Dissecting the Safety Benefits of Protected Intersection Design Features

SAFETY RESEARCH USING SIMULATION

UNIVERSITY TRANSPORTATION CENTER

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Abstract

Protected intersections are an integral component of Complete Streets and are used to facilitate safe crossings for bicyclists and pedestrians at intersections. Their placement is ideal after segments with protected bike lanes where drivers might not be aware of bicyclists' presence. Protected intersections have the ability to increase drivers' awareness by increasing bicyclist visibility. While frequently implemented elsewhere, protected intersections are a relatively new bicycle treatment for North America. As such, there is a need to understand how its design elements contribute to safe interactions between drivers and bicyclists at an intersection. This study used a driving simulation environment to test the effectiveness of different design elements of protected intersections, such as bicycle crossing pavement markings and intersection radii, on the speed and attentiveness of drivers. Participants drove 12 scenarios where the roadway environment consisted of segments leading to protected intersections. Each scenario had two intersections where the drivers were guided to make a right and a left turn, respectively. Moreover, each scenario exposed drivers to different protected intersection designs, i.e., turning radii and pavement marking levels, and assessed their speed as they were completing turns while interacting with bicyclists or not. Participant demographics as well as driving and bicycling history were obtained through a questionnaire. Participants' speed and position were recorded through the simulator. The analysis determined which combination of independent variables (i.e., pavement markings, turning radii of the protected intersection, and demographics) contributes to safe interactions between bicyclists and automobiles in a protected intersection. In particular, intersection approaching, turning, and exiting speeds were analyzed across the different scenarios and participant demographics. The results indicate that the presence of a bicyclist crossing a protected intersection significantly reduces speeds for drivers performing a right turn through that intersection. Larger intersection radii were found to reduce turning speeds as they are accompanied by larger corner islands and bigger curb extensions. Bicycle crossing pavement markings influenced only approaching speeds prior to the actual turn as that is when they were the most visible. Demographics (i.e., age and gender) and bicycling history were also observed to be affecting turning speeds, indicating that design elements alone cannot determine the safety effectiveness of a protected intersection.

1 Introduction

A major barrier to the realization of safer, more comfortable streets is the fact that these integral parts of cities and regions do not serve each road user equitably. Urban roadways and intersections have traditionally been designed to effectively accommodate automobiles without always considering the needs of bicyclists and pedestrians. An increase in bicycling and walking, coupled with the expiring lifespan of road networks, has motivated transportation planners and engineers to re-evaluate, redesign, and reimagine intersections to accommodate all users, with the intended goal of increasing mobility and safety.

Cities have been implementing bicycle facilities to accommodate bicyclists on road networks. A recent trend favors the placement of protected bike lanes instead of conventional bike lanes, aiming to eliminate the interaction between bicyclists and automobiles and thus increase safety. However, given that approximately one-third of bicycle-automobile crashes occur at urban intersections [1], special attention should be given to ensuring safe motorist-bicyclist interactions at intersections.

One way to improve the safety of intersections for all users is by introducing protected intersection elements through minor adjustments to the existing intersection design. Examples of such elements are shown in Figure 1.1. Currently, this is often accomplished through Complete Street projects and policies that encourage redevelopment along corridors to make them suitable for all modes of transportation. Improving the efficiency and safety of intersections by introducing protected intersection elements increases network connectivity and can encourage bicycle use. Ultimately, even minor adjustments to intersections can lead to safety improvements through reductions in crashes between bicyclists and motorists. In addition, cost savings can be realized by municipalities that wish to efficiently improve already constructed protected intersections or retrofit existing intersections to incorporate protected intersection elements with the goal of achieving benefits similar to those of a protected intersection. However, the safety benefits that can be achieved with the use of protected intersection elements have not been extensively studied.

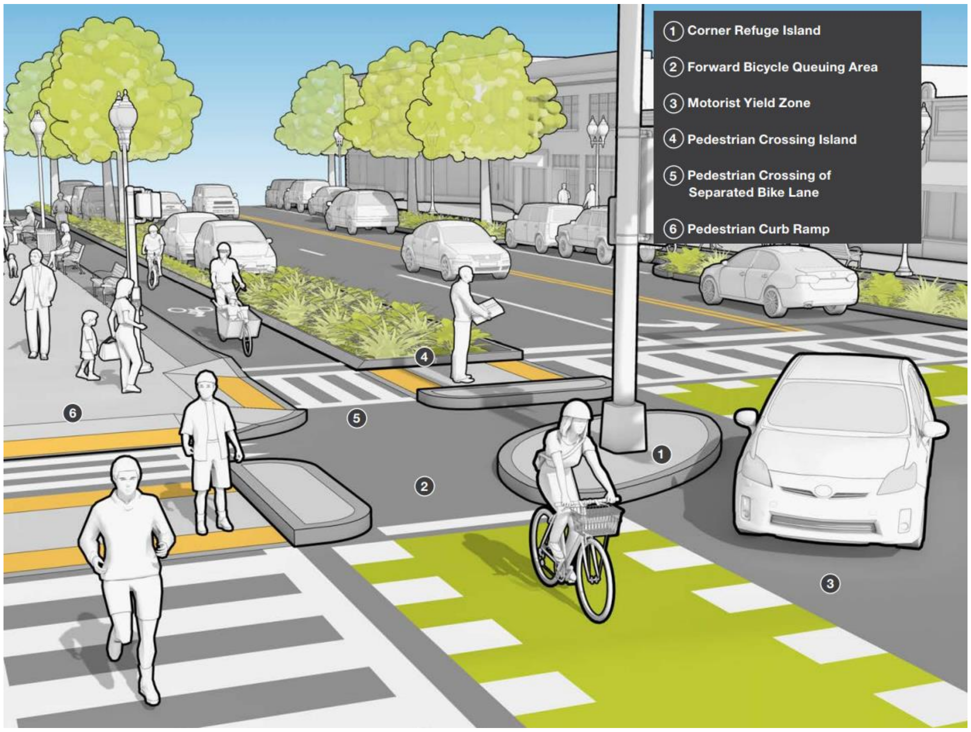


Figure 1.1 - Protected intersection (source: MassDOT *Separated Bike Lane Planning & Design Guide* [2])

The objective of this study was to examine the effects of protected intersection elements and bicyclist presence on the speeds of right-turning vehicles. A driving simulator experiment was designed for this purpose and was used to analyze the behavior of right-turning drivers at protected intersections with different turning radii and pavement markings with and without bicycle-driver interactions.

