# Development and Evaluation of Infrastructure Strategies for Safer Cycling

SAFER SIM

SAFETY RESEARCH USING SIMULATION

UNIVERSITY TRANSPORTATION CENTER


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## Abstract

In recent years there has been an increasing number of recreational and bicycle commuters in the United States. Although bicycle users still represent a very small mode share, municipalities have been attempting to further encourage the health, economic, and environmental benefits of cycling by implementing new and innovative bicycle infrastructure treatments. However, many of these treatments have only been recently implemented in a few locations and are often constructed with little or no understanding of their effects on user behavior. Currently, there is a substantial amount of research investigating bicyclist behavior, as well as operations and safety from the cyclists' perspective of such innovative treatments. However, there is little research conducted from the drivers' perspective towards cyclists and bicycle infrastructure. With approximately 75 percent of all bicycle-vehicle crashes occurring at intersections, there especially is a need to investigate driver behavior at intersections with unfamiliar bicycle treatments. This project report provides an in-depth evaluation of driver behavior from the driver's perspective when approaching new and unfamiliar bicycle infrastructure intersection treatments. It utilizes a driving simulator as well as participant questionnaires to determine whether any patterns or causalities exist between bicycle infrastructure treatments and driver behavior. The results of this study indicate that there is a correlation between driver behavior and the level of familiarity with bicycle infrastructure treatments as well as cycling experience. This in-depth study can help inform design, education, or other countermeasures for safer operations.

## 1 Introduction

Cycling as a utilitarian mode of transportation is one of the most sustainable and cost-effective modes available. Despite these benefits it is also one of the least utilized transportation modes in the United States. Among the many barriers keeping potential cyclists off the road, studies found that at least 40 percent of people feel that safety is the greatest barrier preventing them from cycling [1,2]. In dense urban areas where cycling is especially poised for success, it is also the most dangerous, with urban areas accounting for approximately 69 percent of the cyclist fatalities every year [3]. Between 2011 and 2014 it was found that approximately 75 percent of all bicycle-vehicle collisions in Massachusetts occurred at intersections. This reflects the importance of researching intersection-specific bike infrastructure treatments to improve safety.

Since 2000 there has been a 62 percent increase in bicycle commuting nationally in the United States [4]. Although bicycle users still typically represent only a 1 to 5 percent share of all commuters, municipalities have been attempting to further encourage the health, economic, and environmental benefits of cycling by implementing new and innovative bicycle infrastructure treatments. However, many of these treatments have been only recently implemented in a few locations and are often constructed with little or no understanding of their effects on user behavior. To date there is a substantial amount of research investigating bicyclist behavior operations and safety from the cyclists' perspective of such innovative treatments. However, there is little research conducted from the drivers' perspective towards cyclists and bicycle infrastructure. There is a need to investigate driver behavior at innovative and unfamiliar bicycle infrastructure treatments in order to better evaluate and design these treatments to achieve safe operations for all users.

The objective of this research project is to provide an in-depth analysis of driver behavior when approaching new and unfamiliar bicycle infrastructure treatments, sharrows, bike lanes, bike boxes, and bike merge-lanes. This project utilized a driving simulator, eye tracking, and questionnaires to determine whether any patterns or causalities exist between infrastructure and driver behavior. The benefit of laboratory simulation allows for not only the measurement of driver behavior, but also survey of their background through questionnaires. This combined information provides greater insight into how driver experience as a cyclist and exposure to bicycle infrastructure can affect driver behavior.

## 2 Background

With bicycling on the rise in the United States, transportation agencies are now beginning to accommodate bicyclists more routinely. Although the United States has been slow to adopt bicycle transportation, low-cost treatments such as sharrows, bike lanes, bike boxes, and merge lanes are increasingly found painted on roads across the United States [5, 6, 7]. The purpose of these treatments is to provide allocated space on the roadway for bicycles and to address the common right-hook and left-hook collisions.

Right-hook and left-hook collisions (Figure 2.1) are typically a result of drivers failing to see a cyclist due to cyclist positioning, driver inattention, or unexpected presence of cyclists [8, 9, 10, 11, 12]. An example of these situations could be a cyclist positioned in the driver's blind spot, the driver focusing on automobiles only when turning, or a sudden mixing of bicycle and motorized traffic. To address these two collision types, merge lanes and bike box treatments are often implemented.

