Factors Affecting Vehicle Passing Distance and Encroachments While Overtaking Cyclists

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Abstract
Local governments are becoming increasingly interested in ways to provide safe and comfortable bicycle infrastructure that encourages cycling. This study explores the impacts that bicycle facility, vehicle type, and other variables have on two measures of safety, vehicle passing distance (VPD) and encroachment. Vehicles that pass cyclists at a lateral distance of less than 36 inches are encroaching according to Minnesota statute. Using a bike-mounted radar and camera, researchers recorded and analyzed 2,949 vehicle passes on seven roads with four different types of bicycle facilities. The average passing distance was 70 inches, and overall encroachment rate was 1.12%. Two regression modeling techniques (multivariate OLS, and binomial logit) were used to isolate statistically significant factors influencing passing distance and chance of encroachment. This study found that roads with buffered and bollard bike lanes are correlated with larger passing distances and the lowest chance of encroachment. Relative to roads with protected or buffered bike lanes, passing distances on roads with other types of bike facilities are on average 14-18 inches closer after removing the effect of all other variables on passing distance. However, the logit encroachment model showed that, despite having a lower average passing distance, standard bike lane and shoulder facilities did not significantly differ in chance of encroachment. Additionally, bicycle boulevards had the highest chance of encroachment among all facility types, despite having only the second lowest average passing distance. The presence of oncoming or adjacent traffic, and being female also significantly lowered passing distances. This study confirms that the type of bicycle infrastructure is associated with vehicular passing distance and frequency of encroachments, and finds additional contextual factors such as adjacent lane traffic, parking, and gender are impactful. Considerations that separate large vehicles from bicycles can also help create a safer cycling environment

1. Introduction

State and local governments are interested in providing safe and comfortable bicycle infrastructure that encourages more people to choose cycling as a mode of transportation. To this end Hennepin County, Minnesota's most populous county, collaborated with the University of Minnesota on a study of vehicle passing behavior on the county bicycle network. Guided by ridership goals set forth in the Hennepin County 2040 Bicycle Transportation Plan, the County was interested in understanding how bicycle facilities, or lack thereof, impact relative safety. In this study, two measures of relative safety are: (1) vehicle passing distance (VPD) when overtaking cyclists, and (2) encroachments. Minnesota statute requires a minimum VPD of 3ft (36 Inches) while passing a cyclist. Anything less is an encroachment. This report investigates vehicular encroachment and passing distance while overtaking cyclists on different bicycle facilities across six urban and one suburban roadway in Hennepin County. A C3FT radar system and GoPro camera mounted to a bicycle, sometimes used for police enforcement, are used to measure passing distance. The radar measures the lateral distance of objects between 10 and 99 inches from the left handlebar of a bicycle. We use two regression modeling techniques to identify the effect bicycle facility, road characteristics, vehicular type, and gender have on two dependent variables (1) passing distance and (2) encroachments. Based on our results we discuss policy implications related to the effectiveness of bicycle facilities.

2. Literature Review

Cities and counties are grappling with how to build bicycle infrastructure to encourage greater numbers of cyclists without interfering with traffic flows or exceeding municipal budget limitations. At the center of this question is the need to ensure cyclist safety while sharing the road with vehicles. In theory, increasing the safety of roads for cyclists should result in greater numbers of cyclists (Shackel and Parkin 2014, p. 100). Finding a way to systematically test relative safety lies at the center of balancing the dual demands of safety and cost while building a bike network.

Over the past few years, a number of studies have emerged looking at what variables influence vehicle-cyclist interactions, including lateral passing distance. Researchers are testing to see how bicycle infrastructure, vehicle characteristics, rider characteristics, and other variables impact passing distance and encroachment. Table 1 summarizes the dependent and independent variables of seven different studies and their significance. Significance is indicated as positive or negative for measured variables relative to the dependent variable. For example, if the chart indicates that the dependent variable is passing distance and lane width is significant and positive, then the study found that there is a relationship between wider lane widths and greater passing distance. Variables in Table 1 are represented with a "—" if the variable was not included or measured. Other variables that were not significant are marked with an "NS".

These studies provide helpful background on variables impacting passing distance and encroachments, but none have an exhaustive analysis of all variables with an impact. The presence of an adjacent or oncoming vehicle was consistently found to have an impact on VPD. Three studies found that VPD decreased when there was an adjacent or oncoming vehicle. The literature has mixed findings in regards to geometric roadway characteristics such as lane width, speed limit, and shoulder width. Only half of studies in Table 1 find lane width and speed limit to be significant in regards to changes in passing distance, and it is unclear the effect they have on number of encroachments. Just one of five studies showed a significant difference between vehicle types. In that study, researchers found that trucks have the smallest "comfort zone boundary". Lastly, the apparel of the cyclist does not appear to affect the

Table 1. Vehicle-Bicycle Passing Distance Literature Summary

Author	Dependent Variable	Lane Width	Speed Limit	Bicycle Signage/ Road Type	On Street Parking	Marked Centerline	Shoulder Width	Vehicle Type	Vehicle in Adjacent Lane/ Oncoming Vehicle	Rider Appearance
La Mondia and Duthie (2012)	Bicyclist/ Motorist Lateral Interaction Distance	S (+)	S (-)	S (Sharrow Markings) (+)	S (+)	NS	--	--	--	--
Champan and Noyce (2014)	Lateral Clearing Distance	NS	S (+)	--	--	S (+)	S (+)	NS	S (-)	--
Shackel and Parkin (2014)	Overtaking Lateral Distance and Speed	S (+)	NS	S (Road Type)	--	S (-) (Speed)	--	NS	S (-) When Oncoming Vehicle is Closer	--
Walker, Garrard, and Jowitt (2014)	Lateral Clearing Distance	--	--	--	--	--	--	--	--	NS by Apparel
Dozza, Schindler, Bianchi-Paccinini and Karlson (2016)	Comfort Zone Boundary	NS	NS	--	--	--	NS	S (+) (Trucks)	S (-)	--
Stipancic, Zangenehpou, Miranda-Moreno, Saunier, and Granie (2016)	Conflicts at Intersections	--	--	--	--	--	--	NS	--	S (+) (Female)
Love, Breaud, Burns, Margulies, Romano and Lawrence (2012)	Vehicle Passing Distance (VPD)	S (+)	--	S (+)	--	--	--	NS	--	S

S = Significant (relative to dependent variable) NS = Not Significant (+) Positive Effect (-) Negative Effect lateral passing distance, but evidence does point to the need to account for differences in gender. Stipancic et al. found that female cyclists were more likely to be involved in dangerous conflicts at intersections. Conversely, Love et al. had one female rider in their study, and she had the fewest passes under three feet. There is a lack of clarity of the relationship between vehicle cyclist interactions and gender. Most studies use a form of multivariable regression analysis to analyze their data.

3. Study Background and Methodology

The entirety of this study took place between June and December of 2017. Equipment testing and preliminary study design took place between June and September. Finalizing the study design, data collection, and analysis occurred between late September and December.

To control for extraneous variables, test rides were executed when road conditions were consistent, with the exception of one ride in wintery conditions, and between the hours of 3:00 and 5:30 pm. Some rides were delayed due to construction and weather conditions. Rides were designed to be completed during the evening rush hour. The entirety of the study can be summarized chronologically with the following steps:

1. Equipment Testing
2. Controlling for Cyclist Position
3. Defining a Pass
4. Roadway and Segment Selection
5. Delineation
6. Data Collection and Recording
7. Analytical Procedures

The following sections summarize the design of the study, underlying rationale, and methodology.

3.1 Equipment Testing

Hennepin County's Pedestrian and Bicycle Division purchased the C3FT bike mounted radar ("see 3 feet" trademark radar technology made by Codaxus LLC) and GoPro camera equipment and was interested in testing it to understanding its potential for bike patrol use. They were also interested in testing the relative safety of different bike facilities. The first step in developing the protocol for this study was to understand the technology and potential variables that could affect the ability to measure VPD. Two researchers tested the C3FT bike mounted radar's utility as a tool for study and potential limitations. Figure 1 shows the C3FT bike mounted radar and GoPro mounted on a bike for testing. Testing the equipment took place in the middle of June to the beginning of July, 2017. Overall, the equipment successfully captured VPD, but the lack of endogenous data recording meant researchers would need to watch the entire GoPro recorded video to extract data.

Preliminary study design took place from July to September, 2017. The plan was to develop a protocol for an in-depth research study using the C3FT technology. This involved using the equipment on a test road to give researchers and the County the chance to identify any problems they may encounter in the field, and iteratively refine the protocol to ensure the highest quality data. This allowed researchers to make adjustments and use the equipment for in-depth study. The preliminary study design protocol is described in the report *Recommended Design and Protocol for a Vehicle Passing Distance Experimental Study* produced for Hennepin County.

Figure 1. C3FT Bike Mounted Radar and GoPro

Test rides took place along various roads around the University of Minnesota, and data was collected by watching the ride footage after it was downloaded from the mounted GoPro Cameras. Researchers concluded that the two largest impediments to capturing the highest quality data were (1) controlling for the position of the cyclist, and (2) having a definition of a pass for consistent data recording.

3.2 Controlling Cyclist Position

Controlling for cyclist position is essential to ensure that the data collected are influenced by the study's independent variables, and not the choice of the cyclist of where to ride. The research team determined that placing delineators and markings on the road in a manner consistent across sites was the best course of action to control cyclist position. In addition, it was determined that it would be best to approximate how a cyclist would theoretically ride on a road. Researchers tested a variety of delineation styles on Marshall Street Northeast in Minneapolis, as seen in Figure 2, in August of 2017 to determine the most effective distance between individual delineators, distance from the curb, and distance of the site segment. These tests accomplished the objectives of (1) controlling cyclist position, (2) ensuring feasibility of staying within the bounded zone, (3) not altering driver behavior, and (4) mimicking as closely as possible how cyclists would actually bike. Both delineators and paint markings were used depending on if the road did (delineators) or did not (paint) have a bike facility. Though this could introduce uncertainty into effects, paint was chosen so as to not alter how drivers behaved on a given road without facilities.

