Street Intersection Characteristics and Their Impacts on Perceived Bicycling Safety

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Safety concern is one of the core issues that deter people from bicycling in the US. Earlier studies have explored the associations between intersection design characteristics and bicyclist safety perceptions. Research shows that there are significant links between bicycling choice, safety perceptions, bicycling experience levels and socio-demographics. Yet, the existing bicycling safety-rating models do not control for the individuals' socio-demographics and bicycling experiences that are known to affect bicycling choice. This study develops a Perceived Bicycling Intersection Safety (PBIS) model which helps engineers, planners and decision-makers better understand the contributions of a wide range of intersection features to bicyclists safety perceptions, controlling for socio-demographics and bicycling experiences. The empirical analysis is based on an online visual survey conducted at the main campus of The Ohio State University through March and April 2017. We determine that visual surveys are effective in capturing information about bicycling preferences. We conclude with recommendations for infrastructure decisions and suggestions for future research. The results of this study can help planners design street intersections that bicyclists prefer. Our model can be applied elsewhere to test the effects of different intersection and street features.			
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1. Executive Summary

Encouraging the use of bicycles is regarded as an effective strategy to benefit our living environments, reduce fuel consumption, and promote public health. Safety concern is one of the core issues that deter people from bicycling in the US. National Highway Traffic Safety Administration (NHTSA) reports that street intersections have higher ratios of bicycle crashes as compared to other urban environments (2014). One possible explanation is the high level of interactions between automobiles and bicycles at intersections. Earlier studies have explored the associations between intersection design characteristics and bicyclist safety perceptions. Research shows that there are significant links between bicycling choice, safety perceptions, bicycling experience levels, and socio-demographics. However, the existing bicycling safety-rating models do not control for the individuals' socio-demographics and bicycling experiences that are known to affect bicycling choice.

In this study, we develop a Perceived Bicycling Intersection Safety (PBIS) model to help engineers, planners, and decision-makers better understand the contribution of each intersection feature to bicyclist safety perceptions, controlling for socio-demographics and attitudes towards bicycling. The perceived safety may vary across genders and individuals with various levels of bicycling experiences. The developed model can predict how safe a bicyclist is likely to feel riding through a given street intersection. The developed model can be used to evaluate existing street intersections and project the changes in safety perceptions with respect to changes in intersection features.

The empirical analysis is based on the data collected via an online visual survey at the main campus of The Ohio State University through March and April 2017. We collected information on respondents' safety perceptions at various intersections using a visual preference survey. We also collected data on other factors that are known to affect bicycling decisions such as socio-demographic characteristics, attitudes towards bicycling, and general travel characteristics. We received over 1,000 responses from undergraduate and graduate students as well as faculty and staff members. We estimate a series of Ordered Probit (OP) models to demonstrate the extent to which certain street intersection characteristics (such as traffic volume, intersection configuration, posted road crossings, bike lanes, bicycle boxes, green space, road surface conditions, surrounding neighborhood types, and other features) affect bicycling safety perceptions while controlling for socio-demographics and bicycling experience levels.

Our main PBIS (Perceived Bicycling Intersection Safety) model reveals that provision of various transportation infrastructure – bicycle crossings, intersection crossing markings, cycle tracks, bicycle boxes, traffic diverters, sidewalks, curb ramps, clear curb extensions, and paved shoulders – improve bicyclists' safety perceptions. Increasing number of through auto lanes, traffic volumes, presence of crosswalks, median refuge islands, light rail passing, and visible highway crossings increase people's safety concerns. Our model further implies that planting grass borders and trees along the road, as well as tress behind the sidewalk is the best green strategy to improve cyclists' safety perceptions at the intersection-level. For real-world implementation, we calculate the perceived safety scores at various intersections by using the estimated coefficients of our main PBIS model. As expected, street intersections with low perceived bicycling intersection safety scores turn out to be the ones with higher number of crashes.

2. Project Background

Auto dominant transport policy has led to a number of issues related to environment, energy and sustainability over the past decades. Decision makers, transportation planners and practitioners have been seeking ways to mitigate these adverse effects by encouraging alternative modes of travel. Bicycling is financially affordable, physically possible by most people and is also a fast option for short distance trips.

Numerous researchers have studied the effects of socio-demographics, personal attitudes, land-use factors, built environment attributes, and street design characteristics on bicycling behaviors (e.g., Cervero & Kockelman, 1997; Handy et al., 2002). A person’s perception of safety is one of the undisputed subjective factors that influence the decision to bicycle. Pucher et al. (2003; 2006; 2008) found that safety concern was the core issue that deterred people from bicycling in North America. Traffic Safety Facts 2013 (NHTSA 2014) reports that the number of deaths in bicycle crashes makes up 2 percent of all traffic fatalities in 2012, however, the latest available nationwide travel survey (NHTS 2009) suggests only 1 percent of all trips are bicycle trips. Traffic Safety Facts 2013 also reports that 30 percent of all bicyclist fatalities occurred at intersections. One plausible interpretation of this result is the high level of interactions between traffic flows and bicycles at intersections. A critical question arises: how do the intersection design characteristics affect bicyclists’ perception of hazard or safety?

Earlier studies have identified the associations between detailed intersection design characteristics and bicyclists’ safety perceptions. To date, the most comprehensive publication was the Pedestrian and Bicycle Intersection Safety Index Report of 2006 (Carter et al., 2006). Their model investigates the contributions of intersection attributes, such as traffic volumes, number of lanes, speed limits and presence of bicycle lanes, parking and traffic control devices to bicyclists’ safety perceptions at intersections. Another important indicator – Bicycle level-of-service (BLOS), is also widely used to measure the effects of multiple design and operating features of urban roadways (e.g. width, motor vehicle volumes and speeds) on the quality of bicycle service (Highway Capacity Manual,2010). Yet, prior studies fail to control for individuals’ socio-demographic characteristics and bicycling experiences that are known to affect bicycling decisions. Literature suggests that perceived safety of an experienced cyclist may differ from that of a novice cyclist. There also exist gender differences in bicycling risk perceptions (Akar & Clifton, 2009; Akar et al., 2013). Infrastructure investments may be wasted and the effectiveness of policy interventions may be reduced if policy makers view the influences of cycling-supportive treatments as the same to all people.

The proposed research gives a specific focus on perceived bicycling safety at street intersections, which is in alignment with ODOT’s third strategic focus area, *Transportation Safety*. This project develops a user-friendly modeling tool to identify the impacts of various intersection features as well as demographics and bicycling experiences on bicyclist safety perceptions. With a better understanding of known intersection characteristics, policy makers and practitioners can subsequently facilitate improvements on creating a bicycling friendly neighborhood environment. The findings and the model can be utilized by ODOT and other state agencies, and the methodology is transferable to other settings, locally and nationally.

3. Research Context

3.1 Objectives

The primary objective of this project is to develop a model to quantify the impact of each intersection feature to bicyclist safety perceptions, controlling for socio-demographics and bicycling experience levels. This study uses data from an online survey to collect information on respondents' safety perceptions at various intersections, their socio-demographic characteristics and bicycling experience levels. Visual surveys help respondents picture various intersection characteristics as well as street features at the intersection level. Such surveys have been used in bicycling research before (Evans-Cowley & Akar, 2014; Foster et al., 2015). A *Perceived Bicycling Intersection Safety (PBIS) Model* is developed to help engineers, planners and decision-makers better understand the contribution of each intersection feature to bicyclist safety perceptions.

3.2 Tasks

To achieve the aforementioned objectives, we followed the tasks below.

- Task 1: Select intersection images that cover a wide range of street and intersection features (i.e. an intersection in a busy arterial with a bicycle lane and a bicycle box, an intersection in a busy arterial without a bicycle lane, an intersection in a quiet residential road with a bicycle lane, etc.)
- Task 2: Conduct online survey to capture individuals perceived bicycling safety scores for these images
- Task 3: Develop models to understand the determinants of perceived bicycling intersection safety for people with different demographics and bicycling experiences.
- Task 4: Document the main steps and final results of the above tasks as a comprehensive report.

3.3 Literature Review

The connection between street intersection design and bicycling safety lies at the center of the efforts to improve bicycle travel environment (e.g., Carter et al., 2006; Landis et al., 1997). Several mathematical models have been developed to study bicycling safety. Most of these models examine the determinants of level of service (LOS) or comfort level for bicycling, focusing on whether the bicycling activities are compatible with physical environments (Botma, 1995; Davis, 1987; Epperson, 1994; Foster et al., 2015; Hunter et al., 1999; Majumdar & Mitra, 2017; Sorton & Walsh, 1994; Zhu et al., 2017). A few studies have analyzed the links between intersection characteristics and the perceived safety of bicyclists (Carter et al., 2006; Harkey et al., 1998; Landis et al., 1997; Landis et al., 1998). These studies focus on developing models by quantifying the bicyclist's perception of hazard or safety at intersections. These studies are discussed below.

Landis et al. (1997) develop the first statistically calibrated bicycle level-of-service (LOS) model for roadway segments based on real-time perceptions from 145 bicyclists nationwide. Bicyclists' comfort and safety ratings are scaled from A to F. In their model, the number of bicycle lanes, the number of traffic lanes and on-street parking space, the presence of a stripe separating the motor vehicles and bicycles, and pavement surface are found to be significant predictors of bicycling safety perceptions.

Harkey et al (1998) estimate a bicycle compatibility index (BCI) for urban and rural roadway at midblock locations. The sites selected for the study are located in five cities that represent a range of geographic conditions in U.S. Their participants are asked to watch videotapes of various roadway segments and provide ratings of how comfortable they would feel riding on each segment. BCI model covers some additional factors that may affect bicyclists' perceived levels of comfort and safety, such as curb lane width, traffic speed and type of roadside development. Harkey et al (1998) transform the estimated BCI values into bicycle LOS classifications. A LOS A indicates that a roadway is extremely comfortable for an average bicyclist. This transformation is based on the level of service criteria for vehicles (Highway Capacity Manual 2010), but focuses on bicycling activities.

Landis et al. (1998) develop the intersection LOS model for bicycle through movement. This is the first model that focused on the complex intersection features with a viewpoint of the whole transportation system. This model provides insight on intersection design characteristics that could more safely accommodate bicyclists. Data are collected from bicyclists who ride through 18 selected signalized intersections and record their comfort and safety ratings on a scale of A through F. The roadway traffic volume, the total width of the outside through lane, and the intersection crossing distance are found to be the primary factors affecting the bicycling safety perceptions at the intersection level. It is of interest to note that the presence of a bike lane or a paved shoulder are not found to be statistically significant.

Bicyclist Intersection Safety Index (Bike ISI) developed by Carter et al. (2006) is a more comprehensive safety-rating model for intersections as compared to the other models. This model involves both subjective user ratings and objective data, such as evasive actions that are taken by bicyclists to avoid a collision. 67 intersection approaches in four cities are selected, and this study receives 97 safety ratings with the six-point scale from bicycling experts. The Bike ISI models are estimated for three possible bicycle movements at intersections: through movement, right turn and left turn. Traffic volumes, number of lanes, speed limits and presence of bicycle lanes, parking and traffic control devices are found to affect bicycling safety index values.

