

A STUDY ON DYNAMIC BICYCLE DETECTION AND WARNING DEVICE

by

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DEDICATION

To my wonderful mom and dad who continually motivated and supported me and everyone else who directly or indirectly encouraged me to get a Master's of Science Degree.

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ABSTRACT

This research pertains to the effectiveness and reliability of a Dynamic Bicycle Detection and Warning sign. In rural areas there are fewer safety options due to financing and environmental design restrictions. Rural roads normally have higher speeds and reduced lane widths with limited or no shoulders. Thus, safety on roads in rural environments should be of great concern for designers.

Data concerning interactions between bicycles and vehicles was collected to determine the effectiveness and reliability of the system. Before- and after-installation data was collected via radar traffic recorders and video cameras at two sites along Rim Rock Drive. The data collected before-installation was used to determine a baseline for the interactions between drivers and bicyclists. Two indicators of drivers' reaction were used: vehicle speed and lateral placement in the lane. Three other variables were tested for their effect on the two aforementioned variables: time to opposing vehicle arrival, time between a bicycle and a vehicle, and vehicle class. The variable, lights flashing was added to determine the effects of the system on speed and lateral placement.

Results suggest vehicle speed and lateral placement are both affected by the presence of bicyclists. Before-installation affects were primarily seen when the vehicle was observed within 10 seconds or less of a bicycle, or within approximately 400 feet. After-installation the affects were seen up to four minutes after the bicycle passed the site. Driver reactions were similar before and after up to 20 seconds. After 20 seconds drivers moved over more and after 30 seconds drivers slowed down more after-installation. The system detected a bicycle 86% of the time and detected something else 11% of the time.

In conclusion the system reduced speeds and encouraged drivers to move over. However, no change in driver behavior occurred under 20 seconds. Speeds averaged around 26 miles per hour which is over the posted speed limit. Most drivers were still utilized the right third of the lane. Therefore, the system was reliable and effective, enhancing bicyclist safety, but driver behavior still poses a danger to bicyclists on Rim Rock Drive.

INTRODUCTION

Federal Lands

The Federal Lands are under the direction of the Department of the Interior. Different agencies within the Department of the Interior such as the National Park Service, U.S. Fish and Wildlife Service and Bureau of Land Management manage a total of 630 million acres of land. Each Federal Land Management Agency has a unique mission, which then promotes a specific transportation network. The National Park Service aims to preserve the natural and cultural resources and values of the National Park System for the enjoyment, education, and inspiration of this and future generations (Gleason 2008).

Infrastructure

Some Federal lands such as Yosemite have paved trails intended for only bicycle and pedestrian traffic. The paved trails are not normally crowded but only account for 12-miles. Other national parks such as the Grand Canyon, Cuyahoga Valley, and Acadia National Park have bike paths or paved areas from prior development that are used by bicycles but account for a limited amount of facilities. Bicycle facilities vary and range from unpaved minimally maintained paths to maintained asphalt bike paths. Some of these facilities eventually degrade and become over grown due to the limited staff and budget for maintenance (Gleason 2008).

Transportation networks within national parks have been primarily designed so that the scenery can be viewed through a windshield (Gleason 2008). The National Park System has approximately 5,500 miles of paved roads, 7,000 miles of unpaved roads, 4,600 miles of bicycle and pedestrian multiuse trails, and 130 transit systems. The transit systems include buses, trolleys, trains, streetcars, snow coaches and maintenance facilities. Roads, parking areas, and bridges represent approximately 80 percent of the total transportation assets of the National Park Service. There is an attempt to keep these facilities in good condition but on average the roads and parking lots are in fair condition. Only 26% of the bridges managed by the National Park Service are rated fair or poor. Thankfully, 74% of the other transportation assets are rated good, but 15% are rated in poor condition and 7% are in serious condition. The other transportation assets include unpaved roads and parking areas, trails, docks, constructed waterways and alternative transportation systems (“National Long Range Transportation Plan” 2017).

Current infrastructure within the national park system is being overwhelmed by the amount of vehicular traffic especially during peak season. The majority of roads within the National Parks were designed to park standards. Unfortunately, this means that existing roads are designed with a minimal width, have little to no shoulder, and poor sight distances. Maintaining existing infrastructure is often difficult due to limited budgets and maintenance backlogs (Gleason 2008). The budgetary needs of the National Park Service for transportation are around 1.5 billion dollars, however, the forecasted budget will only total 394 million dollars (“National Long Range Transportation Plan” 2017). Thus, any new infrastructure especially non-motorized transportation is not seen

as a priority. Due to environmental concerns and cost the possibility of widening roads is normally not a feasible option. (Gleason 2008).

Users

There are two types of visitors to federal lands according to the National Park Service: Recreational and Nonrecreational. Recreational visitors enter the area for the purpose of recreating whereas the nonrecreational visitor enters as a commuter or to conduct some type of business. The majority of adult visitors are more than 50 years old and primarily female. Visitors ages 18 to 30 years old only account for 13% of all visitors. Approximately 80% of visitors are non-Hispanic and white (“National Long Range Transportation Plan” 2017).

As stated by the Bureau of Land Management public lands allow visitors to experience a greater sense of self-reliance and improved physical health. Most recreational visitors prefer motor vehicle travel with only a small percentage of people engaging in nonmotorized travel. There are a wide variety of users and usages of Federal lands (“Public Land Statistics 2017” 2018). Unfortunately, a large number of the people traveling through the Federal lands under the direction of the National Park Service do so at high speeds due to impatience to get where they are going. (Gleason 2008). This creates the potential for adverse interactions between vehicle users and other users.

Modern Trends

There is a trend towards different forms of active transportation. Federal lands are no exception to the trend due to congestion, environmental concerns, and personal health. The Long Range Transportation Plan of the National Park Service is to continue the objectives of the past and improve upon them. Current objectives include providing multimodal options, enhancing accessibility for visitors, addressing intermodal gaps, addressing transportation congestion, improving the health of visitors, and adapting park transportation resources to mitigate the effects of climate change. Long Range Transportation Plans have been and continue to be developed for the different regions of the National Park Service (“National Long Range Transportation Plan” 2017).

In recent years the National Park Service has adopted policies encouraging alternative transportation systems, climate-friendly parks, and healthier visitors. These policies which started back in 2004 have continued into 2016 encouraging visitors to leave their cars behind in favor of a different, preferably more active, form of transportation. There have been many pushes to increase the number of bicycle paths made available in national parks. There were plans to add approximately 70 miles of bicycle facilities in the Grand Canyon National Park. Unfortunately, changing existing trail usage to include bicycles could take as short as three months or as long as two years. Federal lands and the local communities surrounding them have been pushing for shared bicycle programs. Unfortunately, these programs are not as common in the United States as in foreign countries. (Gleason 2008). In an attempt to mitigate the effects of climate change and improve air quality, the National Park Service is attempting to raise public

awareness and reduce emissions from vehicles or reduce the number of vehicles used by employees and visitors. Congestion has primarily been managed by the individual parks, but recently the National Park Service has developed a service-wide congestion management program. In an attempt to mitigate congestion, the National Park Service entered into partnerships with local transit agencies and began encouraging the use of alternative transportation systems including a mix of buses, trains, ferries, trams, and non-motorized transportation (“National Long Range Transportation Plan” 2017).

Part of the reason congestion has become a problem is the increase in the number of visitors. The number of visitors to federal lands especially national parks has continued to rise. Commuter traffic has increased by almost 92% over the past 21 years. For example, in the Southeast of the country there has been a 4% increase in recreational visitors and a 52% increase in nonrecreational visitors. However, there has been a 4% decrease in recreational users in the Intermountain region and a 24% increase in nonrecreational users. Both equate to a 56% and 20% increase in the number of users to the roadways (“National Long Range Transportation Plan” 2017).

The larger number of visitors means safety is a major concern of the National Park Service. There were 110067 vehicle crashes reported between 1990 and 2005 and more than 1,600 of those crashes involved pedestrians or bicyclists. Nearly half of the crashes involving pedestrians or bicyclists resulted in an injury or a fatality. With that being said the park service is focusing on education, engineering, enforcement and emergency response. Engineering involves the incorporation of safety countermeasures on roadways to reduce the number of driver errors (“National Long Range Transportation

Plan” 2017). A disproportionate increase in the number of bicyclists in national parks to motorists in theory will reduce the number of accidents between motorists and cyclists. As of 2000, Zion National Park has virtually banned all vehicles during peak season from traveling on roads that connect Zion’s most popular attractions forcing visitors to use the quiet propane-powered buses. Denali National Park restricted private motor vehicle travel on large portions of the roads. At times Great Smoky Mountains National Park, Rock Creek Park, Gateway National Recreation Area, and White Sands National Monument restrict private motor vehicle traffic (Gleason 2008).

Historically paved roads and bridges have been the focus of transportation plans. Unfortunately, over the next six years the majority of funding will still be going towards maintaining the infrastructure for vehicular traffic. All other assets will continue to decline into poor condition due to a lack of funding. However, there are plans to shift funding from the maintenance of lower priority roads towards transit systems (“National Long Range Transportation Plan” 2017).

Bicycle Safety Concerns

Bicyclists are able to use the sidewalk as a pedestrian, but pedestrian facilities are not always available. Thus, bicyclists are primarily found sharing the road with motor vehicles, making them a vulnerable user. This is due to the large difference in mass and speed between bicycles and motor vehicles. When bicyclists are observed utilizing the roadway with motor vehicles there are two main concerns: the road itself and the interactions between vehicles and bicycles.

Roadways

Rural roadways are of concern for both bicyclists and drivers in the United States because the majority of highway facilities are rural facilities and have 2.4 times the fatality rate of urban areas (*Local and Rural Road Safety Program* 2016). Speed limits on rural highways are normally higher with steeper, curvier, more unpredictable roadway geometry, and varying pavement conditions (Johns n.d.). Lane widths can vary from 10-feet to 12-feet with shoulder widths varying between 0 and over 6-feet (*Lane Width* 2014). The combination of higher speed, roadway geometry, and road condition can make for a dangerous road (Johns n.d.). Unfortunately, local agencies often do not have the funding to adequately maintain and improve the safety of rural highways (*Local and Rural Road Safety Program* 2016). Rural highways with high speeds, narrow lanes, and limited shoulders are dangerous for bicyclists forcing them to share the lane with traffic.

Vehicle/Bicycle Interactions

There is little new research currently available solely regarding driver behavior when interacting with bicycles. Most research involves the comparison of a before and after treatment exploring driver behavior changes to improve bicycle safety. Generally, the measured variables used are vehicle speed and lateral distance. However, some research has looked at other variables such as roadway width, vehicle type, pavement type, grade of the road, lane markings, bicycle speed, speed limit, shoulder width, presence of an opposing vehicle, etc. (Chapman and Noyce 2014).

Research in the mid-to-late-1900s showed that drivers tend to underestimate the safe required passing distances when overtaking bicycles (Chapman and Noyce 2014). In the early 2000s research was conducted to determine the effects of bicycle position, helmet use, type of vehicle, and cyclist gender on motor vehicle, bicycle interactions. During these times it was believed riding farther from the edge of the road, wearing a helmet, larger vehicles, and male bicyclists resulted in closer distances when overtaking bicycles (Walker 2007)

More current research confirms some of these original claims and refutes others. One study took a second look at the data collected by Walker to confirm his original conclusions. When performing a multiple logistic regression and considering the effect of sample size it was found that wearing a helmet was not significantly associated with close passing distances. However, wearing a helmet did produce a shorter passing distance. A cyclist's distance from the curb, vehicle size, and road characteristics were found to be of more importance (Olivier and Walter 2013). Another study conducted in Michigan showed that more lateral clearance was given for female cyclists and people not wearing helmets (Kay et al. 2014). Research in New Zealand confirmed the research in the mid-to-late-1900s stating that most accidents are caused by drivers not providing cyclists enough room when performing overtaking maneuvers (Trotter et al. 2016).

When different treatments were applied passing distances and speed tended to be altered but little is known about the driver's behavior before treatment. Driving simulation has provided some insights for overtaking maneuvers, right-turning movements, and bike path crossings. Drivers when passing a bicycle about 81% of the

time do not change lanes but do on average provide 4.1-feet of lateral clearance. Approximately 37.5% of drivers provided less than 3-feet of lateral clearance. Older drivers gave the least amount of lateral clearance with the amount of lateral clearance increasing as age decreased. The primary response overall was for the drivers to slow down (Hamann and Schwarz 2016).

The final impact on driver behavior to be discussed is the effect of roadway geometry. This last study originally considered forty variables but was eventually narrowed down through an initial screening, correlation, multicollinearity, and linear modeling to bicycle speed, if centerline striping was present, if it was on a downhill, presence of an opposing vehicle, speed limit, and shoulder width. There was a low R-squared value but that is to be expected for a behavioral study. It can be seen that road grade, shoulder presence and width, a marked centerline, and design speed or speed limit significantly affect how drivers use rural roadways when overtaking bicyclists. Drivers will typically provide more than three feet of space when overtaking bicyclists. This causes conflicts with oncoming vehicles thus wider roads or shoulders are desirable (Chapman and Noyce 2014).

Objectives

The objective of this research is to determine the effects of an automated bicycle detection and warning device on driver behavior on rural highways. In the process interactions between bicyclists and drivers will be investigated. The effectiveness and accuracy of the Urban ZELT bicycle counter will be tested. It is anticipated this study

will provide a better understanding of the safety benefits of an active warning sign to alert drivers to the presence of bicycles. Generally, the ZELT bicycle counter is used solely to determine number of users. Connecting the device to activate a warning system is a new use of the technology and will hopefully be effective and reliable at enhancing bicyclist safety.

Outline

This thesis is broken into nine chapters. After the introduction is chapter two, a review of relevant literature, which discusses different detection and warning technologies and other similar Intelligent Transportation Systems. Chapter three describes the study sites in Colorado National Monument. All data collection and equipment are then discussed in chapter four. A description and discussion on the system that was implemented can be found in the fifth chapter.

Chapter six begins the discussion on the data collected and contains a description and preliminary analysis of the data. The analysis of the data can be found in chapters seven and eight. Chapter seven discusses the analysis of driver behavior while chapter eight discusses the reliability of the system. Finally, chapter nine completes the document by providing a summary of the results and any conclusions drawn from the study.

LITERATURE REVIEW

Bicycle Detection Warning System

A bicycle detection and warning system has two objectives. The first is detection, ideally identifying the bicycle in mixed traffic. Detection can be accomplished through a variety of sensors. After detection something must then alert the driver to the presence of the bicyclist. The warning can be more active or passive. However, when these two objectives: detection and warning, come together an Intelligent Transportation System device is created.

Detection Technologies

There are a variety of different detection technologies being tested and on the market. Some are old technologies being readapted for use with bicycles while others were designed primarily for use with bicycles or pedestrians. These technologies can be broken down into two types: Intrusive and Nonintrusive. Both options are used for bicycle detection.

Intrusive

Intrusive detectors cause disruptions to traffic because they are installed across or in the pavement (Feng and Wang 2003). There are many different technologies used for detecting vehicles. Not all of them are used for the detection of bicycles. In this case there will only be a discussion pertaining to induction loop detectors, magnetic detectors, and pressure sensor detectors.

Loop Detectors Inductive loops, which were widely used to detect motor vehicles, are typically cut into the pavement and detect the current induced in the wires by any metallic object that passes over the loop (Nordback et al. 2016, Feng and Wang 2003). Loop configurations best shown for counting bicyclists are the parallelogram, quadrupole, and diamond. Two of the induction loops had overcounts in mixed traffic: parallelogram 162%-424% error and diamond 536-556% error. (Nordback et al. 2016). Location and configuration requirements create varied accuracy for induction loops but usually accuracy around 80% can be expected on multi-use paths. In one study, induction loops recorded the same count as the baseline having 100% accuracy (Proulx et al. 2016).

Induction loop detectors can be used to accurately count bicycles on separated paths, but conventional induction loop detectors cannot differentiate between bicycles and motor vehicles Previous studies have shown that there are no discrepancies between manual and induction loop counting. However, when used in the field the conventional loop with little maintenance accuracy will vary substantially. The EcoCounter ZELT was tested in a study for counting accuracy. Internal studies claim accuracies ranging from 74 to 99 percent. In the Nordback study, the EcoCounter ZELT was tested both in mixed traffic and on a separated path with both a single loop configuration and a three-loop configuration. Standard bicycles were primarily used for the study, but six special cases were also presented by a carbon fiber bicycle, bicycle with a trailer, tandem bicycle, bicycles riding side by side and one behind the other, and a bicycle at the speed of someone walking. Induction loops installed on shared roadways tended to over count by about 4% whereas ones installed on separated paths tended to under count by 3%. Of the

special cases only, the carbon fiber and bicycle at a walking speed were counted completely accurately. The bicycle with a trailer was counted 0 to 18% of the time. Side by side bicyclists were counted 100% of the time on a shared roadway but only 50% of the time on a separated path. Bicyclists following one behind the other were counted 50% of the time on the shared roadway and 89% of the time on the separated path. Tandem bicycles were only detected 14% of the time. It was concluded that the system does well counting the standard bicycle. There was no way of truly determining the accuracy because the EcoCounter ZELT only counts the bicycles in fifteen-minute increments thus an absolute percent of accuracy was used. The bins could, by a combination of double counting and undercounting, hide some of the overall error and inaccuracy. It was also seen that if the cyclist was undetected when riding through the center of the left loop and then double counted on the shared roadway when riding between the two side by side induction loops. There is an extremely rare instance of motor vehicles being counted (Nordback et al. 2011).

In another study, there were twelve Global Traffic Technologies' Canoga C900 and C800 induction loops studied on multi-use paths which collect data in bins. Due to loop configuration the direction of a bicyclist can be determined and slow-moving objects such as strollers or standing cyclists will not trigger a count. Data was collected automatically by the induction loop and manually by two counters. Carbon fiber bikes were seen to be detected just as well as steel and aluminum bikes. On average the induction loops under counted by 4% but not all of the detectors had been properly maintained. The detectors which had been maintained had a 1% undercount. Errors in

counting if large were normally due to improperly calibrated sensors whereas the small errors were likely caused by cyclists traveling side by side or in close proximity to each other. It was also found that pedestrians, skateboarders, rollerbladers, strollers, and other objects pulled by pedestrians were unlikely to be detected and counted. Bike trailers were rarely counted as a separate vehicle (Nordback and Janson 2010).

Magnetics Magnetometers are similar to induction loops in placement and detection (Figliozi et al. n.d.). The detector measures the effects a vehicle has on the Earth's magnetic field. These detectors can be adjusted to accommodate for temperature changes. The 3M Company has developed one which is much smaller detecting vehicles traveling at 10+mph (Feng and Wang 2003). It can only detect bicycles within a four-foot span and the accuracy has not been independently verified (Figliozi et al. n.d.).

The Minnesota Department of Transportation tested the 3M Microloop to detect ferrous-metal bicycles and it was found to be 98% accurate. Unfortunately, the 3M Microloop could not detect nonferrous bicycles. Due to unforeseen circumstances, the study did not necessarily account for a real-world setting. (*Bicycle And Pedestrian Detection* 2003). In a different study, the magnetic 3M Microloop was confirmed to have a 2% undercount between the sensor count and the baseline for ferrous bicycles (Feng and Wang 2003).

Pressure Pressure and seismic sensors are installed just below the surface of paved paths and some models can differentiate between bicycles and pedestrians. As with the magnetometer there are no independent verifications of accuracy (Figliozi et al. n.d.). Piezoelectric detectors, a type of pressure sensor, convert kinetic energy into electrical energy when vehicles move over the sensor allowing for the volume, speed, weight, and classification to be done. The LINEAS detector uses quartz allowing for static measurements, increased sensitivity to vertical forces, and overall improvement to the device (Feng and Wang 2003). Typically, the material is located in small incisions in the road surface and then covered with an epoxy. In one study, piezoelectric strips were shown to be both accurate and precise having an average percent deviation, or the difference between the automated count and the manual count of 0.11% over count. More research is still required for this technology (Proulx et al. 2016).

Nonintrusive

Nonintrusive detectors have the option to be installed either above or alongside the roadway providing minimal impact to traffic (Feng and Wang 2003). Most nonintrusive detection technologies are used to detect either bicycles or pedestrians. Some are primarily used for detecting pedestrians over bicyclists but can be used for either and thus will be discussed. In this case, the technologies that will be discussed are pneumatic tube technology, infrared technology, ultrasonic technology, microwave technology, and video cameras.

Pneumatic Tubes Pneumatic tubes are primarily used for short term counting.

When paired with proper sorting algorithms they can tell the difference between bicycles and motor vehicles. EcoCounter's pneumatic tube counter was determined to be 95% accurate in mixed traffic for roads up to 27 feet wide. On roads wider than 27 feet accuracies of 68% or less were observed. Unfortunately, pairs or groups of bicyclists are usually counted as trucks with dual axles and accuracy decreases the farther away from the logger (Figliozi et al. n.d.). Pneumatic tubes tend to perform less accurately and precise than induction loops. The pneumatic tubes can be installed on a temporary base unlike induction loops and perform better in a shared use lane with a -6.3% average percent deviation. This conflicts with prior results but there was low volume traffic for the study. Further testing is required on high volume roadways. Colder temperatures produce less accurate results (Proulx et al. 2016).

Recently pneumatic tubes have been able to classify vehicles and bicycles. There are three types of pneumatic tubes available, which can either count only bicycles, bicycles and vehicles, or volume only. All of these can be deployed in mixed traffic. For one study six different pneumatic tube systems were tested. Two counted only bicycles (EcoCounter), three classified the traffic (JAMAR, Time Mark, and Metro Count), and one strictly recorded volumes (Diamond). The bicycle specific counter was more accurate when counting bicycles. All of the devices to be tested were first tested in a controlled environment using standard bicycles. After special cases such as tandem bicycles, cargo bicycles, Carbon Fiber bicycles, bicycles with trailers, cyclists riding side by side and cyclists riding one after the other were tested. The JAMAR systems error increased as

distance from the counter increased creating a 19% MAPE for standard bikes, 50% error for tandems and bikes with trailers, 49% error for carbon fiber and cargo bikes, 27% error for bikes side by side, and a 75% error for bikes riding one after the other. The TimeMark system's error increases as distance from the counter increased creating a 20% MAPE for standard bikes, under counting of less than 10% for tandems, bikes with trailers, carbon fiber, and cargo bikes, but high undercounting of bikes riding one after the other (64%) and bikes side by side (38%). The MetroCount system's error was at a minimum 36% increasing to 95% error in counting tandems and bikes with trailers. The EcoCounter system's error slightly increased as distance from the counter increased creating a 1.7% MAPE for standard bikes, undercounting tandems (50%), bikes with trailers (100%), cargo bikes (8%), bikes riding one after the other (73%), bikes side by side (58%), and perfectly counting carbon fiber bikes. The field test revealed similar results to the control using the video recordings as the baseline showing actual traffic. All of the pneumatic tubes undercounted in mixed traffic: EcoCounter 23-26% MAPE, JAMAR 22-31% MAPE, TimeMark 50-73% MAPE, and MetroCount 10-73% MAPE. Most of the errors came from false negatives due to groups of cyclists riding over the tubes together or vehicles riding over the tubes at the same time as the bicycle. When not in mixed traffic and substantially shorter distances to the logger, the pneumatic tubes still tended to undercount: EcoCounter 2-32% (possible setup error), JAMAR 0-13%, TimeMark 12-13%, and MetroCount 4-5%. Most of the undercounts were for the same reasons or avoiding the tubes (Nordback et al. 2016).

Infrared Infrared detectors use the infrared radiation or reflection of infrared radiation of a vehicle or person to determine if something is present. Improvements in infrared technology allow for the improved ability of vehicle classification, position, and speed (Feng and Wang 2003). These sensors come as passive or active and are commonly used to count bicycles and pedestrians. Active infrared sensors are around 90% accurate and passive infrared sensors are between 75% and 95% accurate. Both systems have problems with occlusion. There are also concerns with the passive infrared system that it performs inadequately with large groups and will perform poorly in temperatures near body temperature (Figliozi et al. n.d.).

In previous studies there has been no difference between microwave-based and infrared-based sensors detecting bicycles correctly 97% of the time (Feng and Wang 2003). When the Minnesota Department of Transportation tested infrared sensors to detect ferrous-metal bicycles accuracy was found to be 96%. Unfortunately, due to unforeseen circumstances, the study did not necessarily account for a real-world setting (*Bicycle And Pedestrian Detection* 2003). In a different study, the Diamond-traffic counter had a 4% undercount between the sensor count and the baseline for ferrous bicycles. A passive infrared system ASIM DT272 had a 1% overcount between the sensor count and the baseline for ferrous bicycles (Feng and Wang 2003).

Passive Infrared sensors perform better than previous studies suggesting improvements in products. It was found that accuracy was unaffected by temperature or precipitation but affected by volume. Of the two devices tested accuracy ranged from -3.12% to -16.86% average percent deviation. The active infrared was tested at only a

single site limiting the generalization of the findings. However, it was found that temperature and volume had an effect on accuracy creating a 3.5% average percent deviation. There was insufficient evidence to determine the effects of precipitation. However, increased temperatures seem to improve accuracy (Proulx et al. 2016).

Another study building upon a previous study by the Oregon Department of Transportation tested the EcoCounter PYRO Box. The Box was mounted on a pole to record pedestrian traffic on a sidewalk north of the intersection of Hall Boulevard and 99 West in Tigard, Oregon. Counts from the counter were compared to ground truths from video recordings. An overall error rate of a 4% overcount was observed. Some of the error can be attributed to the counter classifying bicycles as pedestrians (Kothuri et al. 2017).

Ultrasonic Ultrasonic and Passive Acoustic sensors function similar to infrared sensors except use sound waves to detect volume, presence, classification, and speed (Feng and Wang 2003). The Minnesota Department of Transportation tested ultrasonic sensors to detect ferrous-metal bicycles and accuracy was found to be 99%. Ultrasonic sensors were also capable of detecting nonferrous bicycles with 100% accuracy. Unfortunately, due to unforeseen circumstances, the study did not necessarily account for a real-world setting (*Bicycle And Pedestrian Detection* 2003). Two additional ultrasonic detectors were tested; the Lane King and ASIM DT272 The Lane King, has the ability to detect vehicles, bicycles, pedestrians, and transit vehicles. The ASIM DT272 had a 1% overcount between the sensor count and the baseline for ferrous bicycles (Feng and Wang 2003).

Microwave Microwave radar emits a low-energy microwave and records the differences in the return to determine volume, occupancy, classification, and speed above a minimal speed (Feng and Wang 2003). In previous studies there has been no difference between microwave-based and infrared-based sensors detecting bicycles correctly 97% of the time. When the Minnesota Department of Transportation tested microwave sensors to detect ferrous-metal bicycles accuracy was found to be 96%. The microwave sensor was 98% accurate when used to detect nonferrous bicycles. Unfortunately, due to unforeseen circumstances, the study did not necessarily account for a real-world setting (*Bicycle And Pedestrian Detection* 2003). Microwave detection sensors can detect bicycles and vehicles distinguishing between the two passing within six feet of the device. Accuracies have been verified between 95% and 100% when detecting bicycles in mixed traffic (Figliozi et al. n.d.). The MS-Sedco SmartWalk had a 4% undercount between the sensor count and the baseline for ferrous bicycles (Feng and Wang 2003).

In 2010 California PATH tested the MS-Sedco InterSector under controlled conditions at the University of California's Richmond Field Station and in the field at the intersection of Russell Street and Telegraph Avenue in Berkeley, California. The MS-Sedco InterSector is advertised to detect trucks, vehicles, motorcycles, bicycles, and pedestrians. The device's ability to detect bicycles at varying speeds and relative position to motor vehicles at varying speeds was first tested under controlled conditions. From the results obtained it was proven the device could detect and classify bicycles. However, if a bicycle and vehicle were observed at similar speeds and in close proximity the device had difficulties distinguishing between the two. Distances exceeding nine meters for the most

part eliminated the problem. Different speeds allowed the device to distinguish the two objects the most. The field test involved the InterSector being installed on a telescopic pole attached to a parked trailer at a signalized intersection in the city of Berkeley, California. Data was collected between the hours of 9 a.m. and 6 p.m. During this time frame 71% of the bicycles observed were correctly identified. Of the 29% incorrect observations more than half were misclassification of the bicycle as a vehicle. The false negatives were broken down into the following errors: Classified as a Vehicle 16.9%, Bicycles Not Detected 5.1%, Bicycle Merged with Another as a car 4.9%, and Multiple Bicycles Counted as one 2.5%. False positives also played a part with only 26.7% of the triggers being bicycles, 57.4% being vehicles that were originally classified as bicycles and 15.9% being vehicles that were classified as bicycles. The system shows the ability to discriminate between bicyclists and motor vehicles but is limited by bicycles having similar speeds to motor vehicles and proximity to both vehicles and other bicycles (Sharafsaleh et al. 2010).

Cameras There are two main types of video cameras being used to detect traffic. The cameras are either standard video cameras or thermal imaging cameras. In this case, traffic can be considered vehicles, bicycles, and pedestrians. Both video and thermal imaging cameras are used to detect and distinguish vehicles, pedestrians, and bicyclists.

Video The use of video can either be manual or automated. Manual video recording requires someone to view the video footage. Automated video image processing uses a pattern recognition algorithm to count pedestrians and bicycles and is currently in the developmental stage for use outdoors. The reported accuracy is 95% for automated video image processing (Figliozzi et al. n.d.). Advancements have been to improve the reliability in non-ideal conditions such as snow, shadows, and low light. The Autoscope solo had a 1% overcount between the sensor count and the baseline for ferrous bicycles (Feng and Wang 2003).

Video detection in the past has proved to be about 86% to 91% accurate when counting pedestrians. When the Minnesota Department of Transportation tested video cameras to detect ferrous-metal bicycles accuracy was found to be 99%. The video camera was also capable of detecting nonferrous bicycles with 100% accuracy. Unfortunately, due to unforeseen circumstances, the study did not necessarily account for a real-world setting (*Bicycle And Pedestrian Detection* 2003).

The Massachusetts Department of Transportation Research Program tested an existing traffic camera, the Autoscope Solo Terra, typically used to detect motor vehicles, to detect and count both pedestrians and bicyclists after some software enhancements. The system was primarily tested counting pedestrians and thus set up on a pedestrian foot bridge, an open pedestrian path, and an urban sidewalk. When counting bicycles, it was found that bicycle and vehicle speeds were similar on the urban road. Thus, size was primarily used to distinguish between motor vehicles and bicyclists. However, when using both speed and size all bicycles were detected but some motor vehicles were

counted as bicycles. This test was also only performed for a short period (Tessier and Ni 2016).

Thermal Imaging Thermal imaging cameras, tested by the Portland Bureau of Transportation, are a combination of automated video image processing and passive infrared technology (Figliozi et al. n.d.). Thermal imaging cameras have not been the most accurate but are continually improving. By detecting the difference between vehicle heat and body heat it is possible to classify the two allowing the device not to be reliant on ambient light levels. The FLIR thermal camera had relatively low error rates except for bicycles riding close together. However, the thermal camera had a problem classifying vehicles as bicycles drastically overcounting in mixed traffic, ranging in error from 367% to 4040% and undercounting in non-mixed traffic, ranging in error from 39% to 72%. Odd shapes attached to cars tended to be the source of error (Nordback et al. 2016).

The objective of this study was to build upon a previous study done by the Oregon Department of Transportation. Thermal imaging cameras can differentiate between heat emitting objects by shape and have the potential to function during poor light or weather conditions better. In this case the FLIR's TrafiSense thermal traffic camera was analyzed. Both controlled environment (parking lot) and mixed traffic (intersection of Hall Boulevard and Highway 99 West in Tigard, Oregon) tests were performed. The weather for the controlled environment was described as mild with highs around 60 degrees Fahrenheit. During the mixed traffic test highs were between 80 and 90-degrees Fahrenheit. There was less than a 1% overall error during the control test

counting bicycles: standard, tandems, bikes with trailers, carbon fiber, and cargo bikes. In mixed traffic conditions there were major issues. The camera tended to overcount classifying vehicles as bicycles and undercount when only focusing on the bike lane. Bike lane error ranged from -39% to -48% whereas the mixed traffic errors ranged from 367% to 4040%. Therefore, although thermal cameras work well under controlled environments the same cannot be said for real world applications (Kothuri et al. 2017).

Warning Technology

There are three main types of warning technology available for alerting drivers to road hazards. The three to be discussed, although not always used to alert drivers to the roadside hazards of bicyclists, perform similar objectives. Rapid Flash Beacons, Pavement Markings, and Signs are all designed to draw the driver's attention and alert them to a hazard or possible hazard coming up ahead on the roadway. There are other warning technologies, but these are ones that could be altered and used in the application of warning drivers to the possible presence of bicyclists.

Rapid Flash Beacons

Rectangular Rapid Flash Beacons or RRFBs are user-actuated amber light-emitting diodes that are either manually triggered or passively by a detection system (Porter et al. 2016). Manual triggered devices involve a pedestrian using a push button whereas a passive detection system refers to one using one of the technologies discussed previously. RRFBs are still a relatively new technology to encourage motor vehicles to yield primarily to pedestrians (Effects Of Yellow Rectangular Rapid-Flashing Beacons

On Yielding At Multilane Uncontrolled Crosswalks 2000). For the most part RRFBs are used at pedestrian midblock crossings but can be used at intersections (Porter et al. 2016).

In one study, RRFBs were setup at crosswalks for uncontrolled intersections. Five experiments were conducted to determine the effectiveness of the RRFBs in areas where vehicles primarily fail to yield to pedestrians crossing the street. The treatments in experiments one, three, and four were the same which involved the placement of RRFBs at the crosswalk while observers took notes on pedestrian vehicle interactions.

Experiment 5 was similar but involved a secondary warning system on top of the RRFB and experiment 2 involved testing a system of flashing lights stretched over the roadway. Most of the areas in the study were four-lane roadways with speed limits around 35mph. The various sites tested were monitored from 7 to up to 730 days after installation. It was found that there was a drastic improvement in vehicles yielding to pedestrians which leveled out as time progressed to a value higher or lower than immediately after implementation. Statistical Z-tests and t-tests along with p-values showed there was strong and convincing evidence the RRFBs improved the rate at which vehicles yielded to pedestrians (Effects Of Yellow Rectangular Rapid-Flashing Beacons On Yielding At Multilane Uncontrolled Crosswalks 2000).

Another study had three RRFBs installed at intersections and two more were on midblock pedestrian crossings around a university campus. The objective was to study driver behavior and pedestrian behavior. There were two observers; one collected pedestrian behavior measurements and the other collected driver behavior measurements. It was found that 77.1% of drivers yielded to pedestrians and only 0.3% of the

pedestrians were nearly hit. Out of all variables collected only four remained significant for the regression model. Drivers were 1.63 times more likely to yield without a median and 1.82 times more likely if the vehicle was a passenger car. Finally, drivers were 1.83 times more likely to yield if the pedestrian had not yet entered the crosswalk. Although used in the model, the RRFBs were not a statistically significant source of change in yielding behavior of the driver in this study. RRFBs were also found not to have any effect on a pedestrian's behavior to look before entering the roadway. People also felt no safer crossing the streets immediately after the installation of the RRFBs than before until two months later (Porter et al. 2016).

When comparing rectangular to circular rapid-flash beacons the cities of Milwaukee, Wisconsin; Flagstaff, Arizona; Austin, Texas; and College Station, Texas were used. The beacons were attached to both pedestrian and school crossing signs at cross walks. Data was collected both during the day and night for 13 to 103 days for each sign type and site. All pedestrians were staged, dressed similarly, and followed a set protocol. The yielding rate for Circular Rapid-Flashing Beacons was 63% and 59% for Rectangular Rapid-Flashing Beacons. This difference was found to not be significant and therefore shape did not have an effect. Luminous intensity did have an effect at night (Fitzpatrick et al. 2015).

Pavement Markings

There were no pavement markings used in the study conducted in Colorado national monument. Pavement markings are a reasonable warning device to alert drivers to the presence of bicyclists. A Cambridge study evaluated the use of shared lane markings. Shared lane markings are called sharrows and convey that motorists and bicyclists must share the road. The urban road used had four lanes, a speed limit of 30 mph, and has a high volume of traffic. Video recording was used to analyze spacing primarily and other data such as gender and helmet use. By using the sharrow there were several behavior differences for both bicyclists and drivers. Fewer bicyclists took the lane and more gave way to motor vehicles when sharrows were present. There was also a decrease in the number of doors opened in front of bicyclists. Overall, the percentage of bicyclists not altering speed or direction to continue safely increased from 73% to 90%. Drivers were observed to be less likely to change lanes when over taking bicycles, but more likely to continue following the bicycles after the installation. Overall, there was an increase in safe overtaking maneuvers with more drivers yielding, slowing down, and having to perform fewer avoidance maneuvers around bicycles. With the sharrows bicyclists were more inclined to ride farther from parked cars but there was no statistical change in the spacing between the bicyclist and the passing motor vehicle. Interestingly, there was an increase in the amount of space between moving motor vehicles and the parked vehicles even when there was no bicycles present. When using sharrows vehicles tended to choose a lane position which provided cyclists with enough space for the overtaking maneuver to occur without the need for changing lanes (Hunter et al. 2011).

In a study by the Florida Department of Transportation, the effectiveness of bicycle and pedestrian pavement markings was investigated. All bicycle and pedestrian pavement markings were taken from the Manual on Uniform Traffic Control Devices and tested on 68 participants classified as young, middle aged, and older. Participants were first tested on knowledge of the pavement markings and there was no statistical difference between the groups. Most people understood Bike Lane and Bike Crossing pavement markings however there was a large percentage of people that misinterpreted the Sharrow. No one knew what the Bicycle Detector marking was. After the knowledge tests, simulations were performed with 104 new participants regarding driver behavior. The only pavement marking tested was the bike lane, which was found to cause a 0.37-foot reduction in distance and 1.77 miles per hour increase in speed (Boot et al. 2013).

In Austin, Shared Lane Markings or Sharrows were installed along Guadalupe Street, East 51st Street, and Dean Keeton Street. Guadalupe Street is a four-lane one-way street with traffic volumes around 800 to 1650 vehicles per hour and a speed limit of 30 miles per hour. East 51st Street is a four lane east west roadway with traffic volumes around 400 vehicles per hour and a speed limit of 30 miles per hour. Dean Keeton Street is a four-lane divided arterial with traffic volumes around 500 vehicles per hour and a speed limit of 30 miles per hour. A camera was set at an intersection to record morning and evening peak periods before and after the Sharrows were installed on the outermost lanes of traffic for each road. The bicyclist and driver's behavior were observed primarily focusing on their position on the roadway and avoidance maneuvers. On all roadways discussed a reduction was seen to the number of avoidance maneuvers by bicyclists, an

increase to the number of drivers moving over for the bicyclist, and an increase to the number of bicyclists that took the lane. However, only the increase in the number of drivers moving over and not encroaching on the bicyclist was shown to be significant. Sharrows were found to increase the safety of the facility for bicyclists (Brady et al. 2010).

Signs

There are two different types of signs: active and passive. A passive sign is what most people would consider a traditional sign. The driver observes it and ideally acknowledges the information being conveyed. An active sign works similar to the traditional passive sign but has an added feature to get the drivers attention. Active signs can either have changing messages or lights to grab the driver's attention to more readily convey the message to the driver. Most active signs are associated with ITS systems and thus only passive signs will be discussed in this section.

For passive signs there have been many studies performed over the years. One study performed on Michigan Highway 109 showed some interesting results pertaining to lateral clearance. Bike lanes reduce the lateral clearance provided by the driver. Michigan Highway 109 has 11-foot lanes and a 4-foot shoulder and required volunteers to ride bicycles along the roadway. The effects of a share the road sign and bicycle warning sign were tested. Most bicyclists are passed at a distance greater than the 3 feet requirement. It was found that share the road signs had no statistical effect on the amount of space a driver would provide for the bicyclist. However, vehicle type did play a role with motorcycles providing about 1.13 feet more than passenger vehicles which provided 1.26

feet more than large vehicles. Less of a buffer was also provided if an opposing vehicle was observed, the bicyclist was located within the travel lane instead of the shoulder, or centerline rumble strips were present. When only analyzing the number of motorists in the right most section of the lane, there was just over a 50% reduction in the number of vehicles observed. Speeds were also reduced by 2.5 mph on average when the sign was present and increased with the size of the buffer zone. It is unclear if these results will equate to a reduction in accidents involving bicyclists (Kay et al. 2014).

The Florida Department of Transportation was interested in the effectiveness of bicycle and pedestrian warning signs. Signs were taken from the Manual on Uniform Traffic Control Devices and tested on 68 participants classified as young, middle aged, and older. Participants were first tested on knowledge of the signs and there was no statistical difference between the groups. There was confusion regarding the slippery when wet bicycle sign. After the knowledge tests, simulations were performed with 104 new participants regarding driver behavior. Three signs were tested: share the road, 3-foot minimum rear-view of bicyclist, and 3-foot minimum side-view of bicyclist signs. The distance between the vehicle and bicycle as well as speed were analyzed. All of the signs had no noticeable effect on the distance between the vehicle and the bicycle or vehicle speed. The size of the bicycle group and presence of oncoming vehicles however did have an impact on driver behavior (Boot et al. 2013).

Intelligent Transportation Systems

There have been several instances of bicycle warning signs being used in an Intelligent Transportation System through the usage of different sensors. In New Zealand, an EcoCounter ZELT Induction loop activates a Bicycle- Activated Electronic Warning Sign (BAWS) on a narrow bridge that stays on for 1 minute 45 seconds. Another example is at Rocky Point on State Route 150 in WA where a radar system detects bicycles and can tell the difference between bicycles, pedestrians, and motorcycles. The BAWS in Noosa Heads, Australia also works off an induction loop and here it has been observed that drivers slow down significantly before over taking a bicycle and break earlier when the BAWS has been activated. BAWS are much better choices than full infrastructure upgrades (Bicycle Activated Warning Signs 2015). This is due to the cost effectiveness of BAWS.

The Portland Bureau of Transportation tested an active warning sign to alert drivers to the potential risk of right-hook conflicts with bicyclists. A ‘right-hook’ occurs when a driver enters an intersection and turns right across the path of the bike lane and collides with a bicyclist continuing through the intersection in the bike lane. For the study an intersection of one two-lane one-way street and one four-lane one-way street with parking allowed on both sides was used. There was a six-foot bike lane on the road of primary interest. A green bike box was originally installed as a safety feature. The active warning sign was installed on a modified traffic signal in November of 2011 and informs drivers to the requirement of yielding to bicyclists when turning right. A bicycle triggers the sign by passing over one of two induction loops located in the bike lane. Video

footage was collected before the installation and after the installation. If a potential conflict was observed both the driver's and bicyclist's behavior was documented. Before installation there were three documented right-hook crashes during the year of data collection. There were four during the two-year period of data collection after installation. However, analysis primarily pertained to crash statistics and a comparison of expected to actual crash statistics. The test concluded with at least 99% and 95% confidence that there was a decrease in the likelihood of right-hook conflicts and the number of conflicts observed after the installation of the active warning sign. From the data it was concluded that the active warning sign significantly reduced the right-hook conflicts between bikes and motor vehicles at the intersection (Paulsen et al. 2015).

There was a Bicycle-Activated Electronic Warning Sign installed on the Waimea River Bridge in Appleby, NZ by Opus in partnership with NZTA Wellington for a case study. The signs are activated when a bicycle passes over the bicycle sensitive induction loops. Installation of the system cost \$45,000 per site. Upon completion of the study the system was removed. This case study found that installation of the signs coincided with a noticeable change in driver behavior. Overall drivers were found to wait behind cyclists and drive more cautiously improving cyclist safety. However, more testing is still required, and implementation has a significant cost ("Bicycle-Activated Electronic Warning Sign" 2016).

There was also an electronic Cyclist Ahead warning sign installed in Victoria, AU outside Lorne on the Deans Marsh-Lorne Road. This area is known to cyclists and the local community as a dangerous area due to the narrow road and no shoulder. The solar

powered detection technology can differentiate bicycles from motorcycles and cars and was installed for a trial period of 12-months. Unfortunately, there are no results from this study (“Revolutionary ‘Cyclists Ahead’ Warning Signs Deployed” n. d.).

STUDY SITES

Colorado Monument

Colorado National Monument is located in western Colorado approximately six miles west of Grand Junction. The national monument, established May 24, 1911, is under the management of the National Park Service and is bordered by both public and private land. To the north is the municipality of Fruita and to the west is McInnis Canyon National Conservation Area. Glade Park is an unincorporated town to the southwest, which has a significant population that commutes to Grand Junction for work. Any commuter traffic to and from Grand Junction has alternative routes through Redlands using State Highway 340 or Interstate 70 (“Maps - Colorado National Monument (U.S. National Park Service)” 2017). This area is also very popular with all types of people and offers many recreation opportunities.

Roads

Within Colorado National Monument there is one main road called Rim Rock Drive. Monument Road connects to Rim Rock Drive at the East Entrance and continues east to Grand Junction. Approximately four miles from the East Entrance Rim Rock Road connects with the East Glade Park Road, which leads to Glade Park. This is the primary route for commuters from Glade Park to Grand Junction. Approximately eight miles farther into the park Rim Rock Road connects with Black Ridge Road, which takes the driver to the McInnis Canyon National Conservation Area. Rim Rock Drive then

continues north until exiting the national monument at the West Entrance (“Maps - Colorado National Monument (U.S. National Park Service)” 2017).

Construction of the first road through the park began in 1912 and was completed in 1921. This road was called the Serpents Trail and is now used as a pedestrian hiking trail through the park. Construction began on the current road, Rim Rock Drive, in 1931 and was finished in 1950. There have been little to no upgrades to the road since completion besides paving and standard maintenance (“Rim Rock Drive Timeline - Colorado National Monument (U.S. National Park Service)” 2015). Thus, Rim Rock Drive was only designed for the vehicles of that era and not the larger vehicles and traffic volumes it currently sees. The road is also narrow with little to no shoulder and frequent hairpin turns. Sharp turns and a tunnel were necessary for the steep climb to the top of the canyon. The road then follows the rim of the canyon requiring additional sharp curves. At times there are rock faces to one side of the road and steep drop offs into the canyon on the other side of the road.

Rim Rock Drive has an approximate average daily traffic volume of around 700 vehicles per day for the East Entrance. This value increases to around 800 to 850 vehicles per day during the summer and decreases to about 620 vehicles per day during the winter. Traffic volume increases slightly on the weekends. The speed limit on the road is posted at 25 miles per hour with advised speeds as low as 15 miles per hour for the frequent sharp turns.

Users

There are two distinct types of users for this roadway. The first and majority of users during the summer months are tourists. The second are commuters or local traffic mostly traveling between Glade Park and Grand Junction. This mix of commuters and tourists leads to a variety of vehicle types using the roadway, especially the first four miles of the East Entrance. During the summer months large recreational vehicles and tour busses are not an uncommon sight. Rim Rock Drive also sees a small percentage of large vehicle traffic such as tractor trailers, dump trucks, and a variety of single unit trucks. These large vehicles and recreational vehicles appear to account for only about 6% of the traffic but have the most difficulty navigating the roadway and staying in their lane. All other motor-vehicle traffic consists of passenger vehicles ranging from small cars to pickup trucks or motorcycles. There is also significant non-motorized traffic most of the year from pedestrians and bicyclists. During the winter months recreational traffic along with nonmotorized-vehicular traffic tend to decrease making the primary users those commuting between Glade Park and Grand Junction (Gleason et al. 2017).

Once in Colorado National Monument, there are a wide variety of activities to participate in. Visitors can take part in hiking, camping, rock climbing, bicycling, ranger programs, or driving the historic Rim Rock Drive. Throughout the park are pull offs for people to stop and take photographs or take part in other activities. With a wide variety of activities and scenery people may become distracted, thus slowing their reaction time.

Bicycle Popularity

One of the most popular activities within Colorado National Monument is bicycling. During the summer months bicycles can account for up to 10% of vehicles on the east hill of the monument or approximately within the first four miles of Rim Rock Drive from the East Entrance. Bicycle usage within the national monument seems to follow a normal distribution. There is very little bicycle traffic during the cold months in the beginning and end of the year averaging about one per day, which eventually grows to a maximum in June of around forty bicycles per day. However, the month of October is an outlier having an average in 2016 of about 98 bicyclists per day (Gleason et al. 2017), likely due to a popular bicycle event in October called the Tour of the Moon.

Study Sites

Both study sites are located within the first four miles of Rim Rock Drive from the East Entrance. The locations were chosen due to the large number of bicycles using this section of roadway and observed and reported conflicts between bikes and motor vehicles. Throughout the year this section also maintains a higher volume of vehicular traffic. This is due to the mixture of commuter and tourist traffic during the summer and then mostly commuter traffic between Glade Park and Grand Junction during the winter.

Site One

The first site is located approximately 0.7 miles from the East Entrance. There are two unofficial pull offs on either side of the roadway with enough room for a vehicle to pull off on the east side of the road. The hillside on the west side prevents vehicles from being able to pull off the road and thus creates a restriction with no shoulder. A view of Site 1 can be seen in Figure 1. The site is an approximately 330-foot-long straight section between two curves, the second curve is the first hairpin turn going up the hillside.



Figure 1. Site 1 before the installation of the Dynamic Bicycle Detection and Warning System facing North.

Warning System Location The warning system for site 1 also known as the lower site was setup slightly off from the original sign it was to replace. The new sign shown in Figure 2 is approximately twenty feet from the induction loops and counter which have a latitude of 39.02784 and longitude of -108.63577. These coordinates are on the west side of the roadway about a foot off the pavement. However, the loops do span the whole lane. When referencing the construction project, the sign, the loops, and the counter were installed at station 183+00. The new asphalt installed was three inches thick, therefore the

saw cuts for the induction loops were only two inches deep on the loops closest to centerline and two and a half inches deep for the induction loops closest to the fog line. This was to enable the wires from the induction loops farthest from the counter to reach the counter. Each of the 44-feet of saw cut was $\frac{3}{8}$ ths inch wide. Backerod was used to insulate the wire from the epoxy and prevent it from floating. All wires for the loops were wrapped tight and counter clockwise. Test readings of 100 and 130 microhenries confirmed the proper functionality of the loops before sealing them.



Figure 2. Site 1 after the installation of the Dynamic Bicycle Detection and Warning System facing North.

Issues Site 1 had the most difficulties primarily due to it being the first of the systems to be installed. As stated, the counter is on the west side of the road about a foot from the pavement edge. This area was used on occasion as an impromptu pull off. To prevent the counter from being run over it was moved back a few feet from the planned location and a ditch was formed to discourage use of the unofficial pull off. The sign was located to ensure the solar panel had enough direct sunlight. There were also some difficulties in determining the proper settings to allow the induction loops to function properly, but the manufacturer was very helpful providing assistance to ensure the device was working. Unfortunately, the location of site 1 is in a very poor cell reception area. The device is supposed to automatically transfer the data gathered. However, due to the poor cell reception the automatic transfer of data feature does not always function.

Site Two

The second site shown in Figure 3 is located approximately 2.4 miles from the East Entrance. Site 2 is also sandwiched between two curves, the second of which is a hairpin turn. However, the straight section of about 800 feet is comprised mostly by a tunnel. Due to the tunnel, lay of the land, and vegetation there is some room for a bicycle to pull off to the side of the road but nothing larger. The whole section is also on an incline. However, due to restrictions posed by terrain site 2 is specifically the area right before the tunnel.



Figure 3. Site 2 before the installation of the Dynamic Bicycle Detection and Warning System facing South.