3.3 Defining a Pass

For consistent data recording from the GoPro camera, a pass was defined as the narrowest distance recorded from a vehicle overtaking a cyclist, where the cyclist was in or adjacent to the travel lane. The radar constantly measures for passing vehicles, and therefore each pass has multiple potential passing distances. For this reason, the narrowest observed measurement was used when recording the data from the video. For some site sections, this was the lane the cyclist was in when there was no bicycle facility or shoulder (Figure 3, A and B). In other instances, this was the lane immediately adjacent to a cyclist riding in a bicycle facility or shoulder (Figure 3, C). Passing vehicles were not counted unless they were in the lane marked with a vehicle in Figure 3. Finally, passes in both directions were counted on the bike boulevard (Figure 3, D) because there were no road markings distinguishing separate lanes of traffic and the road was too narrow to allow cars moving in both directions to pass at the same time.

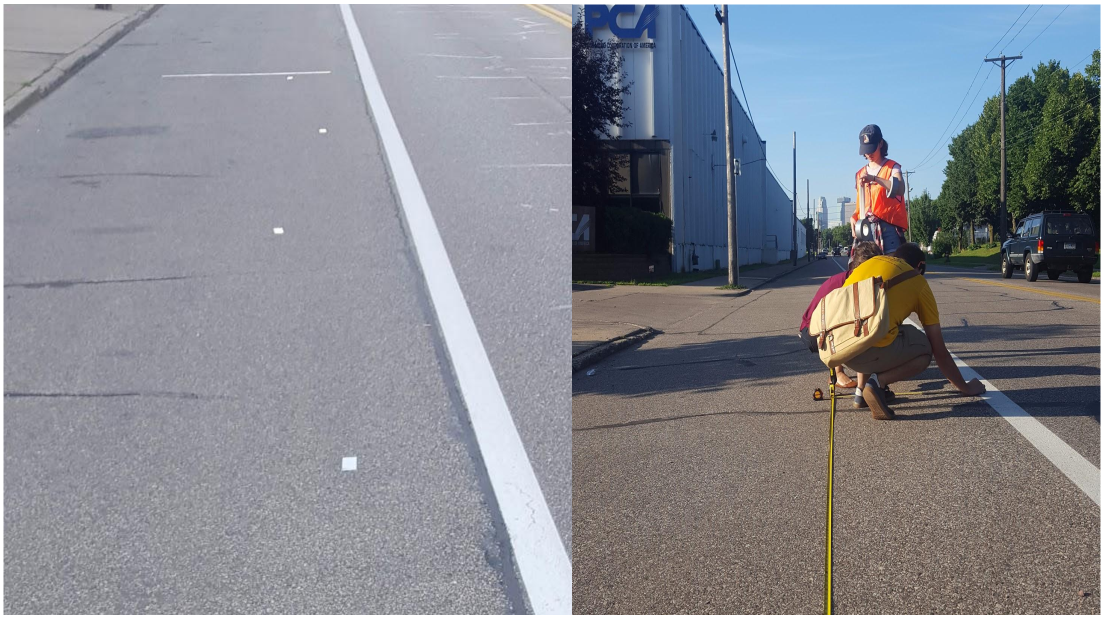

Figure 2. Delineation Testing on Marshall St. NE

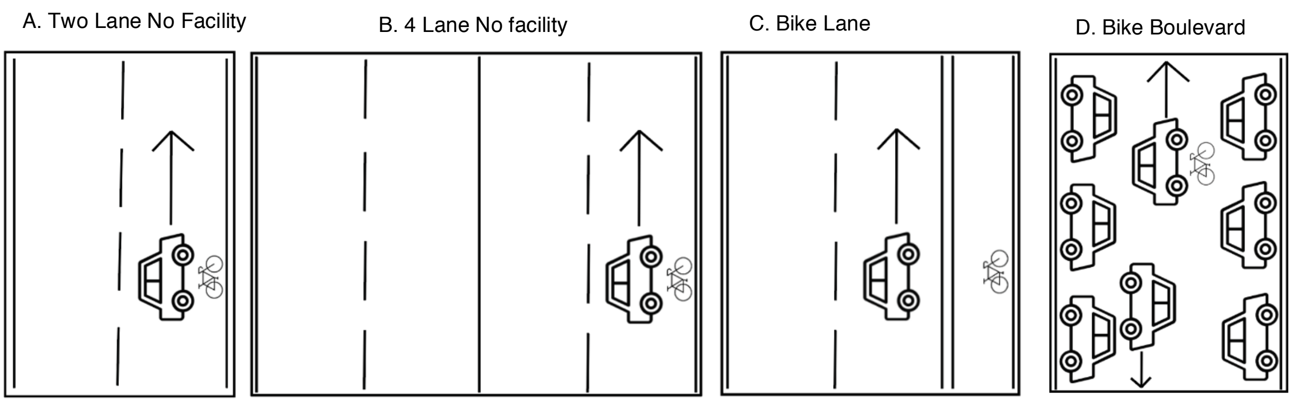

Figure 3. Vehicle Pass Definitions on Four Road Types

<u>3.4 Site Selection</u>

Seven road segments were selected in collaboration with planners at Hennepin County (Figure 4). Primarily urban roads were tested with one exception of a suburban road near the urban border. This was to avoid introducing additional contextual variation into data collection. Table 2 summarizes each road segment and site characteristics. The six categories of bicycle facilities included were (1) buffered bike lane, (2) protected (bollard) bike lane, (3) no facility, (4) shoulder, (5) standard bike lane, (6) bike boulevard. Categories 1 and 2 were collapsed into protected-buffered bike lane and the shoulder and bike lane (4 and 5) were also combined for data analysis. Additional information, including starting and ending intersection, on each road segment can be found in the ride plans submitted to the County (Appendix B).

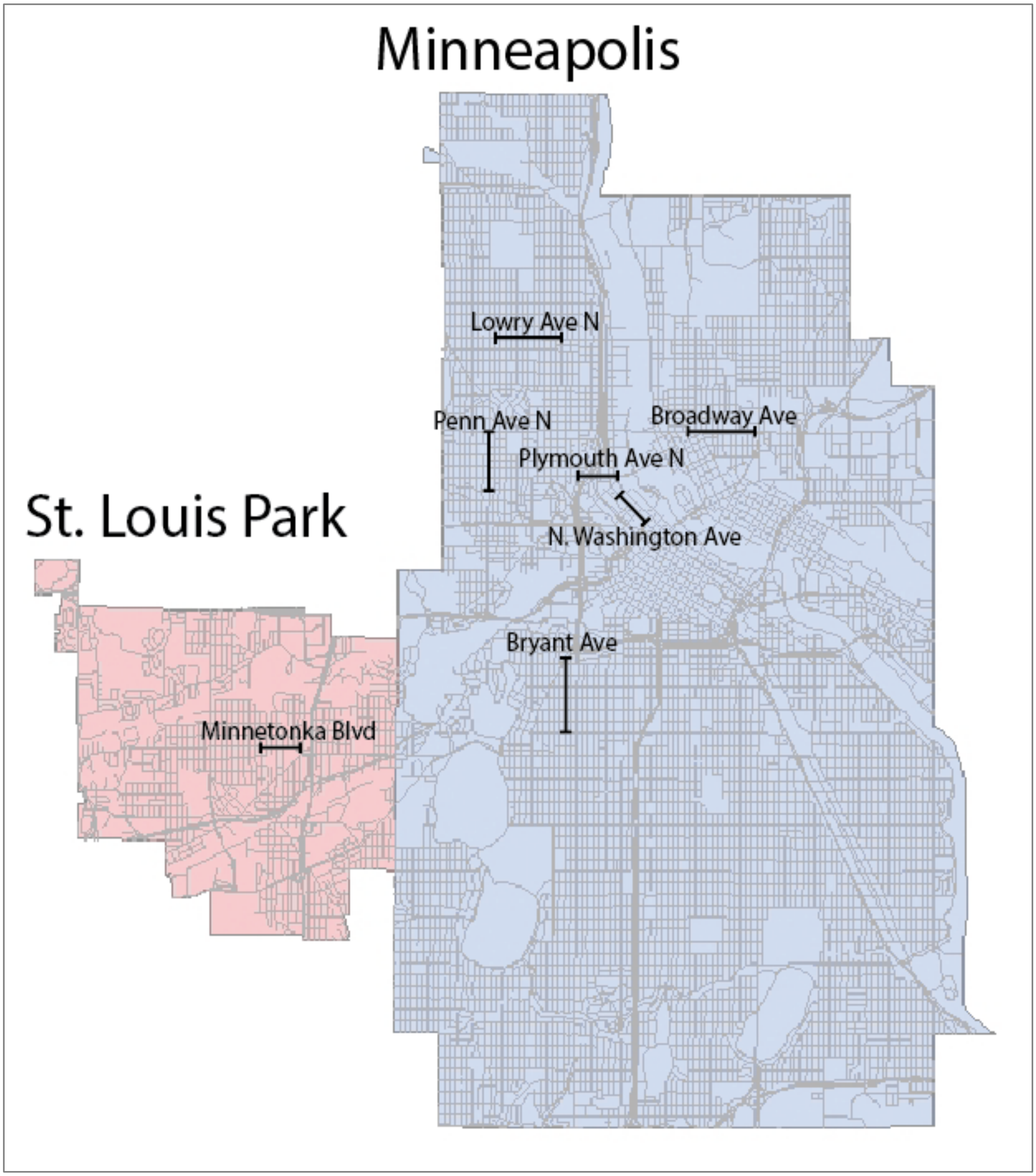

Figure 4. Ride Locations

Table 2. Roadway Summary

Facility	Regression Classification	Roadway	City	Parking	Lanes	Speed Limit	AADT	Type of Delineation	Segment Length (mi)
Bike Boulevard	Bike Boulevard	Bryant Avenue S	Minneapolis	Y	1	30 mph	1,200	Paint	0.78
Shoulder	Bike Lane-Shoulder	Minnetonka Ave	St. Louis Park	N	2	35 mph	14,000	Delineators	0.47
Bike Lane		N. Lowry Ave	Minneapolis	N	2	40 mph	13,400	Delineators	0.62
Buffered Bike Lane	Protected-Buffered Bike Lane	Washington Ave N.	Minneapolis	Y	4	30 mph	14,800	Delineators	0.41
Protected (Bollard) Bike Lane		Plymouth Ave N	Minneapolis	N	2	30 mph	9,700	Delineators	0.31
No Facility	No Facility	Penn Ave N.	Minneapolis	Y	2	40 mph	11,900	Paint	0.50
No Facility		Broadway St NE.	Minneapolis	N	4	40 mph	16,000	Paint	0.51

3.5 Delineation

Before beginning data collection, and in collaboration with Hennepin County's Pedestrian and Bicycle Division, researchers delineated or painted the seven roadways used for testing. Roadways were delineated based on learnings from the preliminary study and testing. Paint was used on roads without a bike facility because of concern about delineators being too much of an obstruction and potentially confusing to drivers. Delineators were placed two feet inside the outside lane, or fog line, and 30 feet apart. Paint was placed 30 feet apart, alternating every 15 feet to create a two-foot path. Figure 5 shows road delineation on Washington Ave N., a buffered bike lane road. Delineators were placed two feet from the inner line of the buffer. Riders traveled in the middle of the two-foot bounded zone between the delineators and the lane line.