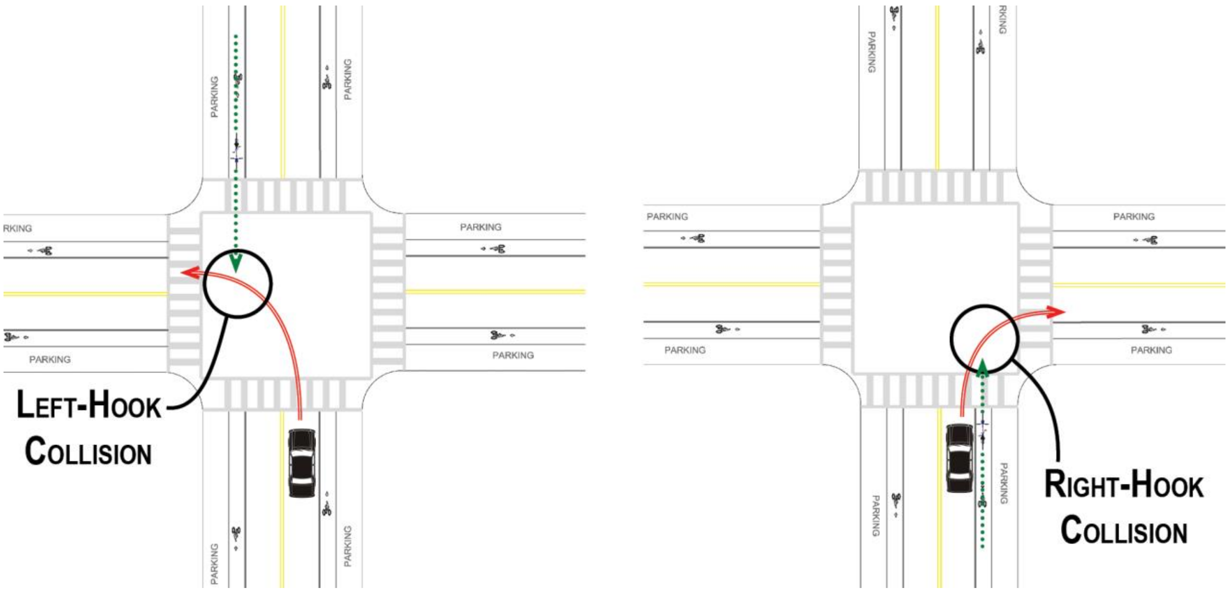
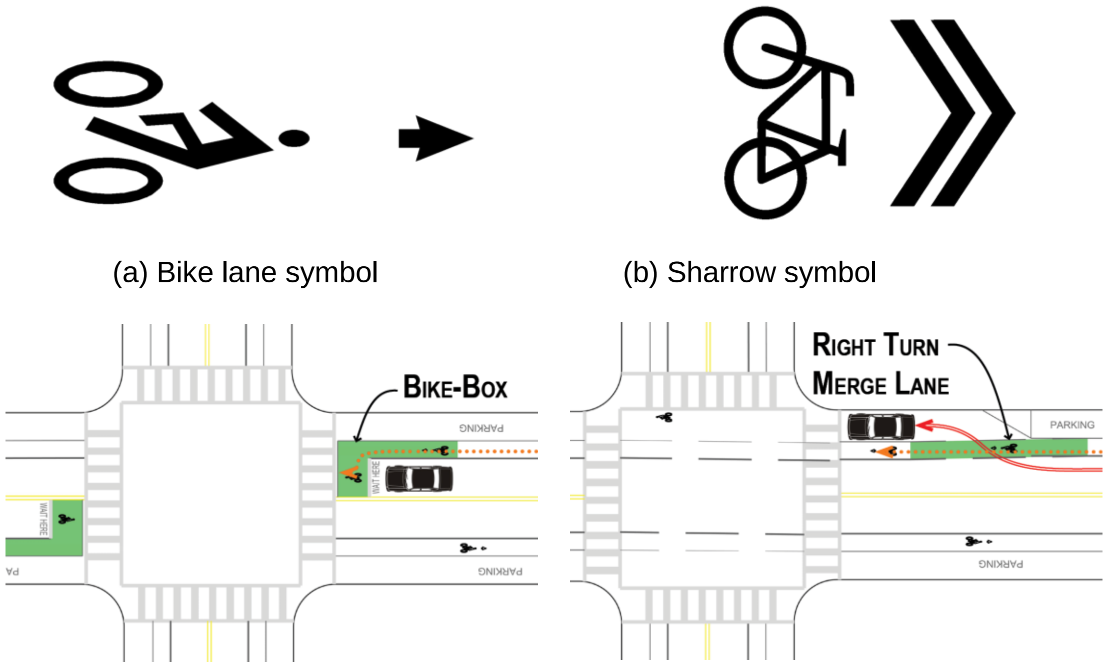



**Figure 2.1 – Illustration of (a) left-hook and (b) right-hook collisions**

Sharrows and bike lanes (Figure 2.2(a) and Figure 2.2(b)) have been found to encourage overall cycling and improve proper cycling behavior, such as reducing sidewalk and wrong-way riding. However, the safety benefits of these midblock treatments are undetermined or vary greatly [13, 14]. More recently, separated bike lanes have further made an appearance in the United States, and the first-ever state-level design guideline document for separated bike lanes was recently published [15]. These separated facilities provide a greatly increased level of safety and comfort to bicyclists, as well as to drivers. However, some argue that midblock separated facilities without intersection treatments may actually increase bicyclist risk at intersections [16].

The bike box is essentially an advanced stop bar at an intersection and is often filled in with a contrasting paint color and bicycle symbol (Figure 2.2(c)). The bike box functions by providing a designated space for cyclists to congregate at the front of a traffic queue, thus ensuring that a cyclist is clearly visible to drivers [9]. The caveat to this treatment is that it assumes that drivers will keep the bike box clear for cyclists. In studies by Dill et al. [5] and Loskorn et al. [7], it was found that not only did motorists frequently encroach upon the bike box, but bicyclists as well would often fail to use the facility as intended [5, 7].

Merge lanes are commonly seen in the United States at signalized intersections. A merge lane functions by positioning cyclists to the left of vehicles, thus mitigating right-hook collisions (Figure 2.2(d)). However, this may simply shift the conflict point from the intersection back to the roadway segment just upstream of the intersection [17, 18]. The popularity of all these treatments is due to the fact that existing intersections can be easily retrofitted, and they are relatively low cost to implement, i.e., surface paint only [7]. However, these treatments are often applied to inappropriate situations or provide minimal safety benefits [9, 19].




(a) Bike lane symbol (b) Sharrow symbol

(c) Bike box (d) Merge lane

**Figure 2.2 – Illustration of bike infrastructure treatments**

Currently the majority of research is being conducted from the bicyclists' perspective or by using crash analysis. Although it is immensely important to continue research from that perspective, these studies often fail to uncover the underlying cause of bicycle-car collisions or near misses. A growing number of studies have begun to investigate bicycle infrastructure from the driver's perspective. One such study using a driving simulator investigated a "right-turn vehicle box" (RTVB) applied to right-turn slip lanes to guide drivers where to position their vehicle. These vehicle boxes are the vehicular version of bike boxes. This study found that the bright-green-colored pavement for bicycles and pedestrians further guided drivers not to block bicycle paths [20].

Although much of the older surface-painted bicycle infrastructure is basic striping or signage only, most contemporary markings are being painted bright green at intersections. Studies have shown that although fully painted treatments are slightly more expensive, the high-contrast colors yield a much higher rate of driver compliance compared to a white striped outline. The fully painted high-contrast colors not only serve to catch the eye of drivers, but to inform drivers of a zone to keep clear. This reduces the number of vehicles impeding bicycle traffic, thus reducing the risk of crashes [9, 20].