In general, the number of studies focusing on perceived bicycling intersection safety is limited and the models discussed above have similar limitations. First, these models do not cover several common street intersection features in U.S. that are known to affect bicycling patterns, such as the presence of roundabouts, bicycling crossings, bicycle boxes, and traffic diverters. Bicycle boxes and traffic diverters are two common types of intersection features in North American cities, but their effects on bicycling safety has not been assessed by empirical studies. Some studies promote roundabouts as tools for increasing bicycling safety. To investigate the effects of a roundabout on bicycling safety, some researchers conducted before and after studies in Europe. Schoon and Minnen (1994) report that after converting intersections with traditional stop signs to roundabouts, there was an 8% reduction in bicyclist crash rate together with a 30% reduction in injury rate. Wegman et al. (2012) propose that converting three-leg or four-leg intersections to roundabouts would reduce the number of potential conflict points. A well-designed modern roundabout could mitigate the crash severity level because of narrower lane widths and slower travel speeds. Bicycle facilities (bicycle tracks/lanes/paths) also play an important role in promoting bicycling safety at or near roundabouts. In a study conducted in Flanders, Belgium, Daniels et al. (2009) find that for roundabouts with mixed traffic, bicycle tracks or grade-separated paths could increase bicycling safety while bicycle lanes may lead to higher collision risks. Reynolds et al. (2009) state that the safest design strategy was to build roundabouts with separate bicycle tracks. The models developed by previous studies do not control for socio-demographic characteristics and bicycling skills. The significant effects of these factors have been discussed in the literature (Akar & Clifton, 2009; Akar et al., 2013; Ewing & Cervero, 2010). There is a need to control for socio-demographics and bicycling levels to determine the true and varying effects of street intersection features on safety perceptions. This study contributes to the existing body of knowledge by developing a Perceived Bicycling Intersection Safety (PBIS) model which contributes to the existing models by quantify the impacts of additional intersection characteristics while controlling for socio-demographic attributes and bicycling skills.

4. Research Approach

4.1 Selection of intersection images

As discussed in the previous sections, a comprehensive understanding of the links between intersection features and people's perception of bicycling safety is the key for designing street intersections. Each street intersection has different characteristics that affect bicyclist safety perceptions. Rather than providing a rating for the whole intersection, we aim to identify the effect of each intersection feature on the overall safety perception. Based on the existing literature, we classify our factors of interest into the following groups: (1) types of intersections and traffic controls, (2) curbs, lanes and road traffic, (3) intersection treatments, (4) presence of cycle tracks, (5) presence of traffic diverters, (6) sidewalk environments, (7) characteristics of the surrounding environment, and (8) green space. The street intersection features that are of interest to this study are presented in Appendix A (Table 4).

Intersection images used in this study are taken from Google Street View. We select 90 intersection images from the metropolitan area of Columbus, Ohio as well as other cities around the world. Each image presents a combination of several intersection-level attributes. Our final selected intersection images represent a variety of intersection designs and traffic conditions for comparative analysis. Figure 1 presents two examples among our final selections. The left image shows a 3-way intersection located at a medium-density residential area in Columbus, Ohio. This image also illustrates the presence of a crosswalk and sidewalks on both sides of the street. The right image is a traditional 4-way intersection with traffic signals. In this image, low traffic volumes are likely to be positively associated with higher perceived bicycling safety. Another interesting feature of this intersection is the presence of both grass borders and trees along the road, as well as trees behind the sidewalk.

Figure 1: Examples of selected intersection images

4.2 Visual Survey

We designed and conducted an online visual survey using Qualtrics, a web-based survey tool. Then, we obtained the necessary IRB (Institutional Review Board) approvals to conduct the online visual survey. Since our study involves human subjects, these approvals are mandatory. Our survey was conducted on the main campus of The Ohio State University (OSU). We sent invitation emails to 20,000 individuals in late March (OSU students, faculty and staff members). We followed up with a reminder email in mid-April. Our survey was open from March 22rd to May 1st. Each participant was asked to rate a randomly selected set of twelve intersections among the total ninety intersection images on a five-point scale of "Very unsafe to cross" to "Very safe to cross". We received valid responses from 1,376 individuals. These respondents rated at least one of our intersection images and provided information on their socio-demographics, general travel characteristics, attitudes towards bicycling and bicycling experience levels. Our survey questionnaires are provided in Appendix C. A descriptive summary of our respondents' characteristics is presented in Appendix A (Table 5). Our resulting sample represents a wide range of individuals – a range much broader than what was found in previous studies (Carter et al., 2006; Foster et al., 2015; Harkey et al., 1998; Hunter et al., 1999; Landis et al., 1997; Landis et al., 1998; Majumdar & Mitra, 2017; Zhu et al., 2017).

4.3 Modelling Approach

In this project, the perception of bicycling intersection safety is defined as a typical ordinal variable that is scaled into five scores:
1 : Very unsafe to cross
2 : Unsafe to cross
3 : Neutral
4 : Safe to cross, and
5 : Very safe to cross.

Ordinal regression models have been widely used to fit data with ordinal responses (Washington et al., 2003). We employ an Ordered Probit (OP) model to investigate the relationships between bicyclist safety perceptions and our factors of interest. Note that because higher scores indicate safer perceptions, coefficients with positive signs indicate positive associations with perceived safety. The estimated coefficients of the OP model cannot be intuitively interpreted as the impacts of explanatory variables in OLS (ordinary least squares) regression models. To present meaningful interpretations, we then compute the average marginal effect of each variable to quantify the impacts on each category of the dependent variable – levels of safety perceptions. The marginal effect of a variable illustrates the change of probability of each safety level caused by one unit increases in the input variable, while keeping other variables at their mean values. We report the mathematical details of modelling approach in Appendix A (Table 6).

We estimate a series of OP models for different genders and bicycling experience groups. Variables that were not statistically significant at least at the 90% level were dropped from our final models. We report our main *Perceived Bicycling Intersection Safety* (PBIS) model in Table 1. The average marginal effects of the explanatory variables are presented in Table 2. This model consists of a wide range of intersection features as well as individuals' socio-demographic characteristics and bicycling experience levels. The results of separate PBIS models for different genders and bicycling experience groups are presented in Appendix A (Table 7 through Table 16). We also summarize the predictors of all aforementioned PBIS models in Appendix A (Table 17). The discussion below is based on the results of the main PBIS model.

Table 1: Main Perceived Bicycling Intersection Safety (PBIS) Model

Variables	Coefficient	Robust Std. Err.	*P* – value
Types of intersections & traffic signal controls [a]			
Complicated intersection without traffic signals	-0.301	0.078	0.000
Roundabout with traffic signals	0.430	0.141	0.002
Roundabout without traffic signals	0.544	0.105	0.000
Road traffic			
Number of through auto lanes	-0.203	0.032	0.000
Main traffic volume	-0.190	0.046	0.000
One-way crossing lanes	0.150	0.076	0.049
Intersection treatments			
Marked or unmarked crosswalk	-0.167	0.093	0.075
Number of marked bicycle crossings	0.281	0.167	0.093
Number of marked bicycle crossings^2	-0.161	0.087	0.066
Two-stage turn box	0.211	0.082	0.010
Bike box	0.359	0.064	0.000
Intersection crossing markings	0.229	0.071	0.001
Through median refuge island	-0.280	0.150	0.062
Crossing median refuge island	-0.802	0.091	0.000
Cycle tracks			
Two-way cycle tracks	0.307	0.120	0.010
One-way cycle tracks	0.267	0.097	0.006
Traffic diverters			
Traffic-calming circle	0.187	0.113	0.099
Forced turning islands	0.184	0.092	0.045
Sidewalk			
Presence of a two-side sidewalk	0.209	0.069	0.003
Curb ramp	0.150	0.066	0.022
Clear curb extension	0.192	0.063	0.002
Paved shoulder	0.623	0.107	0.000
Surroundings			
Light rail passing	-0.362	0.116	0.002
Visible highway crossing	-0.223	0.082	0.007
Green space [b]			
Grass borders with tress along the road	0.338	0.075	0.000
Grass borders along the road, as well as trees behind the sidewalk	0.333	0.111	0.003
Grass borders with trees along the road, as well as trees behind the sidewalk	1.016	0.059	0.000
Trees on the sidewalk, as well as behind the sidewalk	0.245	0.112	0.028
Heavy set of forest	0.438	0.123	0.000
Visible active travelers			
Presence of cyclists	0.164	0.076	0.030
More than 2 visible pedestrians	-0.149	0.064	0.020
Age [c]			
26 – 35 years old	-0.108	0.026	0.000
36 – 50 years old	-0.139	0.029	0.000
51 years and older	-0.155	0.038	0.000
Gender			
Male	0.063	0.024	0.007
Bicycle experience level [d]			
Intermediate cyclist	0.241	0.024	0.000
Advanced, confident cyclist	0.450	0.032	0.000

Table 1 (continued): Main Perceived Bicycling Intersection Safety (PBIS) Model

Threhold_cut1	-1.646	0.119	
Threhold_cut2	-0.550	0.119	
Threhold_cut3	0.130	0.118	
Threhold_cut4	1.417	0.121	
Summary statistics			
Number of observations	12839		
Initial log likelihood	-19130.441		
Final log likelihood	-17550.965		
Cragg & Uhler's Pseudo R2	0.202		

a – Baseline: 3-way intersection with/without traffic signals; 4-way intersection with/without traffic signals; Complicated intersection with traffic signals.
b – Baseline: No green space; Grass borders along the road; Trees on the sidewalk; Trees behind the sidewalk.
c – Baseline: 18– 25 years old.
d – Baseline: I cannot ride a bicycle; A novice cyclist; I don't know how to describe my bicycling skills

