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Title: Observational Study of Buffered Bike Lane Design Implementation of Roadway Bicycling in Portland, Oregon

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Bicyclists are one of the highest and most vulnerable road users. This is due to the higher likelihood of being seriously injured when involved in a crash. This research seeks to understand two different behavioral interactions of an implemented facility user: the motorist (secondary user) and bicyclist (primary user). The resulting model is for road segments only and does not include intersections. For the bicyclists behavior this research attempts to understand the use of available buffered bicycle lane; a bicyclists' sway (or side to side movement) within a buffered bicycle lane; the passing of another bicyclist; and the behavior of vehicles adjacent to the travel lanes under different operating conditions of traffic densities, speeds, and facility design. For the motorist behavior, the research is seeks to understand the motorist and bicyclist behavior during a high-risk vehicle/bicyclist conflict point to define near miss collisions. The data that is to be evaluated by an ANOVA are the non-truncated and truncated data sets for each buffered bicycle lane facility. A binary logistic regression (logit) model was used to evaluate the behavior of near miss collisions between a bicyclist and motorized vehicles.

Observational Study of Buffered Bike Lane Design Implementation of Roadway Bicycling in Portland, Oregon

by

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes the release of my thesis to any reader upon request.

Elizabeth Rios, Author

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OBSERVATIONAL STUDY OF BUFFERED BIKE LANE DESIGN IMPLEMENTATION OF ROADWAY BICYCLING IN PORTLAND, OREGON

1 Introduction

Any traffic related death and serious injuries is a tragedy and are unacceptable when there are tools and capability that can be utilized to prevent them. This concept is known as vision zero or “zero deaths,” and has been adopted by countries, states, and cities around the world. This concept was first implemented and adopted in Sweden in 1997 and has evolved across the country and the world (FHWA, 2015). Swedish transportation system was the first program implementing Vision Zero. It was developed in 1995 and passed legislation in 1997 (McCarthy, 2007). The program's goal is to eliminate fatalities and serious injuries by 2020. The program was developed by highway and traffic engineers, law enforcement, vehicle designers, medical specialists, educators, social scientists, media, government officials and many more.

The Vision Zero program is constructed around identifying targets areas for improvement and assembling countermeasures to be reviewed and implemented. This program is concentrated on the process of the “4 E’s” (education, enforcement, engineering, and emergency medical services), as well as, a combination of strategies from different focus areas. This process relies heavily on adopting a systems-wide or network-wide approach to road safety. A network-wide approach is conducted by examining the complete driving environment (vehicles, roads, the environment, existing infrastructure and multimodal traffic interactions) to optimally manage and reduce the severity of crashes (the force exerted onto a person during a crash does not exceed the threshold of violent force a human body can withstand) within the system.

This program differs from traditional road safety theory of prioritization when designing and defining operational needs of a roadway network system. This method places preventative serious injury and death at the highest priority and focus. The program's core concept is that an accident that results in serious human injury means that the road system components and preventative safety measures were not functioning (i.e. the design of the road system was not designed for human error/mistakes that resulted in serious or fatal injury). This concept is a major shift of responsibility in safety from road users to designers of the transport system (highway agencies, automotive industry, the police, politicians, and legislative bodies).

The traditional road safety theory that is utilized by the transportation professional when designing or improving a road network through Nominal Safety or Substantive Safety (OSU, 2017). In 2010, The U.S Department of Transportation Federal Highways Administration (FHWA) related nominal and substantive safety to road safety theory. Nominal safety refers to a design (or design element) that uses the minimum design criteria of state or national standards and guidance (OSU, 2017). These standards and guidance are based on available material such as the *AASHTO Green Book*, Manual *on Uniform Traffic Control Devices (MUTCD), Urban Bikeway Design Guide,* and much more. If a road network meets the minimum design criteria when constructed, then it can be characterized as nominally safe (Herbel et al., 2010). This does not characterize the actual or expected safety of a roadway only that this road network has met the minimum design elements. While substantive safety, outlined by FHWA, is based on the actual or expected safety on a roadway and is qualified by crash frequency, crash rate, crash type and crash severity (Herbel et al., 2010). There is no direct correlation between nominal (design based on standards) and substantive safety (roadway safety performance) (OSU, 2017). An example that used to illustrated this concept is a roadway could be characterized as nominally safe, while having a higher than expected crash experience; or no a roadway may not meet minimum design criteria and still function at a high level of substantive safety.

Since Vision Zero does not utilize the traditional road safety theories, it must be adopted and recognized by all agencies and the public to be effective. In 2013, Washington State released their new Strategic Highway Safety Plan for "Target Zero". This document was drafted and collaborated by over 120 extended organizations from across Washington State and outlined a very aggressive goal to have zero traffic deaths and serious injuries by 2030 (WSDOT, 2013). This collaborative plan was signed by Washington's Traffic Safety Commission (Governor of Washington, Head of Washington Department of Transportation (WSDOT), Chief of Washington State Patrol, Chief of Department of Licensing, Head of Department of Health, Judge of Clark County District Court, Superintendent of Public Instruction, Head of Department of Social and Health Services, Head of Washington State Association of Counties, Head of Association of Washington Cities, and Head of Washington Traffic Safety Commission.

In 2014, Portland Bureau of Transportation (PBOT) implemented their Vision Zero program and outlined a goal to have zero traffic deaths and serious injuries before 2024. PBOT's approach is to change existing street design; build a complete network that supports all users; educated populace to respect and protect each other; and consistent enforcement of traffic safety laws (Progress, 2014). This will be done by encouraging safe behavior and providing facilities to accommodate all travel modes, designing for slower users like pedestrians and bicyclists, developing and distributing public service announcement to the public, and changing state laws on motorist education. PBOT's focus is that if a system that works for vulnerable users thru re-design to support the most vulnerable road users then it will result in a system that works for everyone.

One major focus group in a Vision Zero program are bicyclists. Bicyclists are one of the highest and most vulnerable road users. This is due to the higher likelihood of being seriously injured when involved in a crash. To improve bicyclists' safety and decrease high severity crashes from occurring, engineers, designers, and planners have developed protected and buffered bicycle lanes. These protected and buffered bicycle lanes provide safe paths for bicyclists on the road networks. The thesis studies the observation, evaluation and analysis of behavioral patterns of vehicles and bicyclists using buffered bike lanes. This thesis uses data obtained from observing and evaluating the behavior patterns of drivers and bicyclists in proximity to buffered bike lanes

The main focus of this thesis is to provide clarity and an initial observational analysis of two different behaviors:

1) Defining bicyclists behavior and lane usage within implemented buffered bicycle lanes and

2) Analyzing motorist and bicyclist behavior at a high risk vehicle/bicyclist conflict point to define near miss collisions.

This analysis uses video data supplied by the Portland Bureau of Transportation of the bicycle, vehicle and pedestrian patterns during the peak travel in Portland, Oregon from 2016, and generated a data set using an ANOVA analysis and Binary Logit Regression model to identify lane usage and behavioral expectancy of bicyclists and motorists.

1.1 Description of Bicycle Lane Designs

The Urban Bikeway Design Guide (NACTO, 2014) defines a bicycle lane as a portion of the roadway that has been designated by striping, signage, and pavement markings for the preferential or exclusive use of bicyclists. The bicycle lanes are facilities that provide bicyclists a space to ride at their ideal speed without interference from adjacent traffic conditions. The purpose of these facilities are to accommodate behavior and movements between bicyclists and motorists. The following section is clarification as to be the use of different bicycle lane design terminology that will be used through this thesis. The three types of bicycle lanes designs that will be discussed are: conventional (painted) bike lanes, buffered bike lanes, and fully separated (protected) bike lanes.

1.1.1 Conventional Bicycle Lane

The conventional bicycle lane does not have a physical barrier (bollards, medians, raised curbs, etc.) that prevents the encroachment of adjacent vehicles. The common location of a conventional bicycle lane is to operate in the same direction of traffic flow, placed along the curbside on the right- hand side or on the left-hand side of the street in specific situations (such as one way street). These bicycle lanes can be designed from four to six feet in width. Figure 1 shows the conventional bike lane in Corvallis, Oregon, U.S.

Figure 1: Conventional Bicycle Lane located in Corvallis, Oregon, U.S

1.1.2 Buffered Bicycle Lane

A buffered bicycle lane as defined by Separated Bike Lane Planning and Design Guide (FHWA, 2015) is a conventional bike lane with a pained buffer used to increase lateral separation between bicyclists and the adjacent vehicle traffic. The Urban Bikeway Design Guide recommends that streets with high traffic volumes, high speeds, high volume of trucks, or high volumes of vehicle density should implement a buffered bike. Figure 2 shows the buffered bike lane in Portland, Oregon, USA.

Figure 2: Buffered Bicycle Lane in Portland, Oregon, USA (Vanderslice, 2010)

1.1.3 Fully Separated (Protected) Bicycle Lanes

The Separated Bike Lane Planning and Design Guide (FHWA, 2015) defines a fully separated bicycle lane as an exclusive facility for bicyclists that is located within or directly next to a roadway segment and that is physically separated from vehicle traffic with a vertical element. This vertical element must separate bicyclists from the adjacent vehicle traffic or sidewalk but it is not limited to on-street parking, raised curbs or medians, bollards, landscaping, or planters. The placement of this facility is along the curbside on the right-hand side or on the left-hand side of the street and can operate as a one-way or two-way facility.

These bicycle lanes are not a shared use path (and side paths) due to their direct placement adjacent to vehicle travel lanes and are for bike-use only facilities. Fully separated bicycle lanes are sometimes referred to as “cycle tracks” or “protected bike lanes”. Figure 3 shows the fully protected bike lane in Chicago, Illinois, USA.

Figure 3: Fully Separated Bicycle Lane in Chicago, Illinois, USA (Vanderslice, 2010)

1.2 Objective

The objective of the research is to provide an analysis of bicyclists and motorist behaviors with implemented buffered bicycle lane designs. This research seeks to understand two different behavioral interactions of an implemented facility user: the motorist (secondary user) and bicyclist (primary user). The resulting model is for road segments only and does not include intersections. For the bicyclists behavior this research attempts to understand the use of available buffered bicycle lane; a bicyclists’ sway (or side to side movement) within a buffered bicycle lane; the passing of another bicyclist; and the behavior of vehicles adjacent to the travel lanes under different operating conditions of traffic densities, speeds, and facility design. For the motorist behavior, the research is seeks to understand the motorist and bicyclist behavior during a high-risk vehicle/bicyclist conflict point to define near miss collisions.

1.3 Scope

The research evaluates observed risk factors associated with different buffered bike lane designs. The goal of the research is to evaluate three constructed buffered bike lanes and evaluate the effectiveness in terms of the behavior of two different user groups on the constructed facility after construction and implantation. The two different user groups are the bicyclists, and motorized vehicles. The study created a database that contains observational data from Portland, Oregon that implemented different buffered bike lane designs and evaluates bicycle and vehicle interactions on these facilities. The thesis examines the impacts of different safety design infrastructure features on bicyclist's behavior and space utilization.

2 Background

Bicycle lanes are used to facilitate bicyclists to ride at their ideal speed without interference from adjacent traffic conditions, as well as, accommodate behavior and movements between bicyclists and motorists (FHWA, 2015). The main design objective of a bicycle lane is to provide and to maintain a facility that is safe. This is achieved by: increasing sight distance and visibility of the bicyclists for motorists, and increasing sight distance and visibility for bicyclists. Bicycle lanes are constructed using different methods that include the use of colored lane markings, to the implementation of permanent or temporary physical barriers. The bicycle lane evaluated in this study have no physical barrier (bollards, medians, raised curbs, etc.) that prevents the encroachment of adjacent vehicles.

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2.1 Planning considerations of buffered bicycling lane design (Study Area)

The *Portland Bicycle Plan for 2030* outlines and modernizes the Transportation System Plan and merges planning efforts by Metro, TriMet, Multnomah County, the Port of Portland, the Portland Development Commission and other bureaus within the City of Portland, as well as efforts by adjacent jurisdictions, to foster a well-connected regional bicycle network. The Transportation System Plan is Portland’s 20-year plan for transportation improvements for all modes of transportation. The planning implementation for bicycle lane construction in Portland utilized two methods which are discussed below: a Pilot Program and an Integrated program where the bike facility is included as a part of a large new construction or major reconstruction project. This discussion is focused on defining the different bicycle lane design by the Federal Highway Administration and showing the process that the Portland Bureau of Transportation implementation of the project

2.1.1 Pilot Program (Corridor Location)

The Separated Bike Lane Planning and Design Guide (FHWA, 2015) outlines how the Pilot Program is used in the planning implementation for bicycle lane construction. The construction cost and planning of fully separated bicycle lane infrastructure is expensive and the permanent elements that are needed such as raised curbs and bicycle signals are challenging to place in the existing network. A Pilot Program allows municipalities to use less costly infrastructure elements (flexible delineator posts instead of permanent raised curbs), while allowing designers the ability to “tweak” designs once they are implemented (Goodman et al., 2015). The “tweaking” of designs allows for designers to observe bicyclists and behaviors of other mode users around the infrastructure, and are not indicative of a failed design. Due to municipalities implementing these low-risk projects for a fully separated bike facility, the level of investment lost is relatively low should a facility fails or is not accepted by the local community. The Pilot Program assures the public that fully separated bike lane concept is not being forced upon them, and provides opportunity for public debate.

The *Portland Bicycle Plan for 2030* provides an example of a successful program that linked Portland’s bicycle way network called “Missing Links” (Vanderslice, 2010). The program’s focus is to efficiently use scarce resources in developing city bikeways in combination with other projects. The main strategy for this is to combine regularly scheduled pavement overlays projects with bicycle lane striping. This program has been able to produce 41 miles of city bicycle facilities expanding Portland’s bicycle network, which has resulted in increasing the number of bicyclists (Goodman et al, 2015).

2.1.2 Bicycle Lanes integrated as a part of large new construction or major reconstruction project

The Separated Bike Lane Planning and Design Guide (FHWA, 2015) outlines how the Integrated as a part onto large new construction or major reconstruction project is used in the planning implementation for bicycle lane construction. Planning a fully separated bike lane from the beginning of a construction project can be highly beneficial, such as working from a blank or relatively blank slate, planners and engineers are able to take advantage of greater design flexibility in new street construction as part of a Complete Streets approach (Goodman et al, 2015). Opportunity to widen an existing roadway provides the ease of adding a fully separated bicycle lane reducing the likelihood of error from user expectancy. Another aspect of a major reconstruction projects is the opportunity for the public to be part of a recreational, tourist, or cultural initiative.

The Director of Portland Bureau of Transportation, Leah Treat, released a new policy that was effective October 19, 2015 that recommended that every bicycle lane be designed as a protected bicycle lane. In the released memo Leah Treat said, "… *I am asking our engineers, project managers and planners to make protected bicycle lanes the preferred design on roadways where separation is called for. I am asking for this design standard for retrofits of existing roadways as well as to new construction*." (Treat, 2015). This new policy for bicycle lane development is currently being implemented on Southwest Bond Street (Anderson, 2015). This project has been driven by the growth of the South Waterfront district, and this project will incorporate a newly built street being planned through a former shipyard. This project will implement permanent improvements of concrete sidewalks, landscaping and the new policy for bicycle lane development. Figure 4 is the current proposed project street design released by the Portland Bureau of Transportation.

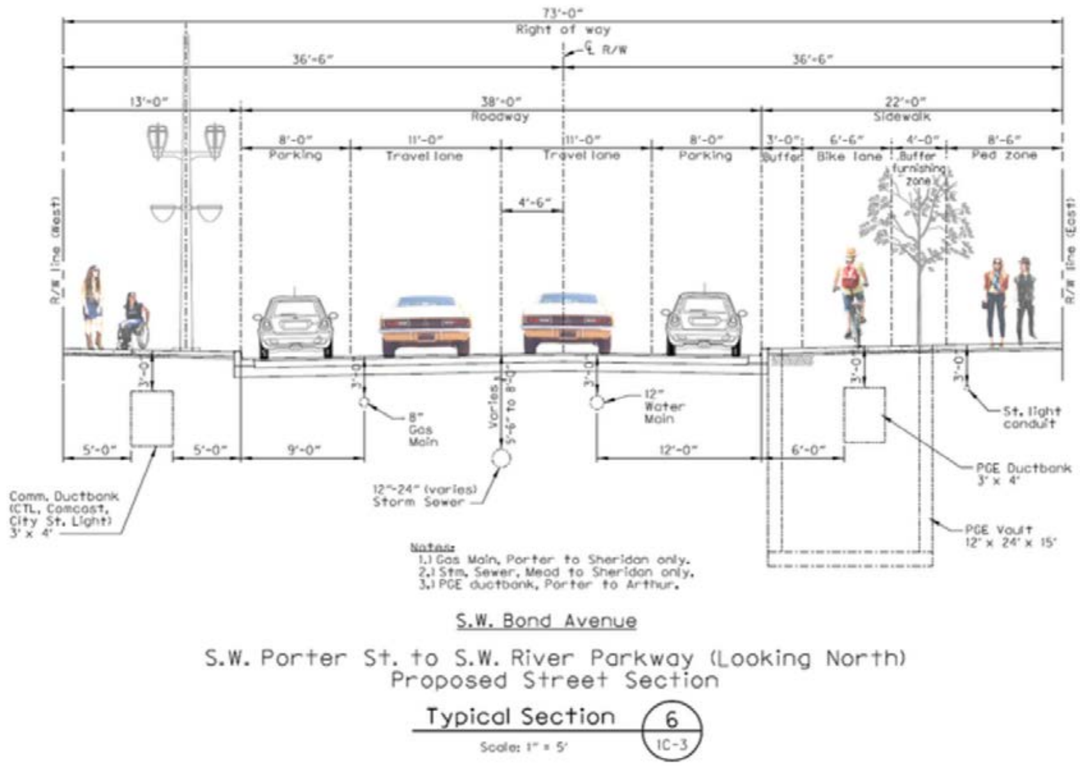

Figure 4: Proposed Street Section for S.W. Porter St. to S.W. River Parkway (Portland, 2016)

2.2 Commonly Added Safety Designs for Bicyclists

The goal of construction or retrofit of a bicycle lane is to provide a space for bicyclists to safely travel adjacent to an existent vehicle travel lane. The focus for transportation engineers and roadway designers is to provide and to maintain a facility that is safe, with increased sight distance and visibility of the bicyclists for motorists, and increased sight distance and visibility for bicyclists. This section focuses on the aspects of a common safety improvement practices for existing of bicycle lane facility advantages, disadvantages and cost of implementation.

2.2.1 Safety Improvement for Existing Lane Construction

There are six different methods that are commonly used to improve bicycle lane safety. The main methods that can be implemented are the placing of traffic control signs, repainting of pavement markings, applying colored pavement paint for the existing bike lane, expanding bicycle lane, installing permanent or temporary devices that fully separate (protect) bicycle lane, and to do nothing. These methods must all be planned and constructed following state and federal guidelines, which promote uniform and safe operations of roadway facilities, and must satisfy five requirements before implementation. These requirements are the same as those for traffic control devices in the Manual of Traffic Control Devices (MUTCD):

(i) the roadway must fulfill a need,

(ii) command attention,

(iii) provide a clear and simple meaning,

(iv) command respect from all roadway users, and

(v) provide adequate warning for a correct response to a situation (Hagen, 2004)

If a roadway segment can fulfill all of these requirements, then the best method of implementation is at the discretion of the traffic engineer or roadway designer. The methods for improved lane safety differ in the range of visibility of a bicyclist, bicyclist comfort and cost of implementation. For the observed study areas, the research will only address the expansion of an existing bicycle lane and applying colored pavement paint for the existing bike lane. Farther discussion of the six different improvement methods (be implemented are the placing of traffic control signs, repainting of pavement markings, installing permanent or temporary devices that fully separate (protect) bicycle lane, and to do nothing) can be found in the Appendix A.

2.2.1.1 Applying colored pavement paint for the existing bike lane

This method is to increase motorist awareness of lane delineation and awareness of high-density ridership. This method has been adopted both is Portland, Oregon and in other countries that have high cycle usage.

2.2.1.2 Expanding bicycle lane

The width of a bike lane is often expanded to provide a bicycle facility that accounts for bicyclists' sway, and passing lane space. However, the expansion of the width of a bicycle lane results in space that is reallocated from the adjacent travel lane, sidewalk width (if a sidewalk is applicable), or shoulder of the road used in the expansion. When a vehicle travel lane is decreased (such as in road diet projects), the resulting motorist expectancy is changed and driving patterns adjusted. The resulting behavior change is that motorists will slow down, as there is not enough width within the lane for bicyclists' sway of a vehicle within the travel lane or adjacent lanes. Additionally, the reallocation of the sidewalk space will results in a change in pedestrian perceived level of comfort. While the bicycle lane does provide a larger buffer for pedestrians from the adjacent traffic, the space available for pedestrians to pass other pedestrians, merchandise displayed by store vendors space in front of their stores, or the ability to pass individuals who use a wheelchair generate increased conflict points for pedestrians. Resulting in pedestrians walking in the bicycle lane ensuing in increase bicyclist-pedestrian conflicts, or pedestrians not using the segment of sidewalk decreasing store front revenue.

2.2.2 Cost of Implementation

For all traffic control devices or roadway retrofits, traffic engineers and roadway designers account for the cost of implementation and cost of maintenance over the anticipated life cycle. This is to ensure that all devices or retrofits are implemented are maintained at an adequate standard level and meet the needs of all. The schedule maintenance for each includes periodic maintenance and unscheduled maintenance.

2.2.2.1 Pavement Markings

Colored pavement or a contrasting paving overlays have been used to distinguish bike lanes from the motor vehicle lanes. In Europe rich red colored overlays have been installed to distinguish vehicle lanes from bicycle lane. In Portland, Oregon vibrant green colored overlays have been installed to distinguish vehicle lanes from bicycle lane (see figure 6, buffered bicycle lanes). The implementation and construction costs can vary due to the project specifications, the scale, and length of the treatment. The cost of a five-foot wide green overlay for a bicycle lane can range from approximately $5,000 to $535,000 per mile, with an average cost around $130,000 (FHWA et al).

The maintenance of pavement markings only requires periodic maintenance due to the loss in retro-reflectivity caused by traffic wear or expanding the existent line width. Pavement markings are subjected to unscheduled maintenance due to a random event of a spilled loads (concrete, paint, solvents, etc.), and pavement damage due to a vehicle crash that may cover or destroy them (Hagen 2004). The cost for pavement markings varies greatly from state to state. Thus, there is no set price on the cost of purchasing pavement marking materials.

2.2.2.2 Expanding Existing Bicycle Lane Width

It is difficult to accurately calculate the cost of expanding the width of a bicycle lane. The cost to acquire land use right of way involves identifying the owner of the land and purchasing the land needed for the project area. This becomes difficult as each foot of space both longitudinally and latitudinally located within a project area can be owned and maintained by different agencies (City, MPO's, State), utilities, or property owners. The impact of converting an existing lane used for motorized traffic to bicycles effect both lane capacity and economic activity influence are the same as design implementation of a road diet. In the study *York Blvd: The Economics of a Road Diet* produced by National Association of City Transportation Officials (NACTO) the evaluated the interactions between road diets, bicycle facilities (such as bike lanes, bike routes, and bike paths), and local economic activity is significantly limited. While existing research suggests that facilities used in road diets and bicycle lanes can boost economic performance, there are negative perceptions because these new facilities often come at the expense of on-street parking. The York Boulevard study offers recommendations to create bicycle facilities that are economically harmonious with the surrounding community and public opinion (McCormic, 2015).

3 Literature Review

3.1 Vulnerable Users

Bicyclists are one of the most vulnerable users in and around roadway infrastructure. These roadway users are also one of the most under reported and least studied as to the factors associated with reporting a bicycle accident to the police and/or hospital (Janstrup et al, 2015). A study in Denmark evaluated the socio-economic background, attitudes, norms and users' choice to report cycling crashes to assist bicyclists providing data for accurate population data to be used in analysis models and prevention measures. The data for the analysis was built around a web-based questionnaire and structural equation models (SEM) to model bicyclists' intention to report a cycling accident in the future. The behavioral framework was built upon the Theory of Planned Behavior (TPB). Results from the questionnaire showed that 61.6% of the respondents said that they were involved in a cycling accident during the last 10 years, and only 38.4% reported their cycling accidents. From this study researched found that under reporting is due to bicyclists attitudes towards time management, the opinions of family and friends negative social norms towards reporting, and perceived difficulties to report (distrust in the police and medical personal, and that attitudes of accident reporting does not have an influential factor correlated with lack of intentions to report future accidents.

The questionnaire asked respondents to provide information only regarding their most recent cycling accident for ease of respondents' recall of the incident and help with reducing the surveys length. This study was limited to bicycle crashes with motorized transport, which are documented to determine fault or an insurance claim. This resulted in excluding single bicyclist falling or colliding against another vulnerable road user or a fixed object, although they can also result in serious injuries. The sample demographics from the questionnaire suggest sample heterogeneity and distribution across the variable categories for Denmark.

Several studies have used surveys to evaluate people prefer bicycle lane facilities and have concluded that fully separated bicycle lanes that isolate bicyclists from motorized facilities are preferred to conventional bicycle lane. These illustrated studies are detailed in Table 1 on user bicycle facility preference.

Table 1: Illustrations of Bicycle Facility Preference

Pucher, J., and R. Buehler. "Making Cycling Irresistible: Lessons from the Netherlands, Denmark, and Germany." Transport Reviews, Vol. 28, No. 4, 2008, pp. 495–528. 3. Tilahun, N.Y., D.M.
Levinson, and K.J. Krizek. "Trails, Lanes, or Traffic: Valuing Bicycle Facilities with an Adaptive Stated Preference Survey." Transportation Research Part A: Policy and Practice, Vol. 41, 2007, pp. 287–301.
Winters, M., and K. Teschke. "Route Preferences Among Adults in the Near Market for Bicycling: Findings of the Cycling in Cities Study." American Journal of Health Promotion, Vol. 25, 2010, pp. 40–47.
Sanders, R.L. "Examining the Cycle: How Perceived and Actual Bicycling Risk Influence Cycling Frequency, Roadway Design Preferences, and Support for Cycling Among Bay Area Residents." PhD dissertation. University of California, Berkeley, 2013.

Dill, J., and M. McNeil. “Four Types of Cyclists? Examination of Typology for Better Understanding of Bicycling Behavior and Potential.” In Transportation Research Record: Journal of the Transportation Research Board, No. 2387, Transportation Research Board of the National Academies, Washington, D.C., 2013, pp. 129–138.)
Monsere, C.M., N. McNeil, and J. Dill. “Multiuser Perspectives on Separated, On-Street Bicycle Infrastructure.” In Transportation Research Record: Journal of the Transportation Research Board, No. 2314, Transportation Research Board of the National Academies, Washington, D.C., 2012, pp. 22–30.

As discussed in section 2.2.2, these facility types are expensive and expansive. Thus, a feasibility study must be conducted of the tradeoffs of providing physical and perceived safety while efficiently using scarce resources for all modes of transportation. To evaluate bicyclist perception of both a physical safety and perceived safety of different implemented bicycle facilities researchers in conducted a study for the ***Level-of-service Model for Protected Bike Lanes*** (Foster, 2015). This study generated a mathematical model to predict bicyclist comfort in protected bicycle lane facilities based on surveys conducted and video data collection in the United States.

Two general groups of sites were selected for this project: protected bike lanes, to be used for model development, and sites of more common types (e.g., standard bike lanes, shared streets, and off-street paths) to be used for comparison (reference) purposes. A total of 221 individuals participated in the survey, provides a wide range of participants in terms of age, gender, and bicycle riding.

From this study a mean confront score was generated for different bicycle facility types. Figure 5 demonstrates the mean score by facility type for all video clips. In this ranking system researchers combined Fully Separated (Protected) bicycle lanes and Buffered bicycles lanes as Protected Bicycle Lanes (PBL). Figure 6 outlines different protected bicycle lanes sites the researchers for the bicycle facilities represented.

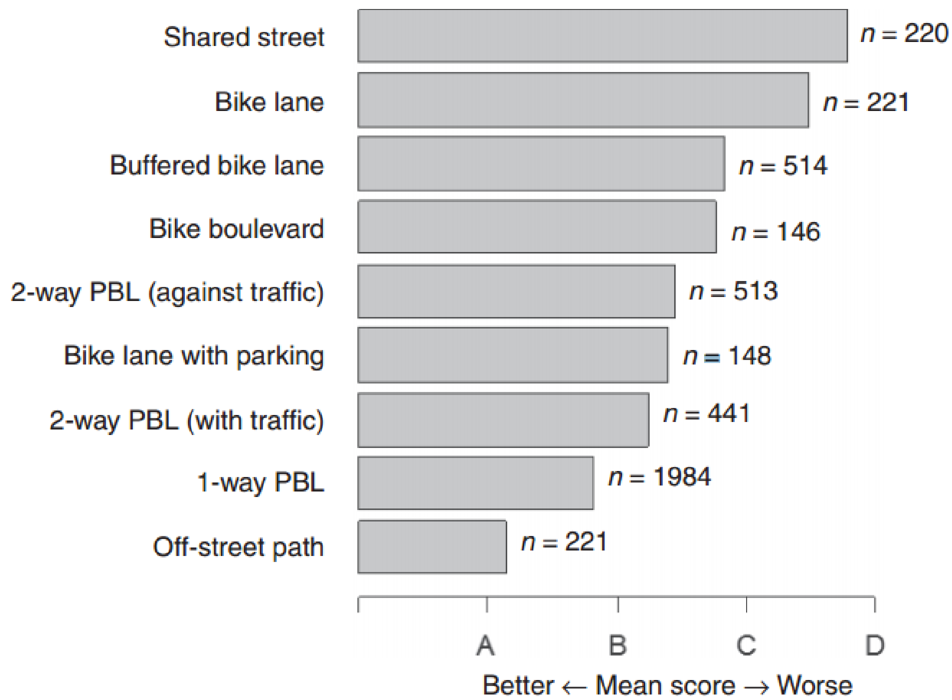

Figure 5: Mean Score by Facility Type

Figure 6: Protected and Buffered Bicycle Lane Faculties

The recommend models from this study is limited in predicted comfort for users as it is only valid for the following conditions: that annual daily traffic volume is between 9,000 to 30,000 vehicles per day; the speed limit for the roadway segment is between 25 mph and 35 miles per hour; and the buffer type is posts, parked cars, raised surface with an unoccupied parking lane, or planters. To provide a more in-depth evaluation of rider comfort the researched conducted in this research evaluates user behavior within an implemented buffered bicycle lane.

3.2 Studies on Bicyclists Behavior

The behavior of cyclists in Portland, Oregon has been studied and defined in two separate studies. From these studies, there is a common finding that people do not ride bicycles because they are afraid to be on the roadway, not because of bicyclists or pedestrian conflicts or injury due to bicycle only crashes, but due to conflicts with motorized transportation. In 2006, the Portland Office (now Bureau) of

Transportation released a study of call *Four Types of Cyclists,* which described and defined the four general categories of bicyclist behavior. These categories are for use of bicycle transportation only, and only their bicyclist willingness to use a bicycle as their main means of transportation (note: people in the following categories may bicycle for recreation) as follows (Geller, 2006):

1. The Strong and the Fearless: represent less than 0.5% of the population of bicyclists in Portland. The riders from this group are comprised of people who will ride a bicycle regardless of roadway or weather conditions. The "type" of bicyclist in this group are comprised of generally young, predominantly male, and fit.
2. The Enthused and the Confident: represent about 7% of the population of bicyclists in Portland. These bicyclists have been attracted to cycling due to the increased bicycle infrastructure that has been developed by the city of Portland. These bicyclists are comfortable with sharing with motorized traffic, but prefer to have a designated bicycle facility (bicycle lanes and bicycle boulevards). These bicyclists are those who are able to cycling is convenient due to the existing bicycle infrastructure.
3. The Interested but Concerned: represent about 60% of the population of bicyclists in Portland. These bicyclists are curious about bicycling as a means of transportation due to a wide variety of sources messages of: how easy it is to ride a bicycle in Portland; how bicycling is booming; the "bicycle culture" in Portland; Portland being a "bicycle-friendly" city; and many more. These riders like cycling, but are afraid to ride due to potential harm and increased conflicts with motorized traffic. These riders would cycle if the perceived safety of their route were safe.
4. No Way No How: represent about 33% of the population of bicyclists in Portland. This group has no interest in bicycling at all and limited exposure to bicycling throughout their lives.

These four categories supplied a fundamental understanding of the atmosphere of bicyclists behavior in Portland and what different types of bicyclists that utilizing bicycle facilities. These numbers are not exact as they are derived from participant's willingness in taking a survey. In 2012 Jennifer Dill, *Four Types of Cyclists' Examining a Typology to Better Understand Bicycling Behavior and Potential,* examined the validity of Geller's four types of cyclists; understand who falls into each type; and use the typology to explore what might increase levels of cycling for transportation. After conducting a random phone survey of adults in Portland, the survey sample was vetted so that age and sex reflected the population of Portland.

The results from this study found that the four types of bicyclist distribution is similar to Geller's 2006 study. Table 2 show the distribution of the survey respondents and Geller's 2006 study respondents.

Table 2: Distribution of Survey Respondents (Dill, 2012)

Type	Description	City of Portland	Rest of region	All	Geller's estimate for City
Strong & Fearless	Very comfortable without bike lanes	6%	2%	4%	<1%
Enthused & Confident	Very comfortable with bike lanes	9%	9%	9%	7%
Interested but Concerned	Not very comfortable, interested in biking more Not very comfortable, currently cycling for transportation but not interested in biking more	60%	53%	56%	60%
No Way No How	Physically unable Very uncomfortable on paths Not very comfortable, not interested, not currently cycling for transportation	25%	37%	31%	33%
n (weighted)		436	479	915	

Note: Weighted data, may not total 100% due to rounding.

This study farther characterized bicyclist into subcategories based on cycling frequency to categorize bicyclists. The two studies that developed bicyclists frequency are *The Role of Attitudes Toward Characteristics of Bicycle Commuting on the Choice to Cycle to Work over Various Distances,* were commuters placed into three groups, non-bicyclists, full-time bicyclists (bicyclists that would ride every working day), and part-time bicyclists (bicyclists that would ride at least once a year) (Heinen, 2011), and *Motivators and Deterrents of Bicycling: Comparing Influences on Decisions to Ride* defined bicyclists who had not ridden a bicycle in the past year as a "potential bicyclist," whereas all others were either occasional, frequent or regular (Winters, 2011). The subcategories that were then generated are as follows:

- Utilitarian bicyclist: Cycled at least once in the past 30 days for work, school, shopping, etc. ("transportation") and usually cycles once a month for transportation in a typical summer or winter month
- Recreational bicyclist: Cycled at least once in the past 30 days, but did not meet the threshold for Utilitarian bicyclist
- Non-bicyclist: Did not cycle in the past 30 days or stated that they "never ride a bicycle" (a screening question).

Table 3 demonstrates the bicyclists' general behavior and the bicyclists' frequency. The distribution of frequency for each of the four behavior types (expect for Not way No How) each have riders a higher number utilitarian bicyclists then for recreational and non-bicyclists.

Table 3: Bicyclists' General Behavior and Bicyclists' Frequency (Heinen, 2011)

Type	Utilitarian	Recreational	Non-cyclist	Unable/ don't know
Strong & Fearless	43%	23%	34%	
Enthused & Confident	46%	31%	23%	
Interested but Concerned	43%	30%	28%	
No Way No How		15%	46%	40%

Note: Weighted data, may not total 100% due to rounding.