The hypotheses that were tested through this experiment were (1) that larger turning radii and more visible bicycle crossing pavement markings reduce driver speed, thereby increasing safety at protected intersections, and (2) that the presence of a bicyclist at the intersection would significantly reduce the driver’s speed through the intersection.

2 Background

A wide range of studies has demonstrated the safety benefits of protected bike lanes in both the European and the North American context [3-5]. A recent trend regarding the implementation of protected bike lanes in the U.S. has been supported by government guidelines published by the Federal Highway Administration (FHWA) [6] and the Massachusetts Department of Transportation (MassDOT) [2]. While FHWA's *Separated Bike Lane Planning and Design Guide* includes guidelines on intersection design after segments with protected bike lanes, it does not provide guidance on protected intersection design. The MassDOT's *Separated Bike Lane Planning and Design Guide* is the first U.S. government document that provides guidelines on protected intersection design. Design guidelines for protected intersections were also recently provided by the National Association of City Transportation Officials (NACTO) [7]. Alta Planning + Design [8] also published design lessons learned from existing U.S. implementations of protected intersections, e.g., the one at Davis, California, aligning them with existing regulations by various federal organizations, such as the American Association of State Highway and Transportation Officials (AASHTO).

Apart from design guidelines, there are a few academic research studies on protected intersections. Warner et al. [9] conducted a driving simulator experiment to study the benefits of various engineering treatments for intersections Among other treatments, they studied the effect of protected intersections on right-hook crashes between drivers and bicyclists. The results indicate that protected intersections with islands and green-colored intersection crossing pavement markings can reduce the frequency of moderate and severe collisions between drivers and bicyclists compared to the case where no intersection treatments are present. One limitation of this study is the presence of conventional bike lanes in advance of the protected intersections. Previous research has shown that drivers behave differently in the presence of protected bike lanes [10], as they are separated from bicyclists. As a result, the effectiveness of protected intersection elements could be different if protected bike lanes were in place.

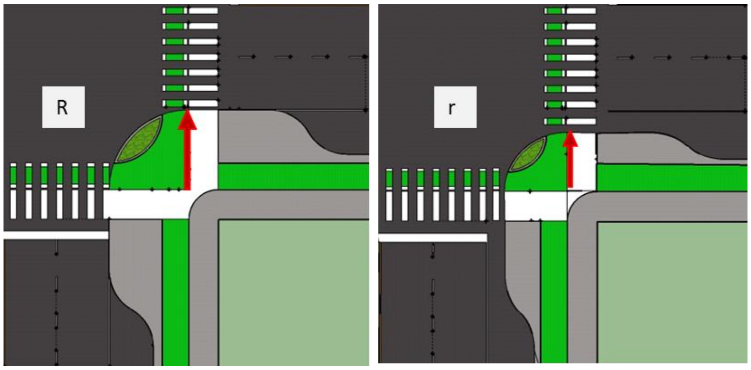
A field study found that combining protected intersections with protected bike lanes was the most effective in terms of reducing the frequency of observed conflicts between drivers and bicyclists when compared to other treatments that merge bicyclists and motorists upstream of the intersection [11]. This is because protected intersections reduce the number of conflict points between bicyclists and motorists (also between pedestrians and motorists) at an intersection, while intersection treatments such as merging zones relocate the conflict points upstream of the intersection.

Overall, research on the safety benefits of protected intersection designs is limited and sparse. When performed, it focuses mostly on comparing protected intersections to unprotected intersections in the presence of conventional bike lanes upstream of the intersection. While these studies are useful in advancing the separation of users at intersections and along roadway segments, they are not informative on the design elements that can be altered to improve intersection safety for all users. Design guidelines indicate the need for implementing protected intersections, but there is no research to date on the impact of certain design elements of protected intersections (e.g., turning radii and crossing pavement markings) or the presence of bicyclists on driver behavior. There is a need to investigate the effect that crossing pavement markings and turning radii as well as interactions with bicyclists have on the behavior of drivers when traveling through a protected intersection.

3 Methodology

Driver behavior at six protected intersection designs was examined using a driving simulator. A driving simulator was chosen for this study because it allows for testing a variety of scenarios that cannot be easily found in the field, especially for protected intersections, which are not common in the U.S. In addition, it allows the researcher to isolate variables of interest by altering one variable at a time, e.g., changing the intersection bicycle crossing pavement markings. Finally, driving simulators facilitate data collection that allows for a comprehensive investigation of the driver's response to design elements through operational data (e.g., speed, lateral position) and eye tracking data (e.g., a participant's gaze).