Driving simulators have for many years been used in determining behavioral aspects of driving, such as effects of alcohol on driving or testing new infrastructure. Now driving simulators are playing an important role in understanding how bicycle infrastructure can be better designed. A large study for the Oregon Department of Transportation by Oregon State University and Portland State University is utilizing a driving simulator to investigate effective intersection design treatments [21]. This study provides an in-depth analysis of the interactions of right-turning vehicles with bicycles, investigating several common treatments and their effectiveness in reducing crashes. The study highlights the goal of reducing crashes and crash severity by improving visual attention and reducing driving speeds of drivers.

Currently there is a lack of research from the driver's perspective. The importance of studying the driver perspective is to better understand why certain drivers may fail to properly interact with bicycle infrastructure. For example, do drivers that do not keep bike boxes clear for cyclists fail to observe the painted treatment, or do they simply not know to do so? This research study, though lacking interaction with cyclists on the road, intends to understand why drivers behave the way they do behind the wheel. This will be accomplished by driving simulation and surveying participants of their bicycling experience and understanding of the bicycle infrastructure. Results of this study yield insights into whether infrastructure fails to modify behavior due to lack of effectiveness or due to lack of education.

## 3 Methodology

Driver behavior at four different bicycle infrastructure treatments was studied with the use of a driving simulator. The benefits of using a driving simulator are the ability to create nearly any driving scenario and the ability collect drive data at a resolution not easily feasible in the field. Accompanying the simulator was an eye-tracking device that tracks and records the participant's gaze, allowing for a highly in-depth level of analysis and investigation of driver sight and behavior.

The experiment consisted of approximately 4 miles (6.4 kilometers) of simulated roadway with fifteen midblock roadway segments placed between sixteen intersections containing either bike boxes with bike lanes, bike merge-lanes with bike lanes, bike lanes only, sharrows only, or no treatment at all. The bike boxes and merge lanes were painted bright green as that is the current state of the practice for these treatments. The sixteen intersections were connected into a continuous drive sequence, and the participant was prompted by an on-screen display to make a left, right, or straight-through maneuver for each of the five intersection types. There was a total of five left turns, five right turns, and six through maneuvers. The participant drove through one of two drive scenarios; the second drive scenario presented the treatments in the reverse order compared to the first drive scenario, which compensates for possible sequencing effects. The scenario was populated with light oncoming traffic and a bicyclist moving in the opposite direction. Traffic was limited to the opposing direction so as not to interfere with the participant's driving path. The study procedure consisted of four steps:

1. The participant completed initial paperwork and a pre-study questionnaire, which focused mostly on demographics and driving history and frequency.

2. The participant was seated in the driver's seat of the vehicle and fitted with the eye tracker. The participant then performed a demo drive to become familiar and comfortable

with the eye tracker and driving simulator. This step was also useful for determining if the participant was susceptible to simulator sickness and should therefore be excluded.

3. The participant drove through one of the two drive scenarios.

4. The participant was asked to complete a post-study questionnaire after the driving portion of the study. This questionnaire focused on bicycling history and frequency as well as familiarity, confusion, preference, and comfort with each of the different treatments.

## 3.1 Participants

The study performed tests on 24 participants between the ages of 19 and 38 years, with a 50 percent split between males and females. All participants had a valid driver's license and were recruited from the area surrounding the University of Massachusetts (UMass) Amherst. UMass Amherst is located in a rural setting, meaning that most participants would most likely be unfamiliar with the bicycle treatments that are more often installed in cities. The average age was 24 years old, with a median age of 22 years. To understand the participants' driving history, they were asked approximately how many miles they drive per week and per year.

## 3.2 Apparatus

### *3.2.1 Driving Simulator*

The simulator is a stationary full-scale vehicle with a simulated driving environment projected onto screens located in front of the vehicle, shown in Figure 3.1. The screens offer a viewing angle of 135 degrees with simulated rearview and side-view mirrors. The participant in the automobile is able to move through the virtual world using the vehicle's physical controls. The simulator is capable of recording position, speed, acceleration, and driver control actuation at a frequency of 60 Hz.

**Figure 3.1 – UMass Amherst Driving Simulator**

*3.2.2 Eye Tracker*

In addition to vehicle data, eye-tracking data were gathered by fitting participants with a mobile eye-tracking device. The eye tracker is an important tool that allows researchers to look at driver inputs in addition to their output actions. The eye-tracking device used in the experiment was a Mobile Eye XG by Applied Science Laboratories. The eye tracker is a pair of safety goggles equipped with two lightweight cameras, one to track eye movements and the other to capture the scene that the user sees. The two videos are recorded, processed, and interleaved on a device that outputs a video file with cross-hairs displaying the driver's gaze and the associated coordinate data in a separate data file.

Figure 3.2 – Eye-tracking device and video output

For this specific experiment, researchers analyzed the data to investigate which drivers saw the treatments and if they checked for bicyclists on the roadway. In particular, the eye tracking was scored by two researchers, one with no prior involvement in the study. The glances were scored as a binary variable to represent whether a participant glanced at a treatment or target zone for a particular roadway segment. The rubric for scoring eye glances contained three categories: whether the participant glanced at the treatment itself, whether the participant checked the side mirror, and whether the participant checked the rear-view mirror. Mirror glances were scored independently of whether the participant glanced at the treatment first. This is to determine whether the presence of the treatment caused the participant to scan the mirrors.

*3.2.3 Questionnaires*

This research included a survey component in which participants were asked to answer both a pre-study and a post-study questionnaire. The pre-study questionnaire asked demographic questions, such as age and race, as well as the participants' driving history and experience. No mention of bicycles or bicycle infrastructure was included in the first questionnaire in order not to bias the study. The post-study questionnaire asked for the participants' bicycling experience and history, their treatment preference, and a ranking of their familiarity, comfort, and understanding of each treatment. The purpose of the supplementary questionnaire was to determine what, if any, preferences and perceptions exist toward certain bicycle infrastructure treatments and whether any prior experience or knowledge of bicycle infrastructure may influence those perceptions. Blank example copies of the questionnaires are attached in Appendices A and B.