Warning System Location The warning system for site 2, also known as the upper site, was installed quicker but with the wires possibly not as tightly wound. Saw cuts were made simultaneously for both loops instead of separate cuts for each loop as they were at site 1. The induction loops and counter in Figure 4 have a latitude of 39.03173 and longitude of -108.64676 with the sign being approximately 20-feet away again. These coordinates are on the east side of the roadway about a foot from the edge of the pavement. The loops do however span the whole lane. When referencing the Rim Rock Drive construction project, the sign, loops, and counter were installed at station 102+00. The new asphalt installed was three inches thick and therefore the saw cuts for the induction loops were only two inches deep on the loops closest to the centerline and two and a half inches deep for the induction loops closest to the fog line. This was to enable the wires from the induction loops farthest from the counter to reach the counter. Each of the 44-feet of saw cut was $\frac{3}{8}$ th inch wide. Backerod was used to insulate the wire from the epoxy and prevent it from floating. All wires for the loops were wrapped tight and

counter clockwise. Test readings of 130 and 150 microhenries confirmed the proper functionality of the loops before sealing them.

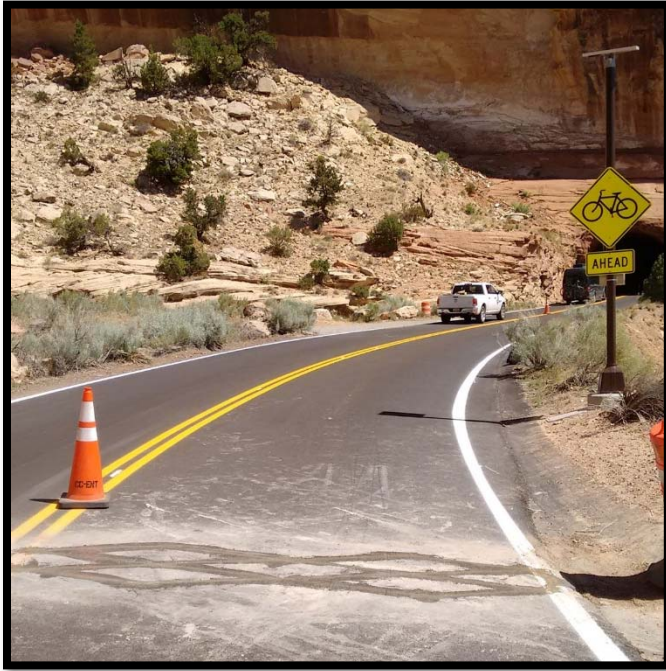


Figure 4. Site 2 after the installation of the Dynamic Bicycle Detection and Warning System facing North.

Issues Considering the upper site or site 2 was the second to install there were fewer problems. The wrapping of the wires and saw cuts were not performed identically to the first site. Thus, there may be some differences between the two with one possibly being more accurate than the other. As stated above the counter is located about a foot off the pavement to the east This area is unfortunately a safety concern for maintenance considering it is on a curve and at the edge of a cliff. All the settings are the same as site 1 except a difference in 0.1 to 0.2 seconds for the time out. There is a possibility that this small difference has made the induction loops overly sensitive considering they were able to pick up the steel toe in the workers boots and epoxy cans.

DATA COLLECTION

Field Data

Data was collected over the course of four different months. The preliminary or before installation data was collected during the months of May and June 2017. After installation data was collected the following year during the months of June, July, and August 2018.

Collection of the preliminary data began at Site 1 on the third of May at 14:50:13 and was completed the eleventh at 07:05:36. After the collection of data at site 1 was completed the equipment was moved to site 2. The data collection began on June tenth at 10:35:40 and then ended on the nineteenth at 07:28:27. There was some extra data collected outside of these parameters, but these were the sections of time that the video and radar records overlapped.

Upon reviewing the before installation data, it was determined that the after-installation data would be collected at site 1 for an additional two weeks to make a total of four weeks beginning June sixth at 17:25:02 and ending the first of August at 10:25:06. The equipment was then moved to site 2 and only had data collected for two weeks beginning August second at 11:35:48 and then being completed on the eighteenth of August at 07:03:55.

There were several variables of interest to be extracted from the video and radar data collected. The video records showed time stamps for when vehicles and bicycles passed by the site, as well as the type of vehicle and where it was positioned on the road. Speed, vehicle type, and time stamp were recorded in the radar data records. Vehicle type was used to match the time stamps from the video and radar data. The video files were considered to have the master time stamp. The actual variables extracted will be discussed later.

Monitoring Equipment

A video camera was used to observe vehicles as they pass the warning system. The camera was also used to confirm the presence of a bicyclist and sign activation. A radar device was used to gather the speeds of the different vehicles observed. Unfortunately, the radar device is unable to pick up the speeds of bicyclists as they pass. Although not discussed in this section the ZELT EcoCounter will be used to count the number of bicyclists in fifteen-minute increments. The ZELT Eco Counter will be discussed further in depth in the next chapter.

Video Camera

The camera selected was required to meet several specifications. A camera that was able to collect and store approximately three weeks of daylight video was desired. The unit would need to have standalone power for at least one week, be portable, weather resistant, and inconspicuous upon setup. There was a desire for the camera to not have a fixed view but to be able to have the view positioning altered to ensure proper view of the

sites, roadway and warning sign. From these requirements two devices were selected as options: MioVision and COUNTcam. In the end the COUNTcam unit in Figure 5 was selected because of the ease and flexibility of the system. The system can be easily set up in varying locations and environments. Replacement and additional parts are normally easier to get locally from hardware and electronic stores with some exceptions. However, the major difference between the two was the size and cost. The COUNTcam was about \$4000 less and is self-contained in a 12-inch by 9-inch 8-pound case.



Figure 5. COUNTcam Camera Left and COUNTcam 200 Unit Right

There were two COUNTcams used for the research. Once a week the COUNTcam unit was removed from the field to charge the battery, which took around 14.5-hours. Even though the battery is reported to last for ten days, charging it weekly ensured no data was lost due to a low battery. Having two units enabled one camera to be left in place during the charging time. A 64-gigabyte SD card was used to record the video files, which were then transferred to an external hard drive as a backup copy. The camera was setup to only record video footage during daylight hours. Unfortunately, the camera does not have a power saving mode for the hours it is not recording. Researchers

from WTI set up the cameras initially, then National Park Service staff maintained the cameras throughout the research period.

Radar Device

A radar device that collects approximately three weeks of data and records vehicles in both directions with separate timestamps for each was required. The device needed to be portable and have a battery life of one week. Along with this it was required to be inconspicuous, weather resistant, completely self-contained, and allow data exportation to excel. Options included Armadillo DC Radar, Jamar Gen1 Radar, Covert Radar, StatTrak, and Stalker Traffic Data Collector. The StatTrak was selected due to the portability, easy setup, and easy data retrieval. An employee from the National Park Service was placed in charge of charging the unit and retrieving the data. Data was retrieved via a Bluetooth connection. The files were downloaded onto a tablet provided by WTI specifically for the radar unit. Files were then emailed and saved to a cloud system.

Data Processing

One researcher over the course of several months reviewed the video records, matched, and compared them to the radar device's records. Screening the video and radar records allowed for the removal of erroneous data entries. Erroneous data entries will be discussed later in greater detail. During the data screening process, there was a noticeable difference in the behavior between motorcycles and passenger vehicles or large vehicles.

The video records revealed that motorcycles tend to stagger themselves in the lane and use the center or left side of the lane no matter the situation.

Further investigation was desired regarding the interactions between the variables. Thus, correlations between class, time lag, time between, and speed were performed. Linear regression was used to determine if the results from the correlation showed any significant interactions. This also revealed the best predictors to be lateral placement and speed. Thus, for the analysis of the data three subgroups were created. The subgroups were Without Motorcycles, Without Large Vehicles, and Passenger Vehicles Only. However, due to the nature of motorcycle behavior observed during the screening process for the preliminary analysis and the analysis only large vehicles and passenger vehicles were considered. Appendixes will contain the data sets including motorcycles.

Four groups of data were collected, the control and the event before the installation of the system and the control and the event after the installation of the system. An event is categorized as when a bicycle passes the site. Vehicles in the event data set for both before and after the installation were only recorded if they arrived within four minutes of the event. When specifically dealing with the after-event data vehicles were only used for analysis if the lights were flashing for an event. The control group consisted of vehicles that arrived a minimum of five minutes after an event took place and no less than five minutes before the next event was recorded. Previous information estimated the average speed of a bicyclist at seven miles per hour. Therefore, bicyclists should have been at least a half mile away from the vehicle and the lights during the after-data collection and the lights would have been off for two minutes.

Performance Measures

There are two main performance measures for driver behavior in this study. The two measures are vehicle speed and lateral placement on the roadway. Considering that actual safety improvements cannot be directly measured or at least not measured well, speed and lateral placement on the roadway will be surrogate measurements for safety. There were other variables that were theorized to have an effect on these surrogate measurements which include Time Lag, Class, and Time Between. All of these variables are described in more detail below including speed and lateral placement.

A closer inspection of the speed, time lag, and time between was performed. Correlations and graphical representations of the data showed improvements when some of the variables were converted to categorical variables. When some of these categories were combined with the existing categories correlation improved along with the graphical representations. These combinations will be discussed with the variables.

Lateral Placement The lateral placement of the vehicle was recorded as a categorical variable with four different options. The lane a driver should be using was divided in thirds creating three different options for lane position and then the opposing lane was treated as a single lane position. The first third of the lane or the third bordering the fog line was categorized as a 1. From there the center third was listed as 2 followed by the last third as 3. It should be noted that a vehicle occupying the first third of the lane never crossed the center yellow line where as a large vehicle utilizing the center third of the lane may cross the center yellow line. Passenger vehicles utilizing the center of the lane would come close to the center yellow line but never cross it. All drivers with the

exception of motorcyclists if they were found in the left third of the lane or section closest to the center yellow line were observed either just crossing it or straddling it. All vehicles recorded as using the opposing lane were clearly observed no longer being in their lane having completely crossed the center yellow line. The opposing lane was recorded as a four for analysis. Unfortunately, due to the video camera's locations a higher degree of accuracy was unable to be obtained.

Speed Speed for vehicles was maintained as a continuous variable for the analysis. When a categorical variable was used any correlations with speed decreased. For graphical purposes vehicle speed was divided into three percentile groups: zero to thirty, thirty to seventy, and seventy to one hundred. Even though the radar device listed vehicle speed out to the tenths place speeds were only recorded to the ones.

Time Lag The variable of Time Lag describes the amount of time between when a bicycle passed the site and when a vehicle is observed passing the site. This variable was used due to the limited ability to watch larger sections of the roadway to determine the interactions between the driver and the bicyclist. If more than one camera was used the variable of time lag may not have been needed, but because only one location could be observed this variable was necessary.

The variable was originally recorded as a continuous variable but transformed into a categorical variable with five options. The first option denoted by a one was for zero to five seconds or when a vehicle was observed immediately after or during the time a bicycle was being observed. A two was used to denote the second time lag category of

five to ten seconds. Three represented the third category: ten to twenty seconds. The fourth time lag category included vehicles observed twenty to thirty seconds after the bicycle. All other vehicle data points from thirty seconds up to four minutes were denoted by a five. There was discussion between using four or five categories for time lag. Correlations and preliminary graphical representations of the data showed that the fifth category was unnecessary for the before installation but was useful for the after installation. Therefore, the fifth category was kept and not combined with the fourth category.

Class Class was listed out using the radar devices break down of large, medium, and small vehicles. Large vehicles were denoted by a three, followed by a two for medium vehicles, and a one for the small vehicles. Contained in the category of small vehicles were motorcycles. Medium sized and large sized vehicles had a wider dispersion of types of vehicles. For this report a medium sized vehicle will be considered a passenger vehicle which will also include pickup trucks and SUVs. A large vehicle is considered any vehicle towing a trailer (i.e. passenger vehicle with a trailer, tractor-trailer, etc.) or single unit truck.

Time Between Time between described the distance in units of seconds an opposing vehicle was observed from the vehicle of interest. This variable was also used due to the limited ability to watch larger sections of the roadway. Originally the variable was recorded as a continuous variable. However, the use of a categorical variable with four options was deemed more appropriate. The first option denoted by a one was for

zero to five seconds or when a vehicle was observed immediately after the vehicle of interest was observed. A two was used to denote the second time between category of five to ten seconds. Three represented the third category: ten to twenty seconds. The final time between category, denoted by a four, included all other opposing vehicles observed at greater than twenty seconds. Originally there were five categories similar to the time lag variable. Correlations with other variables for both the before and after installation showed that the fifth category had no real effect and was therefore combined with the fourth.

Issues

Over the course of the time spans that the data was collected some issues occurred. The problems could be attributed to either equipment error, human interference, or natural interference. When screening the data any events that involved equipment error or human interference were omitted as erroneous data entries from the final processed data. Some equipment error was able to be overcome, and these data points were not treated as erroneous data entries and therefore left in for the final analysis. The natural interference was not able to be overcome and resulted in the removal of large sections of data.

Equipment The equipment had varying degrees of errors. When processing the radar data and comparing it to the video files there were instances of miss classification, phantom vehicles, and missing vehicles. Some medium vehicles were counted as large vehicles, but primarily large vehicles were counted as medium sized vehicles. These problems were easily remedied. Phantom vehicles are any instance when there was a

vehicle recorded by the radar device but not observed on the video recordings. Some of these phantom vehicles could be attributed to the device picking up bicycles and classifying them as medium sized vehicles. Other instances a vehicle was counted more than once. In either instance the phantom vehicle was removed from the data set. There were other instances when a vehicle would be observed in the video recording but not be listed in the radar files. These vehicles were considered missing and since no data was recorded by the radar device could not be used. One other instance where the equipment malfunctioned and created an error was in the case of recording the speed of a vehicle. There were times when a vehicle would have a radar recorded speed that did not appear to match a vehicle in the video recording and was excessively higher than any reasonable and expected value for a roadway with a posted speed limit of 25 miles per hour. Vehicles recorded with unreasonable speeds were also removed during the data screening process.

Interference As stated earlier interference also played a role in the removal of sections of data. The two types were human interference and natural interference. Human interference involved any time a person was observed in the video recordings either working with the equipment or present possibly causing an alteration to driver behavior. There were several instances when national park service personnel who were tasked with the up keep of the data collection equipment were observed performing their duties. However, this would both directly and indirectly alter the data points collected during this time frame.

In the process of performing their duties their presence likely caused drivers to behave differently. Vehicles were observed moving over in the lane and or slowing down due to the presence of a road side hazard in the form of a person and a national park service vehicle. The vehicle primarily observed being used by the national park service was a police officer's car and would cause drivers to slow down. These would be instances of an indirect influence the park service employees had on driver behavior.

When the park service employees directly interacted with the equipment some equipment errors were observed. Some of the errors included alterations to the speed, class, or time stamp of a vehicle. Thus, making the data point unusable. Some of the errors created from the human interaction could also explain the phantom vehicles or missing vehicles. To eliminate the possibility of erroneous data being included in the clean data set, if a human was observed in the vicinity of the site no data points were used until the human was no longer present.

In the case of natural interference there was no way to remedy the problems and like the human interference had to be completely removed. The natural interference can primarily be described as intense sunlight obscuring images being recorded in the video files. This only occurred at site 2. The ZELT Range Bicycle counter, which will be discussed later, only collects values in fifteen-minute bins. Therefore, since it was impossible to determine if the lights were to flash on the sign when a bicycle would pass or if they went off for anything else within the fifteen-minute bin the whole fifteen-minute time period could not be used. On top of this there was no way to determine when the lights started flashing or what started them. The video recordings were only viable up

until eight a.m. for the most part. There were rare instances in the case of overcast days that the lighting permitted the ability to see the sign and if the lights were to flash. In the end the removal of the unusable data due to lighting resulted in 23.5 hours of data when bicycles were observed at site 2.

BICYCLE DETECTION AND WARNING DEVICE

System

As discussed earlier in chapter 3 there were two sites selected for the setup of the system. The dynamic bicycle detection and warning system consisted of two components, a warning sign and a sensor. For the warning sign a Tapco bicycle warning sign with LED lights was selected. A ZELT Range bicycle counter was selected for the sensor.

Sign

Tapco produces all types of signage for road projects. In this case a W11-1 BlinkerSign LED Bike Lane (Symbol) Sign shown in Figure 6 was used. Unlike the traditional W11-1 signs a BlinkerSign has eight LED lights around the outside of the sign to grab the driver's attention. The sign is fluorescent yellow green with dimensions of thirty inches high and thirty inches wide. A solar panel is used to charge the Nickel Metal Hydride battery, which has a life span of up to five years, for the LED lights. Each light has a life expectancy of over 100000 hours. Both the sign and the flash pattern of the sign are MUTCD compliant. The sign is expected to function for up to thirty days without being charged and has a one-year full warranty ("W11-1 SOLAR." 2018; BlinkerSign® LED Bike Lane (Symbol) Sign W11-1." 2018).



Figure 6. W11-1 BlinkerSign LED Bike Lane (Symbol) Sign by Tapco

There are four functional settings for the W11-1 BlinkerSign LED Bike Lane (Symbol) Sign, which costs \$1600. The sign can be set to 24/7 continuous flashing, time clock activation, wireless control activation, or vehicle detection activation. In this case it was desired to have the light flash every time a bicycle passed. Therefore, the vehicle detection activation setting was chosen. For this setting the sign can be activated through a push button or a motion detector. Unfortunately, a motion detector would set the sign off for all vehicles instead of just bicycles and it was undesirable to have the bicyclist stop on a hill to activate the sign. The ZELT Range bicycle counter was installed in place of the push button or motion detector to activate the lights on the sign (“W11-1 SOLAR.” 2018; BlinkerSign® LED Bike Lane (Symbol) Sign W11-1.” 2018).

ZELT Inductive Loop

The ZELT Range Bicycle counter is produced by EcoCounter based out of Lannion, France. There are three different counters currently available: Urban ZELT, ZELT Greenways, and Easy ZELT. The Urban ZELT is used for cycle tracks, bike lanes, and mixed traffic. For multi-use and bike paths a ZELT Greenway device is chosen. When temporary counts are desired the Easy ZELT system is used. Considering the site locations and the mixed traffic conditions the Urban ZELT bicycle counter was selected (“About Us.” 2010; “Urban ZELT - Bicycle Counter.” 2010).

The Urban ZELT bicycle counter shown in Figure 7 was designed specifically for shared roads so that cyclist counts can be determined accurately. Urban ZELT’s inductive loops are forty-three to fifty-nine inches long and sixteen inches wide. The system should function for one to two years with the replaceable battery and works in all weather conditions. EcoCounter’s software provides seamless data transmission allowing easy data collection from around the world (“Urban ZELT - Bicycle Counter.” 2010).



Figure 7. Urban ZELT bicycle counter left and induction loops right

When a ferrous object moves over the induction loops or looped wire an electromagnetic current is induced. Each electromagnetic signature is analyzed using thirteen differentiation criteria. The SIRIUS algorithm developed by EcoCounter to remove motor vehicle electromagnetic signatures from the data sets can be supplemented with a speed classification to only consider possible data points under a set speed threshold (“Urban ZELT - Bicycle Counter.” 2010).

Dynamic Bicycle Detection and Warning System

Together the ZELT bicycle counter and LED Tapco W11-1 sign in Figure 8 function as one complete system. The Urban ZELT bicycle counter induction loops detect electromagnetic signatures of objects passing over the loops. If the object detected is below a set speed threshold and is categorized as a bicycle by the algorithm an event is recorded in a fifteen-minute bin. Each time an event is recorded a signal is sent from the Urban ZELT bicycle counter to the Tapco W11-1 sign. The sign was set to flash for a total of three minutes when a signal was received from the counter. The system functions not only as a warning device but also as a bicycle counter, allowing road owners to document bike use over time.



Figure 8. Dynamic Bicycle Detection and Warning System installed at site 1.

Some alterations were made to create a connection between the sign and the bike counter. Rather than using batteries requiring replacement every one to two years, this system uses rechargeable batteries from EcoCounter that connect to the solar panel for the LED bicycle warning sign. This solar panel was deemed large enough to charge both the battery that powers the sign's flashing lights and the bicycle counter. Therefore, in addition to the wires connecting the sign to the counter, a power wire was run from the solar panel to the counter, so the counter batteries would be charged. Ideally using solar charged batteries will allow for a longer system life before any major maintenance will be required.

PRELIMINARY ANALYSIS

Overview

Chapter 6, the preliminary analysis discusses the processing of the data collected. Later in the chapter a preliminary analysis of the before-data and the after-data is also discussed.

Data Classification And Preliminary Data Analysis

Specific variables were created from the data collected. These variables consisted of direct extractions from the video record or radar device and non-direct extractions. The directly extracted variables included lateral placement of the vehicle with respect to the lane being utilized, vehicle class, and vehicle speed. Non-directly extracted variables included time lag or the time between when a bicycle was observed and the vehicles preceding it and time between or the time between the preceding vehicle and an oncoming vehicle. A time lag variable was created because only a set section of road could be seen and ranged from 1 meaning a vehicle appeared within five seconds, 2 between five and ten seconds, 3 between ten and twenty seconds, 4 between twenty and thirty seconds, and 5 meaning a vehicle arrived at a time greater than thirty seconds. The variable for time between had four categories. These four categories were similar to the time lag categories, with 1 representing an opposing vehicle being observed within five seconds of the vehicle of interest's observation, 2 being between five and ten seconds, 3 between ten and twenty seconds, and 4 meaning that the opposing vehicle was observed

twenty seconds after the vehicle of interest's observation. Class was used from the video record rather than from the radar device due to occasional miss classification. The variable for class was divided into the three categories presented by the radar device, small, medium, and large vehicles. However, the definition of the category was altered to match both the radar device record and the video record. Small vehicles, denoted by a 1, represented motorcycles. Medium vehicles, denoted by a 2, represented passenger cars or anything larger than a motorcycle including pickup trucks but not large vehicles. Large vehicles were denoted by a 3 and represented any vehicle with a trailer or a single unit truck and larger. The speed was recorded as a continuous variable and for graphical purposes broken into percentiles: 0 to 30th percentile, 30th to 70th percentile, and 70th to 100th percentile.

Upon compiling the data into tables in Microsoft Excel several statistical analyses were performed. First a correlation was performed to determine if any of the variables were related. From here t-tests, Z-tests, and linear regression modeling was performed. The t-tests and Z-tests were used to determine if there were any statistical differences between the time lag categories along with any differences between the control and event groups. The event group was only compared to the control group for the before-data sets. Linear regression was used to create a model to predict a vehicles lateral position or speed when encountering a bicycle.

Before Installation

The before installation preliminary analysis is broken down into two data sets of interest: without motorcycles and only passenger vehicles. These two sections were then further broken down into the control group and event group. A comparison will be discussed in the next chapter.

Without Motorcycles Over the course of the study there were 253 bicycles observed at site 1 and 216 at site 2. When two or more bicycles were observed within ten seconds of each other these events were considered a single event. Some events had interference and were not used. After removing these events there was a total of 189 bicycles observed at site 1 and 182 at site 2. These bicycles had 530 vehicle data points for site 1 and 437 vehicle data points for site 2. The control groups for both site 1 and site 2 had over a thousand observations, with site 1 having 1008 observations and site 2 having 1009 observations.

Lateral placement, speed, and time lag will be the variables of primary concern. The linear regression model without motorcycles for speed showed Time lag was statistically significant at the 95% confidence level and p-value of 5.99×10^{-6} for site 1 and 0.016 for site 2. Unfortunately, both models only had an adjusted R-square value of approximately 4% and 1%, explaining 4% and 1% the data for site 1 and site 2 respectively. The linear regression model for lateral placement however modeled about 31% and 37% of the data for site 1 and site 2 respectively. Once again time lag was the only variable of statistical significance at the 95% confidence level having p-values of 3.79×10^{-45} and 1.50×10^{-45} for site 1 and site 2 respectively.

Control When looking at the control the first two noticeable characteristics were the speed and lateral placement. For both site 1 and site 2, the majority of drivers used the right third or center of the lane. This can be seen in Table 1 where just over 2% of the 1008 vehicles for site 1 and none of the 1009 drivers for site 2 utilized the left third of the lane or the opposing lane. The average speed for site 1 was 29.27 miles per hour and 25.44 miles per hour for site 2. When there were no bicyclists present drivers tended to drive close to the fog line at speeds greater than the posted speed limit. Drivers also appeared to react differently between site 1 and site 2 based on the approximate four mile per hour difference in average speed and lack of any driver using the left third of the lane or opposing lane.

Table 1. Without Motorcycles Control Lateral Placement of Site 1 and Site 2 Before Installation

<u>Control</u>			
Site 1	Number of Vehicles	Site 2	Number of Vehicles
Right 1/3	73.51%	Right 1/3	93.76%
Center	24.21%	Center	6.24%
Left 1/3	1.88%	Left 1/3	0.00%
Other Lane	0.40%	Other Lane	0.00%

A closer look at the lateral placement of the vehicle when related to speed can be seen in Figure 9. More people were willing to use the left third of the lane or the opposing lane at site 1. When paired with the speed as drivers moved over to the left the speed tended to increase. Some drivers did slow down but not many. These three trends are shown in Figure 9. It should be noted that only four drivers were observed in the opposing lane. Drivers at site 2 were only willing to use the right third and center of the

lane, which makes it difficult to determine, but it appears that the further over to the left drivers are observed the slower they will go. This can be seen in Figure 9. Graphically there appears to be a difference in driver behavior between site 1 and site 2. Due to the prominence of this difference and scope of the study no statistical tests were done to confirm the significance of the difference.

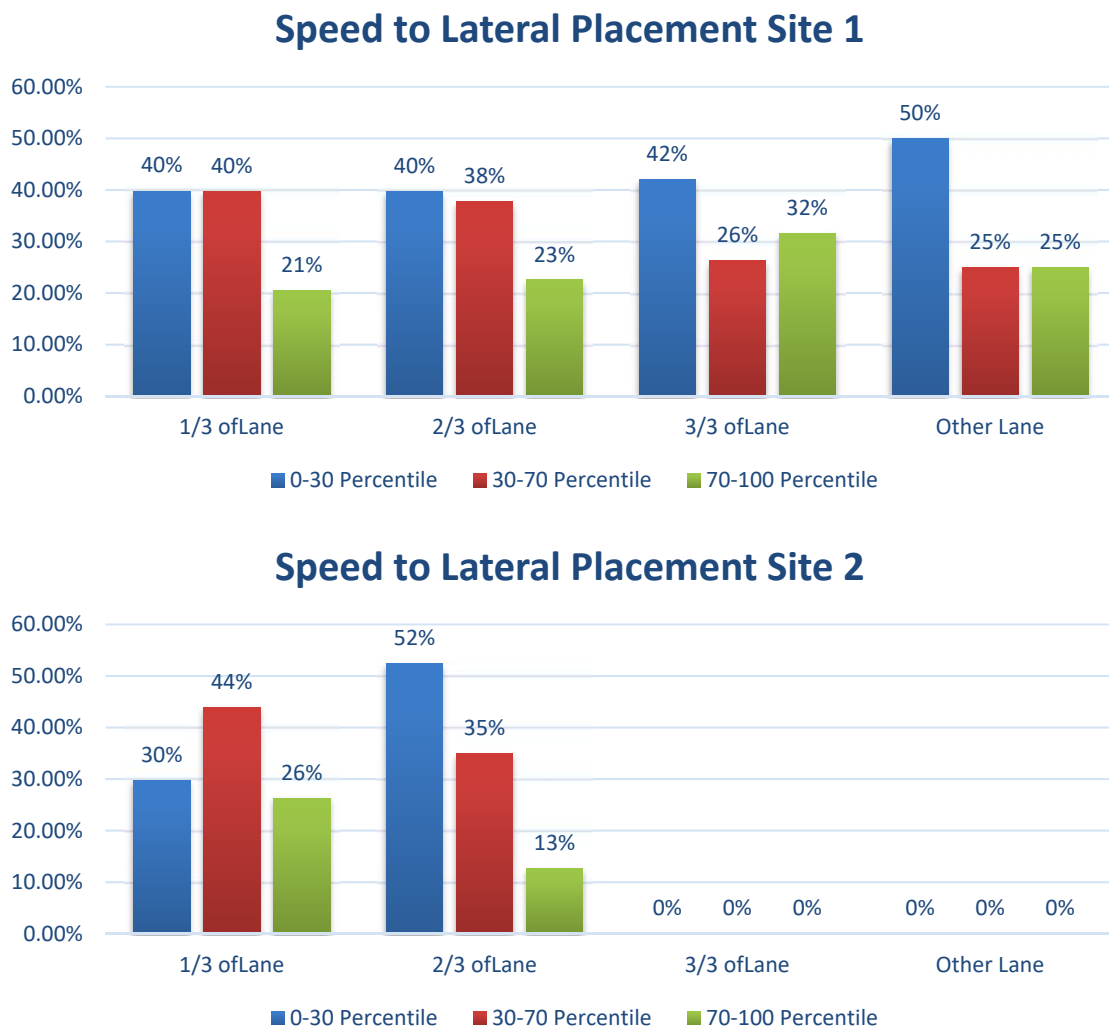


Figure 9. Without Motorcycles Control Speed vs Lateral Placement of Site 1 and Site 2 Before Installation.

Event There are two main trends that can be seen in the event data. The first shows up when analyzing the lateral placement with respect to the time lag. The second can be seen when analyzing the lateral placement with respect to the speed of the vehicles. At this point it is reasonable to state that both event data from site 1 and site 2 maintain the similarity of fewer vehicles utilizing the left third of the lane or opposing lane when comparing site 1 to site 2 in the control data. However, in the case when a bicycle was present there are still a large majority of drivers in the right third of the lane but now just over 7% of the 529 drivers observed at site 1 use the left third of the lane or the opposing lane. The drivers at site 2 also still prefer the right third and center of the lane but now have just under 6% of the 437 drivers observed utilizing the left third and even the opposing lane. Driver use of the lanes can be seen below in Table 2. The average speed for site 1 is 28.36 miles per hour. The average speed for site 2 is 24.73 miles per hour. Drivers at site 1 tend to drive faster than the posted speed limit and stay close to the fog line but will move over for bicyclists. The drivers at site 2 show similar behavior with a higher number of drivers preferring the right third of the lane but tend to go slower than the posted speed limit.

Table 2. Without Motorcycles Event Lateral Placement of Site 1 and Site 2 Before Installation.

Event			
Site 1	Number of Vehicles	Site 2	Number of Vehicles
Right 1/3	70.51%	Right 1/3	85.13%
Center	22.31%	Center	8.01%
Left 1/3	4.16%	Left 1/3	5.95%
Other Lane	3.02%	Other Lane	0.92%

When bicycles are present vehicles tend to alter the lateral position in the lane. As the time lag increased more and more vehicles were observed utilizing the right third of the lane. The closer the bicycle is to the observed vehicle the more frequently drivers chose to utilize the left third of the lane and the opposing lane. Utilization of the center of the lane appears to be normally distributed. Figure 10 shows these trends apply to both site 1 and site 2. Unfortunately, due to driver preference to not cross the centerline some trends are a little more difficult to see at site 2 than site 1. Only the first four time lag categories were used in the figures. However, the majority of the observations are from category 5, greater than 30 seconds. Therefore, it is important to realize that for site 1 there were only 11 observations of vehicles in the opposing lane, 16 in the left third of the lane, 24 in the center of the lane, and 34 in the right third of the lane. There were only 3 observations of vehicles in the opposing lane, 18 in the left third of the lane, 10 in the center of the lane, and 37 in the right third of the lane for site 2.

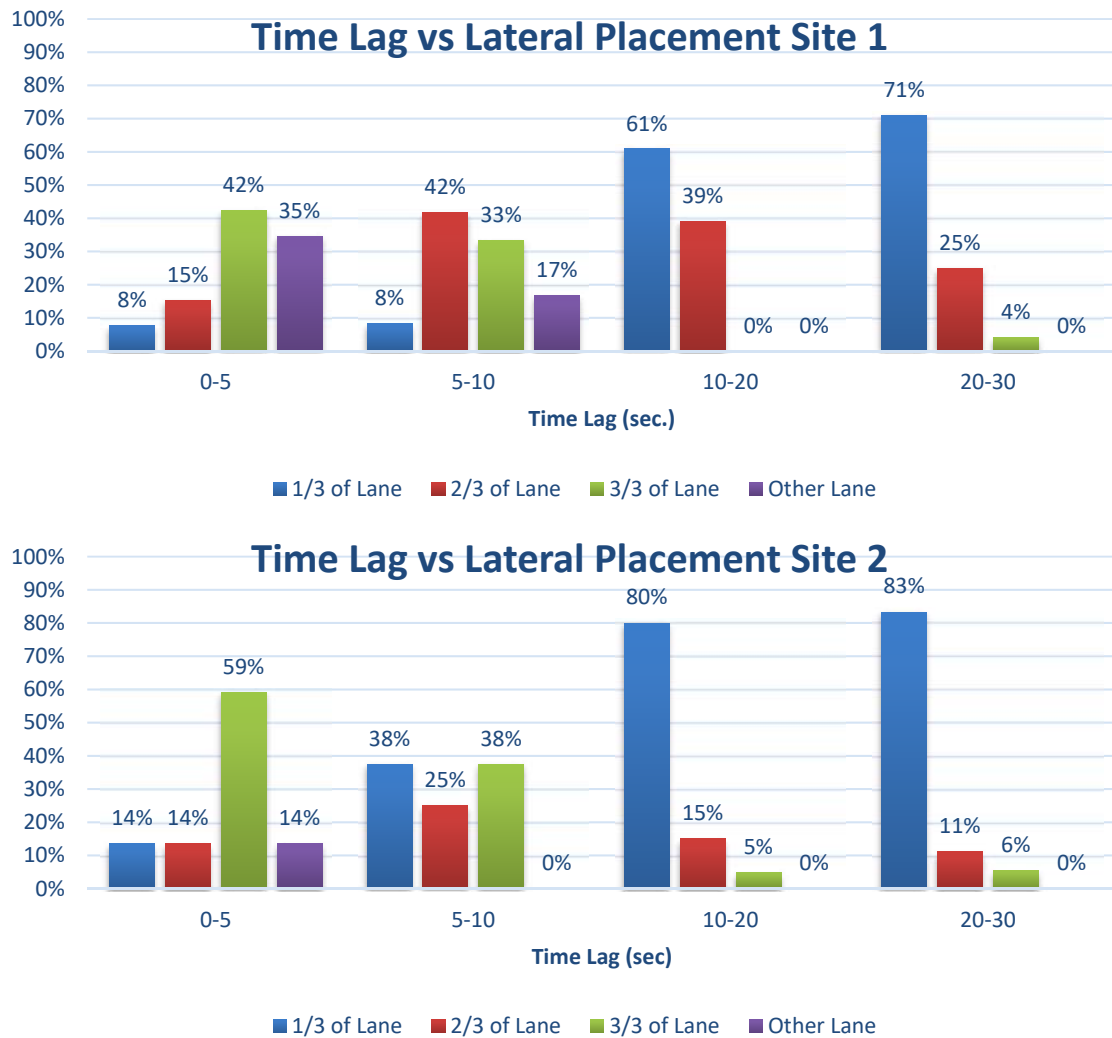


Figure 10. Without Motorcycles Event Time-Lag vs Lateral Placement Before Installation.

As lateral position is altered so is the speed of the vehicle which is shown in Figure 11. At site 1 as the vehicles move over in the lane towards the centerline and into the opposing lane the speed tends to decrease until the vehicle is observed in the opposing lane. Site 2 shows that the number of drivers in the middle percentile increases the farther towards the centerline or into the opposing lane the vehicles are observed. Site 2 continues the increasing trend in the middle percentile until the vehicle is observed in

the opposing lane and at that point there is a drastic increase in the number of vehicles observed in the 0-30 percentile. It should be noted that there were only 22 and 16 vehicles observed in the left third and opposing lane respectively at site 1. There were even less, 4, observed in the opposing lane at site 2 and 26 in the left third of the lane.

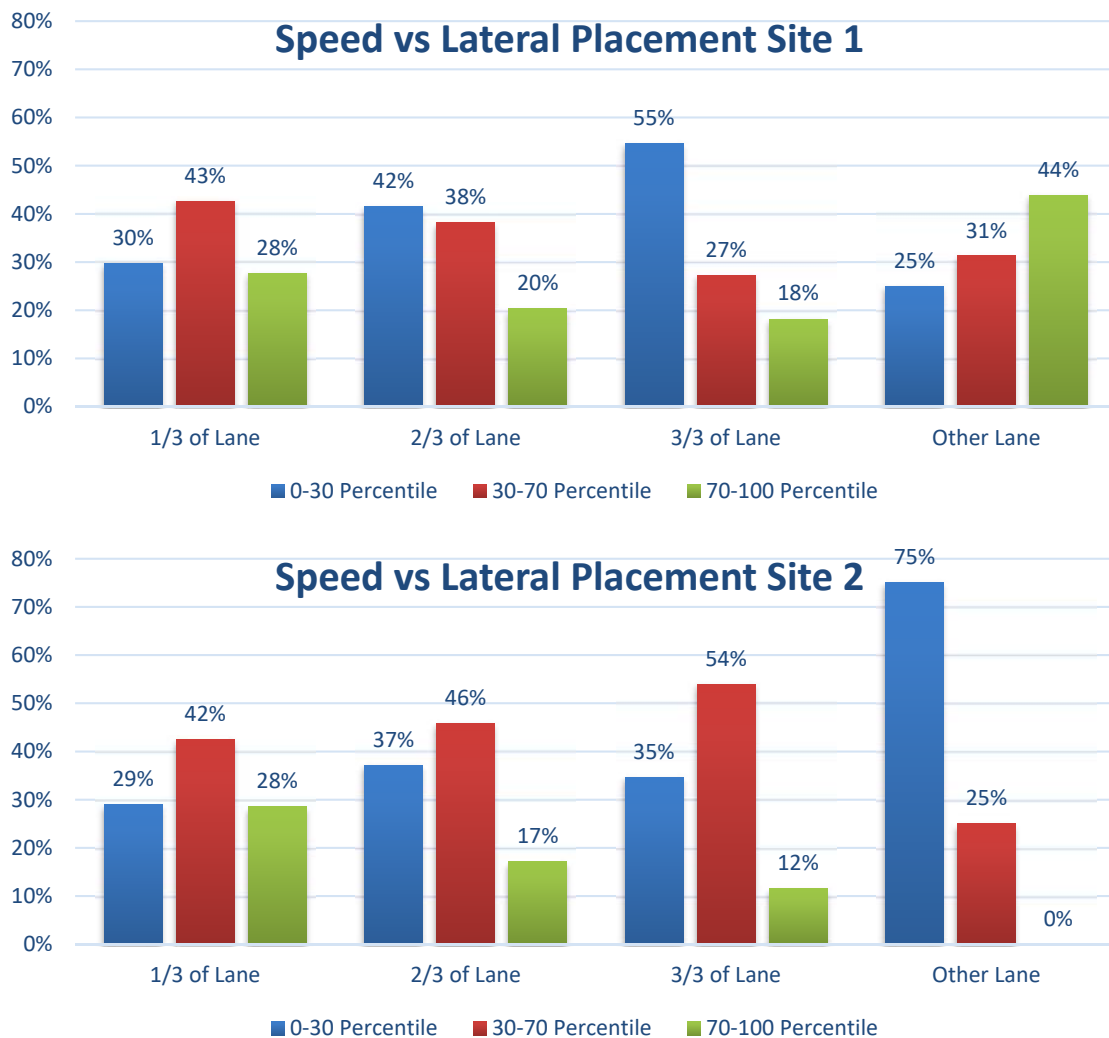


Figure 11. Without Motorcycles Event Speed vs Lateral Placement Before Installation.

Passenger Vehicles Only The same bicycles were used from the data set without motorcycles. When looking at only passenger vehicles there were 502 vehicle data points for site 1 and 417 vehicle data points for site 2. The control groups for both site 1 and site 2 had over a thousand observations when including all vehicle types, but when only passenger vehicles were considered there were 955 at site 1 and 939 at site 2.

Lateral placement, speed, and time lag were once again the variables of primary concern. The linear regression model without motorcycles for speed showed Time lag was statistically significant at the 95% confidence level and p-value of 4.63×10^{-8} for site 1 and 0.0013 for site 2 when looking at speed. Unfortunately, both of these models only explained about 5.6% and 2.2% of the data for site 1 and site 2 respectively. The linear regression model for lateral placement however explained about 29.0% and 34.8% of the data for site 1 and site 2 respectively. Once again time lag was the only variable of statistical significance at the 95% confidence level having p-values of 2.44×10^{-39} and 9.98×10^{-41} for site 1 and site 2 respectively.

Control When looking at the control the first two noticeable characteristics were the speed and lateral placement. For both site 1 and site 2, the majority of drivers used the right third or center of the lane. This can be seen in Table 3 where out of 954 vehicles only 1.68% for site 1 and none of the 939 drivers for site 2 utilized the left third of the lane and even less used the other lane. The average speed for site 1 was 29.38 miles per hour and 25.50 miles per hour for site 2. When there are no bicyclists present drivers still tend to drive close to the fog line at speeds greater than the posted speed limit. Drivers also appear to react differently between site 1 and site 2 based on the 3.88 miles per hour

difference in average speed and lack of any driver using the left third of the lane or opposing lane.

Table 3. Passenger Vehicles Only Control Lateral Placement of Site 1 and Site 2 Before Installation.

<u>Control</u>			
Site 1	Number of Vehicles	Site 2	Number of Vehicles
Right 1/3	73.90%	Right 1/3	93.93%
Center	24.00%	Center	6.07%
Left 1/3	1.68%	Left 1/3	0.00%
Other Lane	0.42%	Other Lane	0.00%

A closer look at the lateral placement of the vehicle when related to speed can be seen in the figure below. A larger number of people were willing to use the left third of the lane or the opposing lane at site 1 in comparison to site 2. When paired with the speed, as drivers moved over to the left side of the lane the speed tended to increase with the 70-100 percentile eventually being the majority at site 1. Site 2 had an opposite result where drivers slowed down as they moved father left in the lane. These three trends are shown in Figure 12. It should be noted that only four drivers were observed in the opposing lane at site 1. Drivers at site 2 were only willing to use the right third and center of the lane, which makes it difficult to determine, but it appears that the further over to the left drivers are observed the slower they will go. Graphically there appears to be a difference in driver behavior between site 1 and site 2. Due to the prominence of this difference and scope of the study no statistical tests were done to confirm the significance to the difference in the proceeding chapters.

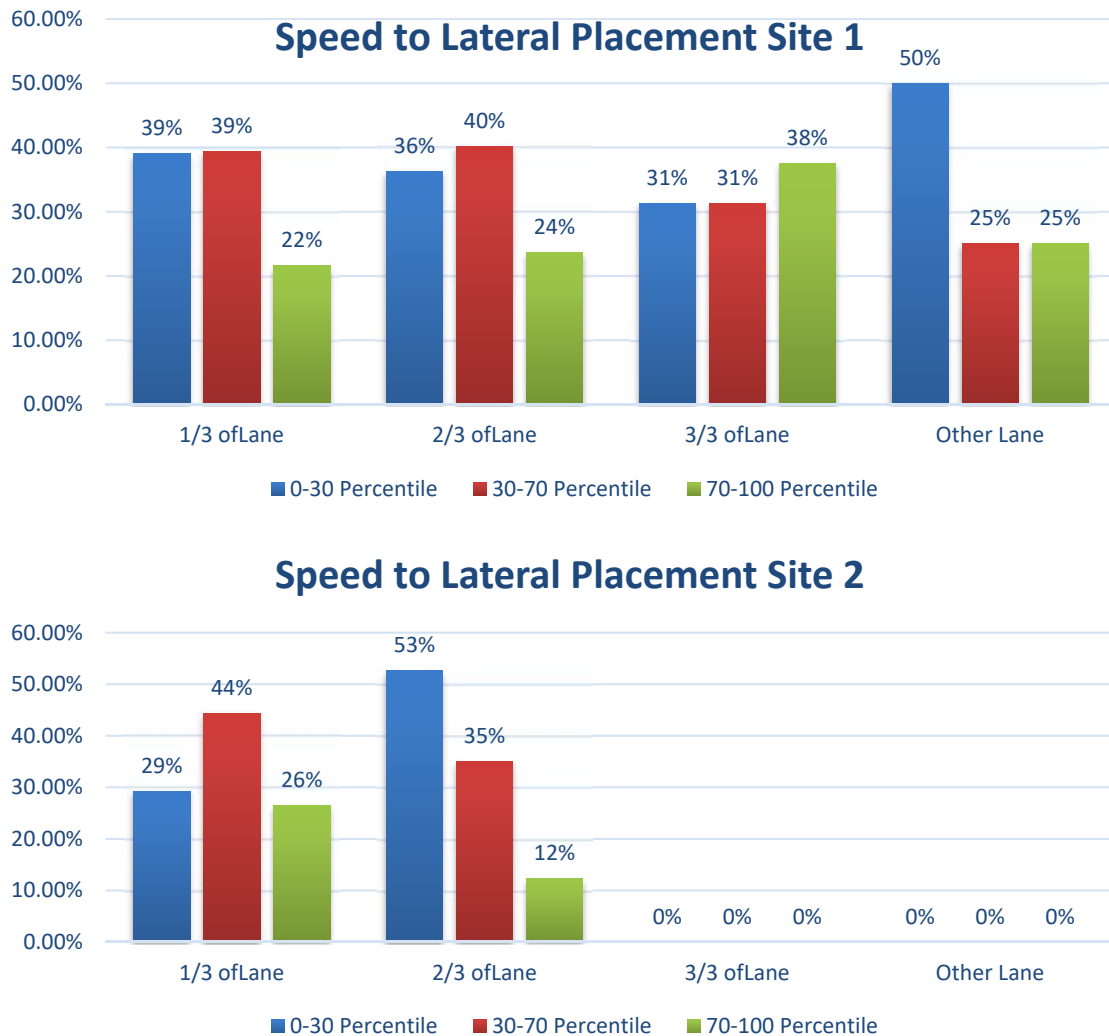


Figure 12. Passenger Vehicles Only Control Speed vs Lateral Placement of Site 1 and Site 2 Before Installation.

Event There are two main trends that can be seen in the event data when only considering passenger vehicles. The first shows up when analyzing the lateral placement with respect to the time lag. The second can be seen when analyzing the lateral placement with respect to the speed of the vehicles. At this point it is reasonable to state that both event data from site 1 and site 2 maintain the similarity of fewer vehicles utilizing the opposing lane and left third of the lane when comparing site 1 to site 2 in the control data.

In the case when a bicycle is present there are still a majority of drivers in the right third of the lane, but now 4.39% and 3.14% of the 501 drivers observed at site 1 use the left third of the lane and the opposing lane respectively. The drivers at site 2 also still prefer the right third and center of the lane, but now have 5.76% of the 417 drivers observed utilizing the left third and 0.96% utilizing the opposing lane. Driver use of the lanes can be seen below in Table 4. Average speeds for site 1 and site 2 are 28.40 miles per hour and 24.76 miles per hour respectively. Drivers at site 1 tend to drive faster than the posted speed limit and stay close to the fog line but will move over for bicyclists. The drivers at site 2 show similar behavior with a higher number of drivers preferring the right third of the lane but tend to go slower than the posted speed limit.

Table 4. Passenger Vehicles Only Event Lateral Placement of Site 1 and Site 2 Before Installation.

Event			
Site 1	Number of Vehicles	Site 2	Number of Vehicles
Right 1/3	69.86%	Right 1/3	84.89%
Center	22.55%	Center	8.39%
Left 1/3	4.39%	Left 1/3	5.76%
Other Lane	3.14%	Other Lane	0.96%

When bicycles are present vehicles tend to alter the lateral position in the lane. As the time lag increased more and more vehicles were observed utilizing the right third of the lane. The closer the bicycle was to the observed vehicle the more frequently drivers chose to utilize the left third of the lane and the opposing lane. Utilization of the center of the lane appears to be normally distributed as before when considering large and passenger vehicles. Figure 13 shows these trends apply to both site 1 and site 2.

Unfortunately, due to driver preference to not cross the centerline some are a little more difficult to see at site 2 than site 1.

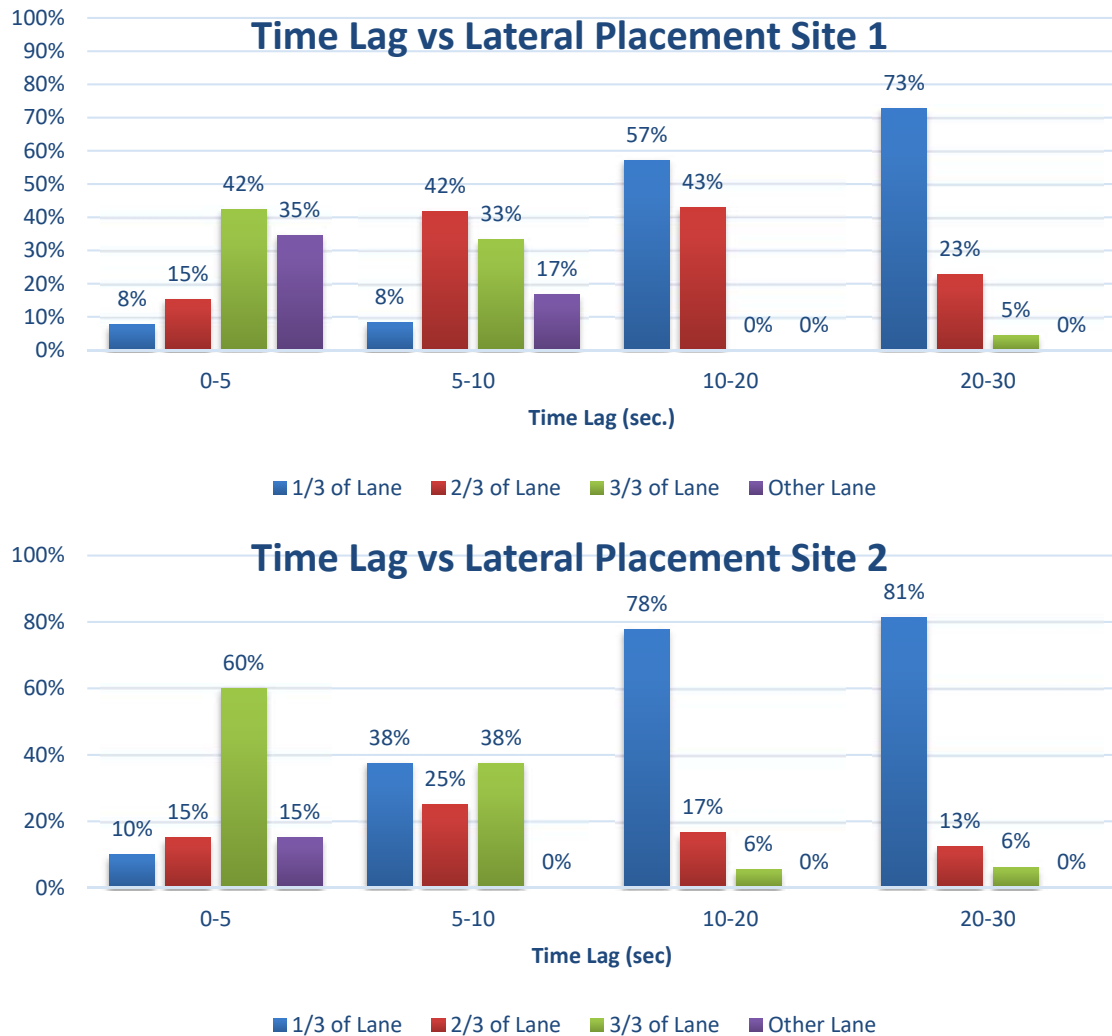


Figure 13. Passenger Vehicles Only Event Time-Lag vs Lateral Placement for Site 1 and Site 2 Before Installation.