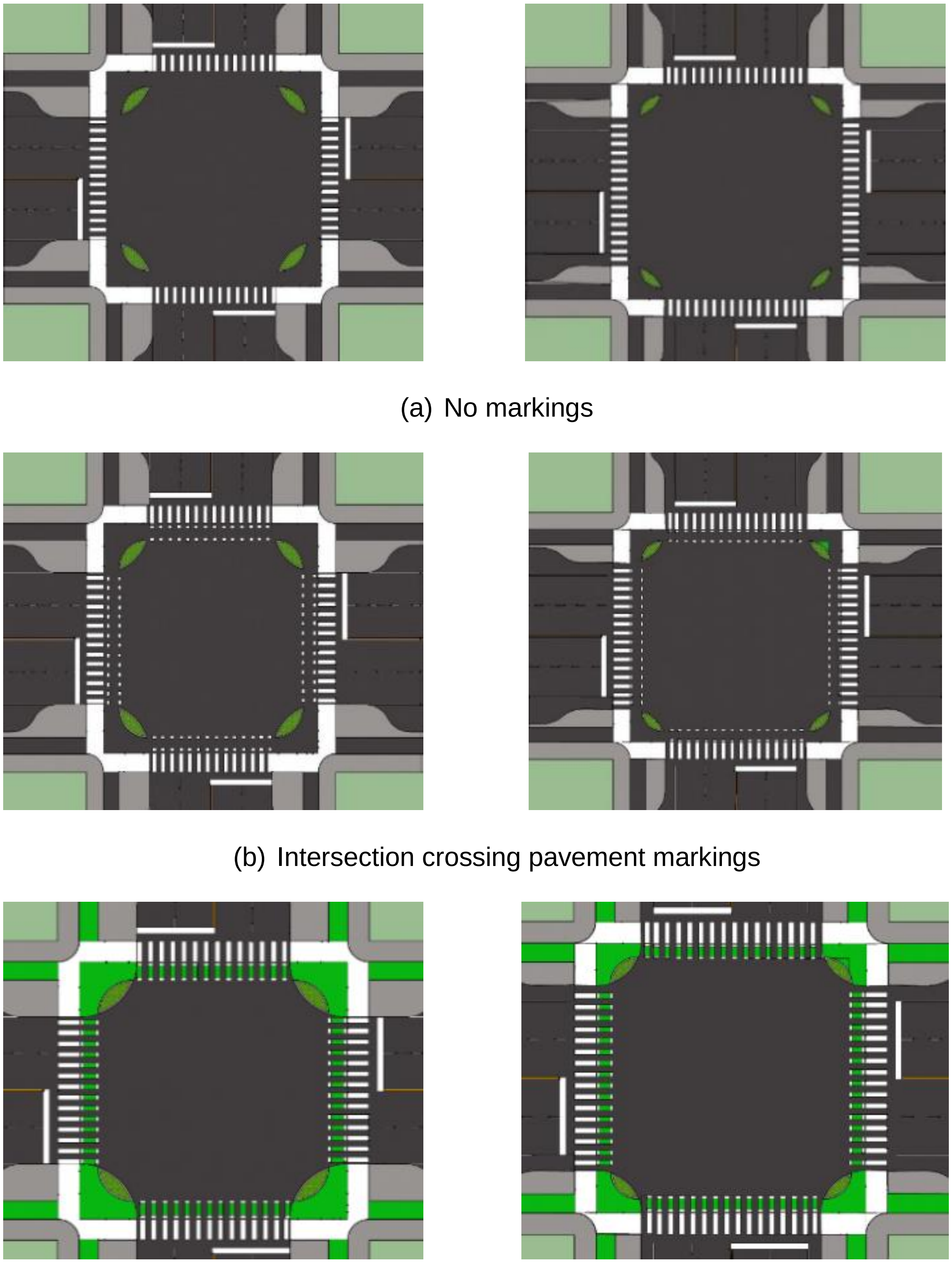
The six designs used in the simulator experiments consisted of combinations of different intersection turning radii and bicycle intersection crossing pavement markings. Two types of turning radii were tested: big (16.4 ft) and small (9.8 ft) (see Figure 3.1). Figure 3.2 shows the three levels of bicycle intersection crossing pavement markings tested: (a) no markings; (b) minimum level of markings (i.e., intersection crossing pavement markings); and (c) maximum level of markings (i.e., green-colored intersection crossing pavement markings). The focus was on right-turn movements at protected intersections. The six intersections with varying turning radii and bicycle intersection crossing pavement markings are displayed in Figure 3.2.



(a) Big turning radius (b) Small turning radius

Figure 3.1 - Turning radii

Big Radius   Small Radius



(a) No markings

(b) Intersection crossing pavement markings

(c) Green-colored intersection crossing pavement markings

Figure 3.2 - Protected intersection designs studied

3.1 Experimental Design

3.1.1 Scenario Description

The experiment consisted of the 12 scenarios shown in Table 3.1, each representing one of the six protected intersections presented earlier (Figure 3.2**Error! Reference source not found.**) with or without a bicyclist crossing the intersection while the participant is completing the turn. The experimental design was within-subjects, as all participants drove through all 12 scenarios. To eliminate the order effect, the Latin square matrix method was used to generate a different order for the 12 scenarios for each participant.

Table 3.1 - Scenarios

Scenario	Bicycle Marking	Turning Radius	Bicyclist Presence
1	No Pavement Marking	Big	No
2	Intersection Crossing Pavement Markings	Big	No
3	Green-Colored Intersection Crossing Pavement Markings	Big	No
4	No Pavement Marking	Small	No
5	Intersection Crossing Pavement Markings	Small	No
6	Green-Colored Intersection Crossing Pavement Markings	Small	No
7	No Pavement Marking	Big	Yes
8	Intersection Crossing Pavement Markings	Big	Yes
9	Green-Colored Intersection Crossing Pavement Markings	Big	Yes
10	No Pavement Marking	Small	Yes
11	Intersection Crossing Pavement Markings	Small	Yes
12	Green-Colored Intersection Crossing Pavement Markings	Small	Yes

Each drive consisted of approximately half a mile of simulated roadway with two intersections separated by a long straight segment. The long segment was used to allow drivers to recover from making turns at intersections since subsequent turns can cause simulator sickness. The drives consisted of either (1) a straight segment followed by a right turn with another straight segment followed by a left turn, or (2) a straight segment followed by a left turn with another straight segment followed by a right turn; see Figure 3.3. The existence of left turns was justified by the need to introduce variability within the experimental design and prevent drivers from clueing in on the nature of the experiment, in particular, the focus on right turns. The speed limit on the straight segment was 35 mph, and drivers, while approaching the intersection, received an indication to make a right or left turn, depending on the scenario configuration. The drive ended after participants completed the second turn. The start and end points of the drives are shown in Figure 3.3. Participants encountered the bicyclist crossing the two intersections of the experiment in half of those and had no interaction with any bicyclists in the other half, depending on the drive.

