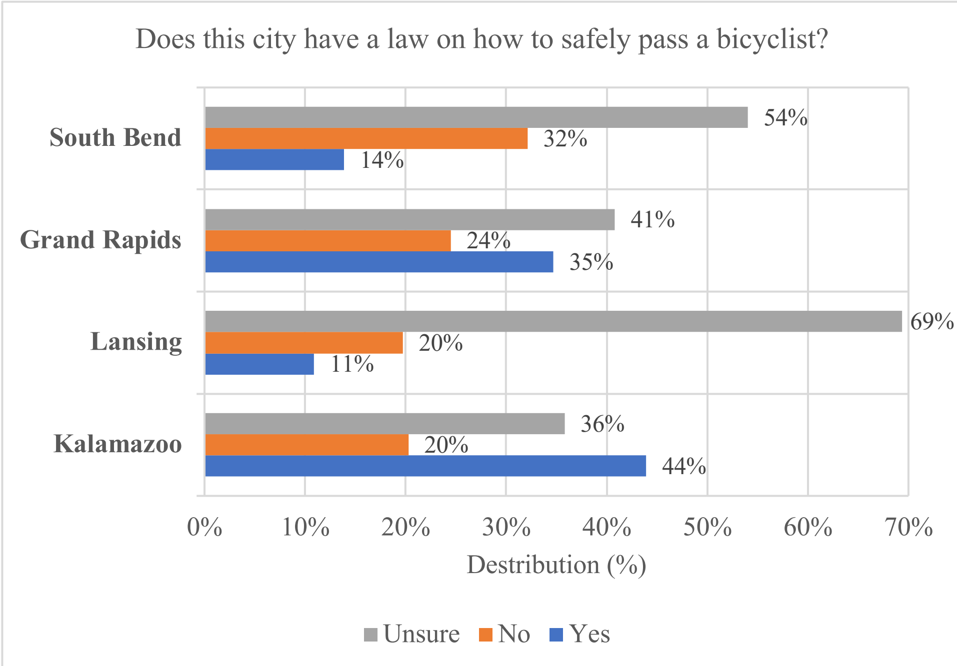


Figure 4-8: Awareness of existing local passing distance law

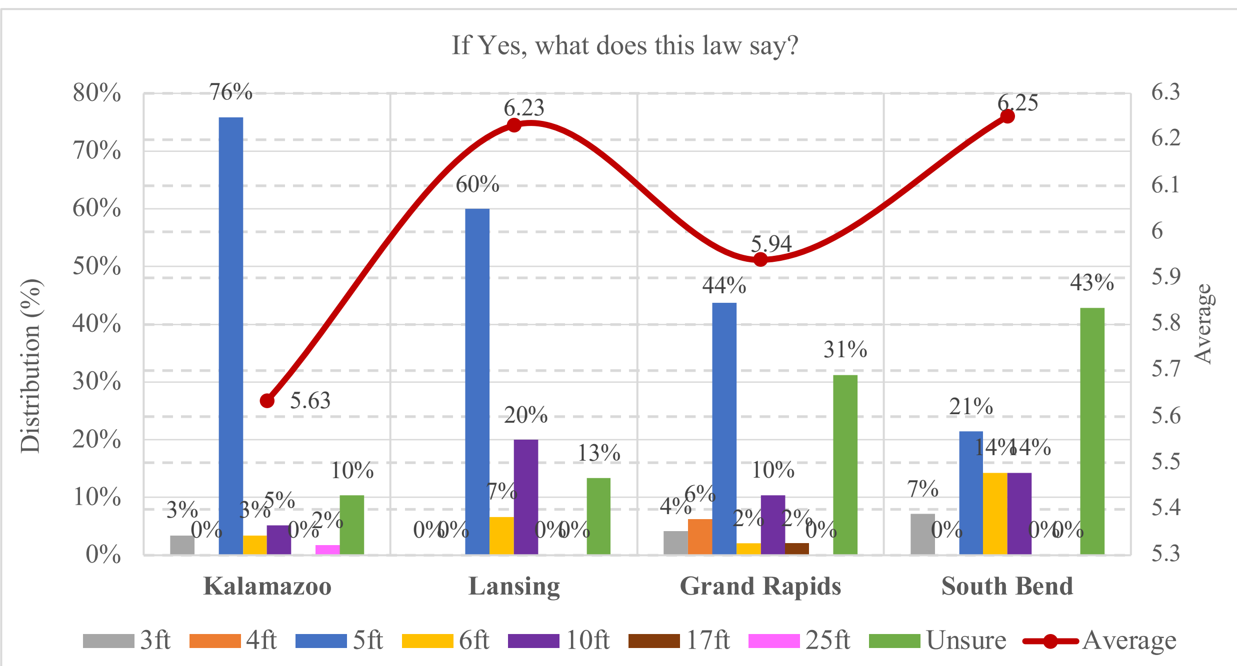


Figure 4-9: How people determine the existing passing distance law in their locations

4.2.7 Awareness of Safely Passing a Bicycle

Cities and bicyclists' advocate groups (for example, the League of Michigan Bicyclists) make efforts to improve public awareness to garner support in Michigan for a five-foot law. This question attempted to find out what percentage of people have seen or heard anything recently about how to safely pass a bicyclist. In total, 58 percent of respondents have not seen or heard anything about how to safely overtake bicyclists. The highest rate of unawareness was in Grand Rapids, while Kalamazoo seems to have provided more advertisement on passing distance. Figure 4-10 provides responses to this question in study area.

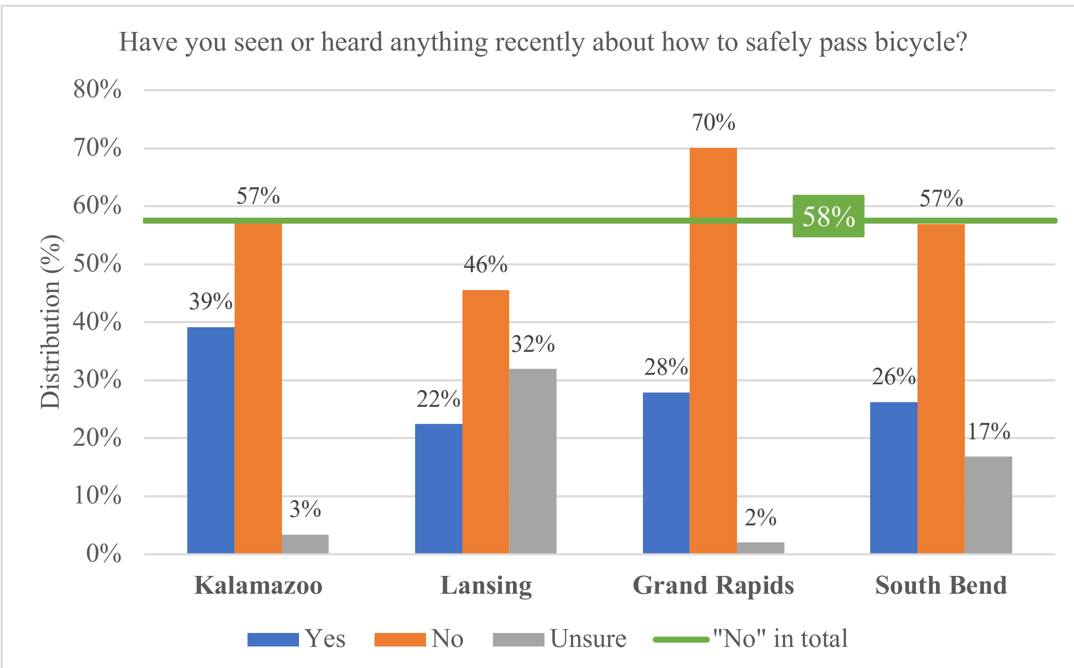


Figure 4-10: Awareness of safely passing a bicycle

An extra question was asked of those who have heard or seen anything recently about passing safely a bicycle. This question aimed to determine what delivery methods are usually employed in each city. There were six sources of information listed in the questionnaire for the participants to check any choice(s) that applies. In all cities except Grand Rapids, street signs were the most frequent source of public awareness. Also, the overall rate of street signs effect was computed 31 percent that was more than other factors. The share of other factors that were asked during the interview is pointed out in Figure 4-11.