# 4 Results

## 4.1 Eye Glances

We first investigated driver behavior at midblock bike lanes, and the eye-glance scoring showed that 79 percent of all participants glanced at the bike lanes at least once during the study. The eye glances typically focused on the bicycle symbol within the bike lane, rather than the striping. Twelve percent of participants occasionally glanced at empty roadway shoulders. We further isolated the eye-glance scoring based on participant survey responses to see if any relationship might exist between the frequency of glances and the cycling frequency of drivers (see Figure 4.1). The scores are averaged based on the number of midblock roadway segments between the intersections at which the 32 participants could have possibly glanced. *n* is the number of participants reported within each cycling-frequency category. The results interestingly show that eye-glance frequency at bike lanes between intersections tended to increase as the cycling frequency of the driver increased. Drivers reported their cycling frequency in the questionnaire as daily, weekly, monthly, yearly, less than once a year, or never. This was further aggregated into groups of frequent, infrequent, and non-cyclists. Frequent cyclists were coded as participants who reported cycling at least daily, weekly, or monthly. Infrequent cyclists were coded as participants who reported cycling yearly or less than once a year. Non-cyclists were coded as participants who reported never cycling.

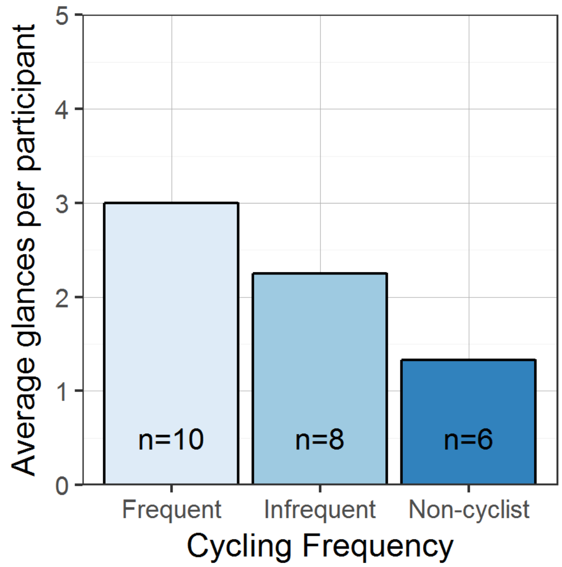



**Figure 4.1 – Eye glances at midblock bike lanes**

Figure 4.2 is a summary showing the average percentage of participant eye glances and glance type per treatment. The colors represent the proportions of cycling frequency. The glances were categorized as glancing at the treatment itself, checking the side mirrors, or checking the rear mirror. All of the treatments attracted eye glances, most exceeding 90 percent with the exception of bike lanes and no treatment. However, despite glancing at the treatments, very few participants checked their mirrors.

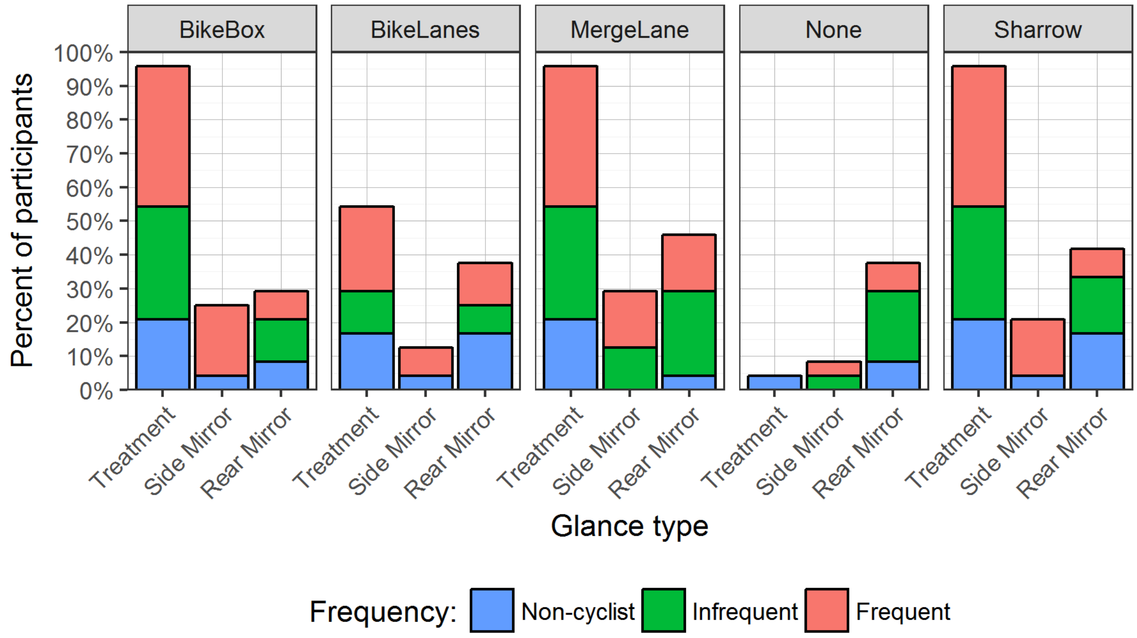


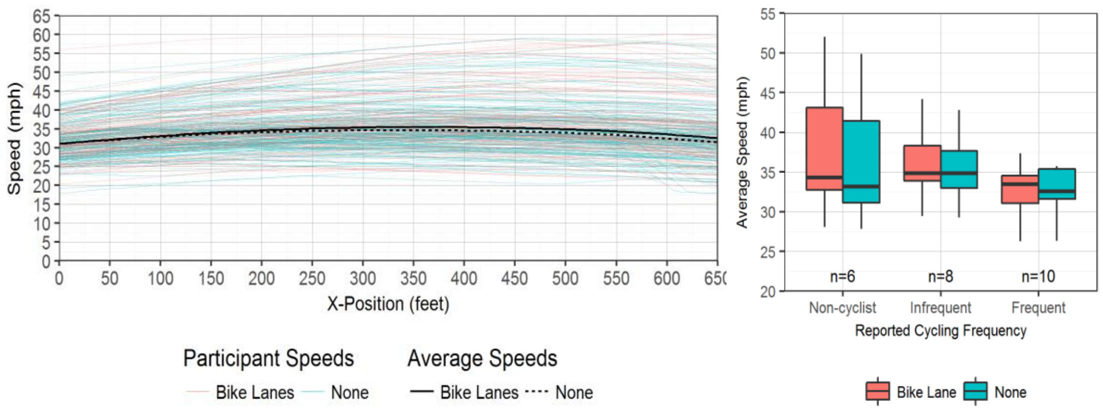

**Figure 4.2 – Eye glances at all treatments**

## 4.2 Midblock Segments

Although this study focused on intersection treatments, there were sixteen midblock segments with bike lanes applied to seven of those midblock segments; the remaining nine had no treatment with only an empty roadway shoulder. Participants drove through all sixteen of these treatments, offering an opportunity to compare participant eye glances, average speed, and lane positioning between the two segment types.