This study was able to provide a greater understanding of the four categories of bicyclists' behavior in Portland and understanding of why some adults do not utilize cyclizing as their main form of transportation. Some findings and conclusions of each of the four categories from this study are as follows (Dill, 2012):

- No Way No How:
  - Women are most likely to be in this category or non-bicyclists. The barriers preventing them from cycling for transportation are not fully understood and more research must be conducted.
  - The large share respondents indicating a physical inability to ride a bicycle.
- The Interested but Concerned:
  - Adults from this group reported that bicycle infrastructure that increases their physical separation from motorized traffic increases reported level of comfort significantly.
  - General concern about the amount of traffic and traffic speeds in neighborhoods, along with a lack of bicycle lanes infrastructure in the surrounding area and destinations, appears to be preventing adults from bicycling either for transportation or recreation.
  - Time constraints was a barrier that this group identified as being an important barrier hindering them from utilizing cycling as a form transportation.

    - Adults in this category responded that they felt less comfortable about cycling in the rain or in the dark due to their lack of knowledge of safe practices.

The studies that have been outlined above highlight the general bicyclists' atmosphere and frequency of Portland bicyclists. These studies did not focus on the general behavior tendencies of bicyclists while utilization of the facility. In the study, *Desire Line Analysis: Trajectories and Behaviour of Copenhagen Bicycle Users at the Bremerholm/Holmens Canal Intersection*, focused on bicyclists' behavior and adherence to traffic laws and interactions with motorized traffic. This study utilized direct observation data to isolate bicyclists preferences and tendencies at intersections (Haldrup, Montebello, Colville-Andersen, & Imbert, 2014). The characteristics of the bicyclist's behavior were categorized into three categories:

- Conformists: bicyclists who stick to all the formal rules and designed routes
- Momentumists: bicyclists who follow their own route and adapt certain formal rules to suit their own ends, without causing any dangerous situations or conflicts (e.g. turning right through a red sign)
- Recklists: bicyclists who recklessly ignore the rules, for instance they ride through a red light, therefore causing a conflict with another user

3.3 Literature on Bicycle Lanes Utilization

American Association of State Highway and Transportation Officials' (AASHTO) 2012 *Guide for the Development of Bicycle Facilities (AASHTO, 2012)* provides general guidance that conventional bicycle lanes should be 5 feet. As this is a general guidance roadway designers and planners may construct bicycle lanes to be wider or narrower in widths. The *Bicycle Guide* also provides the following recommended guidance for bicycle lane widths:

- If parking is permitted on the roadway, the recommended bike lane width is should be between 5 feet and 7 feet, and placed between the parking area and the vehicle travel lane.
- Where parking is permitted on the roadway, the shared area of the bicycle and parking lanes should be a minimum of 12 feet in width and (for increased rider comfort) up to 15 feet wide.
- For roadways that are both high-speed and high-volume, or have a high volume of heavy vehicles, wider bicycle lanes are recommended.

- For urban curbed street where parking is prohibited, the recommended bicycle lane width is 5 feet from the face of the curb or guiderail to the bicycle lane stripe, provided that there is a usable width of 4 feet for bicyclists.
- For roadways that do not have a curb and gutter, the minimum usable bicycle lane width should be 4 feet

In a research study, *Design Guidance for Bicycle Lane Widths* (Fees, 2014) developed more specific guidance on recommending conventional bicycle lane widths for various roadways and traffic characteristics for urban and suburban areas. The bicycle lanes that were evaluated were for conventional bicycle lanes that had already been constructed and constructed temporary lane line of varying widths on the same block. This study was focused on observing bicyclist behavior and expectancy of the varying widths. The time, at which this study was collected, it is unclear if the limited participants are everyday commuters, recreational users, or only one-day bicyclists. Figure 7 and 8 demonstrates the different graphical depictions of the study sites and scenarios conducted for this study.

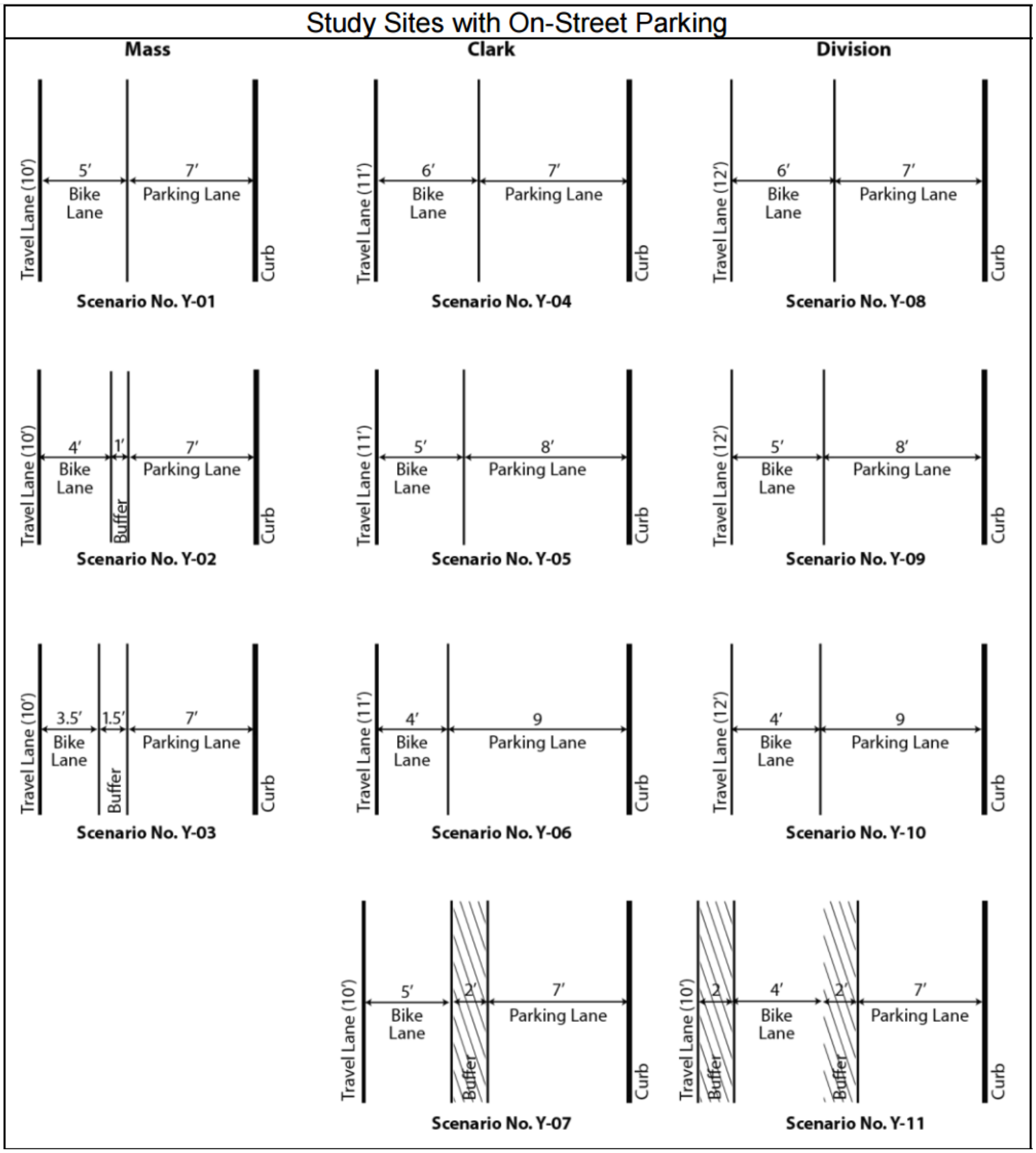

Figure 7: Graphical Depiction of Study Sites with On-Street Parking (Fees, 2014)

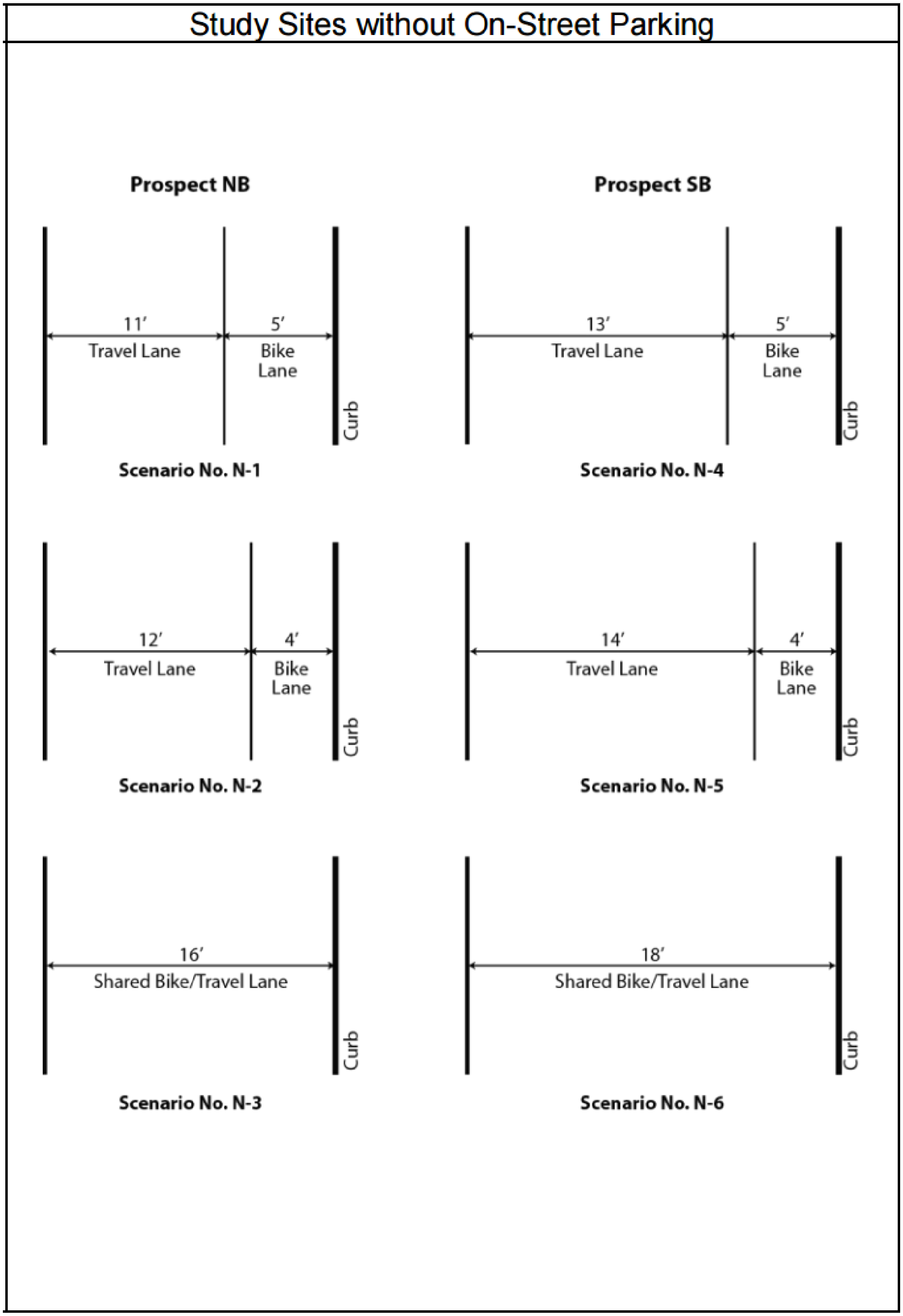

Figure 8: Graphical Depiction of Study Sites without On-Street Parking (Fees, 2014)

The collected data for the different roadway characteristics were:

- Bicycle volume
- Traffic volume
- Vehicle mix (percentage of trucks)
- Lane widths or total roadway width or both
- Presences or absences of on-street parking
- Posted speed limit
- Grade
- Lateral positions
    - Front and rear tight tires to the curb face
    - Total parked vehicle displacement
    - Lateral position of the front tire of each bicyclist (15 inch offset, left and right, representing a typical bicyclist's physical width of 30 inches).
    - Distance from the right tire of the passing vehicle to the curb
    - Distance from the left tire of the passing vehicle to the curb assuming a vehicle wide of 7 feet (width for a passenger car design vehicle).

From the collected lateral positions, the "central positioning" was developed and an effective bicycle lane was constructed. The recommendations from this study are for design guidance for conventional bicycle lanes on urban and suburban roadways with level grades and a posted speed limit of 30 miles per hour.

This research study also conducted a supplemental grade study that utilized a small study group of six volunteers to ride bicycles up moderate grades (three (3) to four (4) percent) to evaluate the effect roadway grades impact the lateral position of bicyclists. The participants were directed to bicycle up the grade of the bicycle lane naturally (repeated five times), while a video recorded the participants lateral positioning (beginning approximately 80 feet from the bottom of the graded roadway and extended to the 60 foot study section). From these video recordings the lateral positions of each bicyclist at six locations along the study section. Two variables were captured to evaluate the bicyclist's sway and drift along for the study area and are as follows:

- Sway: For each rider and run, sway (rider's movements back and forth) was calculated as the difference between the maximum and minimum of the six lateral positions from the curb.
- Deviation from a straight-line trajectory: for each rider and run, as straight-line trajectory was defined by calculating the line connecting the lateral position from when a bicyclist entered the study area and exited the study area. The deviations of other lateral positions that were observed between locations two (2) and five (5) from that line were then calculated and averaged.

From this study group the overall mean estimates and 95-percent confidence intervals of both indicators were calculated. The results are all follows:

- The average sway (rider's movements back and forth) was 6 inches with a 95-percent confidence interval of 4.9 to 7.1 inches.
- The average deviation from a straight-line trajectory for this group was -0.3 inches with 95-percent confidence interval of -1.4 to 0.81 inches.

This supplemental grade study's primary findings are that bicyclists do experience a form of sway on roadways with moderate to steep grades and that there is considerable sway variability between each participant. The largest recorded sway was approximately eight (8) inches, and the general sway from the participants deviated only three (3) to four (4) inches from their individual projected straight line trajectory.

3.4 Research on Painted Bicycle Lanes

The use of pavement markings has assisted motorized traffic procced safely through intersections by delineating the movement that a vehicle should make. Other pavement treatments have been used to aid bicycles and motorized traffic at conflict points. In Europe and Canada, cities used colored pavement markings (e.g. red, yellow, blue, and green) at bicycle and motorized vehicle crossing locations to reduce crash incidence caused by the conflict point. Some cities in the United States have adopted and implanted this practice. In Portland, Oregon, an observational research study was conducted to evaluate if blue colored pavement and signage impacted bicyclist and motorist behavior by assessing behavior prior to installation and after installation. The results of this study found that colored pavement and signage raised both motorist and bicyclist awareness to the potential conflict areas. This reflected in creating a safer riding environment as significantly more motorists would yield for bicyclist. Figure 9 shows motorists and bicyclists yielding behavior before and after blue colored pavement markings had been installed.

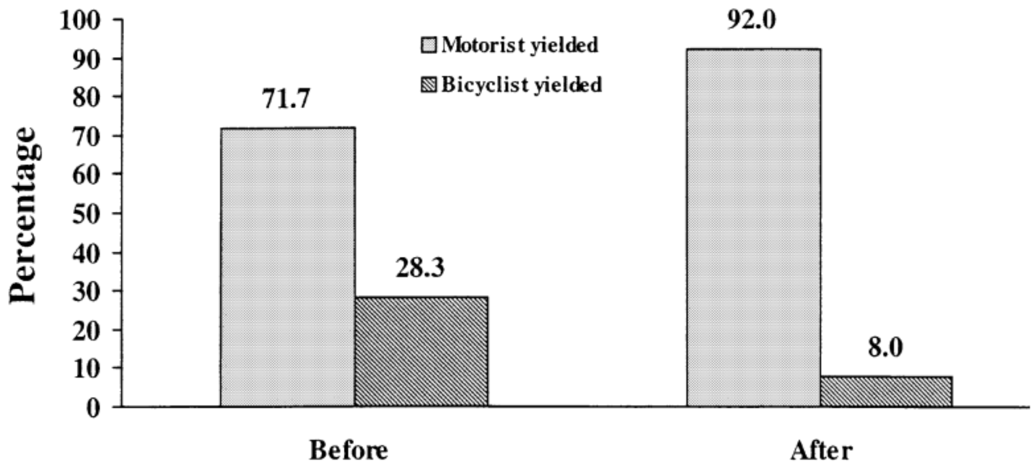

Figure 9: Yielding Behavior of Motorists and Bicyclists Before and After Colored Pavement Installation in Portland, Oregon

A similar study conducted in Austin, Texas evaluated the behaviors of bicyclists and motorists before and after the installation of green colored pavement markings and signs. This study found that the application of color pavement markings to a conflict area substantially improve bicyclist and motorist behavior (Brady, 2010).

A study conducted by the City of Long Beach, California after receiving the Federal Highway Administration granted a Request to Experiment the impact that green painted pavement marking have on motorized-bicycle crashes. The finding of this study showed that colored pavement markings raises motorists and bicyclists awareness to potential areas of conflict and saw a decrease in the accident rate per bicyclist (William 2008).

3.5 Near Miss as Defined by Industry

The increased growth in bicycle usage and awareness of bicyclist concern for safety on roadways has shaped the public's perception of bicycles. Bicycle advocacy groups, Portland Bureau of Transportation leadership, and visible support from the public have facilitated the shift in public opinion. This shift in public opinion has resulted in increased bicycle facilities (bicycle lanes, bike share, etc.) construction to reduced extreme crash events that result in death or serious injuries that can result from bicycle collisions with motorized traffic. However, the perceived status of bicyclist compared to motorized traffic is still low (Daley, 2011). A study by Rachel Aldred and Sian Crosweller (2015) conducted a study on *Investigating the Rates and Impacts of Near Misses and Related Incidences among UK Bicyclists*, provides data that suggests that "very Scary" incidents, or near miss collisions, was a common weekly occurrence, and harassment was experienced on a monthly occurrence for bicyclist.

This research was based on a national cycling 'near miss' research through the evaluation of frequency and experiences provided by participants whom registered on an open online registry. Participants were asked to complete an online diary once a day over a two-week period to record trips and any incidents, and a supplemental questionnaire provided quantitative and qualitative questions that focused on bicycling crash details of the first 10 incidents. For the incidents that the participants experienced a 0–3 scale was used to evaluate how 'scary' and 'annoying'(Aldred, 2015) each incident was. The rating for each of the ratings are as follows: 0-not annoying, 1-not scary, 2-very annoying, and 3-very scary. The reported experiences of participants' incidents as very scary and very annoying are shown in the table 4 below.

Table 4: Participants Responses of Experienced Incidents

			Very annoying incident/s?		Total
			No	Yes	
Very scary incident/s?	No	Count	716	449	1165
		% of total	46.7	29.3	76.0
	Yes	Count	43	324	367
		% of total	2.8	21.1	24.0
Total		Count	759	773	1532
		% of total	49.5	50.5	100.0

An in-depth analysis evaluated the recorded incidents into different categories. Table 5 provides the different description of incident categories.

Table 5: Categories of Incidents

Description	Frequency	Per cent
Cyclist's way blocked (by other road users, road conditions, etc.)	1506	37.7
Problematic pass manoeuvre (usually too close)	1169	29.3
Vehicle pulls out or in across cyclist's path	644	16.1
Person drove (or cycled) at cyclist head on	255	6.4
Near left or right hook (road user turns across cyclist's path)	215	5.4
Other type of incident	107	2.7
Tailgating cyclist, but does not/cannot pass	72	1.8
Person opened car door in cyclist's way	26	.7
All incidents	3994	100

A farther analysis of this study detailed in Table 6 of participants' response of experienced incidents for each of the different description of incident categories.

Table 6: Description of Incident Categories and Participants Responses of Experience

Incident type		All categorised incidents	Of which very scary	Of which very annoying
1. Cyclist's way blocked	Count	1479	91	538
	% within category		6.2	35.8
2. Problematic pass (usually too close)	Count	1159	255	550
	% within category		22.0	47.5
3. Other vehicle pulls in or out	Count	641	105	274
	% within category		16.4	42.6
4. Being driven (occasionally cycled) at	Count	254	44	112
	% within category		17.3	44.3
5. Left or right hook incident	Count	214	47	98
	% within category		22.0	45.6
6. Other type of incident	Count	106	8	36
	% within category		7.5	33.6
7. Other vehicle tailgates cyclist	Count	72	13	25
	% within category		18.1	34.7
8. Dooring incident	Count	26	6	10
	% within category		23.1	38.5
All incidents	Count	3951	569	1643
	% within category		14.4	41.3

The findings of this study one in four participants experienced an incident was rated as being very scary. The participants responded of these incidents few could be avoided, and those whom participated in the dairy entry showed that one in seven did not have an incident said that they would normally expect incidents to happen. While the rates of being killed or seriously injured on roads is higher at night (Johansson, 2009) there was no peak rates of near miss incidents. Another finding of this study was that women seem to experience a higher rate of near-miss incidents than do men. This was based women participants responding to trip distances for shorter, slower trips and higher incident rates.

While there currently is no standard definition of a near miss event for bicyclists in the United States. A reason that near miss studies or implementations of a reporting system have not been conducted is due to the lack of a clear definition of a near miss incident for bicyclists. Currently there has been no clear definition from government, state, or other literature that defines what constitutes a near miss incident for bicyclists or study that has evaluated if women and men have different definitions of a near miss incident. Farther research and government collaboration efforts within state Departments of Transportation agencies and public opinion could standardize the definition of a near miss so that the reporting of these incidents can become more common and standardized. A consistent definition of near-miss incidents could help identify and bring awareness to national trends regarding near miss incidents.

There is a definition provided from State Departments of Transportation for near miss for roadside workers and motorized traffic reporting system and procedure for near miss incidents. Washington Department of Transportation has defined a near miss (near hit): An incident were no property was damaged and no personal injury sustained, but where, given a slight shift in time or position, damage, and/or injury easily could have occurred (Barlow, 2017).

The near miss program is designed to provide employees insight and information about near miss incidences that they witness. The available material that help guide reporters communication of near miss details, the Washington Department of

Transportation created a supplemental booklet that describes the program and provides definitions and abbreviations that are to be used on their report. This supplemental booklet was created to aid in the production of near miss reports.

The rating of a near miss reported is scaled by the definitions of low and high frequency and severity. This is to guide the rate the frequency and potential injury severity of the near miss being reported. Figure 10 the Washington Department of Transportation rating system for near miss incidence.

Figure 10: Washington Department of Transportation Introduction Pages for Near Miss Booklet (Barlow, 2017)

The report for a near miss incident must contain a brief written description of the near miss, a description of the immediate actions taken to eliminate the hazard or mitigate the safety risk, and suggestions for preventing a near miss or injury in the future. The goal of this section is not to define a near miss incident but to bring awareness that a consistent definition of near-miss incidents has not been generated for bicyclist so the definition outlined by other industries must be utilized.

3.6 Summary of Literature Review

Survey research has been conducted of user preference of different bicycle lane infrastructure and behavior at intersection. Only one research project has evaluated and conducted an observational study of conventional bicycle lane utilization. There currently has been no observational studies that have documented bicyclist utilization and behavior within buffered bicycle lanes. As buffered bicycle, lanes are defined as conventional bike lane with a pained buffer used to increase lateral separation between bicyclists and the adjacent vehicle traffic. The research conducted on bicycle lane utilization for conventional bicycle lanes was used as a reference and a basis for analysis to assess the usage of a buffered bicycle lane and bicyclist sway due to grade.

Currently, there is no information that shows whether a government or state entity within the United States has defined a near-miss incident between bicyclist and motorized traffic. The research that has been conducted to assess near miss incidents was conducted in the United Kingdom. This research used survey-based data provided by bicyclists and the definition that was available was defined by the interpretation of the survey questions. The research conducted on near-miss incidents between bicyclists and motorized traffic served as a reference and base of analysis to assess variables that were identified and provide additional explanatory variables to be assessed.

4 Methodology

4.1 Data Collection

The Portland Bureau of Transportation (PBOT) was contacted to help facilitate and locate five different active roadway segments of buffered bicycle lanes located within Portland, Oregon. Two roadway segments were not used. One location was a one way roadway, with an active construction project adjacent to the buffered bicycle lane, and the other buffered bicycle lane located on the opposite side of the roadways was a missing a significant block of time in the provided video material. Three segments of interest in Portland, Oregon were identified after an initial review of the video data collected at these locations and their respective attributes. The segments chosen include SW 3rd Ave between Ash and Burnside, North Interstate Ave 100 feet south of Tillamook, and NW Naito Parkway 100 feet north of Everett. These segments were chosen because of their various designs, levels of bicycle infrastructure, and volumes of vehicular and bicycle traffic. Figure 11 shows a map of downtown Portland, including bicycle routes with each intersection of interest labeled.

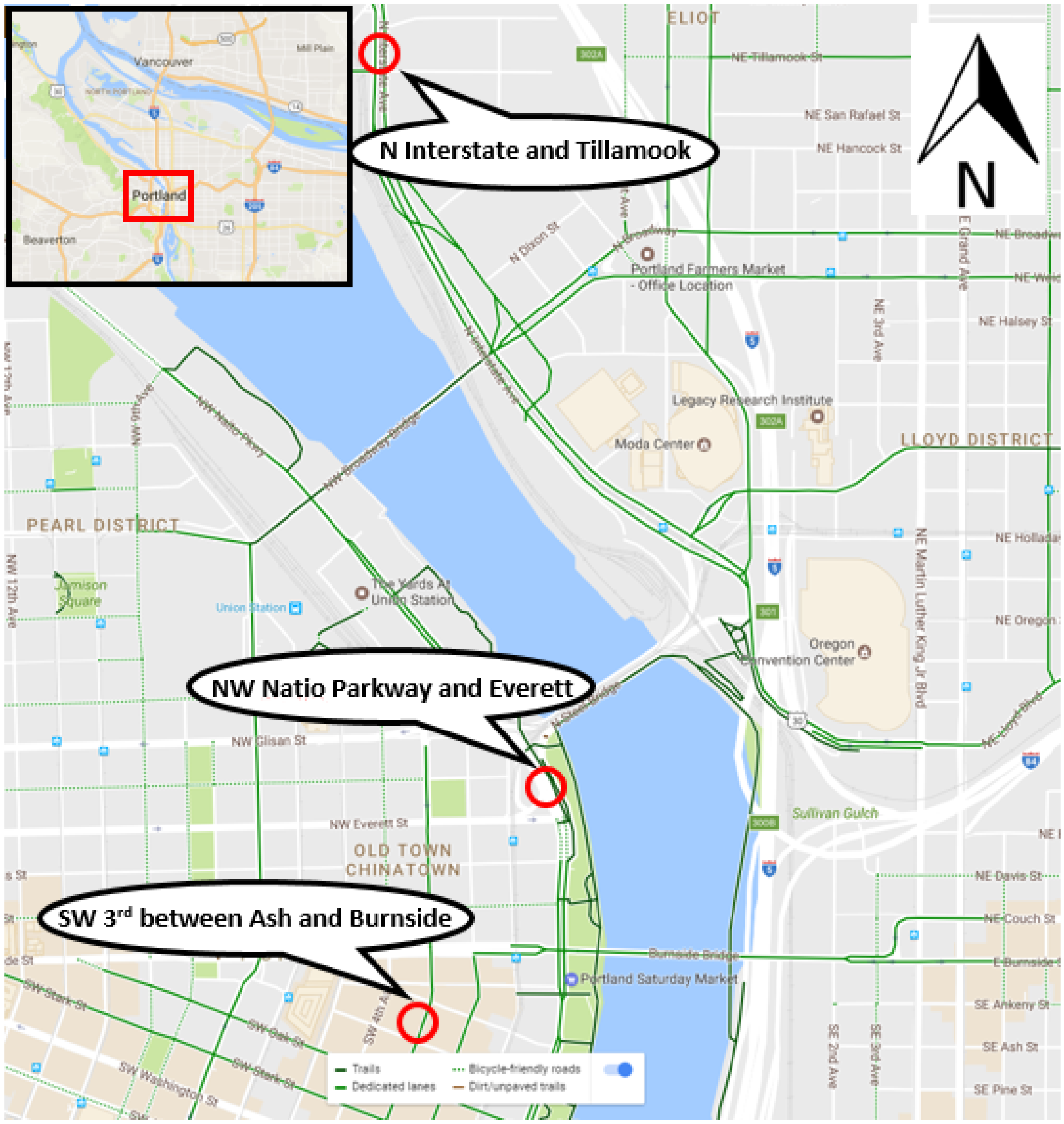

Figure 11: Map of Downtown Portland, Oregon with Bicycle Routes and Observed Roadway Segment Locations

An analysis of daily ridership from Portland's *Hawthorne Bridge Bicycle Counter* found that daily bicyclist commuters travel at 8:00 a.m. to 10:00 a.m. and 5:00 p.m. to 6:00 p.m. The roadway segments for this study were filmed from 7:30 a.m. to 9:30 a.m. on November 29th, 2016, to capture morning peak hour bicycle ridership. Due to the time of day that this data was collected it is unclear if these participants are everyday commuters, recreational users, or only one-day bicyclists. Each camera captured the midsection of the roadway segment. Due to the location of the buffered bicycle lane facilities and direction of the bicyclist, the random parameters of the observations of each bicyclist was preserved cyclist. Figures 12-14 show a street view of each buffered bicycle lane roadway segment from the installed video cameras.

Figure 12: SW 3rd Ave between Ash and Burnside – Facing northeast

Figure 13: North Interstate Ave 100 feet south of Tillamook – Facing north

Figure 14: NW Naito Parkway 100 feet north of Everett – Facing northwest

The data collected and used in the study was from direct observations provided from the video footage of each roadway segment including lateral bicyclist' position, safety device used, clothing, traffic density and conflict zone interactions. In this study the different between a near miss and a conflict is defined as:

i) bicyclists with no motorized traffic and bicyclists with motorized traffic that yield to bicyclists (one vehicle only)

ii) bicyclists with multiple motorized traffic that yield to cyclists and crossed in front of or behind, and/or bicyclists with motorized traffic that came close to bicyclists and/or crossed in front of bicyclist resulting in bicyclist to make a sudden change in direction or speed to avoid collision.

The data collected provide awareness of bicyclists' behavior using the buffered bicycle lane by observing both bicycle and motorized traffic usage and behavior of implemented buffered bicycle lane. Statistical Models used in the analysis for each different buffered bicycle lane facility.

4.1.1 Segment Identification and Selection

Three sites in Portland, Oregon were selected for this study. The study sites were selected to represent three different buffered bicycle lane facilities that had been implemented. The roadway characteristics that factored into the site selection process included:

- Bicycle volume
- Traffic volume
- Vehicle mix (i.e. percent trucks)
- Lane width and/or total roadway width
- Presence/absences of pedestrian facility
- Posted speed limit
- Grade
- Functional classification of roadway segments

Table 7 presents site characterizes information for each observed study site. The posted speed limits and grades were characteristic of interest identified for evaluation, and all filmed video sites had varying posted speed limits, and all sites were on different grades.

Table 7: Roadway Characteristics of Data Collection Sites in Portland, Oregon

Location	**N Interstate Ave**	**NW Naito Parkway**	**SW 3rd Ave**
Direction	South	South East	South West
Beginning of Segment	N Tillamook St	NW Everett St	Ash St.
End of Segment	Pacific Hwy W	Pacific Hwy W	Burnside
Traffic Volume (ADDT)[1]	11300	2400	5970*
Percent Trucks (%)[1]	4.76	4.76	--
Speed Limit (mph)	30	30	25
Presence of Pedestrian Facility	N/A	Sidewalk	Mid-Block Crossing
Number of Lanes	1 to 2	1	2
Single Directional traffic (Yes/No)	Yes	Yes	Yes
Curb, Gutter, Sidewalk, or Guardrail (Yes/No)	No	Yes	Yes
Grade	Uphill	Downhill	Relatively Flat
Travel Lane Width	14 ft	11 ft	10 ft
Buffered Lane Width	1.5 ft to 6 ft	4 ft	2 ft
Bicycle Lane Width	6 ft	10+ ft	6 ft

1 – Information available from the Oregon Department of Transportation TransGIS
*Information available from the Portland Bureau of Transportation Interactive GIS Map (ADT)

Figures 15 thru 17 are the graphical depictions of the geometric designs for each of the study buffered bicycle lane facility. Data was recorded for each study facility.