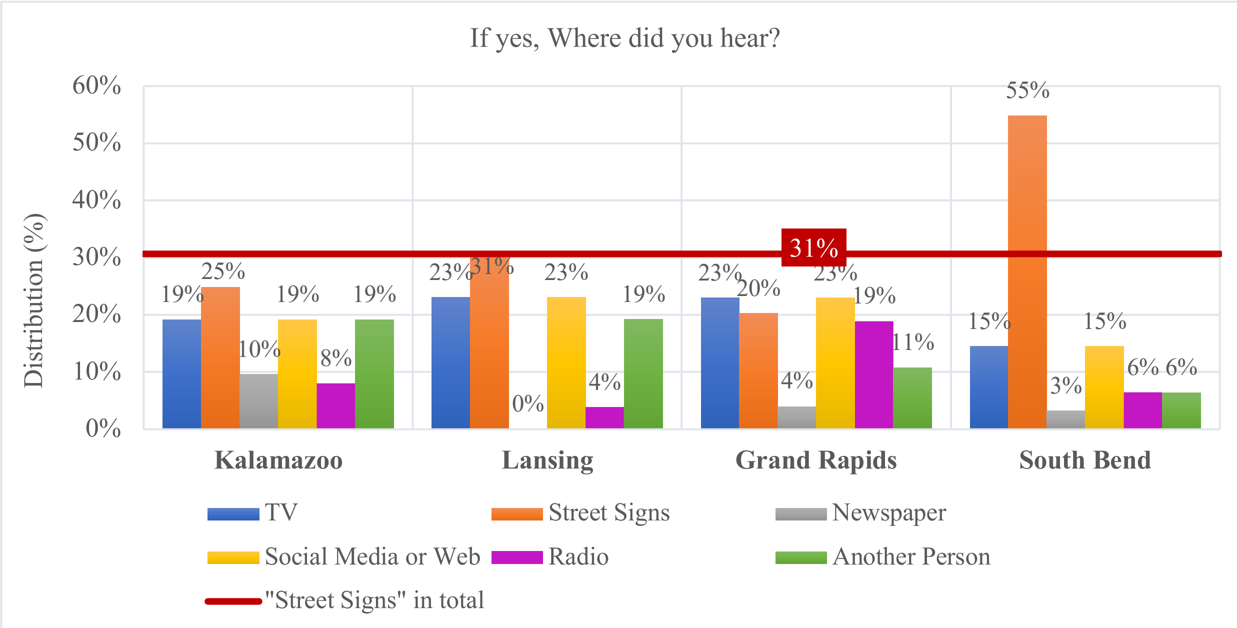


Figure 4-11: Source of information for who have seen or heard about safe passing bicycle

4.2.8 Police Enforcement of Safe Passing Bicycle

Although no police enforcement has been applied to violations of the minimum passing distance law, the need and awareness of enforcement was examined. In order to determine how people are familiar with police enforcement, they were asked if they heard about enforcement of a bicycle passing law. Almost 92 percent of respondents said they had not seen or heard anything about police enforcement of safe passing of bicyclists.

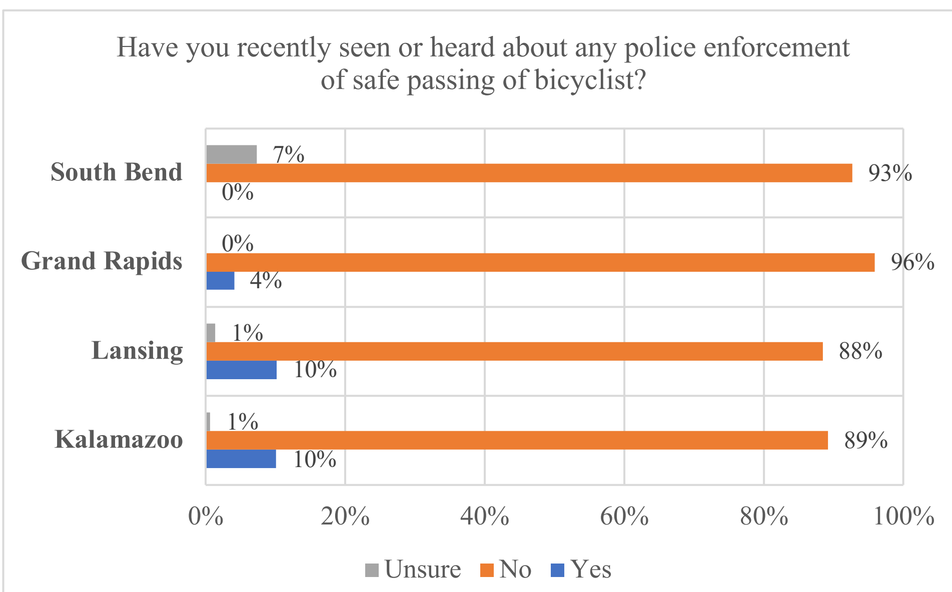


Figure 4-12: Police enforcement of safe passing bicycle

4.2.9 Riding a bicycle

On average, 45 percent of respondents reported that they ride a bicycle. This rate varied between cities. Figure 4-13 shows the distribution of bicycle riding of respondents in each city.

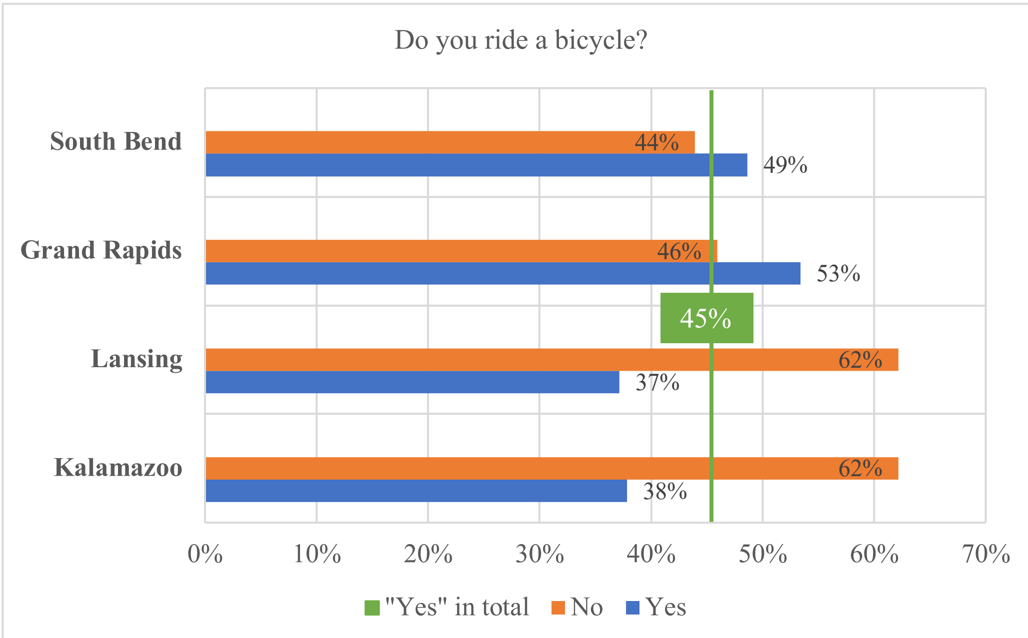


Figure 4-13: Bicycle riding distribution among respondents

In order to assess the riding frequency of respondents, an additional question were added for those who said they rode a bicycle (See Figure 4-14).