As lateral position is altered so is the speed of the vehicle which is shown in Figure 14. At site 1 as the vehicles move over in the lane towards the centerline and into the opposing lane the speed tends to decrease. Site 2 shows that the number of drivers in the middle percentile increases the farther towards the centerline or into the opposing lane the vehicles are observed. The majority of drivers however tend to travel in the 30th to 70th percentile for speed at site 2 as long as the vehicle is partially in the correct lane. Once the vehicle is observed in the opposing lane there is an increase in the number observed in the 70th to 100th percentile for site 1. Only the first four time lag categories were used in the figures. Therefore, it is important to recognize that for site 1 there were only 11 observations of vehicles in the opposing lane, 16 in the left third of the lane, 23 in the center of the lane, and 31 in the right third of the lane. There were only 3 observations of vehicles in the opposing lane, 17 in the left third of the lane, 10 in the center of the lane, and 32 in the right third of the lane for site 2.

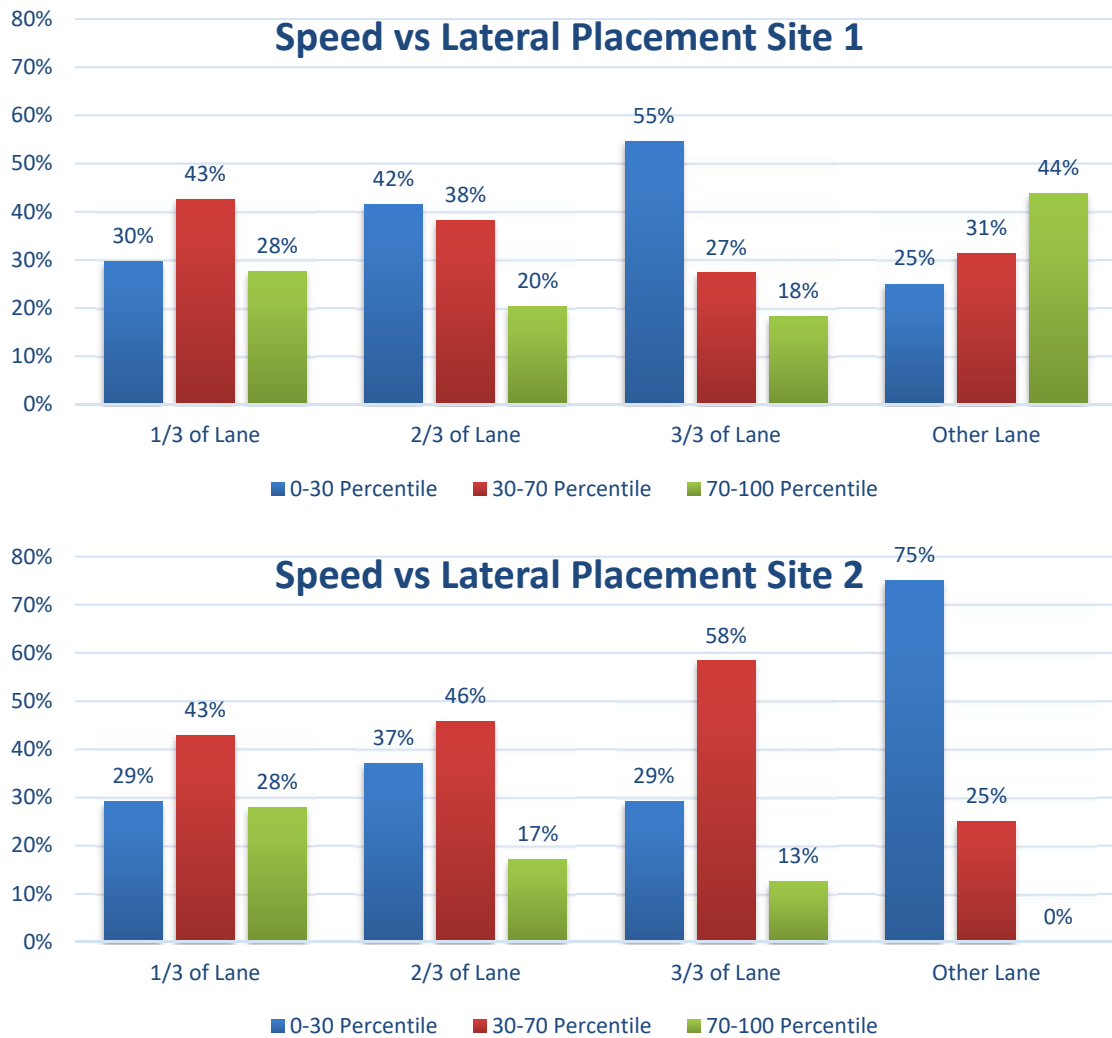


Figure 14. Passenger Vehicles Only Event Speed vs Lateral Placement for Site 1 and Site 2 Before Installation.

After Installation Analysis

The after installation preliminary analysis is broken down into two data sets of interest: without motorcycles and only passenger vehicles. These two sections are then further broken down into the control group and event group. A comparison will be discussed in the next chapter.

Without Motorcycles As stated earlier during the after installation there was a longer data collection period than during the before installation collection period. Unfortunately, due to lighting issues there was very little usable data collected from site 2. Therefore, site 1 will be the primary discussion in this section. Site 2 will be discussed in the control section but not in the event data due to minimal useful vehicle data points.

Over the course of the study there were 733 bicycles observed at site 1. Maintaining consistency with the before-data, when two or more bicycles were observed within ten seconds of each other these events were considered a single event. Some events had interference and were also not used. After removing these events there was a total of 514 bicycles observed at site 1. These bicycles were associated with 1377 vehicle data points. The control groups for both site 1 and site 2 had over a thousand observations, with site 1 having 1012 observations and site 2 having 1008 observations.

Lights flashing will be added to the before-data variables of lateral placement, speed, time lag, class, and time between for the after-data analyses. The linear regression model without motorcycles for speed showed time lag, class, time between, and lights flashing were for the most part statistically significant at the 95% confidence level. Time lag, class, and time between had p-values of 1.1499×10^{-8} , 4.4099×10^{-6} , and 0.0007 respectively. Lights flashing had a p-value of 0.0537 making it probably significant. Unfortunately, the model only reflected an adjusted R-square value of approximately 4.6% indicating the strength or lack thereof in the correlation of the data. The linear regression model for lateral placement however accounted for about 29% of the data and the lights flashing was statistically significant. Time lag, class, time between, and lights

flashing were statistically significant at the 95% confidence level having respective p-values of 4.6456×10^{-99} , 0.0009, 2.3279×10^{-5} , and 0.0175.

Control Similar to before installation when looking at the control after installation the first two noticeable characteristics were the speed and lateral placement. Drivers continue to primarily use the right third of the lane for both site 1 and site 2. Some drivers use the center of the lane with very few observed in the left third of the lane. This can be seen in Table 5 where out of 1012 vehicles just over 1% for site 1 and 0.5% of the 1008 drivers for site 2 utilized the left third of the of the lane. None of the drivers were observed in the opposing lane. The average speed for site 1 was 27.54 miles per hour and 27.61 miles per hour for site 2. Speeds at both sites after the sign installation were observed to be similar. When there are no bicyclists present drivers tend to drive close to the fog line at speeds greater than the posted speed limit. Drivers continue to react slightly different between site 1 and site 2 based on the number of drivers observed in the center and left third of the lane for each site. However, both driver populations are very similar.

Table 5. Without Motorcycles Control Lateral Placement of Site 1 and Site 2 After Installation.

Control			
Site 1	Number of Vehicles	Site 2	Number of Vehicles
Right 1/3	65.22%	Right 1/3	76.88%
Center	33.70%	Center	22.62%
Left 1/3	1.09%	Left 1/3	0.50%
Other Lane	0.00%	Other Lane	0.00%

A closer look at the lateral placement of the vehicle when related to speed can be seen in Figure 15. The speed distributions at site 1 generally remained the same as the vehicle was observed closer to the centerline. The exception were vehicles observed in the left third of the lane which tended to have higher speeds. Site 2 however showed that as drivers moved over in the lane towards the centerline the speeds tended to decrease. These trends can be seen in Figure 15. It should be noted that 11 drivers were observed in the left third of the lane for site 1 and 5 at site 2. Graphically there appears to be a difference in driver behavior between site 1 and site 2 that was not originally seen. Due to project scope there will be no way of determining how much of an effect this difference plays.

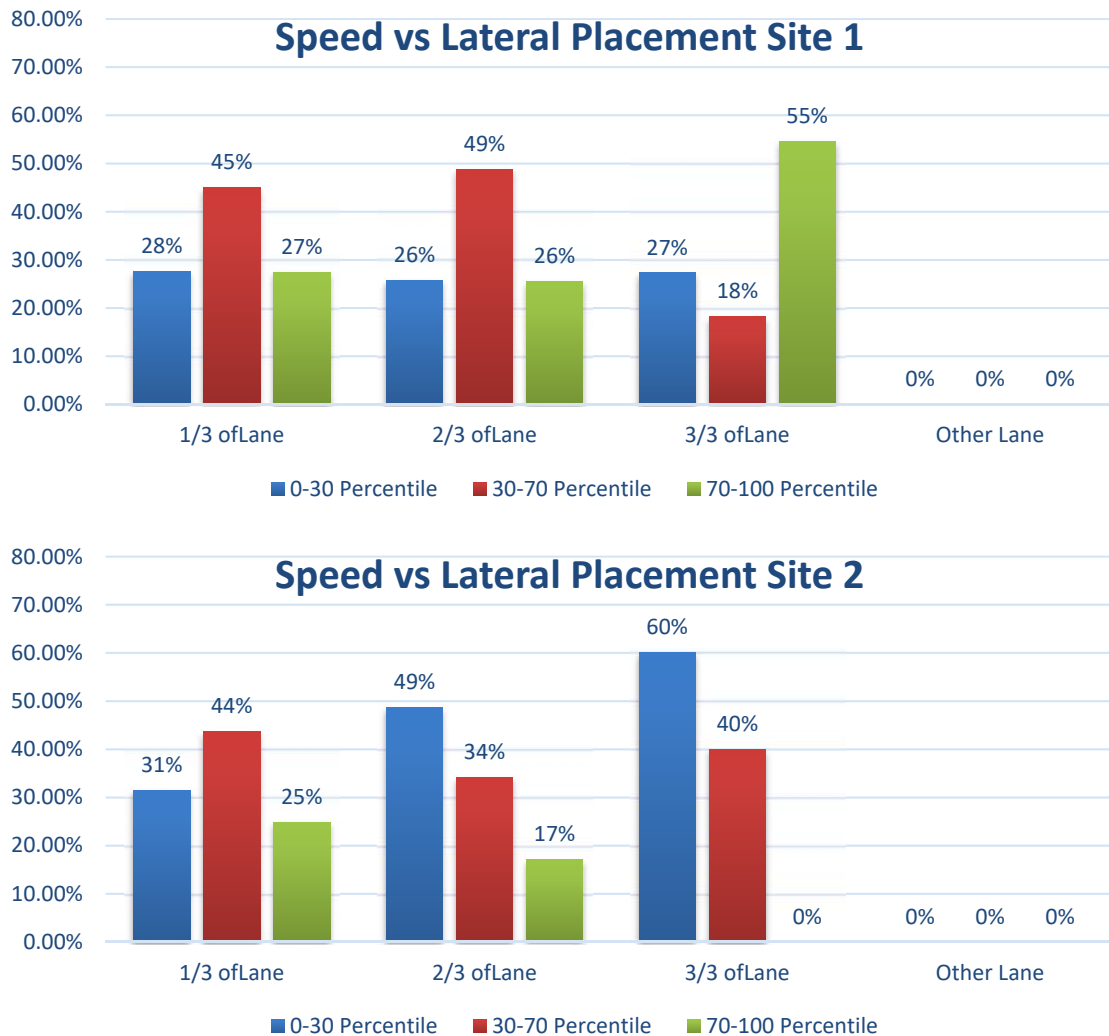


Figure 15. Without Motorcycles Control Speed vs Lateral Placement of Site 1 and Site 2 After Installation.

Event As stated earlier a without motorcycles data set was unable to be generated for site 2. Therefore, only site 1 will be discussed at this point. Once again there are two main trends that can be seen in the event data. The first shows up when analyzing the lateral placement with respect to the time lag. The second can be seen when analyzing the lateral placement with respect to the speed of the vehicles. Overall the majority of drivers continue to use the right third and center of the lane. However, there are some drivers

who utilize the left third of the lane and opposing lane. Approximately 9% and 3% were observed in the left third of the lane and opposing lane respectively for site 1. There were 1338 vehicles observed. Driver use of the lanes can be seen below in Figure 16. The average speed for site 1 was 26.92 miles per hour. The drivers on average drive faster than the posted speed limit and stay close to the fog line but will move over for a bicyclist.

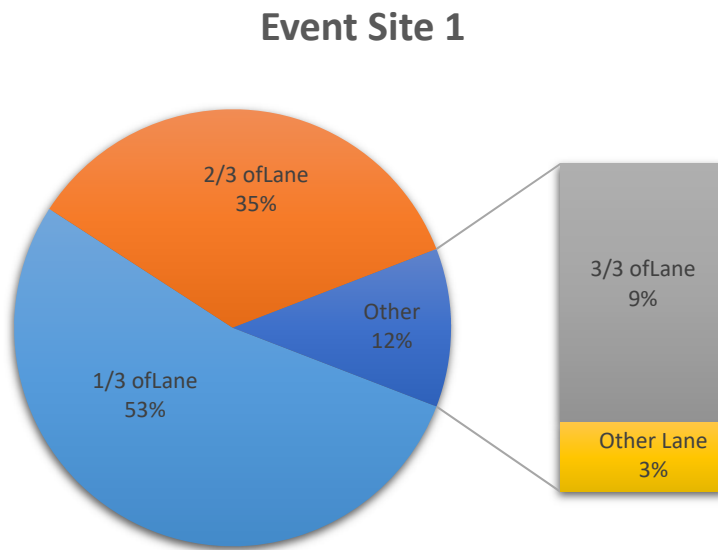


Figure 16. Without Motorcycles Event Lateral Placement of Site 1 After Installation

When bicycles are present vehicles tend to alter the lateral position in the lane. As the time lag increased more and more vehicles were observed utilizing the right third of the lane. The closer the bicycle is to the observed vehicle the more frequently drivers chose to utilize the left third of the lane and the opposing lane. Utilization of the center of the lane appears to follow a similar distribution to the right third of the lane. Figure 17 shows the trends discussed. Only the first four time lag categories were used in the

figures. However, the majority of the observations were from category 5, greater than 30 seconds. Therefore, it is important to recognize that there were 29 observations of vehicles in the opposing lane, 74 in the left third of the lane, 74 in the center of the lane, and 56 in the right third of the lane. Even though these are larger values than the before-data set, they are still relatively small.

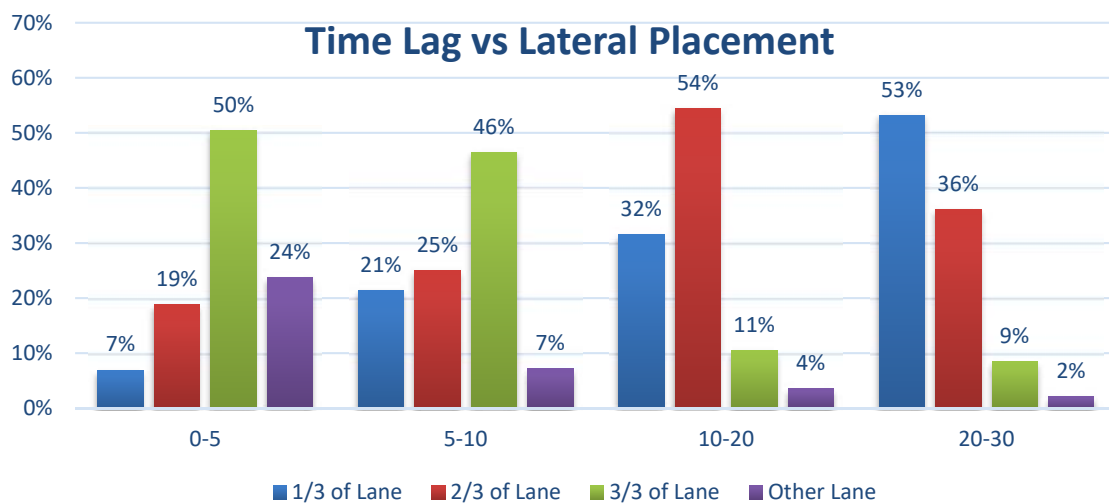


Figure 17. Site 1 Without Motorcycles Event Time-Lag vs Lateral Placement After Installation

As lateral position is altered so is the speed of the vehicle which is shown in Figure 18. As the vehicles move over in the lane towards the centerline and into the opposing lane the speed tends to decrease. Overall the number of drivers in the 30th to 70th percentile stay the same until observed in the opposing lane. In this case all the vehicles are included in the graph. This being said only 33 were observed in the opposing lane whereas there were 124 in the left third, 468 in the center, and 713 in the right third of the lane.

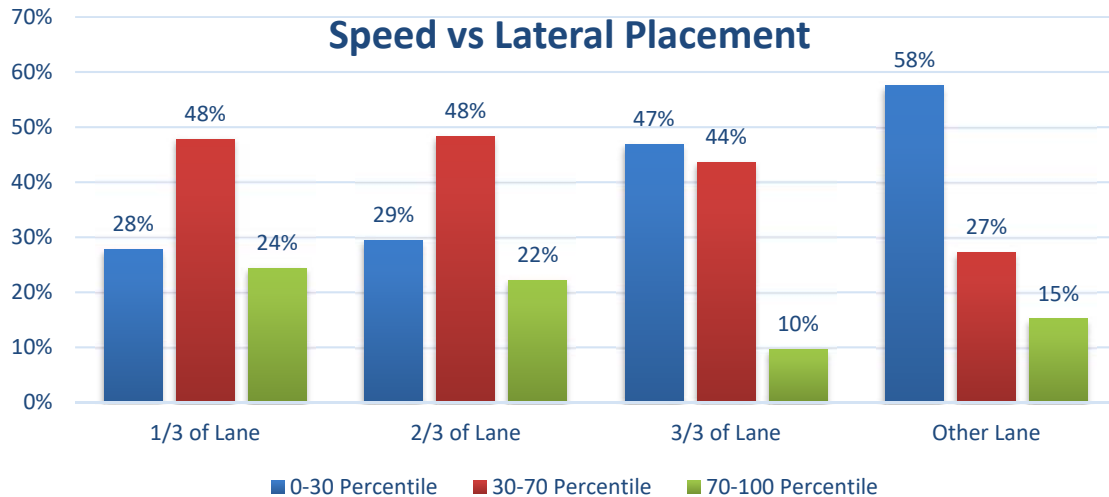


Figure 18. Site 1 Without Motorcycles Event Speed vs Lateral Placement After Installation

Passenger Vehicles Only Considering the lighting issues at site 2 only enough data was collected to provide a brief discussion. Once again site 1 will be the primary site of discussion but site 2 will also be discussed when there is enough relevant data. The same 733 bicycles observed at site 1 will be used along with the 103 bicycles from site 2. Maintaining consistency with the before-data, when two or more bicycles were observed within ten seconds of each other these events were considered a single event. Some events had interference and were not used. After removing these events there was a total of 514 bicycles observed at site 1 and 64 observed at site 2. These bicycles were associated with 1225 vehicle data points at site 1 and 93 at site 2. The control groups for both site 1 and site 2 had over nine hundred observations when only passenger vehicles were considered. Site 1 had 997 observations when bicycles were not present and site 2 had 968.

Unlike in the before-data lateral placement, speed, time lag, time between, and lights flashing will all be variables of concern. The linear regression model for speed showed time lag, time between, and lights flashing were all statistically significant at the 95% confidence level for site 1. Time lag, time between, and lights flashing had p-values of 9.9344×10^{-9} , 0.0019, and 0.0328 respectively. Unfortunately, the model only reflected an adjusted R-square value of approximately 3.5% accounting for only a small portion of the data. Site 2 linear regression analysis showed that only the lights flashing was statistically significant at the 95% confidence level. The respective p-values for lights flashing and time lag were 0.0104 and 0.0720. Thus, time lag was possibly significant but not at the 95% confidence level. However, the model for speed at site 2 accounted for about 9.3% of the variation in the data. The linear regression models for lateral placement accounted for about 30.6% of the data for site 1 and 51.1% of the data for site 2. Once again at site 1, time lag, time between, and lights flashing were all statistically significant at the 95% confidence level with respective p-values of 5.2826×10^{-98} , 1.1417×10^{-5} , and 0.0084. However at site 2, only time lag and the lights flashing were statistically significant at the 95% confidence level having respective p-values of 7.5876×10^{-15} and 0.0260.

Control Similarly, to before installation and without motorcycles, when looking at the control after installation for only passenger vehicles the first two noticeable characteristics were the speed and lateral placement. Drivers continue to primarily use the right third of the lane for both site 1 and site 2. Some drivers also utilize the center of the lane with very few observed in the left third of the lane. This can be seen in

Table 6 where just over 2% of the 997 vehicles for site 1 and 0.52% of the 968 drivers for site 2 utilized the left third of the lane. None of the drivers were observed in the opposing lane. The average speed for site 1 was 27.64 miles per hour and 27.71 miles per hour for site 2. Speeds at both sites after the sign installation were observed to be similar only varying by 0.07 of a mile per hour. When there were no bicyclists present drivers tend to drive close to the fog line at speeds greater than the posted speed limit. Drivers continue to react slightly differently between site 1 and site 2 based on the number of drivers observed in the center and left third of the lane for each site. However, both driver populations are still similar.

Table 6. Passenger Vehicles Only Control Lateral Placement of Site 1 and Site 2 After Installation.

<u>Control</u>			
Site 1	Number of Vehicles	Site 2	Number of Vehicles
Right 1/3	63.89%	Right 1/3	75.83%
Center	34.00%	Center	23.55%
Left 1/3	2.01%	Left 1/3	0.52%
Other Lane	0.00%	Other Lane	0.00%

A closer look at the lateral placement of the vehicle when related to speed can be seen in Figure 19. The speed distributions at site 1 for the right third of the lane and center of the lane essentially remained the same. However, once the vehicle was observed in the left third of the lane the majority of drivers were observed in the highest percentile with the lowest still not changing much. Site 2 however continued to show the trends primarily seen already that as drivers moved over in the lane towards the centerline the speeds tended to decrease. These trends can be seen in Figure 19. It should be noted that

20 drivers were observed in the left third of the lane for site 1 and 5 at site 2. Graphically there appears to be a difference in driver behavior between site 1 and site 2 that was not originally seen. Due to project scope there will be no way of determining how much of an effect this difference plays.

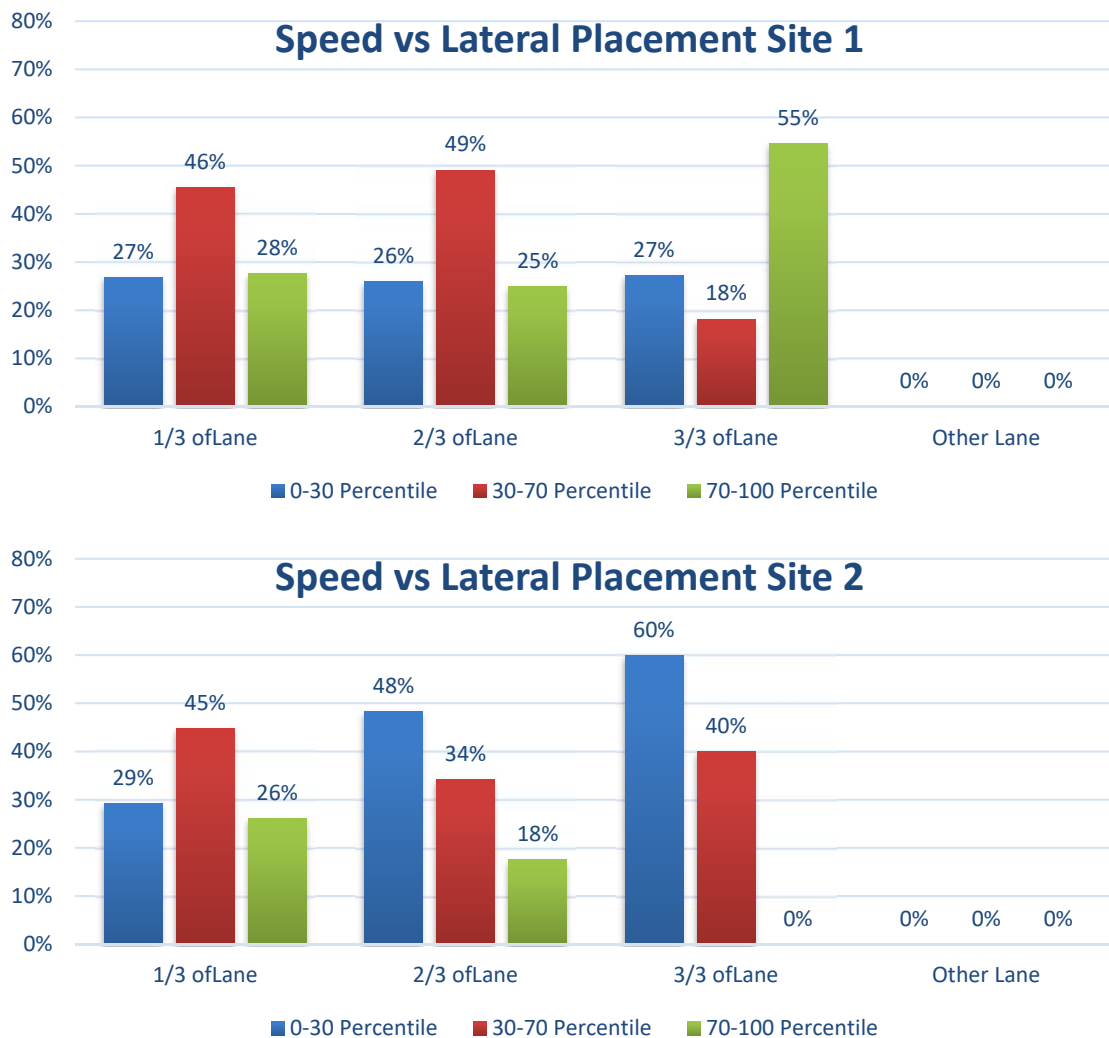


Figure 19. Passenger Vehicles Only Control Speed vs Lateral Placement of Site 1 and Site 2 After Installation.

Event Although there was limited data site 2 will be briefly discussed with site 1.

Once again there are two main trends that can be seen in the event data. The first shows up when analyzing the lateral placement with respect to the time lag. The second can be seen when analyzing the lateral placement with respect to the speed of the vehicles.

Overall the majority of drivers continue to use the right third and center of the lane.

However, there are some drivers who utilize the left third of the lane and the opposing lane. Approximately 9% and 3% were observed in the left third of the lane and opposing lane respectively for site 1. For site 2 approximately 2% and 10% of the vehicles were observed in the left third of the lane and opposing lane. There were however only 93 vehicles recorded for site 2 unlike site 1 which had 1225 vehicles observed. Driver use of the lanes can be seen below in Table 7. The average speed for site 1 was 27.04 miles per hour and 28.03 miles per hour for site 2. Based on the one mile per hour difference in speed between the two sites after the sign installation there may be a difference in driver behavior but for lateral placement the observations appear to be similar.

Table 7. Passenger Vehicles Only Event Lateral Placement of Site 1 and Site 2 After Installation.

Event			
Site 1	Number of Vehicles	Site 2	Number of Vehicles
Right 1/3	52.24%	Right 1/3	51.61%
Center	35.67%	Center	36.56%
Left 1/3	9.39%	Left 1/3	2.15%
Other Lane	2.69%	Other Lane	9.68%

Unfortunately, due to the limited data from site 2 only site 1 will be discussed again. When bicycles are present vehicles tend to alter their lateral position in the lane. As the time lag increased more and more vehicles were observed utilizing the right third or center of the lane at site 1. The closer the bicycle is to the observed vehicle the more frequently drivers chose to utilize the left third of the lane and the opposing lane at site 1. Utilization of the center of the lane appears to follow the same pattern as the right third of the lane until 20-30 seconds is reached. Figure 20 shows the trends discussed. Only the first four time lag categories were used in the figure. However, the majority of the observations are from category 5, greater than 30 seconds. Therefore, it is important to recognize that there were 29 observations of vehicles in the opposing lane, 70 in the left third of the lane, 65 in the center of the lane, and 46 in the right third of the lane. Even though these are larger values than the before-data set, they are still relatively small.

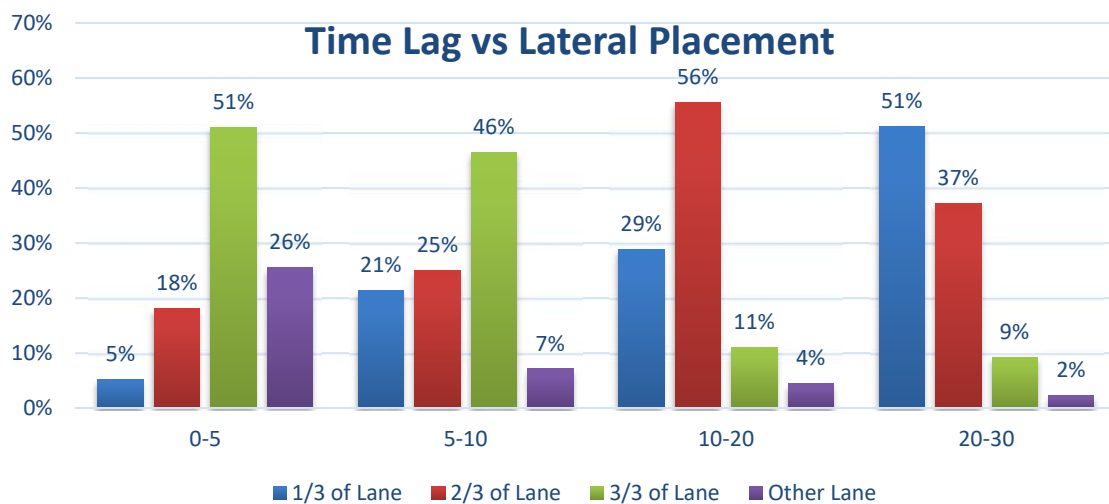


Figure 20. Passenger Vehicles Only Event Time-Lag vs Lateral Placement Site 1 After Installation.

As lateral position is altered so is the speed of the vehicle which is shown in Figure 21. Both site 1 and site 2 will be discussed here. Site 2 should be seen as supplementing site 1. As the vehicles move over in the lane towards the centerline and into the opposing lane the speed observed tends to decrease. Overall the number of drivers in the 30th to 70th percentile stayed the same until observed in the opposing lane for site 1. Site 2 supplements these statements by also showing an increase in the number of vehicles observed at slower speeds as they moved towards the centerline and past it. Due to the low number of observations not many conclusions should be drawn from site 2. There were only 9 vehicles observed in the opposing lane and only 2 in the left third. Whereas there were 48 and 34 observed in the right third of the lane and center of the lane respectively. This being said at site 1 there were 33 observed in the opposing lane 115 in the left third, 437 in the center, and 640 in the right third of the lane.

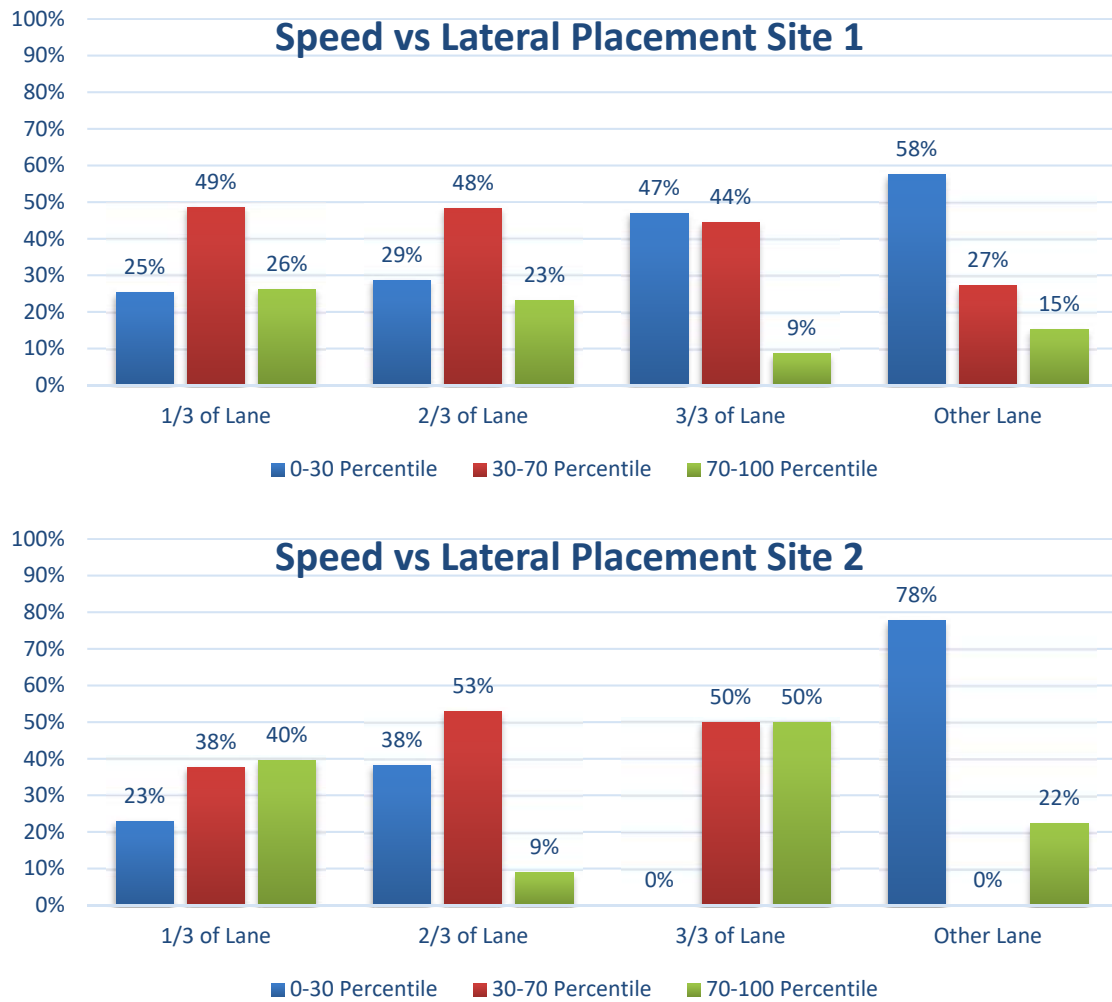


Figure 21. Passenger Vehicles Only Event Speed vs Lateral Placement of Site 1 and Site 2 After Installation.

BEFORE AFTER ANALYSIS

Overview

In the previous chapter an over view of the before- and after-data for site 1 and site 2 was presented. This chapter will go into the comparisons between the different data sets. First to be covered in this chapter is the comparison of the event or presence of a bicycle to the control group or no bicycle before the installation of the system. The objective is to determine how drivers behave around bicycles normally. Following this there is a comparison of the before-control group and after-control group. A comparison such as this tests the effects the static sign being installed has on driver behavior. There is then a direct comparison between the event before-installation group and the after-installation group. The objective was to see if there was any effect on driver behavior from the installation of the full system. The last comparison was between the control group and the event group after-installation. This comparison was primarily made to determine if there was an effect on top of the static sign.

Before Installation Bicycle vs No Bicycle

A comparison of the before-data when there was an event or bicycle present to the control or no bicycle present was performed. The importance of such tests was to determine how drivers react around bicyclists. There was enough data to perform these tests for both site 1 and site 2. Similar to previous sections this one was broken up into the groups without motorcycles and passenger vehicles only.

Without Motorcycles

Before performing any statistical tests, there appear to be differences between the control groups and the event groups. Table 8 contains speed data for site 1 along with the sample size, which is relatively small for all time lag categories except the greater than 30 seconds category. The drivers at site 1 had a speed of 0.91 mile per hour slower than when there is no bicycle present. Speeds also tend to increase the farther away the bicyclist is from the driver. The exception to this trend is 10-20 seconds away. T-tests were performed between the control group and the different event groups to see if the speed differences were significant. These same tests were performed to show if the speed differences in the time lag categories were significant. The difference in speed between the event groups and the control group were found to be statistically significant for the total of event data, 0-5 seconds, 5-10 seconds, 10-20 seconds, 20-30 seconds, and greater than 30 seconds with 95% confidence and p-values of 0.001, 0.0119, 1.1263×10^{-5} , 0.0205, and 0.0025 respectively. Differences between the time lag groups were not necessarily significant. Speeds between 0-5 seconds and 5-10 seconds are statistically the same at a p-value of 0.2824 and 95% confidence. The difference between 5-10 seconds and 10-20 seconds was significant but did not follow the hypothesis which would show an increase in speed. Therefore, a two-tail t-test was performed showing that the two groups were statistically similar with a p-value of 0.085 and 95% confidence. There were statistical similarities between the time lag groups of 10-20 and 20-30 seconds with a p-value of 0.0658 at the 95% confidence level but the groups are not necessarily the same.

The last time lag group of greater than 30 seconds was found to be statistically different from the previous group of 20-30 seconds at 95% confidence and a p-value of 0.0495.

Table 8. Site 1 Without Motorcycles Vehicle Speed Data Before Installation.

Large & Passenger Vehicles	Event			Control		
Category	Mean	Standard Deviation	N	Mean	Standard Deviation	N
Total	28.36	3.50	530	29.27	3.07	1008
Time Lag 0-5 (sec)	26.42	4.23	26	-	-	-
Time Lag 5-10 (sec)	27.25	3.72	12	-	-	-
Time Lag 10-20 (sec)	24.74	4.08	23	-	-	-
Time Lag 20-30 (sec)	26.88	5.38	24	-	-	-
Time Lag 30+ (sec)	28.77	3.11	445	-	-	-

In both the control and event group the majority of drivers preferred to maintain lane position in the right third of the lane. However, there was a 2% and 3% increase in the number of vehicles using the left third of the lane and the opposing lane respectively as seen in

Figure 22. The increase in the number of drivers moving over for bicycles was determined to be significant based on a t-test p-value of 0.0008 and 95% confidence. Similar to the speed data, t-tests were also performed between the time lag categories and the control and each other. Lateral placement was determined to be statistically larger for 0-5 seconds and 5-10 seconds than the control with p-values of 3.0322×10^{-10} and 0.0002 respectively at 95% confidence. For 10-20 seconds, 20-30 seconds, and greater than 30 seconds the lateral placement was determined to be statistically the same as the control group having p-values of 0.1808, 0.3488, 0.3857 at 95% confidence. When comparing the time lag categories to each other 0-5 seconds and 5-10 seconds were shown to be statistically similar with 95% confidence and a p-value of 0.0805 but not necessarily the

same. However, at 95% confidence 5-10 seconds was shown to be different than 10-20 seconds, which was statistically the same as 20-30 seconds each test having a p-value of 0.0003 and 0.3557 respectively. The final time lag category of greater than 30 seconds was also shown to be statistically the same as the previous category of 20-30 seconds at the 95% confidence level having a p-value of 0.3352.

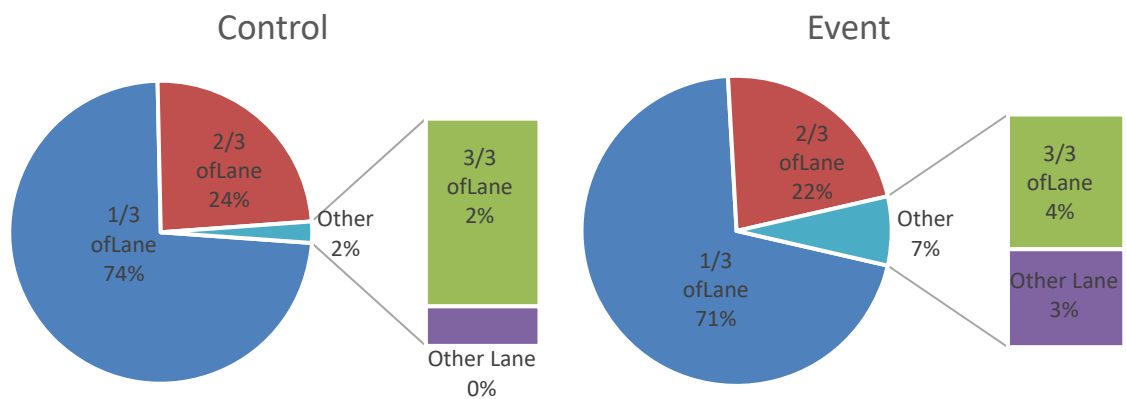


Figure 22. Site 1 Without Motorcycles Lateral Placement Control vs Event Before Installation.

Just like in site 1, site 2 appears to have a trend of increasing speed the farther away the bicycle is from the motor vehicle. The exception here is when the bicycle is within 5-10 seconds of the vehicle. Table 9 contains the sample size and speed data for site 2. Sample sizes for the first three time-lag categories are relatively small especially 5-10 seconds. The majority of observations like in site 1 were greater than 30 seconds. Total observations appear to show only a 0.68 mile per hour difference in speed whether there is a bicycle present or not. Considering the small differences in speed between the event groups and the control as well as between themselves several t-tests were performed to see if these differences were significant. The difference in speed between

the event groups and the control group was found to be statistically significant at the 95% confidence level for the total of event data, 0-5 seconds, 5-10 seconds, 10-20 seconds, and 20-30 seconds with p-values of 0.001, 0.0504, 0.0084, 0.0001, and 0.0137 respectively. There were however statistical similarities between the control and the greater than 30 seconds category at the 95% confidence level having a p-value of 0.0692. The two groups are not necessarily the same but definitely similar. For the most part, there was no difference between the time lag groups. The speeds between 0-5 seconds, 5-10 seconds, and 10-20 seconds were found to be statistically the same at the 95% confidence level with p-values of 0.222 (two-tailed) and 0.4485. A two-tailed t-test was used when comparing the 0-5 second group to the 5-10 second group because it failed to follow the hypothesis that the 0-5 seconds group should have a slower speed. The 10-20 second and 20-30 second time lag categories were found to be statistically similar but not necessarily the same at the 95% confidence level with a p-value of 0.0630. There was, however, a statistical difference at the 95% confidence level with a p-value of 0.0391 between 20-30 and greater than 30 seconds.

Table 9. Site 2 Without Motorcycles Vehicle Speed Data Before Installation.

Large & Passenger Vehicles Category	Event			Control		
	Mean	Standard Deviation	N	Mean	Standard Deviation	N
Total	24.76	4.07	437	25.44	4.20	1009
Time Lag 0-5 (sec)	23.95	4.27	22	-	-	-
Time Lag 5-10 (sec)	21.88	3.23	8	-	-	-
Time Lag 10-20 (sec)	22.00	3.43	20	-	-	-
Time Lag 20-30 (sec)	23.67	3.09	18	-	-	-
Time Lag 30+ (sec)	25.07	4.07	369	-	-	-

Same as at site 1, both the control and event group had the majority of drivers preferring to maintain lane position in the right third of the lane. There were increases in the number of people using the center of the lane, left third of the lane, and the opposing lane of 2%, 6%, and 1% respectively when a bicycle was present, which is shown in Figure 23. The increase in the number of drivers moving over for bicycles was determined to be significant based on a t-test p-value of 1.51×10^{-10} and a 95% confidence level. T-tests were again performed between the time lag categories, the control, and each other. Lateral placement was determined to be statistically larger for 0-5 seconds, 5-10 seconds, 10-20 seconds, and greater than 30 seconds than the control at the 95% confidence level with p-values of 8.0304×10^{-9} , 0.0121, 0.0094, and 0.0058 respectively. The difference in lateral placement between the control and the time lag category of 20-30 seconds was found to be statistically the same with a p-value of 0.1170 at the 95% confidence level. Some of the time lag categories were statistically different from each other, others were similar but not identical. The 0-5 seconds group statistically moved over more than the 5-10 seconds group at the 95% confidence level and a p-value of 0.0293. However, at 95% confidence 5-10 seconds and 10-20 seconds groups were shown to be statistically similar (p-value of 0.0757) primarily utilizing the center of the lane. The 20-30 second category was then statistically the same (p-value of 0.4386) as the 10-20 seconds group. It was also shown that the greater than 30 second group was statistically the same as the 20-30 second group (p-value of 0.2209) with the majority of drivers only utilizing the right third of the lane at the 95% confidence level.

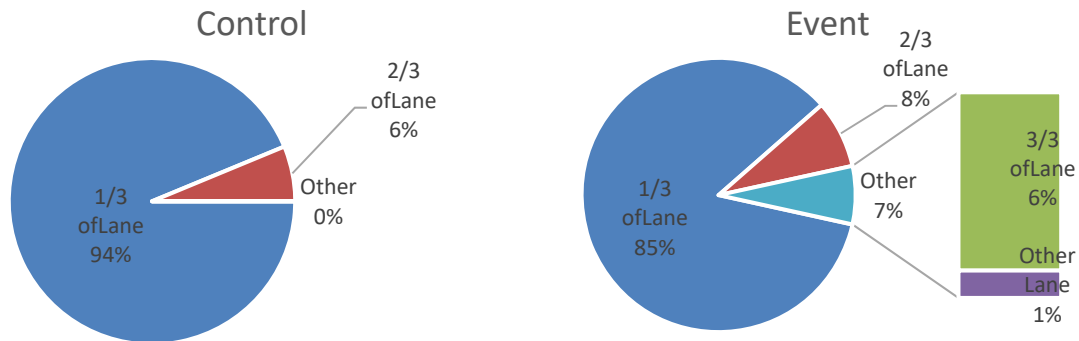


Figure 23. Site 2 Without Motorcycles Lateral Placement Control vs Event Before Installation.

Passenger Vehicles Only

The passenger vehicle only dataset in Table 10 showed similar results to the data set without motorcycles. Listed in the table below are a summary of the speed data for site 1 along with the sample size, which is relatively small for all time lag categories except the greater than 30 seconds category. The drivers at site 1 had a speed reduction of 0.98 mile per hour when there was a bicycle present. Speeds, as they did in the previous data set, tend to increase the farther away the bicyclist is from the driver. The exception to this trend is 10-20 seconds away. T-tests were performed between the control group and the different event groups to determine if any of the speed differences were statistically significant. These same tests were performed to determine if the speed differences in the time lag categories were significant. The difference in speed between the event groups and the control group were found to be statistically significant for the total of event data, 0-5 seconds, 5-10 seconds, 10-20 seconds, 20-30 seconds, and greater than 30 seconds with 95% confidence and p-values of 4.6229×10^{-8} , 0.0008, 0.0087, 5.2867×10^{-5} , 8.2778×10^{-6} , and 0.001 respectively. Differences between the time lag groups were not necessarily significant. Speeds between 0-5 seconds and 5-10 seconds

were statistically the same at a p-value of 0.2824 and 95% confidence. The difference between 5-10 seconds and 10-20 seconds was significant but did not follow the hypothesis which would show an increase in speed. Therefore, a two-tail t-test was performed showing that the two groups are statistically the same with a p-value of 0.1252 and 95% confidence. There were statistical similarities between the time lag groups of 10-20 and 20-30 seconds with a p-value of 0.0626 at the 95% confidence level, but the groups are not necessarily the same. The last time lag group of greater than 30 seconds was found to be statistically different from the previous group of 20-30 seconds at 95% confidence and a p-value of 0.0250.

Table 10. Site 1 Passenger Vehicles Only Speed Data Before Installation.

Passenger Vehicles	Event			Control		
Category	Mean	Standard Deviation	N	Mean	Standard Deviation	N
Total	28.40	3.45	502	29.38	3.07	955
Time Lag 0-5 (sec)	26.42	4.23	26	-	-	-
Time Lag 5-10 (sec)	27.25	3.72	12	-	-	-
Time Lag 10-20 (sec)	24.95	4.19	21	-	-	-
Time Lag 20-30 (sec)	26.45	5.32	22	-	-	-
Time Lag 30+ (sec)	28.83	3.04	421	-	-	-

Again, in both the control and event groups the majority of drivers preferred to maintain lane position in the right third of the lane. However, there was a 2% and 4% increase in the number of vehicles using the left third of the lane and the opposing lane respectively as seen in Figure 24. The increase in the number of drivers moving over for bicycles was determined to be significant based on a t-test p-value of 0.0002 and 95% confidence. Just as before, t-tests were performed between the time lag categories and the control and each other. Lateral placement was determined to be statistically larger for 0-5

seconds and 5-10 seconds than the control with p-values of 2.8462×10^{-10} and 0.0002 respectively at 95% confidence. For 10-20 seconds, 20-30 seconds, and greater than 30 seconds the lateral placement was determined to be statistically the same as the control group having p-values of 0.1037, 0.3969, 0.4811 at 95% confidence. When comparing the time lag categories to each other 0-5 seconds and 5-10 seconds were shown to have statistical similarities with 95% confidence and a p-value of 0.0805 but not necessarily the same. However, at 95% confidence 5-10 seconds was shown to be different than 10-20 seconds, which was statistically the same as 20-30 seconds each test having a p-value of 0.0005 and 0.2529 respectively. The final time lag category of greater than 30 seconds was also shown to be statistically the same as the previous category of 20-30 seconds at the 95% confidence level having a p-value of 0.4038.

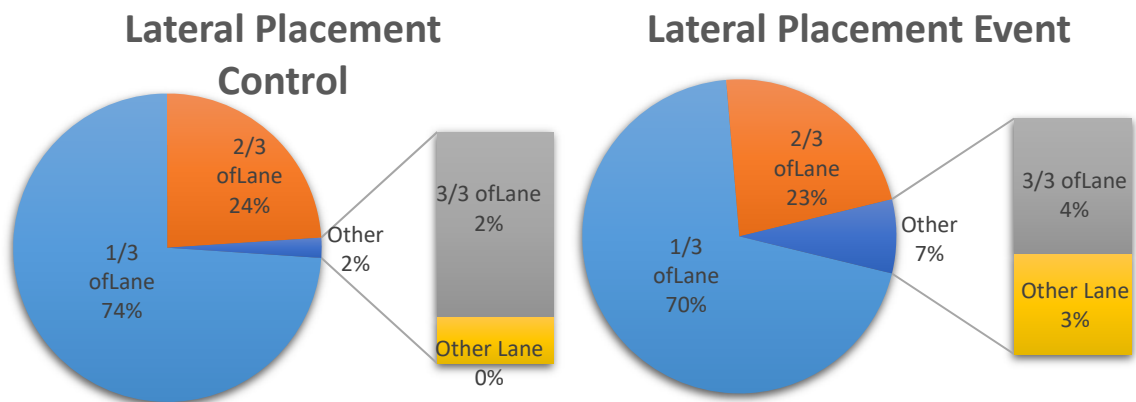


Figure 24. Site 1 Passenger Vehicles Only Lateral Placement Control vs Event Before Installation

Just as with site 1, site 2 appears to have a trend of increasing speed the farther away the bicycle is from the motor vehicle. Similar to the data which removed motorcycles, the exception here is when the bicycle is within 5-10 seconds of the vehicle. Table 11 contains the sample size and speed data for site 2. Sample sizes for the first four time-lag categories are relatively small especially 5-10 seconds. The majority of observations were greater than 30 seconds. Total observations appear to show only a 0.74 mile per hour difference in speed when there is a bicycle present. Considering the small differences in speed between the event groups and the control as well as between themselves several t-tests were performed to see if these differences were significant. The difference in speed between the event groups and the control group were found to be statistically significant at the 95% confidence level for the total of event data, 0-5 seconds, 5-10 seconds, 10-20 seconds, and greater than 30 seconds with p-values of 0.001, 0.0319, 0.0073, 0.0004, and 0.0432 respectively. There were however statistical similarities between the control and the 20-30 seconds category at the 95% confidence level having a p-value of 0.0611. The two groups are not necessarily the same but definitely similar. Generally, there was no difference between the time lag groups. The speeds between 0-5 seconds, 5-10 seconds, and 10-20 seconds were found to be statistically the same at the 95% confidence level with p-values of 0.2319 (two-tailed) and 0.4978. A two-tailed t-test was used when comparing the 0-5 second group to the 5-10 second group because it failed to follow the hypothesis that the 0-5 seconds group should have a slower speed. The 10-20 second and 20-30 second time lag categories were found to be statistically different but did have potential similarities at the 95% confidence

level with a p-value of 0.0536. There was however no statistical difference at the 95% confidence level with a p-value of 0.1252 between 20-30 and greater than 30 second groups.