Figure 5. Delineation on Washington Ave N.

3.6 Data Collection and Recording

Data collection took place during October of 2017. The goal was to achieve approximately 400 passes (200 male and 200 female) for each bike facility. An approximately half mile section of each roadway was painted or delineated. Researchers rode both sides of the ride segment in a circle until a minimum number of passes (200) were obtained. Riders staggered their starts so as to maintain the independence of each observation, and avoid any possible effects of riding in a group. Data on AADT, and lane widths came from the County's database, while vehicle type categories came from the Federal Highway Administration's classification system.

After completing the data collection, researchers reviewed the video footage and documented the total number of passes, the corresponding passing distance, whether there was a car in the adjacent lane or oncoming, and the vehicle type. If a passing car was over 99 inches from the cyclist, it was recorded as 100 inches since the C3FT radar can measure a maximum distance of 99 inches. Recording distant passes in this way may underestimate the distance of some passing vehicles, and changes the distribution of VPD at the tail. Together this lowers the actual average VPD of the distribution to some degree. Finally, all other variables that did not vary by each observation were added to the dataset before analysis began.

3.7 Analytical Procedures

Two dependent variables were used to measure changes in the relative safety on different types of bike facilities. The first is a continuous variable *Passing Distance* which is the narrowest distance between the overtaking car and the left handlebar of the bike measured in inches. The second, *Encroachments,* is a binary variable derived from *Passing Distance* divided into two categories, 0 if *Passing Distance* was greater than or equal to 36 inches, and 1 if the distance measured was less than 36 inches. The same independent variables were used to explain both dependent variables.

Because the two variables take on different forms they have to be modeled differently. Two types of regression modeling techniques were used to determine the effect that different roadway and rider characteristic variables have on the safety of vehicle-cyclist interactions. The two techniques were (1) A multivariate OLS regression where the independent variables are regressed on a continuous passing distance dependent variable, and (2) a logit model where all independent variables are regressed on the binary *Encroachments* variable. The coefficients from the logit were transformed into odds ratios for ease of interpretation using e^{B_j}.

Analyzing the output of these two models together created a more holistic view for designing roads that result in fewer encroachments, and greater relative road safety. With OLS, we determined how average passing distance changes given a set of independent variables, while the logit showed how the odds of encroachment changes using the same explanatory variables. By analyzing the output of these two models, we will gain insight on how to design safer roads. Our alpha level of significance is 5%.

Independent variables were taken by breaking down each site by its geometric characteristics, number of lanes, lane width, presence of on street parking, etc. Other independent variables included gender of the rider, adjacent or oncoming traffic during each pass and vehicle classification of the passing vehicle. A complete list of variables and their definitions can be found in Table 3.

After deciding on the regression modeling techniques, we began systematically specifying our models with the appropriate variables. First, we tested for the normality of our *Passing Distance* dependent variable and found that it satisfied the assumption of normality required for OLS (Appendix C). Next, we created a correlation matrix using statistical software to eliminate any highly correlated variables that may cause problems with multicollinearity in the model (Appendix C). Any variable with a correlation coefficient above 0.60 was considered too high and taken out of the model. This eliminated *Lane Width, Number of Lanes, AADT,* and *Speed Limit (Slow)*. To further justify this decision, we ran the OLS model

Table 3. Original Variables, Definitions, and Units

Variables	Definition	Unit	Included in Final Regression	Hypothesized Effect on Passing Distance	Hypothesized Effect on Encroachment
Passing Distance (Dependent)	Narrowest distance between the overtaking car and the left handlebar of the bike.	Inches (in.)	Y	---	---
Encroachment (Dependent)	Binary variable accounting for whether or not an encroachment occurred. Encroachments are any passing distance < 36 inches as defined by Minnesota statute.	0: No Encroachment 1: Encroachment	Y	---	---
Oncoming Traffic	The presence of a vehicle in the adjacent lane, directly next to or oncoming during the pass.	0: No Oncoming Traffic 1: Oncoming Traffic	Y	(-)	(+)
Category 3 Vehicles	Class of the passing vehicle based on Federal Highway Administration's vehicle classification categories.	0: Categories 1 & 2 1: Category 3	Y	(-)	(+)
All Other Vehicles (Vehicle Categories ≥ 4)	Class of the passing vehicle based on Federal Highway Administration's vehicle classification categories.	0: Categories 1 & 2 1: All other categories	Y	(-)	(+)
No Facility	Roads where no bicycle infrastructure was present. (Penn Avenue N and Broadway Avenue NE)	0: Protected-Buffered Bike lanes 1: No Bicycle Facilities	Y	(-)	(+)
Shoulder-Bike Lane	Roads where either a shoulder, or a traditional bike lane were present. (Lowry Avenue N and Minnetonka Boulevard)	0: Protected-Buffered Bike Lanes 1: Shoulder and Bike Lanes Combined	Y	(-)	(+)
Bike Boulevard	Low speed, single lane road optimized for bike traffic (Bryant Avenue S)	0: Protected-Buffered Bike Lanes 1: Bike Boulevard	Y	(-)	(+)

Table 3. Original Variables, Definitions, and Units, Continued

Variables	Definition	Unit	Included in Final Regression	Hypothesized Effect on Passing Distance	Hypothesized Effect on Encroachment
Parking	Does the road allow for on-street parking	0: No Parking 1: Parking	Y	(-)	(+)
Lane Width	Width of the road lanes	Feet (ft.)	N	Excluded	Excluded
Number of Lanes	Number of lanes on the road	1,2,3,4	N	Excluded	Excluded
Speed Limit (Slow)	Posted Speed Limit of 30 and 35 mph	0: Speed Limit > 35 mph 1: Speed Limit (Slow)	N	Excluded	Excluded
Annual Average Daily Traffic (AADT)	The number of vehicles on each roadway in one day on average	Number of vehicles per day	N	Excluded	Excluded
Female	Effect of being female relative to male	0: Male 1: Female	Y	(-)	(+)

with every independent variable included, and Stata automatically omitted some variables due to high multicollinearity. The variables to be excluded also had variance inflation factors (VIFs) greater than 10.

The primary explanatory bike facility type variables, *No Facility, Bike Lane-Shoulder, and Bike Boulevard*, are derived combinations of the 6 types of facilities described above (*No Facility, Bike Lane, Shoulder, Bike Boulevard, Protected (Bollard) Bike Lane, and Buffered Bike Lane*). The consolidation of these facilities into three variables was based on similarity in function, and are all in reference to a fourth variable *Protected-Buffered Bike Lanes. Protected-Buffered Bike Lanes* are a combination of protected bike lanes and buffered bike lanes and were collapsed for the regression because results were similar. *No Facility* combines the data from the two no facility roads, Broadway Avenue Northeast and Penn Avenue North. *Bike Lane-Shoulder* joins the data from Minnetonka Avenue (shoulder) and Lowry Ave North (bike lane). This was done with the rationale that operationally a shoulder acts like a bike lane by giving the rider the same amount of functional protection, an approximately 4-inch thick painted line. Finally, *Bike Boulevard* contains only the data from Bryant Avenue S as bike boulevards are uniquely designed in comparison to the rest of the facilities in this study.

The Federal Highway Administration (FHWA) has guidance for how to classify vehicles, separating them into 12 different categories based on the number of axles, tires, and size (Appendix D). While recording data from the GoPro camera footage we noted the category that the passing vehicle fell under. Table 4 is a breakdown of the FHWA categories and the groupings to create our explanatory variables. For purposes of modeling, the 12 categories of vehicles in the FHWA classification are reduced to four based on similar results and whether the number of vehicles observed in each category was sufficient for analysis. After processing the data there were not enough Category 1 or Category 4 through 12 vehicles to maintain a statistically robust sample to warrant 12 separate categories. In fact, there were no vehicles above Category 8 recorded. We therefore collapsed Category 1 and Category 2 into a single independent variable to act as the reference for our other two explanatory variables, *Category 3 Vehicles* and *All Other Vehicles*.

Table 4. FHWA Vehicle Classification Summary

FHWA Vehicle Classification	Researcher Groupings
Category 1	Category 1 & 2
Category 2	
Category 3	Category 3
Category 4	All Other Categories
Category 5	
Category 6-12	

Finally, we hypothesize about whether the effect of each explanatory variable on the appropriate dependent variable would be positive or negative. First, in the multivariate OLS model we anticipate that the coefficient on every bike facility type should be negative given that the two facilities included in the reference *Protected-Buffered Bike Lanes* category have the highest overall average lateral passing distance. This would suggest that each facility should decrease passing distance relative to the reference. We follow a similar logic with our vehicular categories. *Category 3 Vehicles* and *All Other Vehicles* contain larger vehicles overall, and have less room to maneuver than the reference category vehicles. Therefore, all coefficients on our vehicular category variables should theoretically be negative.

For the last three explanatory variables, the literature and theory suggest that the presence of oncoming traffic and on street parking should decrease passing distance, or return a negative coefficient. Shackel points out that "an oncoming vehicle may affect: (a) the decision by a driver to overtake a cyclist; (b) the overtaking speed; and (c) the passing distance". Without oncoming traffic, drivers are less constrained and have more space to maneuver around the cyclist. The presence of on street parking should also decrease passing distance as the cyclist must bike further into the travel lane to safely bike past a parked car and avoid the risk of hitting an open door. Based off our summary data, and literature review, we expect *Female* to also have a negative coefficient.