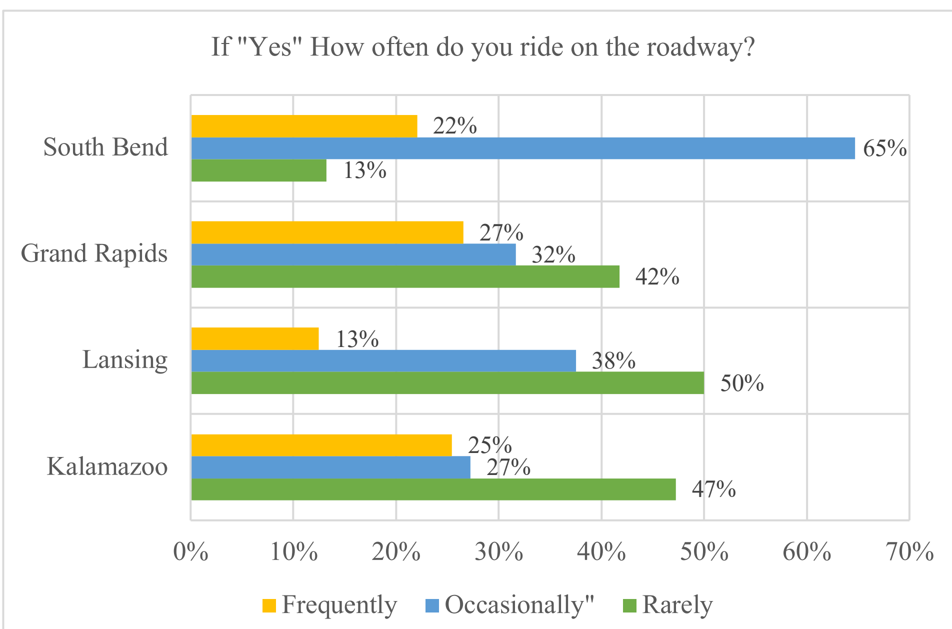


Figure 4-14: Bicycle riding frequency among respondents

The other question asked of bicycle riders was related to safety perception. This question sought to identify unsafe feeling due to adjacent vehicles overtaking. The purpose of this question was not to only recognize riders' perception during overtaking maneuver, but also to distinguish an individual's opinion between driver and rider's perspective. Figure 4-15 provides the respondents' answers to this question.

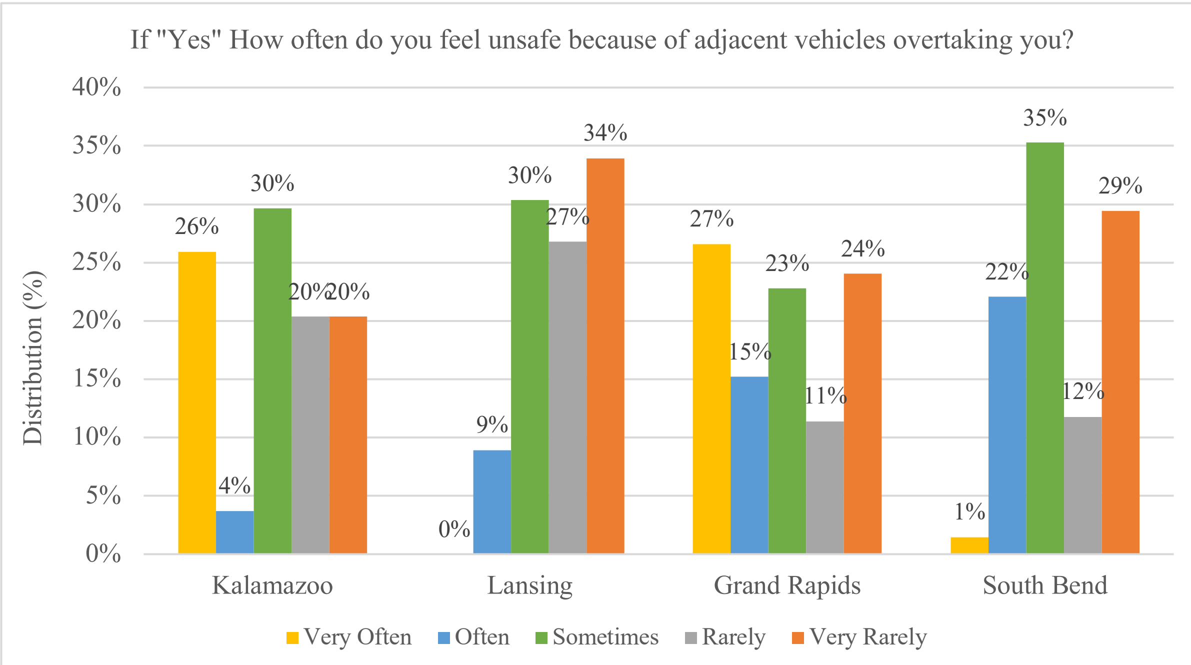


Figure 4-15: Unsafe feeling due to adjacent overtaking vehicles

4.2.10 Keeping Distance to a Bicyclist

This question was designed to determine the distance that drivers in each city tried to keep when passing a bicycle. The responses varied from 2 (2%) to 30 feet (less than 1%). While the answers were scattered, the average distance that drivers keep while passing a bicyclist in Grand Rapids was the closest when compared with other cities. This might have resulted from the lack of education, advertisement or public involvement to new decisions in this area. The average distance in Kalamazoo was highest, that could be due to lots of street signs that recently installed to keep minimum 5 feet for passing a bicyclist. In Figure 4-16 frequency of every distance that is answered by respondents as well as the average value for each city are shown. Additionally, the t-test mean comparison was conducted on each pair city that the results are reflected in Table 4-1.