Table 2: Average Marginal Effects of the Main PBIS Model

Variables	Marginal Effect				
	Very unsafe	Unsafe	Neutral	Safe	Very safe
Types of intersections & traffic signal controls [a]					
Complicated intersection without traffic signals	3.6%	5.8%	1.2%	-5.6%	-5.0%
Roundabouts with traffic signals	-5.1%	-8.3%	-1.8%	8.1%	7.1%
Roundabouts without traffic signals	-6.4%	-10.5%	-2.2%	10.2%	9.0%
Road traffic					
Number of through auto lanes	2.4%	3.9%	0.8%	-3.8%	-3.4%
Main traffic volume	2.2%	3.7%	0.8%	-3.6%	-3.1%
One-way crossing lanes	-1.8%	-2.9%	-0.6%	2.8%	2.5%
Intersection treatments					
Marked or unmarked crosswalk	2.0%	3.2%	0.7%	-3.1%	-2.8%
Number of marked bicycle crossings	-3.3%	-5.4%	-1.1%	5.3%	4.6%
Number of marked bicycle crossings^2	1.9%	3.1%	0.7%	-3.0%	-2.7%
Two-stage turn box	-2.5%	-4.1%	-0.9%	3.9%	3.5%
Bike box	-4.2%	-6.9%	-1.5%	6.7%	5.9%
Intersection crossing markings	-2.7%	-4.4%	-0.9%	4.3%	3.8%
Through median refuge island	3.3%	5.4%	1.1%	-5.2%	-4.6%
Crossing median refuge island	9.5%	15.5%	3.3%	-15.0%	-13.3%
Cycle tracks					
Two-way cycle tracks	-3.6%	-5.9%	-1.3%	5.7%	5.1%
One-way cycle tracks	-3.1%	-5.2%	-1.1%	5.0%	4.4%
Traffic diverters					
Traffic-calming circle	-2.2%	-3.6%	-0.8%	3.5%	3.1%
Forced turn islands	-2.2%	-3.6%	-0.8%	3.4%	3.0%
Sidewalk environments					
Presence of a two-side sidewalk	-2.5%	-4.0%	-0.9%	3.9%	3.5%
Curb ramp	-1.8%	-2.9%	-0.6%	2.8%	2.5%
Clear curb extension	-2.3%	-3.7%	-0.8%	3.6%	3.2%
Paved shoulder	-7.3%	-12.0%	-2.5%	11.7%	10.3%
Surroundings					
Light rail passing	4.3%	7.0%	1.5%	-6.8%	-6.0%
Visible highway crossing	2.6%	4.3%	0.9%	-4.2%	-3.7%
Green space [b]					
Grass borders with tress along the road	-4.0%	-6.5%	-1.4%	6.3%	5.6%
Grass borders along the road, as well as trees behind the sidewalk	-3.9%	-6.4%	-1.4%	6.2%	5.5%

Table 2 (continued): Average Marginal Effects of the Main PBIS Model

Green space [b]					
Grass borders with trees along the road, as well as trees behind the sidewalk	-12.0%	-19.7%	-4.1%	19.0%	16.8%
Trees on the sidewalk, as well as behind the sidewalk	-2.9%	-4.7%	-1.0%	4.6%	4.1%
Heavy set of forest	-5.2%	-8.5%	-1.8%	8.2%	7.2%
Visible active travelers					
Presence of cyclists	-1.9%	-3.2%	-0.7%	3.1%	2.7%
More than 2 visible pedestrians	1.8%	2.9%	0.6%	-2.8%	-2.5%
Age [c]					
26 – 35 years old	1.3%	2.1%	0.4%	-2.0%	-1.8%
36 – 50 years old	1.6%	2.7%	0.6%	-2.6%	-2.3%
51 years old and older	1.8%	3.0%	0.6%	-2.9%	-2.6%
Gender					
Male	-0.7%	-1.2%	-0.3%	1.2%	1.0%
Bicycle experience level [d]					
Intermediate cyclist	-2.8%	-4.7%	-1.0%	4.5%	4.0%
Advanced, confident cyclist	-5.3%	-8.7%	-1.8%	8.4%	7.4%

a – Baseline: 3-way intersection with/without traffic signals; 4-way intersection with/without traffic signals; Complicated intersection with traffic signals.
b – Baseline: No green space; Grass borders along the road; Trees on the sidewalk; Trees behind the sidewalk.
c – Baseline: 18 – 25 years old.
d – Baseline: I cannot ride a bicycle; A novice cyclist; I don't know how to describe my bicycling skills.

5. Research Findings

Types of intersections & traffic signal controls

As expected, complicated intersections (more than 4 ways) without traffic signals are negatively associated with individuals' PBIS scores. However, riding through complicated intersections with traffic signals does not significantly affect safety perceptions as compared to 3-way intersections with/without traffic signals and 4-way intersections with/without traffic signals. This result is not surprising. Complicated intersections include more conflict points as compared to 3 or 4-way intersections. Hence, people are less likely to feel safe while crossing. This effect may be counteracted by the presence of traffic signals. Our results suggest that individuals feel safer riding through roundabouts as compared to traditional intersections. We find that all else being equal, riding through a roundabout with traffic signals instead of a traditional intersection increases the likelihood that one would find this scene "safe" by 8.1% and "very safe" by 7.1%.

Road traffic

The number of through auto lanes is negatively associated with the perception of bicycling safety. This may be because more auto lanes expose bicyclists to more moving vehicles. The main traffic volume also shows a negative impact on bicyclist safety perceptions. On the other hand, crossing a one-way street is positively associated with bicyclist safety perceptions. This is reasonable because one-way streets are designed to have the traffic flow in one direction. Bicyclists would only need to watch out for one directional traffic flow, which decreases the potential automobile-involved conflict points for turning.

Intersection treatments

The number of marked bicycle crossings is positively associated with perceived safety levels. This is because intersections have raised and colored bicycle crossings, which may lead to better recognition and perception of safety as compared to other intersections. However, the negative relationship between the quadratic term of the number of marked bicycle crossings and bicyclist safety perceptions suggests installing several bicycle crossings at intersections may deter people's perceived bicycling safety. One possible explanation for this result is that too many crossings may make motorists and bicyclists confused (Jensen, 2008). Both the presence of bicycle boxes and two-stage turn boxes can significantly increase people's safety perceptions of bicycling at intersections. Furthermore, the results of marginal effects reveal that people may feel safer when they are bicycling through an intersection with bicycle boxes as compared to two-stage turn box. Holding everything else constant, installing a two-stage turn box increases the probability that one would find this intersection "safe" by 3.9% and "very safe" by 3.5%. With respect to installing a bicycle box, the likelihood of reporting "safe" and "very safe" will increase by 6.7% and 5.9%, respectively. This is probably because bicycle boxes offer larger waiting areas for bicyclists, which improves the bicyclists' safety perceptions. However, the cost of installing bicycle boxes is typically much higher than that of two-stage turn box (Weigand et al., 2013). Future research should delve more deeply into the efficiency and effectiveness of these bicycle friendly infrastructure investments.

The presence of intersection crossing markings may significantly improve cyclists' perceptions of safety. This is not surprising because intersection crossing markings indicate the intended path of a bicyclist, which may guide bicyclists through the intersection in a straight path. This treatment contributes to reducing bicyclist stress at intersections by delineating the bicycling zone (Urban Bike Design Guide, April 2011). Interestingly, our results suggest both through median refuge island and crossing median refuge island may deter the safety perceptions of cyclists at the intersection level. In our selected images, most of median refuge islands are placed on well-marked crosswalks. Hence, the potential pedestrian traffic on these islands may force cyclists to adjust their speed, which may deter the perceived safety of cyclists. We find that the presence of crosswalks is negatively associated with bicyclist safety perceptions.

Cycle tracks
The presence of cycle tracks reflects the increase in cyclists' perceptions of safety at intersections. A comparison of marginal effects between one-way cycle tracks ("safe" – 5.0%; "very safe" – 4.4%) and two-way cycle tracks ("safe" – 5.7%; "very safe" – 5.1%) indicates converting one-way cycle tracks to two-way cycle tracks may slightly increase bicyclist safety perceptions. This result might be because two-way cycle tracks allow bicycle movement in both directions, which may decrease the likelihood of bicycle collisions. Also, two-way cycle tracks always have bike traffic signals at intersections.

Traffic diverters, Sidewalk environments, Surroundings
The presence of a traffic-calming circle increases the perceived safety levels of cyclists at the intersection level. This is probably because this facility requires moving vehicles to turn and reduce speed instead of traveling straight ahead through an intersection. Hence, cyclists may feel that the probability of automobile-involved collisions would reduce. Similarly, the presence of forced turn islands also promotes cyclist safety perceptions. With respect to the sidewalk environments, the presence of two-side sidewalks and curb ramps are positively associated with bicyclist safety perceptions. As compared to lack of curbs and unclear curb extensions, clear curb extensions and the presence of paved shoulders are associated with higher safety perceptions. For surrounding environments, we find that the presence of light rail passing and visible highway crossing are negative predictors of individuals' PBIS scores.

Green space
The relationship of green space allocations and bicyclist safety perceptions exhibits an interesting pattern. Our final model suggests that grass borders with trees along the road, grass borders along the road, as well as trees behind the sidewalk, trees both on and behind the sidewalk and heavy set of trees (forest) are positively associated with cyclist's safety perceptions at the intersection level as compared to our base cases. Furthermore, our results imply that grass borders with trees along the road, as well as trees behind the sidewalk (as shown in Figure 1-2) have the highest impacts on individuals' safety perceptions. To our knowledge, this is the first analysis that explores the relationship between green space allocations and bicyclist safety perceptions at the intersection level.

Demographics and bicycling experience levels
The Main PBIS model controls for the effects of socio-demographics and bicycling experience levels that are known to affect bicycling choices. Our results show that all else being equal, younger individuals (18 to 25 years old) are more likely to feel safe as compared to others. As expected, we find that men and women rate the same intersection images differently. Men tend to give higher safety scores as compared to women. The results of the gender-specific PBIS models suggest female cyclists' are more sensitive to road traffic factors and roadway infrastructure as compared to male cyclists (Table 7 through Table 10 in Appendix A). Our results indicate that all else being equal, individuals who identify themselves as intermediate or advanced bicyclists are more likely to give higher safety scores as compared to novice bicyclists. Novice cyclists' PBIS model has more significant predictors as compared to the intermediate and advanced cyclists' models. This result implies investments of transportation infrastructure aimed at promoting perceived bicycling intersection safety should fully consider potential riders' experience levels.

6. Recommendations for Implementation of Research Findings

In this section, we present several examples to demonstrate the application of our Main PBIS model in evaluating bicyclist safety perceptions for existing street intersections. First, we define five hypothetical individuals and predict their safety perceptions for three images. Then, we calculate the perceived bicycling safety scores for ten selected intersections from Franklin County, Ohio using our main PBIS model. We analyze the correlation between bicyclist safety perceptions and actual crash data received from ODOT.

The role of socio-demographics in bicyclist safety perceptions

As discussed, this study contributes to the literature by developing a bicycling intersection safety index accounting for people's socio-demographics and bicycling experience levels. To illustrate how our model works, we calculate the perceived safety scores for three images (Figure 2-1, Figure 2-2, and Figure 2-3) based on five hypothetical individuals. These images represent various street and intersection features.

Figure 2-1: Example Intersection 1 for model application
– The intersection of Blackfriars Rd, Westminster Bridge Rd, and London Rd in London, UK
(Intersection 1 – latitude: 51.49868; longitude: -0.10454)

Figure 2-2: Example Intersection 2 for model application
– The intersection of E 3rd St and S Hawthorne Dr in Bloomington, Indiana
(Intersection 2 – latitude: 39.16429; longitude: -86.52006)

Figure 2-3: Example Intersection 3 for model application
– The intersection of Classon Ave and Dekalb Ave in Brooklyn, New York City
(Intersection 3 – latitude: 40.69033; longitude: -73.96034)

Figure 2-1 (Intersection 1) shows dense roundabout with traffic signals. This image also illustrates the presence of a bike box, a crosswalk, sidewalks on both sides of the streets, as well as two-way cycle tracks. Figure 2-2 (Intersection 2) is a traditional 4-way intersection with low traffic volumes. This image displays the presence of a bike box and grass borders along the road, as well as trees behind the sidewalk. Figure 2-3 (Intersection 3) presents a dense 4-way signalized intersection with limited off-road facilities. Table 18 in Appendix A lists the measurements of intersection characteristics for these three images.