Since the logit model is testing how the probability of being encroached upon differs holding constant all other explanatory variables, we expected that what causes a decrease in passing distance should cause an increase in probability of being encroached upon. Coefficients were expected to be positive where they were negative in the multivariate OLS model, but relying on the same theoretical reasoning. Given our specifications of our two models and hypothesized direction of the effects, our final model equations are as follows:

(1) Multivariate OLS Regression Equation:

$$PassingDistance = \hat{\beta}_0 - \hat{\beta}_1 No\ Facility - \hat{\beta}_2 ShoulderBikeLane - \hat{\beta}_3 Bike\ Boulevard - \hat{\beta}_4 Parking - \hat{\beta}_5 OncomingTraffic - \hat{\beta}_6 Category3Vehicles - \hat{\beta}_7 AllOtherVehicle + \hat{\beta}_8 Female + \varepsilon$$

(2) Logit Regression Equation:

$$L: PR\ (Encroachment = 1) = \hat{\beta}_0 + \hat{\beta}_1 No\ Facility + \hat{\beta}_2 ShoulderBikeLane + \hat{\beta}_3 Bike\ Boulevard + \hat{\beta}_4 Parking + \hat{\beta}_5 OncomingTraffic + \hat{\beta}_6 Category3Vehicles + \hat{\beta}_7 AllOtherVehicles + \hat{\beta}_8 Female + \varepsilon$$

4. Results

After riding each site segment and recording the appropriate data, as described above, there were a total of 2,949 passing events, 1,408 for male riders and 1,541 for the female rider (Table 5).

4.1 Descriptive Statistics

4.1.1 Facility Type, Passing Distance, and Encroachment

The average VPD overall was 70 inches, while the median passing distance was 68 inches (Table 5). The average passing distance was greatest at 90 inches on the bollard bike lane and lowest on the two roadways with no bicycle facilities, and the standard painted bicycle lane road. Median passing distances followed the same pattern. Each median passing distance was within 2 inches of the average for every road segment and the distribution of data generally followed a normal distribution (Table 5).

There were 33 encroachments (passes less than 36 inches) resulting in a 1.12% encroachment rate for all observations. 64% of these encroachments occurred on Broadway Avenue Northeast, a no facility road. The bike boulevard, Bryant Avenue South, had the second highest number of encroachments with 15% of all encroachments. The encroachment rate on Broadway Avenue Northeast was the highest at 5.69%. All other roads had encroachment rates less than, or near 1%.

Table 5. Facility Type Summary

Facility	Total Passes	Average Passing Distance (inches)	Median Passing Distance (inches)	Minimum Passing Distance (inches)	Maximum Passing Distance (inches)	Encroachments	Encroachment Rate
Buffered Bike Lane	426	77	76	34	100	1	0.23%
No Facility (4 Lane)	369	63	64	13	100	21	5.69%
Bike Boulevard	455	65	64	25	100	5	1.10%
No Facility (2 Lane)	437	62	61	23	100	3	0.69%
Bike Lane	425	62	62	33	100	3	0.71%
Shoulder	420	69	67	43	100	0	0.00%
Protected Bike Lane	417	90	92	51	100	0	0.00%
Total	2949	70	68	13	100	33	1.12%

Passes were analyzed in 6" increments to illustrate the distribution of passing distances (Figure 6). Most passes (15%) occurred in the 61-66" (5-5.5 feet) range with some passes in each of the 6" ranges. 72% of the observations are between 49" and 84" or about 4 to 7 feet away from the cyclist. Figure 6 shows the normal distribution of data around the average with the only exception being data over 100 inches or outside of the C3FT radar's measureable range.

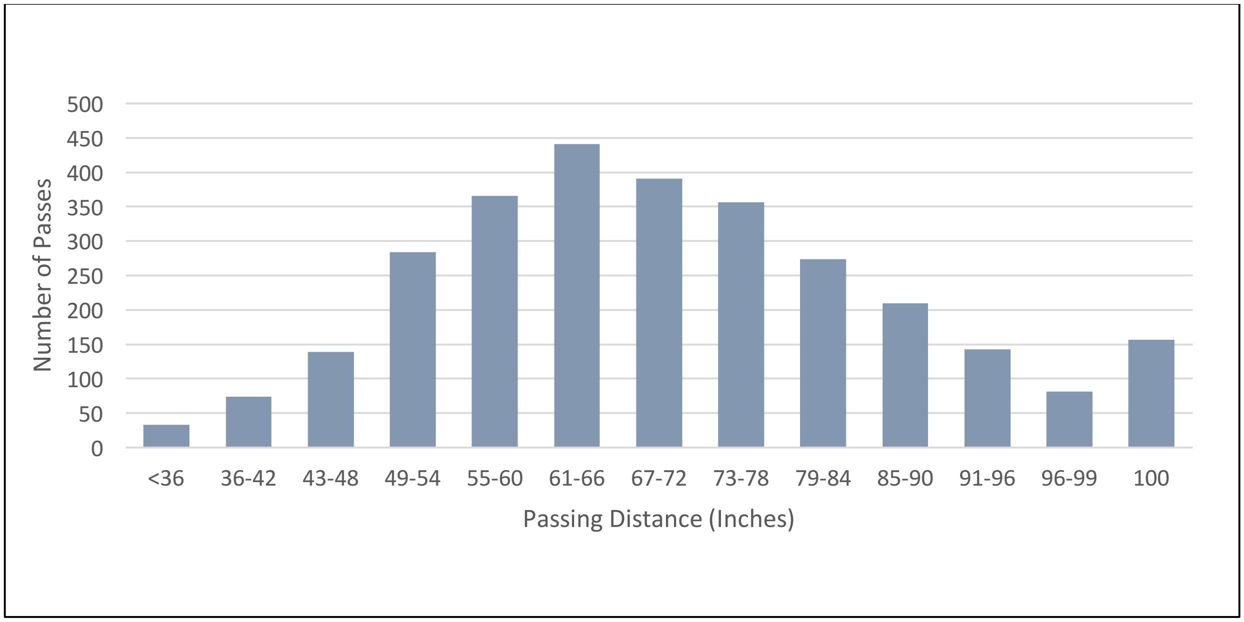

Figure 6. Passing Distance Distribution

4.1.2 Vehicle Type, Passing Distance, and Encroachment

Table 6 breaks down average passing distance and encroachment differences between vehicle classifications. Most vehicles that passed cyclists were lightweight Category 2 vehicles. The smallest vehicles are in Category 1, and larger vehicles are in Categories 4 and above. Table 6 reports the raw data for each vehicle classification, and the final categories used in the regression since these categories were combined for statistical significance. In general, as vehicle size (category) increases, the passing distance decreases. Though few in number, Category 1 vehicles have the largest average passing distance, as seen in Figure 7, and no recorded encroachments. The 1,844 Category 2 vehicles had an average passing distance of 72 inches, while the average of the 984 Category 3 vehicles is 67 inches.

Most encroachments (88%) were Category 2 and Category 3 vehicles. However, these vehicles represented 96% of the total observed passes. To start to get a better idea of the propensity to encroach, it is better to look at the percentage of vehicles in their respective category that encroached. When looked at in this way, Category 4 and 5 vehicles seem to have the highest likelihood of encroachment. 3.1% of category 4 vehicles and 5.3% of category 5 vehicles encroached. Encroachments followed the same trend as passing distance. Bigger vehicles had a higher proportion of encroachments.

4.1.3 Gender, Passing Distance, and Encroachment

On average, passing distance was smaller for the female rider than the two male riders. The average passing distance is 71 inches for the male riders and 68 inches for the female rider, as seen in Table 7.

The minimum observed for male riders is 13 inches and 16 inches for a female rider. More importantly, of the 33 encroachments, the female rider experienced 24 (73%) of them.

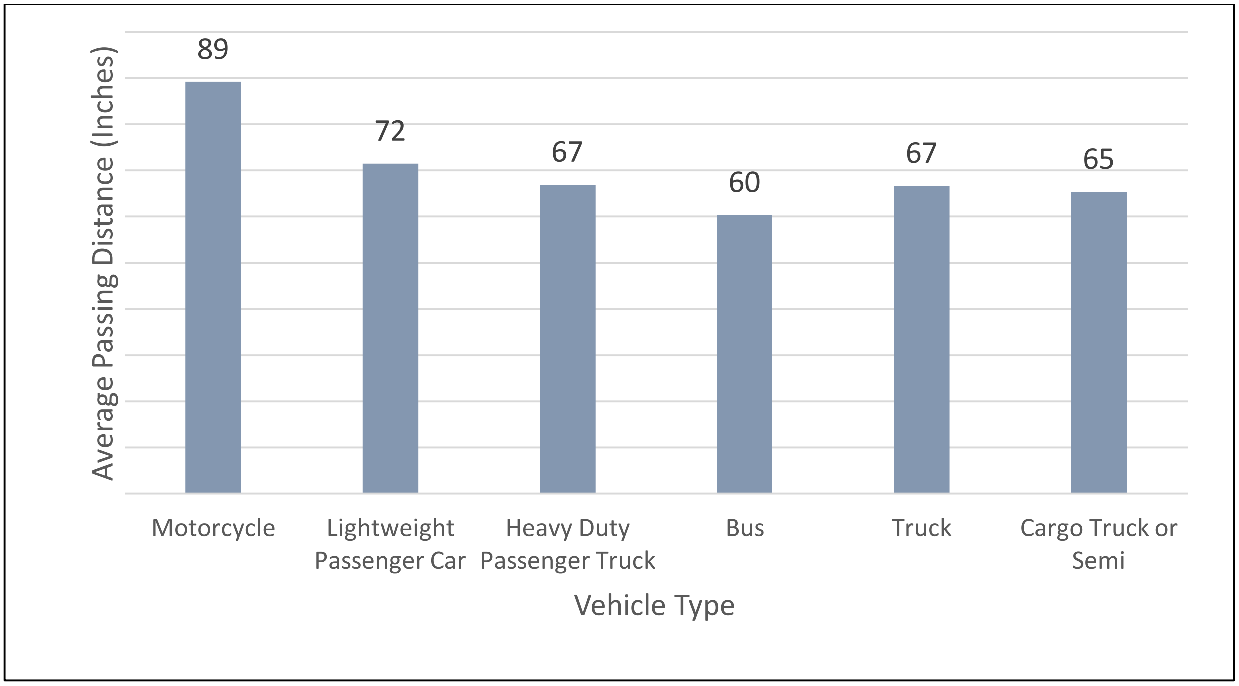

Figure 7. FHWA Average Passing Distance by Vehicle Classification

Table 6. FHWA Vehicle Categories Data Summary

	Individual Categories					Combined Categories	
Summary of Passing Vehicles	Total	Average Passing Distance (Inches)	Number of Encroachments	Encroachment Rate within Category	% Of Total Encroachments	Encroachment Rate within Category	% of Total Encroachments
Category 1 Motorcycle	13	89	0	0.0%	0.0%	0.9%	51.1%
Category 2 Lightweight Passenger Car	1844	72	17	0.9%	51.1%		
Category 3 Heavy Duty Passenger Truck	984	67	12	1.2%	36.4%	1.2%	36.4%
Category 4 Bus	65	60	2	3.1%	6.1%	3.7%	12.1%
Category 5 Truck	38	67	2	5.3%	6.1%		
Category 6-12 Cargo Truck or Semi	5	65	0	0.0%	0.0%		

Table 7. Summary Statistics by Gender

Summary	Total Observations	Average Passing Distance (inches)	Median Passing Distance (inches)	Minimum Passing Distance (inches)	Maximum Passing Distance (inches)	Encroachments	Encroachment Percentage
Total	2949	70	68	13	100	33	1.12%
Male	1408	71	70	13	100	9	0.64%
Female	1541	68	67	16	100	24	1.56%

4.2 Regression Results

Table 8 displays the results of running the regression models.