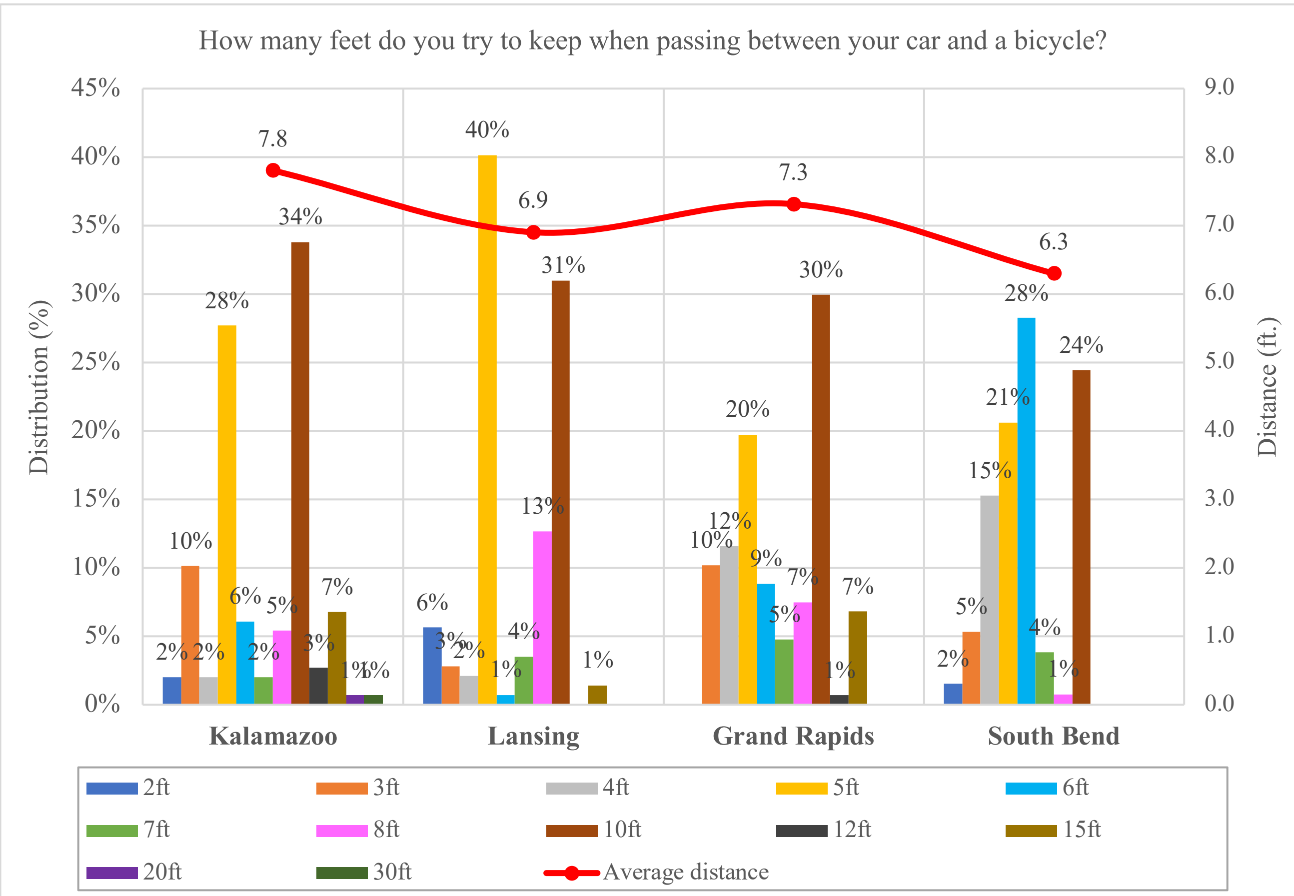


Figure 4-16: Keeping distance to a bicyclist

Table 4-1: T-test mean comparison for each city pair

City	**Kalamazoo**	**Lansing**	**Grand Rapids**	**South Bend**
Kalamazoo	0	2.3212*	1.1241	3.4587*
Lansing	2.3212*	0	1.2557	1.4676
Grand Rapids	1.1241	1.2557	0	2.5674*
South Bend	3.4587*	1.4676	2.5674*	0

* 95% significant level

4.2.11 Perception about five-foot Passing Law

The purpose of the last question in the interview was to determine the respondents' perception about setting the minimum requirement of 5 feet for vehicles overtaking a bicyclist. In overall, 91 percent of participants thought that a minimum 5 feet distance from a bicyclist will be a good policy for drivers. This rate is highest in South Bend and lowest in Lansing. Figure 4-17 depicts details on responses to this question.

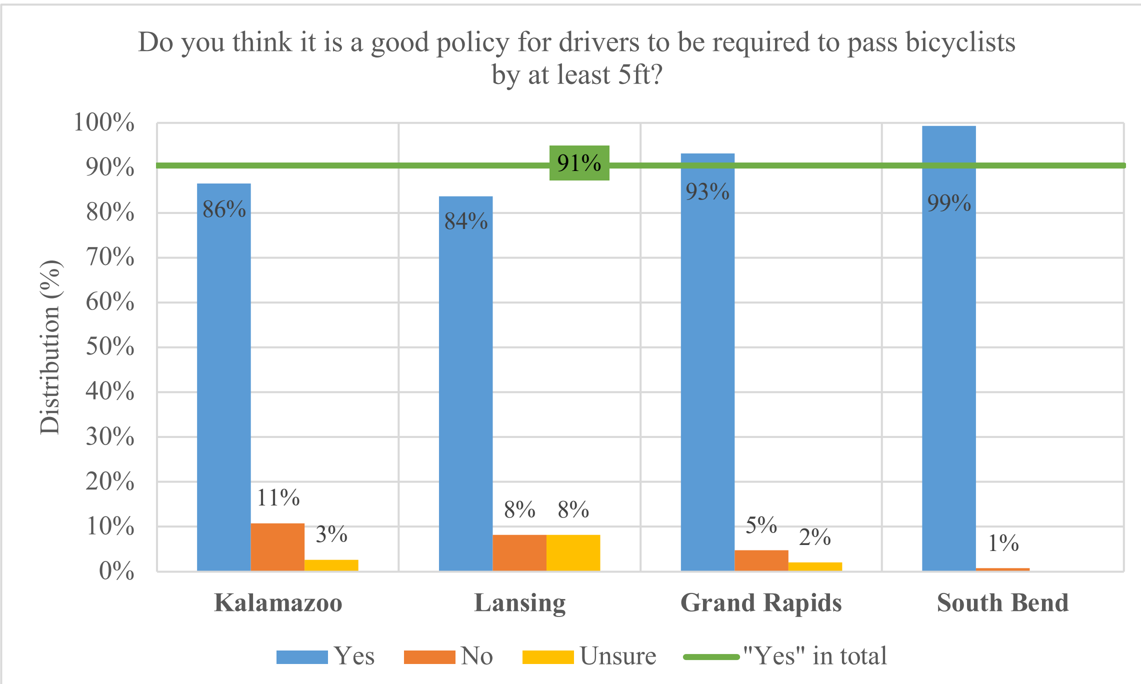


Figure 4-17: Perception about five-foot passing law

4.3 Field Experiment

The field experiment was carried out by riding an instrumented bicycle during spring and summer of 2018. Two male (21 and 26-year-old) bicycle riders, who were familiar with the sites, rode the bicycle. Each bicyclist took a short break every 30 minutes during his daily 3-hour-ride.

As demonstrated in Table 3-2, the segments' length varied from 0.5 to 3.2 miles. The experimental ride was carried out for additional time in the low traffic volume routes and short segments routes to achieve an acceptable number of passing measurements. Table 4-2 indicates the selected sites configurations and characteristics.