We use five hypothetical individuals, representing different ages, genders and bicycling experience levels. The descriptions are as follows:

- Respondent I is a 62-year old female. She does not know how to describe her bicycling skills.
- Respondent II is a 22-year old male. He describes himself as an advanced, confident cyclist who is comfortable riding in most traffic situations.
- Respondent III is a 37-year old female. She describes herself as an intermediate cyclist who is somewhat comfortable riding in some traffic situations.
- Respondent Ⅳ is a 29-year old male. He describes himself as a novice cyclist who prefers to stick to bike trails or paths.
- Respondent Ⅴ is 45-year old female. She cannot ride a bicycle.

We apply our model for each individual. Figure 3-1, Figure 3-2, and Figure 3-3 illustrate the probabilities of how safe each respondent may feel when riding through these intersections. Our results show clear differences across these individuals and intersections. In general, all individuals would find Intersection 3 as the least safe. They would find Intersection 2 slightly safer than Intersection 1. As compared to other individuals, Individual II (young male, describes himself as an advanced cyclist) is more likely to have higher levels of safety perceptions when riding through both intersections. This result highlights the necessity of controlling for socio-demographics and bicycling experiences to determine the true and varying effects of intersection features on safety perceptions.

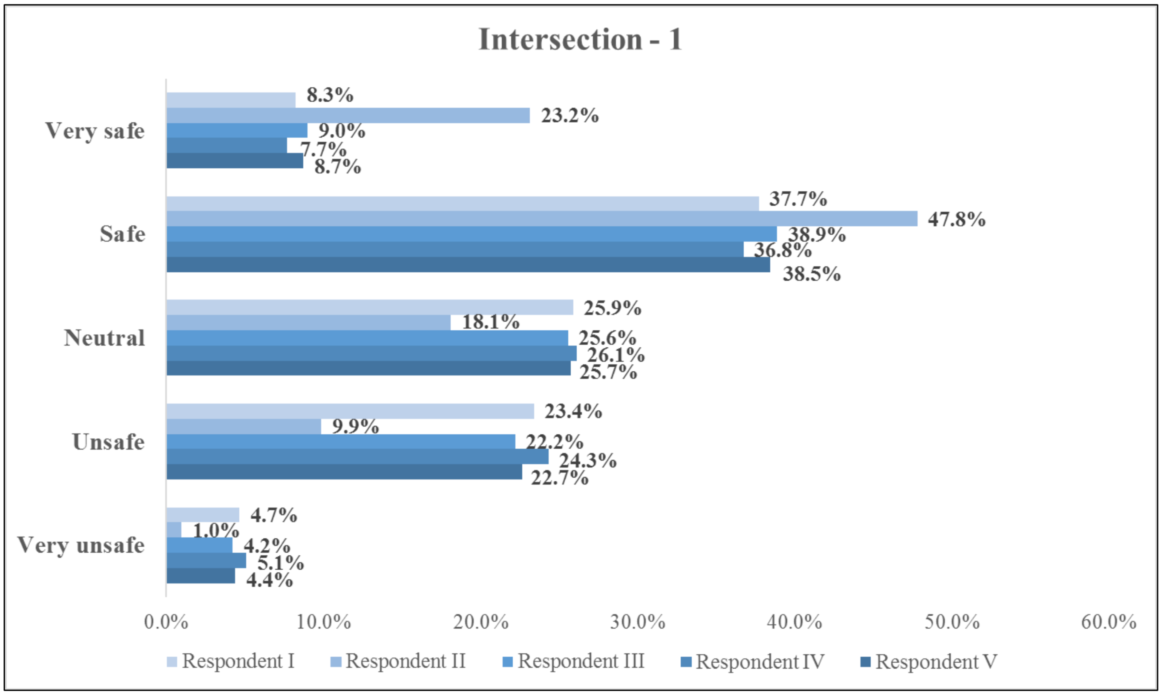

Figure 3-1: Probabilities of each level of safety perceptions for five respondents when riding through Intersection 1

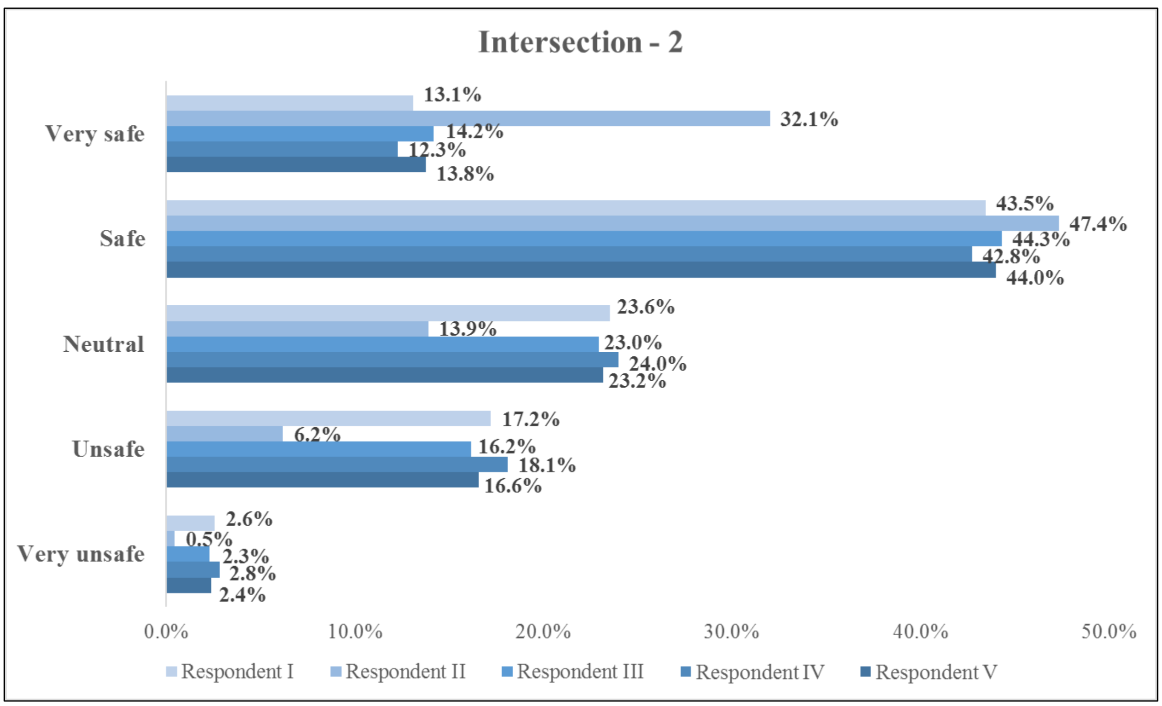

Figure 3-2: Probabilities of each level of safety perceptions for five respondents when riding through Intersection 2

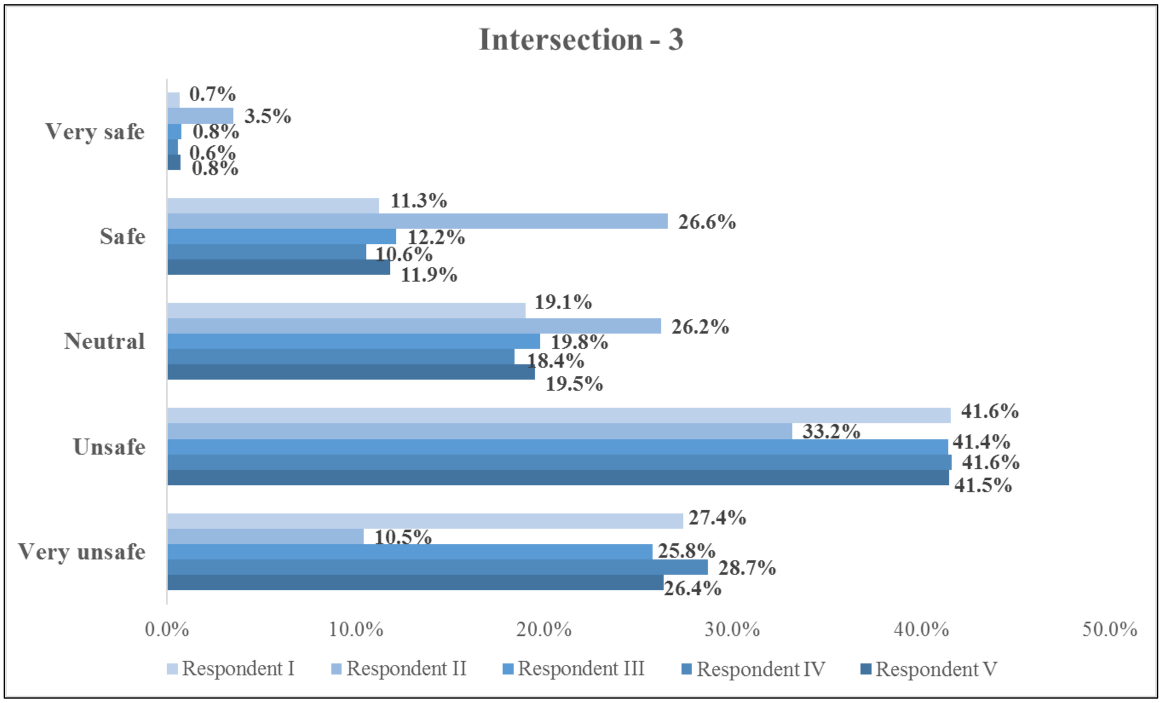

Figure 3-3: Probabilities of each level of safety perceptions for five respondents when riding through Intersection 3

Actual Crashes and the probabilities of bicyclist safety perceptions.

In this section, we demonstrate the outputs of our model on ten intersections from Ohio. These ten intersections are randomly selected among all intersections with reported crashes over the past five years from Franklin County, Ohio. The images of these intersections are presented in Appendix B (Figures 4-1 through Figure 4-10). We then downloaded the actual crash data for these intersections using GIS Crash Analysis Tool (GCAT) developed by ODOT (Link: https://www.dot.state.oh.us/Divisions/Planning/ProgramManagement/HighwaySafety/HSIP/Pages/GCAT.aspx). The crash data provided by GCAT are provided by the Ohio Department of Public Safety, and modified by ODOT for engineering and analysis purposes. We present the number of actual crashes at each intersection in Table 3.