### *4.2.1 Midblock Speeds*

Figure 4.3(a) is a plot of the driving speed for all participants between intersections with averages for when bike lanes are present and not present. Comparing the vehicle speed data at midblock locations with and without bike lanes in Figure 4.1(a), there is almost no difference between the average speeds. In fact, the mathematical mean of speed at segments with bike lanes at 35.3 miles per hour was slightly higher than without bike lanes at 34.8 miles per hour. Performing a t-test on the two data sets yields a p-value of 0.7603, which is well below the 95 percent confidence interval, showing that the difference between the two means is not statistically significant. The roadway did not contain posted speed limits in order to not influence driver speed or distract the driver. This resulted in a very wide range of speeds.




(a) Vehicle speed between intersections (b) Box plot of average speed vs cycling frequency

**Figure 4.3 – Average speed**

To further investigate the speed selection, the average driving speed for each participant is reported based on cycling frequency. This allows us to further investigate whether any difference in the speed selection exists between drivers who cycle and drivers who do not. Figure 4.3(b) is a box plot of average driving speed based on driver's cycling frequency and whether a bike lane was present. Figure 4-3b shows that the average speed increases in drivers who are less-frequent cyclists. The figure demonstrates that not all non-cyclists drove at high speeds, but all high-speed drivers were non-cyclists. As a reminder, the *n* refers to the number of participants within this cycling group, not the number of intersections averaged.

An analysis of variances test (ANOVA) was performed on the three groups of mean speeds. An ANOVA test was chosen for its ability to perform significance testing on more than two groups of means. In this ANOVA test, there were 360 observations from

24 participants with 15 midblock segments (seven with bike lanes, nine without bike lanes). The results of this test yielded a *p*-value of 9.01e-5, meaning that with a confidence of greater than 99 percent, two or more pairs of means in the cycling frequency groups are significantly different. To determine which pairs are not part of the mean, a Tukey Honest Significant Differences (Tukey HSD) test was performed; results are shown in Table 4.1. More specifically, Table 4.1 **– Tukey HSD results for average speed of the cycling frequency groups** shows all possible combinations of cycling frequency comparisons, with mean being the mean speed and $n_a$ and $n_b$ being the sample size of groups *a* and *b*, respectively. The p-value shows the difference in significance for each group pair, with all pairs presenting significantly different speeds. Non-cyclist versus frequent cyclists were the most significantly different; however, in reality, the difference of just 3.69 miles per hour is minimal.

**Table 4.1 – Tukey HSD results for average speed of the cycling frequency groups**

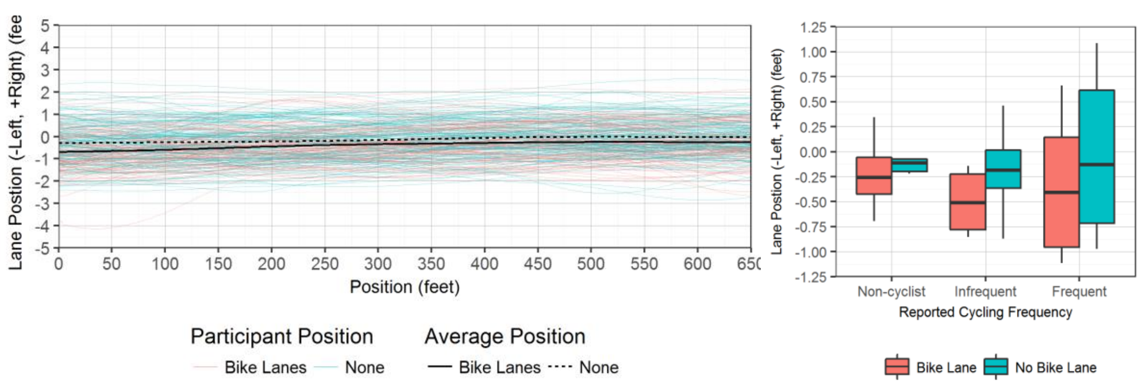
| Group (a) | $n_a$ | $mean_a$ | Group (b) | $n_b$ | $mean_b$ | p-value |
|---|---|---|---|---|---|---|
| Infrequent | 120 | 35.76 | Frequent | 150 | 33.59 | 1.88e-2 |
| Non-cyclist | 90 | 37.28 | Infrequent | 120 | 35.76 | 2.19e-1 |
| Non-cyclist | 90 | 37.28 | Frequent | 150 | 33.59 | 9.48e-5 |

*4.2.2 Midblock Lane Positioning*

Conventional wisdom would suggest that bike lanes designate and allocate roadway space for cyclists and encourage vehicle drivers to allow for more room for cyclists. Figure 4-4(b) displays the relative lane positioning of participants along the midblock segments, with negative being towards the centerline of the road (left), and positive being towards the edge of the road (right).

Again, the lane positioning is isolated based on participant age, gender, and cycling frequency. Figure 4.4(a) shows lane positioning of all participants between intersections, and Figure 4.4(b) is a box plot of the drivers' average positions based on their cycling frequency. The plots in Figure 4.4(b) reflect the consistent lane offset across all cycling frequencies between bike lanes and no bike lanes, but there is no statistically significant difference between the groups themselves. There did appear to be a narrow range of lane positions among non-cyclists and a wide range among frequent cyclists, meaning that non-cyclists tend to drive more on the straight and narrow than cyclists. An ANOVA test was performed, but no statistical significance was found to support this.

Although on average drivers would consistently position their vehicles 0.3 feet to the left when a bike lane was present, there was little difference in the lane positioning overall. Performing a t-test yields a p-value of 0.0916. This does not meet the 95 percent confidence interval, but it does barely exceed the 90 percent confidence interval. This indicates that there is some significant difference in lane positioning when bike lanes are present. However, in reality, a 0.3-foot difference is a negligible amount of distance from a cyclist.