Table 4-2: Sites characteristics

Type of roadway	City*	Length (mi)	AADT (vpd)	Access density (/mi)	Speed (mph)	Lane width (feet)	Shoulder/bike lane width (feet)
2- lane with bike lane	KA	0.9	13,200	8	45	10	3.5
	GR	0.5	11,000	10	30	10	3
	LA	1	9,300	9	35	10	4
	SB	0.9	7,600	16.7	30	8.5	3.5
2-lane with sharrow	KA	1	7,200	8.2	35	9.5	-
	GR	1.5	12,400	14.7	30	9.5	-
	LA	-	-	-	-	-	-
	SB	0.9	9,000	11.8	30	9	-
2-lane with shoulder	KA	1	4,000	10.3	35	10.5	5.5
	GR	0.8	6,100	10.2	25	11	5.5
	LA	0.8	5,300	10.3	30	10	5
	SB	0.8	7,500	13.9	30	9	3.5
2-lane without bike lane, sharrow, or shoulder	KA	0.65	5,700	11	25	11.5	-
	GR	1.1	5,500	10.8	25	10	-
	LA	1.3	5,000	10	25	11	-
	SB	1	7,600	16.7	25	10	-
3- lane with bike lane	KA	0.8	17,300	15	35	9	3
	KA	3.2	16,800	12	35	9	3
	KA	2	18,100	6.8	35	9	3
	GR	2.5	18,700	15	30	9.5	3.5
	LA	0.9	16,400	10.3	35	11	3
	LA	1.5	9,500	15	30	10	3
	SB	2	17,400	20	30	9.5	4
3-lane with sharrow	KA	-	-	-	-	-	-
	GR	1	13,000	13	30	10	-
	LA	-	-	-	-	-	-
	SB	0.5	13,300	13.3	30	10.5	-
3-lane with shoulder	KA	0.5	10,200	6.8	45	10	6
	GR	1.3	13,400	6	45	10.3	4
	GR	0.7	17,200	12.3	40	9.5	3.5
	LA	1	8,800	9	35	10	3.5
	SB	1	12,100	12.5	30	9.5	3
3-lane without bike lane, sharrow, or shoulder	KA	0.5	10,400	12	35	10	-
	GR	0.3	137,000	16.7	30	10.5	-
	LA	0.9	7,800	13.4	30	10	-
	SB	1	12,100	12.5	30	10	-

** KA: Kalamazoo, GR: Grand Rapids, LA: Lansing, SB: South Bend*

4.3.1 Data Measured from C3FT

A C3TF equipment and a camera were mounted on the left edge of the bicycle's handlebar to measure and record the vehicles' overtaking distance. The camera recorded the C3FT's screen and the type of overtaking vehicle. After completing the field experiment, an operator processed the videos. Passing distances (in feet) from motor vehicles to the bicyclist and the type of overtaking vehicles were extracted and reported. Also, large vehicles (including trucks, buses, and minibus) were differentiated from regular passenger vehicles. In this study, an overtaking maneuver was defined when these three conditions occurred: (1) a motor vehicle approaches a moving bicyclist in the same direction, (2) the vehicle approaches from the closest left lane to the bicyclist , and (3) the rear bumper of the vehicle passes the front wheel of the bicycle. The second condition was set to remove cases in which the overtaking vehicle passed with more than one lane width distance. In such cases, a vehicle changed the lane entirely and traveled from either the opposite lane or the center turn lane. This condition also excluded in-street parked vehicles attending to merge with traffic. The third condition definition aimed to eliminate the cases in which a vehicle reached the bicyclist but was not able to pass it. It occurred when the vehicle was unable to complete the act of overtaking due to congested traffic, traffic light, or stop sign.

The overtaking vehicle distance was defined as the lateral distance between the right edge of the vehicle and the left side of the bicycle's handlebar. The C3FT continuously measured the distance at 10 Hz. More than one distance was measured and detected by the C3FT during an overtaking maneuver. In this study, the minimum distance captured by the C3FT was considered as the overtaking distance between a motor vehicle and the bicyclist.

A total of 2,857 motor vehicle-bicycle overtaking maneuvers were derived from approximately 25 hours of video recording. The C3FT was limited to identify objects within 8 ft. According to the second condition of overtaking definition, observations with more than one travel lane (12 ft.) distance to the bicyclist were excluded from the data set. Thus, the overtaking distances in observations within a range of 8 to 12 ft. were not captured, although, the occurrence of each event was measured from the camera data. Table 4-3 indicates an overview of the recorded videos' data from the C3FT.

Table 4-3: Overview of data measured by C3FT (*n* = 2857)

City	Passing law	Bicycle service	Number of observations	Distances with more than 8 ft.	Measured distances	Min. (Feet)	Max. (Feet)
Kalamazoo	5-foot	Bike lane	764	127 17%	637 83%	2.58	8.00
		Shoulder	181	60 33%	121 67%	3.50	8.00
		Sharrow	173	36 21%	137 79%	2.58	8.00
		None	138	25 18%	113 82%	3.33	8.00
Grand Rapids	5-foot	Bike lane	145	28 19%	117 81%	2.50	7.92
		Shoulder	157	35 22%	122 78%	3.00	8.00
		Sharrow	79	7 9%	72 91%	2.08	8.00
		None	42	2 5%	40 95%	3.50	8.00
South Bend	3-foot	Bike lane	223	12 5%	211 95%	3.50	8.00
		Shoulder	153	21 14%	132 86%	3.00	8.00
		Sharrow	226	3 1%	223 99%	2.25	7.92
		None	141	11 8%	130 92%	2.67	8.00
Lansing	Without law	Bike lane	232	30 13%	202 87%	2.67	8.00
		Shoulder	119	30 25%	89 75%	3.42	8.00
		Sharrow	0	-	-	-	-
		None	84	10 12%	74 88%	2.33	7.92
Total			2857	437 15%	2420 85%	2.08	8.00

4.3.2 LiDAR Data Collection

After data collection, LiDAR data was processed by the proposed algorithm. Passing distance was detected for each individual vehicle. A total of 301 vehicles was detected in one of the cities. The data was limited within 12 feet from the bicycle. Due to some limitations in implementing the LiDAR, the device was able to collect data in Lansing at this point. Table 4-4 shows a summary of collected data in Lansing by LiDAR.

Table 4-4: Overview of data measured by LiDAR (*n* = 301)

City	Passing law	Bicycle service	Number of observations	Distances more than 8 ft.	Distances less than 8 ft.	Min. (ft.)	Max. (ft.)	Average (ft.)
Lansing	Without law	Bike lane	218	52 24%	166 76%	2.00	11.89	6.08
		Shoulder	44	21 48%	23 52%	2.41	10.48	6.70
		Sharrow	0	-	-	-	-	
		None	39	8 21%	31 79%	4.81	9.40	6.22
Total			301	81 27%	220 73%			

Chapter 5 Data Analysis

5.1 Overview

This chapter aims to determine drivers' behavior during an overtaking maneuver. The C3FT data was comprehensive and all the sites were included in that data set. Therefore, analyses presented in this chapter are based on the C3FT data, instead of the LiDAR's data. In this chapter, we also seek to examine the effects of roadway configurations, types of overtaking vehicle, and presence of passing law on passing distance. A sample of vehicle detection and clustering obtained from LiDAR data analysis for one of the cities will be presented. The last part of this chapter will address the approach of vehicles' trajectory detection by LiDAR in Lansing.

5.2 Statistical Analysis

5.2.1 Effect of Roadway Types

Four types of roadway, including roadways with bike lane, shoulder, sharrow, and roadways without any of these facilities, were examined to determine the effect of roadway configuration on passing distance. First, the impact of roadways was evaluated regardless of the number of lanes. The one-way analysis of variance (ANOVA) was employed to examine the passing distances between the groups. The results implied that there are significant differences between the groups ($F(3, 2416) = 20.77$, $P < 0.001$). The Scheffe method was adopted to examine the multiple comparisons test. The results revealed that the passing distance in the roadways with sharrow was significantly less than the roadways with a bike lane ($P < 0.001$), shoulder ($P < 0.001$), and those without bike facility ($P < 0.001$). There were no other statistically significant differences among the groups.