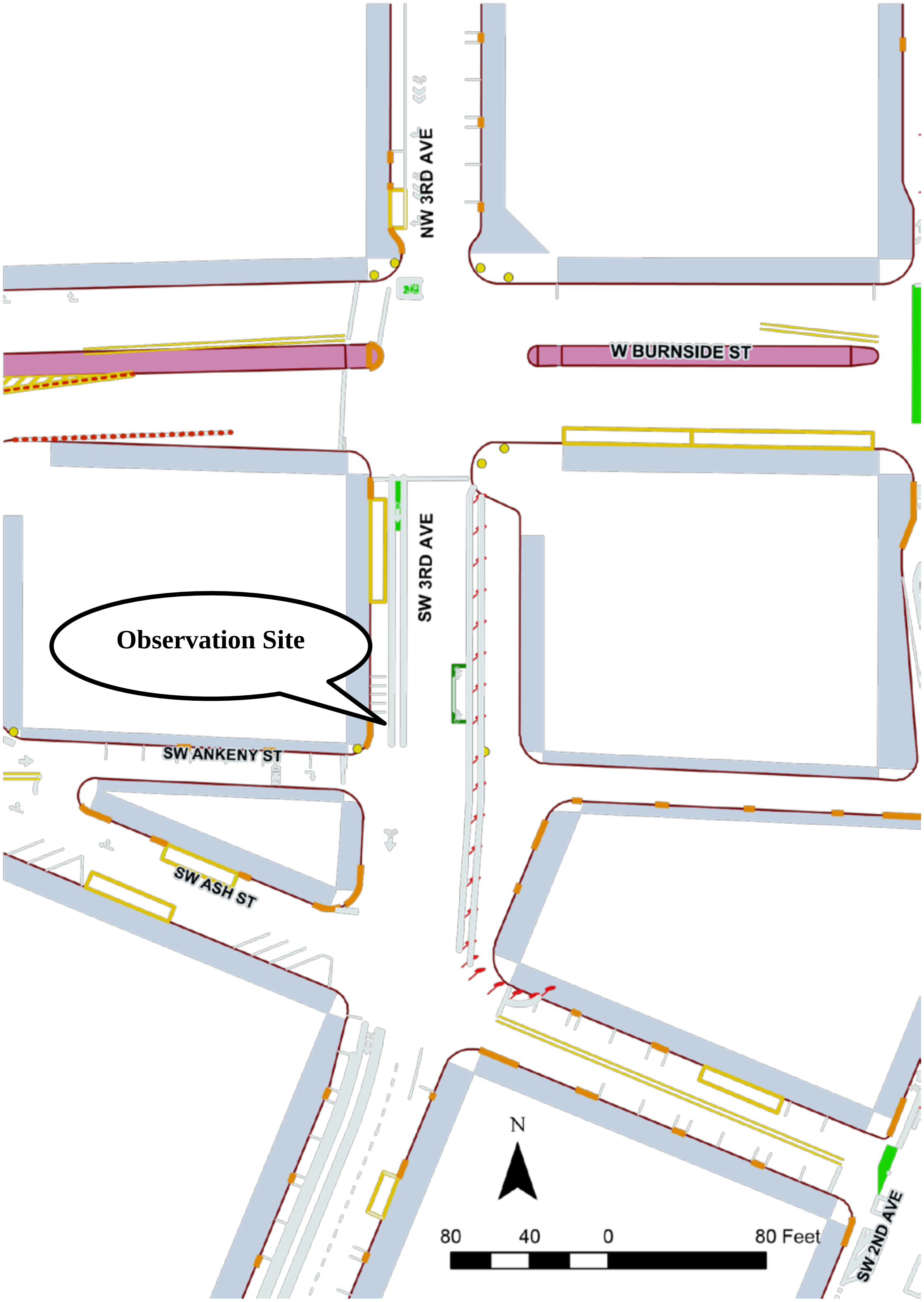

Figure 15: Geometric Design Map for 3rd St Between Ash and Burnside

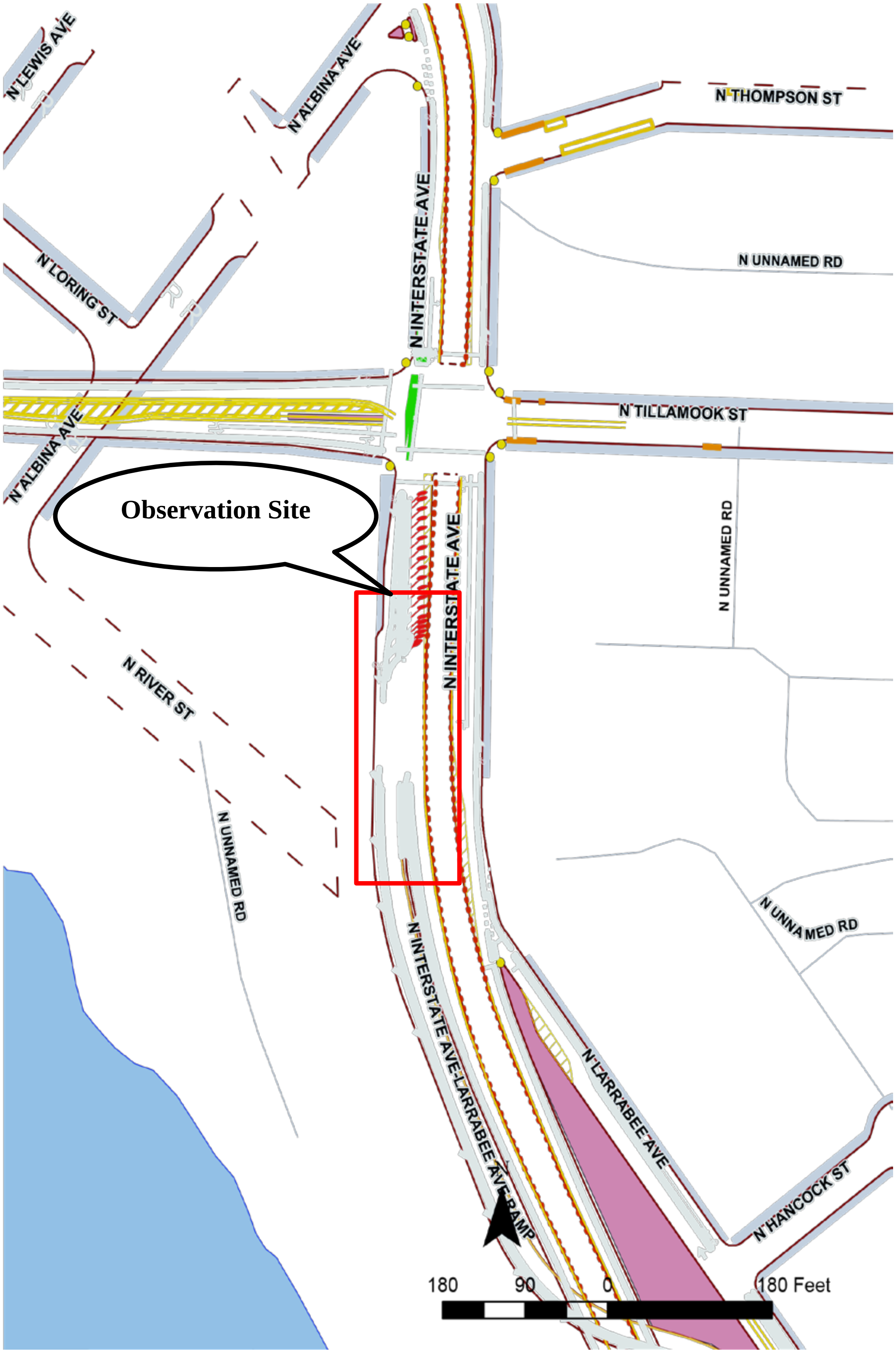

Figure 16: Geometric Design Map for North Interstate and Tillamook

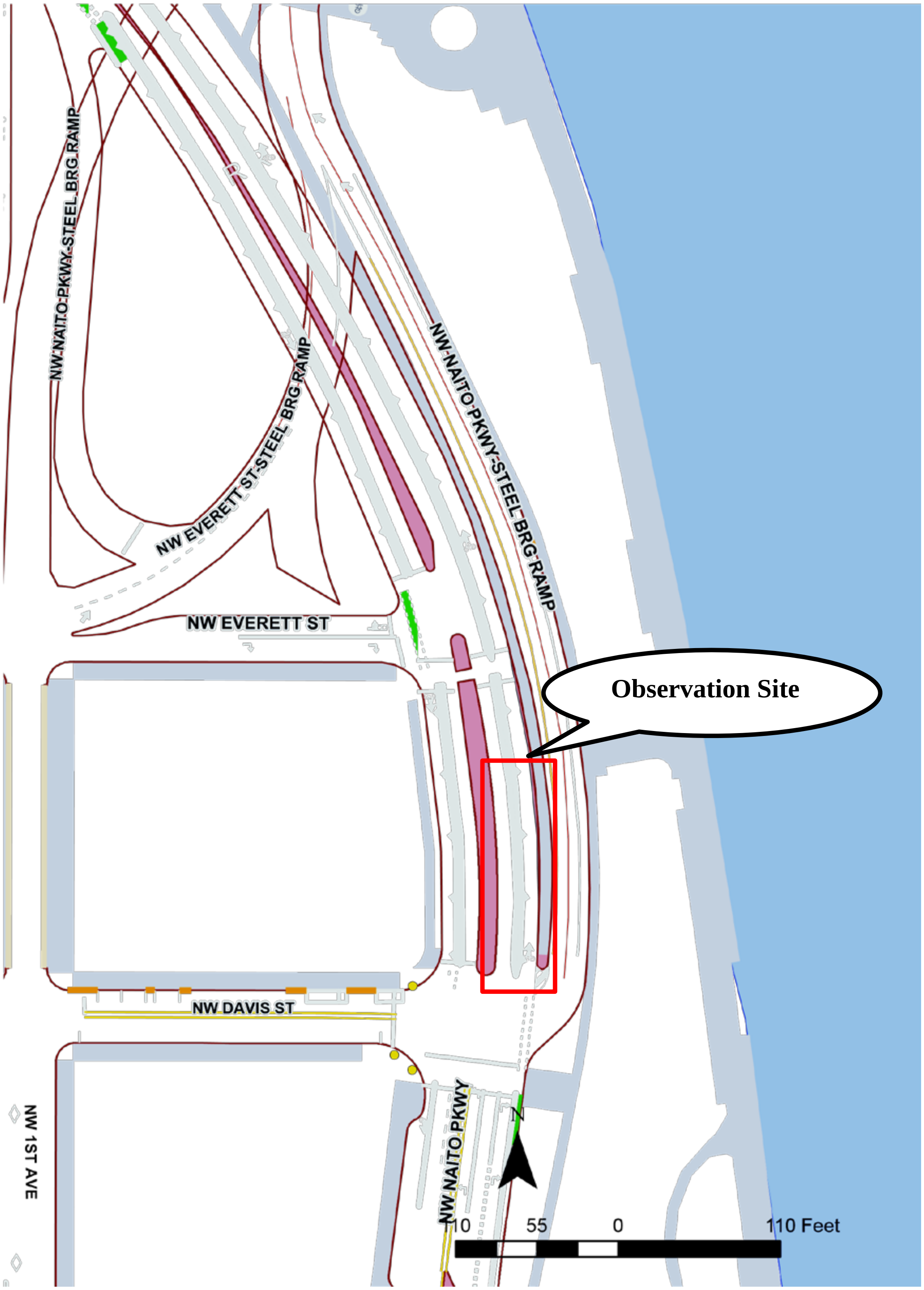

Figure 17: Geometric Design Map for Northwest Naito and Everett

4.1.2 Data Collection Elements

For each study location a video camera was placed approximately 100 feet from the beginning of the intersection to observe the midblock of the roadway segment. Videos were reviewed and the bicyclist lateral position, motorized vehicle traffic, and user behavior was noted. During this review, the data that pertained to the bicyclists' lateral position and safety equipment was collected and measured.

4.1.2.1 Bicyclists Lateral Position:

The distance that was measured if from the motorists right hand side and shoulders left hand side from the tire of the bicycle to inside buffered bicycle lane pavement marking (at the instant the cyclist passed the reference marking). This was done ensure that the adjacent vehicle lane was located to the left of the bicyclist. Thus the shy distance that a bicyclist may subconsciously implement would be constant for each rider in each buffered bicycle lane facility.

4.1.2.2 Bicyclists Safety Equipment:

The safety equipment that was evaluated for this study considered bicyclists' use of headlights, taillights, lights mounted on the bicycle or worn and highly visible clothing to become more visible to motorists. Figure 18 thru 20 are still photos taken from the video data of the different safety equipment observed.

Figure 18: Video Still of Bicyclist Wearing High Visibility Clothing

Figure 19: Video Still of Bicyclist Wearing Helmet

Figure 20: Video Still of Bicyclist Utilize of Headlights, Taillights, Lights Mounted on the Bicycle

4.1.2.3 Other Collected Data

Other data that was collected included:

- Traffic Density: recorded the amount and vehicle type within the adjacent lane during the study time interval.
- Conflict Occurrence: due to infrastructure design a conflict point was evident in a study location due to motorist crossing of the buffered bicycle lane facility resulting in a high conflict point between cyclists and motorist.
- Pedestrian Activity: quantify the complete facility design (streetscape) influence of pedestrian perspective of safety around the buffered bicycle lane infrastructure.(Ewing, 2016)

A final database was generated that included the bicyclist relative lateral position, each bicyclists safety equipment, adjacent traffic density, level of conflict occurrence, and pedestrian activity.

4.1.3 Descriptive Statistics

The database was used to provide the basis for analysis of the effects of bicyclist and motorist behaviors and usage of different buffered bicycle lane designs based on lateral positions of the bicyclist. Each study location provided data on buffered bicycle lane designs that are independent of each of the other buffered bicycle lanes. For each study site, a sample plot of the lateral position of the bicyclists for each location and position of measurement at six different longitudinal positions is provided in the following sections. Each sample point demonstrates the path or the bicycles lateral position in term of overall percentage width available within or around the buffered bicycle lane from the inner right pavement marking to the bicyclist tire. Any negative lateral positions is the lateral positon of a bicyclist to the left of the inner left pavement marking. Within each section there are still video images of the locations of each lateral measurement for each buffered bicycle lane facility.

For each measured point the bicyclist's lateral positions were graphed into histograms and box and whisker plots to visualize the lateral positions of the bicyclist. The use of the histograms and box and whisker plots of the data that was to evaluate if the dataset contained few or many outlier events. These outliers generate conflicting results for any model that is generated using this data. Each buffered bicycle lane facility had indications of outliers within their collected data sets and each data set was analyzed and identified to remove these outliers. A statistical test called the Dixon test was used to identity the outliners. The Dixon test applies a normal distribution to the dataset and isolates data points that are larger than two standard deviations from the mean (outside 95% confidence interval from the sample mean). Given the small sample size, the Dixon test was used to identify and remove the influence outliers for each positional point. The truncation of the dataset or the method of removal of the data after application of the Dixon test to identify the smallest and largest observations or significant outliers produced a data set that is representative of the observed population for each buffered bicycle facility type.

The non-truncated data set and truncated data sets were evaluated by Chi-Square goodness of fit test and Kolmogorov-Smirnov goodness of fit test. These two separate tests evaluated the normal distribution of the data set. The Chi-Square test evaluates the sample data that was collected from a population with a specific distribution. This test can be applied to any univariate distribution to calculate the cumulative distribution function. The Chi-Square test is dependent on how the data is binned and requires a sufficient sample size for the Chi-Square approximation to be valid. The Kolmogorov-Smirnov test is an alternative to the Chi-Square test. Histograms from the non-truncated data and truncated dataset of the observations for lateral position of bicyclists for each of the overall buffered bicycle lane facilities were incorporated. This is to demonstrate if one or both of the datasets follow a normal distribution population.

From the Log-likelihood statistics, the estimate of the parameters to assess the best fit for a model. The Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC) are information-based criterial that assess a model fit. The AIC is defined as follows (JMP):

$$AIC = 2k - 2 * \ln(\hat{L})$$

The BIC is defined as follows (JMP):

$$BIC = -2LogLikelihood + k * \ln(n)$$

Where k is the number of estimated parameters, n is the number of recorded observations, and L is the maximized valued of the likelihood function for the model. The AIC and BIC are used to compare various models for the same data set, but the BIC censures models with more parameters. For AIC and BIC value the smallest values is the preferred model.

From the Kolmogorov-Smirnov test is a robust test that assess the relative distribution of the data. The values of the D statistic and the p-value are not affected by the scale changes. Thus the values of the D statistic and the p-value from the Kolmogorov-

Smirnov test defines the better representation of the population as a large number of outliers can be assessed of a non-normal distribution. The null hypothesis for the Kolmogorov-Smirnov test is that the data is normally distributed and the alternate hypothesis is that the data is not normally distributed.

4.1.3.1 Interstate Highway

Figures 21 and 22 are video stills of the locations of each lateral measurement for each buffered bicycle lane facility. The position points were individually assessed to evaluate and map bicyclists' lateral path. For this location 145 bicyclists paths were measured and mapped. Figure 23 are histograms of each positional point of the measured bicyclist. Figure 24 are box and whisker plots of each positional point of the measured bicyclist.

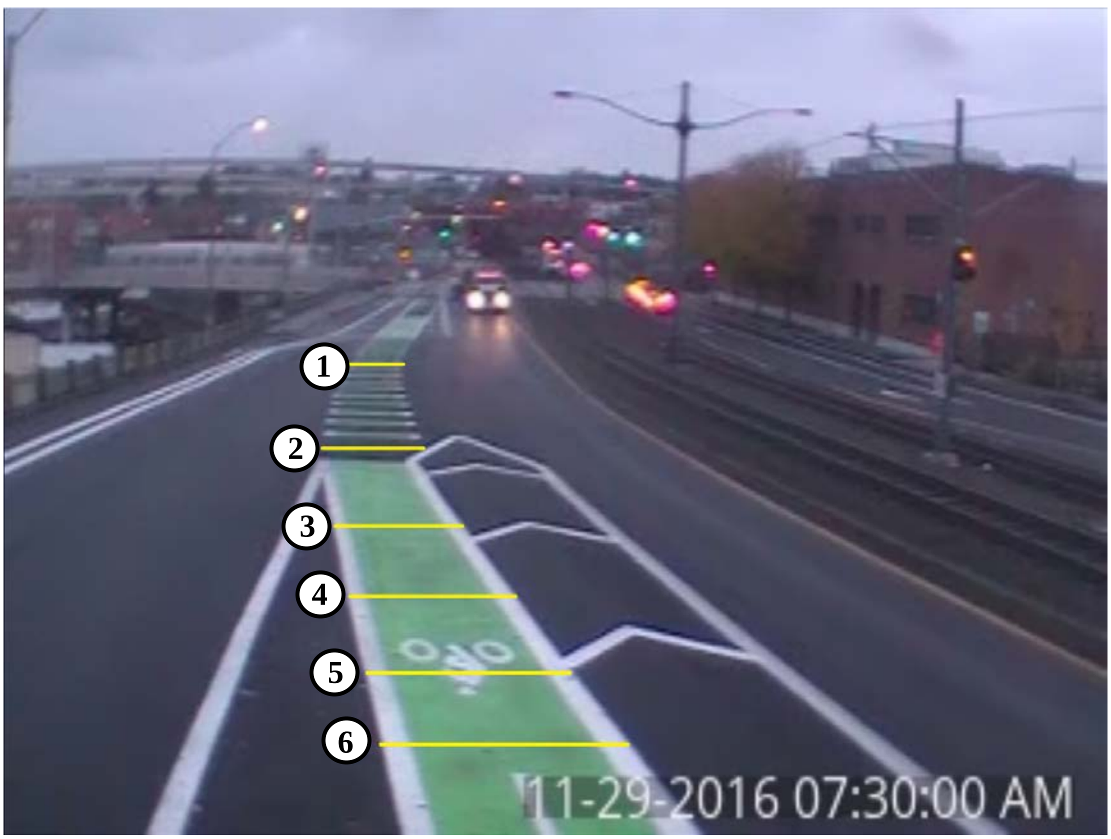

Figure 21: Bicyclist Lateral Position Points for N Interstate Ave

Figure 22: Lateral Positon Measurements of Bicyclist within Buffered Bicycle Lane

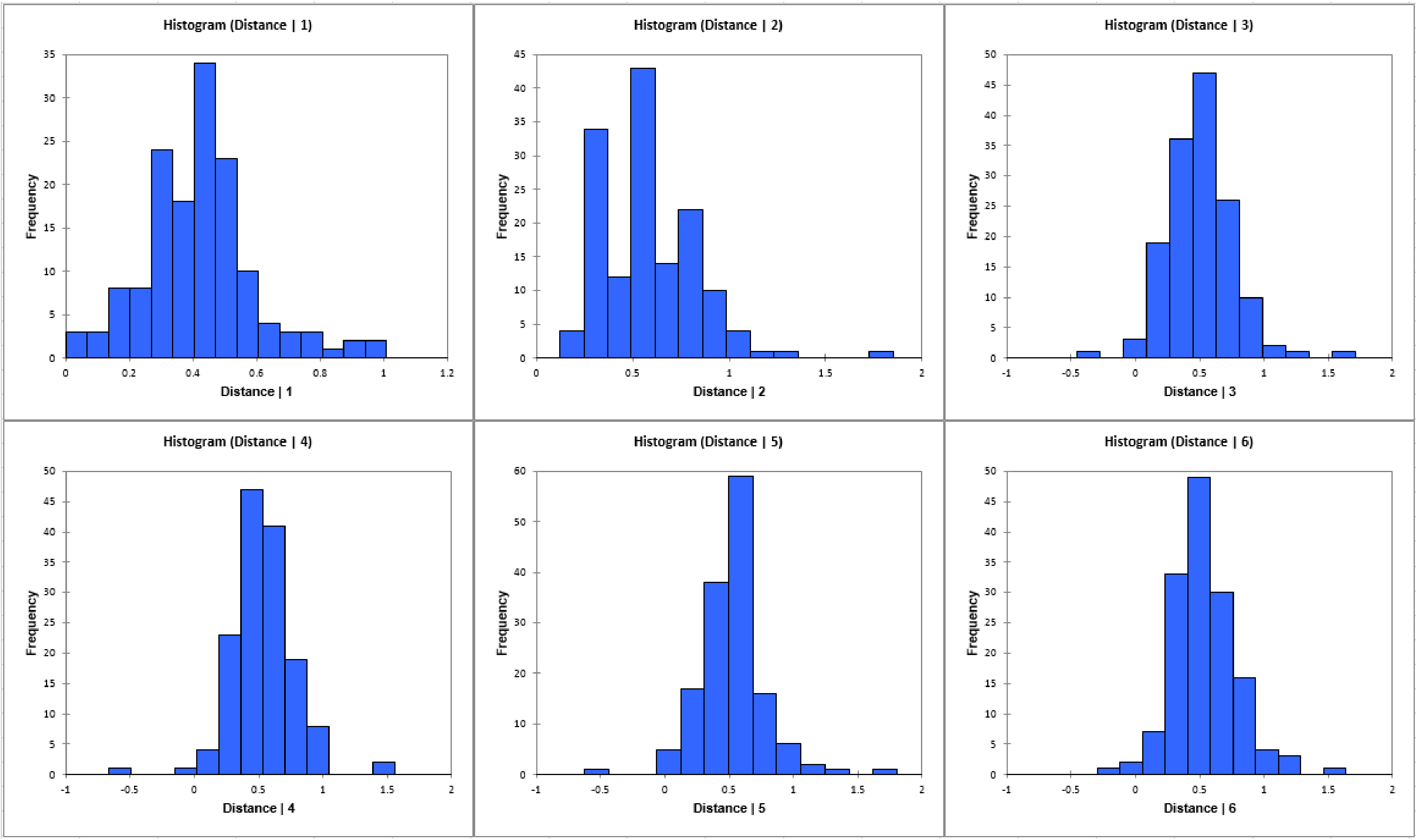

Figure 23: Histograms of Each Positional Point for N Interstate Ave

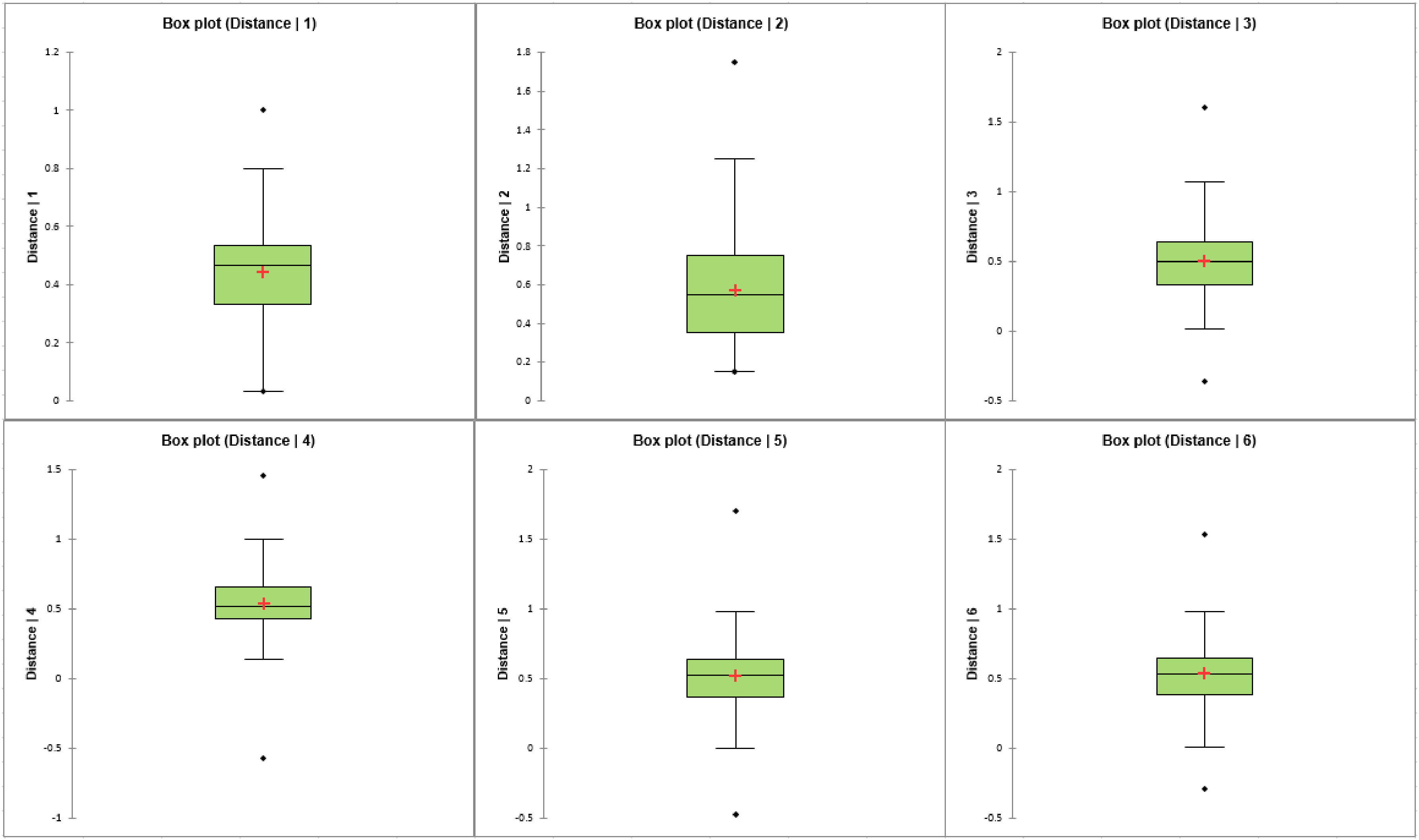

Figure 24: Box and Whisker Plots of Each Positional Point for N Interstate Ave

The truncated lateral positions of bicyclists that were removed from this data set were from bicyclists that passed another bicyclist within the facility. The truncated data includes 139 bicyclists paths were measured and mapped. Figure 25 are histograms of the truncated data for each positional point of the measured bicyclist. Figure 26 are box and whisker plots of the truncated data for each positional point of the measured bicyclist.

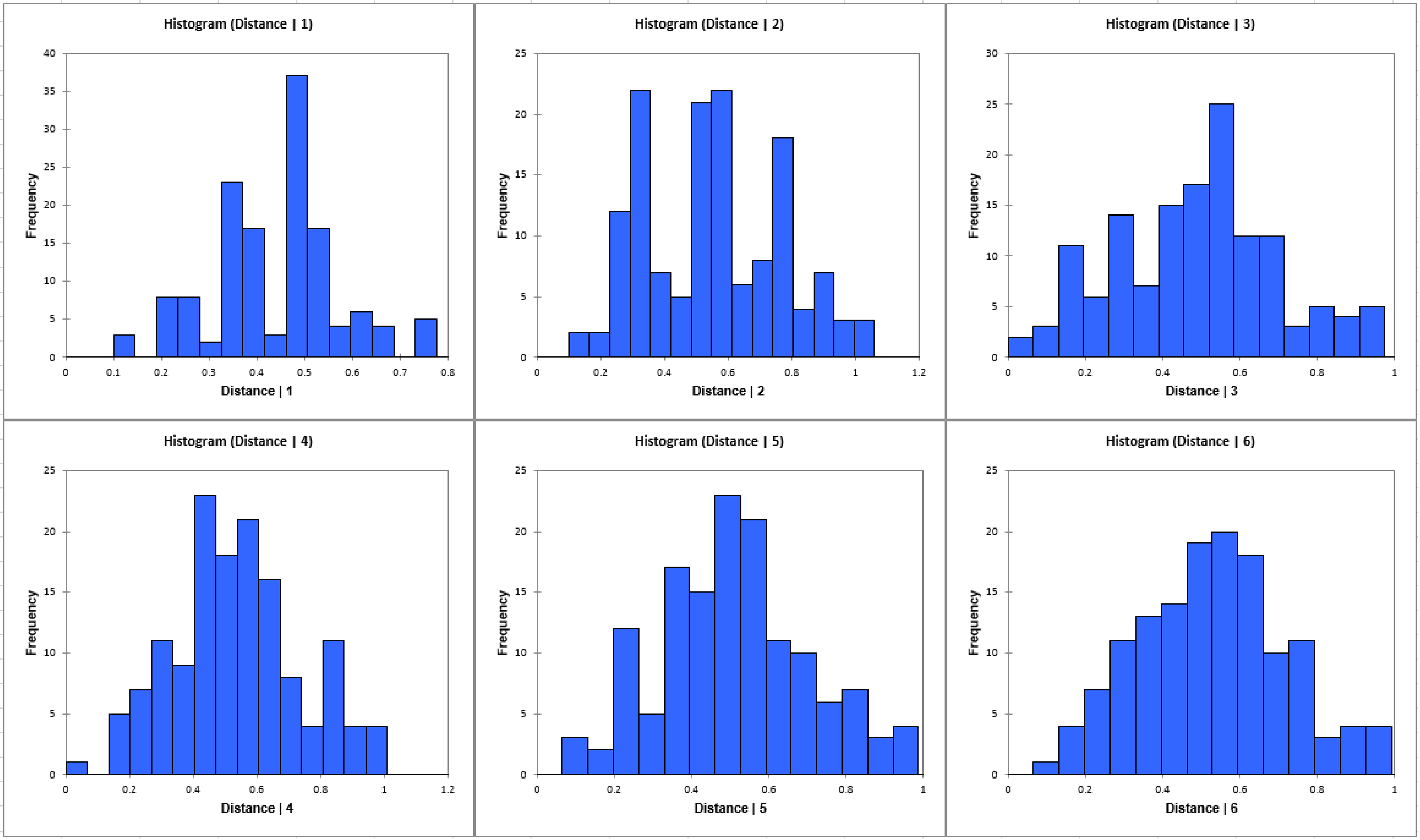

Figure 25: Histograms of the Truncated Data for Each Positional Point for N Interstate Ave

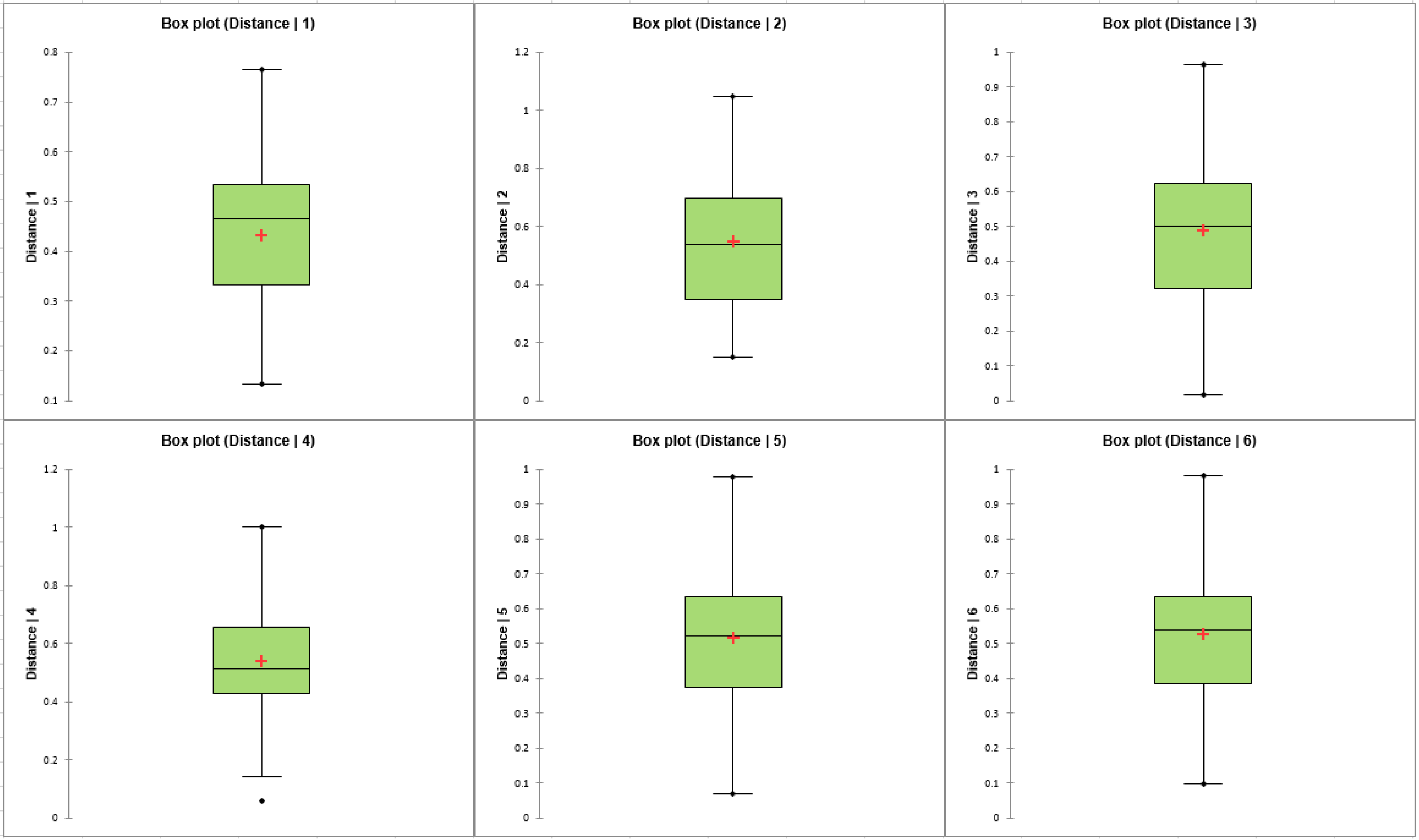

Figure 26: Box and Whisker Plots of the Truncated Data for Each Positional Point for N Interstate Ave Truncated

The results of the Kolmogorov-Smirnov test for the non-truncated data of the Interstate Highway segment resulted in the computed p-value that is lower than the significance level (alpha= 0.05), the null hypothesis that the sample follows a normal distribution should be rejected, and the alterative hypothesis that the sample does not follow a normal distribution should be accepted. The risk to reject the null hypothesis while it is true is lower than 0.01%. The Chi-Square test for the non-truncated data computed the p-value that is lower than the significance level (alpha= 0.05), the null hypothesis that the sample follows a normal distortion should be rejected, and the alterative hypothesis that the sample does not follow the normal distribution should be accepted. The risk to reject the null hypothesis while it is true is lower than 0.01%. Figures 27 and 28 are the histograms of the entire data set of lateral positional points for the non-truncated data set tested for normality.

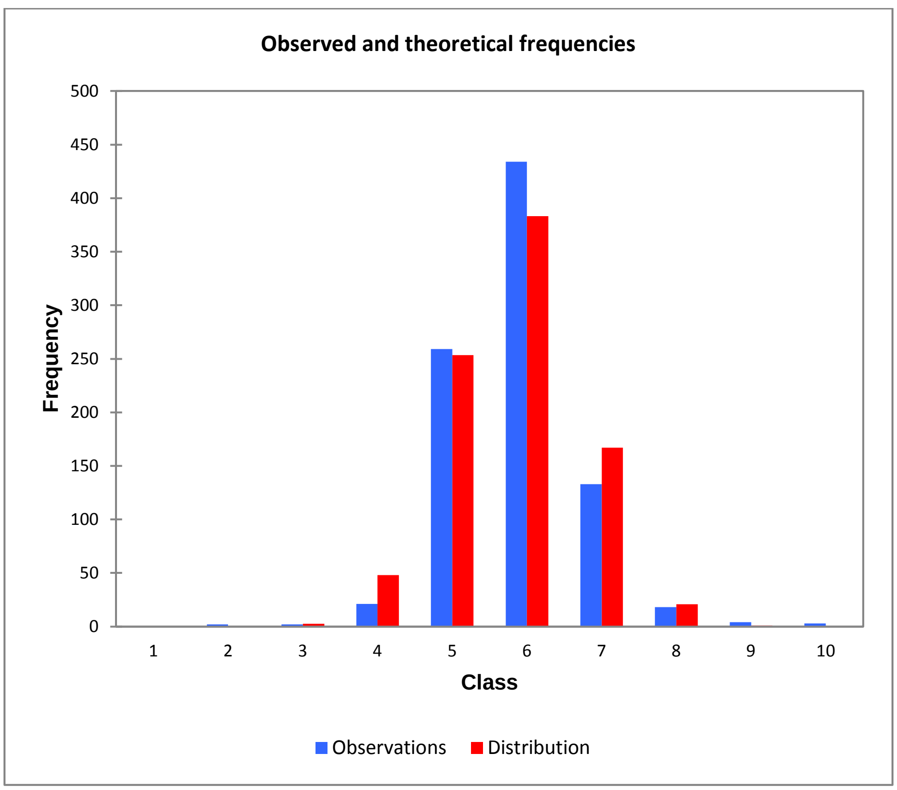

Figure 27: Observed and Theoretical Normal Frequencies for Non-Truncated Data

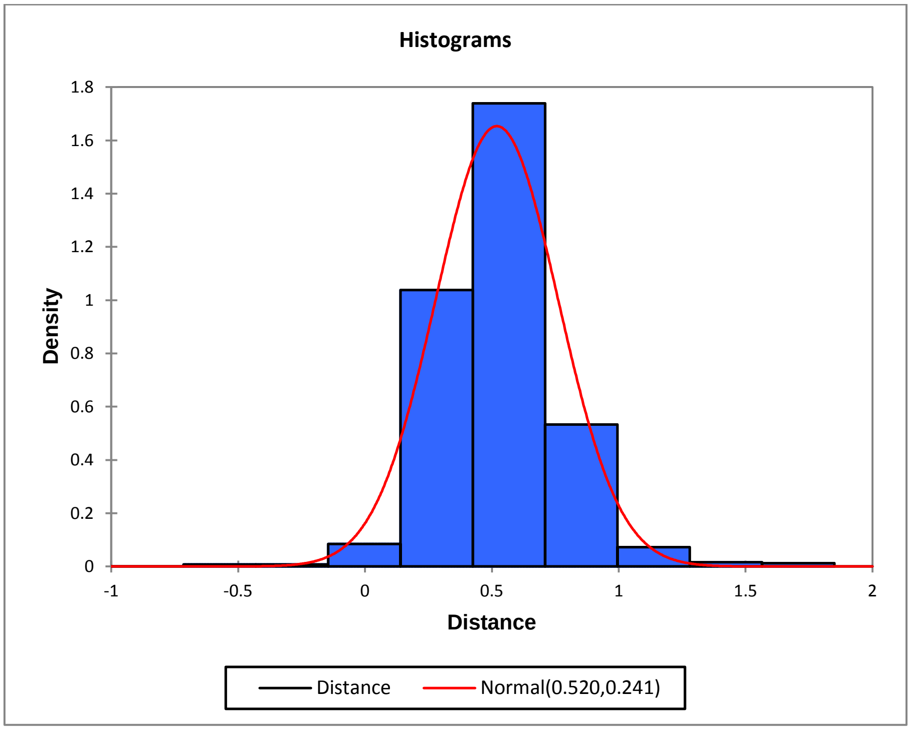

Figure 28: Histogram of Density and Normal for Non-Truncated Data

The results of the Kolmogorov-Smirnov test for the truncated data for the Interstate Highway segment as the computed p-value is lower than the significance level (alpha= 0.05), the null hypothesis that the sample follows a normal distortion should be rejected, and the alterative hypothesis that the sample does not follow ta Normal distribution should be accepted. The risk to reject the null hypothesis while it is true is lower than 4.83%. The Chi-Square test for the non-truncated data as the computed p-value is lower than the significance level (alpha= 0.05), the null hypothesis that the sample follows a normal distortion should be rejected, and the alterative hypothesis that the sample does not follow ta Normal distribution should be accepted. The risk to reject the null hypothesis while it is true is lower than 0.01%.