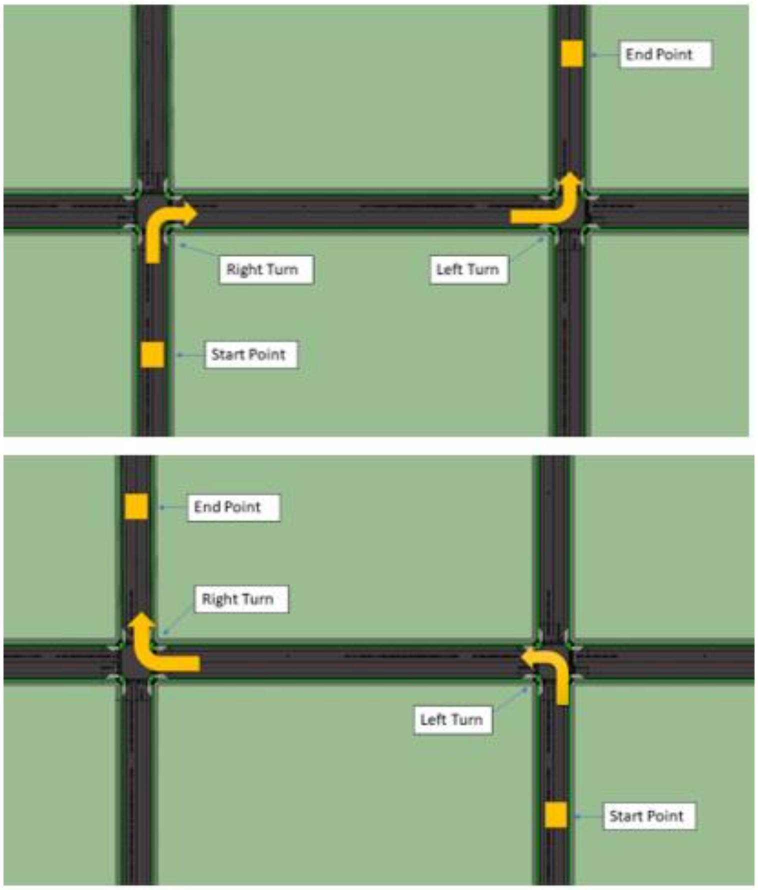


Figure 3.3 - Overview of the turn sequence scenarios

3.1.2 Dependent and Independent Variables

Table 3.1**Error! Reference source not found.** displays the independent variables used in the experiment, namely pavement marking level, bicyclist presence, and intersection turning radius. The parts of the scenario where a bicyclist interacts with the participants, in those scenarios where a bicyclist is present, are shown in Figure 3.4. Participant demographics (i.e., gender and age) and cycling frequency were also considered in the analysis. The dependent variables were the average speed through different parts of the protected intersection. In particular, speed data was captured and analyzed for three segments of each intersection turn: (1) while the participant was entering (approaching speed), (2) travelling within the intersection (turning speed), and (3) exiting the protected intersection (exit speed). For each turn, six different sets of data markers were placed in the scenarios to capture the approach, curve, and exit speeds of participants, as shown in Figure 3.5. Data markers were placed symmetrically for both right and left turns in all scenarios. The data markers for the approach speed were placed so that they captured the driver's speed for 230 feet before the intersection. While on the curve, data markers were placed on the entrance and exit crosswalks of the curve, approximately 50 to 65 feet apart. At the exit, driver speed was captured for 230 feet after the intersection. However, participants were allowed to end their drive at any point after they crossed the exit crosswalk at the second intersection. This resulted in participants driving different lengths along the exit segment, which could bias the outcomes of the analysis. As result, we have chosen to focus our analysis on only the approaching and turning speeds.