In addition, the effect of the number of lanes was examined. An analysis using two-sample t-test mean comparison indicated that average passing distance in 2-lane roadways ($M = 5.69$ ft.) was significantly ($t = 10.46$, $P < 0.001$) less than that of 3-lane roadways ($M = 6.18$ ft.). Then, between groups analysis was performed. The results indicated that the number of lanes was one of the most influential factors in the overtaking distance. The number of lanes makes a difference through all types of roadways, except for the roadways without bike facilities. Figure 5-1 shows the distribution and the significant level of differences among various roadway characteristics.

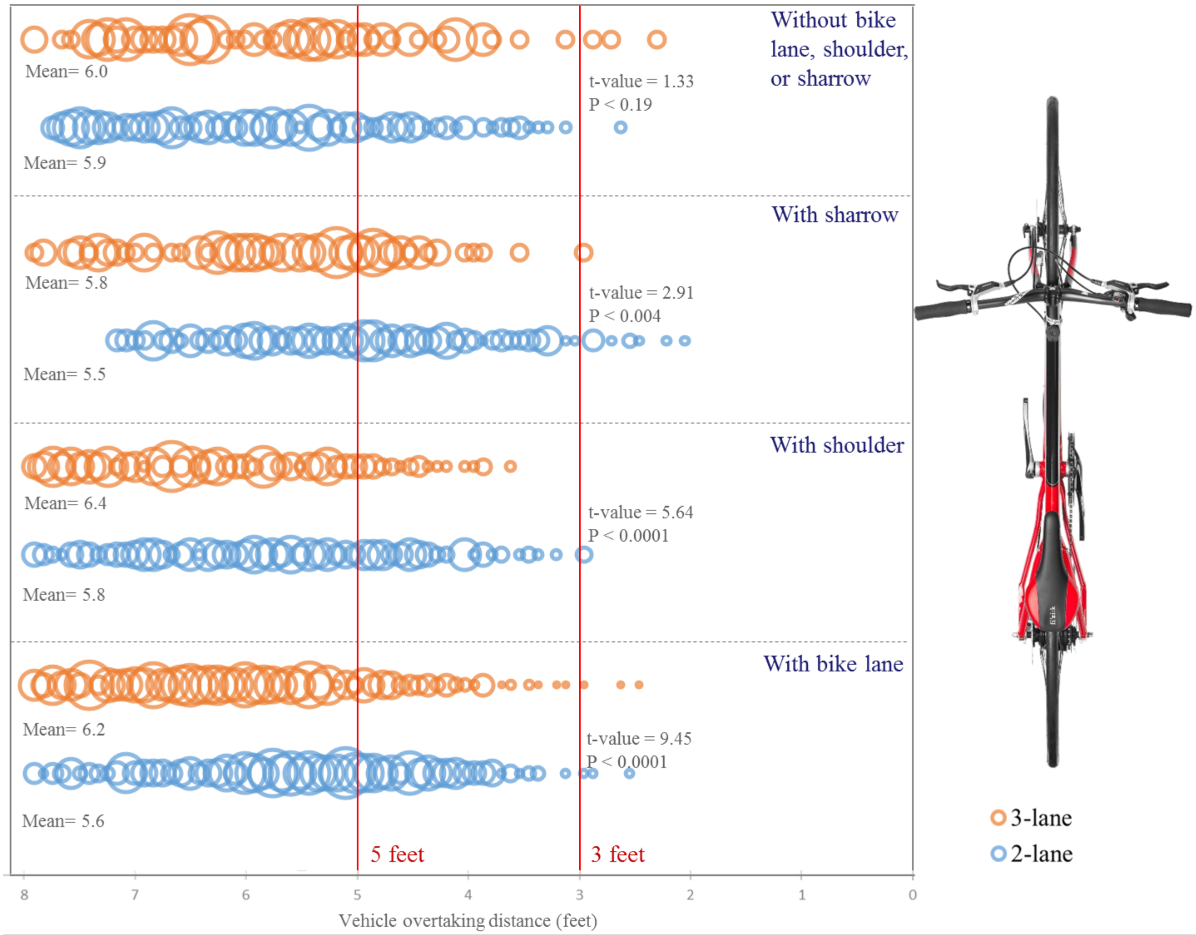


Figure 5-1: Motor vehicle overtaking distance to the bicyclist according to types of roadway

Note that in the comparison of roadway types, the roadways without a bike lane, shoulder, or sharrow were also included. Ten percent of vehicles in roadways with sharrow and 12 percent in roadways without bike facility passed the bicyclist by more than 8 feet. This fact, at the same time, might suggest travel lane width should have a substantial effect on passing distances. Based on FHWA's handbook (2009), shared lane marking in streets with on-street parking should be placed at least in 11 feet from the face of the curb. However, in this study, the average lane width of the sites with sharrow placement was less than 10 feet. Shared lane markings on narrow roads can lead to drivers' overtaking bicyclists negligently.

5.2.2 Effect of Passing Law

To compare vehicle-bicyclist overtaking distances in areas with different passing law, a one-way ANOVA was conducted. The results indicated that there were a few significant levels of difference between the locations with various passing laws ($F(3, 2416) = 42.54$, $P < 0.001$). Employing the Scheffe method revealed that the passing distance in the two cities with five-foot passing law did not differ significantly. Thus, the passing distance observations in Kalamazoo and Grand Rapids- the cities with the same passing law- was considered as one area for further analysis. We also found that passing distances in cities with five-foot law were significantly higher than cities with three-foot law. Table 5-1 illustrates the Scheffe method comparison results among cities.

Table 5-1: The Scheffe method significant level in multiple comparison of ANOVA

City		Grand Rapids	Kalamazoo	Lansing
	Mean (feet)	Mean = 6.05	Mean = 6.19	Mean = 6.02
Kalamazoo	Mean = 6.19	P < 0.274		
Lansing	Mean = 6.02	P < 0.996	P < 0.152	
South Bend	Mean = 5.55	P < 0.001*	P < 0.001*	P < 0.001*