The Chi-Square and Kolmogorov-Smirnov tests both suggest rejection of the null hypothesis that the sample follows a normal distortion at the significance level variable alpha for both test is at the 0.05. This is due to a lack of robust techniques based on strong distributional assumptions. By robust, the statistical technique that performs well under a wide range of distributional assumptions is effected due to the one day of observational data compared to a weeklong observation. Thus, the null hypothesis that the sample follows a normal distribution should be accepted, and the alterative hypothesis that the sample does not follow the Normal distribution should be rejected. Figures 29 and 30 are the histograms of the entire data set of lateral positional points for the non-truncated data set tested for normality.

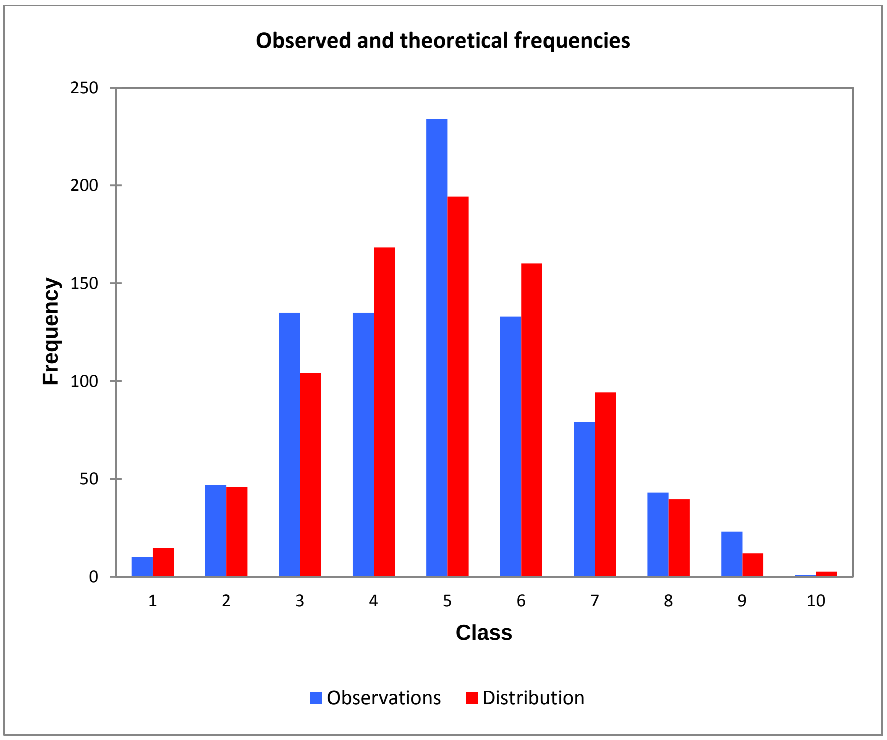

Figure 29: Observed and Theoretical Normal Frequencies for Truncated Data

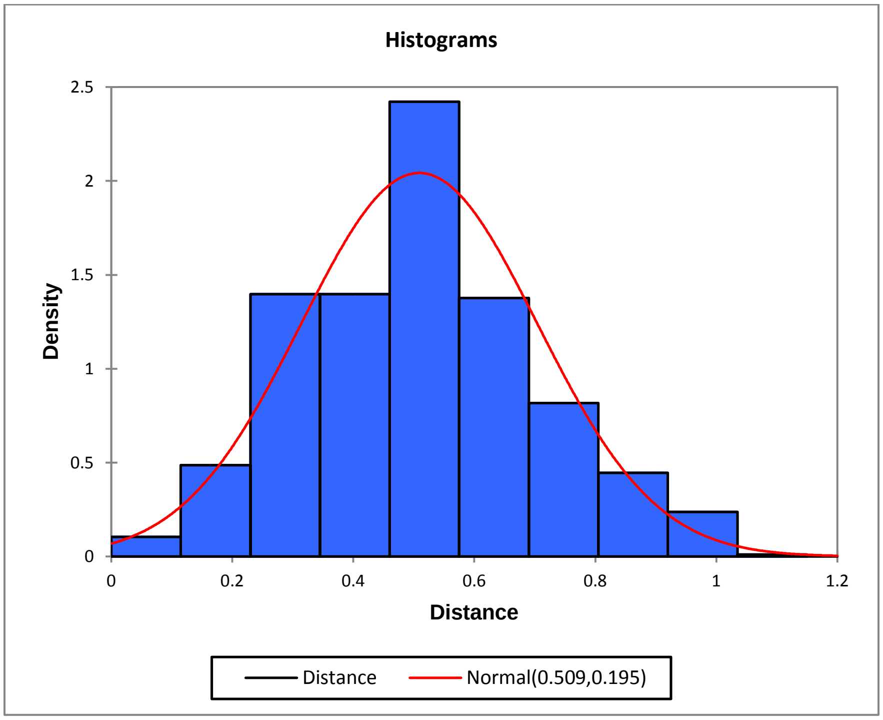

Figure 30: Histogram of Density and Normal for Truncated Data

Table 8 is the descriptive statistics for the lateral positon of a bicyclist for non-truncated data set and the truncated data set. Table 9 details the estimated parameters, Log-likelihood statistics, Pearson skewness and kurtosis, the Kolmogorov-Smirnov test, and Chi-Square test for the non-truncated and the truncated data sets.

Table 8: Descriptive Statistics Bicyclist Lateral Position Truncated for Non-Truncated and Truncated Data

	Non-Truncated Data								Truncated Data							
				Percentiles								Percentiles				
Position Point	No. Of Cyclist	Mean	Std. Dev	5	10	Med	90	95	No. Of Cyclist	Mea n	Std. Dev	5	10	Med	90	95
1	145	0.445	0.171	.16	.23	0.445	.67	.73	137	0.433	0.132	.22	.26	0.433	.60	.65
2	145	0.568	0.250	.16	.25	0.568	.89	.98	142	0.548	0.215	.19	.27	0.548	.82	.90
3	145	0.504	0.256	.08	.18	0.504	.83	.93	141	0.489	0.213	.14	.22	0.489	.76	.84
4	145	0.540	0.247	.13	.22	0.540	.86	.95	142	0.539	0.201	.21	.28	0.539	.80	.87
5	145	0.525	0.256	.10	.20	0.525	.85	.95	139	0.516	0.191	.20	.27	0.516	.76	.83
6	145	0.537	0.243	.14	.23	0.537	.85	.94	139	0.528	0.188	.22	.29	0.528	.77	.84

Table 9: Descriptive Statistics of Overall Distribution

	Non-Truncated Data	Truncated Data
estimated parameters		
μ	0.520	0.509
sigma	0.241	0.195
Log-likelihood statistics		
Log-likelihood (LL)	2.409	179.959
BIC (LL)	8.733	-346.452
AIC (LL)	-0.818	-355.919
Pearson skewness	0.632	0.264
Pearson kurtosis	3.124	-0.266
Kolmogorov-Smirnov test		
D	0.080	0.047
p-Value	<0.0001	0.048
Alpha	0.05	0.05
Chi-Square test		
Chi-Square (observed)	1534.779	44.005
Chi-Square (Critical)	14.067	14.067
DF	7	7
p-Value	<0.0001	<0.0001
Alpha	0.05	0.05

4.1.3.2 Naito Parkway

Figures 31 and 32 are video stills of the locations of each lateral measurement for each buffered bicycle lane facility. The position points were individually assessed to evaluate and map bicyclists' lateral path. For this location 39 bicyclists paths were measured and mapped. Figure 33 are histograms of each positional point of the measured bicyclist. Figure 34 are box and whisker plots of each positional point of the measured bicyclist.

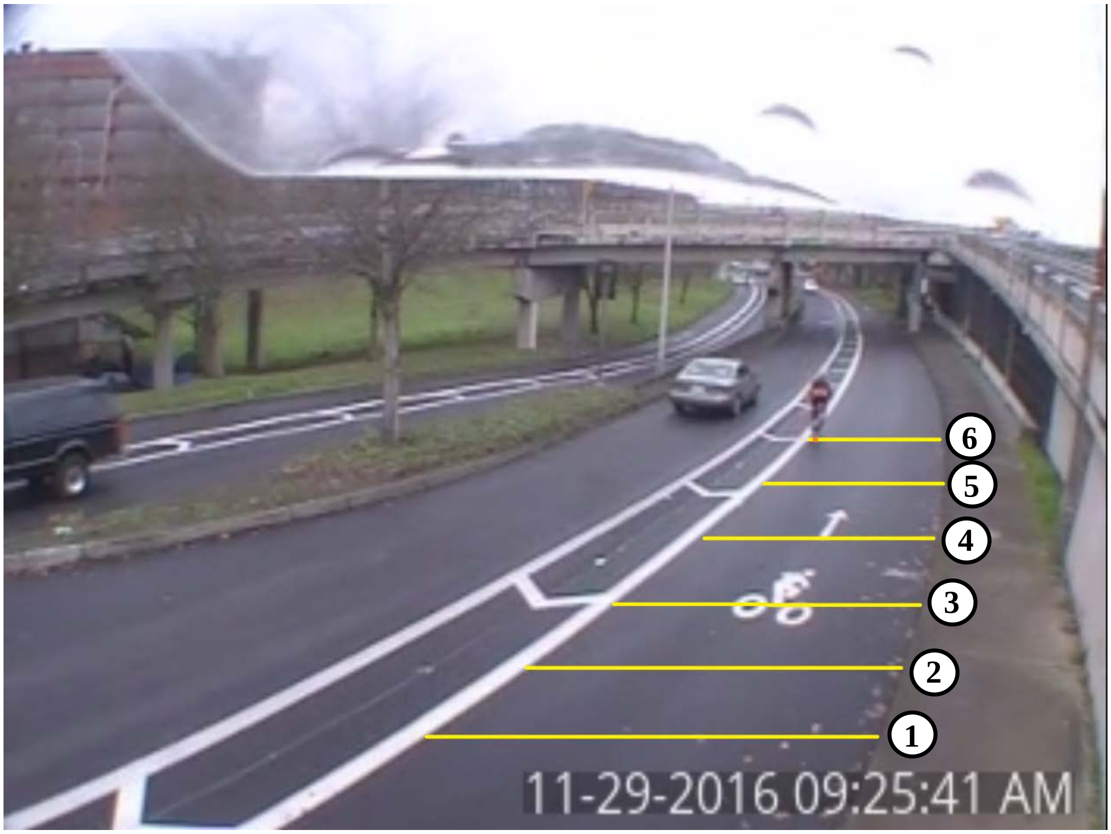

Figure 31: Bicyclist Lateral Position Points for NW Naito Parkway

Figure 32: Lateral Positon Measurements of Bicyclist within Buffered Bicycle Lane

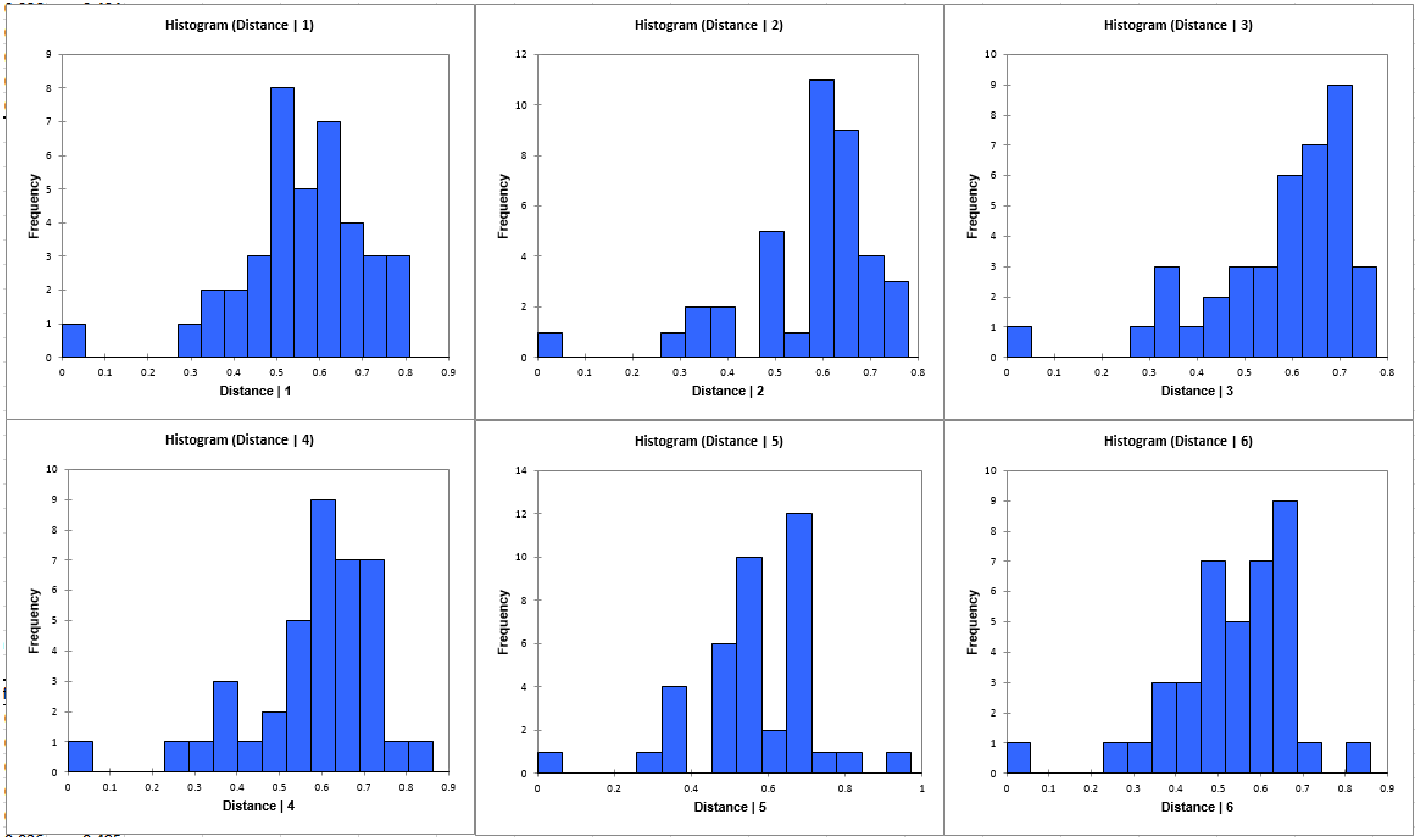

Figure 33: Histograms of Each Positional Point for NW Naito Parkway

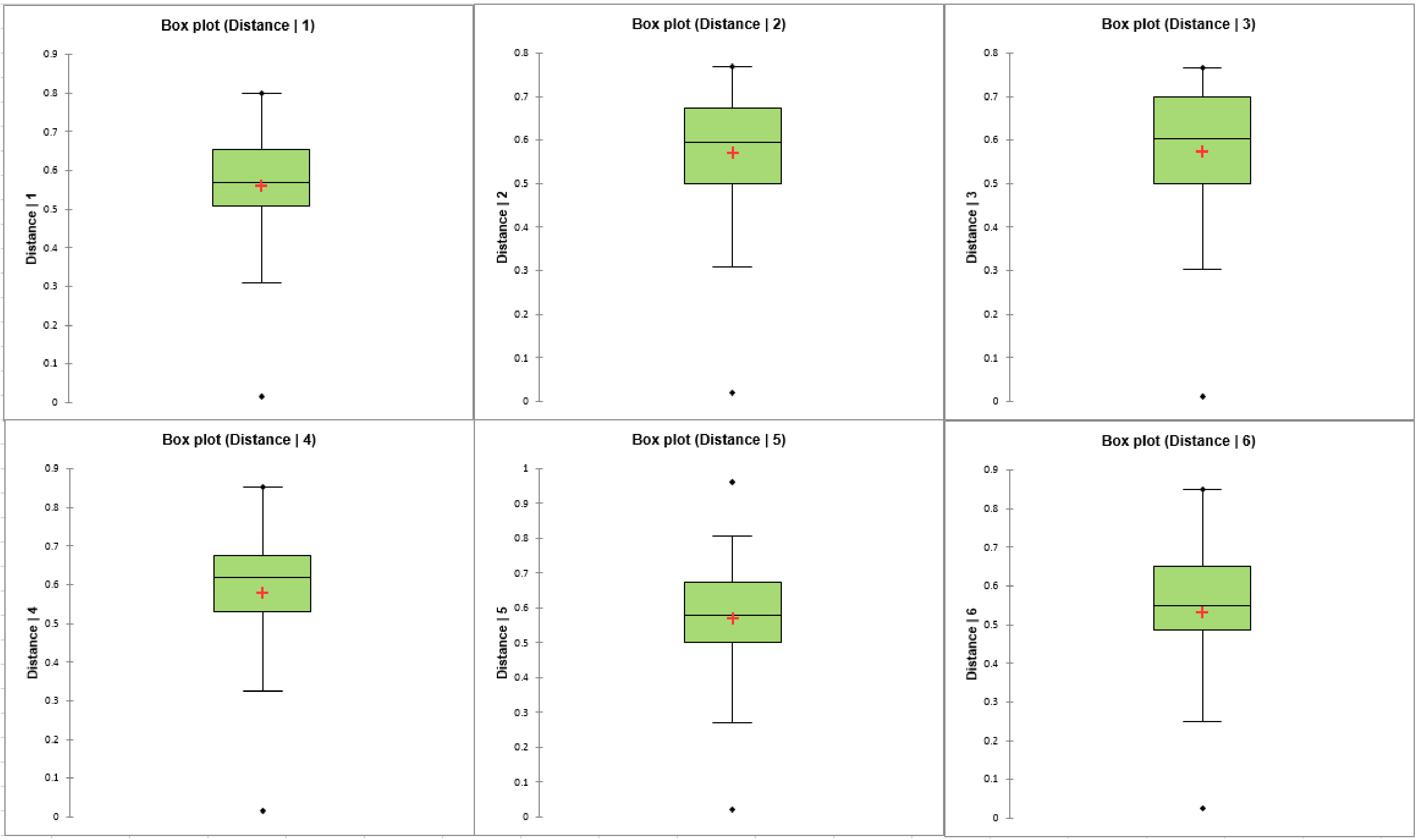

Figure 34: Box and Whisker Plots of Each Positional Point for NW Naito Parkway

The difference between the Naito Parkway data and the Interstate Highway truncated data is that for this data set the observed lateral positions that were removed from this data set were due to signal bicyclist behavior not due to the passing of other bicyclist within the buffered bicycle lane. The truncated data includes 37 bicyclists' paths were measured and mapped. Figure 35 are histograms of the truncated data for each positional point of the measured bicyclist. Figure 36 are box and whisker plots of the truncated data for each positional point of the measured bicyclist.

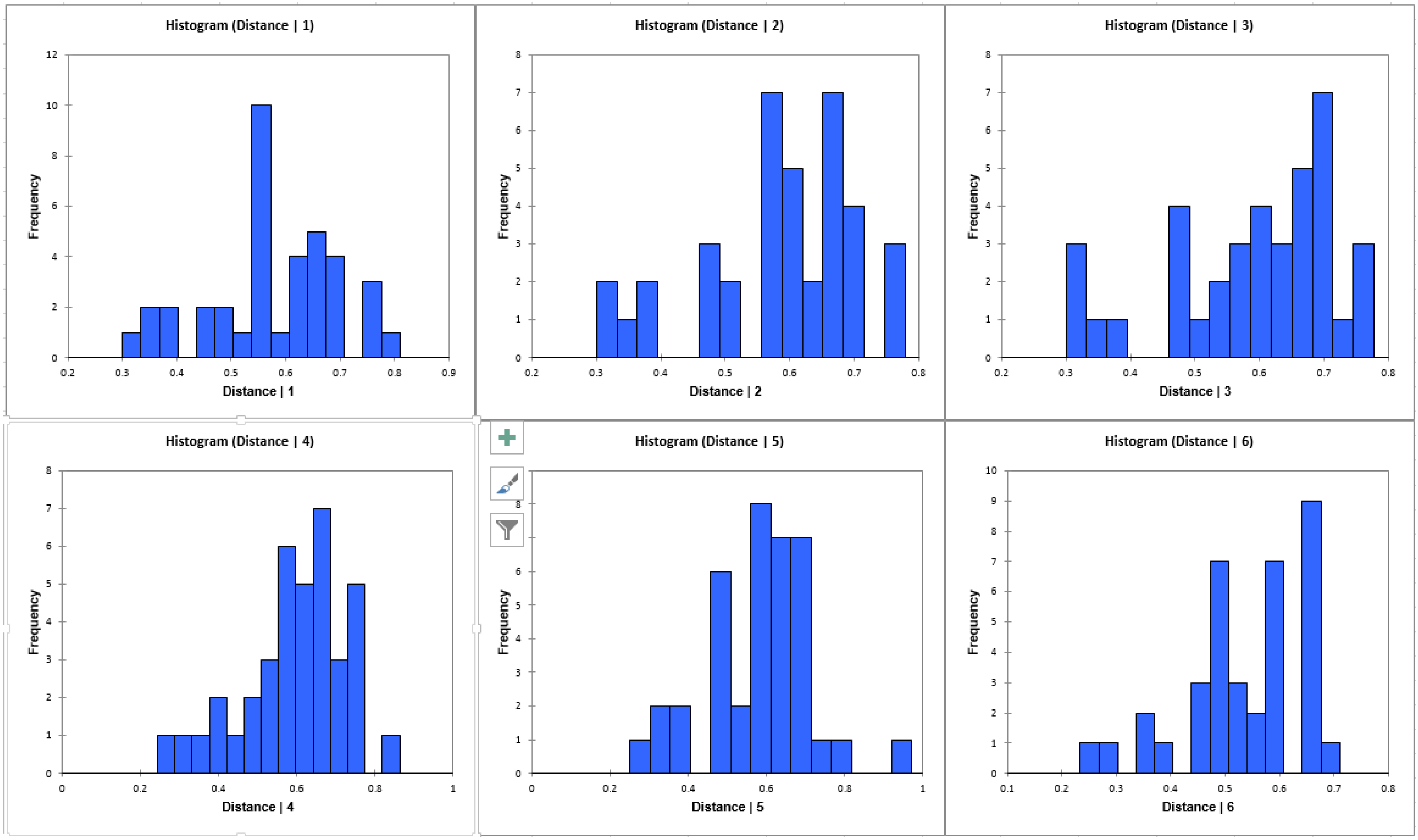

Figure 35: Histograms of the Truncated Data for Each Positional Point for NW Naito Parkway

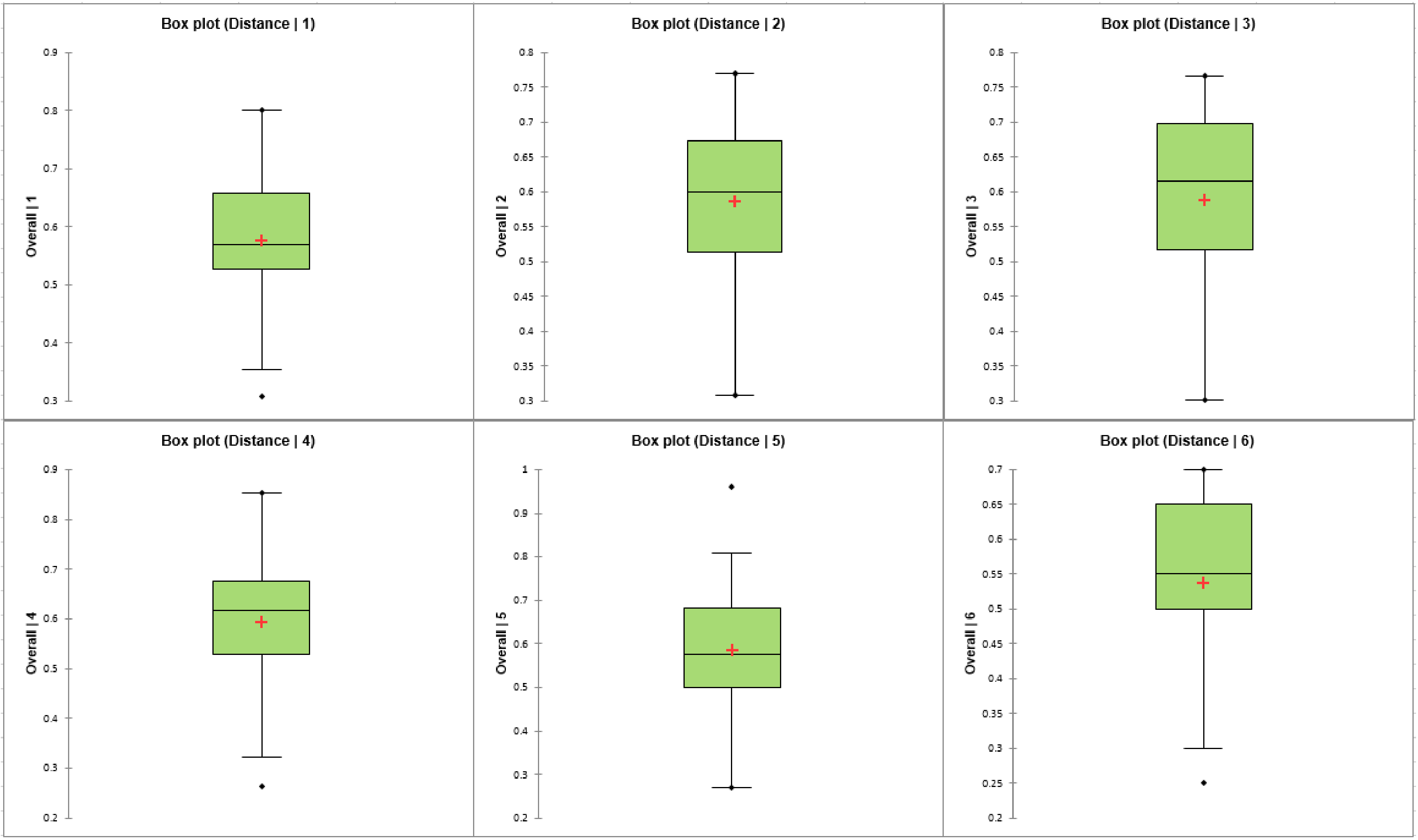

Figure 36: Box and Whisker Plots of the Truncated Data for Each Positional Point for NW Naito Parkway

The results of the Kolmogorov-Smirnov test for the non-truncated data as the computed p-value is lower than the significance level (alpha= 0.05), the null hypothesis that the sample follows a normal distortion should be rejected, and the alterative hypothesis that the sample does not follow ta Normal distribution should be accepted. The risk to reject the null hypothesis while it is true is lower than 0.25%. The Chi-Square test for the non-truncated data as the computed p-value is lower than the significance level (alpha= 0.05), the null hypothesis that the sample follows a normal distortion should be rejected, and the alterative hypothesis that the sample does not follow the Normal distribution should be accepted. The risk to reject the null hypothesis while it is true is lower than 0.01%. Figures 37 and 38 are the histograms of the entire data set of lateral positional points for the non-truncated data set tested for normality.

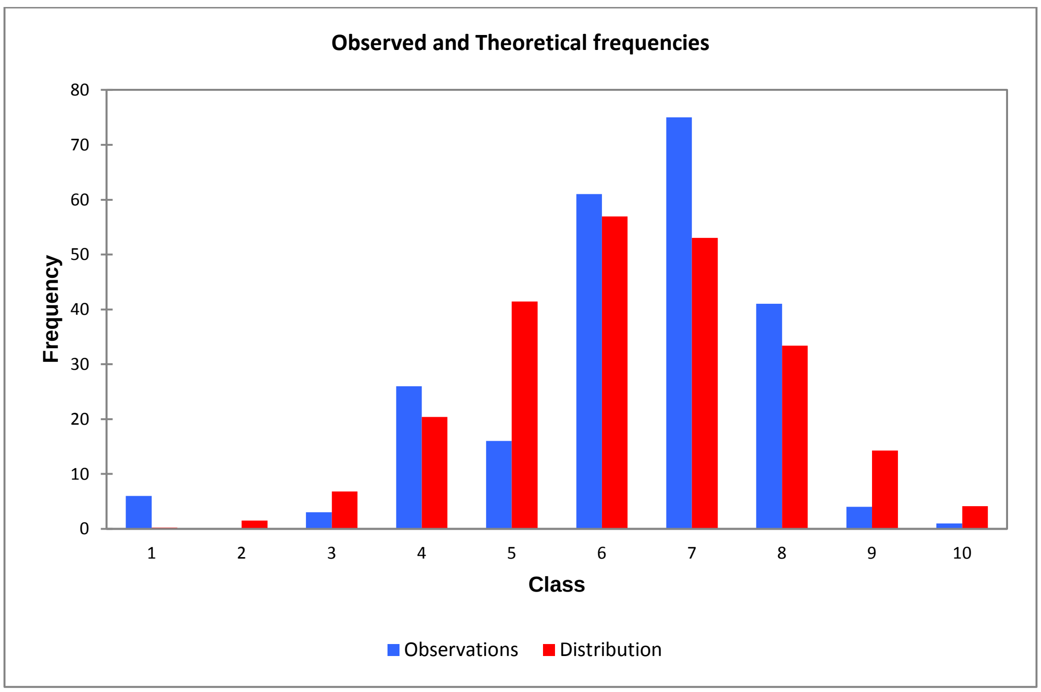

Figure 37: Observed and Theoretical Normal Frequencies for Non-Truncated Data

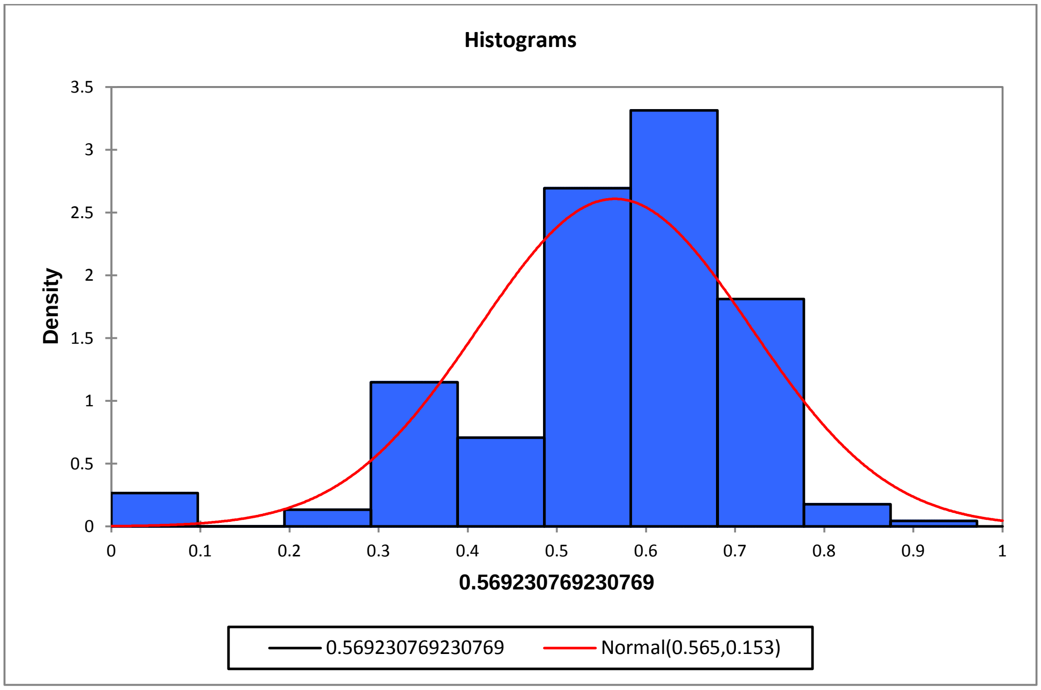

Figure 38: Histogram of Density and Normal for Non-Truncated Data

The results of the Kolmogorov-Smirnov test for the truncated data for the Interstate Highway segment as the computed p-value is lower than the significance level (alpha= 0.05), the null hypothesis that the sample follows a normal distortion should be rejected, and the alterative hypothesis that the sample does not follow ta Normal distribution should be accepted. The risk to reject the null hypothesis while it is true is lower than 2.63%. The Chi-Square test for the non-truncated data as the computed p-value is lower than the significance level (alpha= 0.05), the null hypothesis that the sample follows a normal distortion should be rejected, and the alterative hypothesis that the sample does not follow ta Normal distribution should be accepted. The risk to reject the null hypothesis while it is true is lower than 0.01%.

The Chi-Square and Kolmogorov-Smirnov tests both suggest rejection of the null hypothesis that the sample follows a normal distortion at the significance level variable alpha for both test is at the 0.05. This is due to a lack of robust techniques based on strong distributional assumptions. Robust techniques are the statistical techniques that performs well under a wide range of distributional assumptions is effected due to the one day of observational data compared to a weeklong observation. Thus, the null hypothesis that the sample follows a normal distribution should be accepted, and the alterative hypothesis that the sample does not follow the Normal distribution should be rejected. Figures 39 and 40 are the histograms of the entire data set of lateral positional points for the non-truncated data set tested for normality.