Table 11. Site 2 Passenger Vehicles Only Speed Data Before Installation

Passenger Vehicles	Event			Control		
Category	Mean	Standard Deviation	N	Mean	Standard Deviation	N
Total	24.76	4.05	417	25.50	4.18	939
Time Lag 0-5 (sec)	23.75	3.81	20	-	-	-
Time Lag 5-10 (sec)	21.88	3.23	8	-	-	-
Time Lag 10-20 (sec)	21.89	3.46	18	-	-	-
Time Lag 20-30 (sec)	23.88	3.22	16	-	-	-
Time Lag 30+ (sec)	25.06	4.07	355	-	-	-

Same as at site 1, both the control and event groups had the majority of drivers preferring to maintain lane position in the right third of the lane. There were increases in the number of people using the center of the lane, left third of the lane, and the opposing lane of 2%, 6%, and 1% respectively when a bicycle was present, which is shown in Figure 25. The increase in the number of drivers moving over for bicycles was determined to be significant based on a t-test p-value of 1.2414×10^{-8} and a 95% confidence level. T-tests were again performed between the time lag categories, the control, and each other. Lateral placement was determined to be statistically larger for 0-5 seconds, 5-10 seconds, 10-20 seconds, and greater than 30 seconds than the control at the 95% confidence level with p-values of 8.0276×10^{-9} , 0.012, 0.0548, and 0.0056 respectively. Even though the time lag category of 10-20 seconds was statistically different there were similarities to the control group. The difference in lateral placement between the control and the time lag category of 20-30 seconds was found to be

statistically the same with a p-value of 0.105 at the 95% confidence level. Some of the time lag categories were statistically different from each other. The 0-5 second group statistically moved over more than the 5-10 second group at the 95% confidence level and a p-value of 0.0175. At the 95% confidence level 5-10 second and 10-20 second groups were shown to be statistically different (p-value of 0.0253). The 20-30 second category was then statistically the same (p-value of 0.3503) as the 10-20 second group, primarily utilizing the right third of the lane. It was also shown that the greater than 30 second group was statistically the same as the 20-30 second group (p-value of 0.19) with the majority of drivers utilizing the right third of the lane at the 95% confidence level.

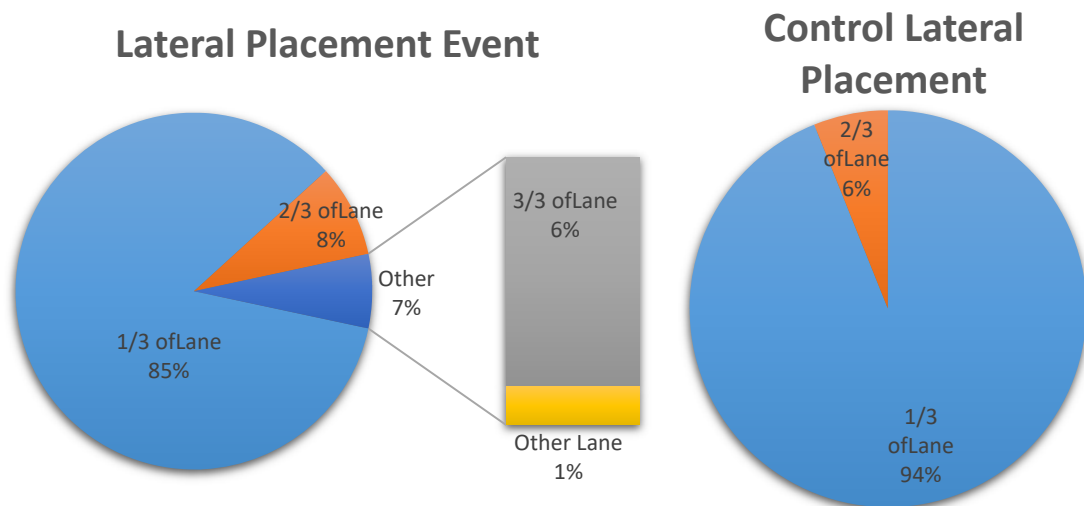


Figure 25. Site 2 Passenger Vehicles Only Lateral Placement Control vs Event Before Installation.

Sign vs No Sign

The main objective was to determine if the sign when activated effected the driver's behavior and improved the safety of bicyclists. However, there is a possibility that the sign itself caused an effect on the driver's behavior even when there has been no event recorded. Therefore, the control groups from both before and after installation were compared. This section sets out to determine if there has been any effect from solely installing the sign and was broken up into the groups without motorcycles and passenger vehicles only. There was enough data recorded to do the comparison for both site 1 and site 2.

Without Motorcycles

For site 1 there were 1008 vehicles observed before the installation and then 1013 vehicles after the installation. Due to the large data set, summarized in Table 12, it was possible to perform a Z-test for both the speed and lateral placement of the vehicles. The average speed of vehicles before the installation was about 29.27 miles per hour. After the installation of the sign but not in the presence of a bicycle and therefore the lights were not flashing the average speed was 27.54 miles per hour. There was approximately a 1.73 mile per hour reduction in speed. This reduction was found to be statistically significant at a 95% confidence level with a p-value of $\sim 1 \times 10^{-33}$.

Table 12. Control Without Motorcycles Before and After averages and p-values for Lateral Placement and Speed for Site 1.

Control Site 1	Without Motorcycles	N	p-value
Lateral Placement After	1.35834156	1013	0.001650039
Lateral Placement Before	1.291666667	1008	
Speed After	27.54096742	1013	0
Speed Before	29.27380952	1008	

The majority of drivers as seen in Figure 26 for both before and after the installation primarily utilized the right third of the lane. A reduction of 9% in the number of vehicles utilizing the right third of the lane was observed. There was a 10% increase in the number of vehicles utilizing the center of the lane. Unfortunately, there was a 1% reduction in the number of vehicles observed in the left third of the lane. No change was observed in the number of vehicles using the opposing lane, which was 0%.

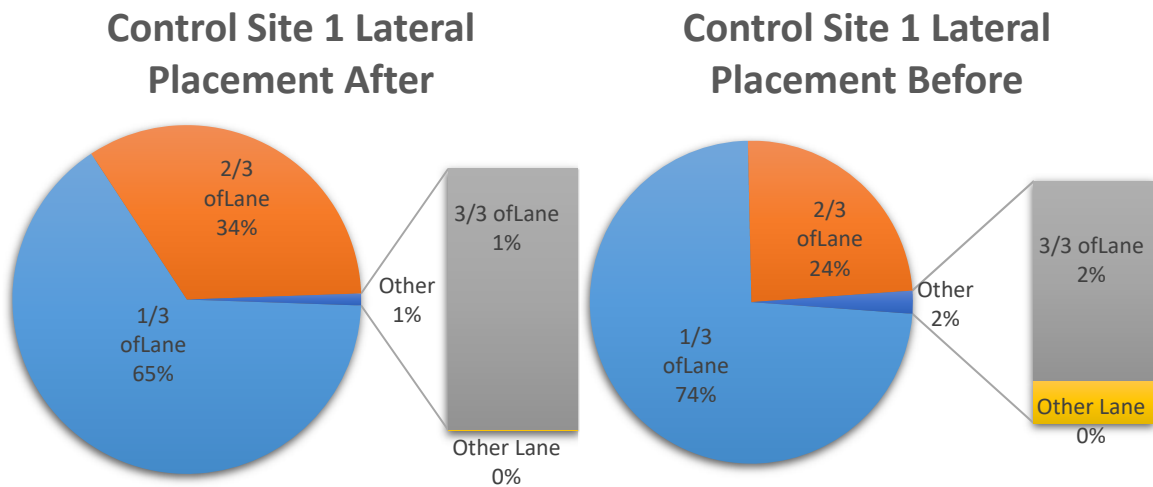


Figure 26. Lateral Placement of Control Vehicles Without Motorcycles Before and After installation of the Dynamic Bicycle Detection and Warning System for Site 1

When lateral position was analyzed fewer vehicles utilized the right side of the lane after the sign was installed than before the installation. Another Z-test was performed to determine if this difference was significant. Based on the 1013 vehicles observed before the installation and then 1008 vehicles after the installation at the 95% confidence level and a p-value of 0 the lower number of vehicles utilizing the right side of the lane after-installation of the sign was shown to be significant.

Although there was limited data for site 2 there was enough data available to test the differences in speed and lateral position from before and after the installation for the control group which is summarized in Table 13. There was a total of 1009 observations before and after installation of the sign. A Z-test was performed to determine if the differences in speed and lateral position from before the installation of the sign and after the installation were significant.

For speed the average before the installation of the sign was 25.44 miles per hour and 27.61 miles per hour after the installation of the sign. This resulted in a 2.21 mile per hour increase in speed. Based on 95% confidence level and a $\sim 1 \times 10^{-33}$ p-value the difference was found to be statistically significant. Lateral position followed a similar pattern to site 1 in that fewer vehicles utilized the right side of the lane after-installation in comparison to before the installation of the sign. The difference in the number of vehicles moving farther left from before-installation to after-installation of the sign was found to be statistically significant at the 95% confidence level with a p-value of $\sim 1.91 \times 10^{-28}$.

Table 13. Control Without Motorcycles Before and After averages and p-values for Lateral Placement and Speed for Site 2

Control Site 2	Without Motorcycles	N	p-value
Lateral Placement After	1.235877106	1009	0
Lateral Placement Before	1.062438057	1009	
Speed After	27.60654113	1009	0
Speed Before	25.44301288	1009	

Similar to site 1 most drivers primarily utilized the right third of the lane both before and after the installation of the system which is shown in Figure 27. However, unlike site 1 there was a 17% reduction from 94% to 77% in the number of vehicles utilizing the right third of the lane. Considering there were no vehicles observed before or after installation utilizing the left third of the lane or opposing lane, the reduction in the vehicles utilizing the right third of the lane resulted in a direct increase to the number of vehicles using the center of the lane. As indicated, there was no change in the number of vehicles utilizing the left third of the lane or the opposing lane for site 2.

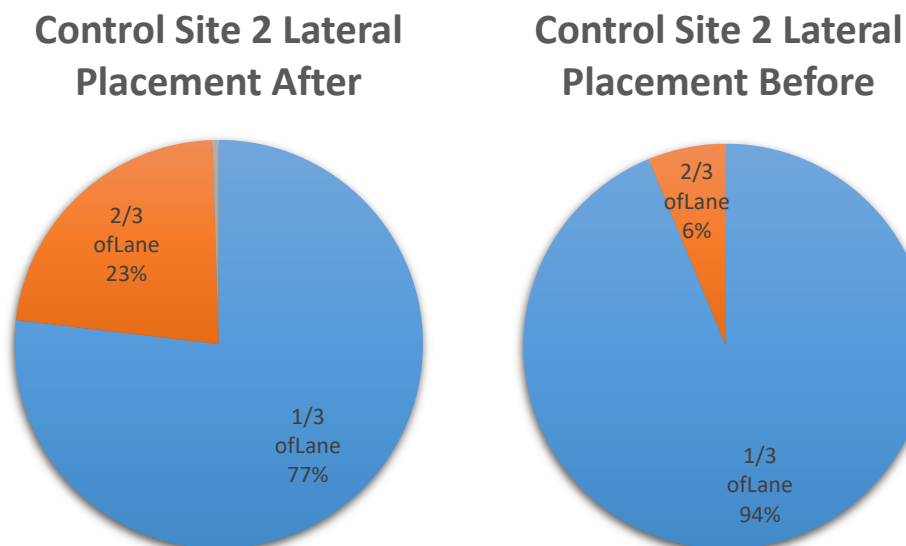


Figure 27. Lateral Placement of Control Vehicles Without Motorcycles Before and After installation of the Dynamic Bicycle Detection and Warning System for Site 2.

When analyzing the changes in lateral position for before and after the installation another Z-test was performed. Based on the 1009 vehicles observed before the installation and the 1009 vehicles after the installation at the 95% confidence level and a p-value of 0 the lower number of vehicles utilizing the right side of the lane after-installation of the sign was shown to be significant.

Passenger Vehicles Only

When only accounting for passenger vehicles, site 1 had 955 vehicles observed before the installation and then 985 vehicles after the installation. Due to the large data set it was possible to perform a Z-test for both the speed and lateral placement of the vehicle. Summaries of the tests and the averages are found in Table 14. The average speed of vehicles before the installation was 29.38 miles per hour. After the installation of the sign but not in the presence of a bicycle and therefore the lights were not flashing the average speed was 27.58 miles per hour. There was approximately a 1.8 mile per hour reduction in speed. This reduction was found to be statistically significant at a 95% confidence level with a p-value of $\sim 1 \times 10^{-33}$.

Table 14. Control Passenger Vehicles Only Before and After averages and p-values for Lateral Placement and Speed for Site 1.

Control Site 1	Passanger Vehicles	N	p-value
Lateral Placement After	1.363451777	985	0.000389918
Lateral Placement Before	1.285863874	955	
Speed After	27.57766497	985	0
Speed Before	29.37801047	955	

The majority of vehicles were passenger vehicles both before and after the sign installation. Thus, just as in the data set without motorcycles, drivers primarily utilized the right third of the lane which is shown in Figure 28. There was a 9% reduction in the number of vehicles utilizing the right third of the lane observed and a 10% increase in the number of vehicles utilizing the center of the lane. Unfortunately, there was a 1% reduction in the number of vehicles observed in the left third of the lane. No change was observed in the number of vehicles using the opposing lane, which was 0%.

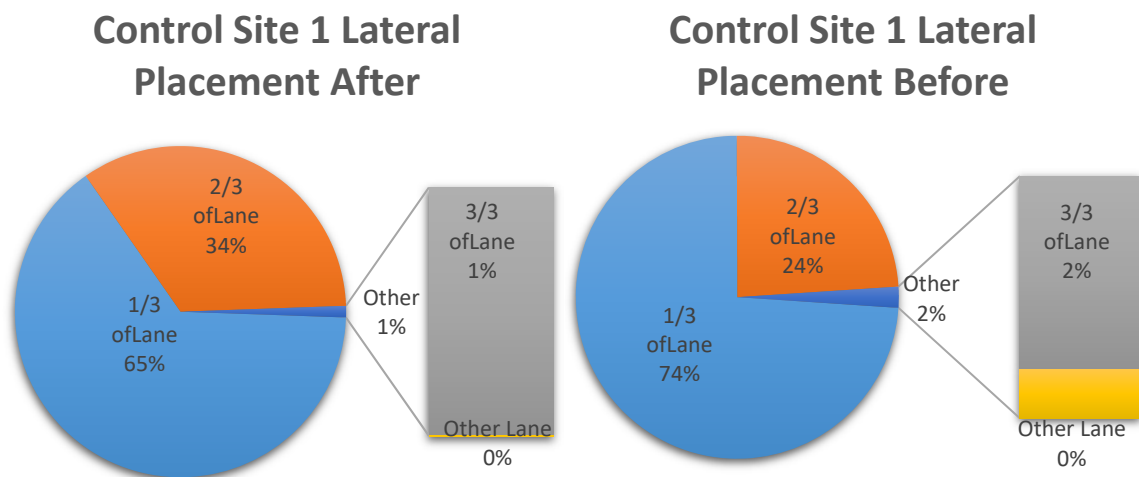


Figure 28. Lateral Placement of Control Passenger Vehicles Before and After installation of the Dynamic Bicycle Detection and Warning System for Site 1.

When lateral position was analyzed fewer vehicles utilized the right side of the lane after the sign was installed. Another Z-test was performed to determine if this difference was significant. Based on the 955 vehicles observed before the installation and then 985 vehicles after the installation at the 95% confidence level and a p-value of 0.0004 the lower number of vehicles utilizing the right side of the lane after-installation of the sign was shown to be significant.

Although there was limited data for site 2 there was enough data available to test the differences in speed and lateral position from before and after the installation. There was a total of 939 observations before-installation of the sign. After the installation there were 968 recorded observations. A Z-test was performed to determine if the differences in speed and lateral position from before the installation of the sign and after the installation were significant. Summaries of the tests and averages can be found in Table 15.

The average speed before the installation of the sign was 25.5 miles per hour and 27.71 miles per hour after the installation of the sign. This resulted in a 2.21 mile per hour increase in speed. Based on 95% confidence level and a $\sim 1 \times 10^{-33}$ p-value the difference was found to be statistically significant. Lateral position followed a similar pattern to site 1 in that fewer vehicles utilized the right side of the lane after-installation in comparison to before the installation of the sign. The difference in the number of vehicles moving farther left from before-installation to after-installation of the sign was found to be statistically significant at the 95% confidence level with a p-value of $\sim 2 \times 10^{-28}$.

Table 15. Control Passenger Vehicles Only Before and After averages and p-values for Lateral Placement and Speed for Site 2.

Control Site 2	Passanger Vehicles	N	p-value
Lateral Placement After	1.245867769	968	0
Lateral Placement Before	1.060702875	939	
Speed After	27.70971074	968	0
Speed Before	25.49946752	939	

Similar to site 1 and the data set without motorcycles most drivers primarily utilized the right third of the lane both before and after the installation of the system as seen in Figure 29. As stated earlier the majority of drivers were in passenger vehicles. Thus, it was still observed that there was a 17% reduction from 94% to 77% in the number of vehicles utilizing the right third of the lane. There were no vehicles observed before or after installation utilizing the left third of the lane or opposing lane. Therefore, the reduction in the vehicles utilizing the right third of the lane resulted in a direct increase to the number of vehicles using the center of the lane.

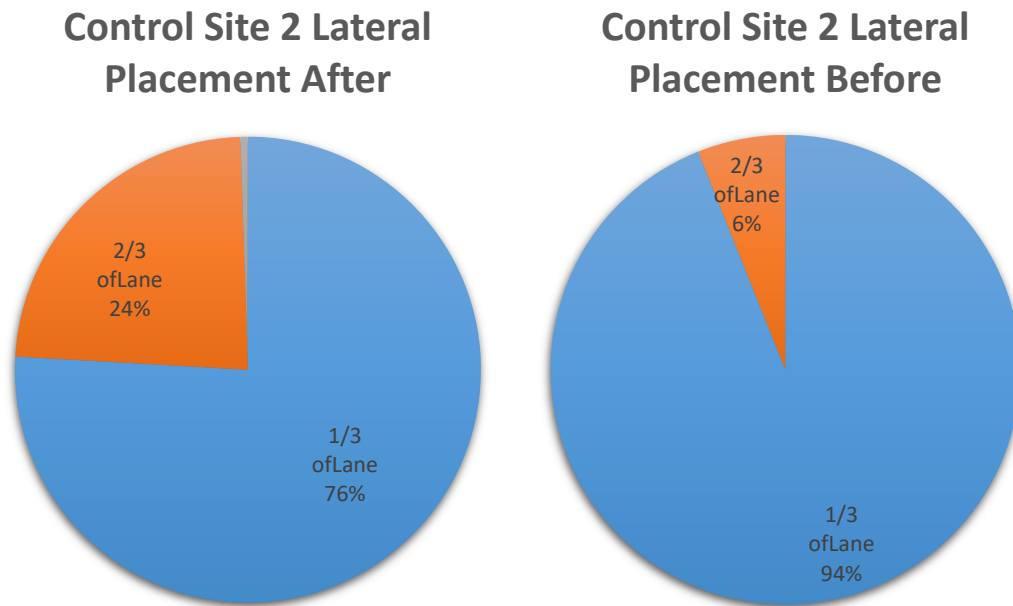


Figure 29. Lateral Placement of Control Passenger Vehicles Before and After installation of the Dynamic Bicycle Detection and Warning System for Site 2.

As expected, when analyzing the changes in lateral position for before and after the sign installation the same results were found as in the without motorcycles data set. Another Z-test was performed and based on the 939 vehicles observed before the installation and then 968 vehicles after the installation at the 95% confidence level and a p-value of 0 the lower number of vehicles utilizing the right side of the lane after-installation of the sign was shown to be significant.

Before vs After Installation

The major interest of the study was if the installation of a dynamic bicycle detection and warning device would have an impact on driver behavior. Ideally, there should be a shift in behavior to create a safer environment for bicyclists. A statistical analysis of the event data from before the installation in comparison to the event data after the installation was performed. The analysis is described below and shows the impact the system had on the driver's behavior for both data sets Without Motorcycles and Passenger Vehicles Only. Site 1 will be the primary focus do to the limited data available from site 2. Caution should be taken when interpreting anything discussed from site 2 because of the relatively small sample size.

Without Motorcycles

Before-event data was compared to after-event data as a whole, but also via time lag. A summary of the comparisons can be found in Table 16. All data for site 1 showed approximately a 1.52 mile per hour reduction in speed from 28.36 miles per hour when a bicycle was present before the installation to 26.84 miles per hour when a bicycle was

present after the installation. At the 95% confidence level the difference in speed was found to be significant with a p-value of 3.33×10^{-16} . For the time lag categories however, there was shown to be no statistical difference between before and after installation of the system for most categories. There was a reduction of 0.76 miles per hour for 0-5 seconds, 1.54 miles per hour for 5-10 seconds, an increase of 1.22 miles per hour for 10-20 seconds and a decrease of 0.27 miles per hour for 20-30 seconds. Time lag category 5, greater than 30 seconds after the event, showed an unexpected decrease in speed of 1.77 miles-per-hour. All of these groups had one tailed t-tests performed due to the small data sets. The final time lag category of greater than 30 seconds was found to be highly statistically significant with a p-value of 0 at the 95% confidence level.

Table 16. Summary of tests performed comparing Before and After Time Lag Categories for speed and Lateral Placement Without Motorcycles.

Site 1 Without Motorcycles	Lateral Placement After	Lateral Placement Before	p-value	Speed After	Speed Before	p-value	N After	N Before
All	1.602094241	1.403773585	2.38619E-07	26.83874346	28.35660377	3.33067E-16	955	530
Time Lag 1	2.973684211	3.038461538	0.381701018	25.65789474	26.42307692	0.209700438	38	26
Time Lag 2	2.333333333	2.583333333	0.221633106	25.70833333	27.25	0.117223789	24	12
Time Lag 3	1.851851852	1.391304348	0.001316582	25.96296296	24.73913043	0.094840663	54	23
Time Lag 4	1.658536585	1.333333333	0.027178484	26.6097561	26.875	0.413762561	41	24
Time Lag 5	1.494987469	1.280898876	4.27448E-10	27	28.76629213	0	798	445

Both before and after the installation of the system the majority of drivers preferred to utilize the right third of the lane. There was, however, a large increase in the number of people using the center of the lane and some small increases to usage of the left third of the lane and the opposing lane. When a bicycle was present after the installation of the system there was a 13%, 5%, and 0% increase in the number of drivers using the center of the lane, left third of the lane, and opposing lane respectively. The increase in the number of drivers moving over for bicycles for the whole data set was

determined to be significant based on a one tailed t-test p-value of 2.39×10^{-7} and a 95% confidence level. T-tests were performed between the time lag categories to determine if the sign had an effect based on when the bicycle was observed. There was no statistical difference for the 0-5 second and 5-10 second after-event groups after the installation when compared to the lateral position of the vehicles before the installation. For time lags of 10-20 seconds, 20-30 seconds, and greater than 30 seconds there was a statistically significant difference. At the 95% confidence level the p-values of 10-20 seconds, 20-30 seconds, and greater than 30 seconds were 0.0013, 0.0272, and 4.2745×10^{-10} respectively.

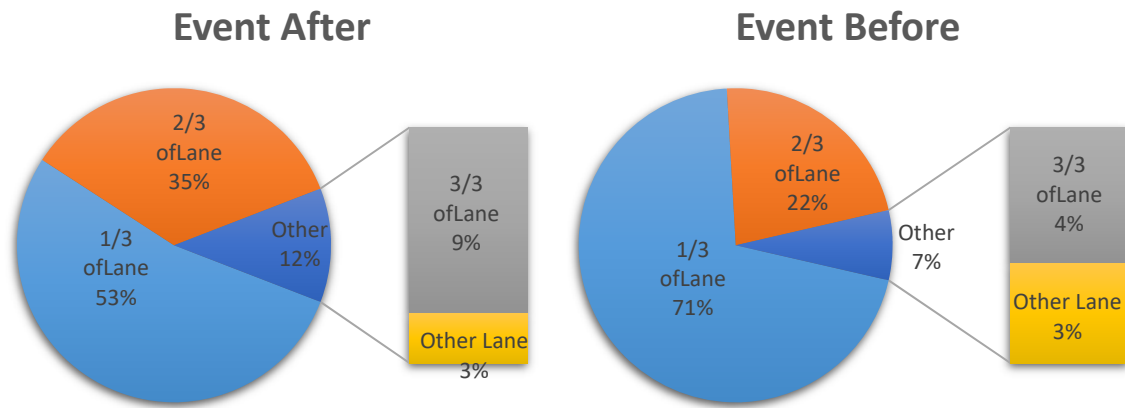


Figure 30. Lateral Placement of Vehicles Without Motorcycles Before and After installation of the Dynamic Bicycle Detection and Warning System for Site 1.

There were only passenger vehicles for site 2 after the motorcycles were removed from the after-installation data set. Although there was a data set before-installation for without motorcycles there could be no comparison made. The comparison between passenger vehicles for before-installation and after-installation will be discussed next for both site 1 and site 2.

Passenger Vehicles Only

Similar to the previous section the before-event data was compared to after-event data together and separated by time lag. This comparison is then shown in Table 17. All data for site 1 when only considering passenger vehicles showed an approximate 1.44 mile per hour reduction in speed from 28.40 miles per hour when a bicycle was present before the installation to 26.96 miles per hour when a bicycle was present after the installation. At the 95% confidence level the difference in speed was found to be significant with a p-value of 3.2419×10^{-14} . For the time lag categories however, there was shown to be no statistical difference between before and after installation of the system. The exception was time lag category 5 or greater than 30 seconds after the event and possibly category 3, 10-20 seconds after the event. There was a reduction of 0.84 miles per hour for 0-5 seconds, 1.54 miles per hour for 5-10 seconds, an increase of 1.58 miles-per-hour for the 10-20 seconds, and a 0.14 mile per hour increase for 20-30 seconds. All of these groups had one tailed t-tests performed due to the small data sets. At the 95% confidence level the difference between the before and after installation speeds for the 10-20 seconds after a bicycle was shown to be slightly significant with a p-value of 0.0600. The final time lag category of greater than 30 seconds showed a reduction in speed of approximately 1.77 miles-per-hour. This was found to be highly statistically significant with a p-value of 0 at the 95% confidence level.

Table 17. Summary of tests performed comparing Before and After Time Lag Categories for speed and Lateral Placement Passenger Vehicles Only for Site 1.

Site 1 Passenger Vehicles	Lateral Placement After	Lateral Placement Before	p-value	Speed After	Speed Before	p-value	N After	N Before
All	1.62183908	1.416334661	3.33407E-07	26.95517241	28.40039841	3.24185E-14	870	502
Time Lag 1	3.055555556	3.038461538	0.46856202	25.58333333	26.42307692	0.190259034	36	26
Time Lag 2	2.333333333	2.583333333	0.221633106	25.70833333	27.25	0.117223789	24	12
Time Lag 3	1.906976744	1.428571429	0.002351129	26.53488372	24.95238095	0.060019956	43	21
Time Lag 4	1.702702703	1.318181818	0.016628575	26.59459459	26.45454545	0.455971969	37	22
Time Lag 5	1.506849315	1.287410926	8.58167E-10	27.10684932	28.82897862	0	730	421

Even when considering only passenger vehicles, both before and after the installation of the system the majority of drivers preferred to utilize the right third of the lane as seen in Figure 31. There was however a major decrease in the number of people using the right third of the lane in favor of the center and left third of the lane. When a bicycle was present after the installation of the system there was a 13% and 5% increase in the number of drivers using the center of the lane and left third of the lane respectively. There was no change in the percentage of vehicles moving over into the opposing lane. The increase above in the number of drivers moving over for bicycles for the whole data set was determined to be significant based on a one tailed t-test p-value of 3.3341×10^{-7} and a 95% confidence level. T-tests were performed between the time lag categories to determine if the sign had an effect based on when the bicycle was observed. There was no statistical difference for 0-5 seconds and 5-10 seconds after a bicycle after installation when compared to the lateral position of the vehicles before the installation. This was just like the data set without motorcycles. For time lags of 10-20 seconds, 20-30 seconds, and greater than 30 seconds there was a statistically significant difference once again. At the 95% confidence level the p-values of 10-20 seconds, 20-30 seconds, and greater than 30 seconds were 0.0024, 0.0166, and 8.5816×10^{-10} respectively.

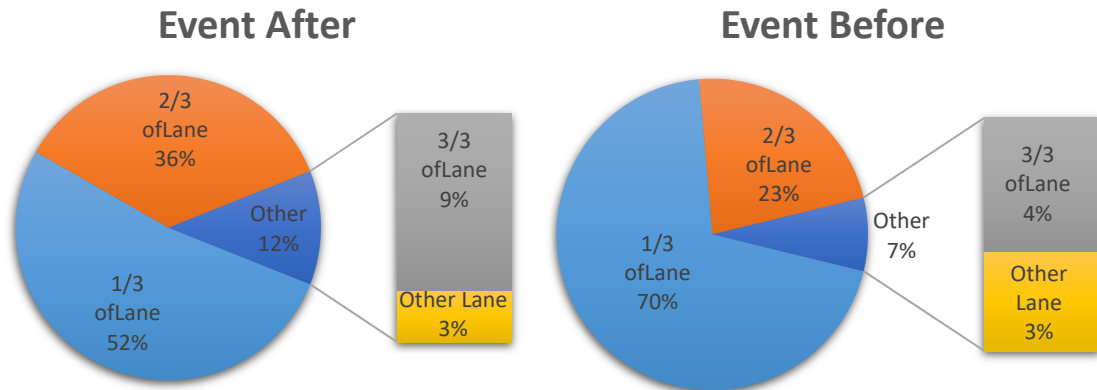


Figure 31. Lateral Placement of Passenger Vehicles Before and After installation of the Dynamic Bicycle Detection and Warning System for Site 1.

There was limited data for site 2. Due to very low sample sizes only the total data set and time lag category 5 of greater than 30 seconds could be reasonably analyzed. The summary of analysis can be seen in Table 18. For speed there was an increase of 2.37 miles per hour over the whole data set and an increase of 2.36 miles per hour for vehicles arriving greater than 30 seconds after the event. These differences in speed were found to be statistically significant with respective p-values of 3.2847×10^{-5} and 4.0553×10^{-6} at the 95% confidence level for a one tailed Z-test. Drivers still continued to prefer the right third of the lane overall for both before and after installation which can be seen in Figure 32. There was however an increase of 28% and 9% in the drivers utilizing the center of the lane and opposing lane. In this case there was a 4% decrease in the number of drivers utilizing the left third of the lane. Overall the increase in drivers moving over for bicyclists was found to be statistically significant with a p-value of 6.7853×10^{-7} at the 95% confidence level. For vehicles arriving greater than 30 seconds after the bicycle the same was found. There was a statistically significant increase in the number of drivers moving over for bicyclists with a p-value of 6.0887×10^{-6} at the 95% confidence level.

Caution should be taken when interpreting anything from site 2 because of the relatively small sample size.

Table 18. Summary of tests performed comparing Before and After Time Lag Categories for speed and Lateral Placement Passenger Vehicles Only for Site 2.

Site 2 Passenger Vehicles	Lateral Placement After	Lateral Placement Before	p-value	Speed After	Speed Before	p-value	N After	N Before
All	1.866666667	1.227817746	6.78531E-07	27.13333333	24.75539568	3.2847E-05	60	417
Time Lag 1	4	2.8	1.79177E-06	23.66666667	23.75	0.492264537	3	20
Time Lag 3	3	1.277777778	0.031145506	24.5	21.88888889	0.104488684	4	18
Time Lag 4	2.5	1.25	0.005878896	26.5	23.875	0.148223655	2	16
Time Lag 5	1.58	1.118309859	6.08872E-06	27.42	25.06197183	4.05529E-06	50	355

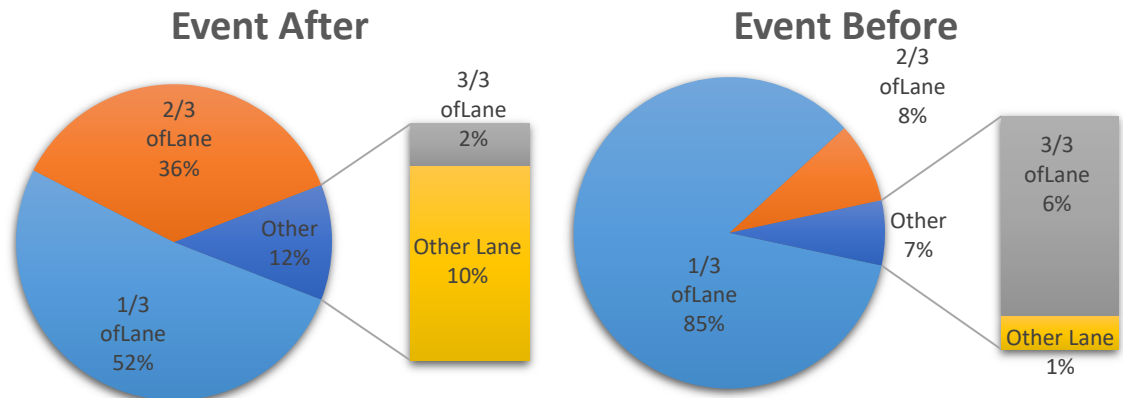


Figure 32. Lateral Placement of Passenger Vehicles Before and After installation of the Dynamic Bicycle Detection and Warning System for Site 2.

After Installation Bicycle vs No Bicycle

Now it is known that there is a statistically significant difference between the behavior of drivers before the installation of the sign and after the installation of the sign. Considering this fact, it is necessary to determine if there is a difference between the sign being activated with the passing of a bicycle and the sign not being activated. There is only one variable being investigated. However, the sign being activated or the bicycle being present could be influencing the lateral placement of the vehicle, the speed of the

vehicle, or both. Such a comparison does not provide much information except to show if there is an effect besides that of the static sign. Due to the limited data site 2 will not be included in this discussion.

Without Motorcycles

Before performing any statistical tests, there appear to be differences between the control group with just the sign and the event group when a bicycle passes and sets off the lights. Table 19 below contains speed data for site 1 along with the sample size, which is larger than the before-data set, but still relatively small for all time lag categories except the greater than 30 seconds category. In this case the drivers reduce speed by about 0.7 of a mile per hour when there is a bicycle present and the lights are flashing. As shown from the before-data set the speeds increase the farther away the bicyclist is from the driver. Both Z-tests and t-tests were performed as appropriate between the control group and the different event groups to see if the speed differences were significant. These tests were performed to determine if the speed differences in the time lag categories were also significant. The difference in speed between the event groups and the control group were found to be statistically significant for the total of event data, 0-5 seconds, 5-10 seconds, 10-20 seconds, 20-30 seconds, and greater than 30 seconds with 95% confidence and p-values of 1.4822×10^{-6} , 1.4502×10^{-5} , 0.0032, 0.0007, 0.0343, and 0.0003 respectively. Differences between the time lag groups were not significant. All time lag categories with respect to speeds, 0-5 seconds, 5-10 seconds, 10-20 seconds, 20-30 seconds, and greater than 30 seconds, were statistically the same as the previous

category at 95% confidence and p-values of 0.4748, 0.3853, 0.1764, and 0.2245 respectively.

Table 19. Site 1 Without Motorcycles Vehicle Speed Data After Installation

Large & Passenger Vehicles	Event			Control		
Category	Mean	Standard Deviation	N	Mean	Standard Deviation	N
Total	26.84	3.41	955	27.54	3.25	1013
Time Lag 0-5 (sec)	25.66	2.70	38	-	-	-
Time Lag 5-10 (sec)	25.71	3.54	24	-	-	-
Time Lag 10-20 (sec)	25.96	3.55	54	-	-	-
Time Lag 20-30 (sec)	26.61	3.21	41	-	-	-
Time Lag 30+ (sec)	27.00	3.42	798	-	-	-

In the case of lateral position for both the control and event group the majority of drivers preferred to maintain lane position in the right third of the lane, which can be seen in Figure 33. However, there was a large portion that also used the center of the lane. Overall there was an 8% and 3% increase in the number of vehicles using the left third of the lane and the opposing lane respectively as seen in Figure 33. There was also a 1% increase in the number of drivers using the center of the lane. The increase in the number of drivers moving over for bicycles was determined to be significant based on a Z-test p-value of 0 and 95% confidence. Similar to the speed data, Z-tests and t-tests were also performed between the time lag categories and the control and each other. Lateral placement was determined to be statistically larger for 0-5 seconds, 5-10 seconds, 10-20 seconds, 20-30 seconds and greater than 30 seconds than the control with p-values of 0, 1.4528×10^{-5} , 1.2874×10^{-6} , 0.0061, and 2.4703×10^{-7} respectively at 95% confidence. When comparing the time lag categories to each other 0-5 seconds and 5-10 seconds were shown to be statistically different with 95% confidence and a p-value of 0.0024. At 95%

confidence 5-10 seconds was shown to be different than 10-20 seconds, which was statistically the same as 20-30 seconds each test having a p-value of 0.009 and 0.1104 respectively. The final time lag category of greater than 30 seconds was determined to be statistically similar to the previous category of 20-30 seconds at the 95% confidence level having a p-value of 0.0883, but not necessarily identical.

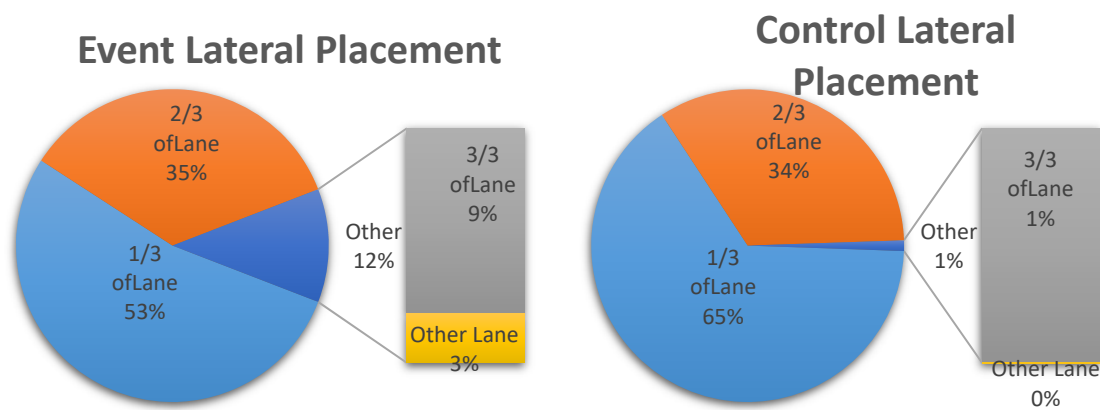


Figure 33. Site 1 Without Motorcycles Lateral Placement Control vs Event After Installation

Passenger Vehicles Only

Once again there appear to be differences between the control group with just the sign and the event group when a bicycle passes and sets off the lights. Table 20, below, contains speed data regarding only passenger vehicles for site 1 along with the sample size, which is larger than the before-data set, but is still relatively small for all time lag categories except the greater than 30 seconds. The drivers had a speed reduction around 0.62 miles per hour when there was a bicycle present and the lights were flashing. Just as with the data set without motorcycles the speeds increase the farther away the bicyclist is from the driver. Both Z-tests and t-tests were performed as appropriate between the

control group and the different event groups to see if the speed differences were significant. These tests were performed to determine if the speed differences in the time lag categories were also significant. The difference in speed between the event groups and the control group were found to be statistically significant for the total of event data, 0-5 seconds, 5-10 seconds, 10-20 seconds, 20-30 seconds, and greater than 30 seconds with 95% confidence and p-values of 3.1318×10^{-5} , 1.0973×10^{-5} , 0.0028, 0.0294, 0.0363, and 0.002 respectively. Differences between the time lag groups were not significant. All time lag categories with respect to speeds, 0-5 seconds, 5-10 seconds, 10-20 seconds, 20-30 seconds, and greater than 30 seconds, were statistically the same as the previous category at 95% confidence and p-values of 0.4423, 0.1822, 0.4688, and 0.1769 respectively.

Table 20. Site 1 Passenger Vehicles Only Speed Data After Installation

Passenger Vehicles	Event			Control		
Category	Mean	Standard Deviation	N	Mean	Standard Deviation	N
Total	26.96	3.43	870	27.58	3.25	985
Time Lag 0-5 (sec)	25.58	2.75	36	-	-	-
Time Lag 5-10 (sec)	25.71	3.54	24	-	-	-
Time Lag 10-20 (sec)	26.53	3.55	43	-	-	-
Time Lag 20-30 (sec)	26.59	3.27	37	-	-	-
Time Lag 30+ (sec)	27.11	3.43	730	-	-	-

In the case of lateral position for both the control and event group the majority of drivers, once again, preferred to maintain lane position in the right third of the lane. However, there was a significant portion that also used the center of the lane. Overall there was an 8% and 3% increase in the number of vehicles using the left third of the lane and the opposing lane respectively as seen in Figure 34. There was also a 2% increase in

the number of drivers using the center of the lane. The increase in the number of drivers moving over for bicycles was determined to be significant based on a Z-test p-value of 0 and 95% confidence. Similar to the speed data, Z-tests and t-tests were also performed between the time lag categories and the control and each other. Lateral placement was determined to be statistically larger for all the data, 0-5 seconds, 5-10 seconds, 10-20 seconds, 20-30 seconds and greater than 30 seconds than the control with p-values of 0, 1.5563×10^{-5} , 3.0657×10^{-6} , 0.0042, and 1.7504×10^{-7} respectively at 95% confidence level. When comparing the time lag categories to each other 0-5 seconds and 5-10 seconds were shown to still be statistically different with 95% confidence and a p-value of 0.0011. At 95% confidence 5-10 seconds was shown to be different than 10-20 seconds, which was statistically the same as 20-30 seconds each test having a p-value of 0.0242 and 0.1211 respectively. The final time lag category of greater than 30 seconds was shown to be statistically similar, but not necessarily identical, to the previous category of 20-30 seconds at the 95% confidence level having a p-value of 0.0657.

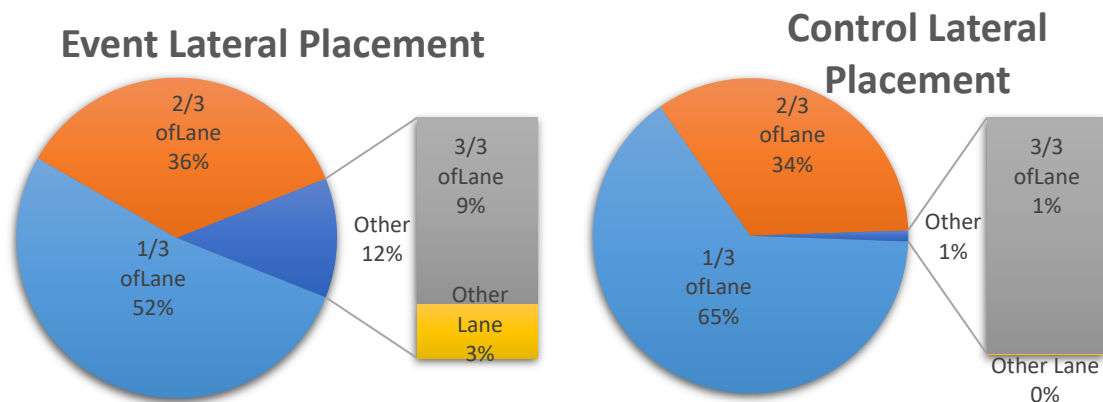


Figure 34. Site 1 Passenger Vehicles Only Lateral Placement Control vs Event After Installation.

RELIABILITY

Overview

Over the course of thirty-one days for site 1 and fifteen days for site 2 all bicycles observed were recorded with the arrival time, if the system detected them, and the type of bicycle. If each day consisted perfectly of thirteen hours of video footage there would have been approximately twenty-eight days of data for site 1. Unfortunately, due to lighting issues site 2 only had the equivalent of about twenty-two-hours.

All of the observed bicycles were placed into fifteen-minute bins based on the arrival time recorded. The EcoCounter produces only fifteen-minute bin data. Any instance where the device went off without the presence of a bicycle was recorded as a false positive. Information related to the incorrect detection; such as time of detection, what the object was, possible related speed, and direction was recorded. These false positives were then placed in fifteen-minute bins as well.

Both sets of binned data were compared to the EcoCounter bin data. For the correct detections error rate, the false positive bin data was subtracted from the EcoCounter bin data. The difference between fifteen-minute bins was then used to determine the under or over count. When determining the percentage of false positives, the same process was used except the difference between the false positives and EcoCounter's fifteen-minute bins were used.

Site 1

Site 1 over the course of the study period had 733 bicycles observed during the hours of interest from 6:30 to 19:30. The EcoCounter showed that there had been 706 observations recorded. Of these observations, the video records proved that 76 of the observations were not bicycles and instead false positives. Upon removing the false positive observations from the appropriate bins, 630 observations recorded by the EcoCounter were bicycles.

$$\text{Percent error} = \frac{\text{recorded value} - \text{exact value}}{\text{exact value}} * 100$$

Equation 1. Percent Error based on the recorded value versus the expected value.

The above equation, Equation 1, was used to determine the percent error. A negative value would represent an under count by the system whereas a positive value would represent an over count. In this case there was an under count of -14.05%. Of the 733 bicycles, a total of 103 were not recorded and therefore did not set the lights off on the warning sign. Table 21 shows all values used for calculating the percent error for the false positives and false negatives.

Table 21. Values used to calculate percent error for Site 1

Times Lights Flashed	Number of Bicycles	True Positives	False Positives	False Negatives
706	733	630	76	103

As stated above there were 76 times the lights flashed on the sign when a bicycle was not present. In these instances, the sign was normally triggered by a pickup truck or trailer. On occasion the lights were set off by cars, single unit trucks, tractor-trailers, and dual-purpose motorcycles. The speeds ranged from 17 miles per hour to 39 miles per hour with the mean, median, and mode being about 26, 26, and 27 miles per hour respectively. A majority of these false positives were also in the lane of interest. However, there were fifteen recorded in the opposing lane. There were two instances where it was not possible to determine what set the sign off. Based on total number of false positives and the total detections, using the formula above the error rate was found to be 10.76%. In other words, the system misidentified something as a bicycle 10.76% of the time the system registered an event.

Site 2

Due to the sun, only a limited number of bicycles could be linked to the system responding. Therefore, for site 2 there were only 101 bicycles recorded. These bicycles were primarily from 06:30:00 to 08:00:00. During the viable hours on the days recorded there were 78 instances that the system went off. There were no false positives recorded during the time used. Once again, Equation 1 used to determine the percent error for site 1 was used. In this case there was an undercount value of -22.77% given. Therefore, for site 2 of the 101 bicycles recorded 23 were missed and did not activate the sign. Table 22 shows all values used for calculating the percent error for the false negatives.

Table 22. Values used to calculate percent error for Site 2

Times Lights Flashed	Number of Bicycles	True Positives	False Negitives
78	101	78	23

Considering no false positives were recorded there is no way of determining the percent error of false positives. Care should also be taken when looking at the data for site 2. There is a lower reliability in the data for site 2 because of the lower number of observations. There is an expectation if the sun would not have prevented the collection of more data that site 2 would more resemble site 1.

CONCLUSIONS

Overview

The objective of this research project was to determine the effects and reliability of an automated bicycle detection and warning system. Before and after tests studied the effects such a device had on driver behavior on rural roadways. Reliability of the system was determined by performing research and tests on the Urban ZELT induction loops by EcoCounter. The research also provided a better understanding of driver behavior around bicycles on rural roadways.

Field data was collected before and after the installation at two sites. The sites were on Rim Rock Drive in Colorado National Monument just outside Grand Junction, Colorado. After all data was collected and processed several statistical tests were performed. This chapter summarizes the most important findings of these tests and the overall research.

Driver Behavior

Although not a primary objective of the research a baseline of driver behavior around bicycles was necessary. Data was collected before the installation of the system for passenger vehicles only and all vehicles excluding motorcycles when a bicycle was present. The reason motorcycles were excluded was that they behaved differently than all other vehicles. Motorcycles were not affected by the presence of a bicycle since they can

share the lane at the same time. Data when a bicycle was present was broken into time lag categories and compared to each other as well as when there was no bicycle present.

Drivers were affected by the presence of a bicycle up to four minutes after the bicycle was observed. Speeds appeared to be slower the closer the vehicle was to the bicycle. Lateral position usually appeared greater the closer the vehicle was observed to the bicycle as well. However, after ten seconds there was no difference in driver behavior with respect to lateral position whether a bicycle was present or not present.

Vehicles observed within ten seconds of the bicycle all appeared to behave similarly. All vehicles observed after ten seconds behaved similarly. This was generally true at both site 1 and site 2. Vehicles observed at site 2 greater than thirty seconds after a bicycle showed the same behavior as when there was no bicycle present. An increase in lateral position was also observed up to four minutes after the bicycle was observed. The exception was between twenty and thirty seconds. However, it is likely that the difference observed here would be significant with a larger number of data points.

Overall there was only a 5% increase in the number of vehicles observed in the left third and opposing lane at site 1 and a 7% increase at site 2. Over 70% utilized the right third of the lane whether a bicycle was present or not. There was an approximate average speed reduction at site 1 of 0.91 miles per hour from 29.27 miles per hour to 28.36 miles per hour. At site 2 there was only a 0.68 mile per hour reduction in speed on average from 25.44 miles per hour to 24.76 miles per hour. Passenger vehicles on average moved over more for bicyclists than the large vehicles. Unfortunately, passenger

vehicles also maintained a higher speed. Although passenger vehicles maintained a higher speed than large vehicles there was an overall greater reduction in average speed.