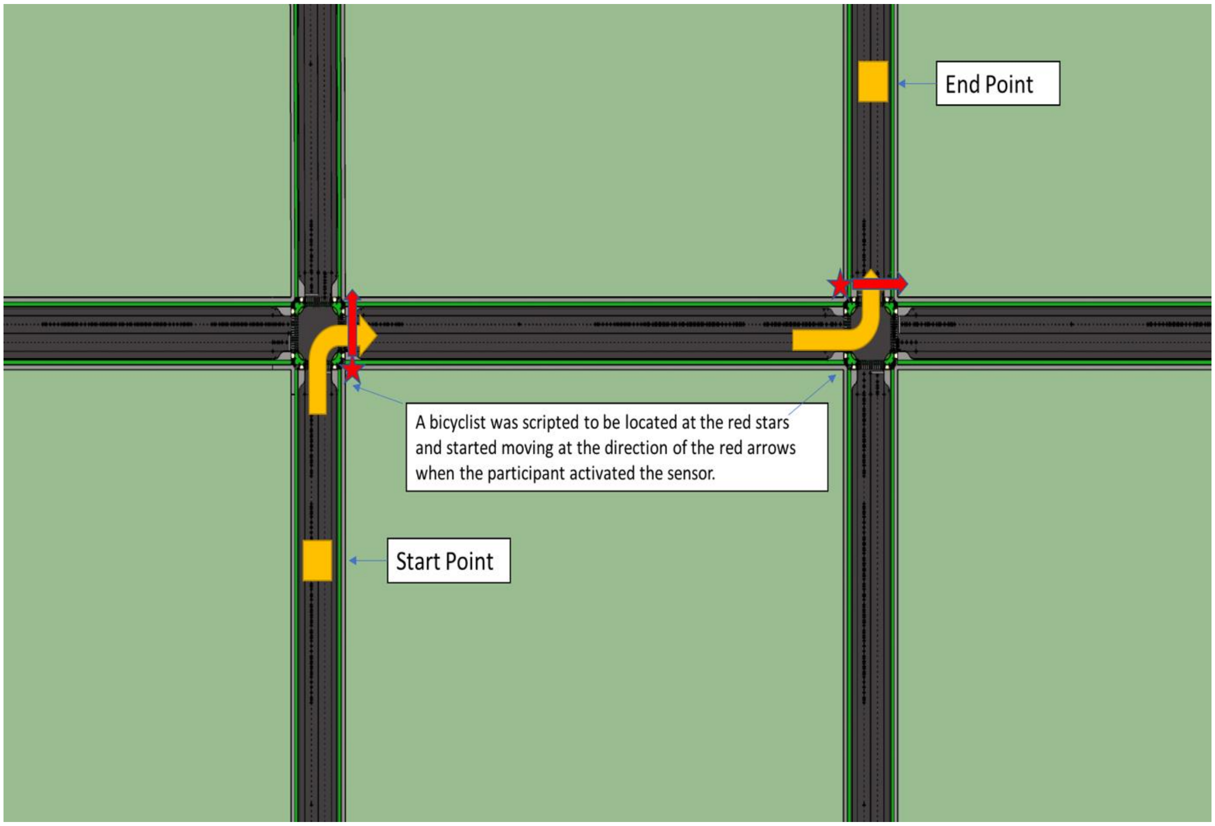


Figure 3.4 - Bicyclist's position when interacting with participant

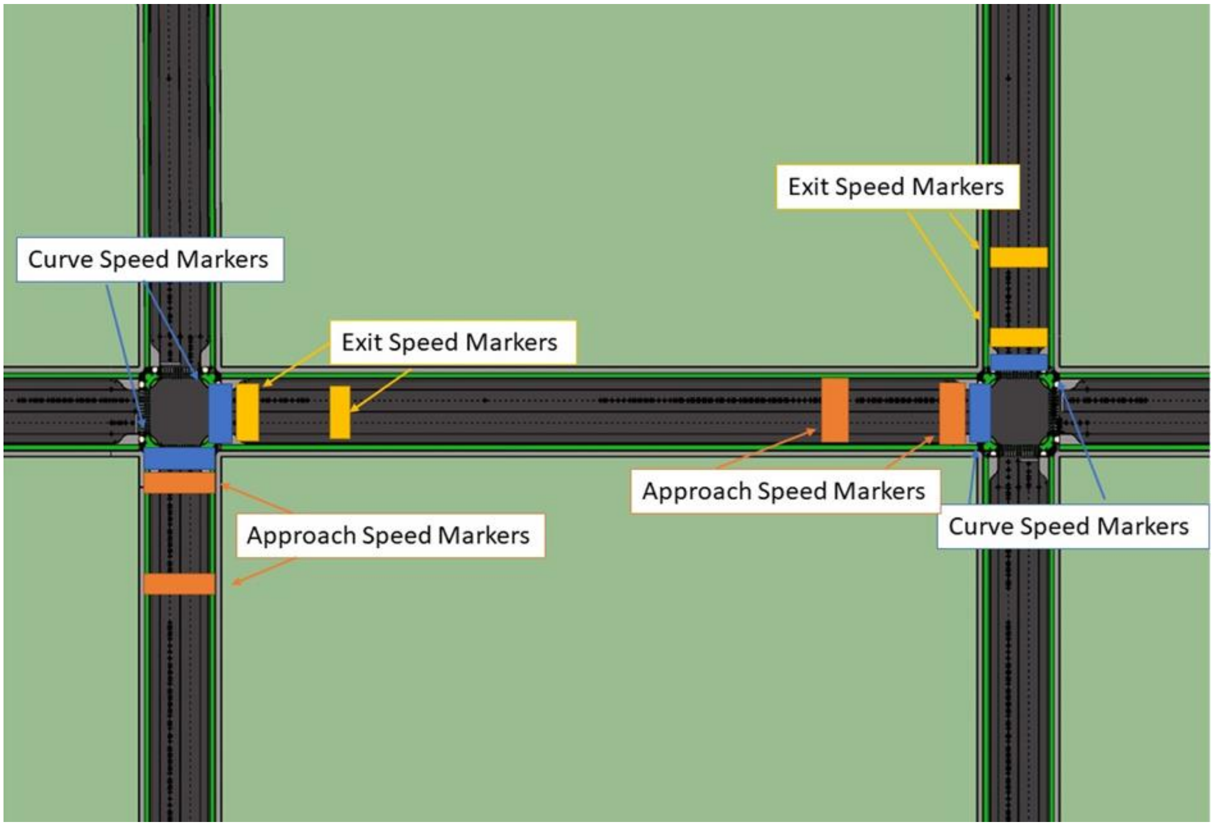


Figure 3.5 - Data markers for speed data collection

A driver's speed at each of these segments may be affected by the intersection turning radii, the presence of a bicyclist, or the type of bicycle crossing pavement markings used, as well as the individual driver behavior and characteristics of the driver.

3.1.3 Participants and Experimental Procedure

Thirty-six participants were recruited for this experiment, 19 male and 17 female. The average age of participants was 25.1 years (SD = 9.6), and the average participant received their license at 16 years and 11 months (SD = 1.8). Participant ages ranged from 18 to 65 years, with the majority of participants falling within the 18-25 age range.

The study procedure consisted of four steps:

1. The participant completed the consent form and a pre-study questionnaire containing demographic-related questions as well as questions related to

driving and bicycling history and frequency (see Appendix A: Pre-Study Questionnaire).

2. The participant drove a test drive. This step was intended to familiarize the participant with the car and the simulator environment through a short drive. It also informed the researchers on whether the participant was susceptible to simulator sickness and should therefore, be excluded from the study.
3. The participant drove the twelve scenarios.
4. The participant was debriefed on the experiment, completed the experiment voucher and was compensated.

3.2 Apparatus

3.2.1 Driving Simulator

The driving simulator used for this study is the Human Performance Laboratory at the University of Massachusetts, Amherst which is a full-body 2013 model Ford Fusion sedan fixed-base simulator. The vehicle is surrounded by six projectors, which display the simulated environment to the driver. The five main projectors of the simulator have a resolution of 1920 x 1200 pixels and an image display refresh rate of 96 Hz. The rear projector has a resolution of 1400 x 1050 pixels and also has a display refresh rate of 96 Hz. These six projectors together generate an approximate 330-degree field of view around the driver, allowing them to be immersed in the simulated environment. The sound system consists of a five-speaker surround system plus a sub-woofer for exterior noise and a two-speaker system plus a sub-woofer for interior vehicle noise. A rendering of the simulator set up in the Human Performance Laboratory is displayed in Figure 3.6.