* *Statistically significant*

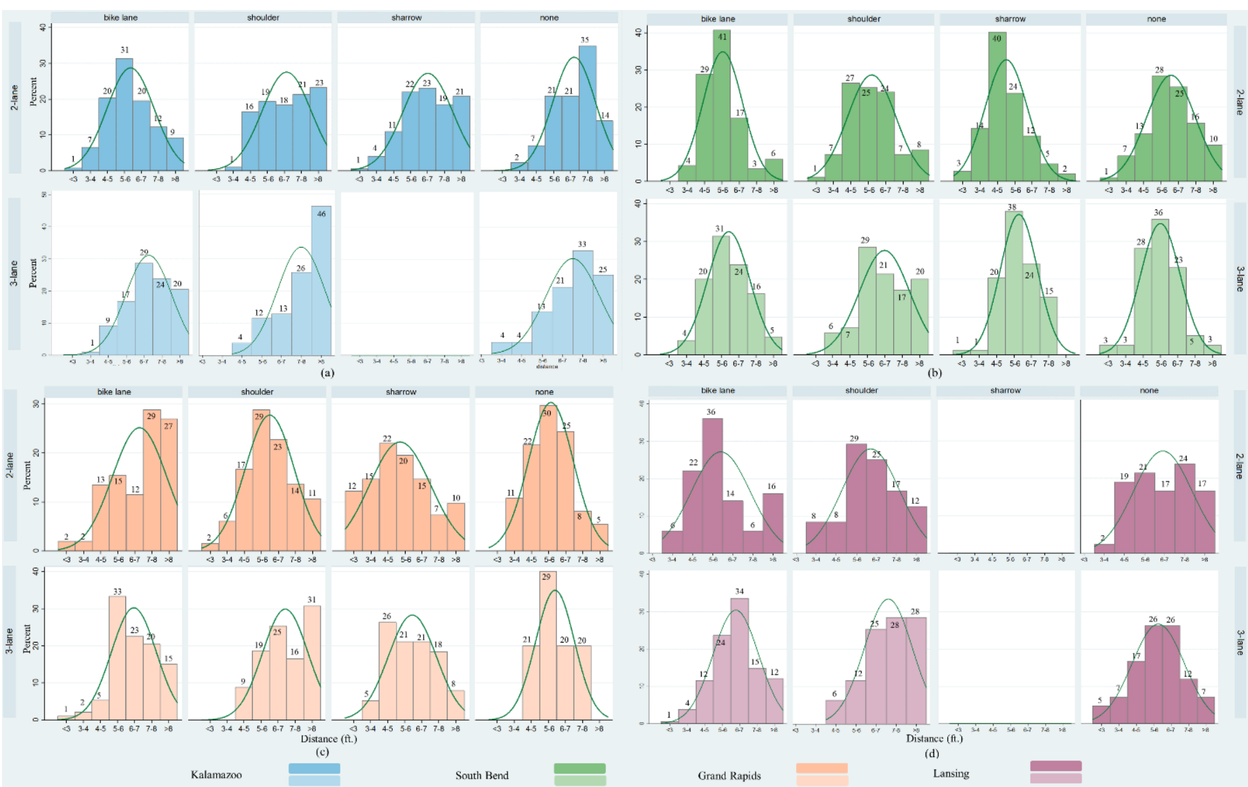


Figure 5-2: Distribution of passing distances in each city and roadway type; (a) Kalamazoo, (five-foot law), (b) South Bend (three-foot law), (c) Grand Rapids (five-foot law), and (d) Lansing (without a passing law)

The results of t-test mean comparison demonstrated that the number of lanes affects the passing distance independently from the passing law. The areas with different passing law were affected by changing the lane numbers. That is, the overtaking distance in 2-lane roadways in the four cities was significantly less than 3-lane roadways ($P < 0.005$). Studying the effect of roadway configuration in different areas specified that the passing distance in 2-lane roadways with bike facility (bike lane, sharrow, or shoulder) and five-foot passing law was significantly higher than the same roadways in areas without the five-foot passing law ($t = 7.51$, $P < 0.001$). Figure 5-2 shows the distribution of passing distances in each city and types of roadway.

Another purpose of this research was to examine the driver's violation of the passing law in different roadways. Figure 5-2 shows that the violation of the passing five-foot law among drivers in roadways with bike lane and shoulder is less than other types of roadways ($P < 0.05$). Similarly, drivers were more likely to violate the three-foot law when driving on a 2-lane road, or there was no bike lane/shoulder on the road ($P < 0.05$).

The results show that drivers kept significantly greater lateral distances in cities with a five-foot passing law. Nevertheless, the average passing distances in Lansing, a city without passing law, was significantly more than passing distances in the area with the three-foot law. The results of the survey could address this contradiction. Around 70 percent of respondents in Lansing were "*unsure*" about the question *"does this city have a law on how to safely pass a bicyclist"*, and 11 percent believed that Lansing had a passing law. It can also be derived that recent discussion (League of Michigan Bicyclists, 2018) on Michigan passing law may have affected drivers' awareness and perception in Michigan. Almost 25 percent of the respondents in Grand Rapids and Kalamazoo were not only aware of a passing law in their cities, but also precisely answered that the law requires to keep at least five feet distance to bicyclists. On the other hand, in South Bend with three-foot law, only 14 percent of the participants were aware of the presence of a passing law.

5.2.3 Effect of Vehicle Type

Types of vehicles overtaking the bicyclist were identified by reviewing the camera video. In this study, vehicle types were divided into two categories: large vehicles (including trucks, buses, and minibuses), and regular passenger cars. Drivers of large vehicles tended to drive closer to the bicyclist ($t = 4.99$, $P < 0.001$). However, the overall violation rate of large vehicles was not significantly different from other vehicles. The analysis also revealed that passenger cars kept more distance when the bicyclist was riding in a bike lane/shoulder ($t = 3.69$, $P < 0.001$). The violation in 2-lane roadways was not significant between vehicle types, however, in 3-lane roadways truck drivers contributed more violations ($t = 2.30$, $P < 0.05$).

5.3 Model Development

This study concentrated on drivers' passing distances in different roadway configurations as well as areas with various distance law while overtaking a bicyclist. Regarding the influential factors on overtaking behavior, an Ordered Probit Model approach was applied to address the stratification of passing distances. The model expressed the relationship of a discrete dependent variable with independent variables. The dependent variable is achieved from C3FT measurements by the video derivation. The overtaking distances were broken down into seven discrete orders (1=less than 3 feet, and 2=between 3 and 4 feet,…, 7=more than 8 feet). Furthermore, independent variables consisted of vehicle type; the number of lanes; availability of a bike lane, shoulder, or sharrow; sort of passing distance law; posted speed limit; lane width; and bike/shoulder width. Table 5-2 presents the remaining variables in the final model after backward elimination.

Table 5-2: Proposed ordered Probit model for passing distances captured by C3FT

Variable	Coefficient	Std. Err.	Z	P value	95% Confidence Interval	
lane	0.443	0.039	11.24	0.000	0.366	0.521
l_wdth	0.100	0.027	3.65	0.000	0.046	0.154
shldr	0.310	0.049	6.34	0.000	0.214	0.406
law5	0.405	0.040	10.16	0.000	0.327	0.483
trck	-0.264	0.055	-4.78	0.000	-0.373	-0.156
μ1	-0.189	0.297			-0.772	0.394
μ2	0.599	0.291			0.029	1.169
μ3	1.472	0.291			0.901	2.043
μ4	2.213	0.293			1.639	2.786
μ5	2.834	0.294			2.259	3.410
μ6	3.440	0.295			2.862	4.017

lane: number of lanes (either 2, or 3), l_wdth: travel lane width, shldr: overtaking bicyclist was in shoulder, law5: presence of five-foot passing law, trck: overtaking by truck

The ordered Probit model developed in this study indicates five influential factors of drivers' bicycle passing distance behavior. The results demonstrate that increasing the number of lanes (in this study, from two to three) as well as the lane width will increase the passing distance to the bicyclist. This fact supports previous investigations (Ibrahim et al., 2018), although the broader lanes do not necessarily provide the safer roads for bicyclists. Since increasing width of travel lane is also associated with greater vehicle speed (Shackel & Parkin, 2014), the risk of bicycling might actually increase. It has also been found that the violation rate of a passing distance law in two-lane roadways (13%) was almost two times higher than the rate in three-lane roadways (6%). Likewise, the violation rate in roads with 10 feet or more width is half of the roads with less than 10 feet lane width.

It is interesting that the presence of five-foot law significantly increased the distance that drivers leave to the bicyclists. The variable of five-foot law (binary) remained in the model, while the presence of three-foot law was not significant. The significant level of the five-foot law variable in the proposed model properly describes the prominence and the necessity of such a law to enhance bicyclists' safety.

The output of the proposed model also reinforced the idea that large vehicle drivers are more likely to pass close to bicyclists (Walker, 2007; and De Ceunynck et al., 2017). In three-lane roadways, where there is more room available to pass safely, trucks' violation rate (11%) was significantly more than the passenger cars (5%). In 2-lane roadways, however, due to insufficient passing space for overtaking maneuver, the violation rates for both vehicle types were almost equal (14% versus 13%).