As we focus on conducting a comparative analysis for multiple street intersections, we calculate perceived scores for a single individual. This way we hold the effects of socio-demographics and bicycling levels constant across all intersections. We choose this individual to be a male between the ages of 36 to 50, and describes himself as an intermediate cyclist who is somewhat comfortable riding in different traffic situations. We report the perceived safety score predictions in Table 3. As expected, our results suggest that as the number of crashes increase, the PBIS scores decrease. This finding may be of great assistance to practitioners and policy makers on effectively allocating scare resources, especially on investments for creating bicycle-friendly environments.

Table 3: Actual Crashes and Predicted Probabilities of Safety Levels by the Main PBIS model

	Actual Crashes	Very unsafe	Unsafe	Neutral	Safe	Very safe
Figure 4-1	2	4.0%	21.6%	25.4%	39.5%	9.5%
Figure 4-2	55	15.5%	37.7%	24.5%	20.3%	2.0%
Figure 4-3	77	25.2%	41.4%	20.0%	12.5%	0.8%
Figure 4-4	1	1.4%	12.0%	20.1%	47.0%	19.5%
Figure 4-5	10	6.0%	26.3%	26.5%	34.6%	6.6%
Figure 4-6	21	5.4%	25.1%	26.3%	36.0%	7.3%
Figure 4-7	32	19.3%	39.7%	22.8%	16.8%	1.4%
Figure 4-8	1	0.8%	8.6%	16.8%	48.0%	25.8%
Figure 4-9	41	32.8%	41.4%	16.6%	8.7%	0.4%
Figure 4-10	60	17.9%	39.1%	23.4%	18.0%	1.6%

7. Conclusions

This research presents a model to predict how safe a bicyclist is likely to feel riding in a given street intersection. Although this research is not the first to develop a model for bicycling safety index at intersections, it is the first model that accounts for individuals' socio-demographics and bicycling experiences. Our model is an extension of other bicycling intersection safety models with a wider range of intersection features being considered.

The empirical analysis is based on the data collected via an online visual survey at the main campus of The Ohio State University through March and April 2017. Ordered probit models are estimated to link street and intersection features to perceived bicycling safety scores. The estimated model covers a wider range of intersection features that are known to affect bicycling safety perceptions as compared to previous studies. The developed model can be used to evaluate perceived bicycling safety for existing and planned street intersections. Decision makers can subsequently facilitate improvements to create bicycle friendly intersections.

Our main PBIS (Perceived Bicycling Intersection Safety) model reveals that provision of various transportation infrastructure – bicycle crossings, intersection crossing markings, cycle tracks, bicycle boxes, traffic diverters, sidewalks, curb ramps, clear curb extensions, and paved shoulders – improve bicyclists' safety perceptions. Increasing number of through auto lanes, traffic volumes, presence of crosswalks, median refuge islands, light rail passing, and visible highway crossings increase people's safety concerns. Our model further implies that planting grass borders and trees along the road, as well as tress behind the sidewalk is the best green strategy to improve cyclists' safety perceptions at the intersection-level. For real-world implementation, we calculate the perceived safety scores at various intersections by using the estimated coefficients of our Main PBIS model. As expected, street intersections with low perceived bicycling intersection safety scores turn out to be the ones with higher numbers of crashes.

Future research related to quantifying bicyclist safety at the intersection level should focus on exploring the relationship between bicyclist safety perceptions and actual bicycle crashes. Our hypothesis is intersections with low perceived bicycling intersection safety scores should be the ones with high accident rates.

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Appendix A. Tables

Table 4: Variables of Interest

Group	Variable and its description (*)		Mean or Percentage across the 90 images (**)
Types of intersections & Traffic signal controls	3-way intersection with traffic signals		4.4%
	3-way intersection without traffic signals		8.9%
	4-way intersection with traffic signals		56.7%
	4-way intersection without traffic signals		18.9%
	Complicated intersection (≥5 ways) with traffic signals		3.3%
	Complicated intersection (≥5 ways) without traffic signals		2.2%
	Roundabout with traffic signals		1.1%
	Roundabout without traffic signals		4.4%
Curbs, Lanes and Road traffic	Width of curb lane	The same as the central lanes	37.5%
		Wider than central lanes	33.3%
		Hold 2 vehicles in a row	12.5%
		Hold more than 2 vehicles in a row	16.7%
	Number of through auto lanes	The number of through auto lanes is 1	23.3%
		The number of through auto lanes is 2	34.4%
		The number of through auto lanes is 3	26.7%
		The number of through auto lanes is 4	11.1%
		The number of through auto lanes is 5	4.4%
	Main traffic volume (Measures: Number of moving vehicles on through auto lanes/ Number of through auto lanes)		0.77
	Cross traffic volume (Measures: Number of moving vehicles on crossing lanes)		1.13
	One-way through lanes		17.8%
	One-way crossing lanes		16.7%
	Left turning lane		20.0%
	Right turning lane		5.6%
	Marked left turning crossing		10.0%
	Marked right turning crossing		5.6%
	Posted speed limit		3.3%

Table 4 (continued): Variables of Interest

Intersection treatments	Stop sign		13.3%
	Number of marked bicycle crossings	The number of marked bicycle crossings is 0	86.7%
		The number of marked bicycle crossings is 1	11.1%
		The number of marked bicycle crossings is 2	2.2%
	Marked pedestrian crosswalk sign		18.9%
	Two-stage turn box		30.2%
	Bike box		36.5%
	Intersect crossing markings		41.8%
	Through median refuge island		18.1%
	Crossing median refuge island		25.1%
	Crosswalk		80.0%
Presence of cycle tracks	Two-way cycle tracks		10.0%
	One-way cycle tracks		10.0%
	On-street bike lanes		23.3%
	Multi-use paths		8.9%
Presence of traffic diverters	Traffic-calming circle		6.7%
	Forced turning islands		2.2%
	Diagonal diverter		2.2%
Sidewalk environments	Two-side sidewalk		90.0%
	Curb ramp		46.7%
	Clear curb extension		40.0%
	Paved shoulder		20.7%
Surroundings	On-street parking		47.8%
	Slope		12.2%
	Street lights		95.6%
	Visible highway crossing		2.2%
	Light rail passing		3.3%
	Under maintenance		2.2%
	Bus stops		4.4%
	Bicycle racks & bike sharing stations		8.9%
	Near gas stations		4.4%
Green space	No green space		13.3%
	Grass borders along the road		5.6%

Table 4 (continued): Variables of Interest

Green space	Grass borders along the road, as well as trees behind the sidewalk	11.1%
	Grass borders with trees along the road	12.2%
	Grass borders and trees along the road, as well as trees behind the sidewalk	2.2%
	Trees on the sidewalk	28.9%
	Trees behind the sidewalk	18.9%
	Trees on the sidewalk, as well as behind the sidewalk	2.2%
	Heavy set of trees	5.6%
Visible active traveler	Presence of cyclists	17.8%
	More than 2 visible pedestrians	30.0%
Weather conditions	Sunny	55.6%
	Cloudy	40.0%
	Snowy	4.4%

*-- Variables without a description in parenthesis are dummy variables: 1, if present; 0, otherwise.
**-- For continuous variables, we report the mean values. We report the percentages for categorical variables. For instance, for the first characteristic "3-way intersection with traffic signals", the reported percentage is 4.4%. This means out of 90 images, 4 images present this feature (90 x 4.4%)

Table 5: Descriptive Summary of Respondents' Characteristics

Survey items	Number of responses	Answers	Percentage
Primary mode of transportation	1373	Auto (drive alone)	56.6%
		Carpool (with 1 or more people)	5.3%
		Bus	5.3%
		Walking	19.1%
		Bicycle	11.9%
		Other	1.8%
Last time that you rode a bicycle (for any purpose)	1375	Within last week	26.9%
		Within last month	9.8%
		Within the last year	30.5%
		More than a year ago	30.0%
		Never	2.8%
Bicycling experience levels	1211	I cannot ride a bicycle	2.5%
		A novice cyclist	34.6%
		An intermediate cyclist	35.2%
		An advanced, confident cyclist	23.5%
		I don't know how to describe my bicycling skills	4.2%
Age	1285	18 – 25 years old	35.6%
		26 – 35 years old	46.7%
		36 – 50 years old	3.3%
		51 years and older	14.4%
Gender	1298	Male	37.9%
		Female	62.1%
International student/staff/faculty	1256	International	11.0%
		Non-international	89.0%
Status at OSU	1233	Faculty	9.7%
		Staff	43.0%
		Graduate/Professional Student	18.1%
		Undergraduate Student	28.5%
		Others	0.7%

Table 6 – Ordered Probit (OP) Model

Following Washington et al (*24*), the OP models are derived by an unobserved latent variable z, which is used as the basis for modeling the safety perception rankings. The latent variable z is defined as a linear function for each observation n:

$$z_n = \beta X_n + \varepsilon_n$$

where X_n is a vector of explanatory variables that determine the safety perception, β is a vector of coefficients, and ε_n is a random error term following the standard normal distribution. Based on this equation, the scores of bicycling safety perception Y for each observation is defined as:

$$Y = \begin{cases} 1 \quad if \quad z_n \le \tau_1 \\ 2 \quad if \quad \tau_1 < z_n \le \tau_2 \\ 3 \quad if \quad \tau_2 < z_n \le \tau_3 \\ 4 \quad if \quad \tau_3 < z_n \le \tau_4 \\ 5 \quad if \quad z_n > \tau_4 \end{cases}$$

where τ is the threshold parameter (cut-off point) to be estimated for each score. The probability of dependent variable Y taking on each score of safety perception is:

$$P(Y=1) = \Phi(\tau_1 - \beta X_n)$$
$$P(Y=2) = \Phi(\tau_2 - \beta X_n) - \Phi(\tau_1 - \beta X_n)$$
$$P(Y=3) = \Phi(\tau_3 - \beta X_n) - \Phi(\tau_2 - \beta X_n)$$
$$P(Y=4) = \Phi(\tau_4 - \beta X_n) - \Phi(\tau_3 - \beta X_n)$$
$$P(Y=5) = 1 - \Phi(\tau_4 - \beta X_n)$$

where $P(Y=j)$ is the probability of safety perception *j*, *j* = 1, 2, 3, 4, 5. $\Phi(.)$ is the cumulative distribution function for standard normal distribution. The coefficient of each variable and threshold parameters can be determined by the Maximum Likelihood Estimation (MLE). Note that because higher scores indicate safer environments, the interpretation of an estimated coefficient is such that positive signs mean improved perceived bicycling safety scores. However, these coefficients cannot be intuitively interpreted as the impacts of explanatory variables as in OLS (ordinary least squares) regression models. To present meaningful interpretations, we then compute the marginal effect of each variable to quantify the impacts on each category of the dependent variable Y. The marginal effect of a variable illustrates the change of probability of each safety level caused by one unit increase in the input variable, while keeping other variables at their mean values, as follows:

$$\partial P(Y=1) / \partial X = -\phi(\tau_1 - \beta X)\beta$$
$$\partial P(Y=2) / \partial X = \left[\phi(\tau_1 - \beta X) - \phi(\tau_2 - \beta X)\right]\beta$$
$$\partial P(Y=3) / \partial X = \left[\phi(\tau_2 - \beta X) - \phi(\tau_3 - \beta X)\right]\beta$$
$$\partial P(Y=4) / \partial X = \left[\phi(\tau_3 - \beta X) - \phi(\tau_4 - \beta X)\right]\beta$$
$$\partial P(Y=5) / \partial X = \phi(\tau_4 - \beta X)\beta$$

where $\phi(.)$ is the probability density function of the standard normal distribution.