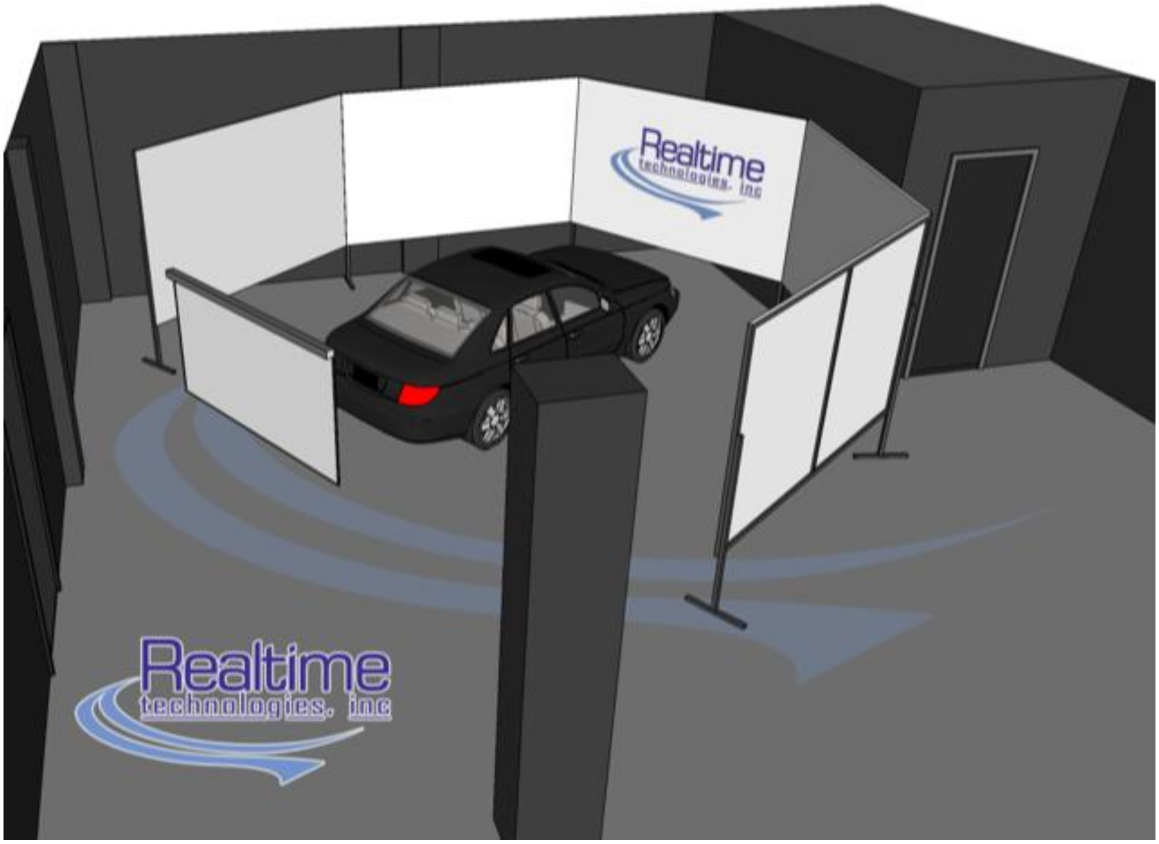


Figure 3.6 - Rendering of the driving simulator at the University of Massachusetts Amherst Human Performance Lab

3.2.2 Questionnaires

Participants were asked to answer a pre-study questionnaire. The pre-study questionnaire collected demographic information such as gender and age. Additionally, participants were asked to provide information regarding their driving history and experience. Specifically, they were asked to provide the age at which they obtained their driving license, an approximation of the miles they had driven during the previous week, and an approximation of the miles they had driven during the previous year. Finally, they were asked questions related to their bicycling history: whether they bike or not and if so, how frequently and on what types of roads. Appendix A presents the pre-study questionnaire.

4 Results

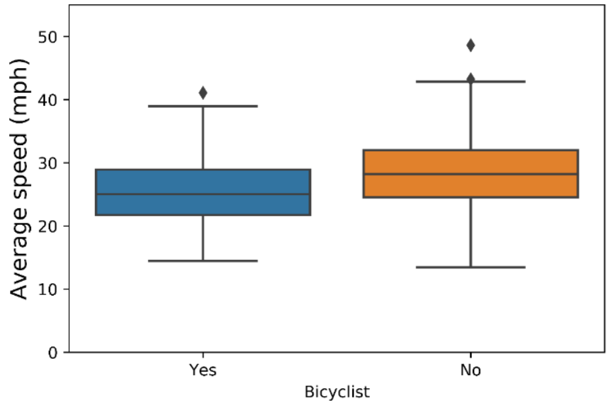
Speed data was recorded from the simulator and was used to analyze driver right-turning behavior, in particular through speeds, at the various protected intersection designs. A total of 432 turns were analyzed from 36 participants, each of whom drove 12 scenarios. While the scenarios included left turns, those were excluded from the analysis. For the right turns, speed data was obtained and analyzed separately for two segments of the turning movement: (1) approaching speed, and (2) turning speed (curve speed).

Box plots were used to display the speed data due to their ability to summarize information in a succinct manner and provide five different data points for analysis, i.e., the 1st quartile, 3rd quartile, median, minimum, and maximum values are all visible and easily discerned. Statistical tests were conducted to determine whether the observed differences in speeds were statistically significant.

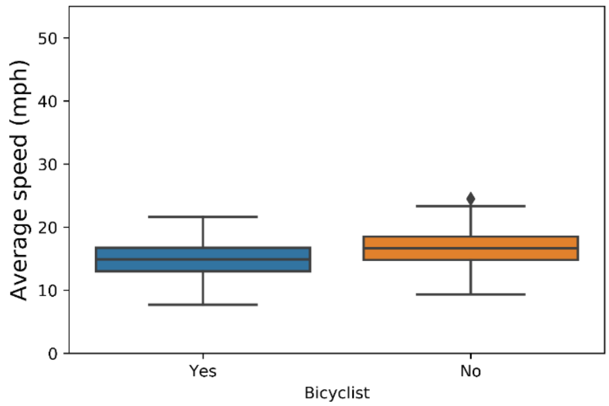
4.1 Impact of bicyclist presence on intersection speed

For this analysis, 216 right turns were used to study driver speeding behavior with and without the presence of a bicyclist at the intersection. Half of the scenarios had a bicyclist present at the intersection. This analysis compares their results with those of scenarios where no bicyclist was present. Overall, all participants braked and yielded to the bicyclists, allowing them to cross the street as they were coded to do.

Figure 4.1 presents the average speed of right turns by segment section and bicycle presence. The box plots reveal small differences between the speeds at each segment when a bicyclist is present versus when it is not. In addition, it is observed that approaching speeds were much higher than the turning speeds.



(a) Intersection approaching speed



(b) Intersection turning speed

Figure 4.1 - Driver speed at the protected intersection by turning segment and bicyclist presence

A Student's t-test was used to test whether the differences in the mean observed speeds were statistically significant at the 95% confidence level. The test was applied two times in order to compare the speeds in the presence of a bicyclist with those when no bicyclist was present at each of the two sections of the turn, i.e., approaching and turning. Table 4.1 presents the results of the Student's t-tests for speed for scenarios with bicyclists versus those without bicyclists and separately for scenarios with small turning radii vs big turning radii.