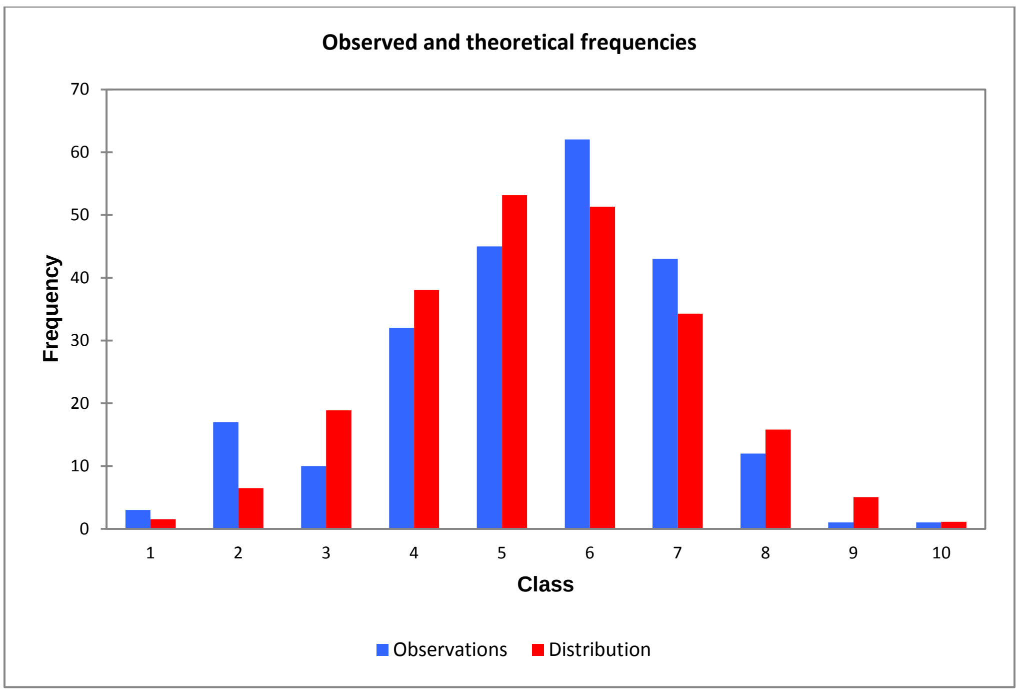

Figure 39: Observed and Theoretical Normal Frequencies for Truncated Data

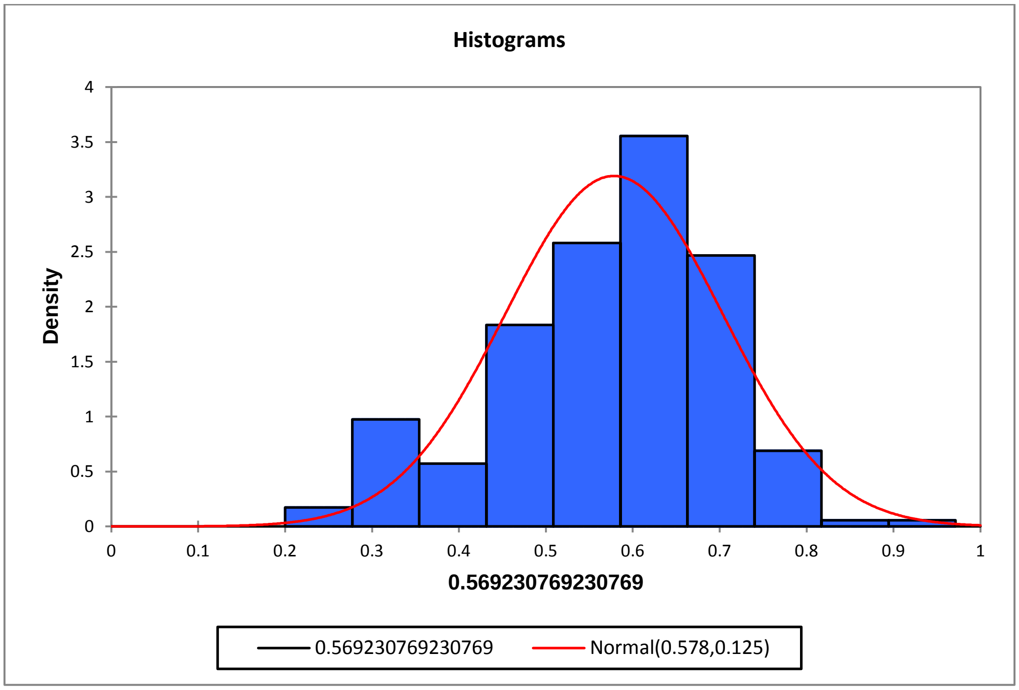

Figure 40: Histogram of Density and Normal for Truncated Data

Table 10 is the descriptive statistics for the lateral positon of a bicyclist for non-truncated data set and the truncated data set. Table 11 details the estimated parameters, Log-likelihood statistics, Pearson skewness and kurtosis, the Kolmogorov-Smirnov test, and Chi-Square test for the non-truncated and the truncated data sets.

Table 10: Descriptive Statistics Bicyclist Lateral Position for Non-Truncated and Truncated Data

	Non-Truncated Data								Truncated Data							
	No. Of Cyclist	Mean	Std. Dev	Percentiles					No. Of Cyclist	Mean	Std. Dev	Percentiles				
Position Point				5	10	Med	90	95				5	10	Med	90	95
1	39	0.561	0.150	.31	.37	0.561	.75	.81	38	0.576	0.122	.37	.42	0.576	.73	.78
2	39	0.572	0.150	.33	.38	0.572	.76	.82	38	0.587	0.121	.39	.43	0.587	.74	.79
3	39	0.574	0.157	.32	.37	0.574	.78	.83	38	0.589	0.129	.38	.42	0.589	.75	.80
4	39	0.580	0.160	.32	.37	0.580	.79	.84	38	0.595	0.132	.38	.43	0.595	.76	.81
5	39	0.571	0.161	.31	.36	0.571	.78	.84	38	0.586	0.135	.36	.41	0.586	.76	.81
6	39	0.532	0.144	.30	.35	0.532	.72	.77	37	0.537	0.109	.36	.40	0.537	.68	.72

Table 11: Descriptive Statistics of Overall Distribution

	Non-Truncated Data	Truncated Data
estimated parameters		
µ	0.565	0.578
sigma	0.153	0.125
Log-likelihood statistics		
Log-likelihood (LL)	106.835	149.232
BIC (LL)	-202.769	-287.623
AIC (LL)	-209.671	-294.464
Pearson skewness	-1.220	-0.457
Pearson kurtosis	2.486	-0.003
Kolmogorov-Smirnov test		
D	0.119	0.097
p-Value	0.003	0.026
Alpha	0.05	0.05
Chi-Square test		
Chi-Square (observed)	185.368	33.672
Chi-Square (Critical)	14.067	14.067
DF	7	7
p-Value	<0.0001	<0.0001
Alpha	0.05	0.05

4.1.3.3 3rd Street

Figures 41 and 42 are video stills of the locations of each lateral measurement for each buffered bicycle lane facility. The position points were individually assessed to evaluate and map bicyclist's lateral path. For this location 106 bicyclists paths were measured and mapped. Figure 43 are histograms of each positional point of the measured bicyclist. Figure 44 are box and whisker plots of each positional point of the measured bicyclist.

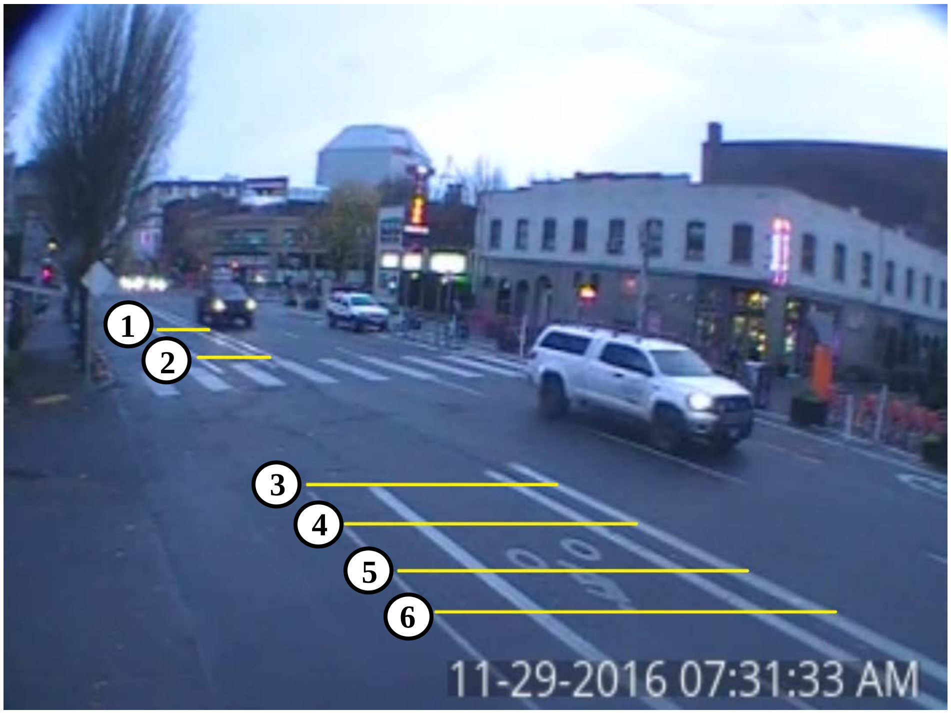

Figure 41: Bicyclist Lateral Position Points for SW 3rd St

Figure 42: Lateral Negative Measurements of Bicyclist within Buffered Bicycle Lane

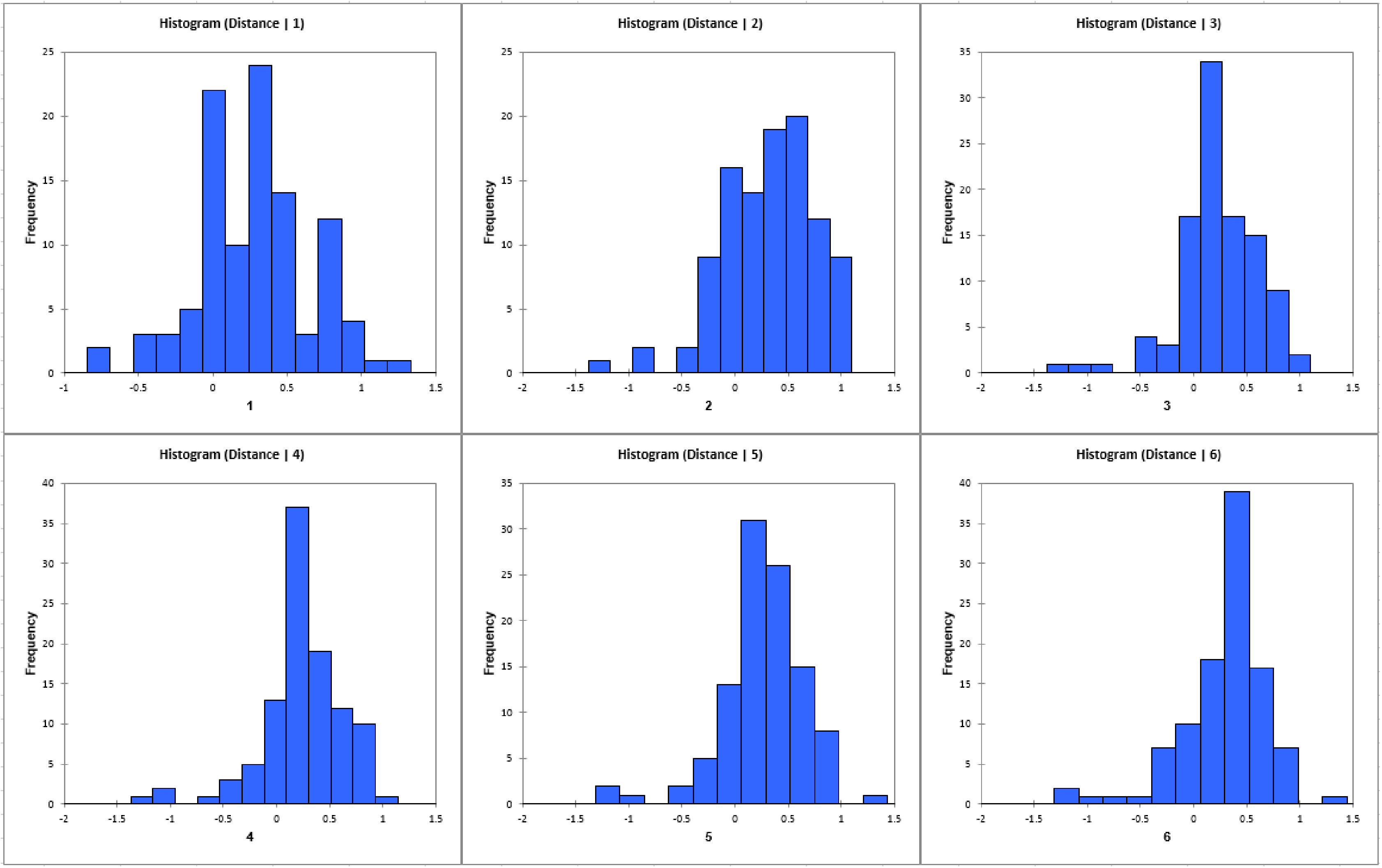

Figure 43: Histograms of Each Positional Point for SW 3rd St.

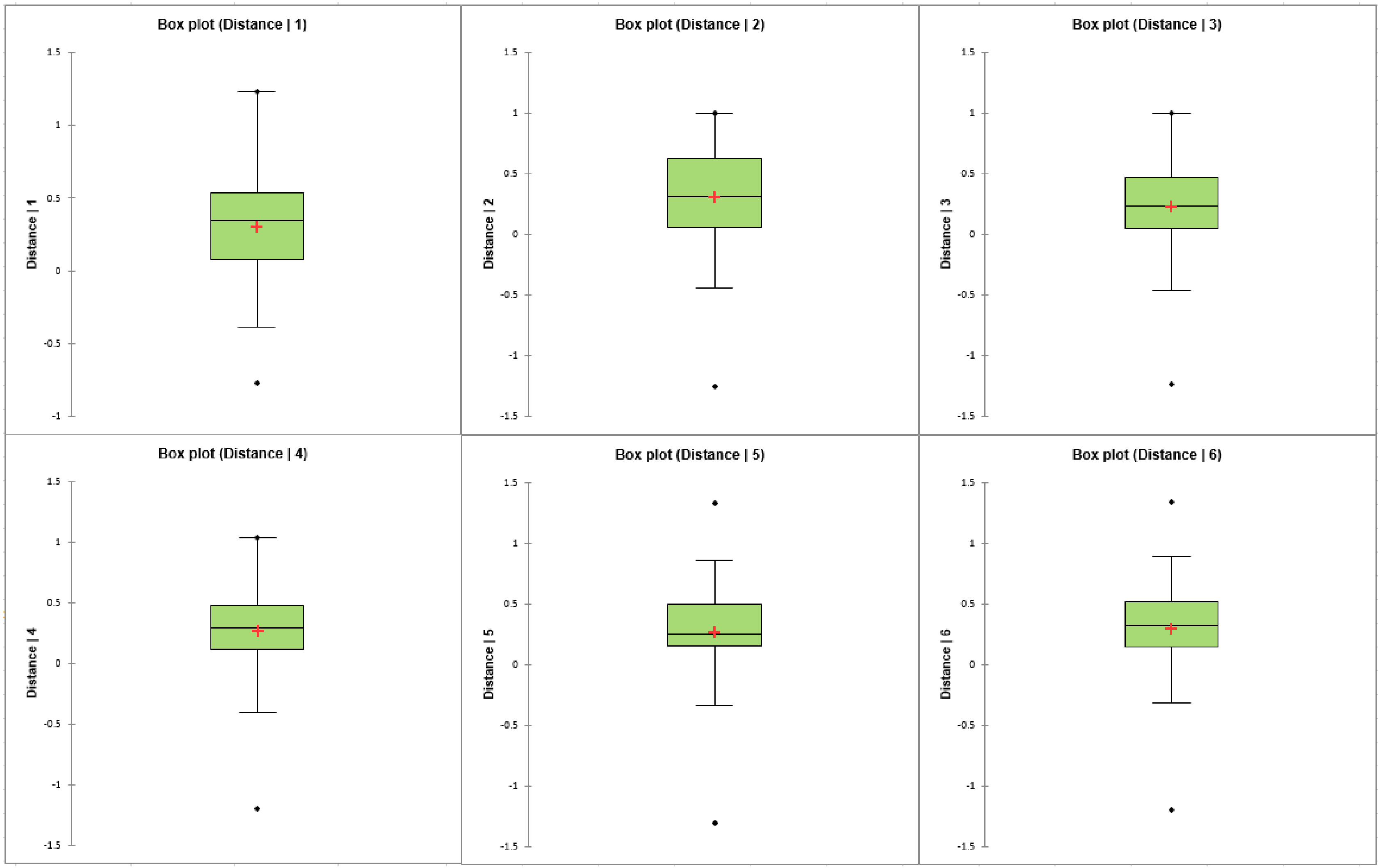

Figure 44: Box and Whisker Plots of Each Positional Point for SW 3rd St.

The histograms of each of the positional points for 3rd street vary from each other were some graphs demonstrate a normal distribution, one looks to follow a bimodal distribution, and three of the graphs are skewed to the right. The one consistent evacuation of the data gathered for this buffered bicycle facility is that there are many outlier events. In this data set the outlier will affect both the results and the normality assumption. Thus for this buffered bicycle lane facility follows the non-normality of the data.

The results of the Kolmogorov-Smirnov test for the non-truncated data as the computed p-value is lower than the significance level (alpha= 0.05), the null hypothesis that the sample follows a normal distortion should be rejected, and the alterative hypothesis that the sample does not follow the Normal distribution should be accepted. The risk to reject the null hypothesis while it is true is lower than 0.01%. The Chi-Square test for the non-truncated data as the computed p-value is lower than the significance level (alpha= 0.05), the null hypothesis that the sample follows a normal distortion should be rejected, and the alterative hypothesis that the sample does not follow the Normal distribution should be accepted. The risk to reject the null hypothesis while it is true is lower than 0.01%. Figures 45 and 46 are the histograms of the entire data set of lateral positional points for the non-truncated data set tested for normality.

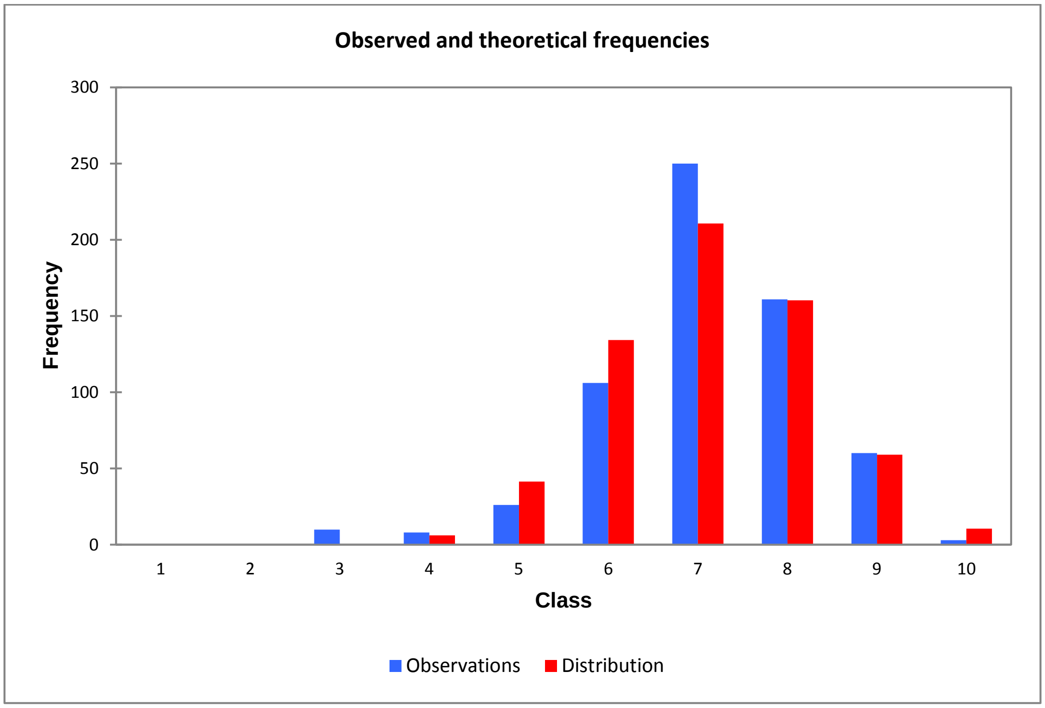

Figure 45: Observed and Theoretical Normal Frequencies for Non-Truncated Data

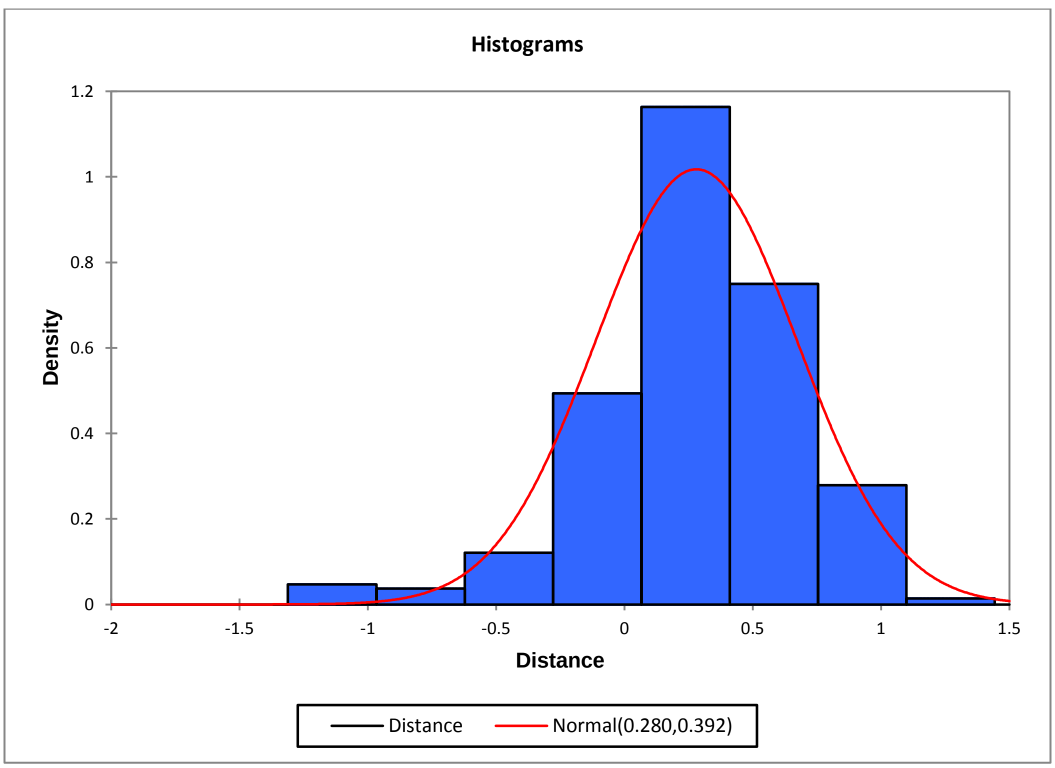

Figure 46: Histogram of Density and Normal for Non-Truncated Data

The results of the Kolmogorov-Smirnov test for the truncated data as the computed p-value is lower than the significance level (alpha= 0.05), cannot reject the null hypothesis that the sample follows a normal distortion. The risk to reject the null hypothesis while it is true is lower than 24.69%. The Chi-Square test for the non-truncated data as the computed p-value is lower than the significance level (alpha= 0.05), cannot reject the null hypothesis that the sample follows a normal distortion. The risk to reject the null hypothesis while it is true is lower than 22.05%. Figures 47 and 48 are the histograms of the entire data set of lateral positional points for the non-truncated data set tested for normality.

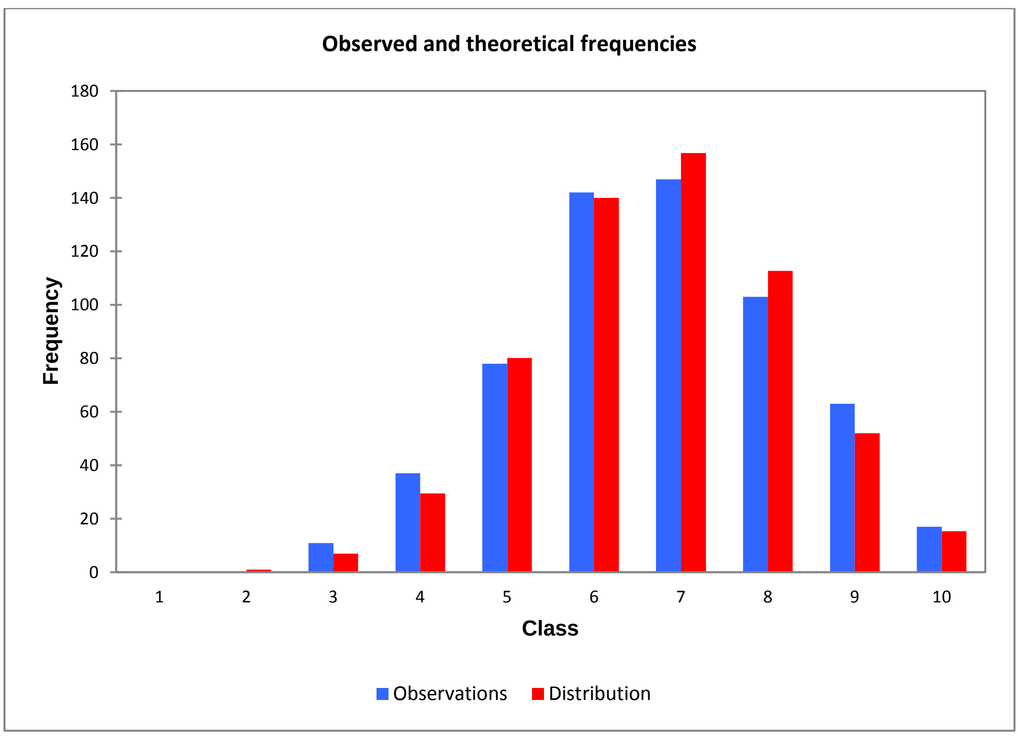

Figure 47: : Observed and Theoretical Normal Frequencies for Truncated Data

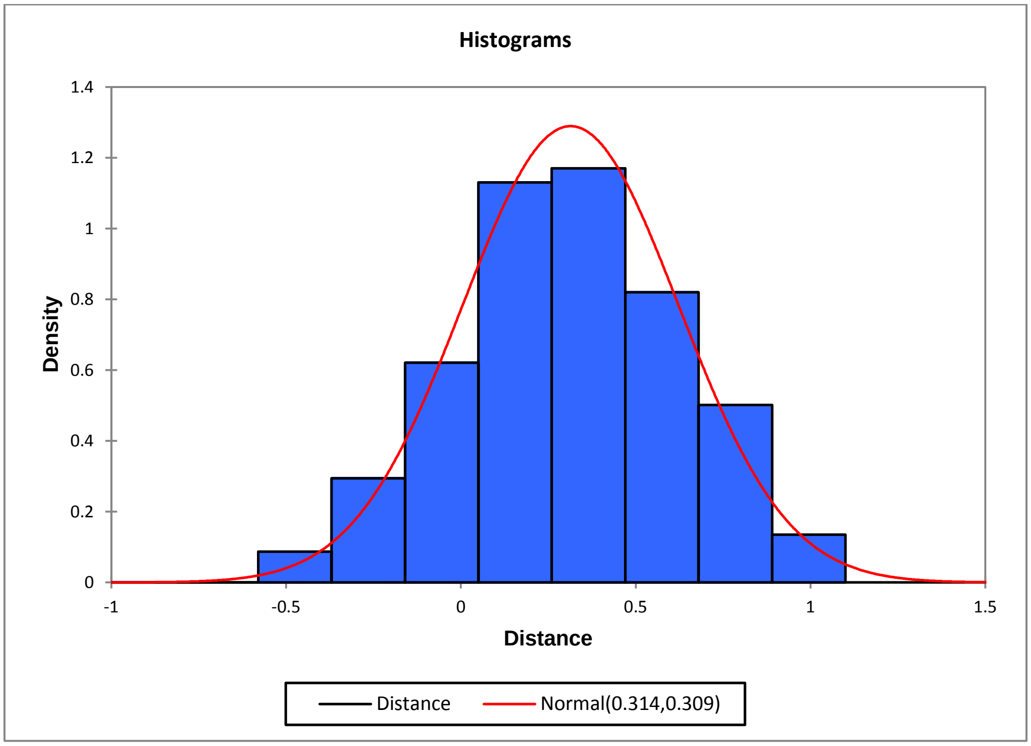

Figure 48: Histogram of Density and Normal for Truncated Data

Table 12 is the descriptive statistics for the lateral positon of a bicyclist for non-truncated data set and the truncated data set. Table 13 details the estimated parameters, Log-likelihood statistics, Pearson skewness and kurtosis, the Kolmogorov-Smirnov test, and Chi-Square test for the non-truncated and the truncated data sets.

Table 12: Descriptive Statistics Bicyclist Lateral Position Prior to Truncated Mean

	Non-Truncated Data							
				Percentiles				
Position Point	No. Of Cyclist	Mean	Std. Dev	5	10	Med	90	95
1	104	0.307	0.396	-0.30	-0.17	0.307	0.78	0.91
2	104	0.310	0.428	-0.39	-0.24	0.310	0.86	1.01
3	104	0.232	0.382	-0.40	-0.26	0.232	0.72	0.86
4	104	0.266	0.390	-0.38	-0.23	0.266	0.77	0.91
5	104	0.272	0.390	-0.37	-0.23	0.272	0.77	0.91
6	104	0.295	0.396	-0.36	-0.21	0.295	0.80	0.95

Table 13: Descriptive Statistics of Overall Distribution

	Non-Truncated Data	Truncated Data
estimated parameters		
µ	0.280	0.013
sigma	0.392	0.309
Log-likelihood statistics		
Log-likelihood (LL)	-301.080	-146.921
BIC (LL)	615.033	306.629
AIC (LL)	606.161	297.841
Pearson skewness	-0.953	-0.109
Pearson kurtosis	2.371	-0.353
Kolmogorov-Smirnov test		
D	0.096	0.042
p-Value	<0.0001	0.247
Alpha	0.05	0.05
Chi-Square test		
Chi-Square (observed)	231.919	9.472
Chi-Square (Critical)	14.067	14.067
DF	7	7
p-Value	<0.0001	0.220
Alpha	0.05	0.05

4.1.3.4 Near Miss

On North Interstate, the observed interaction between bicyclists' and motorized traffic behavior was used to evaluate if a near miss incidence occurred, the bicyclists' characteristics, and the traffic density between the presences of each bicyclist. A non-near miss incidence occurred when bicyclists crossed the conflict zone with no motorized traffic and/or when motorized traffic that yield to bicyclists (one vehicle only). A near miss incidence occurred when a bicyclist crossed the conflict zone with multiple motorized traffic that yield to cyclists and crossed in front of or behind, and/or the motorized traffic came close to bicyclists and/or crossed in front of bicyclist resulting in bicyclist to make a sudden change in direction or speed to avoid collision. Figure 49 and 50 are video stills of when a non- near miss incidence occurred and a near miss incidence occurred.

Figure 49: Video Still of no Near Miss Occurrences

Figure 50: Video Still of a Near Miss Occurrence

The bicyclists were observed from the entrance of the conflict zone and their progress through the conflict zone between positional points 1 to 2, and individually evaluated to determine if a near miss incident occurred. For this location 145 bicyclists paths were observed and evaluated. Figure 51 shows the entrance of the conflict zone and the end of conflict zone. Figure 52 is the histograms of each near miss incident occurred for each bicyclist. Figure 53 is the histograms of bicyclists' characterizes and use of safety equipment.

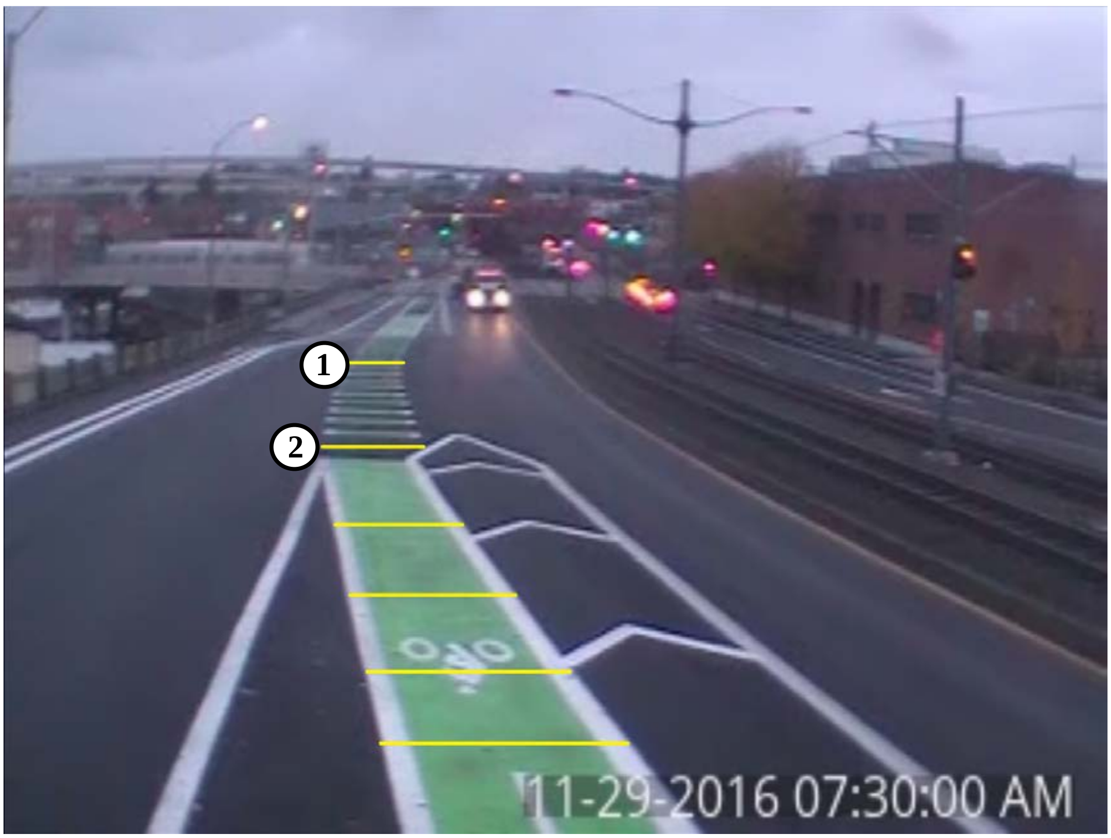

Figure 51: Entrance and End of Conflict Zone

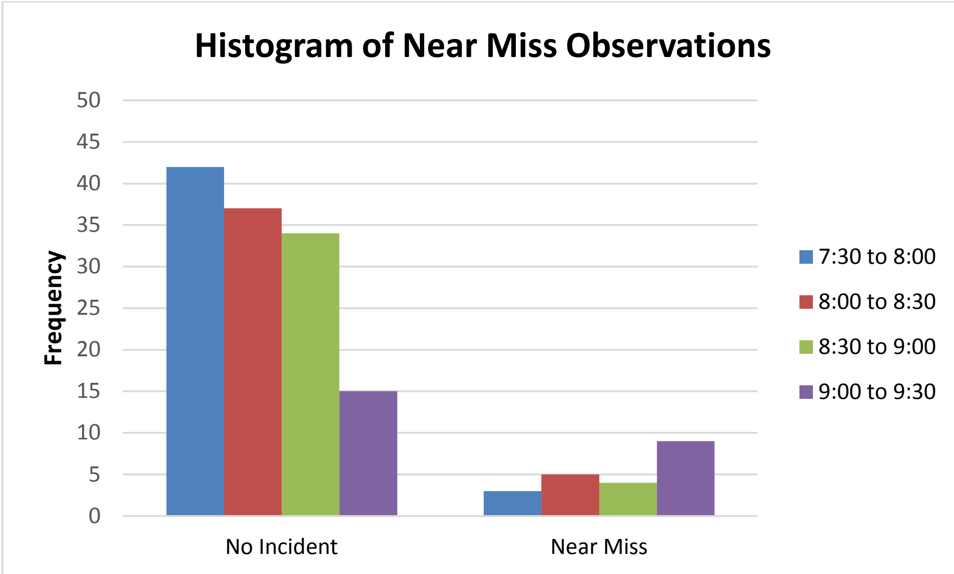

Figure 52: Histogram of Bicyclist Observations for Near Miss Incidents

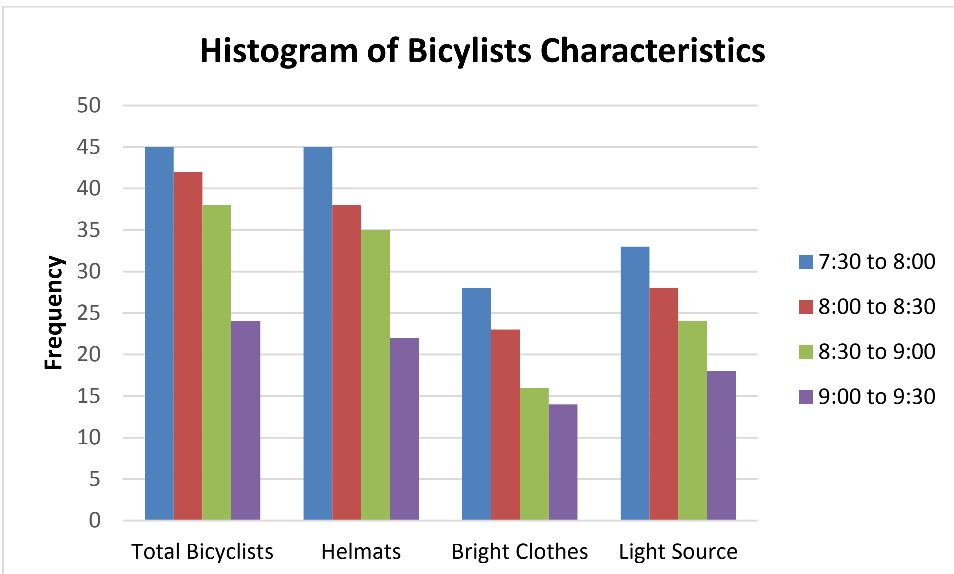

Figure 53: Histogram of Bicyclists Characteristics

From the observational variables that were collected, a correlation matrix was generated to evaluate if any of the collected variables are related. The correlation matrix is comprised of linear associations between two variables for each variable evaluated. A positive linear trend means that both variables consistently rise, and a negative linear trend indicates one variable consistently decreases as another variable rises.