Table 8. Regression Results

Model	(1)	(2)
VARIABLES	Passing Distance (OLS)	Encroachment (Odds Ratio Logistic)
Category 1&2 Vehicles	Reference	Reference
Category 3 Vehicles	-2.647***	1.070
	(0.524)	(0.426)
All Other Vehicles	-6.124***	3.450**
	(1.307)	(2.047)
Adjacent Vehicles	-7.723***	9.011***
	(0.656)	(4.331)
Female	-2.714***	3.828***
	(0.494)	(1.696)
Protected-Buffered Bike Lanes	Reference	Reference
No Facility	-18.13***	17.86***
	(0.675)	(18.49)
Bike Lane-Shoulder	-14.41***	0.811
	(0.686)	(0.981)
Bike Boulevard	-17.24***	94.00***
	(0.814)	(118.1)
Parking	-1.618***	0.052***
	(0.534)	(0.0319)
Constant	86.66***	0.00074***
	(0.589)	(0.00079)
Observations	2,949	2,949
R-squared	0.339	

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

4.2.1 Effect of Bike Facility on Passing Distance and Encroachment

The multivariate OLS regression reinforces the summary statistics findings about passing distance differences between types of bicycle facility, as seen in Table 8. Relative to the *Protected-Buffered Bike Lanes*, passing distance on roads without bike facilities is on average 18.13 inches closer after removing the effect of all other variables on *Passing Distance*. This decrease is followed closely by *Bike Boulevard* and *Bike Lane-Shoulder* which are on average 17.24 inches and 14.41 closer compared to *Protected-Buffered Bike Lanes* respectively.

Interestingly, when it comes to the logit model, a cyclist is actually much more likely to be encroached upon on a bike boulevard than any other bike facility. In fact, the odds that a rider is encroached upon are 94 times greater on the *Bike Boulevard* than the *Protected-Buffered Bike Lanes*, holding all else constant. Moreover, even though one of the two roads included in the *No Facility* category had the majority of total encroachments, when combined with the other no facility road, the odds of being encroached upon relative to *Protected-Buffered Bike Lanes* are 18 times greater. The presence of adjacent vehicles on the no facility roads explains some of this variation. When it comes to the *Bike Lane-Shoulder* category, the odds of an encroachment occurring were 0.811 times greater compared to the reference. However, this coefficient is not significant, which implies that though cars are closer on these roads (14.41 inches closer on average), they are not so close as to result in more encroachments.

4.2.2 Effect of Vehicle Type on Passing Distance and Encroachment

The results from Model 1 show that *Passing Distance* steadily decreases as passing vehicles become larger. Relative to *Category 1&2 Vehicles* (motorcycles and smaller passenger vehicles), *Category 3 Vehicles* (Vans, SUVs and Crossovers) pass cyclists on average 2.65 inches closer, after removing the effect of all other variables on the dependent variable. *All Other Vehicles* pass cyclists about 6 inches closer on average than Category 1&2 Vehicles, holding all else constant. What was not taken into account was whether or not this is a function of the overall size of the vehicle, leaving the driver less room to maneuver the larger the vehicle.

At the 5% level of significance, the odds of getting encroached upon by a vehicle in the *All Other Vehicles* category are 3.45 times greater than *Category 1&2 Vehicles,* at a fixed value. Overall, it appears that larger vehicles pass closer on average than smaller vehicles, but increased proximity does not necessarily translate into higher odds of encroachment in all categories.

4.2.3 Effects of Other Roadway Characteristics on Passing Distance and Encroachment

Other roadway characteristics include whether or not there were adjacent vehicles, and if the road had on street parking. More so than any other variable outside of the three facility types, the presence of an adjacent vehicle played the largest role in reducing the distance between a cyclist and vehicle during a pass. On average, holding all other variables constant, *Adjacent Vehicles* reduce passing distance by approximately 7.7 inches compared to when adjacent vehicles are not present. This distance reduction results in a significant increase in the likelihood of encroachment. Holding all other variables constant, the odds of being encroached on are about 9 times higher with an adjacent vehicle present than without. This fits well with other studies that found adjacent vehicles to be an important factor in determining passing distance, and with our hypothesized relationship.

As already mentioned, when roads had on street parking the route the riders took was set up in a way as to mimic the conditions if a car were parked in every possible parking spot. Therefore, holding rider position constant. Parking had a smaller, but still significant effect in both models. Relative to no on street parking, roads that allow cars to park on the side of the road decreased passing distance by about 1.6 inches on average, holding all other variables constant. However, this translated into a decrease in the odds of an encroachment occurring. Roads with parking have 0.052 times odds of being encroached upon than roads without on street parking, holding all other variables constant at their means. This only partially conforms to our above hypothesis as parking moves cyclists and cars closer together, but actually decreases the likelihood of encroachment. This could be because one of the roads in the *Protected-Buffered Bike Lane* category allowed on street parking.

4.2.5 Effects of Gender on Passing Distance and Encroachment

The variable *Female* measures any differences in effects for the female rider relative to the two male riders. The female rider was passed on average about 2.7 inches closer than the male riders, holding all other variables constant. The likelihood of the female rider being encroached upon are around 3.8 times greater than for a male rider, holding all other variables constant. This matches with the above hypothesis based on the raw number of encroachments, and conforms to past studies that show female riders are more likely to be involved in conflicts at intersections.

5. Discussion

Passing distance and encroachments are important factors for practitioners to consider to improve bicycle safety and cyclist interactions with vehicles. Vehicles that pass closer than 36 inches of a cyclist in Minnesota are encroaching. Strategies should be put in place that can minimize encroachments, and increase this aspect of cyclist safety on roads. Overall, only 1.12% of passes in our study were encroachments, and most of these were on roads without bicycle facilities. Moreover, only one encroachment took place on the lowest risk, *Protected-Buffered Bike Lanes* facilities.

As expected, there are significantly wider passing distances on *Protected-Buffered Bike Lanes* relative to other facility types studied. Our observations show that average passing distance on a bollard bike lane road is 90 inches while our regression modeling showed that facility type was statistically significant and all other types of facilities, including no facilities, have passes that are 14 to 18 inches closer than the *Protected-Buffered Bike Lanes*. Our research confirms Shackel and Parkin (2014) and La Mondia and Duthie (2012) findings that road geometry influences lateral clearance distance.

Importantly, our regression analysis showed that despite having a significantly lower passing distance than *Protected-Buffered Bike Lanes*, *Bike Lane-Shoulder* did not have a statistically significant increased chance of encroachment relative to *Protected-Buffered Bike Lanes*. This means that when expanding bike infrastructure networks, planners should prioritize protected or buffered bike lanes, but that standard bike lanes and wider shoulders may be as safe in terms of risk of encroachment. The rest of the facilities both decreased passing distance and increased the chances of encroachment.

Bike boulevards had the highest odds of an encroachment and had similar passing distances to a no facility site. If planners are trying to promote safety through fewer encroachments and increased passing distance, our research indicates that bicycle boulevards provide no additional benefit than a no facility road. Other factors that may mitigate this include driver awareness and behaviors during passing not captured in this study.

With regards to vehicle type, our study found that Category 3 vehicles had a lower passing distance but didn't have a statistically significant higher probability of encroachments than Category 1&2. Vehicles larger than Category 3 were 6 inches closer on average and had a higher chance of encroachment than Category 1&2, confirming the Dozza et al. study that finds that trucks pass significantly closer. Bicycle safety can be improved by planning roads for large vehicles to drive without interfering with popular bicycle routes.

Confirming Stipenc et al., our study found gender is a significant variable determining passing distance. One limitation to this finding is that there is only one female rider, so it is unclear if VPD and encroachment rates were directly gender related or related to other rider characteristics such as height of the rider, rider appearance etc. Love et al. find that individual rider characteristics are significant. Future studies looking at passing distance and encroachment should include multiple female participants to fill this gap in the literature. Yet, our study found that the female rider was 3.8 times more likely to be encroached upon, warranting prioritizing investment in protected and buffered facilities that had 0% encroachment rates for all riders.

Although the primary focus of this study was not perception of safety, the three researchers felt that in order to feel safe when cycling near traffic, additional research might be needed even when passing distance is above 36 inches. Researchers noticed feeling unsafe during the study even when they weren't encroached upon. A vehicle passing at a high rate of speed, with oncoming traffic and on street parking can create an environment that feels dangerous. Additional research should look to capture perception of safety and vehicle speed in combination with passing distance data to measure the effect these variables have on the feeling of safety. This is a key aspect if a city is working to increase bicycle ridership especially for children or families that have a higher standard for safety when cycling.

6. Conclusion

This study contributes to recent research on VPD while overtaking cyclists. Equipment used in this study was effective and can continue to be used to measure passing distance. Our study showed that overall encroachment rate is low. Key variables explaining passing distance and encroachment are facility type, vehicle type (only passing distance), adjacent vehicles, parking and gender. Protected or buffered bicycle facilities are best at reducing passing distance and rate of encroachment, but bike lanes and wide shoulders also reduce the likelihood of encroachment. Large vehicles were found to lower passing distance and increase encroachments. Results of the study will guide policy makers to install bicycle infrastructure that creates safe environments for traffic and cyclists to coexist without the safety risks associated with encroachment. Additional research is needed to understand how passing distance and a feeling of safety are related to VPD and encroachment, and how this might lead to additional ridership. This research confirms that road design and traffic planning decisions impact how vehicles and cyclists interact.

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Appendix A: Scope of Work

Vehicle Passing Distance Experimental Study

Scope of Work

1. Problem Statement

Hennepin County is interested in expanding bicycle infrastructure to encourage more people to choose cycling as a mode of transportation. Part of this work is understanding what type of bicycle infrastructure will provide a safe environment. Our research will measure passing distance against the encroachment minimum established by Minnesota Statute 169.18, Subdivision 3 of 3ft (36 Inches) as the minimum lateral distance a vehicle must maintain while passing a cyclist.