(a) Lane positioning between intersections, (b) Box plot of position vs cycling frequency

**Figure 4.4 – Lane positioning**

## 4.3 Intersections

Each of the treatment types varies in design, but all intersections are four-way signalized intersections. Driver behavior at intersections in the presence of such treatments is analyzed by comparing it across all treatment types but also through individual analysis, such as stop position for bike boxes and merge position for merge lanes.

### *4.3.1 Intersection Approach Speed*

The speed of an approaching vehicle is critical to a bicyclist who may be waiting at a light or attempting a left or right turn. For the evaluation of sharrows, this is particularly important as sharrows should instruct drivers to slow down. As with midblock speeds, intersection approach speeds varied widely between participants. However, the average approach speed for each treatment type varied only slightly, as shown in Figure 4.5. An ANOVA test was performed on the different intersection approach speeds based on all five treatment types for all participants. The results for the 360 observations (24 participants each interacting with 5 treatment types and each experiencing them while doing 3 turn movements: left, right, and through) yielded a p-value of 0.158, which does not meet the 95 or 90 percent threshold. This shows that the approach speeds do not differ significantly from each other for all treatments.

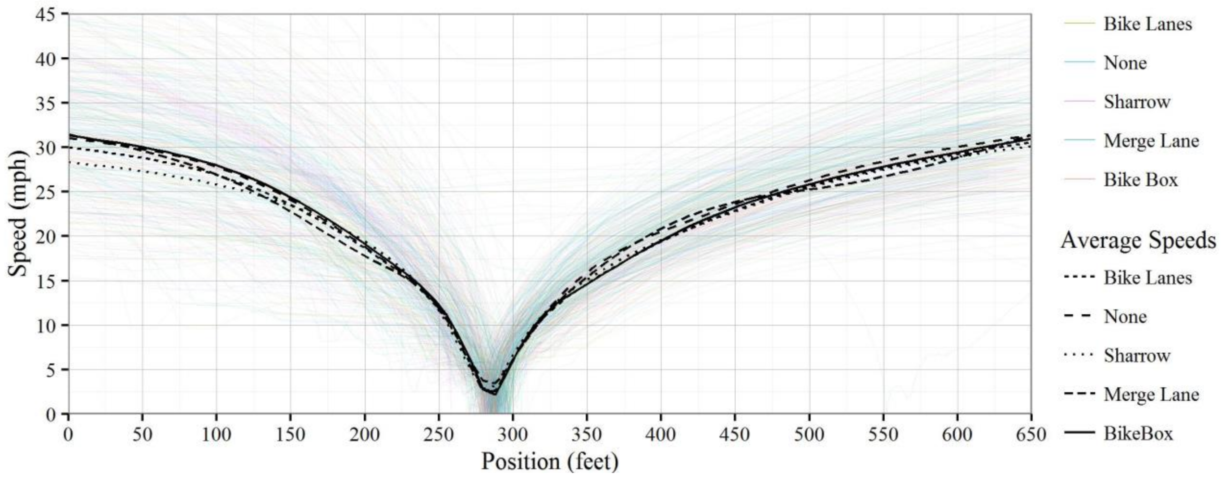



**Figure 4.5 – Intersection approach speeds for all treatment types**

*4.3.2 Merge Maneuvers*

The purpose of merge lanes is to bring awareness to drivers that the lane may be occupied by a cyclist and that they should be cautious. Merge lanes were investigated based on the point at which drivers crossed the bicycle merge lane, shown in Figure 4.6 as a dotted line. The average speed at which vehicles crossed this point was 20.1 miles per hour, and the average cross point was 144.3 feet from the intersection center. Referring back to Figure 4.2, only 10 percent of drivers checked their rearview mirrors and only 8 percent checked their side-view mirrors while navigating a merge lane. Further investigating by cycling frequency also shows little change in driver speed; all groups made the crossing at relatively the same speed.

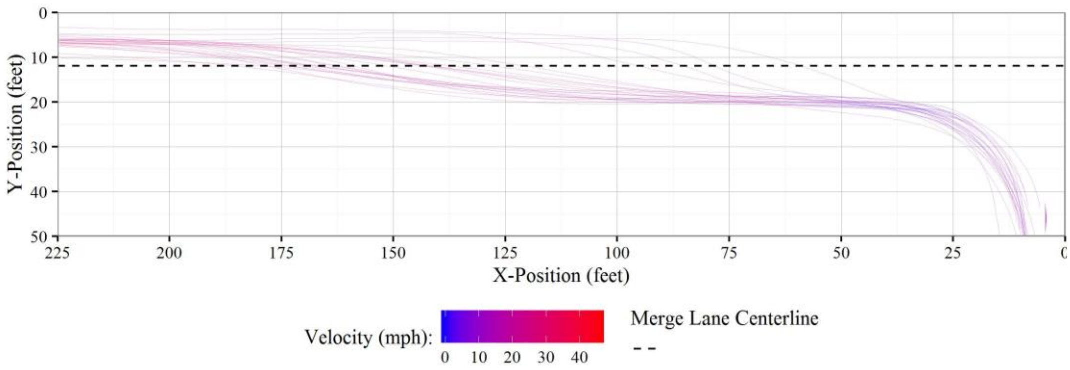
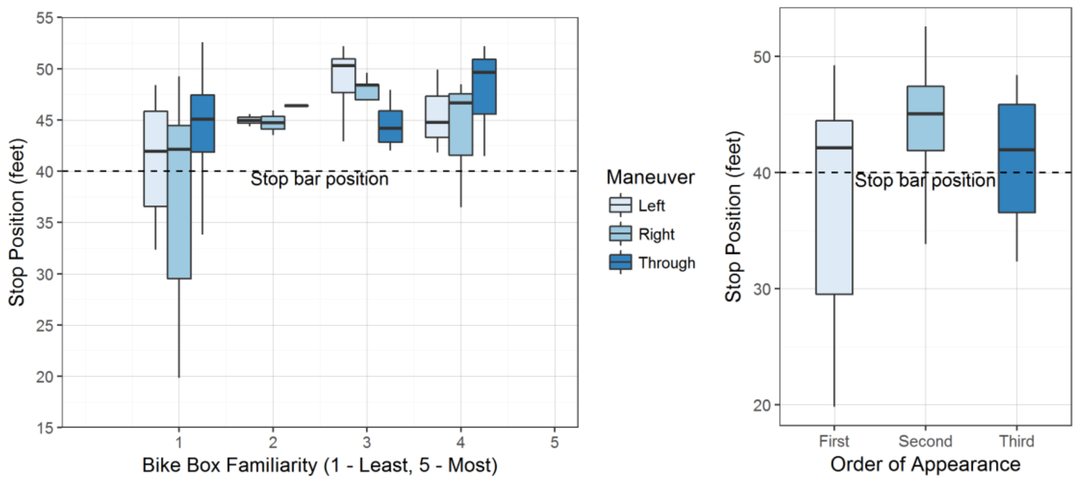