The correlation coefficient, ranges from +1 to -1, indicates two aspects concerning the linear association between two variables: i) the closer the correlation coefficient is towards the absolute value of one, the stronger the linear relationship between the variables; ii) the sign of the coefficient indicates the direction of the relationship. An example is that if a value of one is generated then there is a perfect linear relationship between the two variables, were as a value of zero indicate a complete absence of a linear relationship. For correlation coefficient that have strong correlation does not imply causation only that the measured linear relationship. Table 14 are the correlation matrix for each variable. Table 15 are the descriptive statistics of the variables that are being evaluated. The descriptive statistics that were evaluated for each variable are the mean (the sum of all of the observed divided by the number of observations), the standard deviation (determine how spread out the date is from the mean), the minimum observed data value, the maximum observed data value, the number of observations (cases), and the number of missing observations.

For the variable of time, the time of observations were divided into four equal time segments of 30 minutes based on the time of observation of the bicyclist. The denotation of the period from 7:30 am to 8:00 am was 1, from 8:00 am to 8:30 am was 2, from 8:30 am to 9:00 am was 3, and from 9:00 am to 9:30 am was 4. For the variables associated with bicycle safety equipment (wearing highly visible clothing, mounted or worn light source, and the use of a helmet), they followed a binary count of yes equal to 1 and no equal to 0. For the variables of traffic density, these variables were of the count data collected during observation for delineated by the arrival of each cyclist.

Table 14: Correlation Matrix of Variables

	Time	Clothing	Light Source	Light Vehicles	Medium Vehicles	Heavy Vehicles	Vehicles Crossed
Time	1.00000	0.02294	0.39001	0.16551	-0.52588	-0.36282	0.11772
Clothing	0.02294	1.00000	0.25000	0.04275	-0.26968	0.03748	0.28506
Light Source	0.39001	0.2500	1.00000	0.3251	-0.43823	0.13117	0.18325
Light Vehicles	0.16551	0.04275	0.30251	1.00000	-0.10065	0.21713	0.79781
Medium Vehicles	-0.52588	-0.26968	-0.43823	-0.10065	1.00000	0.23235	-0.04942
Heavy Vehicles	-0.36282	0.03748	0.13117	0.21713	0.23245	1.00000	0.19230
Vehicles Crossed	0.11772	0.28506	0.18325	0.79781	-0.04942	0.19230	1.00000

Table 15: Descriptive Statics of the Variables

Variable	Mean	Std. Dev	Minimum	Maximum	Cases	Missing
Time	2.275	1.064	1.0	4.0	149	0
Clothing	0.544	0.500	0.0	1.0	149	0
Light Source	0.718	0.451	0.0	1.0	149	0
Light Vehicles	13.656	10.661	0.0	57.0	96	53
Medium Vehicles	1.175	0.583	1.0	5.0	63	86
Heavy Vehicles	1.237	0.634	1.0	4.0	38	111
Vehicles Crossed	6.610	4.826	1.0	23.0	87	62

4.2 Analysis and Statistical Methodology

To evaluate the three constructed buffered bike lanes facilities, an analysis using several different statistical methods was done to evaluate lane use by bicyclists on a buffered bicycle lane facility. The analysis compared the overall use of the buffered bicycle lane facilities. A binary logistic regression (logit) model was used to evaluate the behavior of near miss collisions between a bicyclist and motorized vehicles. The study created a database that contains observational data collected from video footage in Portland, Oregon on November 29, 2016 and evaluated the different buffered bike lane designs and bicycle and vehicle interactions on these facilities.

The analysis included two different behavioral interactions of an implemented facility user: (i) bicyclist (primary user) and (ii) the motorist (secondary user). The resulting model is for road segments only and does not apply to any intersections. For the bicyclists behavior analysis included: the use of available buffered bicycle lane width; a bicyclists' sway (or side-to-side movement) within a buffered bicycle lane; and the passing of another bicyclist. For the motorist behavior, the analysis attempts to define near miss collisions by evaluating the motorist and bicyclist behavior during a high-risk vehicle/bicyclist conflict point and the behavior of vehicles adjacent to the travel lanes under different operating conditions of traffic densities for only North Interstate Highway.

4.2.1 Data Analysis for Lateral Position

This study examines three questions using various statistical methods. To provide uniform and consistent measurements as the lateral position of the bicyclist front tire was located as to the percentage of distance within the width of the bicycle lane. This was done to be able to evaluate each buffered bicycle lane on the same measured scale within each buffered bicycle lane facility, and to compare each facility type overall to the other buffered bicycle lane facility. The three behavioral based on bicyclist usage are as follows:

1) For each buffered bicycle lane facility, does a bicyclist follow a central path?

2) Map the projected lateral positional trajectory of bicyclist within each buffered bicycle lane facility.
3) Is the lateral position of bicyclist effected by the bicycle lane facility grade?

Each of the above mentioned questions was analyzed using an analysis of variance (ANOVA) which is a statistical method that evaluates the potential differences in a scale level dependent variable by two or more variables of the same scale. For this analysis an ANOVA is used to examine the potential differences in the mean bicyclist lateral position of each positional point, and the overall variance between each buffered bicycle lane facility. The data is not intended to be unbalanced, but provide some level of hierarchy between the factors evaluated. A one-way ANOVA was used as the number of independent variables being assessed is one and not the number of categories within each variable.

For the ANOVA two hypothesis test (the null and alterative hypothesis), the null hypothesis assumes that there is no significant different between the groups and the alternative hypothesis assumes that there is significant different between the groups. Once the ANOVA has been conducted the critical p-value is compared to the F-ratio to assess rejecting or accepting the null hypothesis. Another aspect of the ANOVA is that the a post-hoc test evaluates which group of lateral positions of each positional point differs from the other groups within a buffered bicycle lane facility, and which buffered bicycle lane facility differs from the other groups. The data that is to be evaluated by an ANOVA are the non-truncated and truncated data sets for each buffered bicycle lane facility to evaluate if the truncated data set without any outliers will impact the results of the ANOVA analysis. The truncated data sets of the overall buffered bicycle lane facility evaluated against each other as these data sets have had the outliers removed and is a better representation of the population. The methods used for each question will be outlined in the following section for each buffered bicycle lane facility. The Lateral Position with the Results section of this thesis will summarize the results of questions asked above.

4.2.1.1 Interstate Highway

There is convincing evidence that for the non-truncated data for Interstate Highway that the mean of the lateral position of the bicyclist front tire at the positional point 1 is not equal to the mean of the lateral positional point at the positional points 2, 3, 4, 5 or 6 (one sample t-test, two-sided p-value= 0.0000). The ANOVA R^2 value that was generated is 0.025 and the adjusted R^2 is 0.020.

There is convincing evidence that for the truncated data for Interstate Highway that the mean of the lateral position of the bicyclist front tire at the positional point 1 is not equal to the mean of the lateral positional point at the positional points 2, 3, 4, 5 or 6 (one sample t-test, two-sided p-value < 0.0001). The ANOVA R^2 value that was generated is 0.039 and the adjusted R^2 is 0.033.

Since both the non-truncated and truncated data sets indicate that there is variance in the means for each lateral position of the bicyclist front tire for each positional point. Then both non-truncated and truncated data sets conclusive ANOVA results will be reported in the results section of this thesis.

4.2.1.2 Naito Parkway

There is convincing evidence that for the non-truncated data for Naito Parkway that the mean of the lateral position of the bicyclist front tire at the positional point 1 is equal to the mean of the lateral positional point at the positional points 2, 3, 4, 5 or 6 (one sample t-test, two-sided p-value= 0.781). The ANOVA R^2 value that was generated is 0.011 and the adjusted R^2 is -0.011. Table 18 are the ANOVA analysis results for the non-truncated data set.

There is convincing evidence that for the truncated data for Naito Parkway that the mean of the lateral position of the bicyclist front tire at the positional point 1 is equal to the mean of the lateral positional point at the positional points 2, 3, 4, 5 or 6 (one sample t-test, two-sided p-value = 0.387). The ANOVA R^2 value that was generated is 0.023 and the adjusted R^2 is 0.001.

Since both the non-truncated and truncated data sets indicate that there is no variance in the means for each lateral position of the bicyclist front tire for each positional point. Then both non-truncated and truncated data sets conclusive ANOVA results will be reported in the results section of this thesis.

4.2.1.3 3rd Street

There is convincing evidence that for the non-truncated data for 3rd Street that the mean of the lateral position of the bicyclist front tire at the positional point 1 is equal to the mean of the lateral positional point at the positional points 2, 3, 4, 5 or 6 (one sample t-test, two-sided p-value= 0.706). The ANOVA R^2 value that was generated is 0.005 and the adjusted R^2 is -0.003.

There is convincing evidence that for the truncated data for 3rd Street that the mean of the lateral position of the bicyclist front tire at the positional point 1 is equal to the mean of the lateral positional point at the positional points 2, 3, 4, 5 or 6 (one sample t-test, two-sided p-value = 0.486). The ANOVA R^2 value that was generated is 0.007 and the adjusted R^2 is -0.001.

Since both the non-truncated and truncated data sets indicate that there is no variance in the means for each lateral position of the bicyclist front tire for each positional point. Then both non-truncated and truncated data sets conclusive ANOVA results will be reported in the results section of this thesis.

4.2.1.4 Influence of Grade

For bicyclists riding on level or flat grades, they are being limited by the mechanical friction of the bicycle and air resistance. For bicyclists climbing a hill or riding on a road that has a slight grade requires additional energy to maintain momentum. To move up a hill a bicyclist must exert a force up the uphill grade that is greater than the force due to gravity and the bicyclist weight, as well as, being limited by the mechanical friction of the bicycle and air resistance. To assess the influence of grade on a bicyclist three different buffered bicycle segments were compared. The data on grades at the three segments studied indicated that 3rd is level or flat, Interstate Highway has an up grade and Naito Parkway is a down grade.

There is convincing evidence that for the truncated data to compare each buffered bicycle lane facility that the mean of the lateral position of the bicyclist front tire for 3rd is not equal to the mean of the lateral positional point of the bicyclist front tire for Interstate Highway and Naito Parkway (one sample t-test, two-sided p-value <0.001). The ANOVA R^2 value that was generated is 0.161 and the adjusted R^2 is 0.160. The truncated data sets indicate that there is variance in the means for each lateral position of the bicyclist front tire for each positional point. Then the truncated data sets conclusive ANOVA results will be reported in the results section of this thesis.

4.2.2 Modeling Method for Near Miss

This section details the different models that have been used to establish which factors influence near miss occurrences. Logit models have been used to model bicycle related crashes, and from these models' relationships from bicycle crashes to examining discrete choices have been developed to understand bicycle usage and crashes. Eluru et al. (2008) created a variation of the logit model, termed as a mixed generalized ordered response logit model (limitations of a standard ordered response logit model), to study pedestrian and bicycles injury severities in crashes. Another study done by Kim et al. (2007) used a multinomial logit model to predict the probability of different severity levels for bicycle-motor vehicle crashes in North Carolina. Another study used a mixed multinomial model to examine three different types of crashes and the factors involved in those crashes (Pai 2011).

Boufous et al. (2012) used a logit model to determine the risk factors for bicycles in Victoria, Australia and Schepers and Brinker (2011) used a logit model to determine visual risk factors perceived by bicycles through a questionnaire. Finally Parkin et al. (2007) used a logit model and a non-linear least squares model to find the perceived cycling risks and route acceptability of cyclists.

A binary logit model is used to analysis the observed near miss occurrence data. A logit model is a regression model where the binary dependent variable is categorical. For this observational study the dependent variable has only two outcome categories (no near miss occurrences or a near miss occurrence was observed). The binary logit model is used to estimate the probability that the dependent variable occurrence given the values of the independent variables, or simply that probability of an occurrence of a successful near miss response based on explanatory variables. This allows the ability to isolate different risk factors effect on the probability (both negativity and positively) of an occurrence of a successful near miss incident. Safety Performance Functions and general observed behavior were also utilized to help describe the mathematical relationships between near miss frequency and significant factors of the bicyclist.

The binary logit modes does not assume a linear relationship between the dependent variable and the independent variables, that homogeneity of variance does not need to be satisfied, and errors need to be independent but not normally distributed. This model relies on large-sample approximations therefore the maximum likelihood estimation rather than ordinary least squares to estimate the parameters. An important assumption of the binary logit model is that it that the dependent variable does not need to be normally distributed, but is assumed a distribution from an exponential family, and a linear relationship between the response and explanatory variable. The standard binomial logit formulation will be used for this project in the equation outlined below (Washington, 2011):

$$\pi_i = \Pr(Y_i = 1|X_i = x_i) = \frac{exp(\beta_0 + \beta_1 * x_i)}{1 + exp(\beta_0 + \beta_1 * x_i)}$$

Or

$$\Pr(Y_i = 1|X_i = x_i) = F(\beta_0 + \beta_1 * X)$$

$$F(\beta_0 + \beta_1 * X) = \frac{1}{1 + e^{-(\beta_0 + \beta_1 * x_i)}}$$

Where Y is a the binary response variable were Y_i=1 is where a near miss observation occurred and Y_i=0 is where a near miss observation did not occurred, β_1 are estimate parameters consistent with the outcomes of the variables. X_i are explanatory variables that can be discrete, continuous or a combination of both.

Once the function has been established then provide a probabilistic of these outcomes can be generated with the equations outlined below (PennState, 2017):

$$logit(\pi_i) = \log\left(\frac{\pi_i}{1 - \pi_i}\right)$$

$$= \beta_0 + \beta_1 * x_i + \cdots + \beta_k * x_{ik}$$

$$= \beta_0 + \beta_{Time} * x_{Time} + \beta_{Light\ Source} * x_{Light\ Source} + \beta_{Helmet} * x_{Helmet} + \beta_{Light\ Vehicels} * x_{Light\ Vehicels} + \beta_{Medium\ Vehicels} * x_{Medium\ Vehicels} + \beta_{Heavy\ Vehicels} * x_{Heavy\ Vehicels} + \beta_{Vehicels\ Crossed} * x_{Vehicels\ Crossed}$$

Where $logit(\pi_i)$ are the probabilities that a near miss indecent will occur respectively to the explanatory variables.

The problem with the binary logit is that there are not closed-form solutions. Thus the maximum likelihood estimation of the likelihood functions require numerical integration (Newton-Raphson or Iteratively re-weighted least squares). However, this model can generate logistic regression which is simpler to interpret the results, have more than two outcomes that are not ordered, and provide probabilistic of these outcomes.

5 Results

5.1 Lateral Position

To assess the lateral position and to track the possible sway of lateral position of a bicycle, the study that was by the *Design Guidance for bicycle lane widths,* utilized the front tire of each bicyclist and placed 15 inch offset, left and right, representing a typical bicyclist's physical width of 30 inches. This research study utilized observational lateral positions from these video recordings for bicyclist's sway and drift along for the study area for only an upgrade bicycle lane of a conventional bicycle lane facility. This study was utilized to assess the lateral projection and usage of the three different buffered bicycle lane facility types for each have different grades. The three different are Interstate Highway (uphill grade), Naito Parkway (down grade), and 3rd Street (level facility which shall be the control grade facility type).

The difference *Design Guidance for Bicycle Lane Width* and this research is that the observed bicyclists account for one observational path of each bicyclists to be account and recorded. Also that bicycle lane facility types being evaluated cannot be compared as one is a conventional bicycle lane and the other is a buffered bicycle lane facility.

5.1.1 Interstate Highway

The data that was collected for N Interstate Ave is skewed and the statistical analysis has confirmed that within the dataset there are extreme outlier events that show the variability of bicyclists use within this facility. An analysis of the raw observational data collected showed that this data set is influenced by extreme events. This demonstrates that bicyclists for this facility type are over utilizing the buffered bicycle lane width. Analysis of the observational data for these events shows that the outliers are a result of one bicyclist passing of another bicyclist, or for a bicyclist to physically provide a greater buffer from motorized traffic and bicyclist sway due to a change in grade.

Table 16 is a summary of the ANOVA analysis results for the non-truncated data set and compared to the lateral positional point 1. The mean of the lateral position of the bicyclist front tire at the positional point 2 is estimated to be 12.3 percent (8.9 inches) farther to the bicyclists' left than the lateral position of the bicyclist front tire at the positional point 1. With 95% confidence, the mean of the lateral position of the bicyclist front tire at the positional point 2 is estimated to be 6.8 to 17.8 percent (4.8 to 12.8 inches) farther to the bicyclists' left than the lateral position of the bicyclist front tire at the positional point 1.

The mean of the lateral position of the bicyclist front tire at the positional point 4 is estimated to be 9.4 percent (6.7 inches) farther to the bicyclists' left than the lateral position of the bicyclist front tire at the positional point 1. With 95% confidence the mean of the lateral position of the bicyclist front tire at the positional point 4 is estimated to be 3.9 to 14.9 percent (2.8 to 16.1 inches) farther to the bicyclists' left than the lateral position of the bicyclist front tire at the positional point 1.

The mean of the lateral position of the bicyclist front tire at the positional point 5 is estimated to be 7.9 percent (5.7 inches) farther to the bicyclists' left than the lateral position of the bicyclist front tire at the positional point 1. With 95% confidence the mean of the lateral position of the bicyclist front tire at the positional point 5 is estimated to be 2.5 to 13.4 percent (1.8 to 6.4 inches) farther to the bicyclists' left than the lateral position of the bicyclist front tire at the positional point 1.

The mean of the lateral position of the bicyclist front tire at the positional point 6 is estimated to be 9.1 percent (6.5 inches) farther to the bicyclists' left than the lateral position of the bicyclist front tire at the positional point 1. With 95% confidence the mean of the lateral position of the bicyclist front tire at the positional point 6 is estimated to be 3.6 to 14.6 percent (2.6 to 10.5 inches) farther to the bicyclists' left than the lateral position of the bicyclist front tire at the positional point 1.

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Table 16: ANOVA Analysis Results for Non-Truncated Data

Source	Value	Std. Error	t-static	Pr > |t|	Lower Bound (95%)	Upper Bound (95%)
Intercept	0.445	0.020	22.515	<0.0001	0.407	0.484
Position 1	0.000	0.000				
Position 2	0.123	0.028	4.398	<0.0001	0.068	0.178
Position 3	0.058	0.028	2.090	0.037	0.004	0.113
Position 4	0.094	0.028	3.367	0.001	0.039	0.149
Position 5	0.079	0.028	2.841	0.005	0.025	0.134
Position 6	0.091	0.028	3.261	0.001	0.036	0.146

Figure 54 is the ANOVA variance of the means for the non-truncated data set distance as described above for the lateral position of the bicyclist front tire at the positional points. Figure 56 the projected lateral distance for bicyclist for Interstate Highway representing a typical bicyclist's physical width. For this graph the scaled used for the variance between the means is from 40% to 58% of the overall lane width.

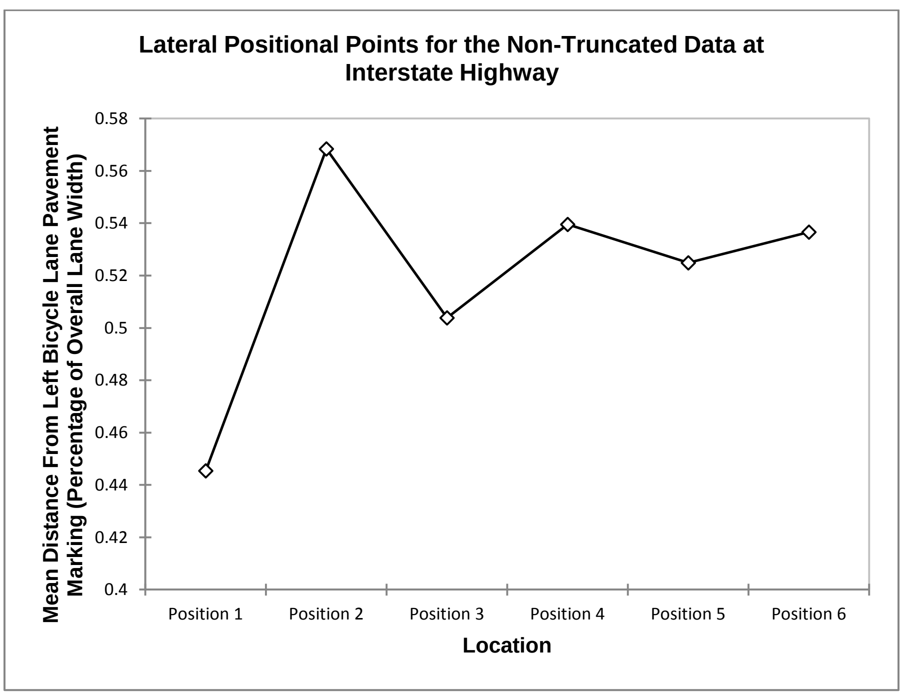

Figure 54:Non-Truncated ANOVA Means Distance for Each Positional Point

Table 17 is a summary of the ANOVA analysis results for the truncated data set and compared to the lateral positional point 1. The mean of the lateral position of the bicyclist front tire at the positional point 2 is estimated to be 11.4 percent (8.2 inches) farther to the bicyclists' left than the lateral position of the bicyclist front tire at the positional point 1. With 95% confidence the mean of the lateral position of the bicyclist front tire at the positional point 2 is estimated to be 6.9 to 16.0 percent (5.0 to 11.5 inches) farther to the bicyclists' left than the lateral position of the bicyclist front tire at the positional point 1.

The mean of the lateral position of the bicyclist front tire at the positional point 3 is estimated to be 5.6 percent (4.0 inches) farther to the bicyclists' left than the lateral position of the bicyclist front tire at the positional point 1. With 95% confidence the mean of the lateral position of the bicyclist front tire at the positional point 3 is estimated to be 1.1 to 10.1 percent (0.8 to 7.3 inches) farther to the bicyclists' left than the lateral position of the bicyclist front tire at the positional point 1.

The mean of the lateral position of the bicyclist front tire at the positional point 4 is estimated to be 10.5 percent (7.6 inches) farther to the bicyclists' left than the lateral position of the bicyclist front tire at the positional point 1. With 95% confidence the mean of the lateral position of the bicyclist front tire at the positional point 4 is estimated to be 6.0 to 15.1 percent (4.3 to 10.9 inches) farther to the bicyclists' left than the lateral position of the bicyclist front tire at the positional point 1.

The mean of the lateral position of the bicyclist front tire at the positional point 5 is estimated to be 8.3 percent (6.0 inches) farther to the bicyclists' left than the lateral position of the bicyclist front tire at the positional point 1. With 95% confidence the mean of the lateral position of the bicyclist front tire at the positional point 5 is estimated to be 3.7 to 12.8 percent (2.7 to 9.2 inches) farther to the bicyclists' left than the lateral position of the bicyclist front tire at the positional point 1.

The mean of the lateral position of the bicyclist front tire at the positional point 6 is estimated to be 9.5 percent (6.8 inches) farther to the bicyclists' left than the lateral position of the bicyclist front tire at the positional point 1. With 95% confidence the mean of the lateral position of the bicyclist front tire at the positional point 6 is estimated to be 4.9 to 14.0 percent (3.5 to 10.0 inches) farther to the bicyclists' left than the lateral position of the bicyclist front tire at the positional point 1.

Table 17: ANOVA Analysis Results for Truncated Data

Source	Value	Std. Error	t-static	Pr > |t|	Lower Bound (95%)	Upper Bound (95%)
Intercept	0.433	0.016	26.376	<0.0001	0.401	0.465
Position 1	0.000	0.000				
Position 2	0.114	0.023	4.973	<0.0001	0.069	0.160
Position 3	0.056	0.023	2.419	0.016	0.011	0.101
Position 4	0.105	0.023	4.581	<0.0001	0.060	0.151
Position 5	0.083	0.023	3.581	0.000	0.037	0.128
Position 6	0.095	0.023	4.100	<0.0001	0.049	0.140

Figure 55 is the ANOVA variance of the means for the truncated data set distance as described above for the lateral position of the bicyclist front tire at the positional points. Figure 57 the projected lateral distance for bicyclist for Interstate Highway representing a typical bicyclist's physical width. For this graph the scaled used for the variance between the means is from 40% to 58% of the overall lane width.

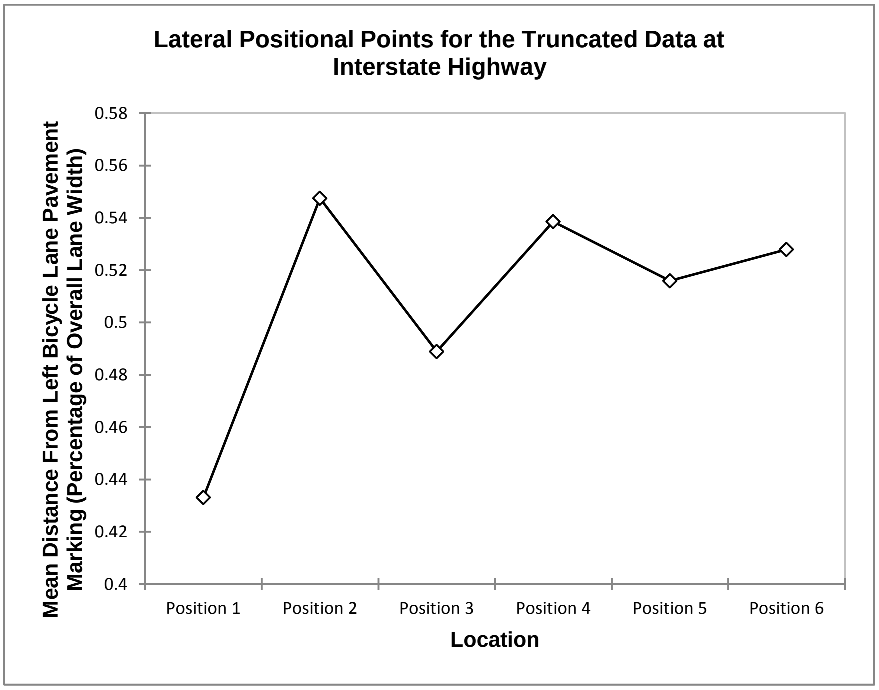

Figure 55: Truncated ANOVA Means Distance for Each Positional Point

From the *Design Guidance for Bicycle Lane Width* and the results of the ANOVA analysis for each positional point a projected use of Interstate Highway buffered bicycle lane can be constructed. Figure 56 and 57 is the projected bicycle path for significant positional point use of Interstate Highway buffered bicycle lane for the non-truncated and truncated data set. For this buffered bicycle lane type the grade was uphill. The Observational data of this facility showed that cyclists were swaying as can be observed from variance in the means. This may be due to one bicyclist passing of another bicyclist, for a bicyclist to physically provide a greater buffer from motorized traffic, and bicyclist sway due to the uphill grade as observed in this study.

As discussed in the *Design Guidance for Bicycle Lane Width* riders that face an uphill included slope will demonstrate in weaving patter to ease the climb. The patter was observed in the video footage and in the recorded observation of the lateral position of the cyclist for Interstate Highway. The key for bicyclist when climbing a hill is to utilized their available power to maintain their speed. This can be done utilizing two different methods remaining seated (in the saddle), or to stand up (out of the saddle).

The first method is to remained seated, in the saddle, is a method that is implied when bicyclist face long gradual climbs. This method is more efficient and effective for a bicyclist as they are able adjust the pedal stroke and utilize other muscles within the leg and core (Tejvan, 2015). When a bicyclist is in the saddle they are able utilize these other muscles within the leg and core bicyclist will shift within the saddle from side to side to fully engage muscles. The result is that bicyclist will have a gradual or minimal sway or weave within their climb.

The second method is to stand up, out of the saddle or standing on the pedals, is a method that is implied when the grade of the slope becomes very steep. This method reduces the aerodynamics resulting in greater exertion and tiring a bicyclist rapidly (Tejvan, 2015).
When a bicyclist is out of the saddle they are able utilize other muscles and upper body strength as they pull up against the handlebars. As their center of gravity is farther from the roads surface and harder to control overall stability resulting in a greater swaying or weaving movement.

Both of these climbing methods were observed in the video footage and can account for the variance between the means at each lateral positional point. However in the recorded observation the method the bicyclist utilized while climbing was not recorded.

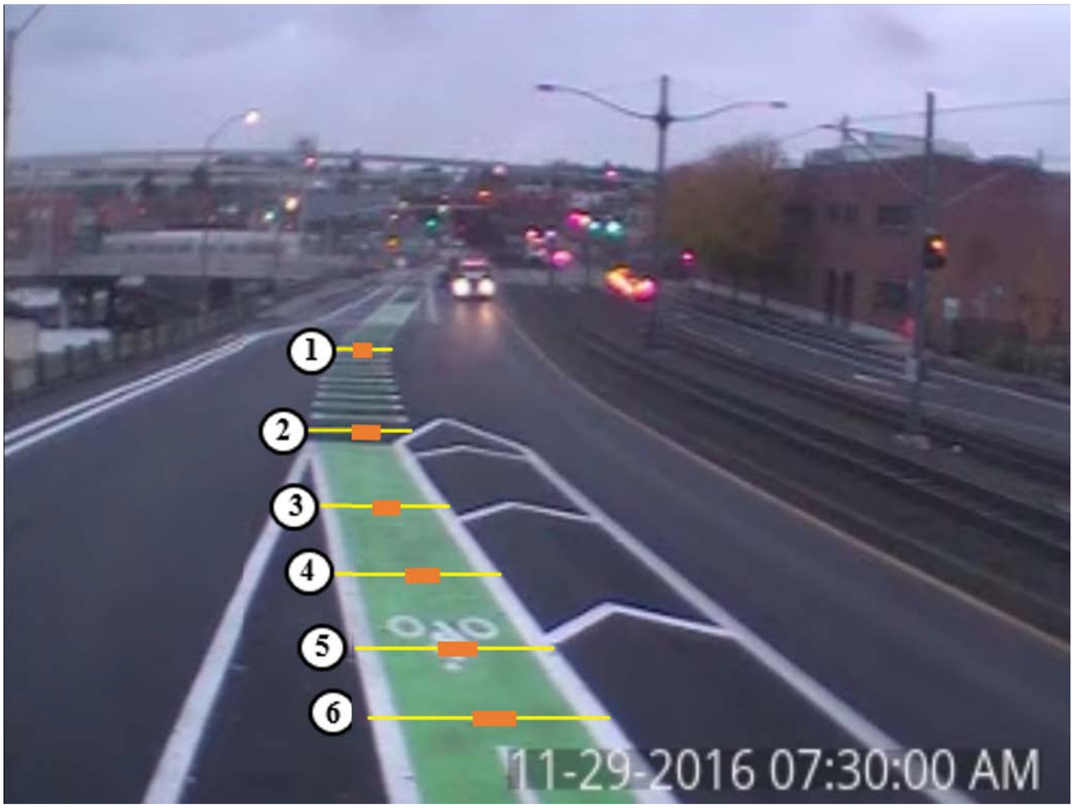

Figure 56: Projected Lateral Path for Non-Truncated Data

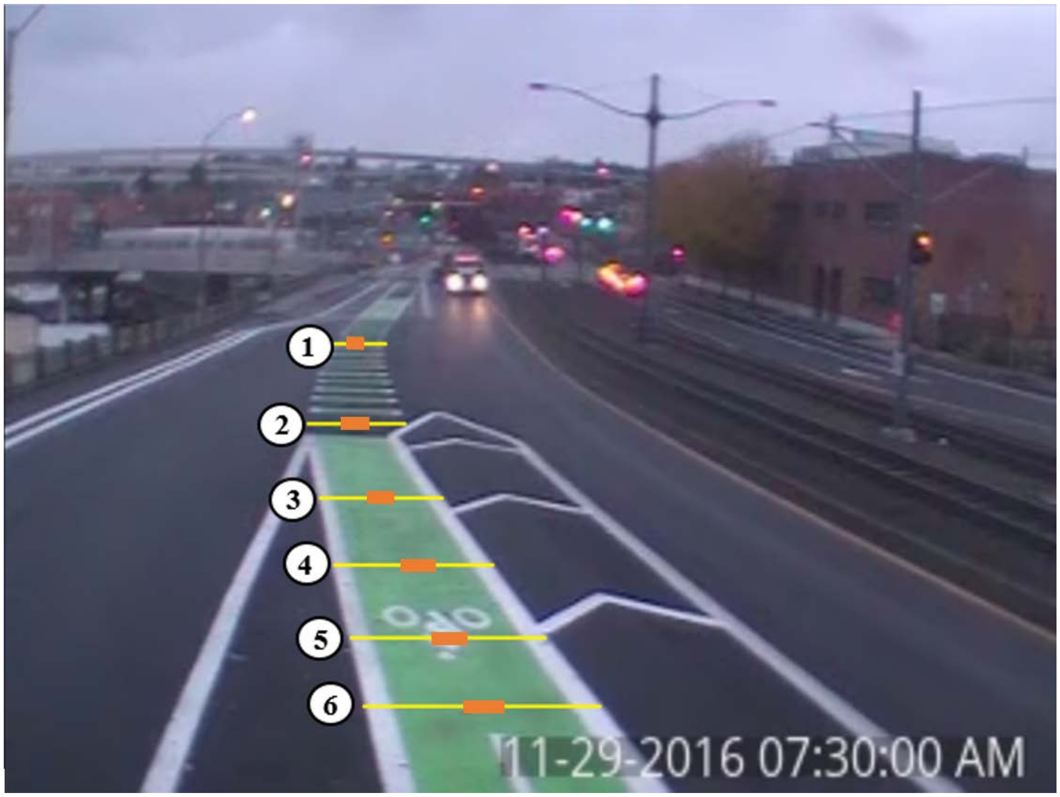

Figure 57: Projected Lateral Path for Truncated Data

5.1.2 Naito Parkway

The data that was collected for Naito Parkway is skewed and the statistical analysis has confirmed that within the dataset there are few extreme outliers and this demonstrates that the bicyclist use of the facility for this location is fairly representative of the population. The observational data collected showed the influence of the outliers. Analysis of the observational data for these events shows that the outliers are a result of different bicyclist utilized behavior for a downhill facility.