There is limited research on the effect bicycle infrastructure has on encroachment. Our research will investigate vehicular encroachment into the bicycle right of way on urban roadways. We will measure vehicle encroachment using field experiments on seven roadways, each with different types of bicycle infrastructure. To gather passing distance data we will use a C3FT radar and GoPro camera set-up originally used for police enforcement and compare how passing distance varies by road type.

2. Goals of the Agreement

The goal of our study will be to measure and determine variables that impact the probability of vehicle-bicycle encroachment and overall lateral distance. Our main purpose is to determine how encroachment differs based on the type of bicycle infrastructure and to test the influence of other variables such as vehicle type and gender on encroachment.

3. Objectives of the Agreement/Deliverables

Task: We will aim to measure passing distance of 200 cars on seven different road types for a female rider and for a male rider. Several bike infrastructure, road, and bike rider characteristics will be analyzed to determine leading factors influencing vehicle encroachment.
The following road types will be chosen in urban settings to isolate bicycle infrastructure, thus eliminating the need for urban vs rural setting as an independent variable.

Roads that will be studied include:

- Bryant Avenue S
- Minnetonka Ave
- Washington Ave
- Plymouth Ave N
- Marshall St. NE
- NE Lowry Ave
- N Lowry Ave from W Broadway Ave to 3rd St

Deliverable: A written report and analysis of encroachment on seven roadway types. A regression analysis will be performed to determine variables that have the most impact on encroachment.

Interim reports include:

- Scope of work
- Draft to client before the final submission
- Final draft that will also be submitted to a journal for publishing

4. Administration

There will be several ongoing deadlines that the group will meet. These include:

- Weekly group meetings that will take place on Tuesdays
- Weekly email or phone calls to touch base with the client
- Project team and client meeting prior to the grant deadline at the end of October
- Monthly project report drafts will be submitted to the instructor

5. Timeline

Field work 9/21-10/15

- 9/15 - Draft scope of work
- 9/21 - First road test
- 10/15 - Complete all data collection

Reports 9/27-12/12

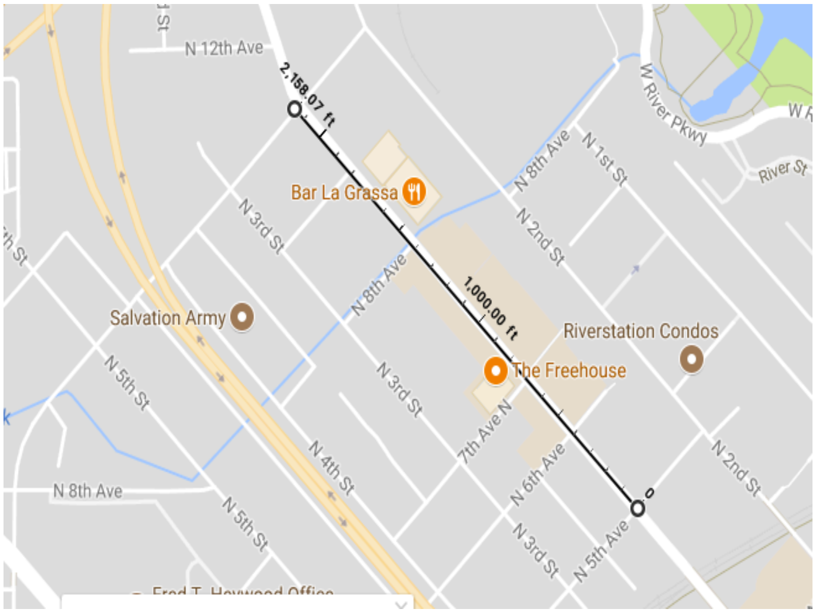
- 9/27 - First draft - *Initial literature review, draft of ride plans, overview of first test results*
- 10/24 - Second draft - *Initial analysis including summary statistics, ride observations, complete literature review*
- 11/21 - Third Draft - *Complete statistical analysis, initial conclusions, full report draft*
- 12/12 - Final Draft
- Mid December - Presentation

6. Glossary

- Encroachment: Minnesota Statute 169.18, Subdivision 3 establishes 3ft (36 Inches) as the minimum lateral distance a vehicle must maintain while passing a cyclist.
- Urban: Within the Minneapolis city boundary.
- Delineators: Reflective raised pavement marker used to aid researchers in maintaining a consistent riding position in the road.

Appendix B: Ride Plans

Ride Plan I: Final Methodology Testing with Hennepin County



Location:

N. Washington Ave. (Meet at Whole Foods.)

Hennepin County Classification:

Buffered bike lane

Distance:

Approximately **0.40 miles** (2,158 feet) between 5th Ave N. and 10th Ave N. for a total of approximately **.80 miles** or two thirds of a mile after delineating both sides of the road. Delineating both sides of the road is ideal because it allows the riders to maximize their collection time by biking a circular route.

Delineation Style:

Delineators should be placed in intervals of 30ft in a single line. Each delineator should be placed **2ft (24in) from the inner line of the buffer** on the side closest to traffic. This will control for rider position.

(See Appendix for visual example)

Estimated Number of Delineators Needed:

(Total Distance of Route/30ft between delineators) * 1 line

(2,158ft/30ft) * 1 * 2 = 144

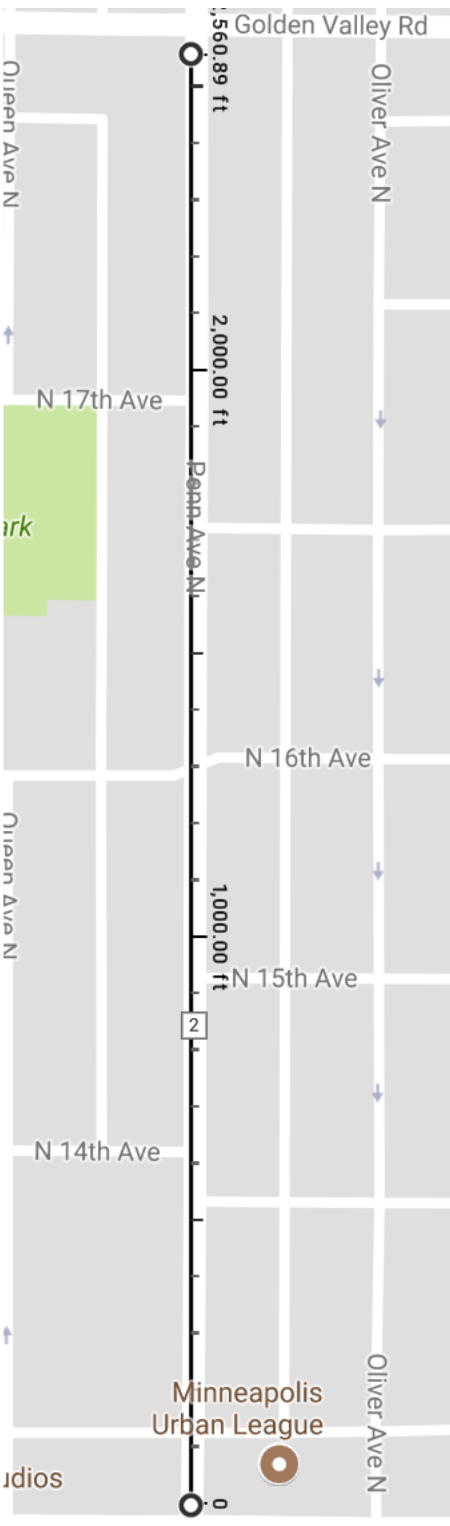
Therefore, it is recommended to **bring 150-160** delineators to have some backup delineators.

Purpose of Ride:

This ride will give the researchers a chance to field test the entirety of the draft protocol created this summer (2017), finalize design elements (i.e. the use of delineators, time it takes to capture and analyze the appropriate number of passes, appropriate distance to delineate, etc.), and be an example for mutual learning and communication between the county and researchers for the future data collection portion of the study.

Figure B1: How to Delineate Washington Ave Buffered Bike Lane (Not to Scale)

Ride Plan: Penn Ave North



Location:

Penn Avenue North

Hennepin County Classification:

Two lane road with no bike facilities

Distance:

A little less than **0.5 miles** (2,561 ft) between Golden Valley Road and Plymouth Avenue North for a total of **approximately 1 mile** after delineating both sides of the road. Delineating both sides of the road is ideal because it allows the riders to maximize their collection time by biking a circular route. It also gives the researchers flexibility in measuring time of day and capturing the most passes possible.

Delineation Style:

Penn Avenue North has parking on both sides of the road and no bike facilities. On a single side of the road, paint should be placed in two parallel lines separated by 2 ft. Each painted demarcation should be in intervals of 15ft, alternating between the two lines. To clarify, the two parallel lines are offset by 15 ft, but in an individual line, distance between the marks is 30 ft. This will be done on both side of the road to maximize passes in a circular route.

Given that large SUVs approach a width of 80 inches (6.5 ft), Paint should be placed placed inches 90 inches (7.5 ft) feet and 114 inches (9.5) feet from the curb. This controls for rider position under the assumption that the average rider would ride approximately in the path created if cars were parked in every available spot.