**Figure 4.6 – Drive path at merge lane**

*4.3.3 Bike Box Stop Position*

Bike boxes showed very promising results with 73.6 percent of the participants yielding properly behind the advanced stop bar, which was located 40 feet from the center of the intersection. However, 26.4 percent is still a relatively high rate of failure-to-yield violations. Relating participants to their questionnaire responses yields insight into their behaviors. Figure 4.7(a) shows that the participants who responded as not familiar with bike boxes tended to fail to yield more than those who were familiar. There still appears to be a range of stop positions within the unfamiliar group, suggesting that either some participants responded correctly, or that participants learned to use the boxes during their drive. Each participant would encounter three occurrences of bike boxes during their drive. Figure 4.7(b) shows the behavior of the unfamiliar participants based on the order of appearance of bike boxes. It would appear that there is some level of driver comprehension occurring, but not for all participants.




(a) Bike box stop position vs familiarity, (b) “Unfamiliar” bike box stop positions

**Figure 4.7 – Bike box compliance**

### 4.4 Open Responses

At the end of the post-drive questionnaire, an open response section was allocated for the question "*What about the treatments made it difficult to understand them?*" Twenty-two of the 24 participants responded to this question, with two responses claiming no difficulty in understanding. The participant responses have been coded into seven categories as shown in Table 4.2 **– Questionnaire open response answers**. Although one participant responded by saying they did not even notice a bike box in the simulation, the majority of the subjects, 19 out of the 24, said they simply had not seen the facilities before or were not sure of their function.

**Table 4.2 – Questionnaire open response answers**

| Coded response category | Quantity |
|---|---|
| Had never seen a bike box before, or were not sure how they function | 5 |
| Had never seen a merge lane before, or were not sure how they function | 5 |
| Stated their unfamiliarity made it difficult to understand the treatments | 5 |
| Had never seen green pavement marking before | 3 |
| Had never seen a sharrow before | 1 |
| Did not notice a bike box during simulation | 1 |
| No problem with understanding treatments | 2 |

# 5 CONCLUSIONS

The purpose of this study was to conduct an in-depth study on the effects that bicycle infrastructure treatments may have on drivers and to investigate whether the driver's experience as a cyclist also affects their driving behavior. In this study, sharrows, bike lanes, merge lanes, and bike boxes were evaluated using a driving simulator, eye-tracking device, and survey questionnaire. This combination of tools enables researchers to not only measure resulting behavior, but to begin linking behavior to the drivers themselves, enabling a depth of study than is not achievable by field studies alone.

The results of the study show that cycling experience and familiarity influence driver behavior. For example, drivers drove faster in general regardless of bike lanes being present if they were less-frequent cyclists or non-cyclists than if they were frequent cyclists. In addition, familiarity with infrastructure also influenced behavior. For example, drivers who had any familiarity with bike boxes stopped appropriately behind the advanced stop bar and kept the box clear. Simple surface treatments are generally intended to bring legitimacy to cyclists on the roadway and awareness to drivers. The presence of these facilities should instruct drivers to be routinely cautious for cyclists, not just as a special exception when a bicyclist is present. However, this study found no evidence of this behavior for merge lanes and sharrows. The argument could be made that these treatments would be more effective if a bicyclist were present, but it is somewhat concerning when considering that many bicycle-vehicle crashes are caused by a driver being unaware of bicyclists on the road. In other words, if the treatment is only effective when a bicyclist is present, what happens when the driver does not see the bicyclist? Future studies should address this question by including driver interaction with cyclists; this would help determine how dependent driver behavior is on bicyclist presence rather than on infrastructure treatment alone.

Despite studying four different treatments, this study has only begun to scratch the surface of the complex relationship between drivers, cyclists, and their surroundings. Although the experiment lacked interaction with bicyclists, the results highlight how drivers behave towards these treatments when not forced to react to bicycles. This is especially true for the bike box, which should be left clear for potential cyclists approaching, not just for cyclists already in queue. This is an important factor to consider because bicyclists have the ability to enter the roadway at unexpected entry points (e.g., from sidewalks), thus making it imperative that drivers are continuously more vigilant when driving in bicycle-friendly areas, not just as an exception when a cyclist is present. This study has shown that infrastructure alone is not enough to improve safety, but that complementary information or education should be provided to familiarize and instruct drivers about these new bicycle infrastructure treatments.