Table 18 is a summary of the ANOVA analysis results for the non-truncated data set and compared to the lateral positional point 1. The mean of the lateral position of the bicyclist front tire at the positional point 1 to the lateral position of the bicyclist front tire at the positional point 2, 3, 4, 5 and 6 there was on variance of the means. With

95% confidence, the mean of the lateral position of the bicyclist front tire for the positional points are projected to be within or around the mean of optional point 1.

Table 18: ANOVA Analysis Results for Non-Truncated Data

Source	Value	Std. Error	t-static	Pr > |t|	Lower Bound (95%)	Upper Bound (95%)
Intercept	0.561	0.025	22.515	<0.0001	0.513	0.610
Position 1	0.000	0.000				
Position 2	0.011	0.035	0.312	0.756	-0.058	0.079
Position 3	0.013	0.035	0.371	0.711	-0.056	0.082
Position 4	0.019	0.035	0.534	0.594	-0.050	0.087
Position 5	0.010	0.035	0.277	0.782	-0.059	0.078
Position 6	-0.029	0.035	-0.841	0.401	-0.098	0.039

Figure 58 is the ANOVA variance of the means for the non-truncated data set distance as described above for the lateral position of the bicyclist front tire at the positional points. Figure 60 the projected lateral distance for bicyclist for Naito Parkway representing a typical bicyclist's physical width. For this graph the scaled used for the variance between the means is from 52% to 60% of the overall lane width.

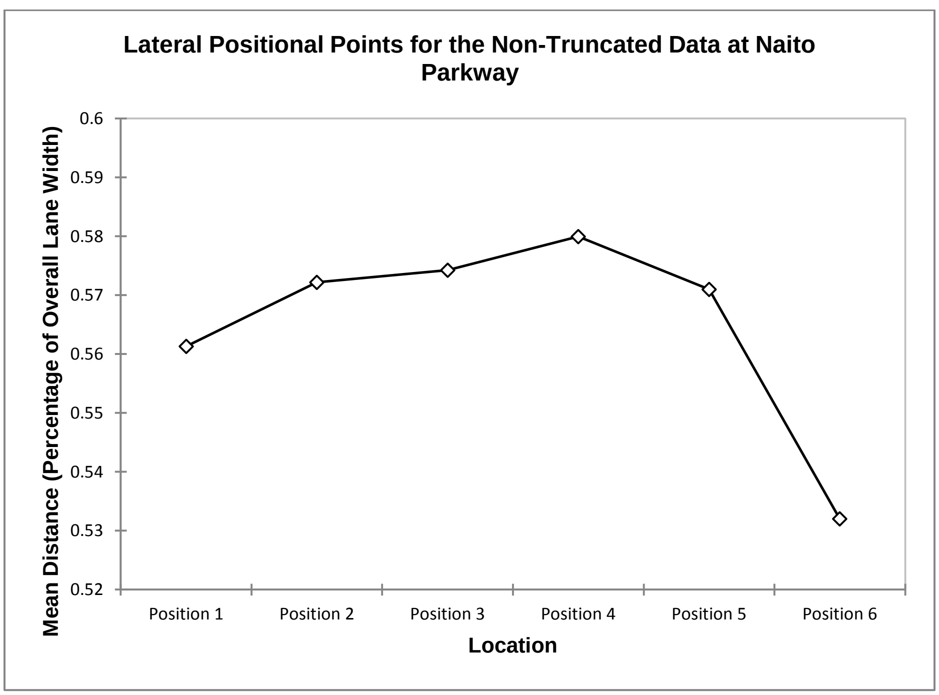

Figure 58: Non-Truncated ANOVA Means Distance for Each Positional Point

Table 19 is a summary of the ANOVA analysis results for the truncated data set and compared to the lateral positional point 1. The mean of the lateral position of the bicyclist front tire at the positional point 1 to the lateral position of the bicyclist front tire at the positional point 2, 3, 4, 5 and 6 there was on variance of the means. With 95% confidence, the mean of the lateral position of the bicyclist front tire for the positional points are projected to be within or around the mean of optional point 1.

Table 19: ANOVA Analysis Results for Truncated Data

Source	Value	Std. Error	t-static	Pr > |t|	Lower Bound (95%)	Upper Bound (95%)
Intercept	0.576	0.020	26.376	<0.0001	0.536	0.616
Position 1	0.000	0.000				
Position 2	0.011	0.029	0.385	0.700	-0.045	0.068
Position 3	0.0113	0.029	0.466	0.642	-0.043	0.070
Position 4	0.019	0.029	0.667	0.506	-0.037	0.076
Position 5	0.010	0.029	0.342	0.732	-0.047	0.066
Position 6	-0.039	0.029	-1.336	0.183	-0.095	0.018

Figure 59 is the ANOVA variance of the means for the truncated data set distance as described above for the lateral position of the bicyclist front tire at the positional points. Figure 61 the projected lateral distance for bicyclist for Naito Parkway representing a typical bicyclist's physical width. For the graph the scaled used for the variance between the means is from 52% to 60% of the overall lane width.

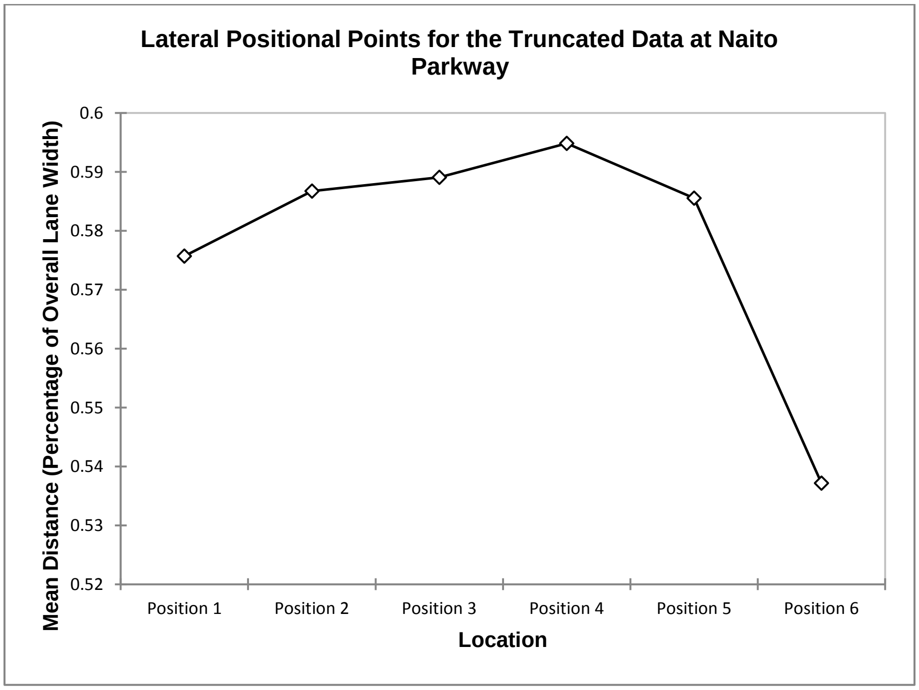

Figure 59: Truncated ANOVA Means Distance for Each Positional Point

From the *Design Guidance for Bicycle Lane Width* and the results of the ANOVA analysis for each positional point a projected use of Naito Parkway buffered bicycle lane can be constructed. Figure 60 and 61 is the projected bicycle path for significant positional point use of Naito Parkway buffered bicycle lane for the non-truncated and truncated data set. For this buffered bicycle lane type the grade was downhill. It can be concluded that due to the downhill grade and adjacent traffic location bicyclist lateral positon was observed to be located closer to the right bicycle lane marking due to the anticipated approach of a curve located at the bottom of the grade, and emergency escape due to the lateral force exerted on the bicyclist in the event of a fall or unanticipated collision. That for bicyclist that utilize this facility are more like to be riders that follow the definition of Momentumists bicyclists.

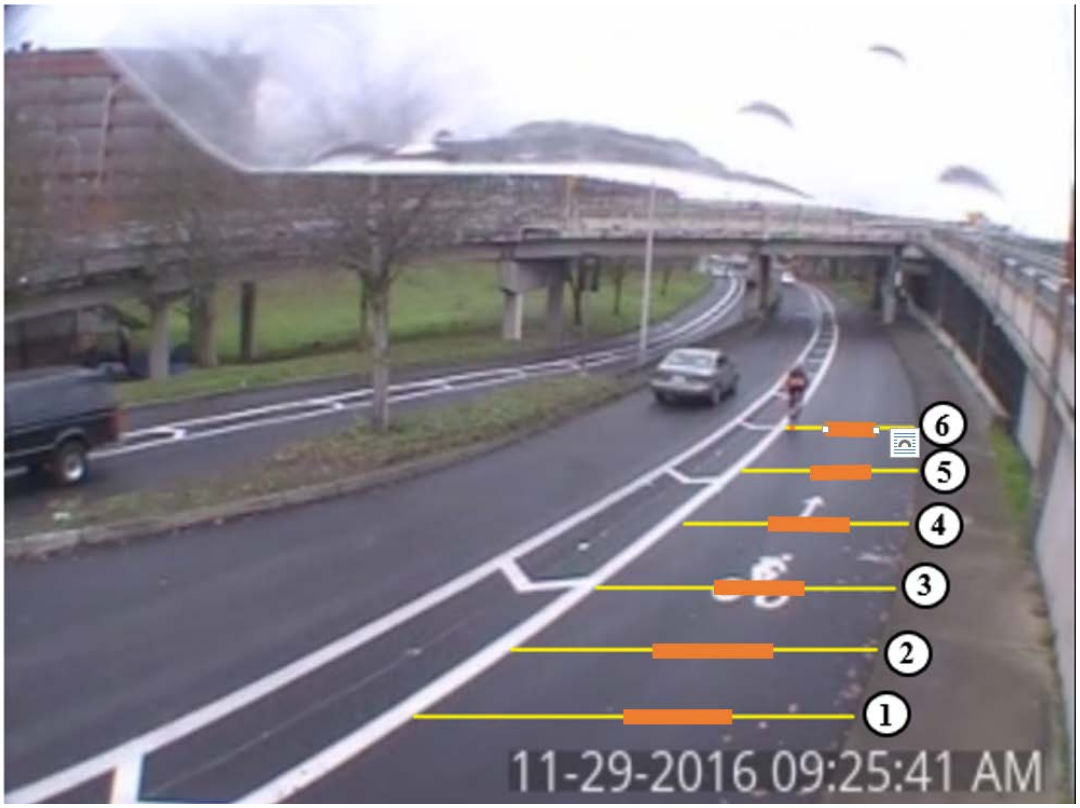

Figure 60: Projected Lateral Path for Non-Truncated Data

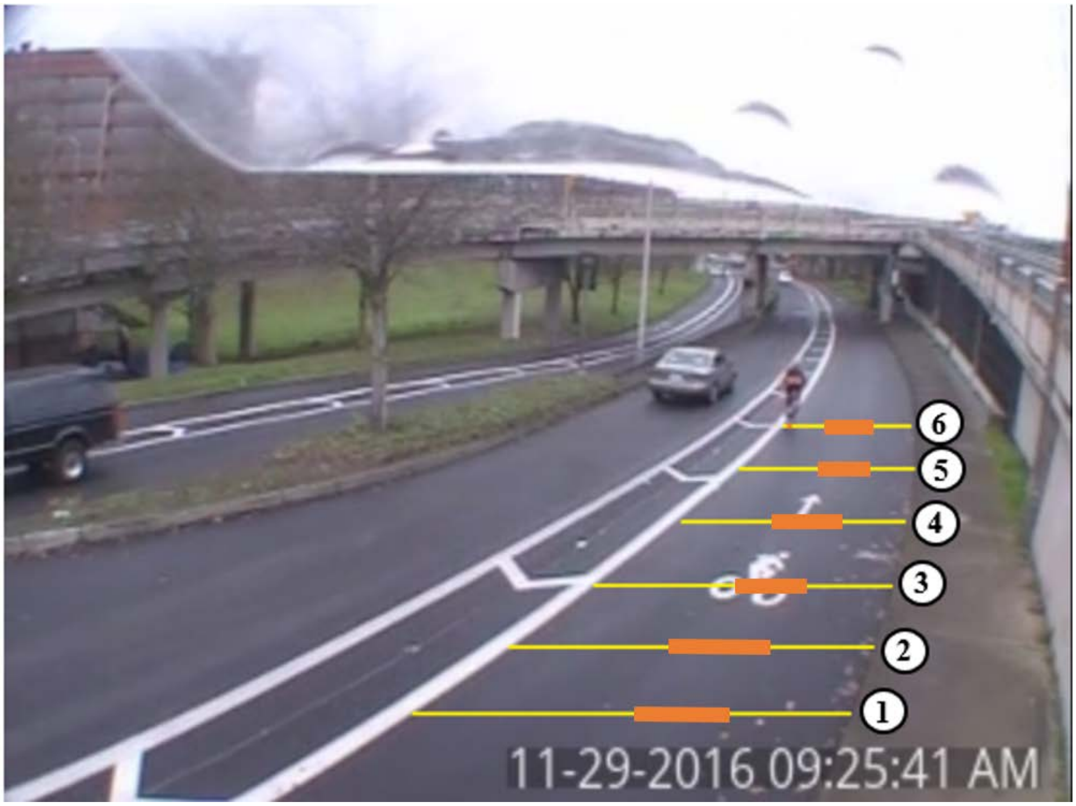

Figure 61: Projected Lateral Path for Truncated Data

5.1.3 3rd Street

The data that was collected for 3rd Street is skewed and the statistical analysis has confirmed that within the dataset there are extreme outlier events that show the variability of bicyclists use within this facility. An analysis of the raw observational data collected showed that this data set is influenced by extreme events. This demonstrates that bicyclists for this facility type are over utilizing the buffered bicycle lane width. Analysis of the observational data for these events shows that the outliers are a result of a bicyclist to physically provide a greater buffer from motorized traffic.

Table 20 is a summary of the ANOVA analysis results for the non-truncated data set and compared to the lateral positional point 1. The mean of the lateral position of the bicyclist front tire at the positional point 1 to the lateral position of the bicyclist front tire at the positional point 2, 3, 4, 5 and 6 there was on variance of the means. With

95% confidence, the mean of the lateral position of the bicyclist front tire for the positional points are projected to be within or around the mean of optional point 1. Table 20 is a summary of the ANOVA analysis results for the non-truncated data set.

Table 20: ANOVA Analysis Results for Non-Truncated Data

Source	Value	Std. Error	t-static	Pr > |t|	Lower Bound (95%)	Upper Bound (95%)
Intercept	0.307	0.039	7.966	<0.0001	0.231	0.383
Position 1	0.000	0.000				
Position 2	0.003	0.054	0.058	0.954	-0.104	0.110
Position 3	-0.075	0.054	-1.371	0.171	-0.182	0.032
Position 4	-0.041	0.054	-0.757	0.449	-0.148	0.066
Position 5	-0.035	0.054	-0.642	0.521	-0.142	0.072
Position 6	-0.012	0.054	-0.226	0.821	-0.119	0.095

Figure 62 is the ANOVA variance of the means for the non-truncated data set distance as described above for the lateral position of the bicyclist front tire at the positional points. Figure 62 the projected lateral distance for bicyclist for 3rd Street representing a typical bicyclist's physical width. For this graph the scaled used for the variance between the means is from 20% to 36% of the overall lane width.

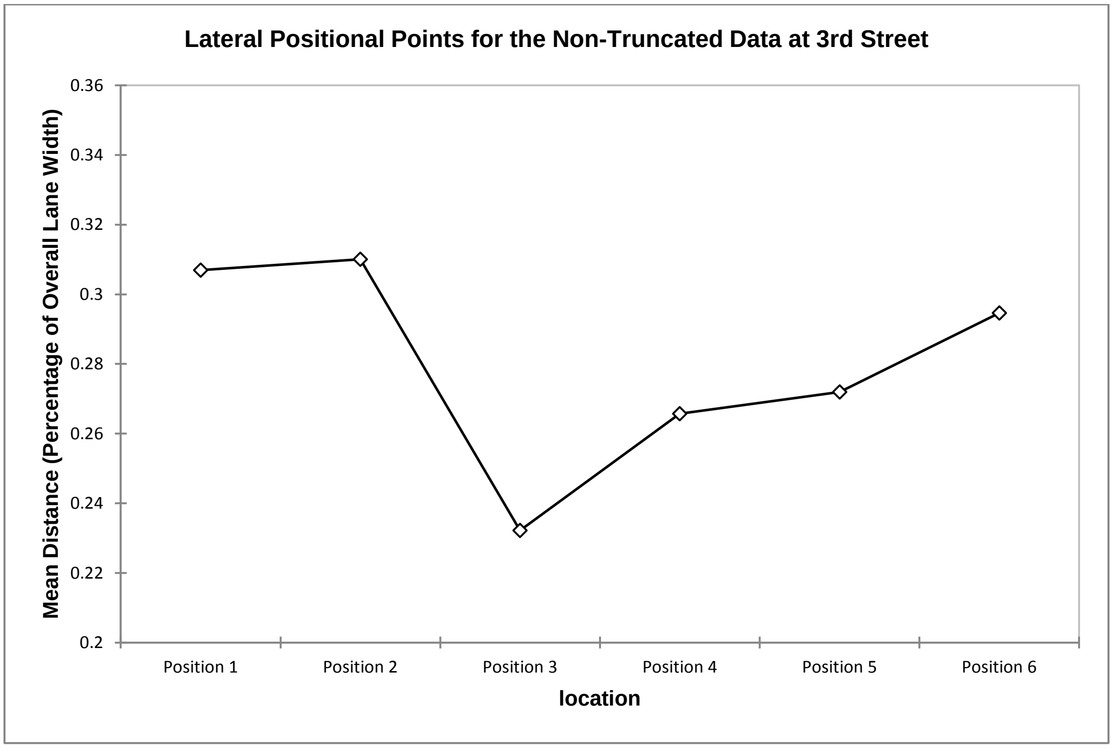

Figure 62: Non-Truncated ANOVA Means Distance for Each Positional Point

Table 21 is a summary of the ANOVA analysis results for the truncated data set and compared to the lateral positional point 1. The truncated data set was analyzed by the mean of the lateral position of the bicyclist front tire at the positional point 1 to the lateral position of the bicyclist front tire at the positional point 2, 3, 4, 5 and 6 there was on variance of the means. With 95% confidence, the mean of the lateral position of the bicyclist front tire for the positional points are projected to be within or around the mean of optional point 1.

Table 21: ANOVA Analysis Results for Truncated Data

Source	Value	Std. Error	t-static	Pr > |t|	Lower Bound (95%)	Upper Bound (95%)
Intercept	0.312	0.031	10.057	<0.0001	0.251	0.372
Position 1	0.000	0.000				
Position 2	0.039	0.044	0.886	0.376	-0.047	0.125
Position 3	-0.047	0.044	-1.068	0.286	-0.133	0.039
Position 4	-0.004	0.044	-0.086	0.932	-0.090	0.082
Position 5	0.000	0.044	0.009	0.992	-0.086	0.087
Position 6	0.025	0.044	0.558	0.577	-0.062	0.111

Figure 63 is the ANOVA variance of the means for the non-truncated data set distance as described above for the lateral position of the bicyclist front tire at the positional points. Figure 65 the projected lateral distance for bicyclist for 3rd Street representing a typical bicyclist's physical width. For this graph the scaled used for the variance between the means is from 20% to 36% of the overall lane width.

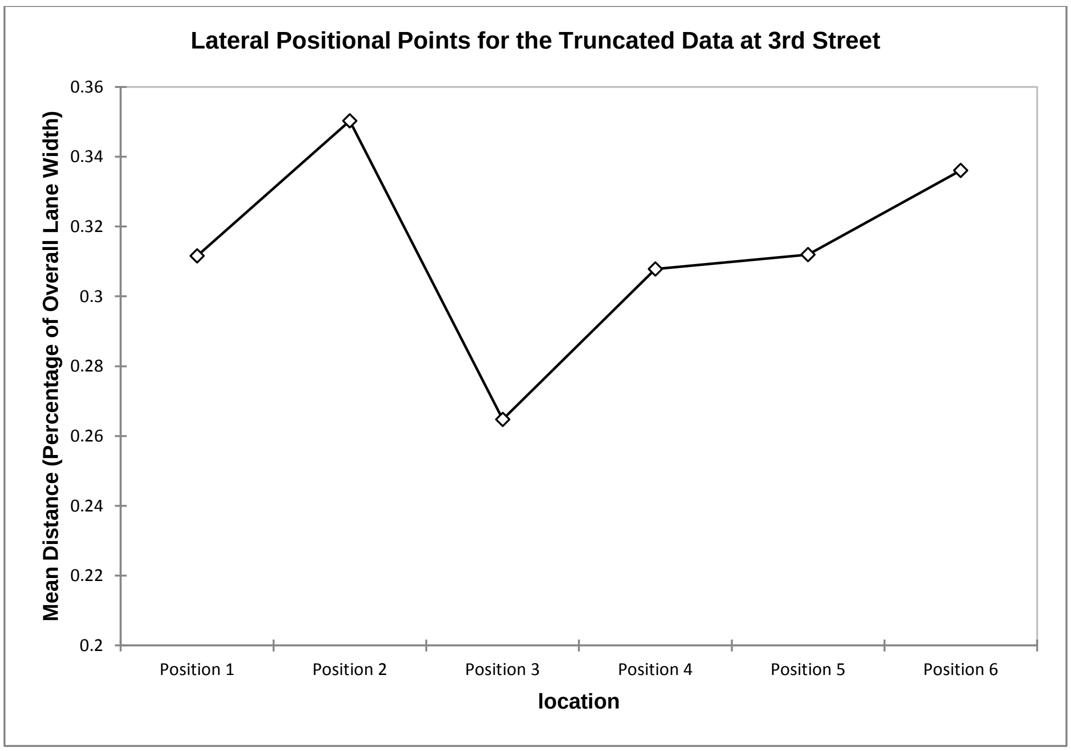

Figure 63: Truncated ANOVA Means Distance for Each Positional Point

From the *Design Guidance for Bicycle Lane Width* and the results of the ANOVA analysis for each positional point a projected use of 3rd Street buffered bicycle lane can be constructed. Figure 64 and 65 is the projected bicycle path for significant positional point use of 3rd Street buffered bicycle lane for the non-truncated and truncated data set. For this buffered bicycle lane type the grade was relatively level. While a buffer space between the bicyclist and adjacent motorized traffic is available, bicyclist were observed to farther distance themselves. This observation demonstrates that bicyclist that utilize this facility are more like to be riders that follow the definition of Momentumists bicyclists.

Bicyclist were observed lateral positon was observed to be located closer to the bicyclists' right bicycle lane marking and outside of the provided bicycle lane due to the anticipated adjacent traffic location. As discussed in section 3.1, people prefer fully separated bicycle lanes that isolate bicyclists from the motorized traffic with a physical vertical buffer. Bicyclist perception in protected bicycle lane facilities of both a physical safety and perceived safety is positively impact comfort. It can be concluded that due to 3rd Streets buffered bicycle lane facility does not provide the physical vertical barrier bicyclist will laterally providing a greater horizontal barrier.

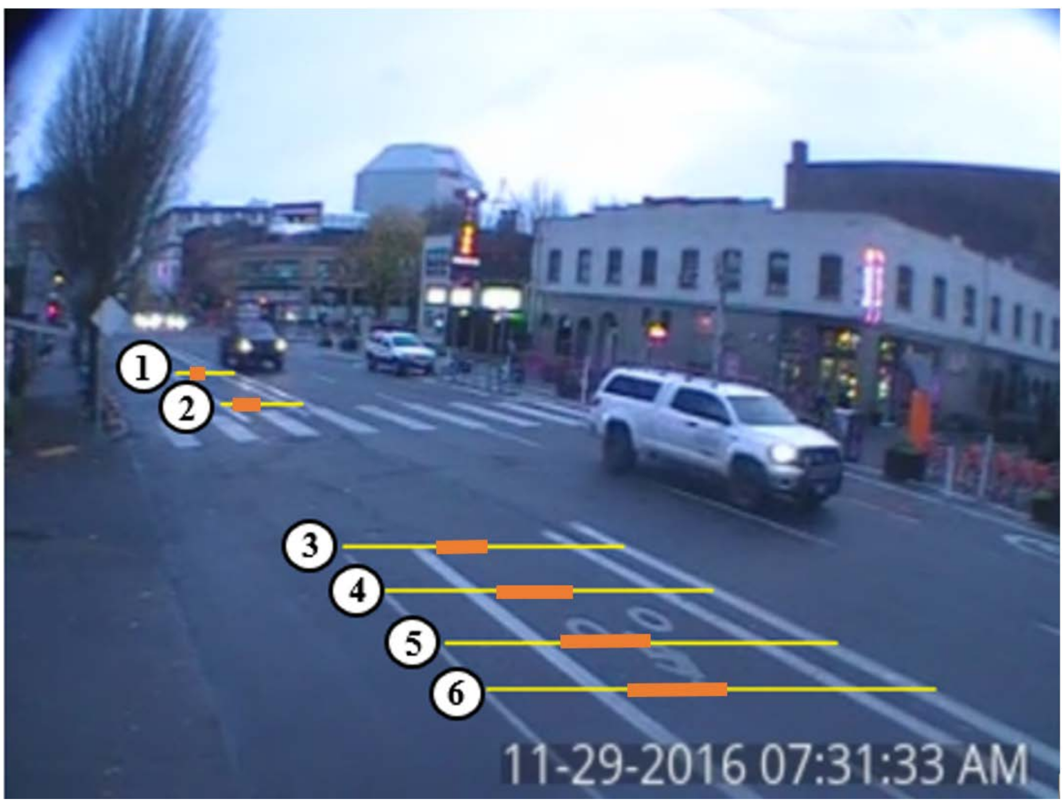

Figure 64: Projected Lateral Path for Non-Truncated Data

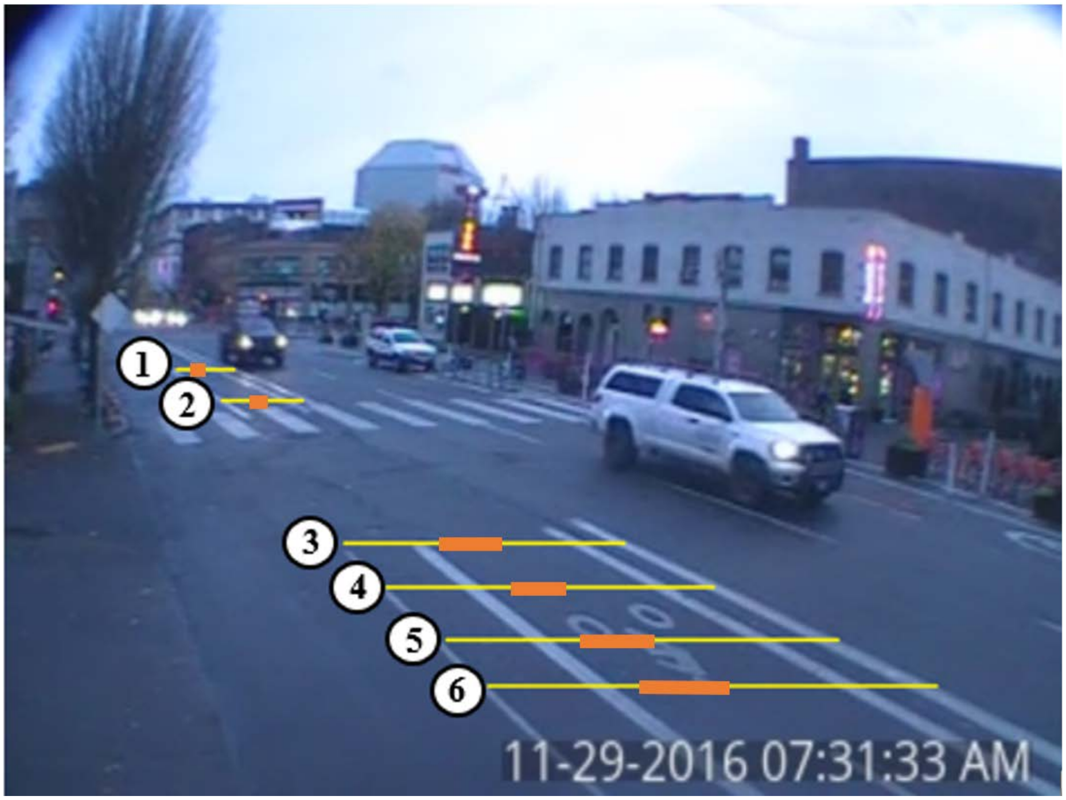

Figure 65: Projected Lateral Path for Truncated Data

5.1.4 Grade Impact to Rider Sway

The observational data collected for all three buffered bicycle lane facilities showed is prevalent to the influence of outliers. Analysis of the observational data for these different facility types is compared by the truncated data from 3rd Street, Interstate Highway, and Naito Parkway.

The mean of the lateral position of the bicyclist front tire for the buffered bicycle facility for Interstate Highway is estimated to be 19.5 percent (23.5 inches) farther to the bicyclists' left than the lateral position of the bicyclist front tire for the buffered bicycle facility for 3rd Street. With 95%, confidence the mean of the lateral position of the bicyclist front tire for the buffered bicycle facility for Interstate Highway is estimated to be 17.0 to 22.0 percent (20.5 to 26.5 inches) farther to the bicyclists' left than the lateral position of the bicyclist front tire for the buffered bicycle facility for

3rd Street. As discussed in Section 5.1.1 of this thesis provides a greater in-depth analysis of rider path and user behavior within this buffered bicycle facility type.

The mean of the lateral position of the bicyclist front tire for the buffered bicycle facility for Naito Parkway is estimated to be 26.5 percent (19 inches) farther to the bicyclists' left than the lateral position of the bicyclist front tire for the buffered bicycle facility for 3rd Street. With 95%, confidence the mean of the lateral position of the bicyclist front tire at the positional point 4 is estimated to be 22.8 to 30.1 percent (16.5 to 21.7 inches) farther to the right than the lateral position of the bicyclist front tire for the buffered bicycle facility for 3rd Street. Section 5.1.2 of this thesis provides a greater in-depth analysis of the bicyclist's projected path and user behavior within this buffered bicycle facility type. Table 22 is a summary of the ANOVA analysis results for the truncated data set.

Table 22: ANOVA Analysis Results for Truncated Data

Source	Value	Std. Error	t-static	Pr > |t|	Lower Bound (95%)	Upper Bound (95%)
Intercept	0.314	0.010	32.469	<0.0001	0.295	0.333
3rd Street	0.000	0.000				
Interstate	0.195	0.013	15.445	<0.0001	0.170	0.220
Naito	0.265	0.018	14.363	<0.0001	0.228	0.301

Figure 66 is a graph of the mean differences generated from the ANOVA analysis to evaluate the mean distance for each buffered bicycle lane facility compared to 3rd Street. To account for the shy distance that a bicyclist may subconsciously implement while riding next to the adjacent vehicle traffic, the measurement of the front tire of the bicycle to the right inside buffered bicycle lane pavement marking with the adjacent vehicle lane was located to the left of the bicyclist.

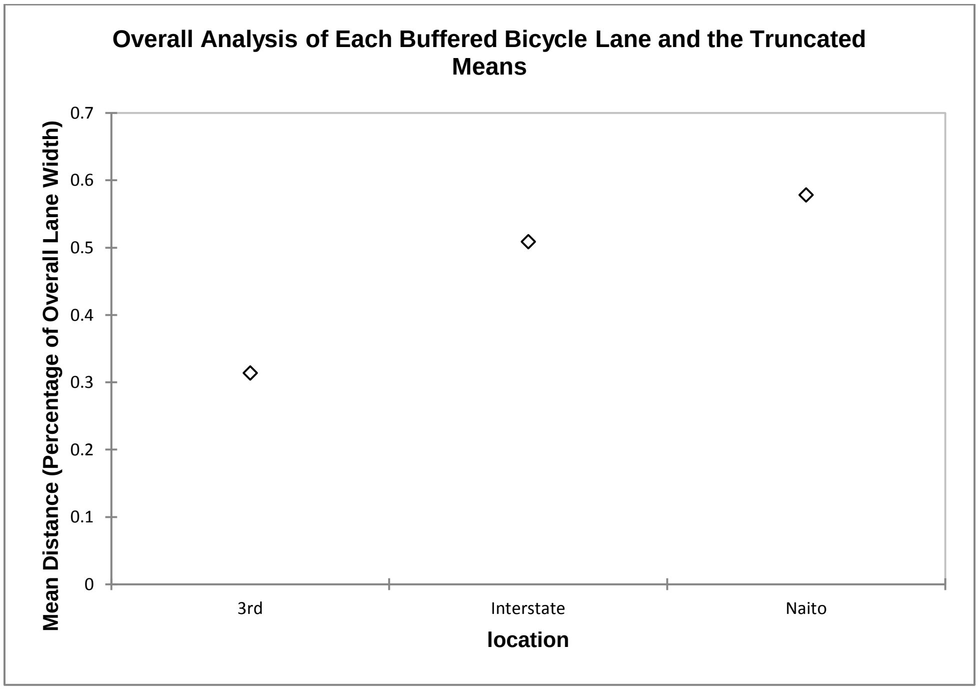

Figure 66: Truncated ANOVA Means Distance for Each Buffered Bicycle Lane Facility

The controlled base case for this evaluation as to the impact grade will incur on bicyclist 3rd Street was chosen as the grade was relatively level. While a buffer space between the bicyclist and adjacent motorized traffic is available, bicyclist were observed to farther distance themselves. Bicyclist were observed lateral positon was observed to be located closer to the left bicycle lane marking and outside of the provided bicycle lane due to the anticipated adjacent traffic location. Refer to section 5.1.3 for the in-depth analysis of this buffered bicycle lane facility type.

The controlled base case for this evaluation as to the impact grade will incur on bicyclist 3rd Street was chosen as the grade was relatively level. While a buffer space between the bicyclist and adjacent motorized traffic is available, bicyclist were observed to farther distance themselves. Bicyclist were observed lateral positon was observed to be located closer to the left bicycle lane marking and outside of the provided bicycle lane due to the anticipated adjacent traffic location. Refer to section 5.1.3 for the in-depth analysis of this buffered bicycle lane facility type.