Table 4.1 – Student's t- test results (confidence level = 95%)

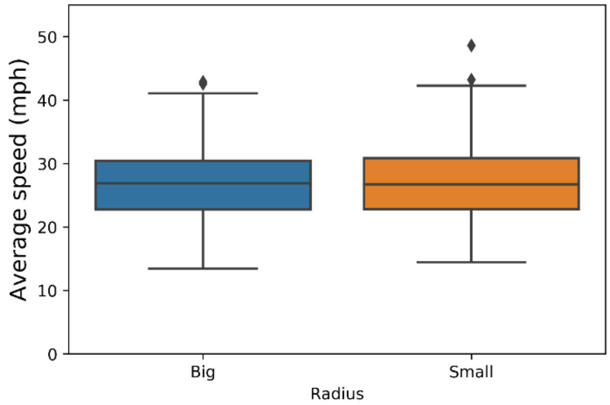
Intersection Turning Segment	Bicyclist Presence			Turning Radius		
	Speed (mph)		P-value	Speed (mph)		P-value
	Yes	No		Big	Small	
Approaching	25.3	28.4	3.97×10^{-8}*	26.9	26.9	0.99
Turning	14.8	16.8	2.62×10^{-11}*	15.4	16.1	0.04*

* Statistically significant at the 95% confidence level

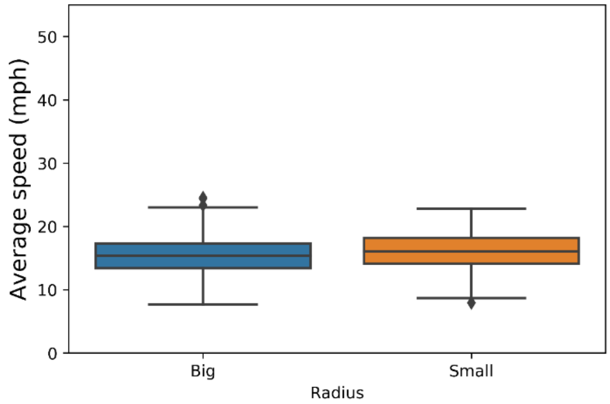
Bicyclist presence was found to significantly affect approaching and turning speeds. When a bicyclist was present, drivers approached the intersection at an average speed of 25.3 mph, while in the absence of bicyclists participant speeds averaged 28.4 mph. On the turning part of the intersection, participants drove at 14.8 mph when the bicyclist was present and at 16.7 mph when the bicyclist was not present. Drivers were able to view the bicyclists while approaching the intersection and allow them to cross the street before they continued with their turning movement.

4.2 Impact of turning radius on intersection speed

The study used 216 right turns for the driver speed analysis for each intersection turning radius size (large or small). The speed statistics are presented through the boxplots of Figure 4.2. Overall, small differences are observed between median speeds for scenarios with small and big turning radii for the two turn segments. Therefore, it seems that the examined turning radii did not impact driver speeding behavior when approaching the intersection.



(a) Intersection approaching speed



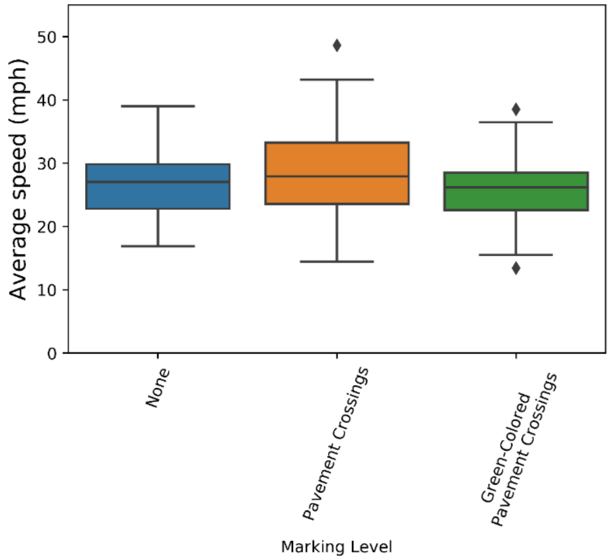
(b) Intersection turning speed

Figure 4.2 - Driver speed at the protected intersection by turning segment and intersection turning radius

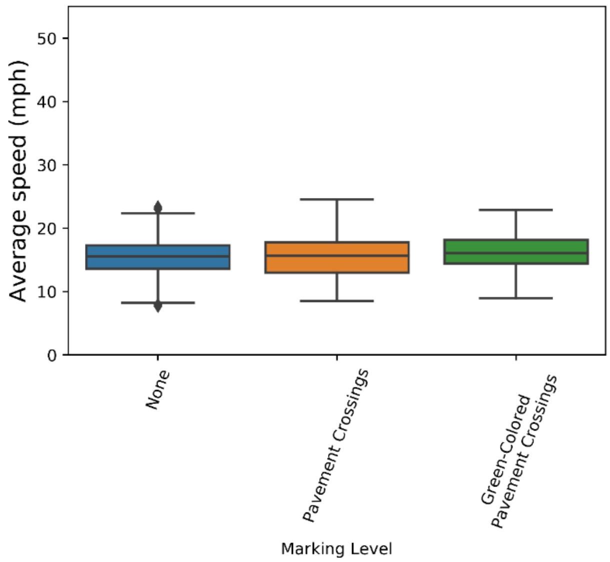
In order to confirm the statistical significance of this observation, Student's t-tests were performed; see Table 4.1. These tests revealed that only the turning (i.e., curve) speed differences between the small and big radii were statistically significant, with big radii resulting in lower mean speeds. However, it should be mentioned that their difference was estimated to be approximately 0.7 mph, which realistically is not very big.

4.3 Impact of intersection crossing pavement markings on intersection speed

Across all scenarios, there were 144 protected intersections without intersection crossing pavement markings for bicyclists, 144 protected intersections that displayed intersection crossing pavement markings, and 144 protected intersections where these markings were also green-colored. Figure 4.3 presents the speed boxplots along the two turning segments under the presence of the three crossing pavement markings.



(a) Intersection approaching speed



(b) Intersection turning speed

Figure 4.3 - Driver speed at the protected intersection by turning segment and pavement marking level

The analysis of variance (ANOVA) test was used to study the statistical difference between mean speeds. It was implemented two times (i.e., for the two segments of the turn), and the results are presented in Table 4.2.