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## Appendix A: Pre-Study Questionnaire

Date: ___________

Participant ID: _______________
(HPL Admin. use only)

**HUMAN PERFORMANCE LABORATORY**
**PRE-STUDY QUESTIONNAIRE**

This is a ***strictly confidential*** questionnaire. Only a randomly generated participant ID number, assigned by the research administrator, will be on this questionnaire. No information reported by you here will be traced back to you personally in any way. **You can skip any questions you do not feel comfortable answering.**

**Section 1: Demographics**

**Gender:** ☐ Male ☐ Female

**Date of Birth (month/day/year):** _____/_____/______ **Age:** ______

**Race / Ethnicity:**
(check all that apply)
(question asked for reporting purposes)

☐ Black / African American ☐ Asian
☐ Caucasian ☐ American Indian / Native Alaskan
☐ Hispanic / Latino ☐ Other

Have you participated in a study at this laboratory in the past? ☐ Yes ☐ No

**Section 2: Driving History**

Approximately how old were you when you got your driver's license? _____ **Years** _____ **Months**

About how many miles did you drive in the past week?
☐ Less than 50 ☐ Less than 100 ☐ 100-200 ☐ 200-300 ☐ 300-500 ☐ 500 or more

About how many miles did you drive in the past 12 months?
☐ Less than 5,000 ☐ 5,000 to 10,000 ☐ 10,001 to 15,000 ☐15,001-20,000 ☐ More than 20,000

Do you usually wear glasses or contacts while driving?
☐ No
☐ Yes, glasses
☐ Yes, contacts

Do you ever get motion sickness symptoms while driving or riding in a car? ☐ Yes ☐ No
**(If you respond Yes to this question, please bring it to the immediate attention of the experimenter.)**

Do you have any other restrictions on your driver's license? ☐ Yes ☐ No

If yes, please describe: ________________________________________________

Is there anything related to your background or health, including any medications that might cause to you drive much better or worse than other drivers?
☐ Yes ☐ No

If yes, please describe: ________________________________________________

**Figure A.1 - Example of Pre Study Questionnaire**

## Appendix B: Post-Study Questionnaire

Date: ___________

Participant ID: _______________
(HPL Admin. use only)

**HUMAN PERFORMANCE LABORATORY**
**POST-STUDY QUESTIONNAIRE**

This is a ***strictly confidential*** questionnaire. Only a randomly generated participant ID number, assigned by the research administrator, will be on this questionnaire. No information reported by you here will be traced back to you personally in any way. **You can skip any questions you do not feel comfortable answering.**

This study examines the use of roadway bicycle infrastructure treatments, some of which you encountered during your drives. In particular, this research focuses on car driver behavior and performance when approaching these bicycle-related infrastructure treatments, especially when drivers are not familiar with the new geometry associated with a specific treatment. The specific focus of this study was not fully disclosed to you at the beginning of your participation so as to not influence or bias your behavior during the simulator drives.

**Section 1: Bicycling History**

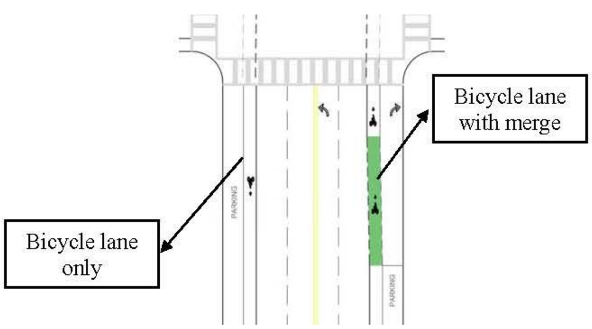
Do you bicycle for commuting purposes or for recreational purposes?
☐ Yes, for commuting only ☐ Yes, for recreation only ☐ Yes, both for commuting & recreation ☐ No

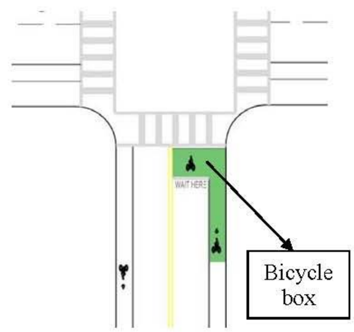
How often do you bicycle?
☐ > 4 times a week ☐ 1-2 times a week ☐ 1-2 times a month ☐ a few times a year ☐ less than once a year

If a bicyclist, approximately how old were you when you started bicycling? _____ **Years** _____ **Months**

**Section 2: Familiarity with Bicycle Infrastructure Treatments**

1. Were you familiar with any of the bicycle treatments presented to you? If so, with which one(s)? (You can choose more than one option).




☐ Bicycle lane with merge for right-turning vehicles ☐ Bicycle box

☐ Bicycle lane only ☐ None

**Figure B.1 - Example of Post Study Questionnaire (Page 1)**

Date: ___________

Participant ID: _______________
(HPL Admin. use only)

2. Please rate your familiarity from 1-5 (1 being not familiar at all; 5 being very familiar) for the following bicycle infrastructure treatments:

| | not familiar | | | very familiar |
|---|---|---|---|---|---|
| Bicycle lane | 1 | 2 | 3 | 4 | 5 |
| Bicycle lane with merge for right-turning vehicles | 1 | 2 | 3 | 4 | 5 |
| Bicycle box | 1 | 2 | 3 | 4 | 5 |

3. Please rate the level of your comfort from 1-5 (1 not comfortable at all; 5 very comfortable) for when you encountered the following bicycle infrastructure treatments during the driving simulator drives:

| | not comfortable at all | | | | very comfortable |
|---|---|---|---|---|---|
| Bicycle lane | 1 | 2 | 3 | 4 | 5 |
| Bicycle lane with merge for right-turning vehicles | 1 | 2 | 3 | 4 | 5 |
| Bicycle box | 1 | 2 | 3 | 4 | 5 |

4. Please rate the level of your confusion from 1-5 (1 no confusion at all; 5 very confused) for when you encountered the following bicycle infrastructure treatments during the driving simulator drives:

| | no confusion at all | | | | very confused |
|---|---|---|---|---|---|
| Bicycle lane | 1 | 2 | 3 | 4 | 5 |
| Bicycle lane with merge for right-turning vehicles | 1 | 2 | 3 | 4 | 5 |
| Bicycle box | 1 | 2 | 3 | 4 | 5 |

What about the treatments made it difficult to understand them?

______________________________________________
______________________________________________
______________________________________________

5. As a bicyclist, which bicycling treatment would make you feel the safest?
☐ None ☐ Bicycle lane only ☐ Bicycle box ☐ Bicycle lane with merge for right-turning vehicles

6. As a driver, what treatment would you rather see be implemented for bicyclists?
☐ None ☐ Bicycle lane only ☐ Bicycle box ☐ Bicycle lane with merge for right-turning vehicles

If different from above, why?

______________________________________________
______________________________________________

Any additional comments?

______________________________________________
______________________________________________

**Figure B.2 - Example of Post Study Questionnaire (Page 2)**