Table 7: Perceived Bicycling Intersection Safety (PBIS) Model for Males

Variables	Coefficient	Robust Std. Err.	*P* – value
Types of intersections & traffic signal controls [a]			
3-way intersection with traffic signals	0.297	0.120	0.013
Complicated intersection without traffic signals	-0.426	0.064	0.000
Roundabout with traffic signals	0.891	0.129	0.000
Roundabout without traffic signals	0.771	0.099	0.000
Road traffic			
Number of through auto lanes	-0.131	0.026	0.000
One-way crossing lanes	0.247	0.072	0.001
Intersection treatments			
Marked or unmarked crosswalk	-0.295	0.082	0.000
Two-stage turn box	0.263	0.077	0.001
Bike box	0.519	0.059	0.000
Intersection crossing markings	0.236	0.065	0.000
Through median refuge island	-0.256	0.104	0.014
Crossing median refuge island	-0.758	0.096	0.000
Cycle tracks			
Two-way cycle tracks	0.406	0.107	0.000
One-way cycle tracks	0.346	0.082	0.000
Traffic diverters			
Traffic-calming circle	0.276	0.101	0.006
Forced turning islands	0.163	0.063	0.010
Sidewalk			
Presence of a two-side sidewalk	0.327	0.085	0.000
Clear curb extension	0.249	0.061	0.000
Paved shoulder	0.753	0.136	0.000
Surroundings			
Light rail passing	-0.353	0.124	0.005
Green space [b]			
Grass borders with tress along the road	0.424	0.069	0.000
Grass borders along the road, as well as trees behind the sidewalk	0.415	0.086	0.000
Grass borders with trees along the road, as well as trees behind the sidewalk	1.133	0.079	0.000
Trees on the sidewalk, as well as behind the sidewalk	0.410	0.081	0.000
Heavy set of forest	0.413	0.115	0.000
Visible active travelers			
More than 2 visible pedestrians	-0.153	0.060	0.011
Age [c]			
36 – 50 years old	-0.111	0.041	0.007
51 years and older	-0.176	0.045	0.000
Bicycle experience level [d]			
Novice cyclist	-0.152	0.081	0.062
Intermediate cyclist	0.129	0.080	0.107
Advanced, confident cyclist	0.287	0.083	0.001
Threhold_cut1	-1.512	0.151	
Threhold_cut2	-0.431	0.157	
Threhold_cut3	0.316	0.158	
Threhold_cut4	1.575	0.162	
Summary statistics			
Number of observations	5109		
Initial log likelihood	-7419.860		

Table 7 (continued): Perceived Bicycling Intersection Safety (PBIS) Model for Males

Summary statistics	
Final log likelihood	-6924.981
Cragg & Uhler's Pseudo R2	0.186

a – Baseline: 3-way intersection without traffic signals; 4-way intersection with/without traffic signals; Complicated intersection with traffic signals.
b – Baseline: No green space; Grass borders along the road; Trees on the sidewalk; Trees behind the sidewalk.
c – Baseline: 18– 25 years old; 26-35 years old.
d – Baseline: I cannot ride a bicycle; I don't know how to describe my bicycling skills.

Table 8: Perceived Bicycling Intersection Safety (PBIS) Model for Females

Variables	Coefficient	Robust Std. Err.	*P* – value
Types of intersections & traffic signal controls [a]			
3-way intersection with traffic signals	0.249	0.099	0.012
Complicated intersection without traffic signals	-0.285	0.072	0.000
Roundabout with traffic signals	0.700	0.157	0.000
Roundabout without traffic signals	0.374	0.104	0.000
Road traffic			
Number of through auto lanes	-0.204	0.037	0.000
Main traffic volume	-0.274	0.054	0.000
Left turning lane	-0.189	0.078	0.015
Intersection treatments			
Number of marked bicycle crossings	0.327	0.165	0.047
Number of marked bicycle crossings^2	-0.190	0.081	0.018
Bike box	0.318	0.069	0.000
Intersection crossing markings	0.215	0.088	0.015
Crossing median refuge island	-0.873	0.102	0.000
Cycle tracks			
Two-way cycle tracks	0.316	0.145	0.029
One-way cycle tracks	0.205	0.093	0.028
Traffic diverters			
Forced turning islands	0.326	0.128	0.011
Sidewalk			
Presence of a two-side sidewalk	0.173	0.082	0.036
Curb ramp	0.217	0.075	0.004
Clear curb extension	0.167	0.064	0.009
Paved shoulder	0.514	0.092	0.000
Surroundings			
Light rail passing	-0.412	0.134	0.002
Visible highway crossing	-0.287	0.089	0.001
Green space [b]			
Grass borders with tress along the road	0.328	0.096	0.001
Grass borders along the road, as well as trees behind the sidewalk	0.331	0.114	0.004
Grass borders with trees along the road, as well as trees behind the sidewalk	1.034	0.071	0.000
Heavy set of forest	0.613	0.180	0.001

Table 8 (continued): Perceived Bicycling Intersection Safety (PBIS) Model for Females

Visible active travelers			
Presence of cyclists	0.278	0.085	0.001
More than 2 visible pedestrians	-0.209	0.075	0.005
Age [c]			
26 – 35 years old	-0.112	0.031	0.000
36 – 50 years old	-0.088	0.034	0.010
51 years and older	-0.092	0.046	0.048
Bicycle experience level [d]			
Intermediate cyclist	0.206	0.028	0.000
Advanced, confident cyclist	0.548	0.046	0.000
Threhold_cut1	-1.687	0.140	
Threhold_cut2	-0.570	0.136	
Threhold_cut3	0.073	0.135	
Threhold_cut4	1.386	0.140	
Summary statistics			
Number of observations	7730		
Initial log likelihood	-11419.41		
Final log likelihood	-10547.184		
Cragg & Uhler's Pseudo R2	0.213		

a – Baseline: 3-way intersection without traffic signals; 4-way intersection with/without traffic signals; Complicated intersection with traffic signals.
b – Baseline: No green space; Grass borders along the road; Trees on the sidewalk; Trees behind the sidewalk; Trees on the sidewalk, as well as behind the sidewalk.
c – Baseline: 18– 25 years old.
d – Baseline: I cannot ride a bicycle; A novice cyclist; I don't know how to describe my bicycling skills.

Table 9: Average Marginal Effects of Males' PBIS Model

Variables	Marginal Effect				
	Very unsafe	Unsafe	Neutral	Safe	Very safe
Types of intersections & traffic signal controls [a]					
3-way intersection with traffic signals	-2.8%	-5.7%	-2.1%	5.1%	5.6%
Complicated intersection without traffic signals	4.0%	8.2%	3.0%	-7.3%	-8.0%
Roundabout with traffic signals	-8.4%	-17.2%	-6.2%	15.2%	16.7%
Roundabout without traffic signals	-7.3%	-14.9%	-5.4%	13.2%	14.4%
Road traffic					
Number of through auto lanes	1.2%	2.5%	0.9%	-2.2%	-2.5%
One-way crossing lanes	-2.3%	-4.8%	-1.7%	4.2%	4.6%
Intersection treatments					
Marked or unmarked crosswalk	2.8%	5.7%	2.1%	-5.0%	-5.5%
Two-stage turn box	-2.5%	-5.1%	-1.8%	4.5%	4.9%
Bike box	-4.9%	-10.0%	-3.6%	8.9%	9.7%
Intersection crossing markings	-2.2%	-4.6%	-1.7%	4.0%	4.4%
Through median refuge island	2.4%	4.9%	1.8%	-4.4%	-4.8%
Crossing median refuge island	7.2%	14.6%	5.3%	-12.9%	-14.2%
Cycle tracks					
Two-way cycle tracks	-3.8%	-7.8%	-2.8%	6.9%	7.6%
One-way cycle tracks	-3.3%	-6.7%	-2.4%	5.9%	6.5%
Traffic diverters					
Traffic-calming circle	-2.6%	-5.3%	-1.9%	4.7%	5.2%
Forced turn islands	-1.5%	-3.1%	-1.1%	2.8%	3.0%
Sidewalk environments					
Presence of a two-side sidewalk	-3.1%	-6.3%	-2.3%	5.6%	6.1%
Clear curb extension	-2.4%	-4.8%	-1.7%	4.2%	4.7%
Paved shoulder	-7.1%	-14.6%	-5.3%	12.9%	14.1%
Surroundings					
Light rail passing	3.3%	6.8%	2.5%	-6.0%	-6.6%
Green space [b]					
Grass borders with tress along the road	-4.0%	-8.2%	-3.0%	7.2%	7.9%
Grass borders along the road, as well as trees behind the sidewalk	-3.9%	-8.0%	-2.9%	7.1%	7.8%
Grass borders with trees along the road, as well as trees behind the sidewalk	-10.7%	-21.9%	-7.9%	19.3%	21.2%
Trees on the sidewalk, as well as behind the sidewalk	-3.9%	-7.9%	-2.9%	7.0%	7.7%
Heavy set of forest	-3.9%	-8.0%	-2.9%	7.1%	7.7%

Table 9 (continued): Average Marginal Effects of Males' PBIS Model

Visible active travelers					
More than 2 visible pedestrians	1.4%	3.0%	1.1%	-2.6%	-2.9%
Age [c]					
36 – 50 years old	1.1%	2.2%	0.8%	-1.9%	-2.1%
51 years old and older	1.7%	3.4%	1.2%	-3.0%	-3.3%
Bicycle experience level [d]					
Novice cyclist	1.4%	2.9%	1.1%	-2.6%	-2.9%
Intermediate cyclist	-1.2%	-2.5%	-0.9%	2.2%	2.4%
Advanced, confident cyclist	-2.7%	-5.6%	-2.0%	4.9%	5.4%

a – Baseline: 3-way intersection without traffic signals; 4-way intersection with/without traffic signals; Complicated intersection with traffic signals.
b – Baseline: No green space; Grass borders along the road; Trees on the sidewalk; Trees behind the sidewalk.
c – Baseline: 18– 25 years old; 26-35 years old.
d – Baseline: I cannot ride a bicycle; I don't know how to describe my bicycling skills.