There was a definite difference in driver behavior between site 1 and site 2. Drivers at site 2 moved over in the lane less frequently than at site 1. They also maintained an average speed approximately 4 miles per hour slower whether a bicycle was present or not. As drivers moved over in the lane speeds tended to decrease. An exception occurs at site 1 when the vehicle was observed in the opposing lane. These drivers showed an increase in speed. One explanation for the differences between site 1 and site 2 could be roadway geometry. At site 2 there was a tunnel which may have influenced driver behavior. More study should be done investigating the effects of tunnels on driver behavior. One possible explanation for the increase in speed when the vehicle is in the opposing lane is the fact that drivers reacted more by changing lateral position to maintain higher speeds and wanted to return to their travel lane in as short a time as possible.

As time lag increased fewer vehicles were observed in the left third of the lane and more were observed in the right third. Drivers are more likely to react and change their position on the roadway the closer they are to the bicycle. As time lag increased so did speed. Once again, drivers were more likely to react and change their speed the closer they were to the bicycle. Even though there was some data to show a change in speed on average up to four minutes after the bicycle was observed, drivers primarily react to the presence of a bicycle only when it is within their field of view. Thus, lateral position was found to be the best measure of driver behavior.

Rim Rock Drive is fairly dangerous for bicyclists. There is about an 18.4 to 21.4 mile per hour difference in speed at site 1 and a 14.76 to 17.76 mile per hour difference in speed at site 2 between bicycles and vehicles. Considering the drivers reluctance to move over towards the centerline for bicyclists there is not only a speed issue but a spacing issue. The combination of high-speed differences and minimal space creates a dangerous situation which can and has led to accidents which include crashes, near misses, and drivers running cyclists off the road. This section of Rim Rock Drive was a prime candidate for the installation of a dynamic bicycle detection and warning device due to road geometry and limited site distance. The study also revealed that lateral position was a better predictor of driver behavior than speed.

Effectiveness

The primary objective of the project was to determine the effect an automated bicycle detection and warning system would have on driver behavior. If the system was effective drivers should move over and slow down more for bicycles after the installation of the system. In short, the system was effective and had both an effect when there was a bicyclist and when there was not a bicyclist. Drivers overall tended to slow down and move over more after the installation of the system at least at site 1. Due to limited data caused by the lighting at site 2 only assumptions can be made about the effectiveness of the system when a bicycle was present. The effects of the sign at both site 1 and site 2 can be discussed when no bicycle was present.

When the sign was installed driver behavior was changed. At both site 1 and site 2 there was an increase in the number of people moving over in the lane. At site 1 there was a reduction in speed, however, at site 2 an increase in speed was observed. As discussed in the driver behavior section large vehicles tended to move over in the lane less and maintain slower speeds than passenger vehicles. Thus, the passenger vehicle only data set had a higher speed than the without motorcycles data set.

Large and passenger vehicles showed a statistically significant reduction in speed of 1.73 mile per hour on average from 29.27 miles per hour to 27.54 miles per hour at site 1. However, on average drivers maintained a speed that was 2.54 miles per hour above the posted speed limit. A 9% reduction in the number of drivers using the right third of the lane along with an increase of 10% and 1% was observed in the number of drivers using the center and left third of the lane respectively. These changes were found to be significant at the 95% confidence level.

Site 2 behaved differently having a statistically significant increase in speed of 2.17 miles per hour from 25.44 miles per hour to 27.61 miles per hour. No explanation for the increase in speed can be given considering the reduction in speed at site 1. However, there was a continued increase in lateral position seen at site 2 with a reduction of 17% in the number of drivers in the right third of the lane. All of these drivers shifted into the center of the lane. The shift in drivers was found to be significant at the 95% confidence level. Before the installation of the sign at site 1 as drivers were observed farther left in the lane speed increased. However, after the installation as drivers moved over in the lane towards centerline a reduction in speed was observed matching site 2.

The sign by itself affected driver behavior. Both speed and lateral position were affected creating a safer environment for bicyclists. This is beneficial to know that even if the system does not activate, the bicyclist is in a safer environment than before the installation took place. Drivers are also now more likely to be found doing the speed limit or at least closer to it making the section of roadway at site 1 safer for all users.

Unfortunately, the section of roadway at site 2 has become more dangerous for all users if the system is not activated. There is a recommendation that the National Park Service continue to focus on the section of Rim Rock Drive that contains site 1 and site 2 for continued speed enforcement.

A change in driver behavior was observed when a bicycle was present after the installation of the system. Overall there appeared to be an increase in the number of drivers moving over for bicycles at site 1 and site 2. However, there appeared to be an increase in driver speed at site 2 and a reduction in speed at site 1. Unfortunately, due to the lighting at site 2 a break down into time lag categories could not be done with any meaningful results.

When time lag was taken into account a different story was told. The sign did not have any effect on driver behavior until after ten seconds. If the vehicle was observed within ten seconds of the bicyclist there was no change in driver behavior from before the system was installed. However, after ten seconds there was a statistical increase in the amount and frequency that drivers moved over for the bicyclists. Speed was not affected until after 30 seconds where a reduction in speed of 1.77 miles per hour was observed.

Overall there was an average 1.52 mile per hour reduction in speed from 28.36 miles per hour to 26.84 miles per hour. There were 18% fewer drivers observed in the right third of the lane. Of those drivers 13% moved over to the center of the lane and 5% shifted to the left third of the lane. Before and after the installation the larger the time lag the more vehicles were observed in the right third of the lane and the less were observed in the left third and opposing lane. As drivers moved over for bicycles the slower the vehicle was observed.

After the installation of the system there was an increase in the number of drivers moving over for bicycles and reducing speed. Unfortunately, there was no statistical effect under ten seconds for lateral position or under thirty seconds for speed. One explanation for lateral placement is that drivers observed within ten seconds of the bicyclist are already reacting to the bicycle. Thus, the flashing lights on the sign have no effect, but after ten seconds the sign encourages drivers to move over earlier or more for the bicycle. The explanation for speed is similar in that the driver slows down first and then adjusts lateral position. Thus, the difference in speed would be observed later and in this case after thirty seconds. There did appear to be a difference in speed at 0 to 5 seconds, 5 to 10 seconds, and 10 to 20 seconds, but these were shown not to be statistically significant. It would be advisable to collect data for a longer period of time than the two weeks before-installation and four weeks after-installation at site 1. Hopefully with a longer data collection period more events can be observed in time lag categories 0 to 5 seconds, 5 to 10 seconds, 10 to 20 seconds, and 20 to 30 seconds to confirm or refute the statistical insignificance of the speed differences.

There is no doubt of the effects the system had on driver behavior. Drivers more frequently utilized the center and left third of the lane and slowed down. Unfortunately, both before and after the installation the majority, as in over 50%, of the drivers still stayed in the right third of the lane. Drivers also maintained speeds greater than the posted speed limit of 25 mile per hour after the installation. Even though the roadway was in theory made safer for all users, Rim Rock Drive is still fairly dangerous for bicyclists. On average there is still a 16 to 19 mile per hour difference in speed between vehicles and bicycles. Therefore, even though the dynamic bicycle detection and warning sign had an effect on drivers, the cost effectiveness and true effectiveness of such a system can be called into question. Further study within the United States of America is advisable.

Reliability

Considering the system was effective in reducing speed and encouraging drivers to move over more for bicycles, these findings would be less than significant if the system was not reliable. Site 1 and site 2 were definitely different. Unfortunately, due to lighting very little of data collected at site 2 was usable. However, at site 1 it was found that the system was 85.95% reliable. Misidentifications occurred 10.76% of the time. The majority of these misidentifications were trucks and vehicles with trailers. It is unclear the reasoning behind these being the majority of misidentifications. Some reasons for misidentification could include the following:

- Stopping over the sensor
- Trailers and pickup beds inducing a current after the vehicle was expected to have passed. Thus, the sensor would think there was a bicycle following close behind a motor vehicle.
- Opposing lane vehicles could have induced currents similar to bicycles
- Dual-purpose motorcycles can induce currents similar to ferrous bicycles

Site 2 should not be considered as a prime example to show the reliability of the system due to the limited data collected. However, the reliability should still be reported. At site 2 the system was 77.33% reliable. Reliability was solely based on the reliability of the Urban ZELT by EcoCounter considering there were no observed failures in communication between the counter and the sign. Some of the reasons for the system not being activated could include the following:

- The bicyclist not riding over the induction loops. Not riding over the induction loops involved the bicyclist taking the opposing lane to avoid the loops, riding over the outside edge of the loops, or riding through the three inches between the loops.
- Bicycles riding over the induction loops in groups. A tight group can be described as any combination of bicycle riding configurations such as side-by-side or right behind one another.
- The bicycle was not of standard configuration or expected ferrous composition. Although there were only a few tandem bicycles observed not all were detected. There was no possible way to determine the material composition of the bicycles observed. However, the area is known to have many cyclists with carbon fiber bicycles.

An assumption can be made that the system can detect bicycles of different configurations, material compositions, and riding configurations. The system was able to detect tandem and recumbent bicycles. Some of the time bicyclists riding side-by-side, one behind the other, or a combination of the two were also detected. However, the Urban ZELT bicycle counter from EcoCounter may be less reliable when encountering these situations.

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APPENDICES

APPENDIX A

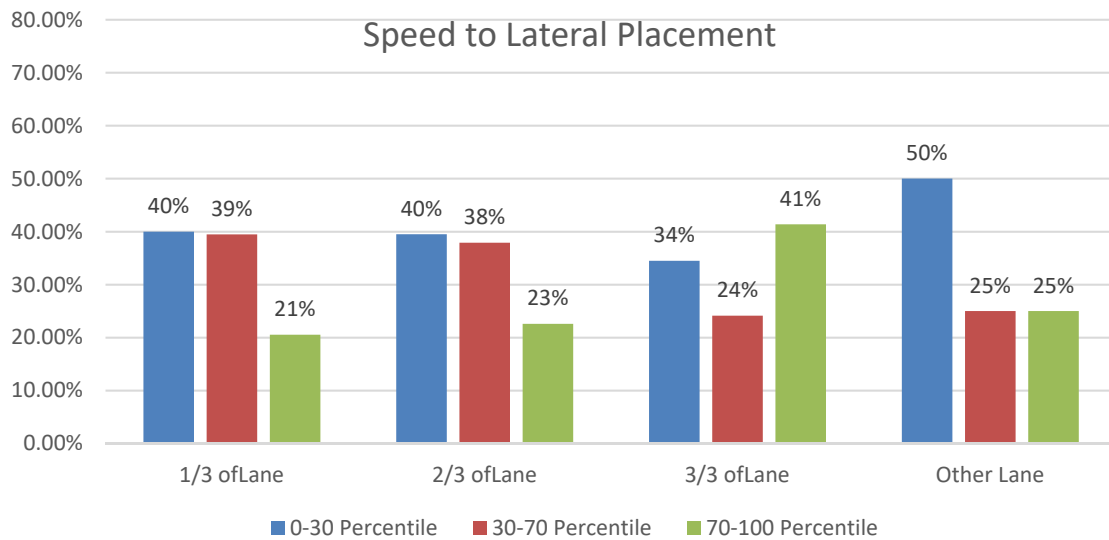
BEFORE INSTALLATION DATA

Site 1 Before Installation Control Statistical Summary Speed all data

<i>All Data</i>	<i>Speed</i>
Mean	29.28265107
Standard Error	0.097844555
Median	29
Mode	30
Standard Deviation	3.134081915
Sample Variance	9.822469453
Kurtosis	1.457211011
Skewness	0.027359254
Range	29
Minimum	13
Maximum	42
Sum	30044
Count	1026

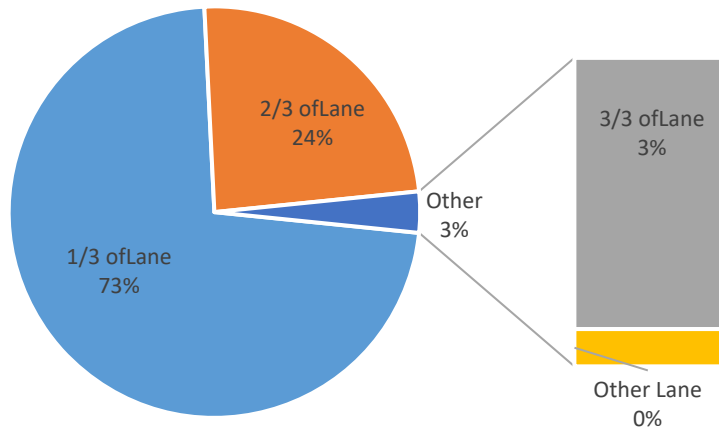
Site 1 Before Installation All Control Data Correlation

<i>All Data</i>	<i>Speed</i>	<i>Class</i>	<i>Lateral Placement</i>
Speed	1		
Class	-0.12989138	1	
Lateral Placement	0.031064308	-0.095464	1



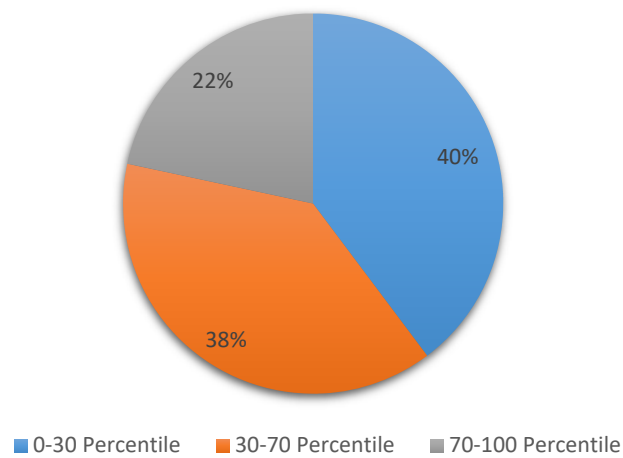
Site 1 Before Installation All Control Data for Speed vs Lateral Placement

Lateral Placement Control



Site 1 Before Installation All Data Control Lateral Placement

Speed Control



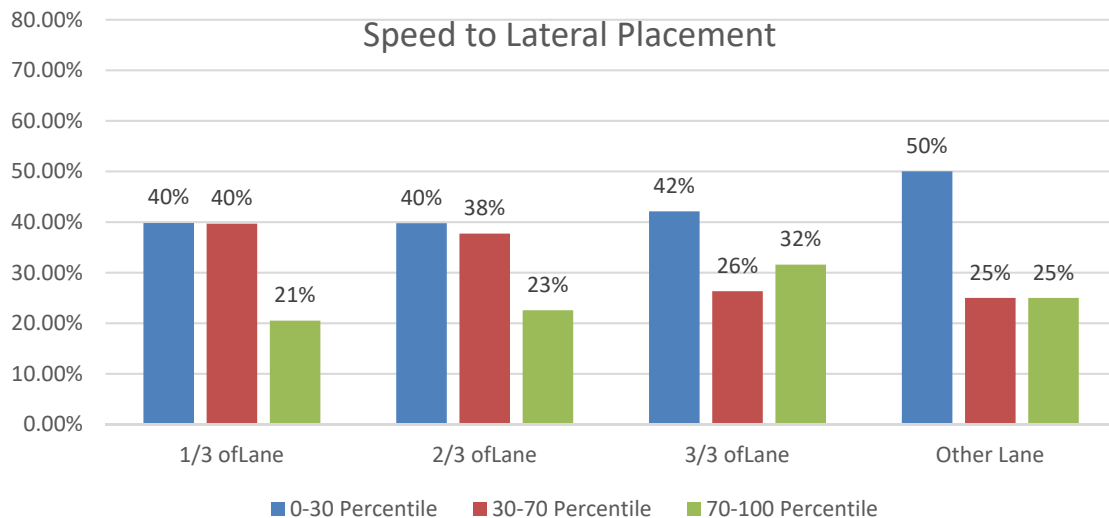
Site 1 Before Installation All Data Control Speed

Site 1 Before Installation Without Motorcycles Control Data Statistical Speed Summary

<i>Without Motorcycles</i>	<i>Speed</i>
Mean	29.27380952
Standard Error	0.09669364
Median	29
Mode	30
Standard Deviation	3.06992791
Sample Variance	9.42445737
Kurtosis	1.032647072
Skewness	0.152133293
Range	24
Minimum	18
Maximum	42
Sum	29508
Count	1008

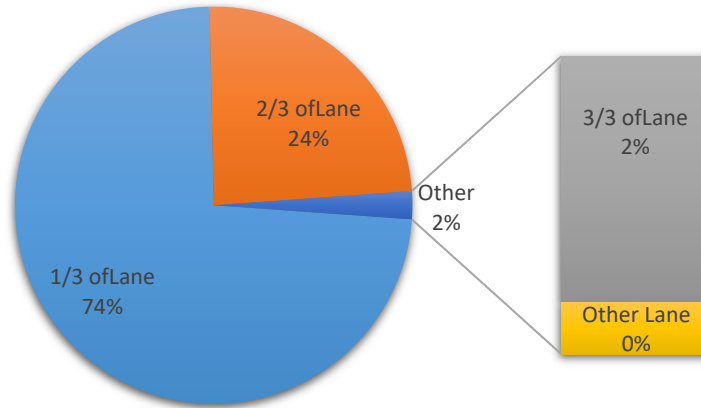
Site 1 Before Installation Without Motorcycles Control Data Correlation

<i>Without Motorcycles</i>	<i>Speed</i>	<i>Class</i>	<i>Lateral Placement</i>
Speed	1		
Class	-0.144152697	1	
Lateral Placement	0.000312208	0.047571648	1



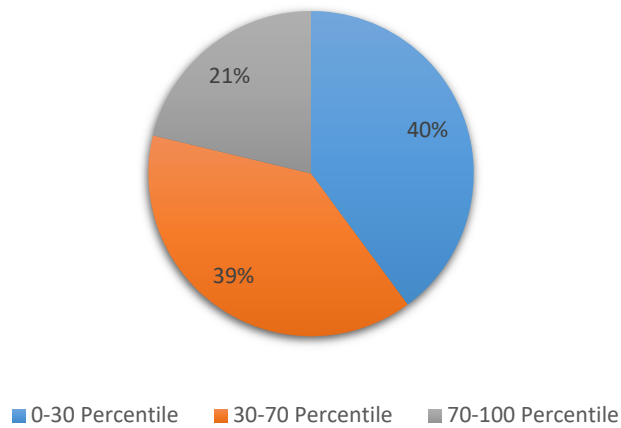
Site 1 Before Installation Without Motorcycles Control Data for Speed vs Lateral Placement

Site 1 Lateral Placement Control



Site 1 Before Installation Without Motorcycles Data Control Lateral Placement

Speed Site 1 Control Before



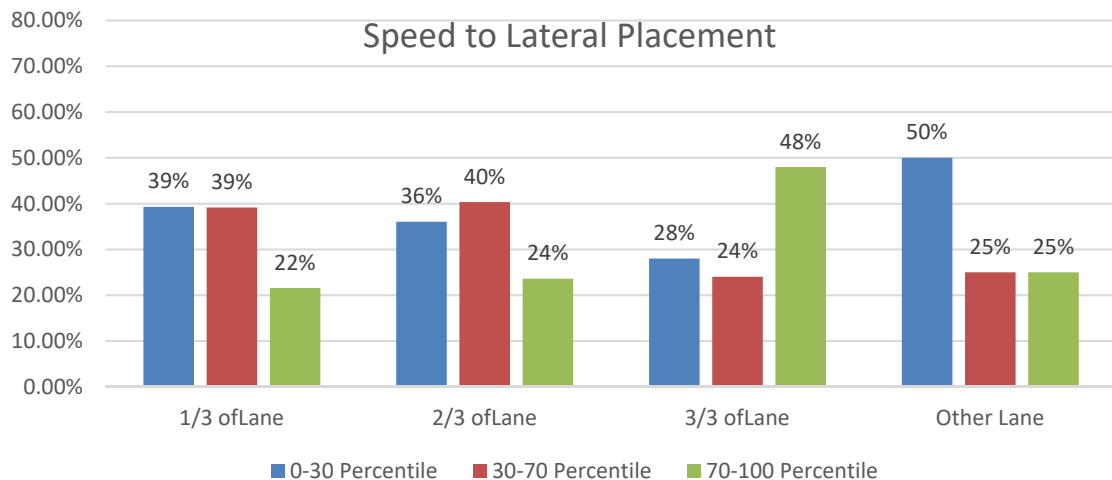
Site 1 Before Installation Without Motorcycles Data Control Speed

Site 1 Before Installation Without Large Vehicles Control Data Statistical Speed Summary

<i>Without Large Vehicles</i>	<i>Speed</i>
Mean	29.38580247
Standard Error	0.10056106
Median	29
Mode	30
Standard Deviation	3.135183564
Sample Variance	9.829375977
Kurtosis	1.417057968
Skewness	0.031964499
Range	29
Minimum	13
Maximum	42
Sum	28563
Count	972

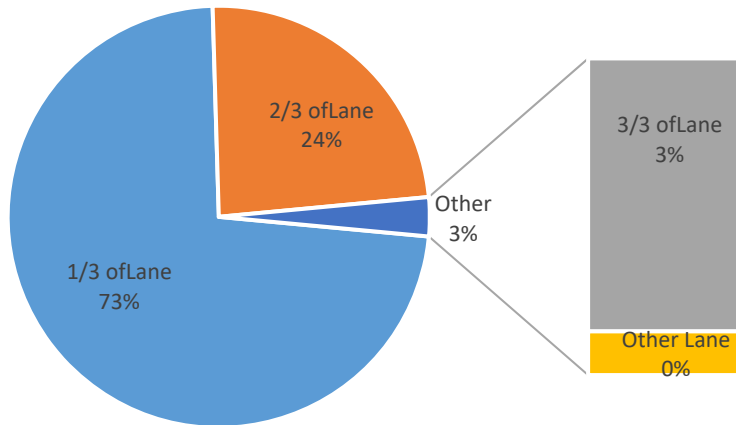
Site 1 Before Installation Without Large Vehicles Control Data Correlation

<i>Without Large Vehicles</i>	<i>Speed</i>	<i>Class</i>	<i>Lateral Placement</i>
Speed	1		
Class	-0.018637455	1	
Lateral Placement	0.053997309	-0.24648855	1



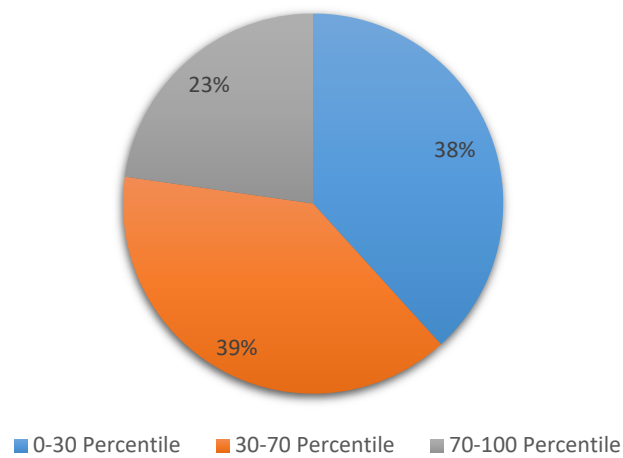
Site 1 Before Installation Without Large Vehicles Control Data for Speed vs Lateral Placement

Lateral Placement Control



Site 1 Before Installation Without Large Vehicles Data Control Lateral Placement

Speed Control



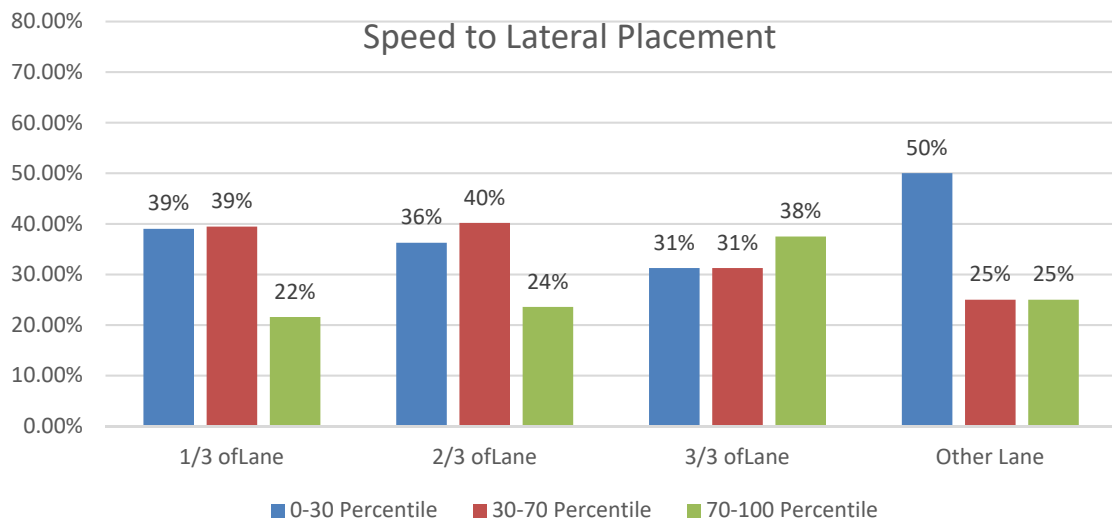
Site 1 Before Installation Without Large Vehicles Data Control Speed

Site 1 Before Installation Passenger Vehicles Only Control Data Statistical Speed Summary

<i>Passenger Vehicles Only</i>	<i>Speed</i>
Mean	29.37801047
Standard Error	0.099216741
Median	29
Mode	30
Standard Deviation	3.066102324
Sample Variance	9.400983459
Kurtosis	0.94770892
Skewness	0.169557757
Range	23
Minimum	19
Maximum	42
Sum	28056
Count	955

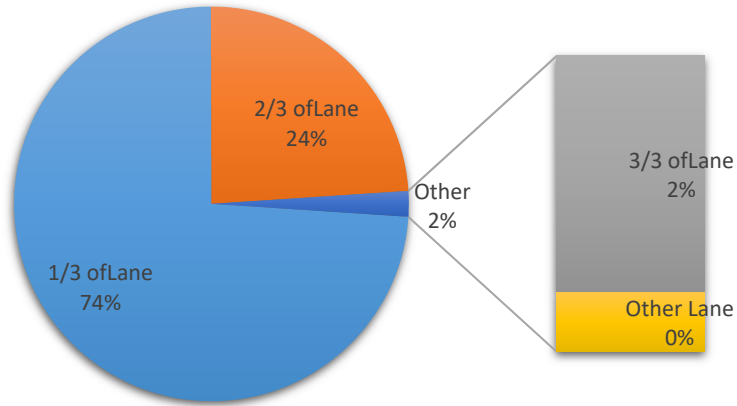
Site 1 Before Installation Passenger Vehicles Only Control Data Correlation

<i>Passenger Vehicles Only</i>	<i>Speed</i>	<i>Lateral Placement</i>
Speed	1	
Lateral Placement	0.023864854	1



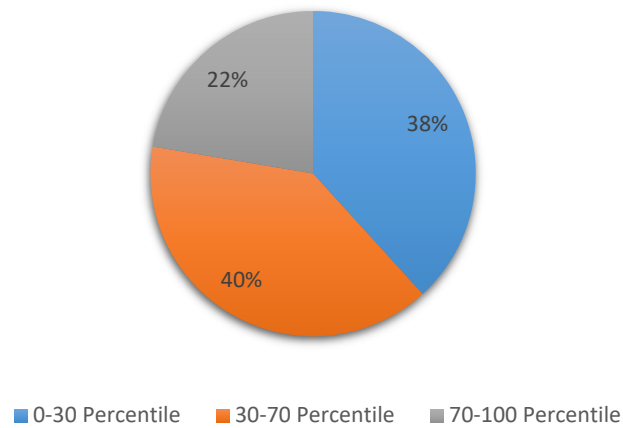
Site 1 Before Installation Passenger Vehicles Only Control Data for Speed vs Lateral Placement

Lateral Placement Control



Site 1 Before Installation Passenger Vehicles Only Data Control Lateral Placement

Speed Control



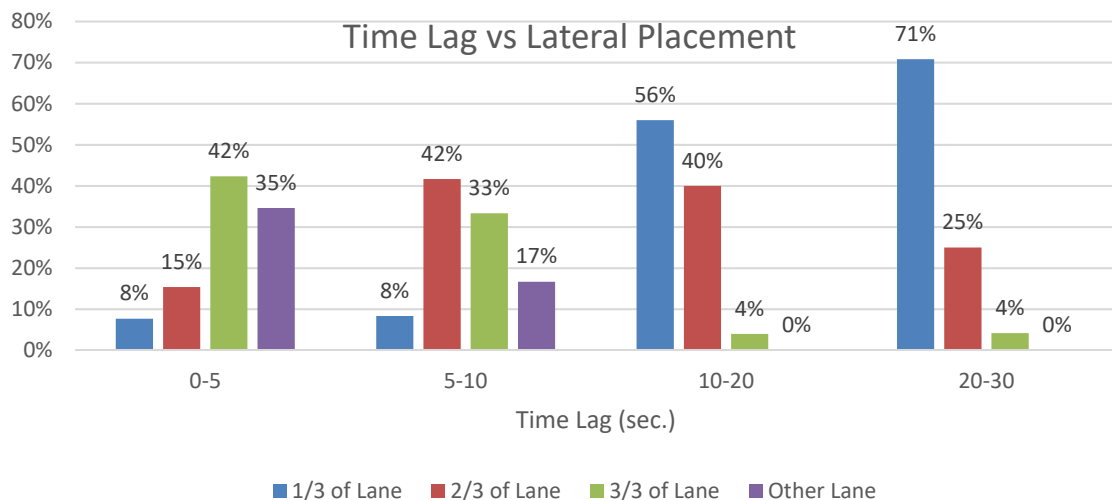
Site 1 Before Installation Passenger Vehicles Only Data Control Speed

Site 1 Before Installation Event Statistical Summary of Speed, Time Lag, and Time Between for all data

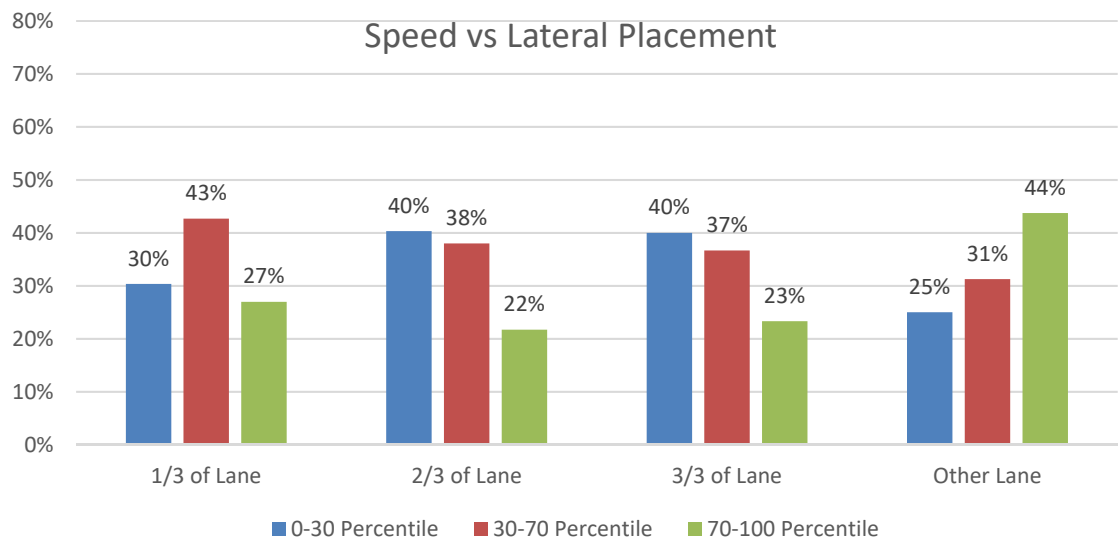
<i>All Data</i>	<i>Speed</i>	<i>Time Lag (s)</i>	<i>Time Between V&OPV (s)</i>
Mean	28.37030411	118.1505885	121.3968157
Standard Error	0.149722988	3.093416744	5.254865927
Median	29	117.0000387	81.99995568
Mode	28	1.999999839	43.99996188
Standard Deviation	3.539927669	73.13821147	124.2417454
Sample Variance	12.5310879	5349.197978	15436.01129
Kurtosis	1.829612919	-1.07183164	8.74403357
Skewness	-0.659235035	-0.03839491	2.46821898
Range	26	426.0000065	847.9566012
Minimum	13	-107.999968	1.94879E-05
Maximum	39	318.0000385	847.9566207
Sum	15859	66046.17898	67860.81995
Count	559	559	559
Confidence Level(95.0%)	0.294089552	6.076164791	10.32173612

Site 1 Before Installation Event Correlation for all data

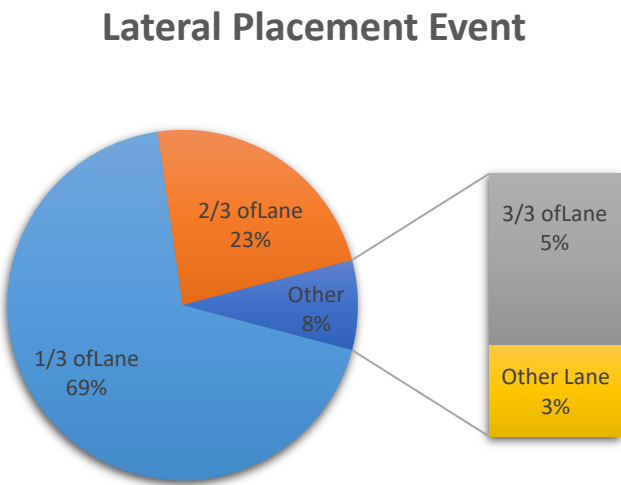
<i>All Data</i>	<i>Speed</i>	<i>Class</i>	<i>Lateral Placement</i>	<i>Time Lag Cat.</i>	<i>Time Between Cat.</i>
Speed	1				
Class	-0.046933732	1			
Lateral Placement	-0.076847359	-0.16355992	1		
Time Lag Cat.	0.214747711	-0.01326553	-0.502280393	1	
Time Between Cat.	0.006485114	0.11227667	0.028845642	-0.077223266	1



Site 1 Before Installation All Event Data Time Lag vs Lateral Placement

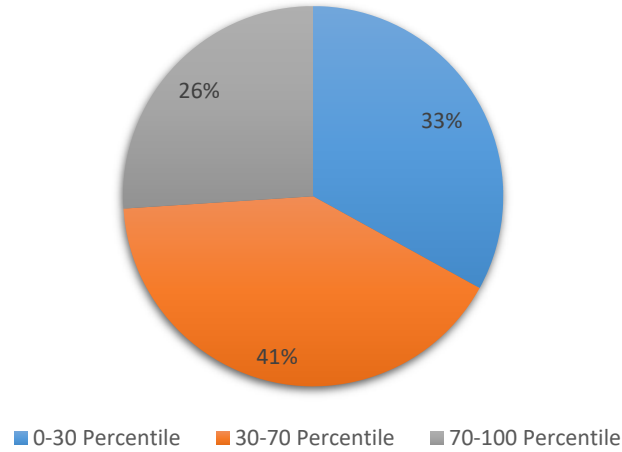


Site 1 Before Installation All Event Data Speed vs Lateral Placement



Site 1 Before Installation All Data Event Lateral Placement

Speed Event



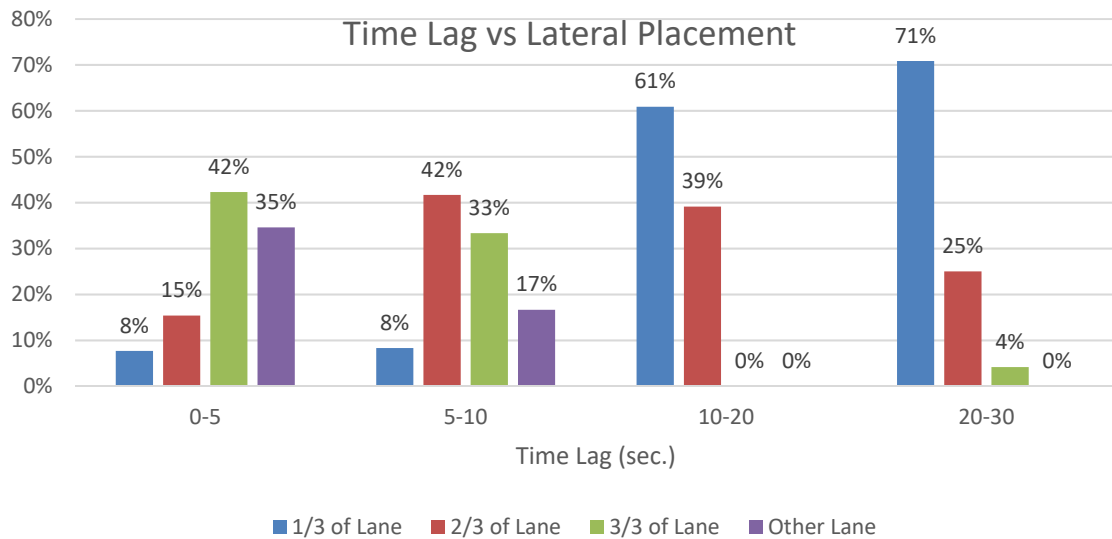
Site 1 Before Installation All Data Event Speed

Site 1 Before Installation Event Statistical Summary of Speed, Time Lag, and Time Between for without motorcycles data

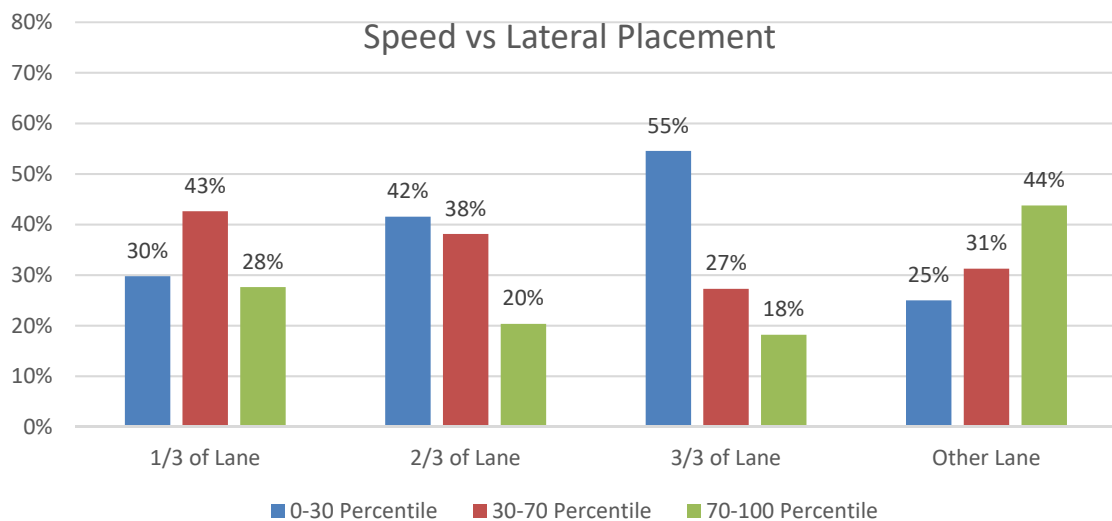
<i>Without Motorcycles</i>	<i>Speed</i>	<i>Time Lag (s)</i>	<i>Time Between (s)</i>
Mean	28.35660377	116.4003376	119.6656981
Standard Error	0.151881847	3.189455304	5.052198806
Median	29	116.0000001	82.9999776
Mode	28	1.999999839	43.99996188
Standard Deviation	3.496582692	73.42677523	116.3103511
Sample Variance	12.22609052	5391.491321	13528.09777
Kurtosis	1.742638433	-1.062404209	8.498021707
Skewness	-0.666786664	0.005639395	2.363304618
Range	26	426.0000065	847.9566012
Minimum	13	-107.999968	1.94879E-05
Maximum	39	318.0000385	847.9566207
Sum	15029	61692.17891	63422.81998
Count	530	530	530
Confidence Level(95.0%)	0.298365589	6.265552686	9.924835052

Site 1 Before Installation Event Correlation for without motorcycles data

Without Motorcycles	Speed	Class	Lateral Placement	Time Lag Cat.	Time Between Cat.
Speed	1				
Class	-0.053083558	1			
Lateral Placement	-0.117728819	-0.07322762	1		
Time Lag Cat.	0.233385795	0.041922607	-0.532768958	1	
Time Between Cat.	0.008433138	0.034939377	0.048837569	-0.067455275	1

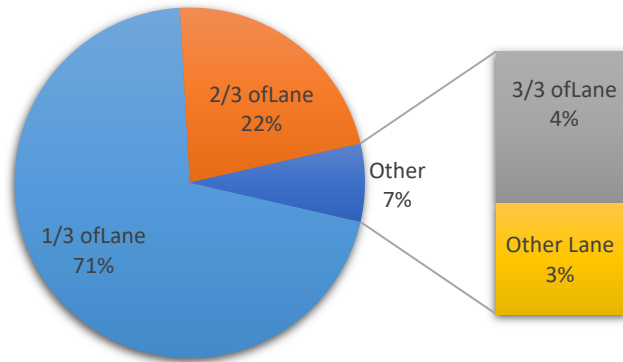


Site 1 Before Installation Without Motorcycles Event Data Time Lag vs Lateral Placement



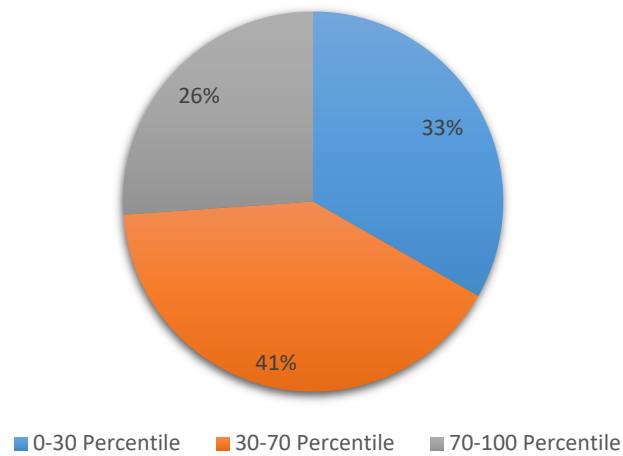
Site 1 Before Installation Without Motorcycles Event Data Speed vs Lateral Placement

Lateral Placement Event



Site 1 Before Installation Without Motorcycles Event Data Lateral Placement

Speed Event



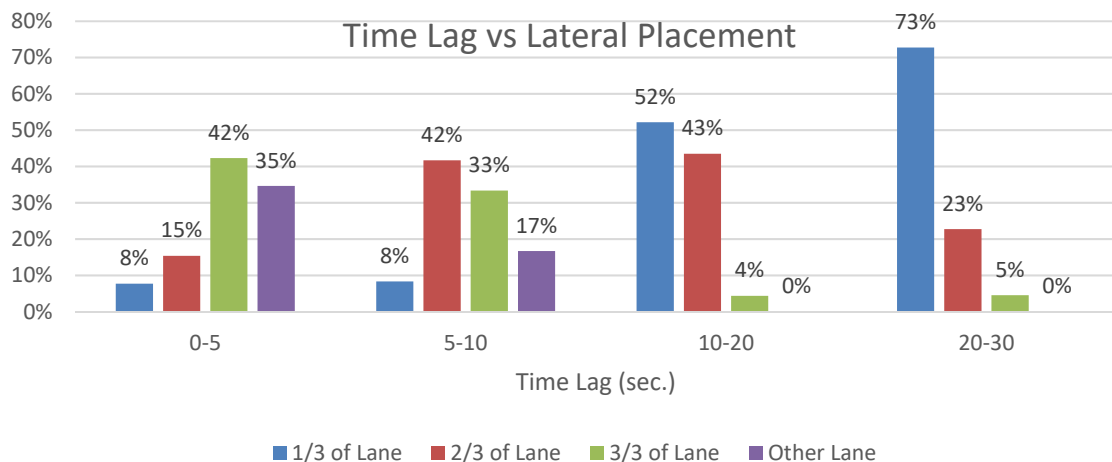
Site 1 Before Installation Without Motorcycles Event Speed Data

Site 1 Before Installation Event Statistical Summary of Speed, Time Lag, and Time Between for without large vehicles data

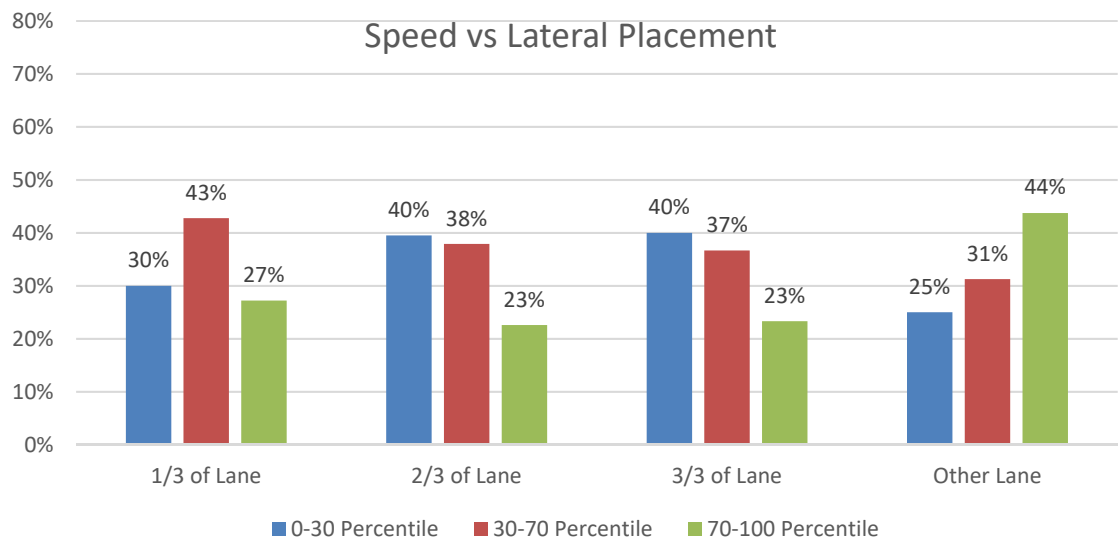
<i>Without Large Vehicles</i>	<i>Speed</i>	<i>Time Lag (s)</i>	<i>Time Between (s)</i>
Mean	28.41242938	116.8590935	121.293447
Standard Error	0.151678453	3.160750217	5.446656952
Median	29	117.0000003	81.99995568
Mode	28	1.999999839	43.99996188
Standard Deviation	3.495192916	72.83454927	125.5096977
Sample Variance	12.21637352	5304.871568	15752.68421
Kurtosis	2.009215543	-1.038073606	8.831102124
Skewness	-0.754725414	-0.013791502	2.49905958
Range	25	426.0000065	847.9566012
Minimum	13	-107.999968	1.94879E-05
Maximum	38	318.0000385	847.9566207
Sum	15087	62052.17864	64406.82037
Count	531	531	531
Confidence Level(95.0%)	0.297964742	6.209135869	10.69968543

Site 1 Before Installation Event Correlation for without larges vehicles data

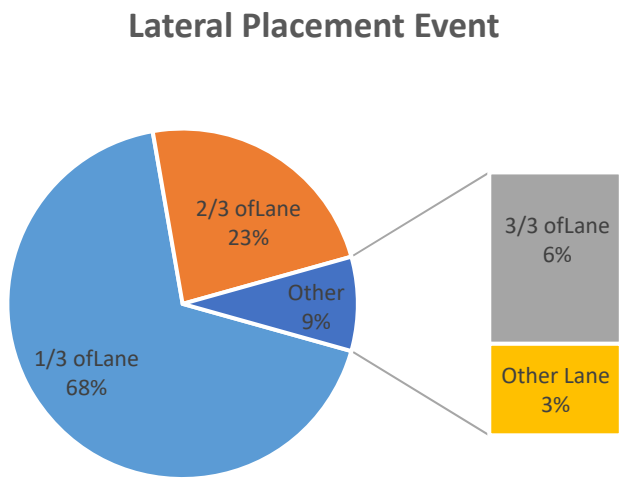
<i>Without Large Vehicles</i>	<i>Speed</i>	<i>Class</i>	<i>Lateral Placement</i>	<i>Time Lag Cat.</i>	<i>Time Between Cat.</i>
Speed	1				
Class	-0.014334804	1			
Lateral Placement	-0.076408921	-0.15582651	1		
Time Lag Cat.	0.220617818	-0.05958194	-0.508717081	1	
Time Between Cat.	-0.007435314	0.121692161	0.038346945	-0.084188721	1



Site 1 Before Installation Without Large Vehicles Event Data Time Lag vs Lateral Placement

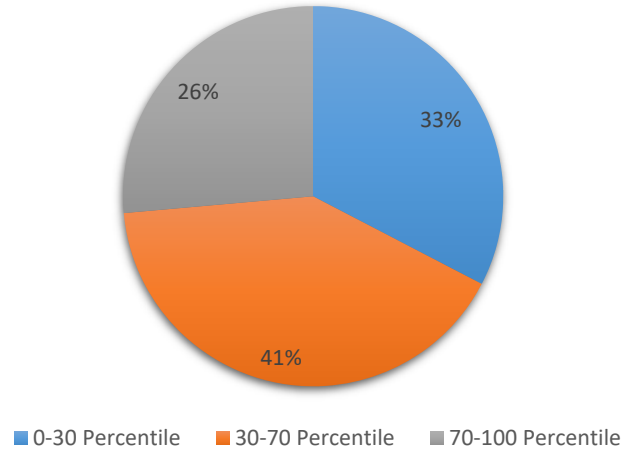


Site 1 Before Installation Without Large Vehicles Event Data Speed vs Lateral Placement



Site 1 Before Installation Without Large Vehicles Event Data Lateral Placement

Speed Event



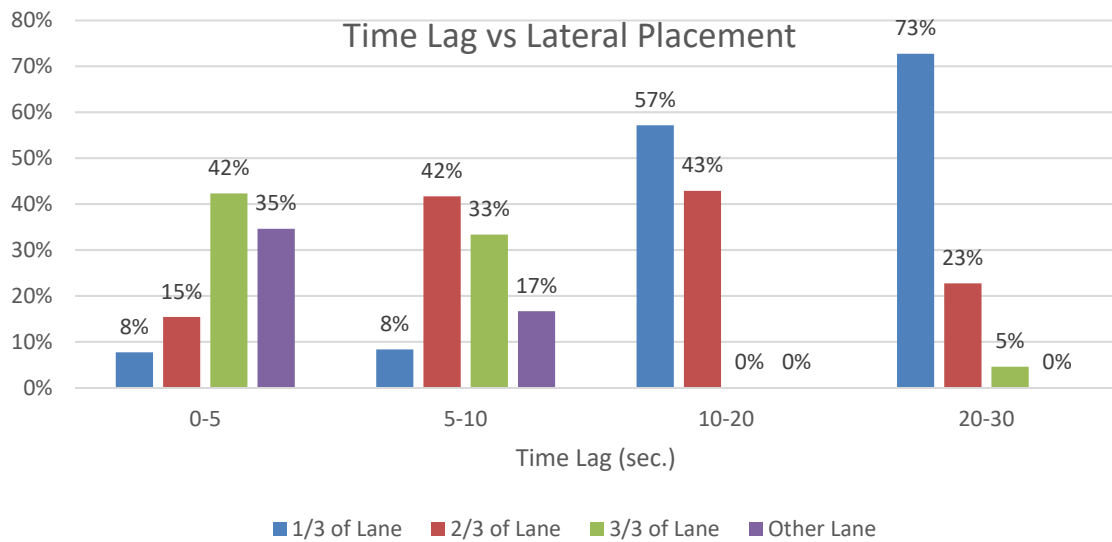
Site 1 Before Installation Without Large Vehicles Event Speed Data

Site 1 Before Installation Event Statistical Summary of Speed, Time Lag, and Time Between for passenger vehicle only data