Table 4.2 - ANOVA for the different levels of intersection crossing pavement markings

Intersection Segment	**Speed (mph)**			**P-value**
	No Marking	**Simple Markings**	**Green-Colored Markings**	
Approaching	26.6	28.2	25.9	0.003*
Turning	15.6	15.4	16.2	0.102

* Statistically significant at the 95% confidence level

The ANOVA revealed that only approaching speeds were impacted by the crossing pavement markings. This result is reasonable in the sense that crossing pavement markings are visible to drivers as they are approaching the intersection and the different color and markings can capture their attention and more significantly affect their speed. However, later on, while the driver is completing the turn bicycle crossing pavement markings do ~~not affect the driver~~seem to have an impact on speed selection. Overall, the green-color pavement marking, which is essentially the most visible display, resulted in the lowest mean approaching speed (25.9 mph).

4.4 Regression Analysis

Linear regression was used to identify the combinations of factors that affect driver speed at each of the two segments of the turn, i.e., approach, and turn. The independent variables for this analysis were: (1) bicyclist presence at the intersection (binary), (2) turning radius (binary), (3) intersection crossing pavement markings (categorical), (4) participant gender (binary), (5) participant age (continuous), and (6) participant being a bicyclist (binary). The dependent variable was the participant's mean speed at a chosen segment of the turn. All the results presented below correspond to the 95% confidence level.

Table 4.3 presents the linear regression results for the approaching speed, which was found to be affected only by bicyclist presence at the intersection. This was the only independent variable to have a p-value lower than 0.05. Overall, this model reported a R^2 equal to 0.08, which indicates a model incapable of fitting the data.

Table 4.3 - Linear regression analysis results for the intersection approach speed

Independent Variables	Coefficient	Standard Error	P-value
Intercept	27.6701	1.213	0.000
Gender	1.0693	0.604	0.077
Age	-0.0037	0.030	0.902
Bicycling	0.9559	0.614	0.120
Bicyclist Presence	-3.0853	0.551	0.000*
Turning Radius	-0.0144	0.551	0.979
Crossing Pavement Markings	-0.3191	0.335	0.342

* Statistically significant at the 95% confidence level

The linear regression model that was developed for participants' average speed on the curve, i.e., speed on the turning part of the intersection, revealed that the following factors were statistically significant: (a) age, (b) gender, (c) bicycling, (d) bicyclist presence, and (e) intersection turning radius; see Table 4.4. In particular, female participants developed higher speeds than male participants at this part of the intersection. Age was also statistically significant, with older drivers choosing lower speeds while completing a right turn at a protected intersection. Similarly, participants who reported being bicyclists developed higher speeds. Both bicyclist presence and bigger radii were found to significantly reduce driver turning speed, which agrees with our initial hypotheses. This model had an R^2 equal to 0.198. Removing non-significant independent variables did not seem to have any impact on the results and actually worsened the model's fit, i.e., it resulted in a lower R^2.

Table 4.4 - Linear regression analysis results for the intersection turning speed

Independent Variables	Coefficient	Standard Error	P-value
Intercept	16.4317	0.596	0.000
Gender	1.4005	0.296	0.000*
Age	-0.0383	0.015	0.010*
Bicycling	0.8821	0.301	0.004*
Bicyclist Presence	-1.8886	0.269	0.000*
Turning Radius	-0.5612	0.269	0.038*
Crossing Pavement Markings	0.2861	0.165	0.084

* Statistically significant at the 95% confidence level

5 Conclusions

The presence of a bicyclist had a larger, more persistent impact on participant speeds than any other variable examined in this experiment. This was anticipated, as the scenarios were such that participants could easily detect the bicyclist when approaching or completing the turn and never failed to stop and yield appropriately to the bicyclist. The presence of a bicyclist motivated lower approaching and turning speeds. Intersection turning radii were found to only affect turning speeds. Smaller radii resulted in higher speeds due to the presence of bigger curb extensions and corner islands that seemed to be slowing down vehicles while performing their turns. Intersection crossing pavement markings seemed to only affect approaching speeds; a more intense display on the pavement increased driver awareness of potential bicyclist presence. The fact that only approaching speed was affected is reasonable given that those markings were first visible as a turn was being initiated.

Additionally, the inclusion of gender, age, and whether or not the participant was a bicyclist as independent variables in the regression analysis improved the regression's goodness of fit. This suggests that there are additional demographic and background factors that affect the participants' speed at protected intersections. Older drivers chose lower speeds at turns, while female drivers and participants who reported being bicyclists chose higher speeds while turning at a protected intersection.

The static nature of the bicyclists at the intersection and the repetitive nature of their movements made portions of the experiment predictable to certain participants. An improved script could be developed to make bicyclist movement dynamic and erratic, causing the driver to encounter the bicyclist unexpectedly in different locations. While this would naturally upset the balance of the experiment and require further experimental controls to be put in place, it could perhaps more accurately capture interactions between bicyclists and motorists in a driving simulation environment.

There are multiple design elements of protected intersections that could be explored to measure the effectiveness of different treatment levels on the safety of protected intersections. In addition to intersection radius and crossing pavement markings, signage types, crosswalk position, and different levels of signalization could be studied to assess their effectiveness in improving safety at protected intersections. These variables could be explored on their own or in conjunction with previously tested variables to formulate a better understanding of what the ideal protected intersection should look like.

6 References

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Appendix A: Pre-Study Questionnaire

HUMAN PERFORMANCE LABORATORY
PROTECTED INTERSECTION Study
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: ____________________

Age: ______

Race / Ethnicity: ☐ Black / African American ☐ Asian
(check all that apply) ☐ Caucasian ☐ American Indian / Native Alaskan
(question asked for reporting purposes) ☐ 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 ☐ 100-199 ☐ 200-299 ☐ 300-499 ☐ 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 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 usually wear glasses or contacts while driving? ☐ No
☐ Yes, glasses
☐ Yes, contacts

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, which might cause to you drive much better or worse than other drivers? ☐ Yes ☐ No

If yes, please describe: ____

Section 3: 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

If you answered No please skip the rest of this questionnaire.

How often do you bicycle on average?
☐ 5 times a week or more ☐ 3-4 times a week ☐ 1-2 times a week ☐ 1-3 times a month

☐ Less than once a month

Do you typically bike on the road, on trails/other paths, or a mixture of both?
☐ Road ☐ Trails/Paths ☐ Both

About how many miles did you bike in the past 12 months?
☐ Less than 100 ☐ 100-250 ☐ 250-500 ☐More than 500

Approximately how old were you when you started cycling?_____ **Years Old**