5.4 Overtaking Trajectory

One of the crucial output of using advanced technology in vehicle-bicycle maneuver is finding efficient ways to gather more information on speed and distance profile before approaching the overtaking zone and after passing the zone. We used LiDAR in this study to test the application of advanced technology and object detection procedure to examine overtaking trajectory of passing vehicles. The developed algorithm was able to provide trajectory's information at different roadway configurations. In Lansing, a total number of 135,461 data frame analyzed for the trajectory detection, and 242 vehicle maneuvers was detected. Figure 5-3 shows different trajectories for different road type.

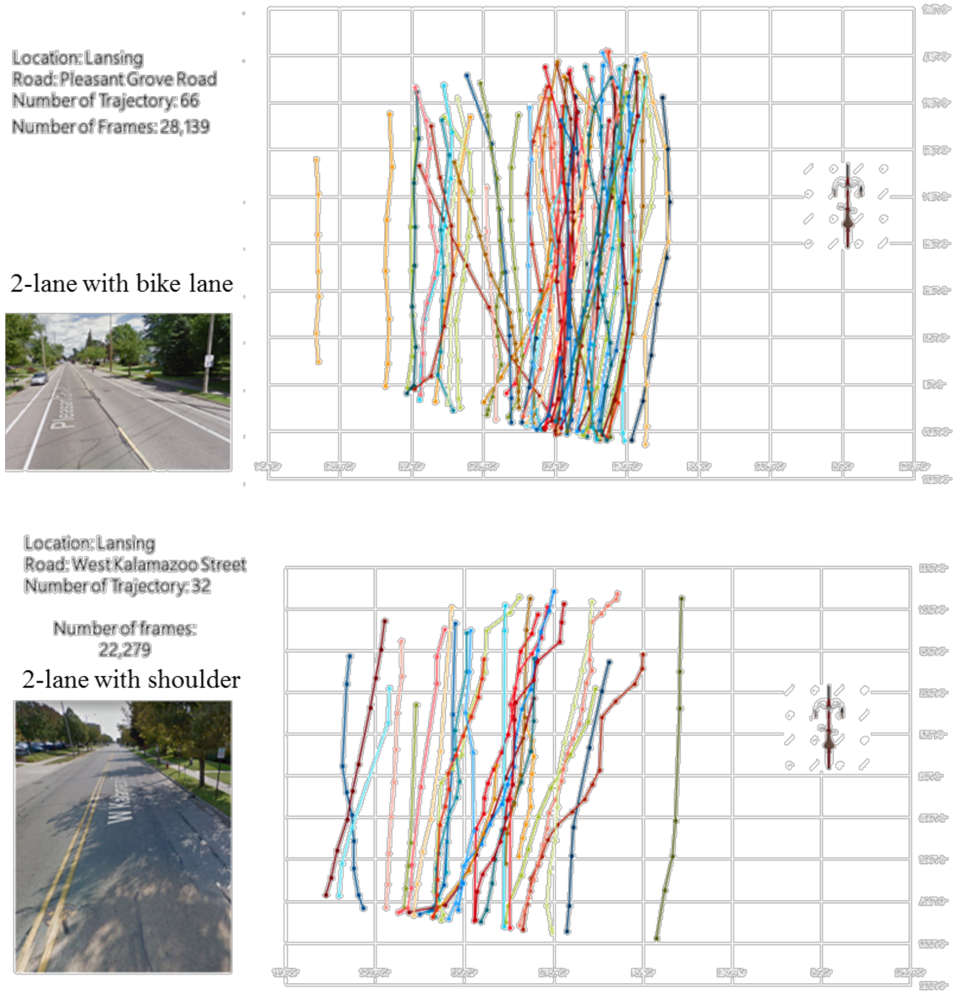


Figure 5-3: Examples of vehicle overtaking trajectory

As shown in the figure, LiDAR can be utilized to not only detect the passing distance, but also catch the attributes of overtaking maneuver, such as lane changing, and relative and absolute speed variations. LiDAR overtaking trajectory information also provides latitude and longitude distance between vehicle and bicycle before and after maneuver. Using LiDAR and similar object detection procedures can evolve the trajectory analysis path in the future.

Chapter 6 Conclusion

The results of this study demonstrated that overtaking distances in locations with five-foot passing law were significantly more than those with a three-foot law or no law. It also has shown that roads with paved shoulders, wider roads, and roads with more lanes contribute to large passing distances. On the other hand, shared use lanes (sharrows) or high truck concentration traffic, are associated with significantly closer passing distance. The survey implemented in four locations with different passing laws illustrated that drivers tend to overestimate the distance that they usually keep from bicyclists and they feel that a five foot passing law is very appropriate.

We recommend designing countermeasures to increase passing distance such as enforcement and drivers' education and awareness. Bicycle infrastructure changes would be also needed to influence better compliance in bicycle passing laws. The results of this study can be used by transportation engineers, policymakers, and legislators to provide efficient designs of road infrastructure associated with bicycle services.

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Appendix

Appendix 1: Survey Sheet

Date ____/____/____ **Bicycle Passing Law Survey** **Site_________**

1. **Are you a licensed driver?**

   ☐ Yes ☐ No (or learner's permit) ***do not interview***

2. **How long have you had a driver's license?** _______________Years

3. **Sex (*observe don't ask*)**

   ☐ Male ☐ Female

4. **Estimate the persons age:**

   ☐ **under 25** ☐ **25-44** ☐ **45 – 65** ☐ **65 or over**

5. **Race (*observe don't ask*)**

   ☐ **White** ☐ **Hispanic** ☐ **African American** ☐ **Asian** ☐ **Unable to determine**

6. **What type of vehicle do you drive most often?** (read categories)

   ☐ Passenger car ☐ Pick-up truck ☐ SUV ☐ Van ☐ Fleet vehicle
   ☐ Other______________________

7. **Does this city have a law on how to safely pass a bicyclist?**
   ☐ Yes ☐ No ☐ Unsure

   ***If Yes*,**

   What does this law say? ____

8. **Have you seen or heard anything recently about how to safely pass a bicycle?**
   ☐ Yes ☐ No ☐ Unsure

   If Yes, go down the list and write in response. Write Yes or No and any comments they may make.

Did you see anything on TV? ____

Did you hear anything on Radio? ____

Did you read about it in the Newspaper? ____

Did you see any street or lawn signs? ____

Did you see or hear anything on social media or web site? ___________________________________

Did you hear about it from someone else?____

9. Have you recently seen or heard about any police enforcement of safe passing of bicyclists?

☐ Yes ☐ No ☐ Unsure

10. Do you ride a bicycle?

☐ Yes ☐ No

If yes: Ask

How often do you ride on the roadway? ☐ Frequently ☐ Occasionally ☐ Rarely

How often do you feel unsafe because of adjacent vehicles overtaking you?

☐ Very often ☐ Often ☐ Sometime ☐ Rarely ☐ Very rarely

11. Do you live in this city, within 50 miles, or more than 50 miles away?

☐ In the city ☐ Within 50 miles More than 50 miles

If No, where do you live?______________________________

12. When you see a bicyclist on the road, how many feet do you try to keep when passing between your car and the bicycle?____ _________ft

13. Do you think it is a good policy for drivers to be required to pass bicyclists by at least 5ft.?

☐ Yes ☐ No ☐ Unsure

Comments (interviewee or interviewer