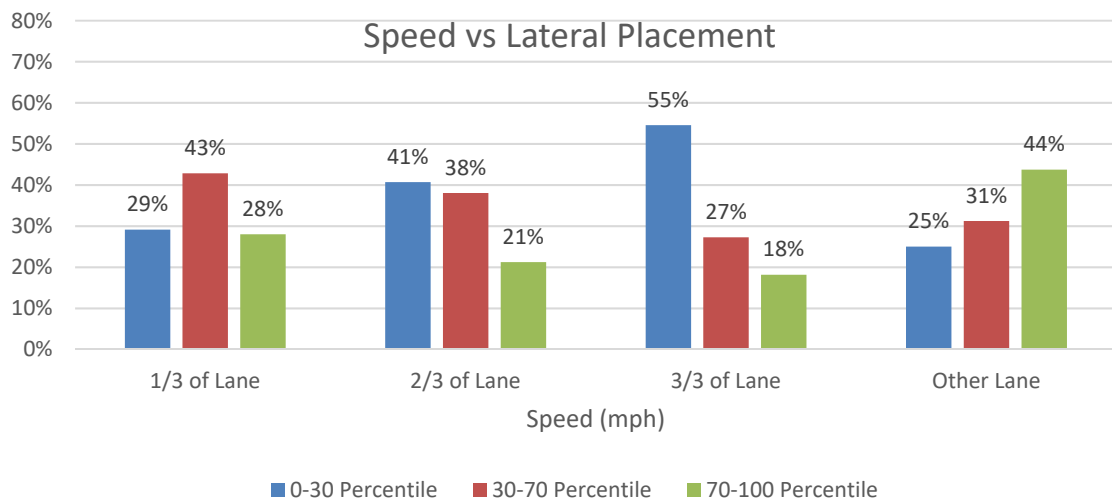
<i>Passenger Vehicles Only</i>	<i>Speed</i>	<i>Time Lag (s)</i>	<i>Time Between (s)</i>
Mean	28.40039841	114.9366107	119.4598016
Standard Error	0.153817849	3.262005431	5.23470894
Median	29	115.5000003	82.9999776
Mode	28	1.999999839	43.99996188
Standard Deviation	3.446343754	73.0863946	117.28552
Sample Variance	11.87728527	5341.621076	13755.8932
Kurtosis	1.922938641	-1.021807737	8.686587192
Skewness	-0.771716852	0.034195697	2.405921245
Range	25	426.0000065	847.9566012
Minimum	13	-107.999968	1.94879E-05
Maximum	38	318.0000385	847.9566207
Sum	14257	57698.17858	59968.8204
Count	502	502	502
Confidence Level(95.0%)	0.302207517	6.408895742	10.28468669

Site 1 Before Installation Event Correlation for Passenger vehicles only data

<i>Passenger Vehicles Only</i>	<i>Speed</i>	<i>Lateral Placement</i>	<i>Time Lag Cat.</i>	<i>Time Between Cat.</i>
Speed	1			
Lateral Placement	-0.118794405	1		
Time Lag Cat.	0.240913022	-0.539994793	1	
Time Between Cat.	-0.007044551	0.058739406	-0.074427785	1

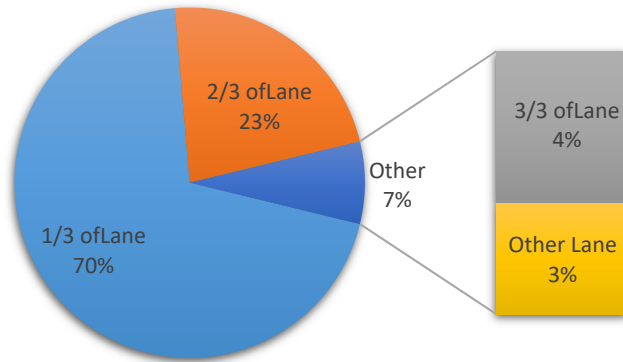


Site 1 Before Installation Passenger Vehicles Only Event Data Time Lag vs Lateral Placement



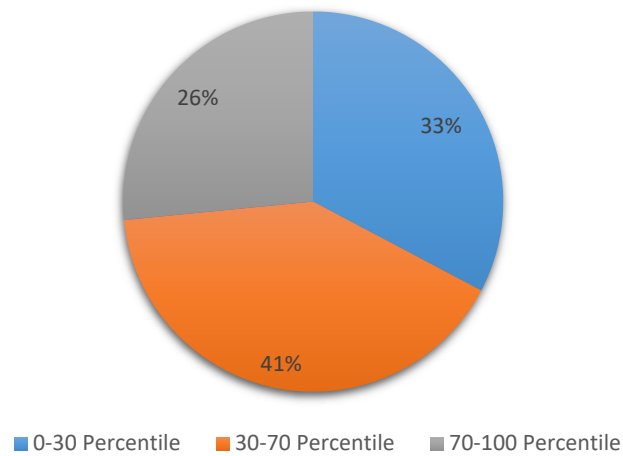
Site 1 Before Installation Passenger Vehicles Only Event Data Speed vs Lateral Placement

Lateral Placement Event



Site 1 Before Installation Passenger Vehicles Only Event Lateral Placement

Speed Event



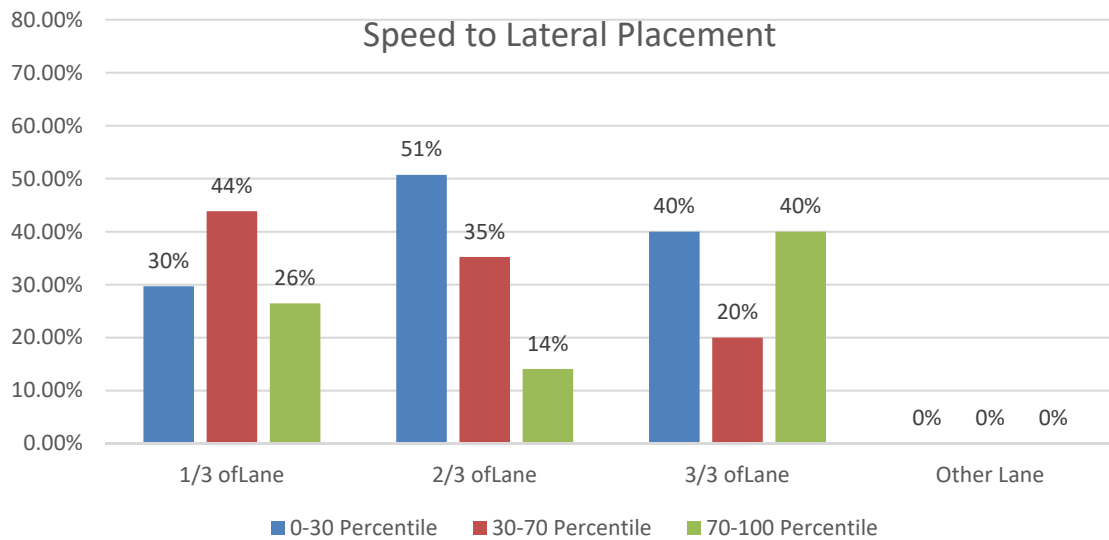
Site 1 Before Installation Passenger Vehicles Only Event Speed Data

Site 2 Before Installation Control Statistical Summary Speed all data

<i>All Data</i>	<i>Speed</i>
Mean	25.46161322
Standard Error	0.131700362
Median	26
Mode	29
Standard Deviation	4.224688154
Sample Variance	17.84799
Kurtosis	-0.168394628
Skewness	-0.226735413
Range	24
Minimum	13
Maximum	37
Sum	26200
Count	1029

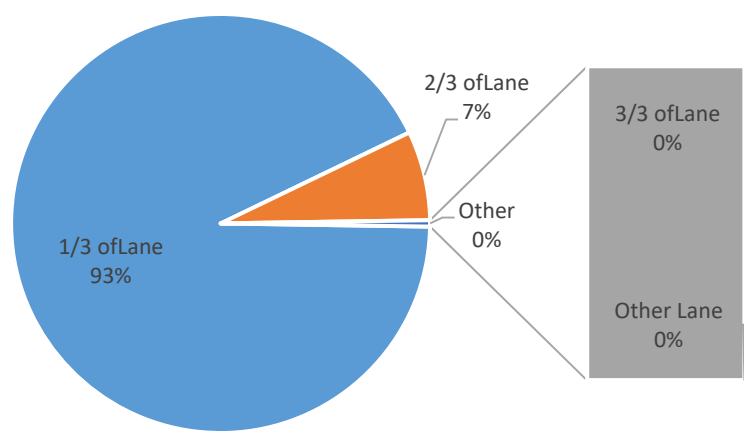
Site 2 Before Installation All Control Data Correlation

<i>All Data</i>	<i>Speed</i>	<i>Class</i>	<i>Lateral Placement</i>
Speed	1		
Class	-0.057654398	1	
Lateral Placement	-0.114273041	-0.185118646	1



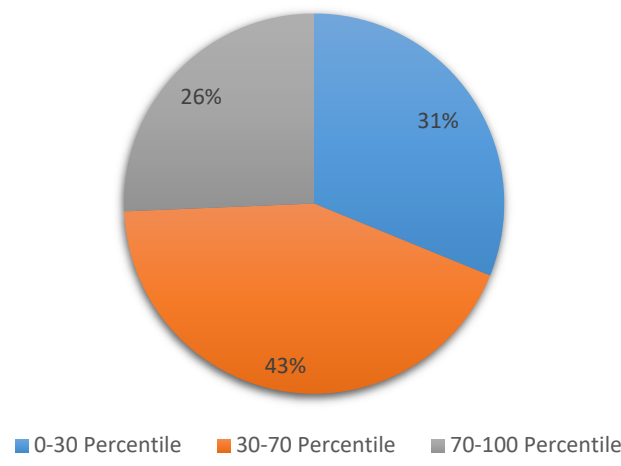
Site 2 Before Installation All Control Data for Speed vs Lateral Placement

Site 2 Lateral Placement Control



Site 2 Before Installation All Data Control Lateral Placement

Speed Control



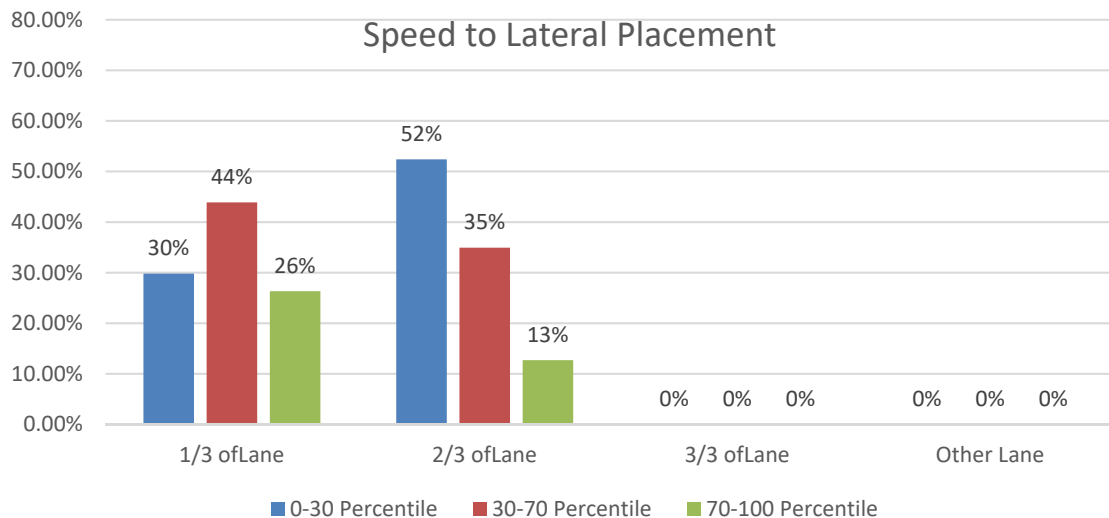
Site 2 Before Installation All Data Control Speed

Site 2 Before Installation Without Motorcycles Control Data Statistical Speed Summary

<i>Without Motorcycles</i>	<i>Speed</i>
Mean	25.44301288
Standard Error	0.132347804
Median	26
Mode	29
Standard Deviation	4.203996261
Sample Variance	17.67358456
Kurtosis	-0.17750749
Skewness	-0.24918536
Range	23
Minimum	13
Maximum	36
Sum	25672
Count	1009

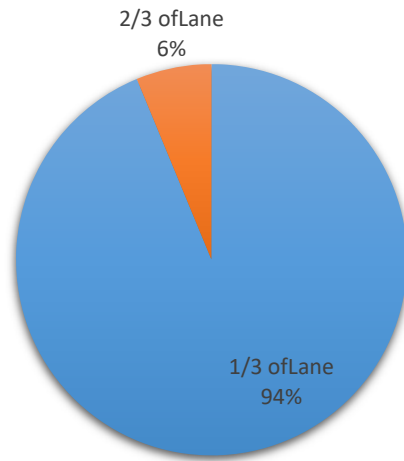
Site 2 Before Installation Without Motorcycles Control Data Correlation

<i>Without Motorcycles</i>	<i>Speed</i>	<i>Class</i>	<i>Lateral Placement</i>
Speed	1		
Class	-0.049208075	1	
Lateral Placement	-0.141265121	0.026266618	1



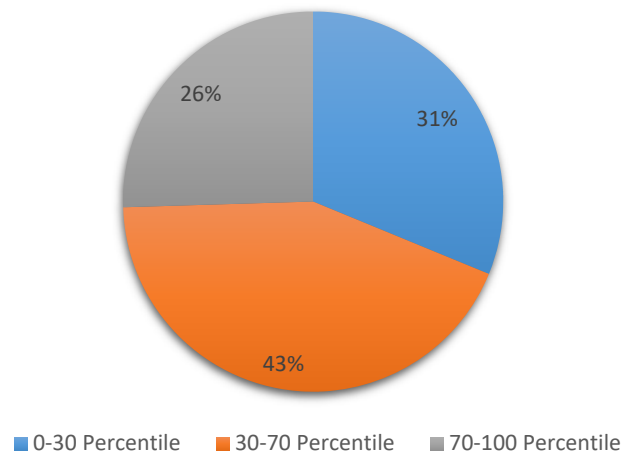
Site 2 Before Installation Without Motorcycles Control Data for Speed vs Lateral Placement

Site 2 Lateral Placement Control



Site 2 Before Installation Without Motorcycles Data Control Lateral Placement

Speed Control



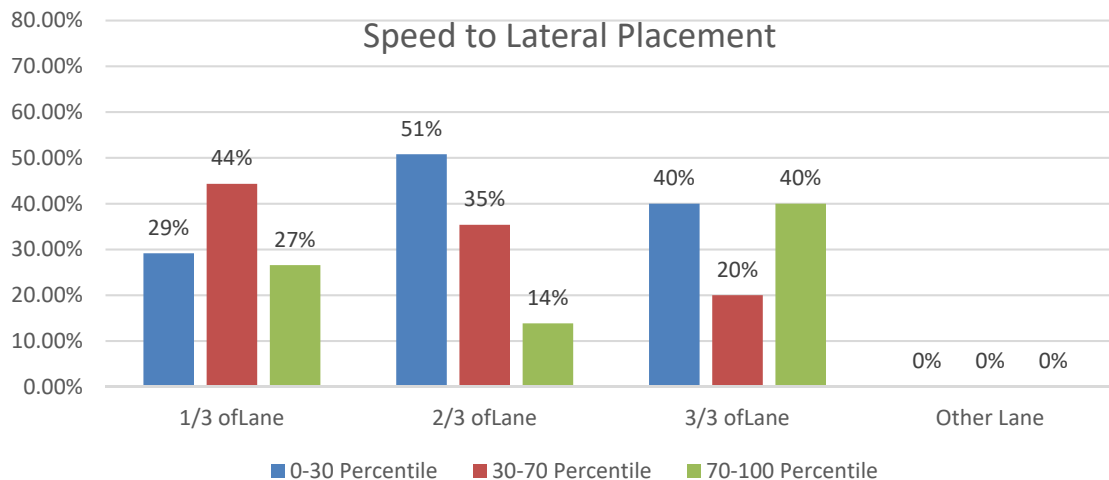
Site 2 Before Installation Without Motorcycles Data Control Speed

Site 2 Before Installation Without Large Vehicles Control Data Statistical Speed Summary

<i>Without Large Vehicles</i>	<i>Speed</i>
Mean	25.51824818
Standard Error	0.135682487
Median	26
Mode	27
Standard Deviation	4.201777964
Sample Variance	17.65493806
Kurtosis	-0.14666353
Skewness	-0.23529266
Range	24
Minimum	13
Maximum	37
Sum	24472
Count	959

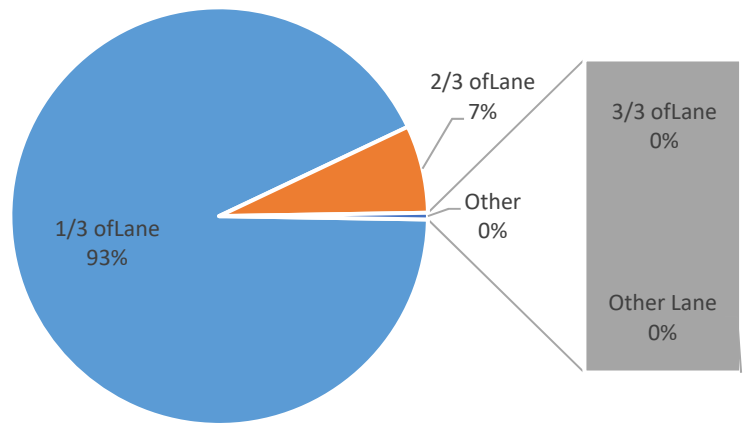
Site 2 Before Installation Without Large Vehicles Control Data Correlation

<i>Without Large Vehicles</i>	<i>Speed</i>	<i>Class</i>	<i>Lateral Placement</i>
Speed	1		
Class	-0.030642346	1	
Lateral Placement	-0.118305529	-0.417514202	1



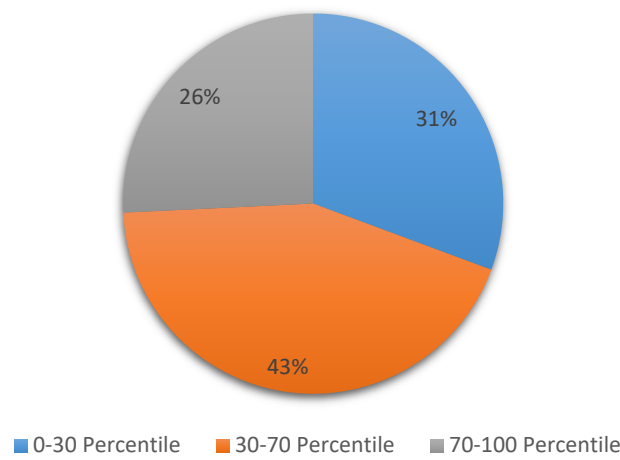
Site 2 Before Installation Without Large Vehicles Control Data for Speed vs Lateral Placement

Lateral Placement Control



Site 2 Before Installation Without Large Vehicles Data Control Lateral Placement

Speed Control



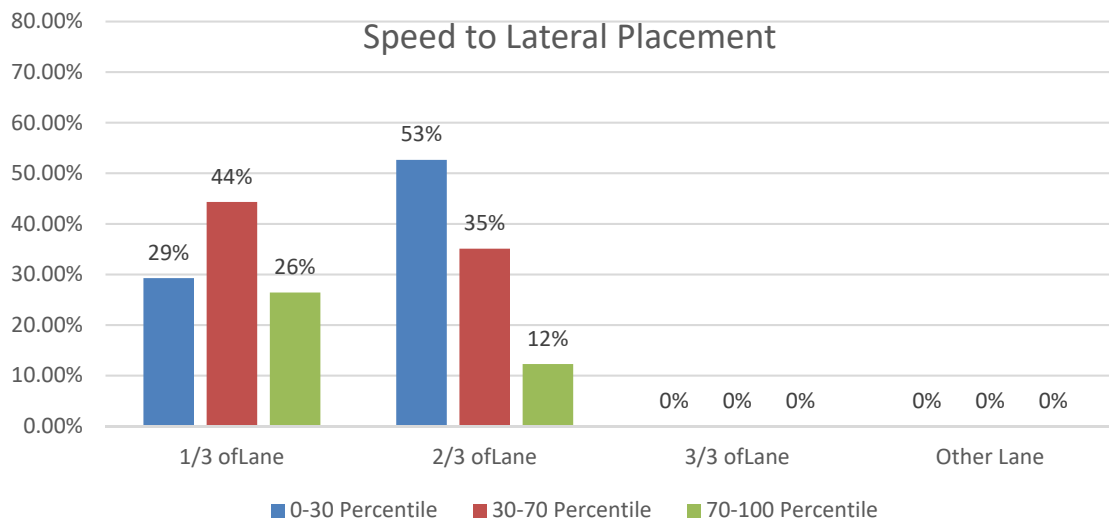
Site 2 Before Installation Without Large Vehicles Data Control Speed

Site 2 Before Installation Without Large Vehicles Control Data Statistical Speed Summary

Passenger Vehicles Only	<i>Speed</i>
Mean	25.49946752
Standard Error	0.136382668
Median	26
Mode	27
Standard Deviation	4.179188684
Sample Variance	17.46561805
Kurtosis	-0.155390315
Skewness	-0.259832457
Range	23
Minimum	13
Maximum	36
Sum	23944
Count	939

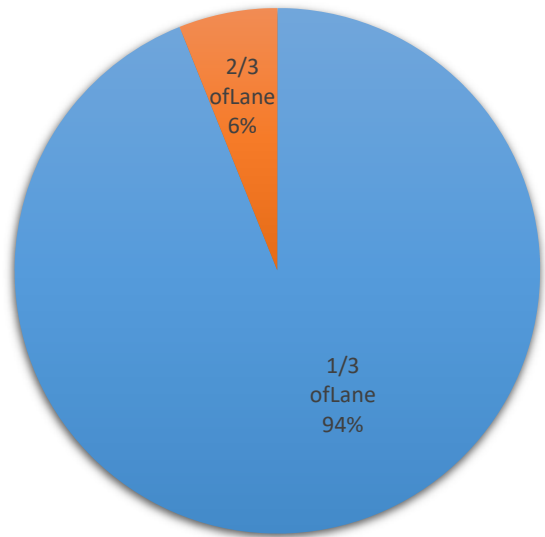
Site 2 Before Installation Without Large Vehicles Control Data Correlation

Passenger Vehicles Only	<i>Speed</i>	<i>Lateral Placement</i>
Speed	1	
Lateral Placement	-0.147850319	1



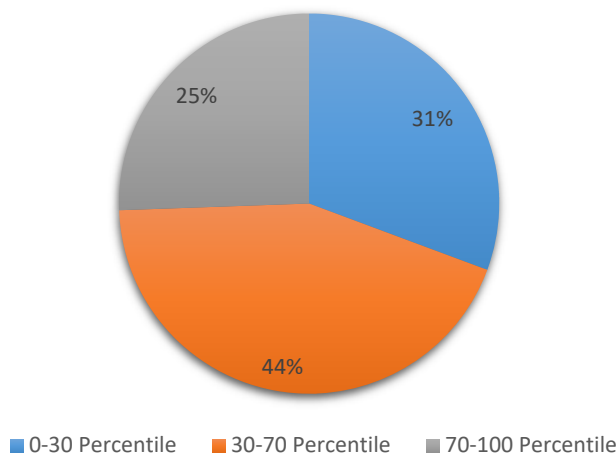
Site 2 Before Installation Without Large Vehicles Control Data for Speed vs Lateral Placement

Control Site 2 Lateral Placement Before



Site 2 Before Installation Passenger Vehicles Only Data Control Lateral Placement

Speed Control



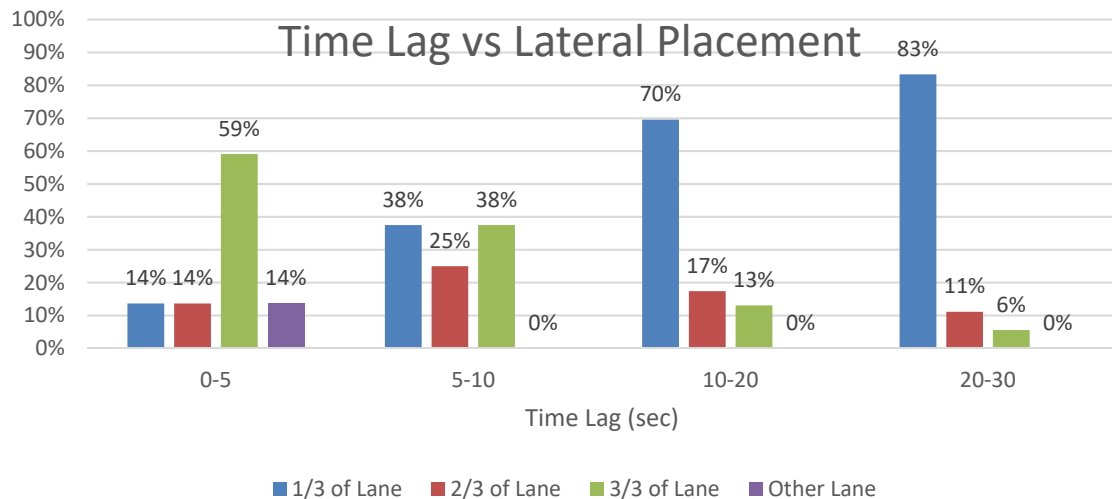
Site 2 Before Installation Passenger Vehicles Only Data Control Speed

Site 2 Before Installation Event Statistical Summary of Speed, Time Lag, and Time Between for all data

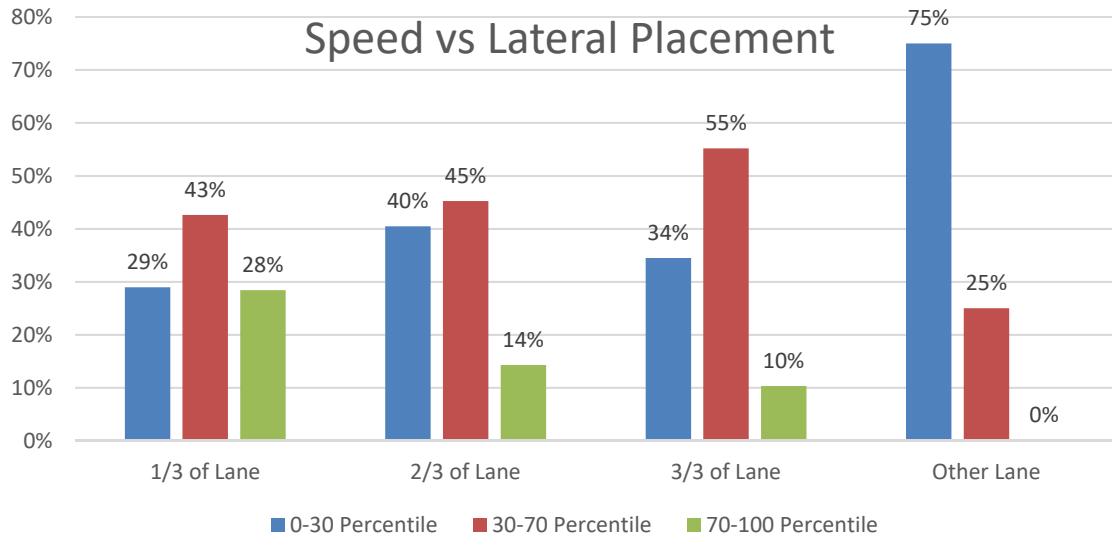
<i>All Data</i>	<i>Speed</i>	<i>Time Lag (s)</i>	<i>Time Between (s)</i>
Mean	24.72767857	111.3325912	87.64285527
Standard Error	0.190963886	3.360061903	4.315067879
Median	25	111.0000002	56.49999561
Mode	24	105	0
Standard Deviation	4.041943622	71.11910548	91.33277198
Sample Variance	16.33730825	5057.927165	8341.675237
Kurtosis	0.172826869	-0.79059352	6.618404413
Skewness	0.091784811	0.131110384	2.104618654
Range	28	436.0000001	637.999987
Minimum	12	-74.99999993	0
Maximum	40	361.0000001	637.999987
Sum	11078	49877.00086	39263.99916
Count	448	448	448
Confidence Level(95.0%)	0.375298506	6.603480042	8.480339184

Site 2 Before Installation Event Correlation for all data

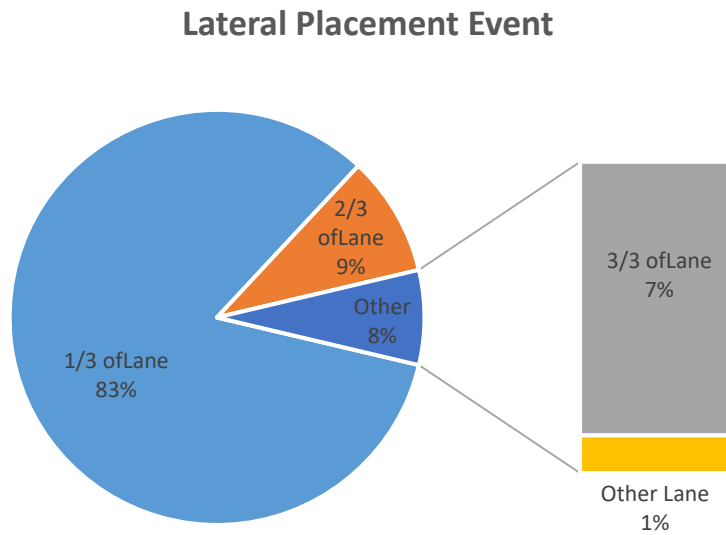
<i>All Data</i>	<i>Speed</i>	<i>Class</i>	<i>Lateral Placement</i>	<i>Time Lag Cat.</i>	<i>Time Between Cat.</i>
Speed	1				
Class	0.034676464	1			
Lateral Placement	-0.134874049	-0.157285187	1		
Time Lag Cat.	0.151464762	-0.037297659	-0.561578924	1	
Time Between Cat.	-0.015108724	0.036089068	0.043441458	-0.028319609	1



Site 2 Before Installation All Event Data Time Lag vs Lateral Placement

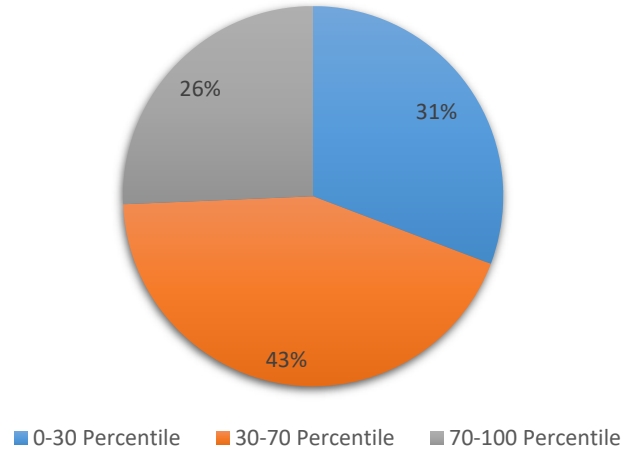


Site 2 Before Installation All Event Data Speed vs Lateral Placement



Site 2 Before Installation All Data Event Lateral Placement

Speed Event



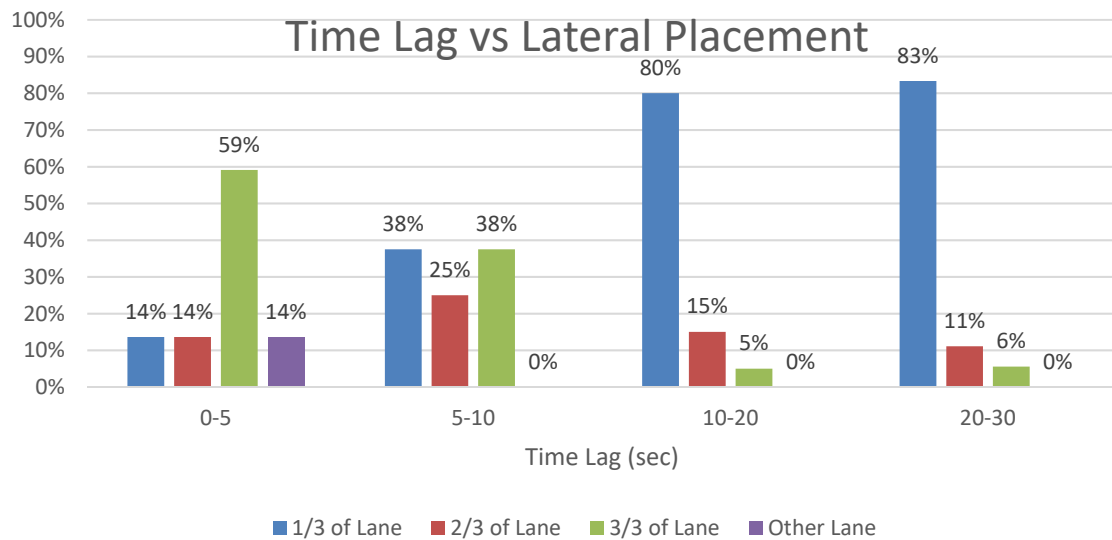
Site 2 Before Installation All Data Event Speed

Site 2 Before Installation Event Statistical Summary of Speed, Time Lag, and Time Between for without motorcycles data

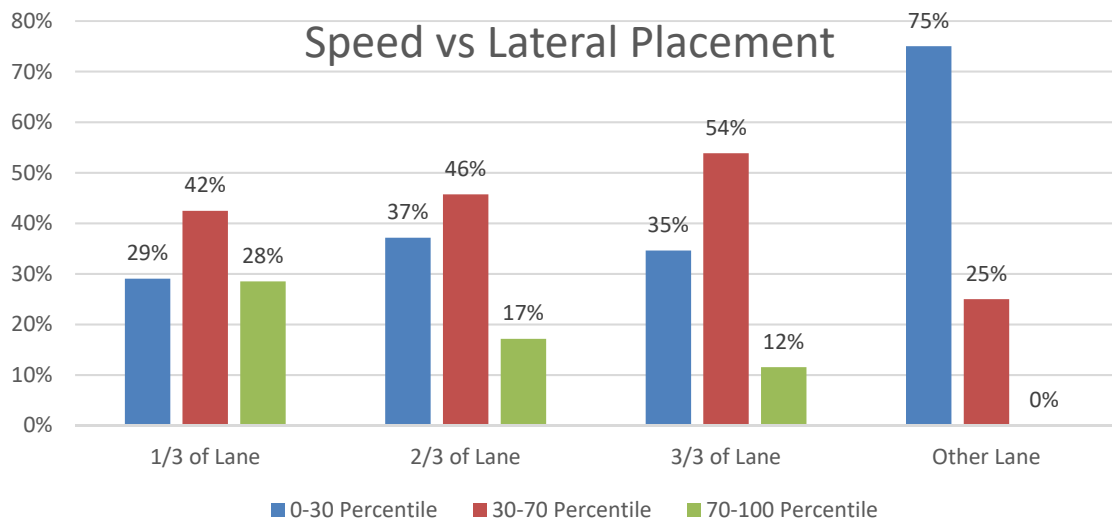
<i>Without Motorcycles</i>	<i>Speed</i>	<i>Time Lag (s)</i>	<i>Time Between (s)</i>
Mean	24.7597254	111.5377594	87.83981503
Standard Error	0.1946335	3.41168146	4.40531756
Median	25	111.0000002	55.99999989
Mode	24	105	0
Standard Deviation	4.068724742	71.31964847	92.091159
Sample Variance	16.55452103	5086.492258	8480.781566
Kurtosis	0.156696821	-0.789723056	6.519617807
Skewness	0.076482894	0.138767699	2.10230013
Range	28	436.0000001	637.999987
Minimum	12	-74.99999993	0
Maximum	40	361.0000001	637.999987
Sum	10820	48742.00085	38385.99917
Count	437	437	437
Confidence Level(95.0%)	0.382536544	6.705386471	8.658298588

Site 2 Before Installation Event Correlation for without motorcycles data

<i>Without Motorcycles</i>	<i>Speed</i>	<i>Class</i>	<i>Lateral Placement</i>	<i>Time Lag Cat.</i>	<i>Time Between Cat.</i>
Speed	1				
Class	0.004864651	1			
Lateral Placement	-0.127895391	-0.00983845	1		
Time Lag Cat.	0.148932521	-0.066681675	-0.574407109	1	
Time Between Cat.	-0.022183848	0.019548193	0.066279596	-0.054603683	1

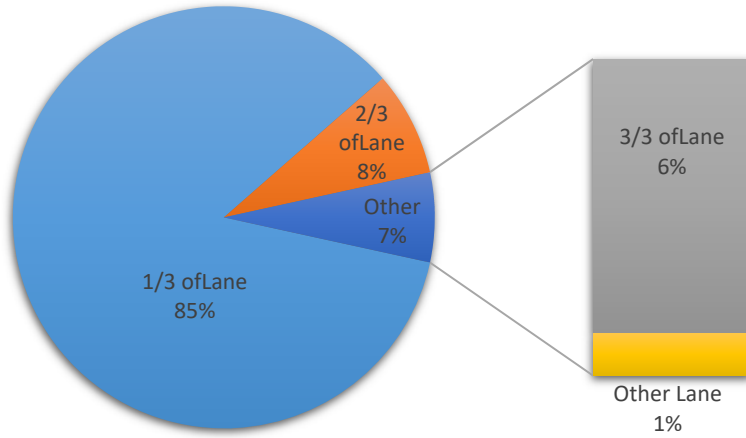


Site 2 Before Installation Without Motorcycles Event Data Time Lag vs Lateral Placement



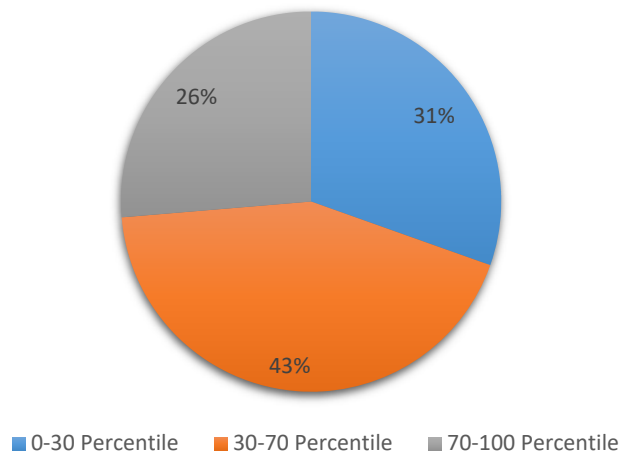
Site 2 Before Installation Without Motorcycles Event Data Speed vs Lateral Placement

Lateral Placement Event



Site 2 Before Installation Without Motorcycles Event Data Lateral Placement

Speed Event



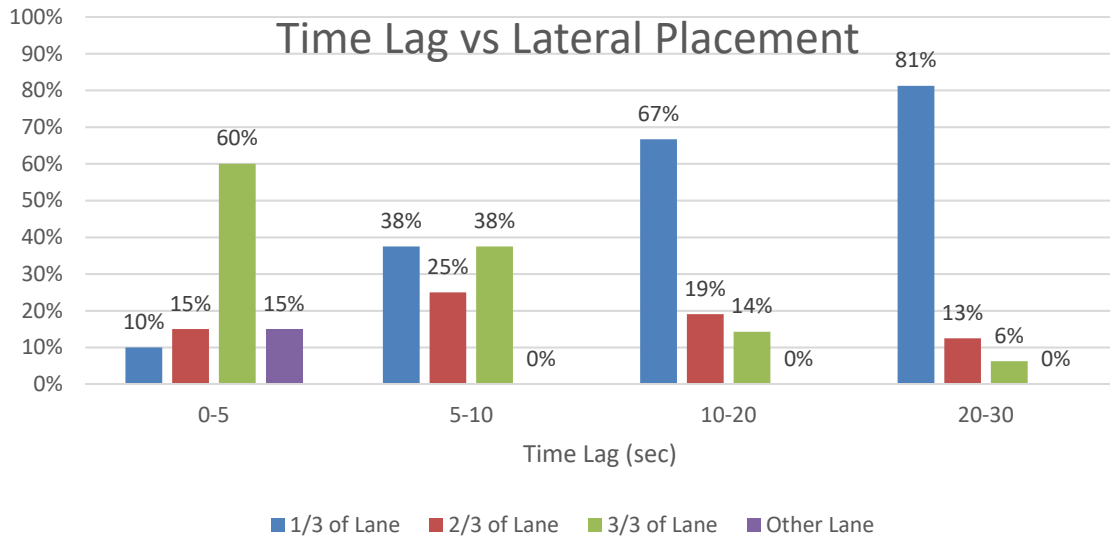
Site 2 Before Installation Without Motorcycles Event Speed Data

Site 2 Before Installation Event Statistical Summary of Speed, Time Lag, and Time Between for without large vehicles data

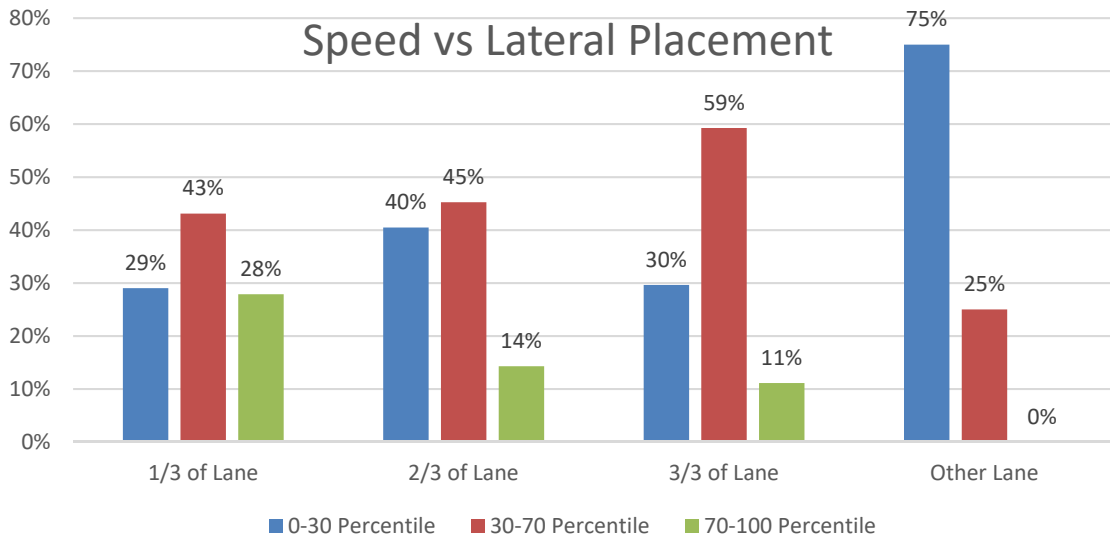
<i>Without Large Vehicles</i>	<i>Speed</i>	<i>Time Lag (s)</i>	<i>Time Between (s)</i>
Mean	24.72196262	112.7897216	88.22663361
Standard Error	0.194643541	3.452910537	4.482115518
Median	25	112.5000065	56.99999258
Mode	24	105	0
Standard Deviation	4.026816884	71.43436864	92.72672686
Sample Variance	16.21525422	5102.869023	8598.245873
Kurtosis	0.25228437	-0.799438014	6.420438023
Skewness	0.083078661	0.109588381	2.090405467
Range	28	436.0000001	637.999987
Minimum	12	-74.99999993	0
Maximum	40	361.0000001	637.999987
Sum	10581	48274.00083	37760.99919
Count	428	428	428
Confidence Level(95.0%)	0.382578725	6.786817092	8.809755678

Site 2 Before Installation Event Correlation for without larges vehicles data

<i>Without Large Vehicles</i>	<i>Speed</i>	<i>Class</i>	<i>Lateral Placement</i>	<i>Time Lag Cat.</i>	<i>Time Between Cat.</i>
Speed	1				
Class	0.051179256	1			
Lateral Placement	-0.119201879	-0.24787766	1		
Time Lag Cat.	0.159804351	0.027030732	-0.577955084	1	
Time Between Cat.	-0.003469073	0.034044936	0.040013887	-0.016386828	1

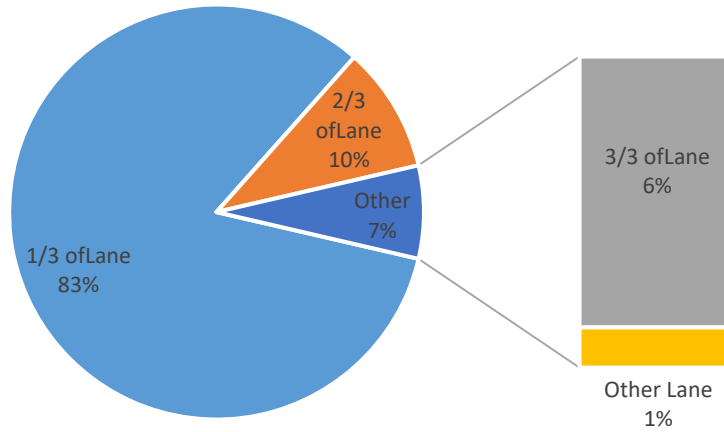


Site 2 Before Installation Without Large Vehicles Event Data Time Lag vs Lateral Placement



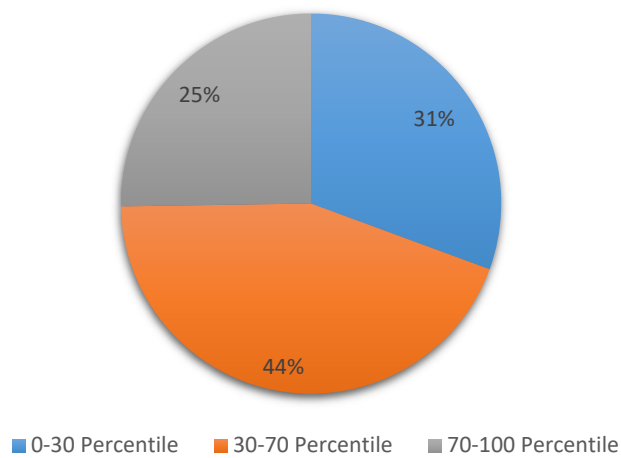
Site 2 Before Installation Without Large Vehicles Event Data Speed vs Lateral Placement

Lateral Placement Event



Site 2 Before Installation Without Large Vehicles Event Data Lateral Placement

Speed Event



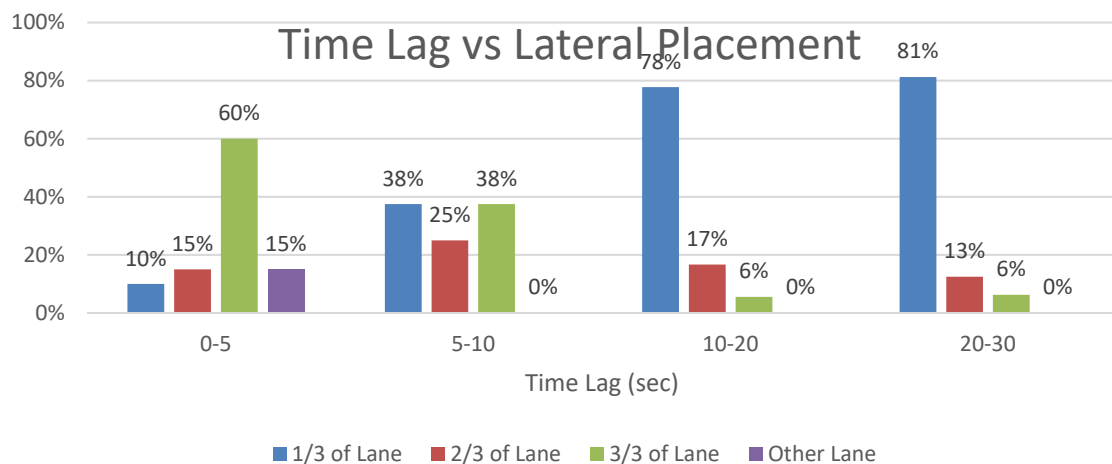
Site 2 Before Installation Without Large Vehicles Event Speed Data

Site 2 Before Installation Event Statistical Summary of Speed, Time Lag, and Time Between for passenger vehicle only data

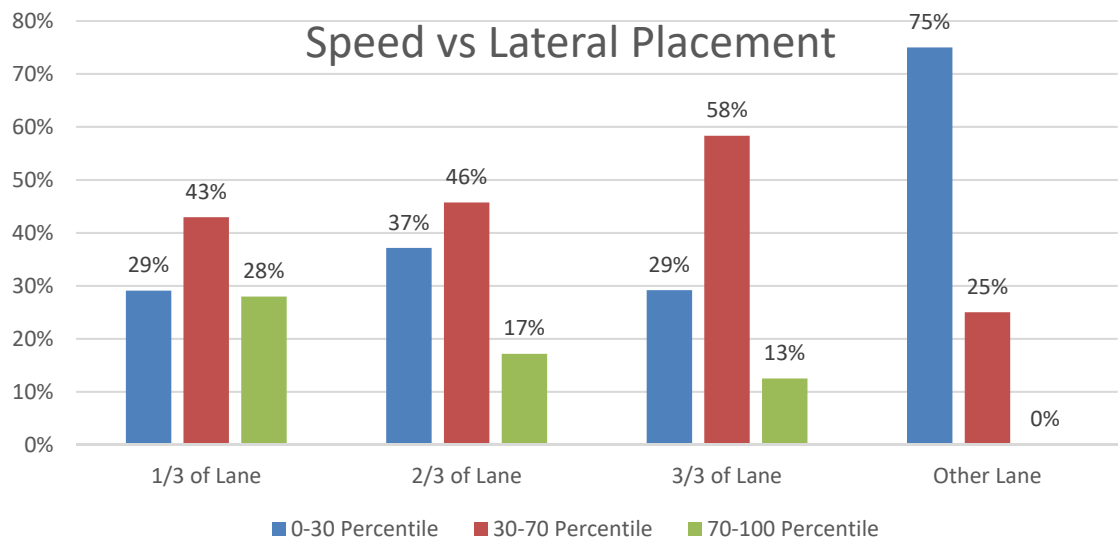
<i>Passenger Vehicles Only</i>	<i>Speed</i>	<i>Time Lag (s)</i>	<i>Time Between (s)</i>
Mean	24.75539568	113.0431674	88.44843932
Standard Error	0.198556088	3.50856827	4.580891701
Median	25	112.000013	55.99999989
Mode	24	105	0
Standard Deviation	4.054630057	71.64699153	93.54445563
Sample Variance	16.4400249	5133.291395	8750.565179
Kurtosis	0.235964272	-0.79957469	6.313525884
Skewness	0.06706158	0.116696946	2.086835041
Range	28	436.0000001	637.999987
Minimum	12	-74.99999993	0
Maximum	40	361.0000001	637.999987
Sum	10323	47139.00082	36882.99919
Count	417	417	417
Confidence Level(95.0%)	0.390298308	6.896732669	9.004580506