Table 10: Average Marginal Effects of Females' PBIS Model

Variables	Marginal Effect				
	Very unsafe	Unsafe	Neutral	Safe	Very safe
Types of intersections & traffic signal controls [a]					
3-way intersection with traffic signals	-3.3%	-4.8%	-0.6%	4.9%	3.8%
Complicated intersection without traffic signals	3.7%	5.4%	0.7%	-5.6%	-4.3%
Roundabout with traffic signals	-9.2%	-13.3%	-1.8%	13.8%	10.5%
Roundabout without traffic signals	-4.9%	-7.1%	-0.9%	7.4%	5.6%
Road traffic					
Number of through auto lanes	2.7%	3.9%	0.5%	-4.0%	-3.1%
Main traffic volume	3.6%	5.2%	0.7%	-5.4%	-4.1%
Left turning lane	2.5%	3.6%	0.5%	-3.7%	-2.8%
Intersection treatments					
Number of marked bicycle crossings	-4.3%	-6.2%	-0.8%	6.4%	4.9%
Number of marked bicycle crossings^2	2.5%	3.6%	0.5%	-3.8%	-2.9%
Bike box	-4.2%	-6.1%	-0.8%	6.3%	4.8%
Intersection crossing markings	-2.8%	-4.1%	-0.5%	4.2%	3.2%
Crossing median refuge island	11.5%	16.6%	2.2%	-17.2%	-13.1%

Table 10 (continued): Average Marginal Effects of Females' PBIS Model

Cycle tracks					
Two-way cycle tracks	-4.1%	-6.0%	-0.8%	6.2%	4.8%
One-way cycle tracks	-2.7%	-3.9%	-0.5%	4.0%	3.1%
Traffic diverters					
Forced turn islands	-4.3%	-6.2%	-0.8%	6.4%	4.9%
Sidewalk environments					
Presence of a two-side sidewalk	-2.3%	-3.3%	-0.4%	3.4%	2.6%
Curb ramp	-2.9%	-4.1%	-0.5%	4.3%	3.3%
Clear curb extension	-2.2%	-3.2%	-0.4%	3.3%	2.5%
Paved shoulder	-6.8%	-9.8%	-1.3%	10.1%	7.7%
Surroundings					
Light rail passing	5.4%	7.9%	1.0%	-8.1%	-6.2%
Visible highway crossing	3.8%	5.5%	0.7%	-5.6%	-4.3%
Green space [b]					
Grass borders with tress along the road	-4.3%	-6.3%	-0.8%	6.5%	4.9%
Grass borders along the road, as well as trees behind the sidewalk	-4.4%	-6.3%	-0.8%	6.5%	5.0%
Grass borders with trees along the road, as well as trees behind the sidewalk	-13.6%	-19.7%	-2.6%	20.4%	15.6%
Heavy set of forest	-8.1%	-11.7%	-1.5%	12.1%	9.2%
Visible active travelers					
Presence of cyclists	-3.6%	-5.3%	-0.7%	5.5%	4.2%
More than 2 visible pedestrians	2.7%	4.0%	0.5%	-4.1%	-3.1%
Age [c]					
26 – 35 years old	1.5%	2.1%	0.3%	-2.2%	-1.7%
36 – 50 years old	1.2%	1.7%	0.2%	-1.7%	-1.3%
51 years old and older	1.2%	1.8%	0.2%	-1.8%	-1.4%
Bicycle experience level [d]					
Intermediate cyclist	-2.7%	-3.9%	-0.5%	4.1%	3.1%
Advanced, confident cyclist	-7.2%	-10.5%	-1.4%	10.8%	8.3%

a – Baseline: 3-way intersection without traffic signals; 4-way intersection with/without traffic signals; Complicated intersection with traffic signals.
b – Baseline: No green space; Grass borders along the road; Trees on the sidewalk; Trees behind the sidewalk; Trees on the sidewalk, as well as behind the sidewalk.
c – Baseline: 18– 25 years old.
d – Baseline: I cannot ride a bicycle; A novice cyclist; I don't know how to describe my bicycling skills.

Table 11: Perceived Bicycling Intersection Safety (PBIS) Model for Novice Bicyclists

Variables	Coefficient	Robust Std. Err.	*P* – value
Types of intersections & traffic signal controls [a]			
3-way intersection with traffic signals	0.287	0.105	0.006
Complicated intersection without traffic signals	-0.472	0.073	0.000
Roundabout with traffic signals	0.613	0.149	0.000
Roundabout without traffic signals	0.645	0.106	0.000
Road traffic			
Number of through auto lanes	-0.160	0.035	0.000
Main traffic volume	-0.203	0.053	0.000
Left turning lane	-0.244	0.087	0.005
One-way crossing lanes	0.197	0.073	0.007
Intersection treatments			
Marked or unmarked crosswalk	-0.220	0.108	0.041
Bike box	0.421	0.078	0.000
Intersection crossing markings	0.215	0.094	0.023
Through median refuge island	-0.359	0.155	0.021
Crossing median refuge island	-0.840	0.073	0.000
Cycle tracks			
Two-way cycle tracks	0.241	0.131	0.066
One-way cycle tracks	0.240	0.088	0.006
Traffic diverters			
Traffic-calming circle	0.212	0.127	0.094
Sidewalk			
Presence of a two-side sidewalk	0.232	0.069	0.001
Curb ramp	0.192	0.068	0.005
Clear curb extension	0.251	0.061	0.000
Paved shoulder	0.589	0.100	0.000
Surroundings			
Light rail passing	-0.463	0.187	0.013
Visible highway crossing	-0.449	0.102	0.000
Green space [b]			
Grass borders with tress along the road	0.372	0.101	0.000
Grass borders along the road, as well as trees behind the sidewalk	0.293	0.100	0.003
Grass borders with trees along the road, as well as trees behind the sidewalk	1.048	0.075	0.000
Heavy set of forest	0.537	0.131	0.000
Visible active travelers			
Presence of cyclists	0.223	0.083	0.007
More than 2 visible pedestrians	-0.208	0.073	0.004
Age [c]			
26 – 35 years old	-0.137	0.042	0.001
36 – 50 years old	-0.100	0.040	0.013
Threhold_cut1	-1.606	0.124	
Threhold_cut2	-0.489	0.120	
Threhold_cut3	0.138	0.121	
Threhold_cut4	1.458	0.126	
Summary statistics			
Number of observations	4555		
Initial log likelihood	-6751.287		
Final log likelihood	-6247.012		
Cragg & Uhler's Pseudo R2	0.209		

a – Baseline: 3-way intersection without traffic signals; 4-way intersection with/without traffic signals; Complicated intersection with traffic signals.
b – Baseline: No green space; Grass borders along the road; Trees on the sidewalk; Trees behind the sidewalk; Trees on the sidewalk, as well as behind the sidewalk.
c – Baseline: 18– 25 years old; 51 years old and older.

Table 12: Perceived Bicycling Intersection Safety (PBIS) Model for Intermediate Bicyclists

Variables	Coefficient	Robust Std. Err.	*P* – value
Types of intersections & traffic signal controls [a]			
3-way intersection with traffic signals	0.404	0.115	0.000
Complicated intersection without traffic signals	-0.230	0.075	0.002
Roundabout with traffic signals	0.635	0.189	0.001
Roundabout without traffic signals	0.610	0.170	0.000
Road traffic			
Number of through auto lanes	-0.176	0.039	0.000
Main traffic volume	-0.230	0.063	0.000
Intersection treatments			
Marked or unmarked crosswalk	-0.311	0.102	0.002
Two-stage turn box	0.230	0.109	0.036
Bike box	0.348	0.076	0.000
Intersection crossing markings	0.284	0.094	0.003
Crossing median refuge island	-0.626	0.164	0.000
Cycle tracks			
Two-way cycle tracks	0.394	0.129	0.002
One-way cycle tracks	0.228	0.103	0.026
Traffic diverters			
Forced turning islands	0.300	0.100	0.003
Sidewalk			
Presence of a two-side sidewalk	0.253	0.106	0.017
Curb ramp	0.219	0.075	0.004
Clear curb extension	0.195	0.076	0.011
Paved shoulder	0.441	0.124	0.000
Surroundings			
Light rail passing	-0.417	0.091	0.000
Green space [b]			
Grass borders with tress along the road	0.491	0.096	0.000
Grass borders along the road, as well as trees behind the sidewalk	0.429	0.119	0.000
Grass borders with trees along the road, as well as trees behind the sidewalk	1.073	0.078	0.000
Heavy set of forest	0.644	0.180	0.000
Visible active travelers			
Presence of cyclists	0.202	0.082	0.014
Age [c]			
36 – 50 years old	-0.117	0.046	0.011
51 years and older	-0.176	0.057	0.002
Gender			
Male	0.124	0.031	0.000
Threhold_cut1	-1.786	0.160	
Threhold_cut2	-0.671	0.163	
Threhold_cut3	0.057	0.160	
Threhold_cut4	1.317	0.162	

Table 12 (continued): Perceived Bicycling Intersection Safety (PBIS) Model for Intermediate Bicyclists

Summary statistics	
Number of observations	4571
Initial log likelihood	-6675.224
Final log likelihood	-6215.346
Cragg & Uhler's Pseudo R2	0.193

a – Baseline: 3-way intersection without traffic signals; 4-way intersection with/without traffic signals; Complicated intersection with traffic signals.
b – Baseline: No green space; Grass borders along the road; Trees on the sidewalk; Trees behind the sidewalk; Trees on the sidewalk, as well as behind the sidewalk.
c – Baseline: 18–25 years old; 26-35 years old.

Table 13: Perceived Bicycling Intersection Safety (PBIS) Model for Advanced Cyclists

Variables	Coefficient	Robust Std. Err.	*P* – value
Types of intersections & traffic signal controls [a]			
Complicated intersection without traffic signals	-0.318	0.118	0.007
Roundabout with traffic signals	0.647	0.212	0.002
Roundabout without traffic signals	0.400	0.202	0.048
Road traffic			
Number of through auto lanes	-0.186	0.035	0.000
Main traffic volume	-0.115	0.044	0.008
One-way crossing lanes	0.137	0.082	0.095
Intersection treatments			
Two-stage turn box	0.339	0.093	0.000
Bike box	0.512	0.071	0.000
Intersection crossing markings	0.131	0.074	0.077
Through median refuge island	-0.289	0.110	0.009
Crossing median refuge island	-0.773	0.135	0.000
Cycle tracks			
Two-way cycle tracks	0.453	0.147	0.002
One-way cycle tracks	0.365	0.100	0.000
Traffic diverters			
Traffic-calming circle	0.314	0.131	0.016
Forced turning islands	0.435	0.090	0.000
Sidewalk			
Presence of a two-side sidewalk	0.290	0.124	0.020
Clear curb extension	0.164	0.071	0.022
Paved shoulder	0.870	0.157	0.000
Green space [b]			
Grass borders with tress along the road	0.225	0.094	0.017
Grass borders along the road, as well as trees behind the sidewalk	0.285	0.112	0.011
Grass borders with trees along the road, as well as trees behind the sidewalk	1.040	0.127	0.000
Heavy set of forest	0.296	0.125	0.018
Visible active travelers			
Presence of cyclists	0.180	0.087	0.038
More than 2 visible pedestrians	-0.191	0.072	0.008

Table 13 (continued): Perceived Bicycling Intersection Safety (PBIS) Model for Advanced Cyclists

Age [c]			
26 – 35 years old	-0.146	0.054	0.006
36 – 50 years old	-0.174	0.053	0.001
51 years and older	-0.190	0.062	0.002
Gender			
Male	-0.072	0.043	0.094
Threhold_cut1	-1.970	0.177	
Threhold_cut2	-0.960	0.181	
Threhold_cut3	-0.219	0.180	
Threhold_cut4	1.080	0.180	
Summary statistics			
Number of observations	3033		
Initial log likelihood	-4300.67		
Final log likelihood	-4058.824		
Cragg & Uhler's Pseudo R2	0.157		

a – Baseline: 3-way intersection with/without traffic signals; 4-way intersection with/without traffic signals; Complicated intersection with traffic signals.
b – Baseline: No green space; Grass borders along the road; Trees on the sidewalk; Trees behind the sidewalk; Trees on the sidewalk, as well as behind the sidewalk.
c – Baseline: 18– 25 years old.