Section 5.1.1 of this thesis, bicyclist on Interstate Highway utilize two different methods remaining seated (in the saddle), or to stand up (out of the saddle) for climbing uphill. Both of these climbing methods were observed in the video footage and can account for the variance between the means at each lateral positional point. For bicyclist remaining in the saddle may have a gradual or minimal sway or weave, were as, bicyclist out of the saddle may face a harder to control overall stability resulting in a greater swaying or weaving movement. From this study group the overall mean estimates and 95-percent confidence intervals of Interstate Highway were calculated. The results are as follows:

- The average sway of a riders movements back and forth was 13.5 inches with a 95-percent confidence interval of 12 inches to 16 inches not including the width of the riders.
- The average deviation from a straight-line trajectory for this group with a 95-percent confidence interval of 14 inches to 60 inches not including a riders width.

For bicyclist on Naito Parkway, as discussed in section 5.1.2 of this thesis, were observed to be located closer to the left bicycle lane marking due to the anticipated approach of a curve located at the bottom of the grade, and emergency escape due to the lateral force exerted on the bicyclist in the event of a fall or unanticipated collision.

Highly dependent on the location of the adjacent motorized travel lane and the grade. While the location of the travel lane and recorded lateral position of the bicyclist is constant for all facility types. However a full comparison between the three buffered bicycle lane facility types cannot be full conducted as there are many confounding variables that are effecting bicyclist behavior and utilization of the different facility types.

5.2 Near Miss

The results and summary statistics of the binary logit model are outlined in table 23 and include the marginal effects that were produced. For this model, the R^2 and adjusted R^2 cannot be used to assess the measure of fit as these values are based on data variation and continuous data. For this model, the McFadden Pseudo R^2 is used as a measure of fit using the likelihood function. This is used due to the improvement in the values of the relative estimated parameters to assess the log likelihood. The calculation of the log likelihood function is outlined below (Washington, 2011):

$$\chi^2 = -2[LL(\beta_R) - LL(\beta_U)]$$

Where the $LL(\beta_R)$ is equal to the log-likelihood at zero, only the estimated constant and $LL(\beta_U)$ is equal to the log-likelihood with the estimated parameters. A model that has a value of the log-likelihood with the estimated parameters closer to zero compared to the value of the log-likelihood at zero is considered a better fit model for the assessed estimated parameters. For this model the χ^2 is equal to 17.972 with seven degrees of freedom thus 62.8 percent confident that the log likelihood at convergent is more significant.

To assess the McFadden Pseudo R^2 the following calculation is used (McFadden, 1974) (McFadden, 1977):

$$\text{McFadden Pseudo } R^2 = 1 - \frac{LL(\beta_U)}{LL(\beta_R)}$$

From Danial McFadden in the study *Conditional Logit Analysis of Qualitative Choice Behavior* and *Quantitative Methods for Analyzing Travel Behavior of Individuals: Some Recent Developments* a model with an exceptional fit of the McFadden Pseudo R^2 is between 0.20 and 0.40 (McFadden, 1974) (McFadden, 1977). The McFadden Pseudo R^2 for this binary logit model is 0.148. While this is not an exceptional model due to this model being data dependent, it is a good model of fit to assess estimated parameters.

Table 23: Binary Logit Model Summary

Variable	Coefficient	t-Statistic	Marginal Effects	t-Statistic
Constant Variable	-4.196	-3.56		
Time	0.770	2.77	0.0812	2.71
Clothing	-0.677	-1.28	-0.0728	-1.27
Light Source	1.462	1.79	0.1233	2.38
Light Vehicles	-0.002	-1.62	-0.0003	-1.61
Medium Vehicles	-0.001	-0.33	-0.2410D-04	-0.33
Heavy Vehicles	0.001	0.93	0.7254D-04	0.93
Vehicles Crossed	0.002	1.59	0.0002	1.57
Number of Observations			149	
McFadden Pseudo R^2			0.148	
Log Likelihood Function			-51.607	
Restricted log Likelihood			-60.593	
Chi-Square (7 Degrees of Freedom)			17.972	
P-Value (8 Degrees of Freedom)			0.62787	

The other method to assess the measure of fit is evaluating the fraction correctly predicted equal to the actual observation of a successful incident for which the prediction probability is equal to 50 percent. Table 24 are the of the binary logit model predictability. For the binary logit regression model the correct prediction of a near miss incident occurring equal to the actual success events recorded and no events recorded correctly predicted is 78.52 percent.

Table 24: Summary Statistics of Model Predictability

Analysis of Predictions	Threshold= 0.5
Sensitivity = Actual Successful Events Correctly Predicted	23.81%
Specificity = Actual No Events Correctly Predicted	87.50%
Positive Predictive Value = Predicted Success were Actual Success	23.81%
Negative Predictive Value = Predicted No Events were Actual No Events	88.19%
Correct Prediction = Actual Success and No Events Correctly Predicted	78.52%

The assessed estimated parameters within this model are discrete variables, indicators variables, and to assess the impact that these variables have on the occurrence of a near miss incident the marginal effect will be utilized. To calculate the marginal effect for the discrete variable the following equation is used (Washington, 2011):

$$M_{X_{ink}}^{Pn(i)} = Pr\left[P_n(i) = 1|\bar{X}_{(X_{ink})}, X_{(X_{ink})} = 1\right] - Pr\left[P_n(i) = 1|\bar{X}_{(X_{ink})}, X_{(X_{ink})} = 0\right]$$

To calculate the marginal effect for the count collected variable the following equation is used (Washington, 2011):

$$\frac{\partial P_n(i)}{\partial X_{nk(i)}} = \left(1 - P_n(i)\right) * P_n(i) * \beta_k(i)$$

From this equation the effect of a 1 unit increase in an explanatory variable, indicator variable, while all other variables remain constant or equal to their means. A summary of the important findings of the estimation results (Table 23) are outlined in the follow sections:

For this model, the constant has a significant effect on the likelihood that a near miss incident may occur. These findings represent that the constant for this model has significance for this model. This means that there is an unobserved significant impact between all variables evaluated to cause an impact. If the constant is significant that means that, the mean value of dependent variable, the occurrence of a near miss incident, is significantly different from 0. As recorded observations are zero centered, but there is significance in an unobserved variable. This is due to some variables being omitted from the function and some important data may not have been collected or available at the time of this study.

5.2.1 Use of Safety Equipment

The results from the binary logit model found that for bicyclists who use of headlights and lights mounted on the bicycle or worn of safety equipment increased the likelihood of a near miss incident. There is a 0.12 increase probability of a bicyclist who uses headlights, taillights, and lights mounted on the bicycle or worn being involved in a near miss incident. While this result is surprising, the recorded observation of bicyclist utilizing this safety equipment was only seen from the front aspect of the bicyclist. During the time of day and date that this study occurred there was lower visibility and front mounted headlights, and lights mounted on the bicycle or worn by the bicycles were used to light the path. The view from the mounted camera of the bicyclist did not provide the opportunity to observe if the bicyclist had a rear mounted taillights.

5.2.2 Traffic Characteristics

That vehicles that were classified as lightweight (includes passenger cars, trucks and SUVs that do not require a special provisional license to drive), decreased the likelihood of a near miss incident. There is a low (0.0003) decreased probability of a vehicles that were classified as lightweight being involved in a near miss incident. This can be due in large part to driver behavior to bicyclist utilizing the buffered bicycle lane and increasing traffic congestion to allow the bicyclist to safely progress through the conflict zone. This finding is congruent of studies that found that colored pavement and signage raised both motorist and bicyclist awareness to the potential conflict areas from the observational research conducted in Portland, Oregon. Those motorists would yield for bicyclist creating a safer riding environment in conflict zones.

For vehicles, an increase in near-miss incidents occurred between bicyclists and motorized traffic that crossed completely through the conflict zone. There is a 0.0002 increase in probability of in near-miss incidents occurred between bicyclist and motorized traffic that crossed completely through the conflict zone. While the type of motorized traffic that crossed thought the conflict zone was not completely evaluated, it can be inferred that driver behavior of not accessing a large enough space, rate of bicyclist speed, and added stress of impacting traffic congestion to allow the bicyclist to safely progress through the conflict zone.

5.2.3 Time of Day

The results from the binary logit model found that there is an increase in the likelihood of bicyclists being involved in a near miss incident if they travel after 7:30 am to 8:00 am. There is a 0.0812 increase in probability of in near-miss incidents occurring between bicyclist and motorized traffic after 7:30 am to 8:00 am. This may be due to the lower exposure that bicyclist had to motorized traffic during this period (lightweight and motorized traffic that crossed completely through the conflict zone) compared to the other recorded periods. It is unclear if the period between 7:30 am to 8:00 am is the safest time of travel for bicyclist for this buffered bicycle lane facility as this study was only conducted for one day during the week.

6 Conclusion

Clear conclusions on the user behavior of bicyclist and motorists for each buffered bicycle lane facility evaluated from this study cannot be inferred due to the small sample size. However, from the observations that were gathered the conditions and user behavior for bicyclist and motorists can be used to provide uniform and consistent measurements on the lateral position of the bicycle’s front tire using various statistical methods. The lateral position of the bicycle's front tire was located and measured from the painted bicycle lane from adjacent motorized traffic to the left of the bicyclist, and the percentage of distance within the width of the bicycle lane was also noted. These percentage measurements were made to evaluate each buffered bicycle lane on the same measurement scale within each buffered bicycle lane facility, and to compare each facility type overall to the other buffered bicycle lane facility.

6.1 Lateral Position

The review of literatures has shown that only one research project has evaluated and conducted an observational analysis of conventional bicycle lane utilization. The survey of relevant literature did not show that there are any documented observational research activities related to the utilization and behavior of bicyclists within buffered bicycle lanes. The research conducted on bicycle lane utilization for conventional bicycle lanes served as a reference and a basis for analysis to assess use of a buffered bicycle lane by bicyclists and bicyclist sway due to grade. The results of the observational study reported in this thesis support the conclusions reported by survey data collected in other research activities that bicyclist prefer separation from motorized traffic.

To assess bicyclist behavioral usage of each buffered bicycle lane facility this study evaluated whether a bicyclist follow a projected lateral positional trajectory within each buffered bicycle lane facility. It was determined that for the Naito Parkway and 3rd Street buffered bicycle lane facilities bicyclists tended to follow a central position in the bike lane. For the Interstate Highway buffered bicycle lane facility the projected lateral positional trajectory could be constructed but not the bicyclists' central position.

The central tendency of lateral position of bicyclists on Naito Parkway were impacted due to the downhill grade and location of adjacent traffic, and the bicyclist lateral positon was observed to be located closer to the left side of the bicycle lane marking. It was observed that bicyclist anticipated the approach of a curve located at the bottom of the grade, and emergency escape due to the lateral force exerted on the bicyclist in the event of a fall or unanticipated collision.

The central tendency of lateral position of bicyclists on 3rd Street were observed to farther position themselves to the far right more than the buffer space between the bicyclist and adjacent motorized traffic is available. Bicyclist lateral positon was observed to be located closer to the right bicycle lane marking and outside of the provided bicycle lane due to the anticipated adjacent traffic location. It can be concluded for this level grade buffered bicycle facility bicyclist will move to a lateral position that laterally provides a greater horizontal barrier from motorized traffic as this buffered bicycle lane facility does not provide the physical vertical barrier.

The projected lateral positional trajectory of Interstate Highway could not be evaluated for this buffered bicycle lane facility. The observational data of this facility showed that cyclists were swaying due to the uphill grade. The variance in the means of each measured positional point from the observational data set and the truncated observational data set confirmed these observations. This may be due to one bicyclist passing of another bicyclist, or a bicyclist to physically providing a greater buffer from motorized traffic, and bicyclist sway due to the uphill grade as observed in this study.

As discussed in the *Design Guidance for Bicycle Lane Width* riders that face an uphill inclined slope will cycle in a weaving pattern to ease the up hill climb. The pattern was observed in the video footage and in the recorded observation of the lateral position of the cyclist for Interstate Highway. The key for bicyclist when climbing a hill is to use their available power to maintain their speed. Two different methods show this: remaining seated (in the saddle), or to standing up (out of the saddle). Both of these climbing methods were observed in the video footage and can account for the variance between the means at each lateral positional point.

The critical overall location of a bicyclist using each facility is highly dependent on the location of the adjacent motorized travel lane and the grade. While the location of the travel lane and recorded lateral position of the bicyclist is constant for all facility types. A full comparison between the three buffered bicycle lane facility types cannot be full conducted, as there are many confounding variables that are effecting bicyclist behavior and utilization of the different facility types.

6.2 Near Miss

Currently, there is no information that shows whether a government or state entity within the United States has defined a near-miss incident between bicyclist and motorized traffic. The research that has been conducted to assess near miss incidents was conducted in the United Kingdom. This research used survey-based data provided by bicyclists and the definition that was available was defined by the interpretation of the survey questions. The research conducted on near-miss incidents between bicyclists and motorized traffic served as a reference and base of analysis to assess variables that were identified and provide additional explanatory variables to be assessed.

The results of this thesis project was to conduct an exploratory research study to identify research variables, as well as, to identify other variables that were not evaluated within this study, but would add value to the overall study. This includes but is not limited to variables that provide definition of a near-miss incident at conflict points between bicyclist and motorized traffic, characterizes and demographics of bicyclist that used the facility type, and planning considerations for future research.

To assess near-miss incidents a binary logit model was used and found that while this is not an exceptional model due to this model being data dependent, it is a good model of fit to assess estimated parameters. Some significant findings from this model are as follows:

- That bicyclists who use of headlights and lights mounted on the bicycle or wore bright colored clothing there was an increased likelihood of a near miss incident.
- That vehicles that were classified as lightweight (includes passenger cars, trucks and SUVs that do not require a special provisional license to drive), decreased the likelihood of a near miss incident.
- For vehicles, an increase in near-miss incidents occurred between bicyclists and motorized traffic that crossed completely through the conflict zone.
- That there is an increase in the likelihood of bicyclists being involved in a near miss incident if they travel between 7:30 am to 8:00 am.

For this model, the constant has a significant effect on the likelihood of a new miss. This means that there is an unobserved significant likelihood between all variables evaluated to cause an impact. The mean value of dependent variable, the occurrence of a near miss incident, is significantly different from 0. As recorded observations are zero centered, but there is significance in an unobserved variable. This is due to some variables being omitted from the function; some important data may not have been collected or available at the time of this study; or sampling error.

6.3 Future Planned

The placement of cameras is important in gathering observational data such as video footage. For future research activities, different locations and heights of cameras should be considered for observation of a bicycle lane to obtain additional variables that include the perspective of motorized traffic when approaching a bicyclist. This would provide information on the use of a rear light. Additional bicyclist characteristics, such as gender, age and the ethnicity of bicyclists could also provide additional data. Recommended future research topics related to buffered bicycle lane utilization and observed behavior of bicyclist and motorists are as follows:

- Future research should be conducted to see if bicyclist sway while going up a high is effected by a bicyclists remaining seated or standing while climbing.

- Future research should be conducted for the same facility type at different grades to assess the impact grade and rider sway.
- Future research should be conducted for a buffered bicycle lane facility at consistent times over multiple days of the week.
- Future research should be conducted to assess the different distributions of a binary logit regression model on the effect to all the assessed estimated parameters and find the best distribution of the betas for the collected data set.
- Evaluate data gathered by Portland State University (PSU) for the Oregon Department of Transportation (ODOT) on near miss as well as GIS data from an on line app developed by PSU in modeling near miss incidents.

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8 Appendix A

This discussion is focused on four aspects of bicycle lane design before implementation: (i) common bicycle lane construction, (ii) the motivation of implementation of buffered bicycle lane design, (iii) common safety improvement practices for existing of bicycle lane facilities, and (iv) the ethical dilemmas of implementation.

8.1 Commonly Added Safety Options for Bicyclists

The goal of construction or retrofit of a bicycle lane is to provide a space for cyclists to safely travel adjacent to an existent vehicle travel lane. The main focus for transportation engineers and roadway designers is to provide and to maintain a facility that is safe, with increased sight distance and visibility of the bicyclists for motorists, and increased sight distance and visibility for bicyclists. This section focuses on the aspects of a common safety improvement practices for existing of bicycle lane facility advantages, disadvantages and cost of implementation.

8.1.1 Safety Improvement for Existing Lane Construction

There are six different improve methods that are commonly used to improve bicycle lane safety. The main methods that can be implemented are the placing of traffic control signs, repainting of pavement markings, applying colored pavement paint for the existing bike lane, expanding bicycle lane, installing permanent or temporary devices that fully separate (protect) bicycle lane, and to do nothing. These methods must all be planned and constructed following state and federal guidelines, which promote uniform and safe operations of roadway facilities, and must satisfy five requirements before implementation.

If a roadway segment can fulfill all of these requirements, then the best method of implementation is at the discretion of the traffic engineer or roadway designer. The methods for improved lane safety differ in the range of visibility of a bicyclist, bicyclist comfort and cost of implementation. A detailed list of the different advantages and disadvantages traffic control signs, repainting of pavement markings, applying colored pavement paint, expanding bicycle lane, installing permanent or temporary devices that fully separate (protect) bicycle lane, and to do nothing are listed below:

8.1.1.1 Traffic Control Signs

The installation of bike lane signs, bicycle warning signs, and improve retro-reflectivity of existing signs. All of these options improve motorist visibility of bicyclists utilizing the roadway. Signs also cautions motorists that bicyclists are prevalent on this roadway segment, and that motorists should use increased awareness when approaching due to an increase in bicyclist conflicts. Traffic engineers or roadway planners may add a supplemental plaque to provide increased clarity as to the conflict that motorists may experience. Some examples of bicycle lane signs are:

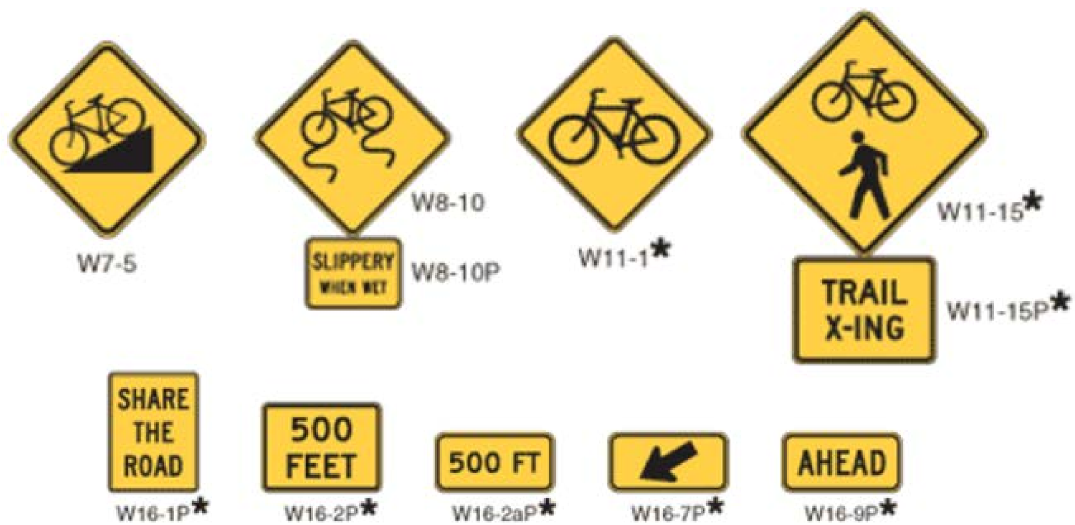

Figure 67: Bicycle Warning Signs and Supplemental Roadway Plaques

- Repainting of Exiting Pavement Markings: Due to continual exposure to the elements, the vibrancy of painted line markings become faded over time. To increase painted line longevity, common methods are to increasing pavement lines, increased use of raised reflective pavement markings, and increased the brightness of pavement markings.

8.1.1.2 Installing permanent or temporary devices that fully separate (protect) bicycle lane

A survey conducted by Portland State University evaluated bicyclist perceived level of different buffered or fully separated bicycle lane facilities. However, the use of protected bicycle lanes in the United States is a new practice, and farther research must be conducted as to the increased risks and cost to motorists and pedestrians when fully separated devices are installed.

8.1.1.3 Do Nothing

Is considered when the location of any placement of signs or pavement markings would become too distracting or negatively affect motorist safety and expectancy. Traffic engineers or roadway designers may also choose to not improve a roadway segment due to the random influx of bicyclist incidence, or event occurrence does not warrant the infrastructure improvement cost.

8.1.2 Cost of Implementation

For all traffic control devices or roadway retrofits, traffic engineers and roadway designers account for the cost of implementation and cost of maintenance over the anticipated life cycle. This is to ensure that all devices or retrofits are implemented are maintained at an adequate standard level and meet the needs of all. The schedule maintenance for each includes periodic maintenance and unscheduled maintenance.

8.1.2.1 Traffic Signs

There are several circumstances that directly affect sign visibility. Due to this, they are accounted in for the overall cost of installations of traffic signs. The costs that are evaluated for traffic signs are outlined by Lawrence T. Hagen (2004) below:

- The retro-reflective sheeting used on sign faces has a limited design life. After a few years of weathering, signs begin to lose their retro-reflectivity sheeting. An example of a retro-reflective sheeting deterioration is a sign that appears adequate in the daytime may be nearly invisible at night.

- The collection of dust and dirt to signs. Due to roadway treatments during the winter, seasonal pollen accumulation, and common roadway dust and dirt, signs will have particulates clings to the sign. This results in a reduction in nighttime visibility of the sign message. Some State Department of Transportation Agencies account for this and have created periodic program of washing the signs.
- Vegetation of growth and mildew can obstruct the visibility of a sign. For sign locations with nearby vegetation, a planned program of trimming may be required.
- Signs may get damaged or taken down either by vandals or vehicles. Agencies must have the appropriate materials and personnel to respond quickly to and replace downed signs to minimize the exposure to lack of advanced warning caused by the absence of a particular sign.
- Graffiti placed on signs. Some of the commercially available graffiti removers accelerate the degeneration of sign retro-reflectivity sheeting material. Some agencies have found it more efficient to replace the signs rather than try to clean them.

The overall cost of placing one traffic sign can range due to the type of sign, the color choice of the sign, the total square footage, and the expected sign life. An example of the variability in the cost for a sign is $3.50 per sq. foot, with an expected sign life of 15 years can cost $363,000 (total cost, including Installation); to a sign that is $0.75 per sq. foot, with an expected sign life of 5 years can cost $1,508,980 (total cost, including Installation) (WSDOT 2015).The difference in the price of a sign is dependent on the factors that directly influence sign deterioration (refer to the list above).

8.1.2.2 Instillation of Permanent or Temporary Devices

A study was conducted on *Cost Analysis of Bicycle Facilities* evaluated different cases in the Portland, Oregon region. This study encompassed the Portland (Metro) region and ten cities in the metropolitan region, and identify and document costs for a range of recently completed bicycle infrastructure projects. The documented costs evaluated each type of bicycle facility and range of possible costs. The objective of this study was to provide objective information on the true costs for permanent or temporary devices used for bicycle infrastructure. Table 1 provides an overview of cost findings for installation of permanent or temporary devices used for bicycle infrastructure.

8.2 Ethics of Implementation

When evaluating the impact that a project will have on the surrounding community and infrastructure, it is vital to ensure that a project does not impact the rights of all property owners, the beneficence of this project, and transportation investments. A frequent dilemma that arises when constructing or expanding a facility is how much land is available for use in a construction project. In most, construction projects that are focused on establishing or expanding already existing bicycle lane infrastructure a retro-fit of existing street is the common practice. These retrofits utilized the land usage that has been designated as a lane for vehicle use. In most infrastructure projects designers and planners will expand an existent bicycle lane facility, and in acute situations, entire thru lanes will be converted for a bicycle lane facility. Both of these land acquisitions will be discussed and evaluated in this observational report.

Another ethical dilemma is concerning beneficence. This ethical issues that is called into question is the first canon of ASCE code of ethics which states, “Engineers shall hold paramount the safety, health, and welfare of the public and shall strive to comply with the principles of sustainable development in the performance of their professional duties.” (Code Web). The dilemma that comes from this canon is the safety of the individual bicyclist and welfare of the public health, or if the welfare of the public economic growth and added stress to vehicle infrastructure. For the benefit of the bicyclist, these bicycle lanes provide an added level of proceed safety and greater visibility for motorists utilizing the same space. For the motorist, the land acquisition will result in lanes that have been reduced in width resulting in the motorist interaction on a road diet, or an unanticipated bottleneck for motorists. As for the society, there are two different aspects that are influential as to the implementation of a bicycle facility. Studies have shown the public benefit of increased bicyclists health and well-being (Aldred, 2015). However, the adverse impact that can result in economic growth due to the reduction in available roadway capacity resulted from land acquisition. Both of these solutions are for the well-being and safety of the motorist. The perspective of public welfare is contingent on the socioeconomic benefits and determination of if the bicyclist or the motorist requires the higher priority. While at the same time provide more multi-model options for a growing population. This becomes a dilemma for roadway designers and planners to integrate multi-model infrastructure when the existent infrastructure has been designed around motorists.

The ethical dilemma concerning short and long term transportation investments for the implementation of bicycle lane. Bicycle lanes can contribute to greater mobility for the “last mile” connection for transit use. This connection drives economic expansion for the surrounding small businesses and access to employment opportunities for lower-income communities. For this reason engineers and planner must ensure their actions do not impose “disproportionately high and adverse effects” on low-income and minority populations, as specified by the DOT Order 5610.2(a), Title VI of the Civil Rights Act of 1964, and the Environmental Justice Executive Order 12898 (FHWA 17). The disproportionately high and adverse effects that can result from renovation and retro-fit of adjacent facilities is an influx of more affluent residents. The influx of affluent residents and increased property values can result in the displacing of lower-income families and small businesses.

To minimize the projects impact to the local community, engineers and planners can utilize opportunities for early and ongoing public engagement to maintain a strong public involvement program to ensure all social, economic, and environmental concerns are addressed. Successful outreach programs start as early as possible and involves all stakeholders with information as to the proposed to the roadway and city roadway network. The *Separated Bike Lane Planning and Design Guide* (2015) and created by the U.S Department of Transportation Federal Highway Administration outlines the best outreach stagiest that can be used:

- Outreach to the general public during planning and design stages, including residents along a potential separated bike lane corridor;
- Outreach to the business community along the proposed corridor;
- Coordination with transit agencies that operate service along or intersecting with the proposed corridor;
- Coordination with enforcement and public safety agencies such as police and fire departments;
- Coordination with State and county Departments of Transportation (especially for separated bike lanes along or intersecting with state or county-controlled roads);
- Coordination with maintenance divisions;
- Coordination with other partners such as advocacy groups, public health organizations, and others; and
- Outreach during implementation with a public education focus on how different user groups (bicyclists, motorists, pedestrians) should interact with the new facility (especially around conflict areas like intersections and driveways). (FHWA, 2015)

9 Appendix B

9.1 NLogit 5 Model Command File

```
RESET

READ
;NVAR=11
;NOBS=149
;FILE="C:\Users\riose.ONID\Dropbox\Buffer\Elizabeth\Data\Model_Data\M
odel_Data.csv"$


LOGIT
;LHS=X3
;RHS=ONE,X1,X2,X5,X6,X8,X9,X10,X11
;MARGINAL EFFECTS
;SUMMARIZE$


DSTAT
;RHS=X1,X2,X5,X6,X8,X9,X10,X11
;OUTPUT=2$
```

9.2 NLogit 5 Output

```
|-> RESET
|-> READ
  ;NVAR=11
  ;NOBS=149

;FILE="C:\Users\riose.ONID\Dropbox\Buffer\Elizabeth\Data\Model_Data\M
odel_Data.csv"$
|-> LOGIT
  ;LHS=X3
  ;RHS=ONE,X1,X5,X6,X8,X9,X10,X11
  ;MARGINAL EFFECTS
  ;SUMMARIZE$
Normal exit:  6 iterations. Status=0, F=  51.60702

---------------------------------------------------------------------
--------
Binary Logit Model for Binary Choice
Dependent variable            X3
Log likelihood function    -51.60702
Restricted log likelihood   -60.59315
Chi squared [  7 d.f.]    17.97228
Significance level         .01210
McFadden Pseudo R-squared   .1483029
Estimation based on N =  149, K =  8
Inf.Cr.AIC =  119.2 AIC/N =   .800
Model estimated: May 17, 2017, 15:14:19
Hosmer-Lemeshow Chi-Square =  6.17294
P-value= .62787 with deg.fr. =    8
```

```
--------+-------------------------------------------------------------
--------
        |          Standard          Prob.    95% Confidence
      X3| Coefficient    Error     z   |z|>Z*       Interval
--------+-------------------------------------------------------------
--------
Constant|  -4.19645***   1.17902  -3.56 .0004  -6.50729 -1.88561
      X1|   .76965***    .27790   2.77 .0056    .22497  1.31434
      X5|  -.67684      .52929  -1.28 .2010  -1.71422   .36055
      X6|  1.46170*     .81678   1.79 .0735   -.13916  3.06256
      X8|  -.00243      .00150  -1.62 .1050   -.00538   .00051
      X9|  -.00023      .00069   -.33 .7412   -.00158   .00113
     X10|    .00069      .00074    .93 .3506   -.00076   .00213
     X11|    .00234      .00148   1.59 .1129   -.00055   .00524
--------+-------------------------------------------------------------
--------
Note: ***, **, * ==> Significance at 1%, 5%, 10% level.
----------------------------------------------------------------------
--------


----------------------------------------------------------------------
--------
Partial derivatives of E[y] = F[*] with
respect to the vector of characteristics
Average partial effects for sample obs.
--------+-------------------------------------------------------------
--------
        |   Partial   Standard        Prob.    95% Confidence
      X3|    Effect     Error     z   |z|>Z*       Interval
--------+-------------------------------------------------------------
--------
      X1|   .08125***    .03003   2.71 .0068    .02239   .14011
      X5|  -.07281      .05724  -1.27 .2033   -.18499   .03937   #
      X6|   .12330**     .05174   2.38 .0172    .02190   .22470   #
      X8|  -.00026      .00016  -1.61 .1075   -.00057   .00006
      X9|-.24100D-04    .7298D-04    -.33 .7412 -.16714D-03 .11894D-03
     X10| .72546D-04    .7790D-04    .93 .3517 -.80132D-04 .22522D-03
     X11|    .00025      .00016   1.57 .1157   -.00006   .00056
--------+-------------------------------------------------------------
--------
# Partial effect for dummy variable is E[y|x,d=1] - E[y|x,d=0]
Note: nnnnn.D-xx or D+xx => multiply by 10 to -xx or +xx.
Note: ***, **, * ==> Significance at 1%, 5%, 10% level.
----------------------------------------------------------------------
--------

+----------------------------------------+
| Fit Measures for Binomial Choice Model |
| Logit  model for variable X3      |
+----------------------------------------+
|          Y=0     Y=1    Total|
| Proportions .85906  .14094  1.00000|
| Sample Size   128     21     149|
+----------------------------------------+
| Log Likelihood Functions for BC Model |
|       P=0.50  P=N1/N  P=Model|
| LogL =   -103.28  -60.59  -51.61|
+----------------------------------------+
| Fit Measures based on Log Likelihood  |
| McFadden = 1-(L/L0)      =  .14830|
| Estrella = 1-(L/L0)^(-2L0/n) =  .12240|
```

```
| R-squared (ML)        =  .11363|
| Akaike Information Crit.   =  .80009|
| Schwartz Information Crit.  =  .96138|
+----------------------------------------+
| Fit Measures Based on Model Predictions|
| Efron            =  .15219|
| Ben Akiva and Lerman     =  .79179|
| Veall and Zimmerman     =  .23998|
| Cramer            =  .14015|
+----------------------------------------+
+---------------------------------------------------------+
|Predictions for Binary Choice Model. Predicted value is |
|1 when probability is greater than .500000, 0 otherwise.|
|Note, column or row total percentages may not sum to   |
|100% because of rounding. Percentages are of full sample.|
+------+---------------------------------+----------------+
|Actual|     Predicted Value     |        |
|Value |    0        1    | Total Actual  |
+------+----------------+----------------+----------------+
| 0  |  128 ( 85.9%)|   0 (  .0%)|  128 ( 85.9%)|
| 1  |   19 ( 12.8%)|   2 ( 1.3%)|   21 ( 14.1%)|
+------+----------------+----------------+----------------+
|Total |  147 ( 98.7%)|   2 ( 1.3%)|  149 (100.0%)|
+------+----------------+----------------+----------------+
+---------------------------------------------------------+
|Crosstab for Binary Choice Model. Predicted probability |
|vs. actual outcome. Entry = Sum[Y(i,j)*Prob(i,m)] 0,1.  |
|Note, column or row total percentages may not sum to   |
|100% because of rounding. Percentages are of full sample.|
+------+---------------------------------+----------------+
|Actual|   Predicted Probability   |        |
|Value |  Prob(y=0)    Prob(y=1)  | Total Actual  |
+------+----------------+----------------+----------------+
| y=0 |  112 ( 75.2%)|   15 ( 10.1%)|  128 ( 85.2%)|
| y=1 |   15 ( 10.1%)|   5 ( 3.4%)|   21 ( 13.4%)|
+------+----------------+----------------+----------------+
|Total |  127 ( 85.2%)|   21 ( 13.4%)|  149 ( 98.7%)|
+------+----------------+----------------+----------------+

---------------------------------------------------------------------
--
Analysis of Binary Choice Model Predictions Based on Threshold =
.5000
---------------------------------------------------------------------
--
Prediction Success
---------------------------------------------------------------------
--
Sensitivity = actual 1s correctly predicted           23.810%
Specificity = actual 0s correctly predicted           87.500%
Positive predictive value = predicted 1s that were actual 1s  23.810%
Negative predictive value = predicted 0s that were actual 0s  88.189%
Correct prediction = actual 1s and 0s correctly predicted    78.523%
---------------------------------------------------------------------
--
Prediction Failure
---------------------------------------------------------------------
--
False pos. for true neg. = actual 0s predicted as 1s      11.719%
False neg. for true pos. = actual 1s predicted as 0s      71.429%
False pos. for predicted pos. = predicted 1s actual 0s     71.429%
False neg. for predicted neg. = predicted 0s actual 1s     11.811%
```

```
False predictions = actual 1s and 0s incorrectly predicted   20.134%
---------------------------------------------------------------------
--
|-> DSTAT
  ;RHS=X1,X5,X6,X8,X9,X10,X11
  ;OUTPUT=2$

Descriptive Statistics for  7 variables
--------+------------------------------------------------------------
---------
Variable|    Mean    Std.Dev.   Minimum   Maximum   Cases Missing
--------+------------------------------------------------------------
---------
   X1|   2.275168   1.064533     1.0     4.0   149    0
   X5|   .543624   .499773     0.0     1.0   149    0
   X6|   .718121   .451432     0.0     1.0   149    0
   X8|   13.65625   10.66112     0.0     57.0    96   53
   X9|   1.174603   .583086     1.0     5.0    63   86
   X10|   1.236842   .633916     1.0     4.0    38   111
   X11|   6.609195   4.825697     1.0     23.0    87   62
--------+------------------------------------------------------------
---------

DSTAT results are matrix LASTDSTA in current project.


--------+------------------------------------------------------------
--
Cor.Mat.|   X1    X5    X6    X8    X9   X10   X11
--------+------------------------------------------------------------
--
   X1| 1.00000  .02294  .39001  .16551 -.52588 -.36282  .11772
   X5| .02294 1.00000  .25000  .04275 -.26968  .03748  .28506
   X6| .39001  .25000 1.00000  .30251 -.43823  .13117  .18325
   X8| .16551  .04275  .30251 1.00000 -.10065  .21713  .79781
   X9| -.52588 -.26968 -.43823 -.10065 1.00000  .23245 -.04942
   X10| -.36282  .03748  .13117  .21713  .23245 1.00000  .19230
   X11| .11772  .28506  .18325  .79781 -.04942  .19230 1.00000
```