Site 2 Before Installation Event Correlation for Passenger vehicles only data

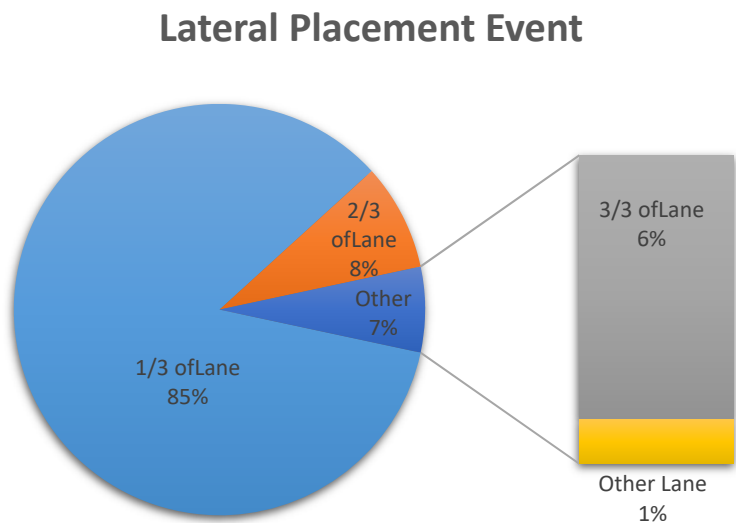
<i>Passenger Vehicles Only</i>	<i>Speed</i>	<i>Lateral Placement</i>	<i>Time Lag Cat.</i>	<i>Time Between Cat.</i>
Speed	1			
Lateral Placement	-0.111090458	1		
Time Lag Cat.	0.157139292	-0.591603609	1	
Time Between Cat.	-0.010577651	0.063527958	-0.044066426	1



Site 2 Before Installation Passenger Vehicles Only Event Data Time Lag vs Lateral Placement

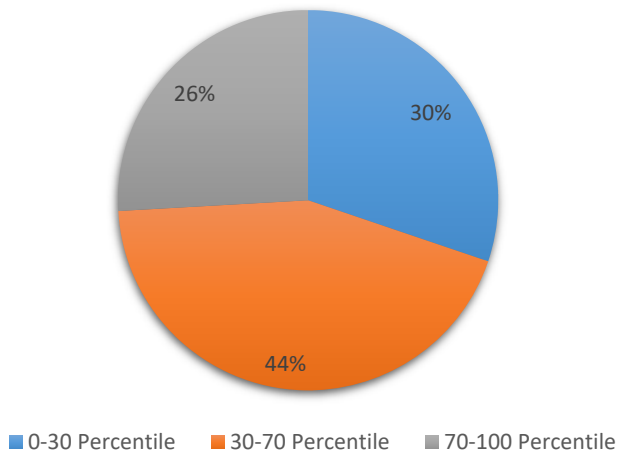


Site 2 Before Installation Passenger Vehicles Only Event Data Speed vs Lateral Placement



Site 2 Before Installation Passenger Vehicles Only Event Lateral Placement

Speed Event



Site 2 Before Installation Passenger Vehicles Only Event Speed Data

APPENDIX B

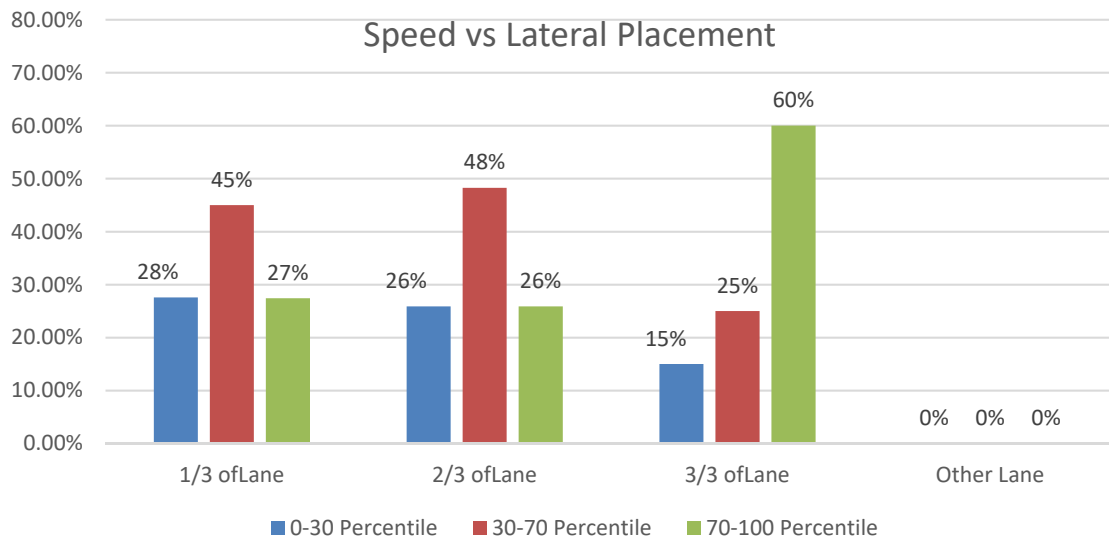
AFTER INSTALLATION DATA

Site 1 After Installation Control Statistical Summary Speed all data

<i>All Data</i>	<i>Speed (mph)</i>
Mean	27.60487805
Standard Error	0.10407556
Median	28
Mode	27
Standard Deviation	3.332043704
Sample Variance	11.10251524
Kurtosis	0.54389196
Skewness	0.105073631
Range	25
Minimum	16
Maximum	41
Sum	28295
Count	1025

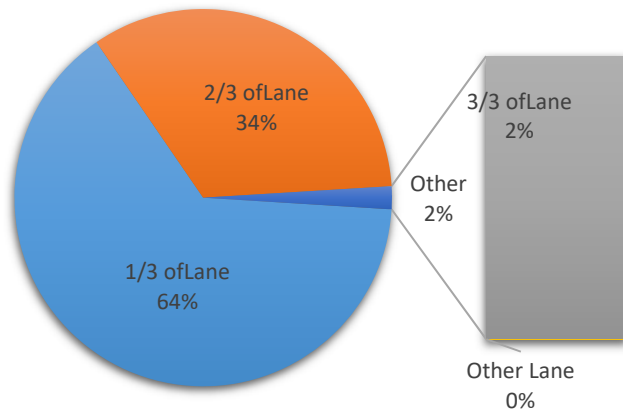
Site 1 After Installation All Control Data Correlation

<i>All Data</i>	<i>Lateral Position</i>	<i>Vehicle size</i>	<i>Speed Cat.</i>
Lateral Position	1		
Vehicle size	-0.208424741	1	
Speed Cat.	0.027452662	-0.086521607	1

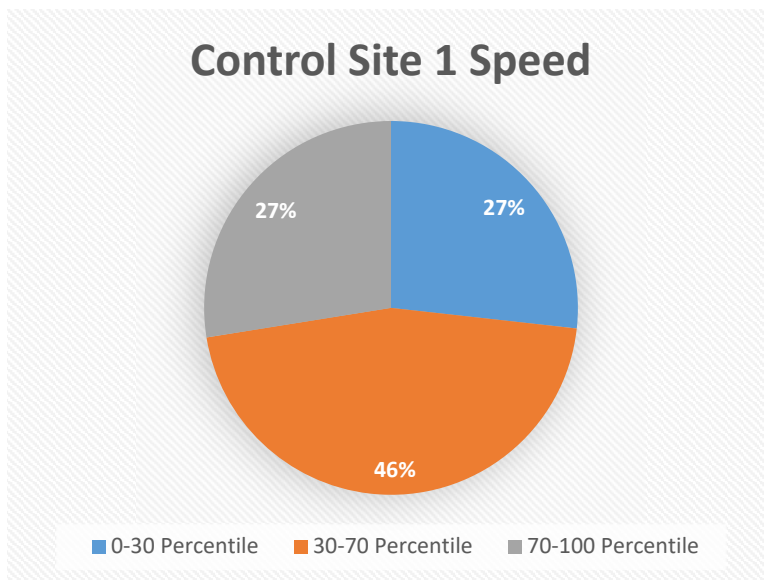


Site 1 After Installation All Control Data for Speed vs Lateral Placement

Control Site 1 Lateral Placement



Site 1 After Installation All Data Control Lateral Placement



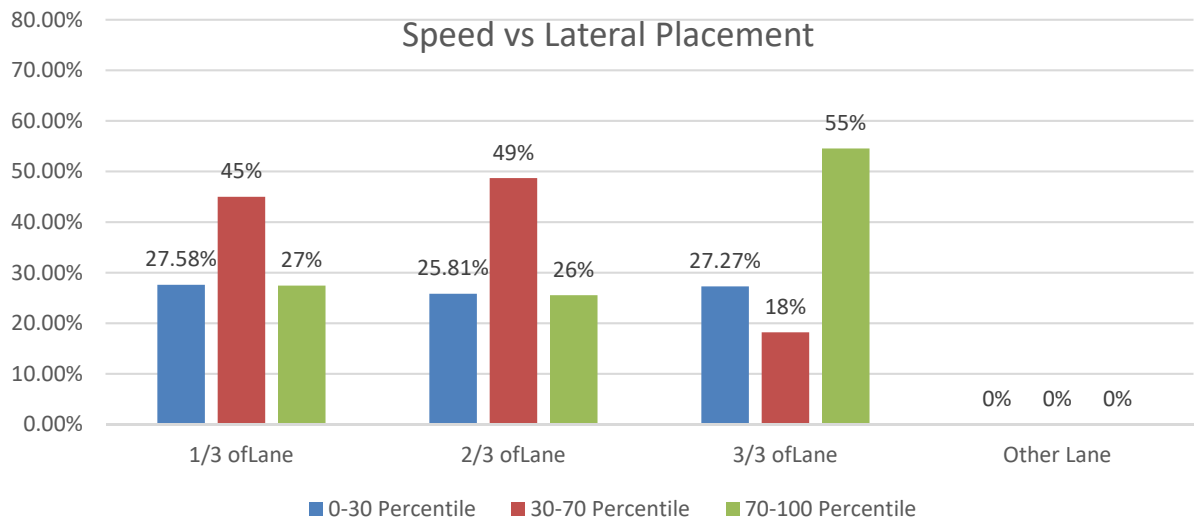
Site 1 After Installation All Data Control Speed

Site 1 After Installation Without Motorcycles Control Data Statistical Speed Summary

<i>Without Motorcycles</i>	<i>Speed (mph)</i>
Mean	27.54096742
Standard Error	0.102018297
Median	28
Mode	27
Standard Deviation	3.247003765
Sample Variance	10.54303345
Kurtosis	0.180696506
Skewness	-0.038755766
Range	22
Minimum	16
Maximum	38
Sum	27899
Count	1013

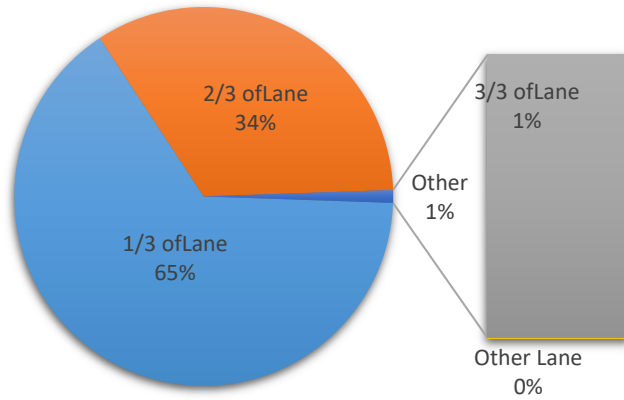
Site 1 After Installation Without Motorcycles Control Data Correlation

	<i>Lateral Position</i>	<i>Vehicle size</i>	<i>Speed Cat.</i>
Lateral Position	1		
Vehicle size	-0.060419828	1	
Speed Cat.	-0.000456908	-0.04304658	1



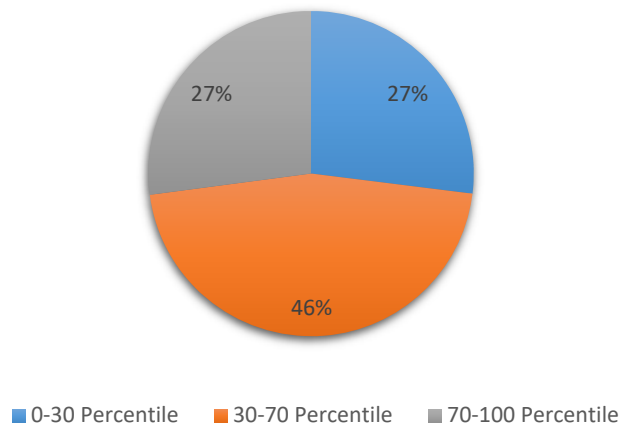
Site 1 After Installation Without Motorcycles Control Data for Speed vs Lateral Placement

Control Site 1 Lateral Placement After



Site 1 After Installation Without Motorcycles Data Control Lateral Placement

Control Site 1 Speed After



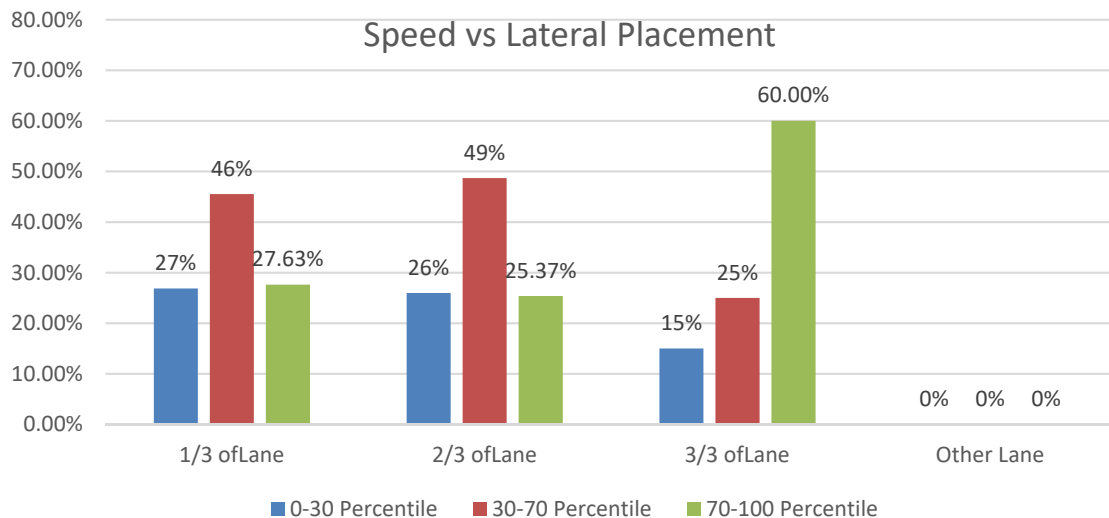
Site 1 After Installation Without Motorcycles Data Control Speed

Site 1 After Installation Without Large Vehicles Control Data Statistical Speed Summary

<i>Without Large Vehicles</i>	<i>Speed (mph)</i>
Mean	27.64292879
Standard Error	0.105530592
Median	28
Mode	27
Standard Deviation	3.332160835
Sample Variance	11.10329583
Kurtosis	0.558705581
Skewness	0.108761421
Range	25
Minimum	16
Maximum	41
Sum	27560
Count	997

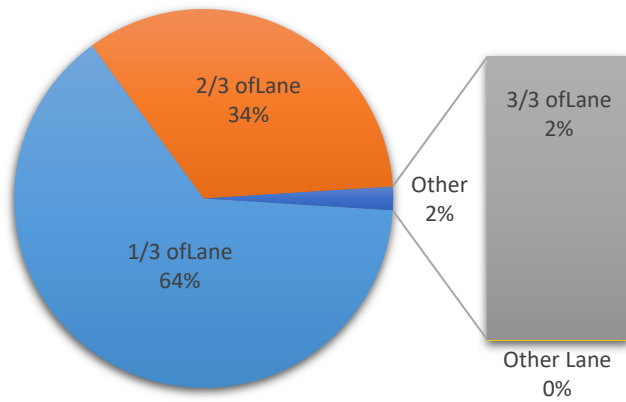
Site 1 After Installation Without Large Vehicles Control Data Correlation

<i>Without Large Vehicles</i>	<i>Lateral Position</i>	<i>Vehicle size</i>	<i>Speed Cat.</i>
Lateral Position	1		
Vehicle size	-0.287930462	1	
Speed Cat.	0.017013845	-0.09206543	1



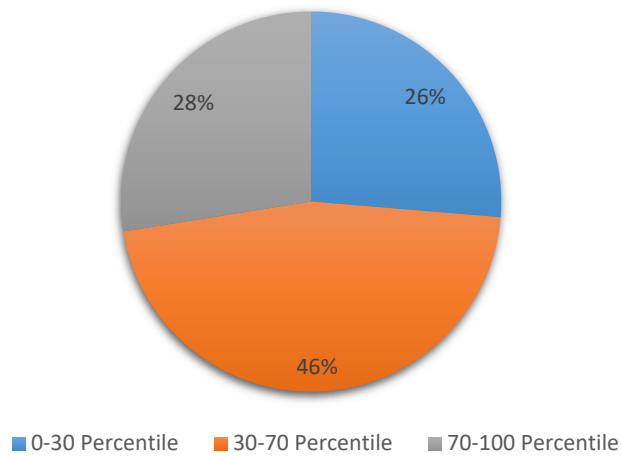
Site 1 After Installation Without Large Vehicles Control Data for Speed vs Lateral Placement

Control Site 1 Lateral Placement



Site 1 After Installation Without Large Vehicles Data Control Lateral Placement

Control Site 1 Speed



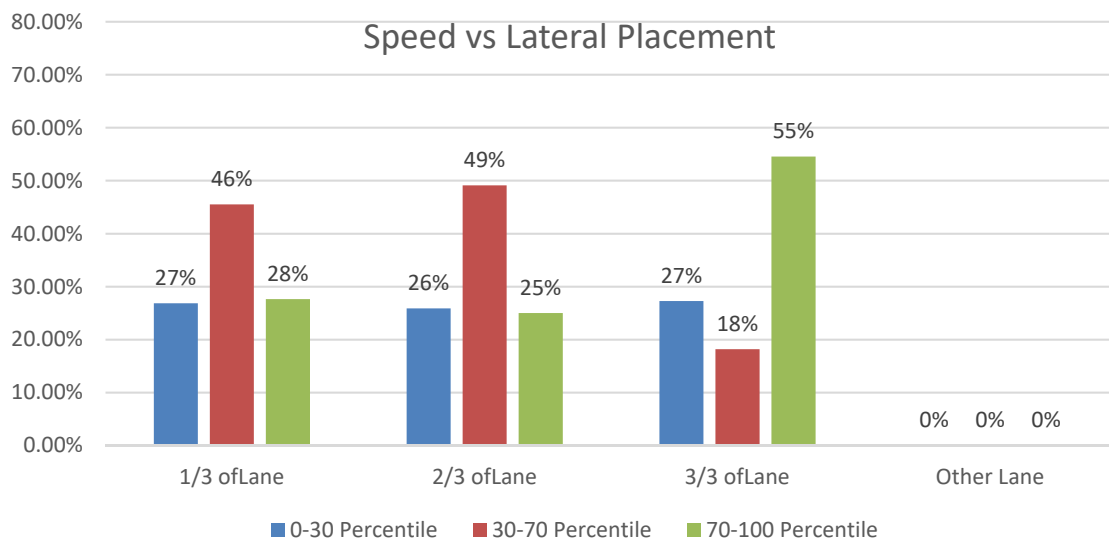
Site 1 After Installation Without Large Vehicles Data Control Speed

Site 1 After Installation Without Large Vehicles Control Data Statistical Speed Summary

Passanger Vehicles Only	<i>Speed (mph)</i>
Mean	27.57766497
Standard Error	0.103408087
Median	28
Mode	27
Standard Deviation	3.245432787
Sample Variance	10.53283397
Kurtosis	0.192994595
Skewness	-0.037242433
Range	22
Minimum	16
Maximum	38
Sum	27164
Count	985

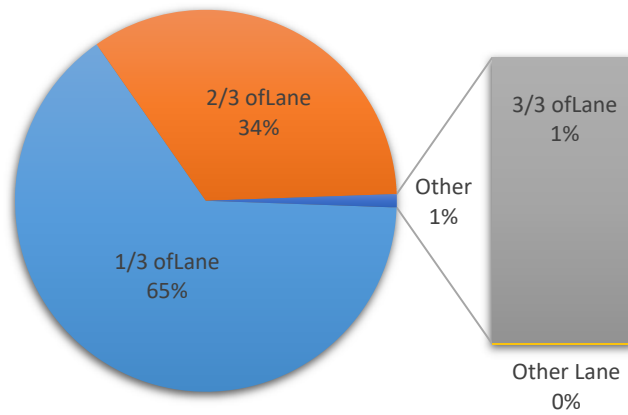
Site 1 After Installation Without Large Vehicles Control Data Correlation

	<i>Lateral Position</i>	<i>Speed Cat.</i>
Lateral Position	1	
Speed Cat.	-0.011972908	1



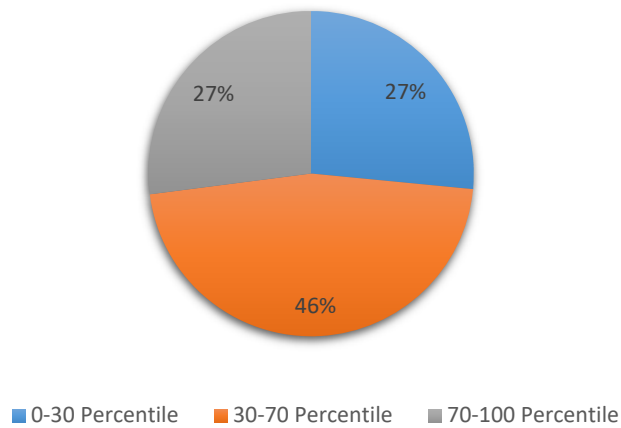
Site 1 After Installation Without Large Vehicles Control Data for Speed vs Lateral Placement

Control Site 1 Lateral Placement After



Site 1 After Installation Passenger Vehicles Only Data Control Lateral Placement

Control Site 1 Speed After



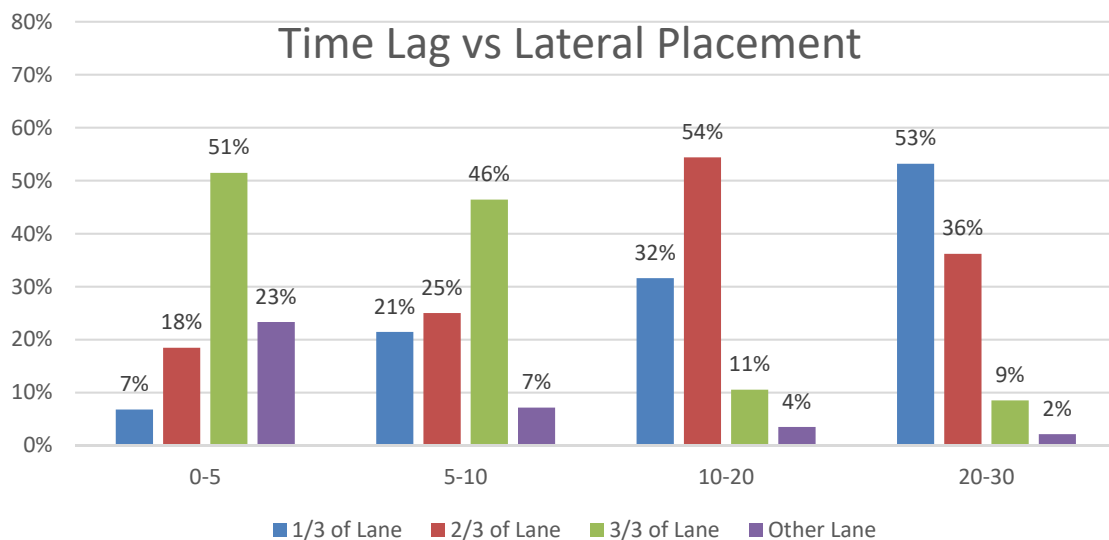
Site 1 After Installation Passenger Vehicles Only Data Control Speed

Site 1 After Installation Event Statistical Summary of Speed, Time Lag, and Time Between for all data

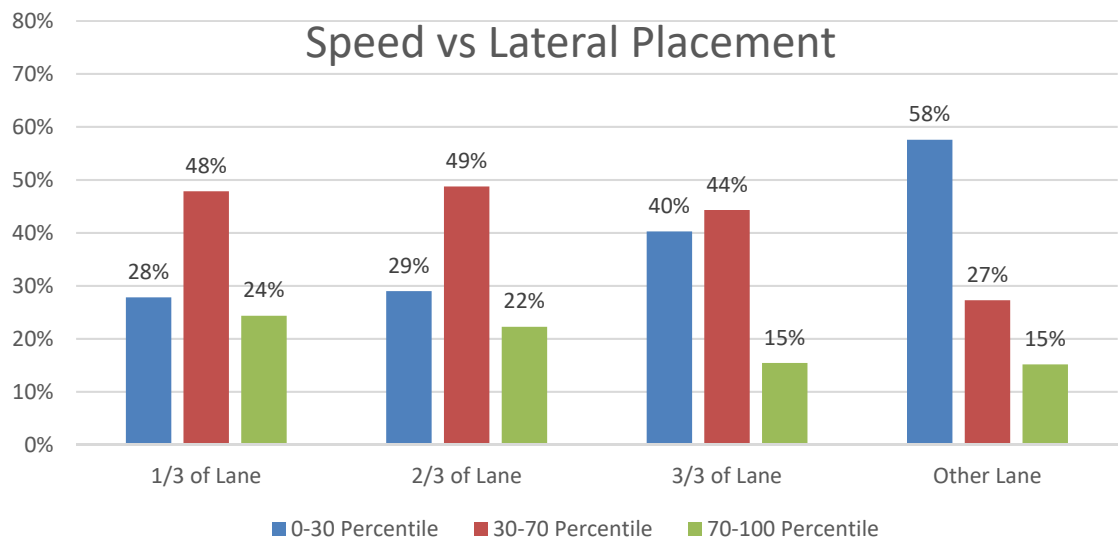
<i>All Data</i>	<i>Speed</i>	<i>Time Lag (s)</i>	<i>Time Between (s)</i>
Mean	26.97530864	116.356577	115.795936
Standard Error	0.093372245	2.063945343	3.115082758
Median	27	116.0000001	81.99999968
Mode	26	226	0
Standard Deviation	3.464852644	76.5887819	115.5943372
Sample Variance	12.00520385	5865.841513	13362.05079
Kurtosis	0.784401291	0.166125669	3.821726573
Skewness	-0.022751743	0.221157603	1.780537477
Range	31	573.0000195	716.0000228
Minimum	13	-20.00000027	-2.26311E-05
Maximum	44	553.0000193	716.0000002
Sum	37145	160223.0066	159451.0038
Count	1377	1377	1377

Site 1 After Installation Event Correlation for all data

<i>All Data</i>	<i>Speed</i>	<i>Class</i>	<i>Lateral Placement</i>	<i>Lights Flash</i>	<i>Time Between Cat.</i>	<i>Time Lag Cat.</i>
Speed	1					
Class	-0.15550921	1				
Lateral Placement	-0.1011999	-0.16093252	1			
Lights Flash	-0.04287433	0.06605962	-0.030680828	1		
Time Between Cat.	0.098637693	0.003205382	0.088849949	-0.00303312	1	
Time Lag Cat.	0.151438201	-0.02418009	-0.498708	0.119157057	0.039958165	1

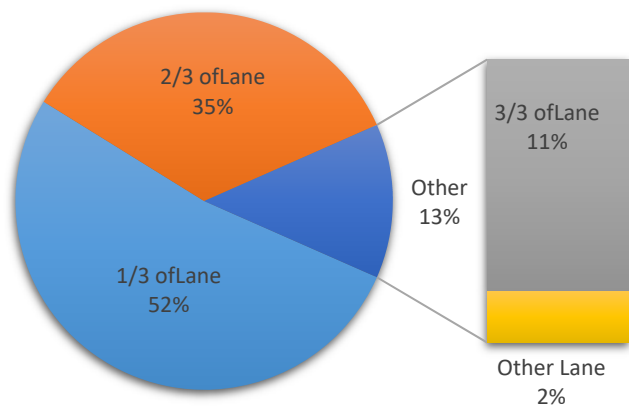


Site 1 After Installation All Event Data Time Lag vs Lateral Placement

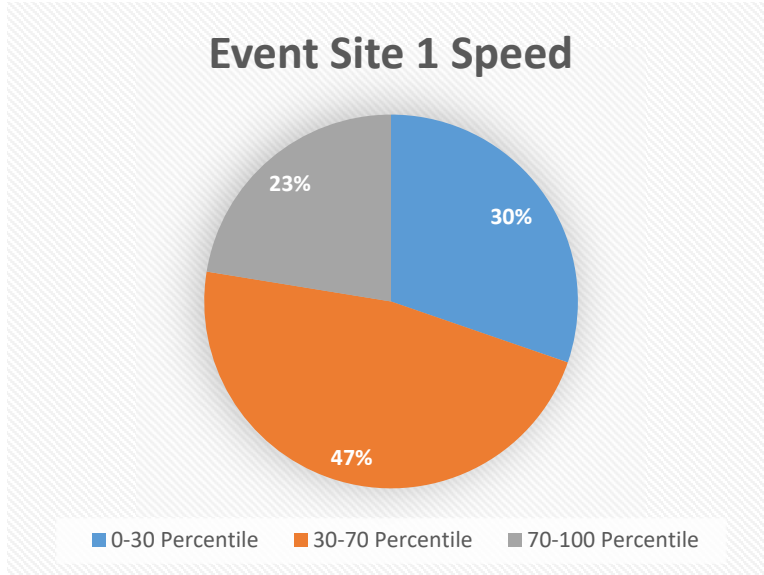


Site 1 After Installation All Event Data Speed vs Lateral Placement

Event Site 1 Lateral Placement



Site 1 After Installation All Data Event Lateral Placement



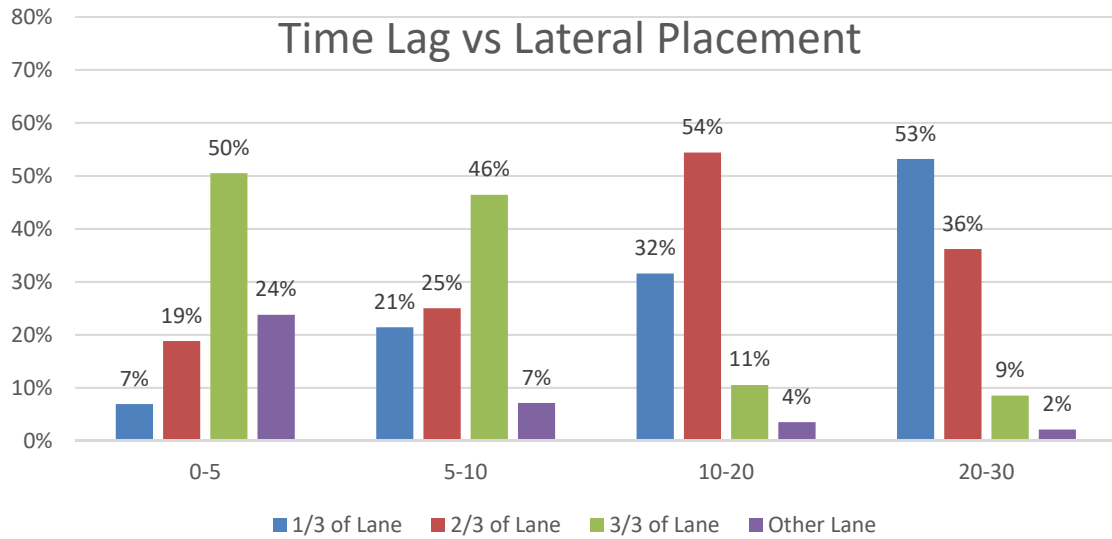
Site 1 After Installation All Data Event Speed

Site 1 After Installation Event Statistical Summary of Speed, Time Lag, and Time Between for without motorcycles data

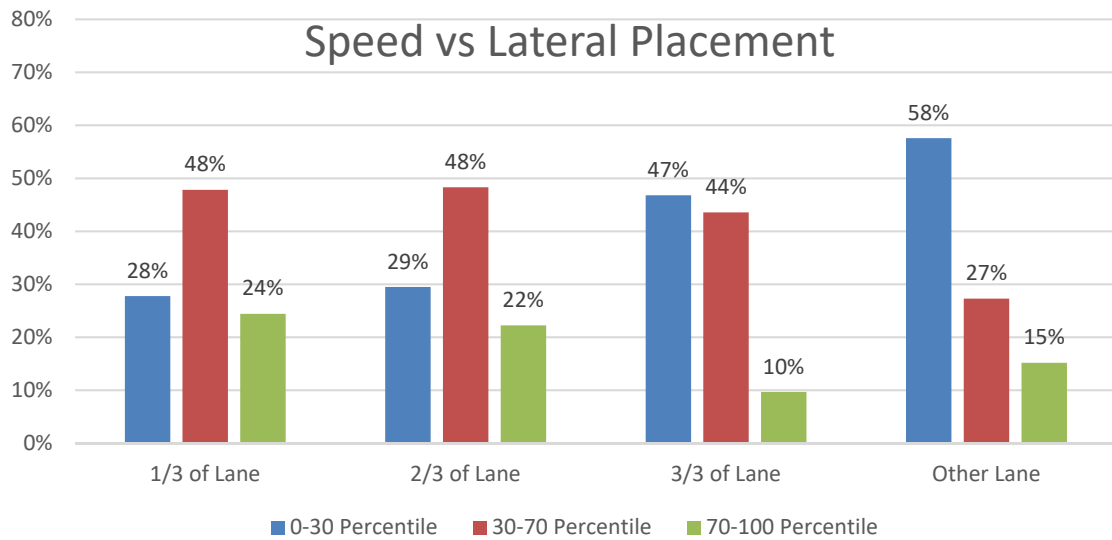
<i>Without Motorcycles</i>	<i>Speed</i>	<i>Time Lag (s)</i>	<i>Time Between V&OPV (s)</i>
Mean	26.91629297	115.4162978	114.6629324
Standard Error	0.094408999	2.085953737	3.176880739
Median	27	115.5000113	80.00002876
Mode	26	226	0
Standard Deviation	3.453356774	76.30143909	116.2061113
Sample Variance	11.92567301	5821.909607	13503.86031
Kurtosis	0.817555741	0.249436358	3.905273211
Skewness	-0.016718461	0.237990197	1.81333634
Range	31	573.0000195	716.0000228
Minimum	13	-20.00000027	-2.26311E-05
Maximum	44	553.0000193	716.0000002
Sum	36014	154427.0065	153419.0036
Count	1338	1338	1338

Site 1 After Installation Event Correlation for without motorcycles data

<i>Without Motorcycles</i>	<i>Speed</i>	<i>Class</i>	<i>Lights Flash</i>	<i>Time Between Cat.</i>	<i>Lateral Placement</i>	<i>Time Lag Cat.</i>
Speed	1					
Class	-0.12266129	1				
Lights Flash	-0.03594041	0.031311564	1			
Time Between Cat.	0.092793105	0.029269862	0.00556936	1		
Lateral Placement	-0.13712589	-0.07050871	-0.013828101	0.074546288	1	
Time Lag Cat.	0.152188028	-0.00273415	0.125582205	0.040099212	-0.524141906	1

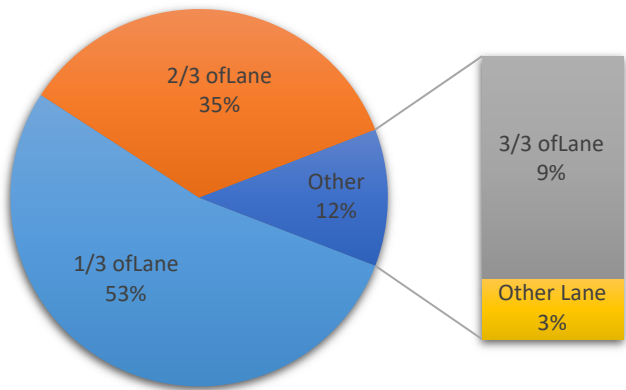


Site 1 After Installation Without Motorcycles Event Data Time Lag vs Lateral Placement



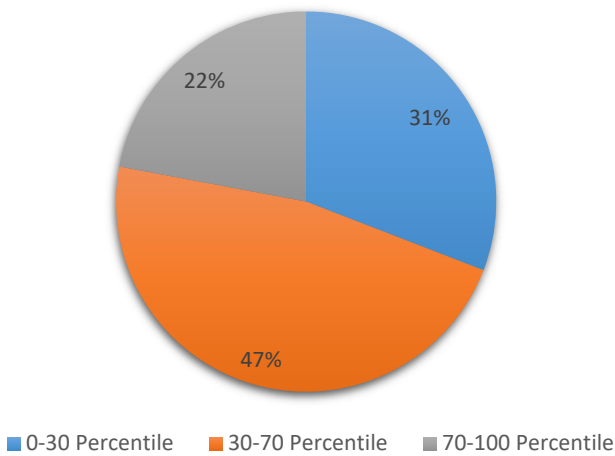
Site 1 After Installation Without Motorcycles Event Data Speed vs Lateral Placement

Event After Lateral Placement



Site 1 After Installation Without Motorcycles Event Data Lateral Placement

Event Site 1 Speed



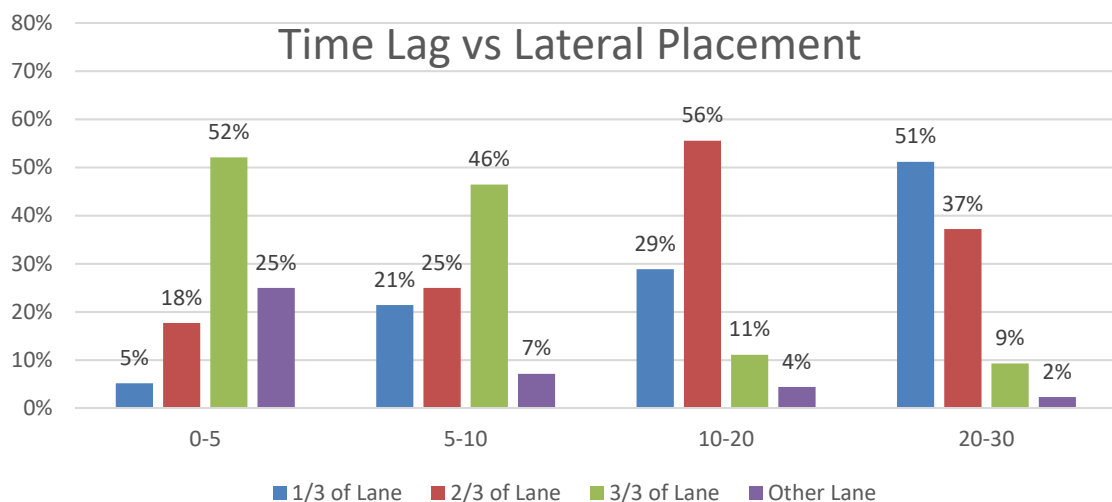
Site 1 After Installation Without Motorcycles Event Speed Data

Site 1 After Installation Event Statistical Summary of Speed, Time Lag, and Time Between for without large vehicles data

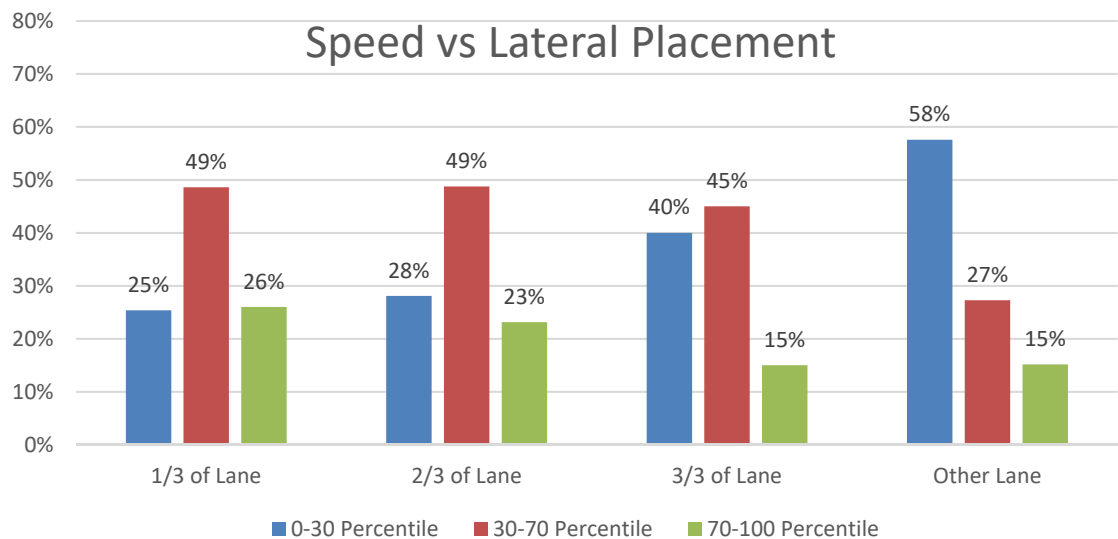
<i>Without Large Vehicles</i>	<i>Speed</i>	<i>Time Lag (s)</i>	<i>Time Between (s)</i>
Mean	27.10522152	116.7610807	111.8386103
Standard Error	0.097714742	2.156566109	3.091905459
Median	27	116.5000096	81.99999968
Mode	26	226	0
Standard Deviation	3.474030512	76.67191542	109.9258273
Sample Variance	12.068888	5878.582614	12083.68752
Kurtosis	0.820142933	0.283431121	4.012835924
Skewness	-0.029168215	0.238636818	1.790462422
Range	31	573.0000195	675.0000226
Minimum	13	-20.00000027	-2.26311E-05
Maximum	44	553.0000193	675
Sum	34261	147586.006	141364.0034
Count	1264	1264	1264

Site 1 After Installation Event Correlation for without larges vehicles data

<i>Without Large Vehicles</i>	<i>Speed</i>	<i>Class</i>	<i>Lateral Placement</i>	<i>Lights Flash</i>	<i>Time Between Cat.</i>	<i>Time Lag Cat.</i>
Speed	1					
Class	-0.0973556	1				
Lateral Placement	-0.12086981	-0.19159592	1			
Lights Flash	-0.04724055	0.074779153	-0.024933538	1		
Time Between Cat.	0.102304491	-0.04098786	0.092001424	-0.016246377	1	
Time Lag Cat.	0.159168401	-0.04128895	-0.51380343	0.118944198	0.050066578	1

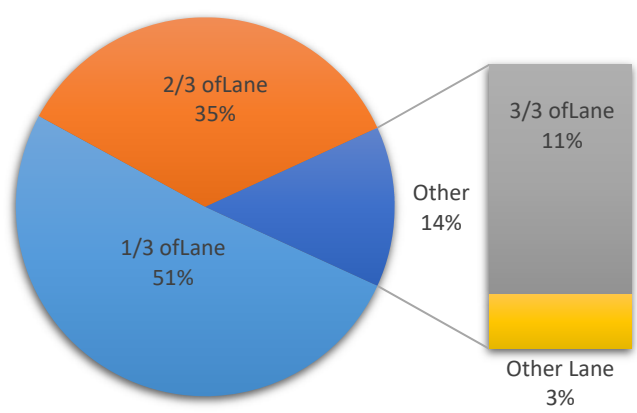


Site 1 After Installation Without Large Vehicles Event Data Time Lag vs Lateral Placement



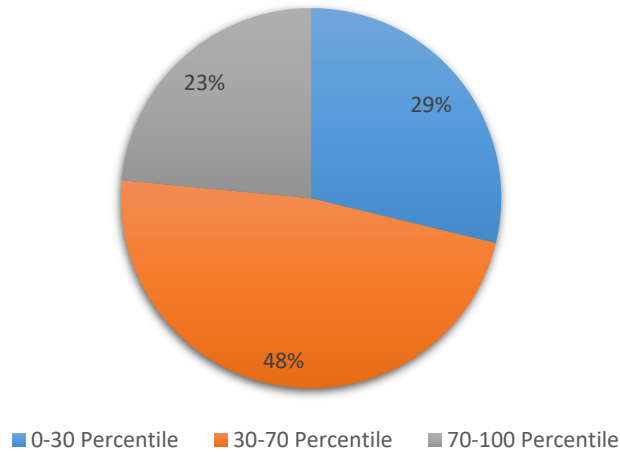
Site 1 After Installation Without Large Vehicles Event Data Speed vs Lateral Placement

Event Site 1 Lateral Placement



Site 1 After Installation Without Large Vehicles Event Data Lateral Placement

Event Site 1 Speed



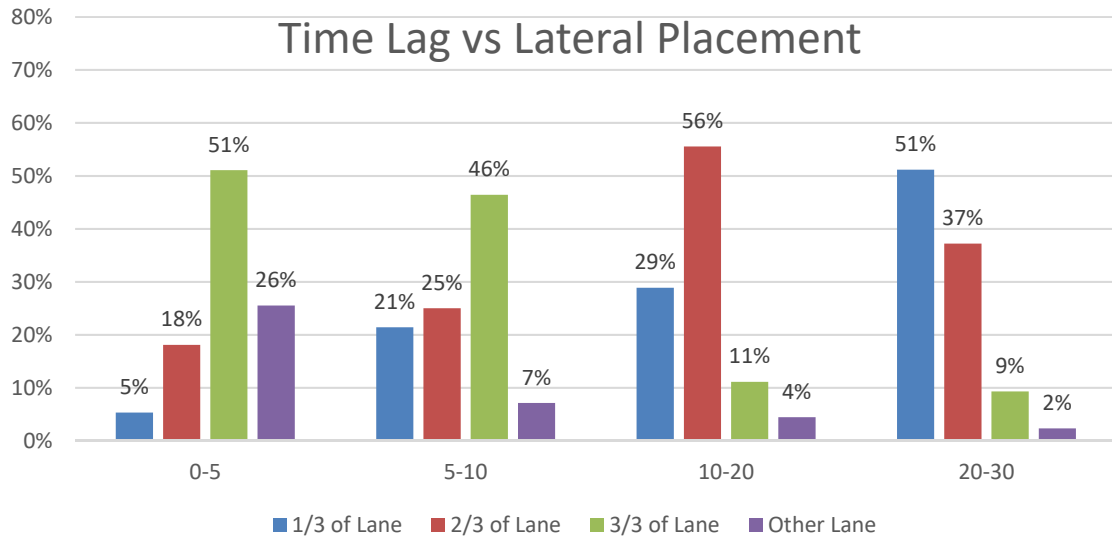
Site 1 After Installation Without Large Vehicles Event Speed Data

Site 1 After Installation Event Statistical Summary of Speed, Time Lag, and Time Between for passenger vehicle only data

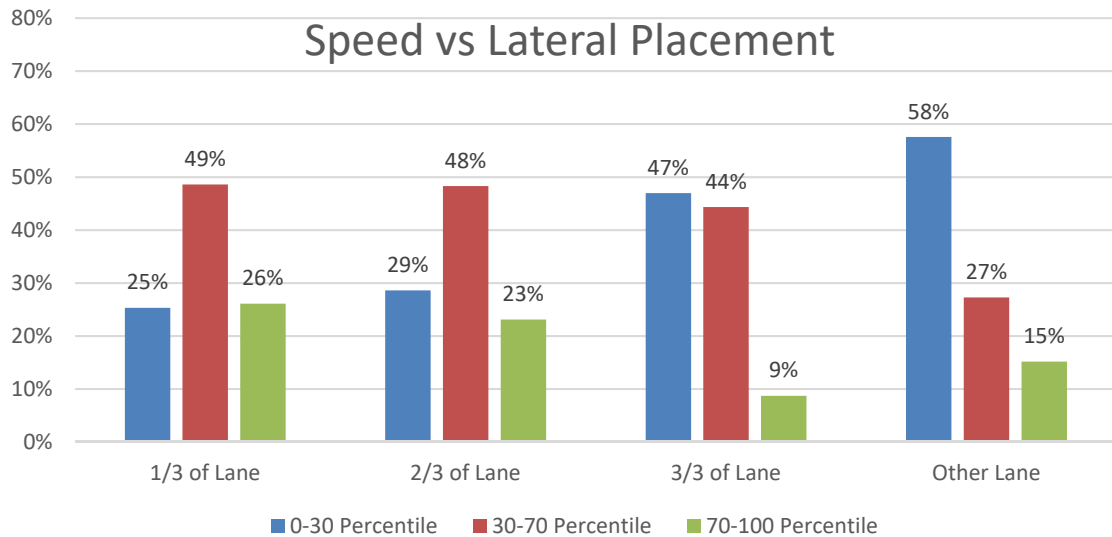
<i>Passenger Vehicles Only</i>	<i>Speed</i>	<i>Time Lag (s)</i>	<i>Time Between (s)</i>
Mean	27.04489796	115.7469436	110.4751046
Standard Error	0.09897612	2.181885414	3.154148269
Median	27	116.0000001	79.99999984
Mode	26	226	0
Standard Deviation	3.464164186	76.3659895	110.3951894
Sample Variance	12.00043351	5831.764352	12187.09785
Kurtosis	0.854104184	0.380663159	4.147665943
Skewness	-0.02180231	0.257910044	1.833699651
Range	31	573.0000195	675.0000226
Minimum	13	-20.0000003	-2.26311E-05
Maximum	44	553.0000193	675
Sum	33130	141790.0059	135332.0032
Count	1225	1225	1225

Site 1 After Installation Event Correlation for Passenger vehicles only data

<i>Passenger Vehicles Only</i>	<i>Speed</i>	<i>Lateral Placement</i>	<i>Lights Flash</i>	<i>Time Between Cat.</i>	<i>Time Lag Cat.</i>
Speed	1				
Lateral Placement	-0.15872567	1			
Lights Flash	-0.04056397	-0.007104195	1		
Time Between V&OPV Cat.	0.096194477	0.076684606	-0.00740019	1	
Time Lag Cat.	0.160400044	-0.541137959	0.125780923	0.050372052	1

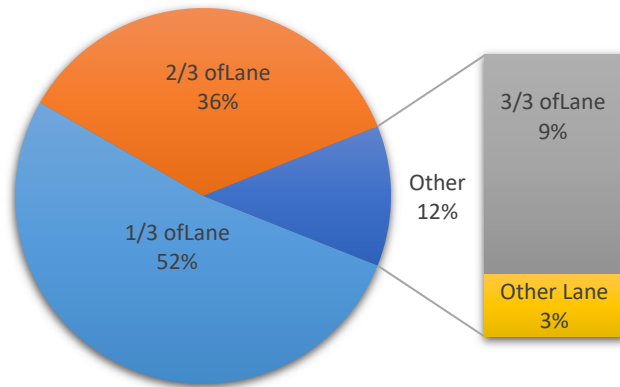


Site 1 After Installation Passenger Vehicles Only Event Data Time Lag vs Lateral Placement



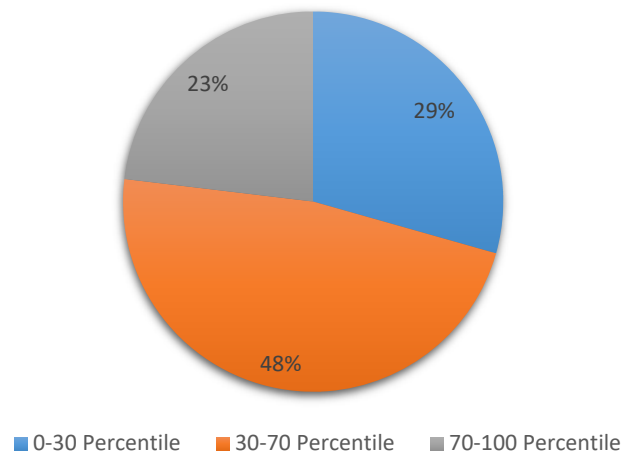
Site 1 After Installation Passenger Vehicles Only Event Data Speed vs Lateral Placement