(See Appendix for visual example)

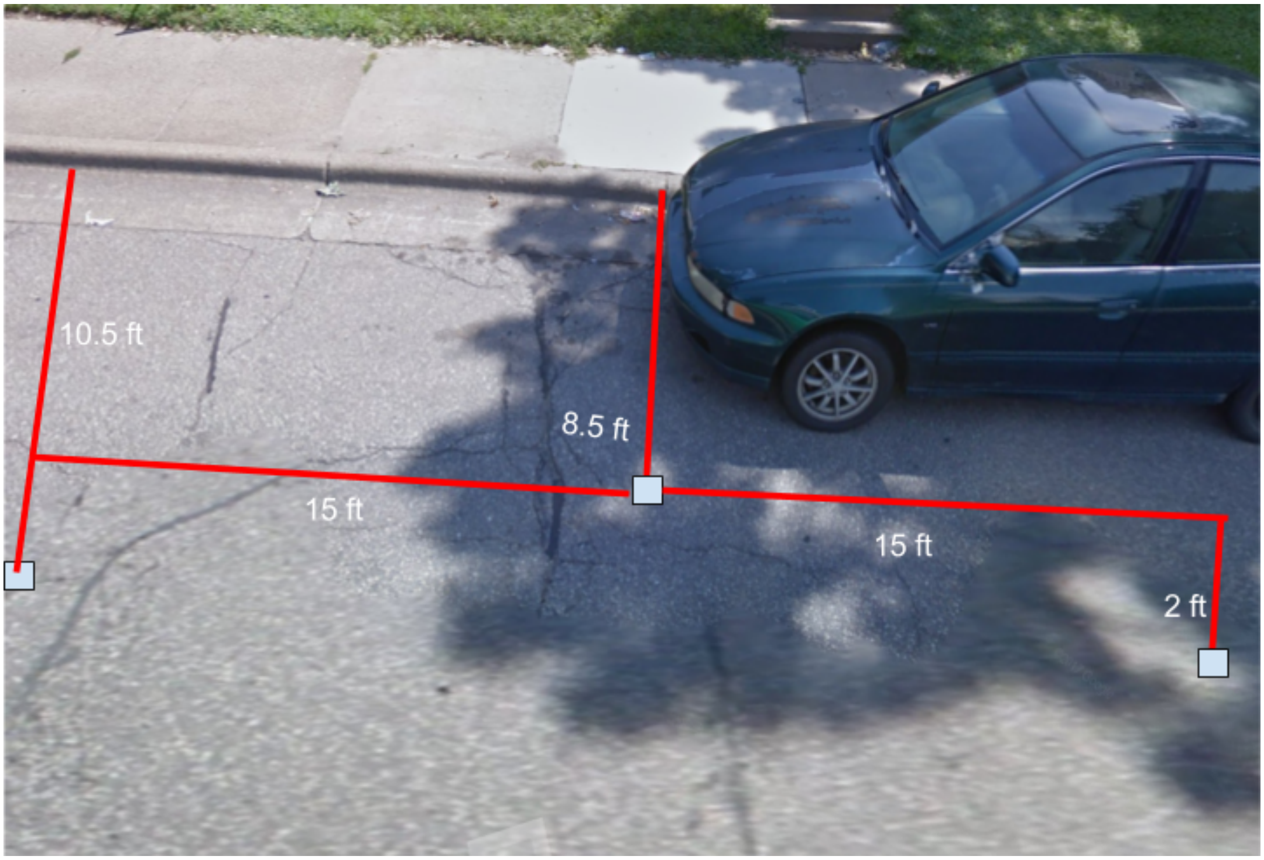
Estimated Number of Delineators Needed:

To ensure that driver behavior is not influenced by the presence of delineators sticking out of the ground, paint will be used to delineate.

Purpose of Ride:

Data collection of passing distance on a two lane road without a bicycle facility.

Figure B2: How to Delineate Penn Avenue (Not to Scale)



Ride Plan: Lowry Ave N.

Location:

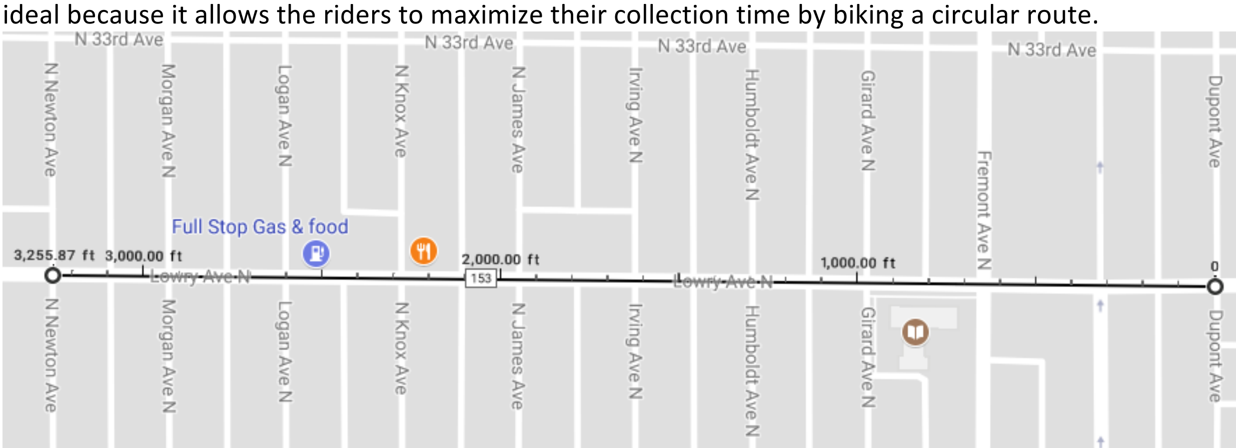
Lowry Ave North

Hennepin County Classification:

Bike Lane (Traditional)

Distance:

Approximately **0.62 miles** (3,256 feet) between N Newton Ave and Dupont Ave for a total of approximately **1.24 miles** after delineating both sides of the road. Delineating both sides of the road is ideal because it allows the riders to maximize their collection time by biking a circular route.



(Image Courtesy of Google Maps)

Delineation Style:

Delineators should be placed in intervals of 30ft in a single line. Each delineator should be placed **2ft (24in) from the inner line of the bike lane** on the side closest to traffic. This will control for rider position.

(See Appendix for visual example)

Estimated Number of Delineators Needed:

(Total Distance of Route*2/30ft between delineators) * 1 line *2 sides of the road

(3,256ft/30ft) * 1 * 2 = 217

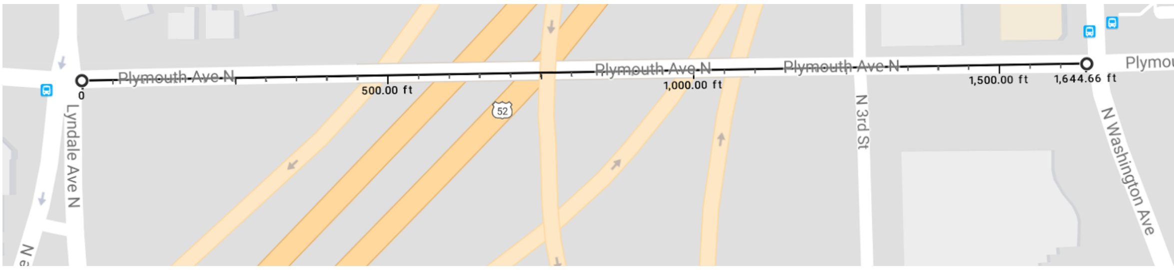
Therefore, it is recommended to **bring 220 - 230** delineators to have some backup delineators.

Purpose of Ride:

Data collection of passing distance on a road with a bike lane.

Figure B3: How to Delineate N Lowry Ave- Bike Lane (Not to Scale)

Ride Plan: Plymouth Avenue North



<u>Location:</u>

Plymouth Avenue North

<u>Hennepin County Classification:</u>

Protected Bike Lane

<u>Distance:</u>

The ride will take place on Plymouth Avenue North between Lyndale Avenue North and North Washington Avenue. The round trip distance is about 3,290 feet (0.62 miles).

<u>Delineation Style:</u>

Delineators should be placed in intervals of 30ft in a single line. Each delineator should be placed **<u>2ft (24in) from the line of the bike lane</u>** closest to traffic. This will control for rider position.

(See Appendix)

<u>Estimated Number of Delineators Needed:</u>

Total Distance * 2 lines/Distance Between Delineators

(1645 ft*2)/30 ft =110

Therefore, it is recommended to **<u>bring 110-120</u>** delineators incase backup delineators are needed.

<u>Purpose of Ride:</u>

Data collection of passing distance on bullard bike lanes.

Figure B4. Example of road delineation on Plymouth Ave N.


2 ft
30 ft
Plymouth Ave N

Ride Plan: Minnetonka Blvd.

Location:

Minnetonka Blvd.

Hennepin County Classification:

Urban road with shoulder

Distance:

Approximately **0.47 miles** (2,475 feet) between Webster Avenue South and Dakota Ave S. for a total of **approximately .94 miles** after delineating both sides of the road. Both sides of the road should be delineated to allow for a maximum number of passes.

Delineation Style:

Delineators should be placed in intervals of 30ft in a single line. Each delineator should be placed **2ft (24in) from the fog line** to control for rider position.

(See Appendix for visual example)

Estimated Number of Delineators Needed:

(Total Distance of Route/30ft between delineators) * 1 line

(4,950ft/30ft) * 1 = 165

Therefore, it is recommended to **bring 170-175** delineators incase backup delineators are needed.

Purpose of Ride:

Data collection of passing distance on a road with a shoulder.

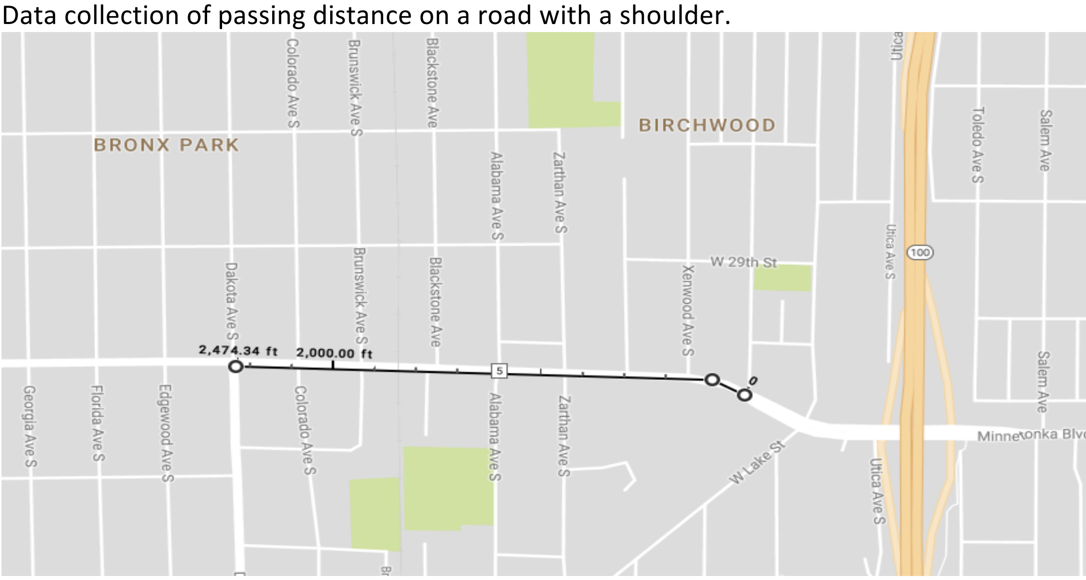


Figure B5. Example of road delineation on Minnetonka Blvd.