Event Site 1 Lateral Placement



Site 1 After Installation Passenger Vehicles Only Event Lateral Placement

Event Site 1 Speed



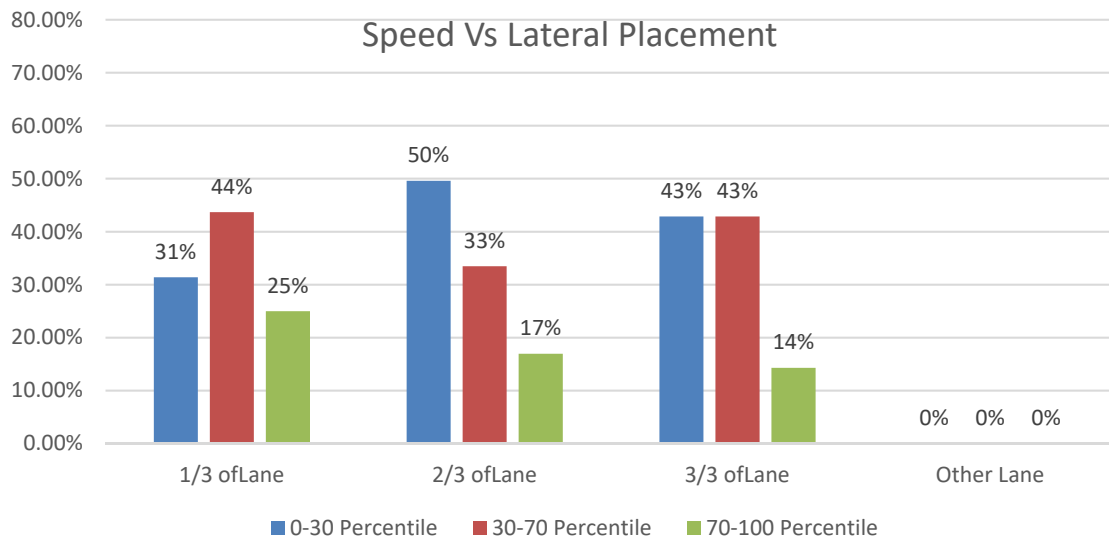
Site 1 After Installation Passenger Vehicles Only Event Speed Data

Site 2 After Installation Control Statistical Summary Speed all data

<i>All Data</i>	<i>Speed (mph)</i>
Mean	27.57017544
Standard Error	0.12686285
Median	28
Mode	27
Standard Deviation	4.063573745
Sample Variance	16.51263158
Kurtosis	0.244203705
Skewness	-0.236563569
Range	25
Minimum	15
Maximum	40
Sum	28287
Count	1026

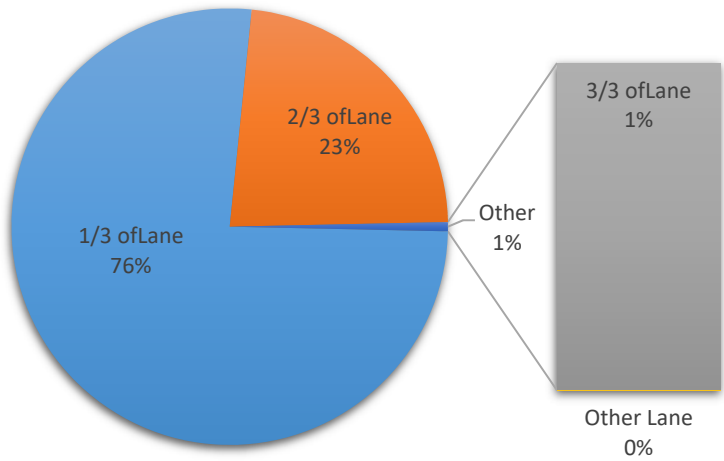
Site 2 After Installation All Control Data Correlation

<i>All Data</i>	<i>Speed (mph)</i>	<i>Lateral Position</i>	<i>Vehicle size</i>
Speed (mph)	1		
Lateral Position	-0.197165876	1	
Vehicle size	-0.036749301	-0.124540407	1



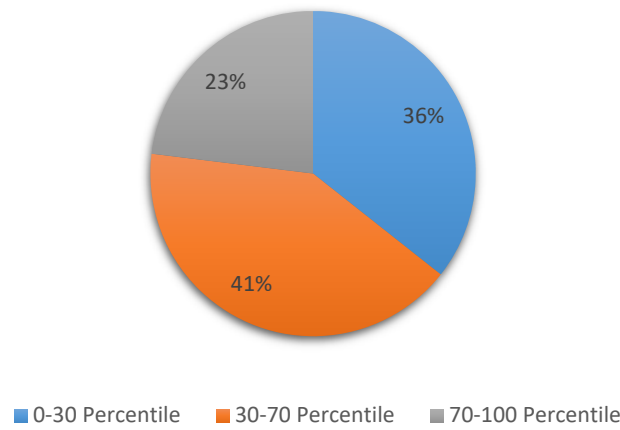
Site 2 After Installation All Control Data for Speed vs Lateral Placement

Control Lateral Placement



Site 2 After Installation All Data Control Lateral Placement

Control Speed



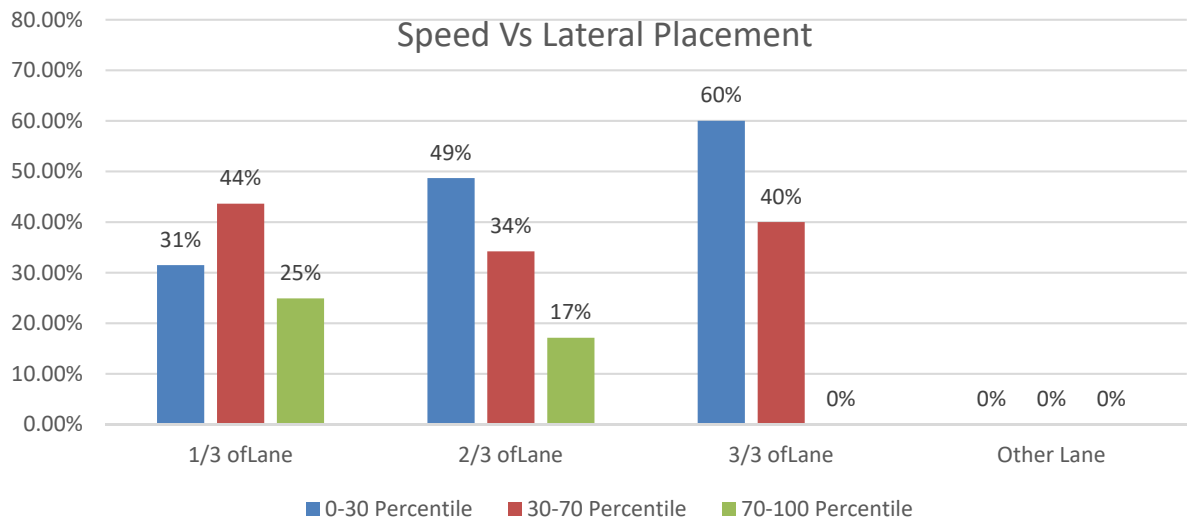
Site 2 After Installation All Data Control Speed

Site 2 After Installation Without Motorcycles Control Data Statistical Speed Summary

<i>Without Motorcycles</i>	<i>Speed (mph)</i>
Mean	27.60654113
Standard Error	0.126955254
Median	28
Mode	27
Standard Deviation	4.032703221
Sample Variance	16.26269527
Kurtosis	0.255763778
Skewness	-0.218076454
Range	25
Minimum	15
Maximum	40
Sum	27855
Count	1009

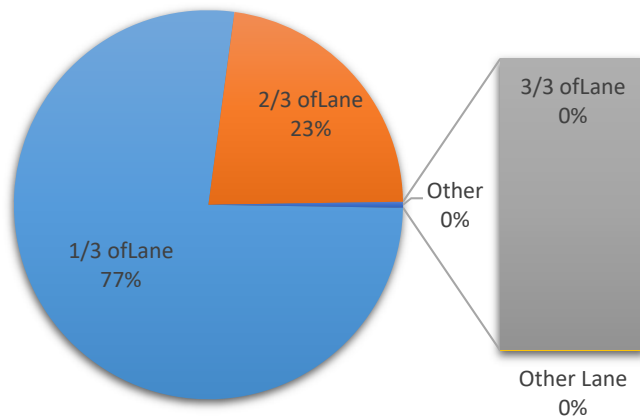
Site 2 After Installation Without Motorcycles Control Data Correlation

<i>Without Motorcycles</i>	<i>Speed (mph)</i>	<i>Lateral Position</i>	<i>Vehicle size</i>
Speed (mph)	1		
Lateral Position	-0.1930451	1	
Vehicle size	-0.081577995	-0.069566297	1



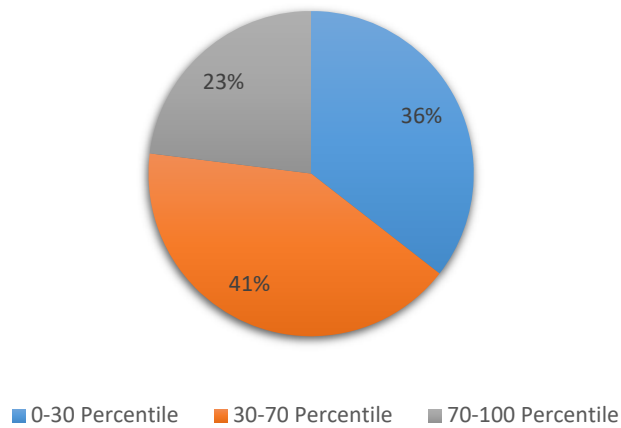
Site 2 After Installation Without Motorcycles Control Data for Speed vs Lateral Placement

Control Site 2 Lateral Placement After



Site 2 After Installation Without Motorcycles Data Control Lateral Placement

Control Site 2 Speed After



Site 2 After Installation Without Motorcycles Data Control Speed

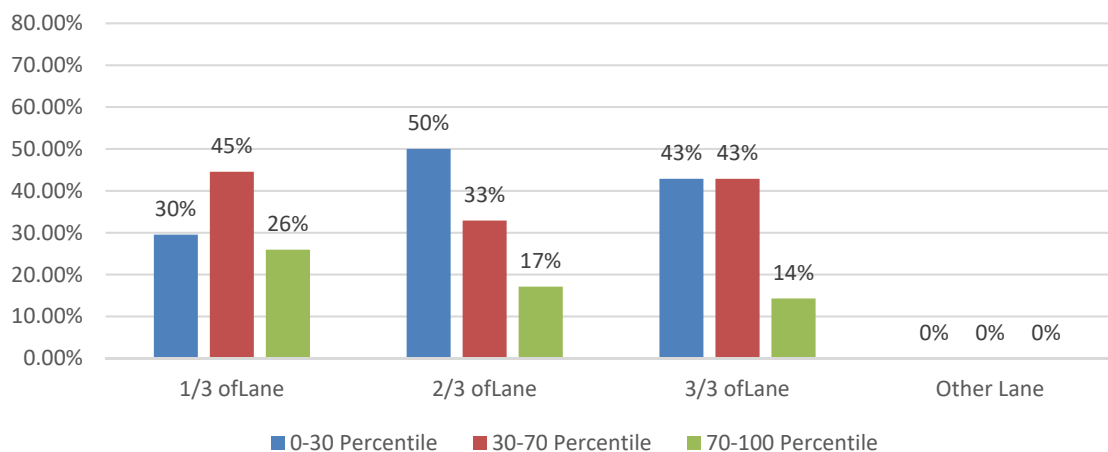
Site 2 After Installation Without Large Vehicles Control Data Statistical Speed Summary

<i>Without Large Vehicles</i>	<i>Speed (mph)</i>
Mean	27.653125
Standard Error	0.130702772
Median	28
Mode	27
Standard Deviation	4.049677265
Sample Variance	16.39988595
Kurtosis	0.255156813
Skewness	-0.28462743
Range	25
Minimum	15
Maximum	40
Sum	26547
Count	960

Site 2 After Installation Without Large Vehicles Control Data Correlation

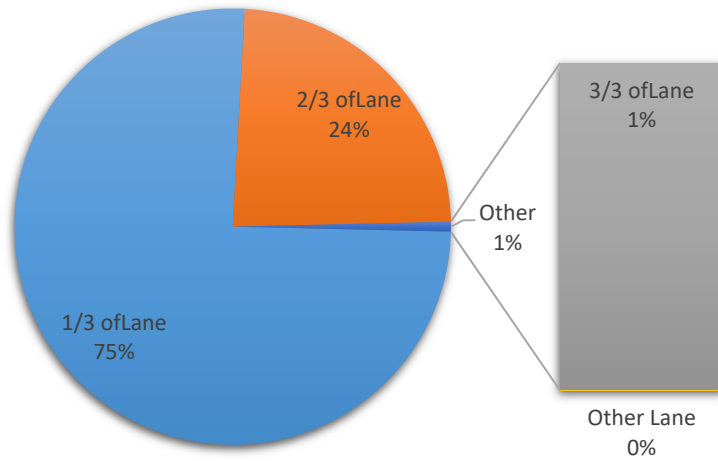
<i>Without Large Vehicles</i>	<i>Speed (mph)</i>	<i>Lateral Position</i>	<i>Vehicle size</i>
Speed (mph)	1		
Lateral Position	-0.21930698	1	
Vehicle size	0.074350893	-0.135193284	1

Speed Vs Lateral Placement



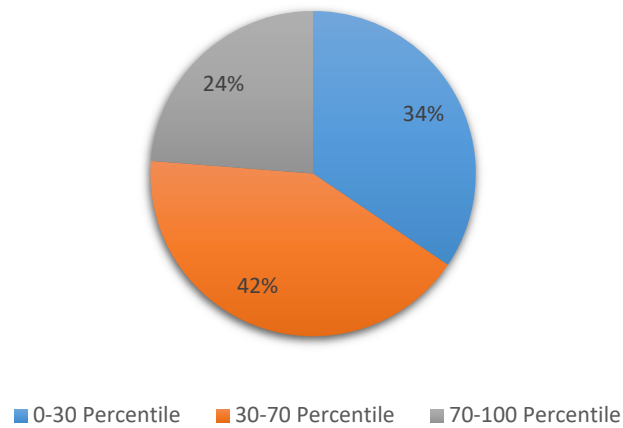
Site 2 After Installation Without Large Vehicles Control Data for Speed vs Lateral Placement

Control Lateral Placement



Site 2 After Installation Without Large Vehicles Data Control Lateral Placement

Control Speed



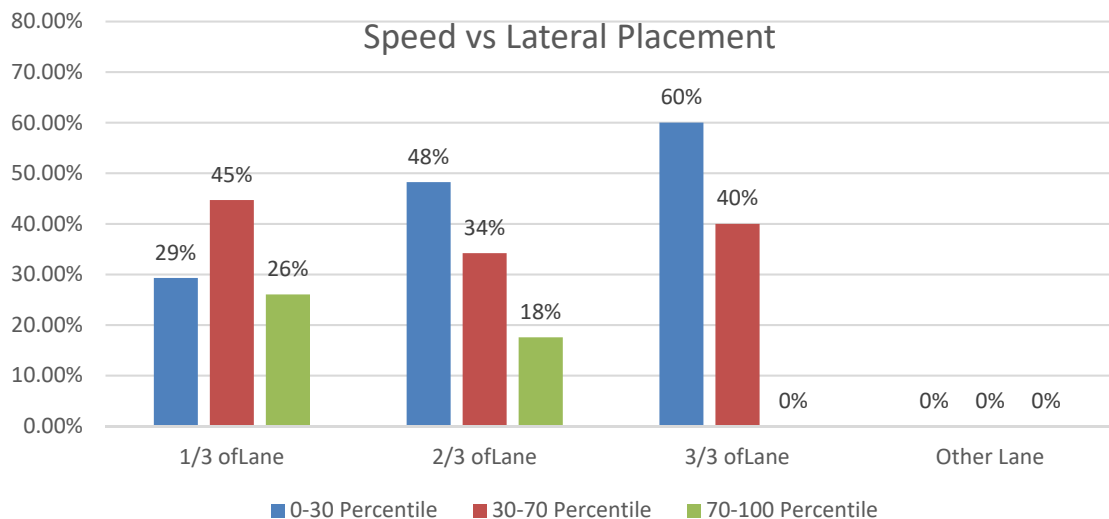
Site 2 After Installation Without Large Vehicles Data Control Speed

Site 2 After Installation Passenger Vehicles Only Control Data Statistical Speed Summary

<i>Passenger Vehicles Only</i>	<i>Speed (mph)</i>
Mean	27.70971074
Standard Error	0.128554186
Median	28
Mode	27
Standard Deviation	3.999667608
Sample Variance	15.99734097
Kurtosis	0.275959506
Skewness	-0.267771711
Range	25
Minimum	15
Maximum	40
Sum	26823
Count	968

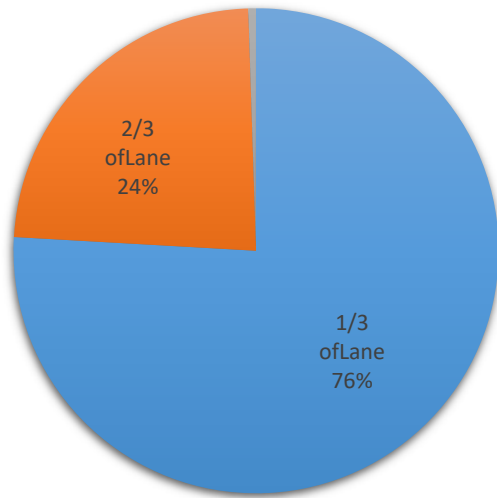
Site 2 After Installation Passenger Vehicles Only Control Data Correlation

<i>Passenger Vehicles Only</i>	<i>Speed (mph)</i>	<i>Lateral Position</i>
Speed (mph)	1	
Lateral Position	-0.209635175	1



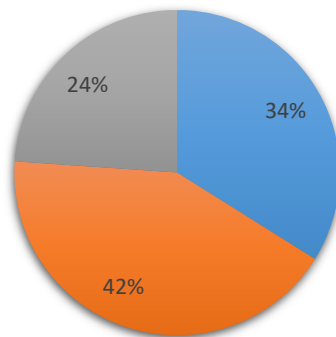
Site 2 After Installation Passenger Vehicles Only Control Data for Speed vs Lateral Placement

Control Site 2 Lateral Placement After



Site 2 After Installation Passenger Vehicles Only Data Control Lateral Placement

Control Speed



■ 0-30 Percentile ■ 30-70 Percentile ■ 70-100 Percentile

Site 2 After Installation Passenger Vehicles Only Data Control Speed

Site 2 After Installation Event Statistical Summary Speed all data

<i>All Data</i>	<i>Speed</i>	<i>Time Lag (s)</i>	<i>Time Between (s)</i>
Mean	27.55263158	116.0350877	77.57894733
Standard Error	0.406646401	6.740123909	6.99591664
Median	28	121	58.99999996
Mode	29	100.0000001	0
Standard Deviation	4.341795447	71.9648304	74.69594941
Sample Variance	18.8511877	5178.936815	5579.484858
Kurtosis	-0.522876408	-1.192393063	1.534552816
Skewness	-0.195658281	-0.034028882	1.291829975
Range	19	256.9999997	328.9999996
Minimum	18	-16.99999957	0
Maximum	37	240.0000002	328.9999996
Sum	3141	13228	8843.999996
Count	114	114	114

Site 2 After Installation All Event Data Correlation

<i>All Data</i>	<i>Lights Flash</i>	<i>Time Between Cat.</i>	<i>Speed</i>	<i>Class</i>	<i>Lateral Placement</i>	<i>Time Lag Cat.</i>
Lights Flash	1					
Time Between Cat.	-0.033784531	1				
Speed	-0.297113066	0.081302629	1			
Class	0.136084194	-0.096962289	-0.233495669	1		
Lateral Placement	0.234850936	0.064649193	-0.381005732	0.0062387	1	
Time Lag Cat.	-0.133074657	-0.074858437	0.295784606	-0.1730054	-0.674537609	1

Site 2 After Installation Event Statistical Summary of Speed, Time Lag, and Time Between for passenger vehicle only data

<i>Passenger Vehicles Only</i>	<i>Speed</i>	<i>Time Lag (s)</i>	<i>Time Between (s)</i>
Mean	28.03225806	123.5806452	74.36559137
Standard Error	0.446128118	7.331595744	7.115634514
Median	29	130.9999998	55.00000028
Mode	29	100.0000001	14.00000013
Standard Deviation	4.302303763	70.70334887	68.6206942
Sample Variance	18.50981767	4998.963542	4708.799672
Kurtosis	-0.356606084	-1.173356764	0.651984079
Skewness	-0.284536608	-0.163107296	1.079524422
Range	19	238.0000003	305.0000003
Minimum	18	1.999999839	0
Maximum	37	240.0000002	305.0000003
Sum	2607	11493	6915.999997
Count	93	93	93

Site 2 After Installation Event Correlation for Passenger vehicles only data

<i>Passenger Vehicles Only</i>	<i>Lights Flash</i>	<i>Time Between Cat.</i>	<i>Speed</i>	<i>Lateral Placement</i>	<i>Time Lag Cat.</i>
Lights Flash	1				
Time Between Cat.	-0.025134128	1			
Speed	-0.283262102	0.129451615	1		
Lateral Placement	0.24765961	-0.005760848	-0.382714996	1	
Time Lag Cat.	-0.119182824	0	0.213220909	-0.703483057	1

APPENDIX C

BEFORE INSTALLATION STATISTICAL SUMMARIES

Statistical Summary of All Data for Site 1

All Vehicles Site 1				
<i>Control Lateral Position Observations 1026</i>	<i>p-Value</i>	<i>Time Lag</i>	<i>Mean</i>	<i>p-value</i>
1.30994152	3.76105E-10	<i>Lateral Placement 1 Observations 26</i>	3.038461538	0.080455082
1.30994152	0.00023994	<i>Lateral Placement 2 Observations 12</i>	2.583333333	
1.30994152	0.061175893	<i>Lateral Placement 3 Observations 25</i>	1.48	0.000678528
1.30994152	0.417363782	<i>Lateral Placement 4 Observations 24</i>	1.333333333	0.188576258
1.30994152	0.429727067	<i>Lateral Placement 5 Observations 472</i>	1.315677966	0.444027015
<i>Control Speed Observations 1026</i>	<i>p-Value</i>	<i>Time Lag</i>	<i>Mean</i>	<i>p-value</i>
29.28265107	0.001020389	<i>Speed 1 Observations 26</i>	26.42307692	0.282404004
29.28265107	0.013019555	<i>Speed 2 Observations 12</i>	27.25	
29.28265107	0.000210336	<i>Speed 3 Observations 25</i>	25.4	0.122432558
29.28265107	0.019779936	<i>Speed 4 Observations 24</i>	26.875	0.156986248
29.28265107	0.000985685	<i>Speed 5 Observations 472</i>	28.73940678	0.052787947

Statistical Summary of Without Motorcycles Data for Site 1

Without Motorcycles Site 1				
<i>Control Lateral Position Observations 1008</i>	<i>p-Value</i>	<i>Time Lag</i>	<i>Mean</i>	<i>p-value</i>
1.291666667	3.03221E-10	<i>Lateral Placement 1 Observations 26</i>	3.038461538	0.080455082
1.291666667	0.000214393	<i>Lateral Placement 2 Observations 12</i>	2.583333333	
1.291666667	0.180791891	<i>Lateral Placement 3 Observations 23</i>	1.391304348	0.000343868
1.291666667	0.348824892	<i>Lateral Placement 4 Observations 24</i>	1.333333333	0.355694905
1.291666667	0.385656607	<i>Lateral Placement 5 Observations 446</i>	1.282511211	0.335171627
<i>Control Speed Observations 1008</i>	<i>p-Value</i>	<i>Time Lag</i>	<i>Mean</i>	<i>p-value</i>
29.27380952	0.001046615	<i>Speed 1 Observations 26</i>	26.42307692	0.282404004
29.27380952	0.011877605	<i>Speed 2 Observations 12</i>	27.25	
29.27380952	1.12629E-05	<i>Speed 3 Observations 23</i>	24.73913043	0.042269746
29.27380952	0.020104673	<i>Speed 4 Observations 24</i>	26.875	0.065846288
29.27380952	0.002460859	<i>Speed 5 Observations 446</i>	28.77802691	0.049495057

Statistical Summary of Without Large Vehicles Data for Site 1

Without Large Vehicles Site 1				
<i>Control Lateral Position Observations 972</i>	<i>p-Value</i>	<i>Time Lag</i>	<i>Mean</i>	<i>p-value</i>
1.303497942	3.50326E-10	<i>Lateral Placement 1 Observations 26</i>	3.038461538	0.080455082
1.303497942	0.000230806	<i>Lateral Placement 2 Observations 12</i>	2.583333333	
1.303497942	0.027349527	<i>Lateral Placement 3 Observations 23</i>	1.52173913	0.000995505
1.303497942	0.449566496	<i>Lateral Placement 4 Observations 22</i>	1.318181818	0.123235244
1.303497942	0.287675638	<i>Lateral Placement 5 Observations 450</i>	1.322222222	0.487842466
<i>Control Speed Observations 972</i>	<i>p-Value</i>	<i>Time Lag</i>	<i>Mean</i>	<i>p-value</i>
29.38580247	0.00074819	<i>Speed 1 Observations 26</i>	26.42307692	0.282404004
29.38580247	0.009739108	<i>Speed 2 Observations 12</i>	27.25	
29.38580247	0.000675688	<i>Speed 3 Observations 23</i>	25.65217391	0.163558843
29.38580247	0.008887566	<i>Speed 4 Observations 22</i>	26.45454545	0.299951498
29.38580247	0.000354795	<i>Speed 5 Observations 450</i>	28.78444444	0.027017346

Statistical Summary of Passenger Vehicles Only for Site 1

Passanger Vehicles Site 1				
<i>Control Lateral Position Observations 955</i>	<i>p-Value</i>	<i>Time Lag</i>	<i>Mean</i>	<i>p-value</i>
1.285863874	2.84615E-10	<i>Lateral Placement 1 Observations 26</i>	3.038461538	0.080455082
1.285863874	0.000207082	<i>Lateral Placement 2 Observations 12</i>	2.583333333	
1.285863874	0.103705409	<i>Lateral Placement 3 Observations 21</i>	1.428571429	0.000484851
1.285863874	0.396948135	<i>Lateral Placement 4 Observations 22</i>	1.318181818	0.252929958
1.285863874	0.481125785	<i>Lateral Placement 5 Observations 421</i>	1.287410926	0.4037879
<i>Control Speed Observations 955</i>	<i>p-Value</i>	<i>Time Lag</i>	<i>Mean</i>	<i>p-value</i>
29.37801047	0.000764869	<i>Speed 1 Observations 26</i>	26.42307692	0.282404004
29.37801047	0.0086855	<i>Speed 2 Observations 12</i>	27.25	
29.37801047	5.28666E-05	<i>Speed 3 Observations 21</i>	24.95238095	0.06259933
29.37801047	8.27777E-06	<i>Speed 4 Observations 22</i>	26.45454545	0.155723133
29.37801047	0.001034751	<i>Speed 5 Observations 421</i>	28.82897862	0.024997401

Site 1 Lateral Placement Control/Event Data Statistical Comparison

Site 1	<i>Control Lateral Position</i>	<i>Event Lateral Placement</i>	p-Value	N Event	N Control
All Vehicles	1.30994152	1.431127013	0.0003277	559	1026
Without Motorcycles	1.291666667	1.403773585	0.000805474	530	1008
Without Large Vehicles	1.303497942	1.444444444	6.57985E-05	531	972
Passanger Vehicles Only	1.285863874	1.416334661	0.000206536	502	955

Site 1 Speed Control/Event Data Statistical Comparison

Site 1	<i>Control Speed</i>	<i>Event Speed</i>	p-Value	N Event	N Control
All Vehicles	29.28265107	28.37030411	1.68995E-07	559	1026
Without Motorcycles	29.27380952	28.35660377	1.75116E-07	530	1008
Without Large Vehicles	29.38580247	28.41242938	4.43144E-08	531	972
Passanger Vehicles Only	29.37801047	28.40039841	4.62291E-08	502	955

Statistical Summary of All Data for Site 2

All Vehicles Site 2				
<i>Control Lateral Position Observations 1029</i>	<i>p-Value</i>	<i>Time Lag</i>	<i>Mean</i>	<i>p-value</i>
1.078717201	9.51203E-09	<i>Lateral Placement 1 Observations 22</i>	2.727272727	
1.078717201	0.013007143	<i>Lateral Placement 2 Observations 8</i>	2	0.029336875
1.078717201	0.011513182	<i>Lateral Placement 3 Observations 23</i>	1.5	0.075692792
1.078717201	0.141703662	<i>Lateral Placement 4 Observations 18</i>	1.222222222	0.154619559
1.078717201	0.006388291	<i>Lateral Placement 5 Observations 377</i>	1.137931034	0.264188067
<i>Control Speed Observations 1029</i>	<i>p-Value</i>	<i>Time Lag</i>	<i>Mean</i>	<i>p-value</i>
25.46161322	0.049087333	<i>Speed 1 Observations 22</i>	23.95454545	
25.46161322	0.008391064	<i>Speed 2 Observations 8</i>	21.875	0.111117579
25.46161322	0.000172404	<i>Speed 3 Observations 23</i>	22.05	0.448458368
25.46161322	0.012960222	<i>Speed 4 Observations 18</i>	23.66666667	0.054786605
25.46161322	0.046603483	<i>Speed 5 Observations 377</i>	25.04774536	0.041508455

Statistical Summary of Without Motorcycles Data for Site 2

Without Motorcycles Site 2				
<i>Control Lateral Position Observations 1009</i>	<i>p-Value</i>	<i>Time Lag</i>	<i>Mean</i>	<i>p-value</i>
1.062438057	8.03039E-09	<i>Lateral Placement 1 Observations 22</i>	2.727272727	
1.062438057	0.012107625	<i>Lateral Placement 2 Observations 8</i>	2	0.029336875
1.062438057	0.009388563	<i>Lateral Placement 3 Observations 20</i>	1.5	0.075692792
1.062438057	0.116960483	<i>Lateral Placement 4 Observations 18</i>	1.222222222	0.438586132
1.062438057	0.00575998	<i>Lateral Placement 5 Observations 369</i>	1.119241192	0.220943949
<i>Control Speed Observations 1009</i>	<i>p-Value</i>	<i>Time Lag</i>	<i>Mean</i>	<i>p-value</i>
25.44301288	0.050412324	<i>Speed 1 Observations 22</i>	23.95454545	
25.44301288	0.008412353	<i>Speed 2 Observations 8</i>	21.875	0.111117579
25.44301288	0.000174256	<i>Speed 3 Observations 20</i>	22.05	0.448458368
25.44301288	0.013658853	<i>Speed 4 Observations 18</i>	23.66666667	0.062975405
25.44301288	0.069247781	<i>Speed 5 Observations 369</i>	25.07317073	0.039117674

Statistical Summary of Without Large Vehicles Data for Site 2

Without Large Vehicles Site 2				
<i>Control Lateral Position Observations 959</i>	<i>p-Value</i>	<i>Time Lag</i>	<i>Mean</i>	<i>p-value</i>
1.078206465	9.46541E-09	<i>Lateral Placement 1 Observations 20</i>	2.8	
1.078206465	1.84956E-07	<i>Lateral Placement 2 Observations 8</i>	2	0.017469741
1.078206465	0.009723684	<i>Lateral Placement 3 Observations 18</i>	1.555555556	0.109256013
1.078206465	0.126696561	<i>Lateral Placement 4 Observations 16</i>	1.25	0.10486029
1.078206465	0.006979688	<i>Lateral Placement 5 Observations 364</i>	1.137362637	0.225884274
<i>Control Speed Observations 959</i>	<i>p-Value</i>	<i>Time Lag</i>	<i>Mean</i>	<i>p-value</i>
25.51824818	0.031175164	<i>Speed 1 Observations 20</i>	23.75	
25.51824818	0.007312802	<i>Speed 2 Observations 8</i>	21.875	0.115959951
25.51824818	0.000174603	<i>Speed 3 Observations 18</i>	21.94444444	0.479847892
25.51824818	0.059969518	<i>Speed 4 Observations 16</i>	23.875	0.044576696
25.51824818	0.033094918	<i>Speed 5 Observations 364</i>	25.05494505	0.125970936

Statistical Summary of Passenger Vehicles Only Data for Site 2

Passanger Vehicles Site 2				
<i>Control Lateral Position Observations 939</i>	<i>p-Value</i>	<i>Time Lag</i>	<i>Mean</i>	<i>p-value</i>
1.060702875	8.02756E-09	<i>Lateral Placement 1 Observations 20</i>	2.8	0.017469741
1.060702875	0.012016835	<i>Lateral Placement 2 Observations 8</i>	2	
1.060702875	0.054785864	<i>Lateral Placement 3 Observations 15</i>	1.333333333	0.025342369
1.060702875	0.105021215	<i>Lateral Placement 4 Observations 16</i>	1.25	0.350264332
1.060702875	0.00555138	<i>Lateral Placement 5 Observations 355</i>	1.118309859	0.190063485
<i>Control Speed Observations 939</i>	<i>p-Value</i>	<i>Time Lag</i>	<i>Mean</i>	<i>p-value</i>
25.49946752	0.031909539	<i>Speed 1 Observations 20</i>	23.75	0.115959951
25.49946752	0.007307682	<i>Speed 2 Observations 8</i>	21.875	
25.49946752	0.000423854	<i>Speed 3 Observations 15</i>	21.86666667	0.497801335
25.49946752	0.061136185	<i>Speed 4 Observations 16</i>	23.875	0.053552831
25.49946752	0.04326927	<i>Speed 5 Observations 355</i>	25.06197183	0.125206723

Site 2 Lateral Placement Control/Event Data Statistical Comparison

Site 2	<i>Control Lateral Position</i>	<i>Event Lateral Placement</i>	p-Value	N Event	N Control
All Vehicles	1.078717201	1.25	6.6843E-09	448	1029
Without Motorcycles	1.062438057	1.226544622	5.04648E-06	437	1009
Without Large Vehicles	1.078206465	1.252336449	8.73258E-09	428	959
Passanger Vehicles Only	1.060702875	1.227817746	1.24141E-08	417	939

Site 2 Speed Control/Event Data Statistical Comparison

Site 2	<i>Control Speed</i>	<i>Event Speed</i>	p-Value	N Event	N Control
All Vehicles	25.46161322	24.72767857	0.000778462	448	1029
Without Motorcycles	25.44301288	24.7597254	0.001847685	437	1009
Without Large Vehicles	25.51824818	24.72196262	0.000395297	428	959
Passanger Vehicles Only	25.49946752	24.75539568	0.00100439	417	939

APPENDIX D

AFTER INSTALLATION STATISTICAL SUMMARIES

Statistical Summary of All Data for Site 1

All Vehicles Site 1				
<i>Control Lateral Position Observations 1025</i>	<i>p-Value</i>	<i>Time Lag</i>	<i>Mean</i>	<i>p-value</i>
1.374634146	0	<i>Lateral Placement 1 Observations 39</i>	2.974358974	0.002145917 0.008834523 0.105428574 0.118469701
1.374634146	1.80587E-05	<i>Lateral Placement 2 Observations 24</i>	2.333333333	
1.374634146	1.65597E-06	<i>Lateral Placement 3 Observations 55</i>	1.854545455	
1.374634146	0.009044506	<i>Lateral Placement 4 Observations 41</i>	1.658536585	
1.374634146	2.25106E-07	<i>Lateral Placement 5 Observations 817</i>	1.515299878	
<i>Control Speed Observations 1025</i>	<i>p-Value</i>	<i>Time Lag</i>	<i>Mean</i>	<i>p-value</i>
27.60487805	2.59933E-05	<i>Speed 1 Observations 39</i>	25.76923077	0.469729837 0.383999706 0.17449735 0.200350339
27.60487805	0.003009481	<i>Speed 2 Observations 24</i>	25.708333333	
27.60487805	0.000361867	<i>Speed 3 Observations 55</i>	25.96363636	
27.60487805	0.02591799	<i>Speed 4 Observations 41</i>	26.6097561	
27.60487805	0.000207484	<i>Speed 5 Observations 817</i>	27.04283966	

Statistical Summary of Without Motorcycles Data for Site 1

Without Motorcycles Site 1				
<i>Control Lateral Position Observations 1013</i>	<i>p-Value</i>	<i>Time Lag</i>	<i>Mean</i>	<i>p-value</i>
1.35834156	0	<i>Lateral Placement 1 Observations 38</i>	2.973684211	0.002429528 0.00904436 0.110387824 0.088295933
1.35834156	1.45277E-05	<i>Lateral Placement 2 Observations 24</i>	2.333333333	
1.35834156	1.28741E-06	<i>Lateral Placement 3 Observations 54</i>	1.851851852	
1.35834156	0.006191712	<i>Lateral Placement 4 Observations 41</i>	1.658536585	
1.35834156	2.47027E-07	<i>Lateral Placement 5 Observations 798</i>	1.494987469	
<i>Control Speed Observations 1013</i>	<i>p-Value</i>	<i>Time Lag</i>	<i>Mean</i>	<i>p-value</i>
27.54096742	1.45019E-05	<i>Speed 1 Observations 38</i>	25.65789474	0.474849811 0.385346772 0.176374675 0.224500192
27.54096742	0.003249307	<i>Speed 2 Observations 24</i>	25.708333333	
27.54096742	0.000696773	<i>Speed 3 Observations 54</i>	25.96296296	
27.54096742	0.034296962	<i>Speed 4 Observations 41</i>	26.6097561	
27.54096742	0.000314147	<i>Speed 5 Observations 798</i>	27	

Statistical Summary of Without Large Vehicles Data for Site 1

Without Large Vehicles Site 1				
<i>Control Lateral Position Observations 1025</i>	<i>p-Value</i>	<i>Time Lag</i>	<i>Mean</i>	<i>p-value</i>
1.380140421	0	<i>Lateral Placement 1 Observations 37</i>	3.054054054	0.000502007 0.024187836 0.121082522 0.090192813
1.380140421	1.94513E-05	<i>Lateral Placement 2 Observations 24</i>	2.333333333	
1.380140421	5.93175E-06	<i>Lateral Placement 3 Observations 43</i>	1.906976744	
1.380140421	0.006134912	<i>Lateral Placement 4 Observations 37</i>	1.702702703	
1.380140421	1.36171E-07	<i>Lateral Placement 5 Observations 749</i>	1.52870494	
<i>Control Speed Observations 1025</i>	<i>p-Value</i>	<i>Time Lag</i>	<i>Mean</i>	<i>p-value</i>
27.64292879	2.0825E-05	<i>Speed 1 Observations 37</i>	25.7027027	0.497260748 0.182175603 0.468829076 0.156898071
27.64292879	0.002552073	<i>Speed 2 Observations 24</i>	25.70833333	
27.64292879	0.022407374	<i>Speed 3 Observations 43</i>	26.53488372	
27.64292879	0.027834282	<i>Speed 4 Observations 37</i>	26.59459459	
27.64292879	0.00140845	<i>Speed 5 Observations 749</i>	27.15086782	

Statistical Summary of Passenger Vehicles Only Data for Site 1

Passenger Vehicles Site 1				
<i>Control Lateral Position Observations 985</i>	<i>p-Value</i>	<i>Time Lag</i>	<i>Mean</i>	<i>p-value</i>
1.363451777	0	<i>Lateral Placement 1 Observations 36</i>	3.055555556	0.001137322 0.024187836 0.121082522 0.065664604
1.363451777	1.55627E-05	<i>Lateral Placement 2 Observations 24</i>	2.333333333	
1.363451777	3.0657E-06	<i>Lateral Placement 3 Observations 43</i>	1.906976744	
1.363451777	0.004202318	<i>Lateral Placement 4 Observations 37</i>	1.702702703	
1.363451777	1.75042E-07	<i>Lateral Placement 5 Observations 730</i>	1.506849315	
<i>Control Speed Observations 985</i>	<i>p-Value</i>	<i>Time Lag</i>	<i>Mean</i>	<i>p-value</i>
27.57766497	1.09735E-05	<i>Speed 1 Observations 36</i>	25.58333333	0.44234095 0.182175603 0.468829076 0.1768741
27.57766497	0.002752752	<i>Speed 2 Observations 24</i>	25.70833333	
27.57766497	0.029406597	<i>Speed 3 Observations 43</i>	26.53488372	
27.57766497	0.036261851	<i>Speed 4 Observations 37</i>	26.59459459	
27.57766497	0.002030824	<i>Speed 5 Observations 730</i>	27.10684932	

Site 1 Lateral Placement Control/Event Data Statistical Comparison

<i>Site 1</i>	<i>Control Lateral Position</i>	<i>Event Lateral Placement</i>	<i>p-Value</i>	<i>N Control</i>	<i>N Event</i>
<i>All Vehicles</i>	1.374634146	1.618852459	0	1025	976
<i>Without Motorcycles</i>	1.35834156	1.602094241	0	1013	955
<i>Without Large Vehicles</i>	1.380140421	1.639325843	0	997	890
<i>Passanger Vehicles Only</i>	1.363451777	1.62183908	0	985	870

Site 1 Speed Control/Event Data Statistical Comparison

<i>Site 1</i>	<i>Control Speed</i>	<i>Event Speed</i>	<i>p-Value</i>	<i>N Control</i>	<i>N Event</i>
<i>All Vehicles</i>	27.60487805	26.88012295	8.37119E-07	1025	976
<i>Without Motorcycles</i>	27.54096742	26.83874346	1.48226E-06	1013	955
<i>Without Large Vehicles</i>	27.64292879	26.9988764	1.95078E-05	997	890
<i>Passanger Vehicles Only</i>	27.57766497	26.95517241	3.13175E-05	985	870

Statistical Summary of All Data for Site 2

All Vehicles Site 2				
<i>Control Lateral Position Observations 1026</i>	<i>p-Value</i>	<i>Time Lag</i>	<i>Mean</i>	<i>p-value</i>
1.243664717	1.38486E-37	<i>Lateral Placement 1 Observations 6</i>	3.666666667	0.210804548
1.243664717	0.008120636	<i>Lateral Placement 3 Observations 5</i>	3.2	
1.243664717	0.160271566	<i>Lateral Placement 4 Observations 3</i>	2	0.086829274
1.243664717	0.036539836	<i>Lateral Placement 5 Observations 62</i>	1.532258065	0.154304031
<i>Control Speed Observations 1026</i>	<i>p-Value</i>	<i>Time Lag</i>	<i>Mean</i>	<i>p-value</i>
27.57017544	0.001186839	<i>Speed 1 Observations 6</i>	22.5	0.257401142
27.57017544	0.032286672	<i>Speed 3 Observations 5</i>	24.2	
27.57017544	0.483618763	<i>Speed 4 Observations 3</i>	27.66666667	0.125104824
27.57017544	0.236094598	<i>Speed 5 Observations 62</i>	27.08064516	0.405226491

Statistical Summary of Passenger Vehicles Only Data for Site 2

Passenger Vehicles Site 2				
<i>Control Lateral Position Observations 1025</i>	<i>p-Value</i>	<i>Time Lag</i>	<i>Mean</i>	<i>p-value</i>
1.245867769	0	<i>Lateral Placement 1 Observations 3</i>	4	0.090845057
1.245867769	5.95689E-15	<i>Lateral Placement 3 Observations 4</i>	3	
1.245867769	3.41757E-05	<i>Lateral Placement 4 Observations 2</i>	2.5	0.307568159
1.245867769	0.000682033	<i>Lateral Placement 5 Observations 50</i>	1.58	0.043429235
<i>Control Speed Observations 1025</i>	<i>p-Value</i>	<i>Time Lag</i>	<i>Mean</i>	<i>p-value</i>
27.70971074	0.195018085	<i>Speed 1 Observations 3</i>	23.66666667	0.423365696
27.70971074	0.054849934	<i>Speed 3 Observations 4</i>	24.5	
27.70971074	0.334613389	<i>Speed 4 Observations 2</i>	26.5	0.309322369
27.70971074	0.313489613	<i>Speed 5 Observations 50</i>	27.42	0.37863348

Site 2 Lateral Placement Control/Event Data Statistical Comparison

<i>Site 2</i>	<i>Control Lateral Position</i>	<i>Event Lateral Placement</i>	<i>p-Value</i>	<i>N Control</i>	<i>N Event</i>
<i>All Vehicles</i>	1.243664717	1.857142857	1.66672E-07	1026	77
<i>Passanger Vehicles Only</i>	1.866666667	1.245867769	8.65991E-07	968	60

Site 2 Speed Control/Event Data Statistical Comparison

<i>Site 2</i>	<i>Control Speed</i>	<i>Event Speed</i>	<i>p-Value</i>	<i>N Control</i>	<i>N Event</i>
<i>All Vehicles</i>	27.57017544	26.66233766	0.038072632	1026	77
<i>Passanger Vehicles Only</i>	27.13333333	27.70971074	0.158594475	968	60

APPENDIX E

BEFORE AFTER INSTALLATION STATISTICAL SUMMARIES

Site 1 Control Before After Installation Statistical Summary for Lateral Placement and Speed

Control Site 1	Lateral Placement After	Lateral Placement Before	p-value	Speed After	Speed Before	p-value	N After	N Before
All Data	1.374634146	1.30994152	0.002982695	27.60487805	29.28265107	0	1025	1026
Without Motorcycles	1.35834156	1.291666667	0.001650039	27.54096742	29.27380952	0	1013	1008
Without Large Vehicles	1.380140421	1.303497942	0.000682676	27.64292879	29.38580247	0	997	972
Passanger Vehicles	1.363451777	1.285863874	0.000389918	27.57766497	29.37801047	0	985	955

Site 1 All Data Before After Installation Statistical Summary for Lateral Placement and Speed

Site 1 All Data	Lateral Placement After	Lateral Placement Before	p-value	Speed After	Speed Before	p-value	N After	N Before
All	1.618852459	1.431127013	8.43431E-07	26.88012295	28.37030411	5.02794E-08	976	559
Time Lag 1	2.974358974	3.038461538	0.381376418	25.76923077	26.42307692	0.245168629	39	26
Time Lag 2	2.333333333	2.583333333	0.221633106	25.70833333	27.25	0.117223789	24	12
Time Lag 3	1.854545455	1.48	0.009500517	25.96363636	25.4	0.299462856	55	25
Time Lag 4	1.658536585	1.333333333	0.027178484	26.6097561	26.875	0.413762561	41	24
Time Lag 5	1.515299878	1.315677966	1.12636E-08	27.04283966	28.73940678	0	817	472

Site 1 Without Motorcycles Before After Installation Statistical Summary for Lateral Placement and Speed

Site 1 Without Motorcycles	Lateral Placement After	Lateral Placement Before	p-value	Speed After	Speed Before	p-value	N After	N Before
All	1.602094241	1.403773585	2.38619E-07	26.83874346	28.35660377	3.33067E-16	955	530
Time Lag 1	2.973684211	3.038461538	0.381701018	25.65789474	26.42307692	0.209700438	38	26
Time Lag 2	2.333333333	2.583333333	0.221633106	25.70833333	27.25	0.117223789	24	12
Time Lag 3	1.851851852	1.391304348	0.001316582	25.96296296	24.73913043	0.094840663	54	23
Time Lag 4	1.658536585	1.333333333	0.027178484	26.6097561	26.875	0.413762561	41	24
Time Lag 5	1.494987469	1.280898876	4.27448E-10	27	28.76629213	0	798	445

Site 1 Without Large Vehicles Before After Installation Statistical Summary for Lateral Placement and Speed

Site 1 Without Large Vehicles	Lateral Placement After	Lateral Placement Before	p-value	Speed After	Speed Before	p-value	N After	N Before
All	1.638920135	1.444444444	1.11877E-06	27.0056243	28.41242938	8.12683E-14	889	531
Time Lag 1	3.054054054	3.038461538	0.471083024	25.7027027	26.42307692	0.226012413	37	26
Time Lag 2	2.333333333	2.583333333	0.221633106	25.70833333	27.25	0.117223789	24	12
Time Lag 3	1.906976744	1.52173913	0.014418774	26.53488372	25.65217391	0.223728762	43	23
Time Lag 4	1.702702703	1.318181818	0.016628575	26.59459459	26.45454545	0.455971969	37	22
Time Lag 5	1.528074866	1.323660714	2.05605E-08	27.15909091	28.796875	0	748	448

Site 1 Passenger Vehicles Only Before After Installation Statistical Summary for Lateral Placement and Speed

Site 1 Passanger Vehicles	Lateral Placement After	Lateral Placement Before	p-value	Speed After	Speed Before	p-value	N After	N Before
All	1.62183908	1.416334661	3.33407E-07	26.95517241	28.40039841	3.24185E-14	870	502
Time Lag 1	3.055555556	3.038461538	0.46856202	25.58333333	26.42307692	0.190259034	36	26
Time Lag 2	2.333333333	2.583333333	0.221633106	25.70833333	27.25	0.117223789	24	12
Time Lag 3	1.906976744	1.428571429	0.002351129	26.53488372	24.95238095	0.060019956	43	21
Time Lag 4	1.702702703	1.318181818	0.016628575	26.59459459	26.45454545	0.455971969	37	22
Time Lag 5	1.506849315	1.287410926	8.58167E-10	27.10684932	28.82897862	0	730	421

Site 2 Control Before After Installation Statistical Summary for Lateral Placement and Speed

Control Site 2	Lateral Placement After	Lateral Placement Before	p-value	Speed After	Speed Before	p-value	N After	N Before
All Data	1.245867769	1.060702875	0	27.70971074	25.49946752	0	1026	1029
Without Motorcycles	1.235877106	1.062438057	0	27.60654113	25.44301288	0	1009	1009
Without Large Vehicles	1.252083333	1.078206465	0	27.653125	25.51824818	0	960	959
Passanger Vehicles	1.245867769	1.060702875	0	27.70971074	25.49946752	0	968	939

Site 2 All Data Before After Installation Statistical Summary for Lateral Placement and Speed

Site 2 All Data	Lateral Placement After	Lateral Placement Before	p-value	Speed After	Speed Before	p-value	N After	N Before
All	1.857142857	1.25	3.84143E-07	26.66233766	24.72767857	0.000136018	77	448
Time Lag 1	3.666666667	2.727272727	0.010144738	22.5	23.95454545	0.233171823	6	22
Time Lag 3	3.2	1.434782609	0.009198892	24.2	22.04347826	0.100210057	5	23
Time Lag 4	2	1.222222222	0.159577336	27.66666667	23.66666667	0.026230061	3	18
Time Lag 5	1.532258065	1.137931034	3.56116E-05	27.08064516	25.04774536	0.0001636	62	377

Site 2 Passenger Vehicles Only Before After Installation Statistical Summary for Lateral Placement and Speed

Site 2 Passanger Vehicles	Lateral Placement After	Lateral Placement Before	p-value	Speed After	Speed Before	p-value	N After	N Before
All	1.866666667	1.227817746	6.78531E-07	27.13333333	24.75539568	3.2847E-05	60	417
Time Lag 1	4	2.8	1.79177E-06	23.66666667	23.75	0.492264537	3	20
Time Lag 3	3	1.277777778	0.031145506	24.5	21.88888889	0.104488684	4	18
Time Lag 4	2.5	1.25	0.005878896	26.5	23.875	0.148223655	2	16
Time Lag 5	1.58	1.118309859	6.08872E-06	27.42	25.06197183	4.05529E-06	50	355