Ride Plan: Broadway St NE

Location:

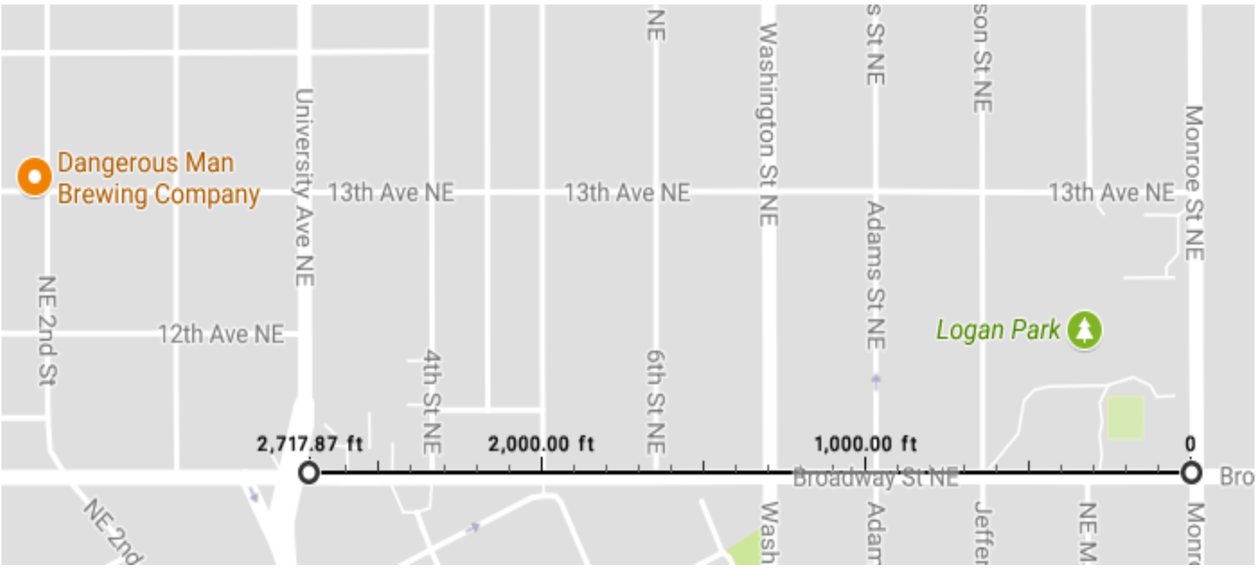
Broadway St NE

Hennepin County Classification:

4 Lane road with no bicycle facility

Distance:

Approximately **0.51 miles** (2,717 feet) between Monroe st and University for a total of approximately **1.02 miles** after painting both sides of the road. Painting both sides of the road is ideal because it allows the riders to maximize their collection time by biking a circular route.



(Image Courtesy of Google Maps)

Paint Style:

Paint should be placed in intervals of 30ft in a single line. The paint strip should be a similar size to a delineator (A few inches long). Each paint strip should be placed **2ft from the curb**. This will control for rider position.

(See Appendix for visual example)

Estimated Number of Paint Stripes (Size of a delineator):

(Total Distance of Route/30ft between paint) * 1 line * 2 Sides of the road

(2,717ft/30ft) * 1 * 2 = 181

Purpose of Ride:

Data collection of passing distance on a four lane road without a bicycle facility.

Figure B6: How to paint Broadway St NE four lane road without bicycle facility (Not to Scale)

Ride Plan: Data Collection on Bryant Ave S.

<u>Location:</u>

Bryant Avenue S.

<u>Hennepin County Classification:</u>

Bike boulevard

<u>Distance:</u>

Approximately **<u>0.8 miles</u>** (4,117 feet) between Aldrich Avenue South and 28th St for a total of **<u>approximately 1.6 miles</u>** after delineating both sides of the road. Both sides of the road should be delineated to allow for a maximum number of passes.

<u>Paint Style:</u>

Bryant Ave S. has parking on both sides of the road and no bike facilities. On a single side of the road, paint should be placed in two parallel lines separated by 2 ft. Each painted demarcation should be in intervals of 15ft, alternating between the two lines. To clarify, the two parallel lines are offset by 15 ft, but in an individual line, distance between the marks is 30 ft.

Given that large SUVs approach a width of 80 inches (6.5 ft), and that Bryant Avenue is so narrow, paint should be placed placed 90 inches (7.5 ft) feet and 114 inches (9.5) feet from the curb. This controls for rider position under the assumption that the average rider would ride approximately in the path created if cars were parked in every available spot.

(See Appendix for visual example)

<u>Estimated Number of Delineators Needed:</u>

To ensure that driver behavior is not influenced by the presence of delineators sticking out of the ground, paint will be used to delineate.

<u>Purpose of Ride:</u>

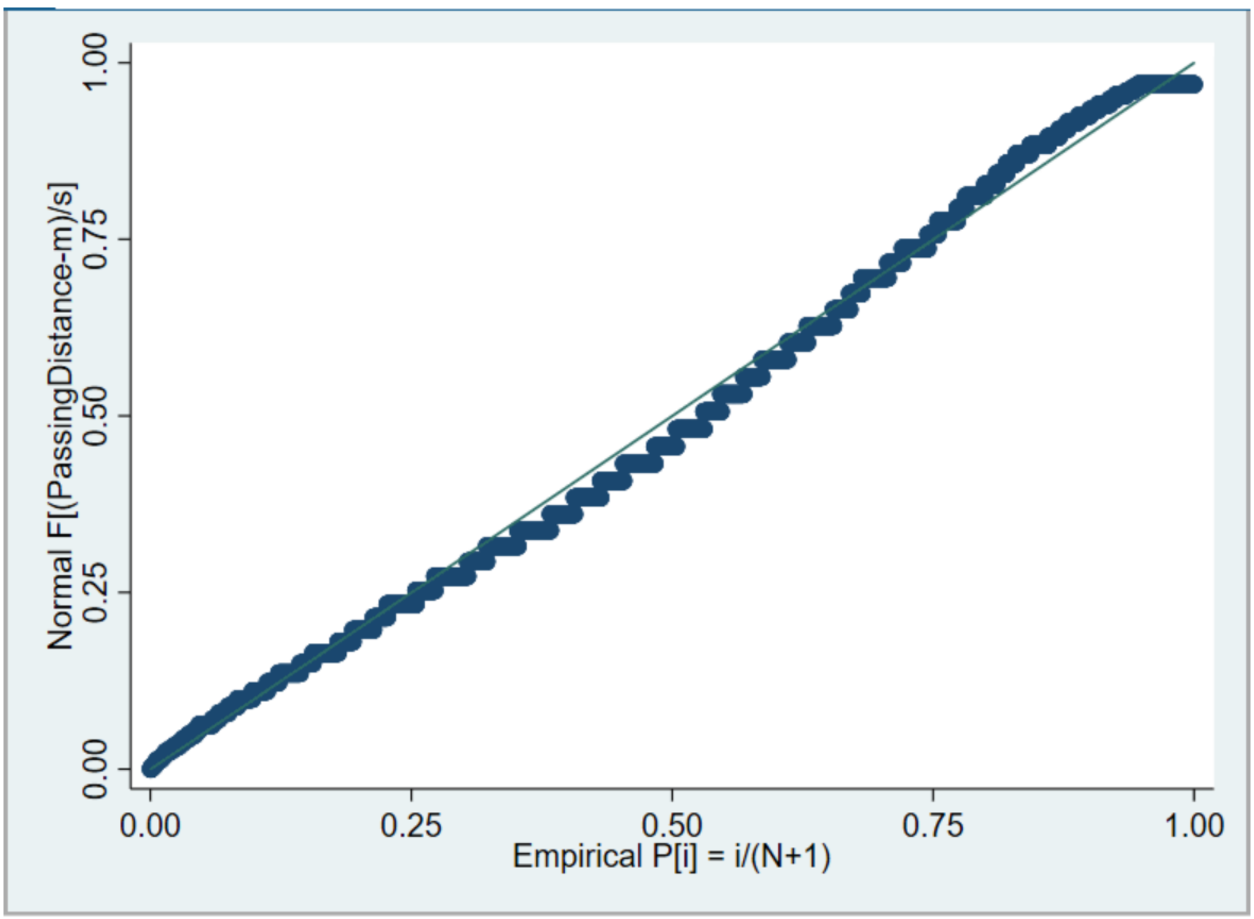
Data collection of passing distance on a road with a bike boulevard.

Figure B7. Example of painted lines on Bryant Ave S.

Appendix C: Normality of Data and Correlation Table

```
. corr PassingDistance OncomingTraffic Gender LaneWidth Lanes Parking Cat3 Cat456 NoFacility ShouldBlane Bikeblvd MPHDUM AADTUpdate
(obs=2,949)
```

	Passin~e	Oncomi~c	Gender	LaneWi~h	Lanes	Parking	Cat3	Cat456	NoFaci~y	Should~e	Bikeblvd	MPHDUM	AADTUp~e
PassingDis~e	1.0000												
OncomingTr~c	-0.3029	1.0000											
Gender	-0.0877	-0.1404	1.0000										
LaneWidth	0.0335	0.1061	-0.0379	1.0000									
Lanes	0.2053	-0.1008	-0.0643	-0.1476	1.0000								
Parking	-0.1236	0.0421	0.0273	0.6132	-0.5355	1.0000							
Cat3	-0.1222	0.0269	0.0760	-0.0088	-0.0474	0.0776	1.0000						
Cat456	-0.0834	0.0364	0.0346	-0.0029	0.0238	-0.0354	-0.1380	1.0000					
NoFacility	-0.2746	0.1590	-0.0170	0.0980	0.3672	-0.0588	0.0049	0.0627	1.0000				
ShouldBlane	-0.1593	0.2917	-0.0279	-0.2801	-0.2714	-0.1189	0.0621	0.0042	-0.3887	1.0000			
Bikeblvd	-0.1263	-0.2262	0.1076	-0.1888	-0.6620	0.3565	0.0302	-0.0483	-0.2619	-0.2707	1.0000		
MPHDUM	0.3800	-0.2898	0.0293	0.0406	-0.2067	0.4032	-0.0018	-0.0656	-0.7245	-0.1099	0.3616	1.0000	
AADTUpdate	-0.0088	0.2110	-0.0968	0.1141	0.7073	-0.2706	0.0121	0.0339	0.3102	0.3100	-0.9201	-0.4049	1.0000



Appendix D: Federal Highway Administration Vehicle Classifications