Table 14: Average Marginal Effects of Novice Cyclists' PBIS Model

Variables	Marginal Effect				
	Very unsafe	Unsafe	Neutral	Safe	Very safe
Types of intersections & traffic signal controls [a]					
3-way intersection with traffic signals	-4.4%	-5.2%	-0.1%	6.1%	3.7%
Complicated intersection without traffic signals	7.3%	8.6%	0.1%	-10.0%	-6.1%
Roundabouts with traffic signals	-9.5%	-11.2%	-0.2%	13.0%	7.9%
Roundabouts without traffic signals	-10.0%	-11.7%	-0.2%	13.6%	8.3%
Road traffic					
Number of through auto lanes	2.5%	2.9%	0.0%	-3.4%	-2.1%
Main traffic volume	3.2%	3.7%	0.1%	-4.3%	-2.6%
Left turning lane	3.8%	4.4%	0.1%	-5.2%	-3.1%
One-way crossing lanes	-3.1%	-3.6%	-0.1%	4.2%	2.5%
Intersection treatments					
Marked or unmarked crosswalk	3.4%	4.0%	0.1%	-4.7%	-2.8%
Bike box	-6.5%	-7.7%	-0.1%	8.9%	5.4%
Intersection crossing markings	-3.3%	-3.9%	-0.1%	4.6%	2.8%
Through median refuge island	5.6%	6.5%	0.1%	-7.6%	-4.6%
Crossing median refuge island	13.0%	15.3%	0.3%	-17.8%	-10.8%
Cycle tracks					
Two-way cycle tracks	-3.7%	-4.4%	-0.1%	5.1%	3.1%
One-way cycle tracks	-3.7%	-4.4%	-0.1%	5.1%	3.1%
Traffic diverters					
Traffic-calming circle	-3.3%	-3.9%	-0.1%	4.5%	2.7%
Sidewalk environments					
Presence of a two-side sidewalk	-3.6%	-4.2%	-0.1%	4.9%	3.0%
Curb ramp	-3.0%	-3.5%	-0.1%	4.1%	2.5%
Clear curb extension	-3.9%	-4.6%	-0.1%	5.3%	3.2%
Paved shoulder	-9.1%	-10.7%	-0.2%	12.5%	7.6%
Surroundings					
Light rail passing	7.2%	8.4%	0.1%	-9.8%	-6.0%
Visible highway crossing	7.0%	8.2%	0.1%	-9.5%	-5.8%
Green space [b]					
Grass borders with tress along the road	-5.8%	-6.8%	-0.1%	7.9%	4.8%
Grass borders along the road, as well as trees behind the sidewalk	-4.5%	-5.3%	-0.1%	6.2%	3.8%
Grass borders with trees along the road, as well as trees behind the sidewalk	-16.2%	-19.1%	-0.3%	22.2%	13.5%
Heavy set of forest	-8.3%	-9.8%	-0.2%	11.4%	6.9%

Table 14 (continued): Average Marginal Effects of Novice Cyclists' PBIS Model

Visible active travelers					
Presence of cyclists	-3.5%	-4.1%	-0.1%	4.7%	2.9%
More than 2 visible pedestrians	3.2%	3.8%	0.1%	-4.4%	-2.7%
Age [c]					
26 – 35 years old	2.1%	2.5%	0.0%	-2.9%	-1.8%
36 – 50 years old	1.6%	1.8%	0.0%	-2.1%	-1.3%

a – Baseline: 3-way intersection without traffic signals; 4-way intersection with/without traffic signals; Complicated intersection with traffic signals.
b – Baseline: No green space; Grass borders along the road; Trees on the sidewalk; Trees behind the sidewalk; Trees on the sidewalk, as well as behind the sidewalk.
c – Baseline: 18– 25 years old; 51 years old and older.

Table 15: Average Marginal Effects of Intermediate Cyclists' PBIS Model

Variables	Marginal Effect				
	Very unsafe	Unsafe	Neutral	Safe	Very safe
Types of intersections & traffic signal controls [a]					
3-way intersection with traffic signals	-4.1%	-8.1%	-2.2%	7.2%	7.1%
Complicated intersection without traffic signals	2.3%	4.6%	1.2%	-4.1%	-4.0%
Roundabouts with traffic signals	-6.4%	-12.7%	-3.4%	11.3%	11.2%
Roundabouts without traffic signals	-6.2%	-12.2%	-3.3%	10.9%	10.8%
Road traffic					
Number of through auto lanes	1.8%	3.5%	1.0%	-3.1%	-3.1%
Main traffic volume	2.3%	4.6%	1.2%	-4.1%	-4.1%
Intersection treatments					
Marked or unmarked crosswalk	3.2%	6.2%	1.7%	-5.5%	-5.5%
Two-stage turn box	-2.3%	-4.6%	-1.2%	4.1%	4.1%
Bike box	-3.5%	-6.9%	-1.9%	6.2%	6.1%
Intersection crossing markings	-2.9%	-5.7%	-1.5%	5.1%	5.0%
Crossing median refuge island	6.3%	12.5%	3.4%	-11.2%	-11.0%

Table 15 (continued): Average Marginal Effects of Intermediate Cyclists' PBIS Model

Cycle tracks					
Two-way cycle tracks	-4.0%	-7.9%	-2.1%	7.0%	7.0%
One-way cycle tracks	-2.3%	-4.5%	-1.2%	4.1%	4.0%
Traffic diverters					
Forced turn islands	-3.0%	-6.0%	-1.6%	5.4%	5.3%
Sidewalk environments					
Presence of a two-side sidewalk	-2.6%	-5.0%	-1.4%	4.5%	4.5%
Curb ramp	-2.2%	-4.4%	-1.2%	3.9%	3.9%
Clear curb extension	-2.0%	-3.9%	-1.1%	3.5%	3.4%
Paved shoulder	-4.5%	-8.8%	-2.4%	7.9%	7.8%
Surroundings					
Light rail passing	4.2%	8.3%	2.3%	-7.4%	-7.3%
Green space [b]					
Grass borders with tress along the road	-5.0%	-9.8%	-2.7%	8.8%	8.7%
Grass borders along the road, as well as trees behind the sidewalk	-4.4%	-8.6%	-2.3%	7.7%	7.6%
Grass borders with trees along the road, as well as trees behind the sidewalk	-10.9%	-21.4%	-5.8%	19.2%	18.9%
Heavy set of forest	-6.5%	-12.8%	-3.5%	11.5%	11.4%
Visible active travelers					
Presence of cyclists	-2.1%	-4.0%	-1.1%	3.6%	3.6%
Age [c]					
36 – 50 years old	1.2%	2.3%	0.6%	-2.1%	-2.1%
51 years old and older	1.8%	3.5%	1.0%	-3.1%	-3.1%
Gender					
Male	-1.3%	-2.5%	-0.7%	2.2%	2.2%

a – Baseline: 3-way intersection without traffic signals; 4-way intersection with/without traffic signals; Complicated intersection with traffic signals.
b – Baseline: No green space; Grass borders along the road; Trees on the sidewalk; Trees behind the sidewalk; Trees on the sidewalk, as well as behind the sidewalk.
c – Baseline: 18–25 years old; 26-35 years old.

Table 16: Average Marginal Effects of Advanced Cyclists' PBIS Model

Variables	Marginal Effect				
	Very unsafe	Unsafe	Neutral	Safe	Very safe
Types of intersections & traffic signal controls [a]					
Complicated intersection without traffic signals	2.5%	5.7%	3.2%	-4.8%	-6.7%
Roundabouts with traffic signals	-5.2%	-11.7%	-6.5%	9.7%	13.7%
Roundabouts without traffic signals	-3.2%	-7.2%	-4.0%	6.0%	8.4%
Road traffic					
Number of through auto lanes	1.5%	3.4%	1.9%	-2.8%	-3.9%
Main traffic volume	0.9%	2.1%	1.1%	-1.7%	-2.4%
One-way crossing lanes	-1.1%	-2.5%	-1.4%	2.0%	2.9%
Intersection treatments					
Two-stage turn box	-2.7%	-6.1%	-3.4%	5.1%	7.2%
Bike box	-4.1%	-9.3%	-5.1%	7.7%	10.8%
Intersection crossing markings	-1.1%	-2.4%	-1.3%	2.0%	2.8%
Through median refuge island	2.3%	5.2%	2.9%	-4.3%	-6.1%
Crossing median refuge island	6.2%	14.0%	7.7%	-11.6%	-16.3%
Cycle tracks					
Two-way cycle tracks	-3.6%	-8.2%	-4.5%	6.8%	9.6%
One-way cycle tracks	-2.9%	-6.6%	-3.7%	5.5%	7.7%
Traffic diverters					
Traffic-calming circle	-2.5%	-5.7%	-3.1%	4.7%	6.6%
Forced turn islands	-3.5%	-7.9%	-4.3%	6.5%	9.2%
Sidewalk environments					
Presence of a two-side sidewalk	-2.3%	-5.3%	-2.9%	4.3%	6.1%
Clear curb extension	-1.3%	-3.0%	-1.6%	2.5%	3.5%
Paved shoulder	-7.0%	-15.7%	-8.7%	13.0%	18.4%
Green space [b]					
Grass borders with tress along the road	-1.8%	-4.1%	-2.2%	3.4%	4.8%
Grass borders along the road, as well as trees behind the sidewalk	-2.3%	-5.1%	-2.8%	4.3%	6.0%
Grass borders with trees along the road, as well as trees behind the sidewalk	-8.3%	-18.8%	-10.4%	15.6%	22.0%
Heavy set of forest	-2.4%	-5.4%	-3.0%	4.4%	6.3%
Visible active travelers					
Presence of cyclists	-1.4%	-3.2%	-1.8%	2.7%	3.8%
More than 2 visible pedestrians	1.5%	3.4%	1.9%	-2.9%	-4.0%

Table 16 (continued): Average Marginal Effects of Advanced Cyclists' PBIS Model

Age [c]					
26 – 35 years old	1.2%	2.6%	1.5%	-2.2%	-3.1%
36 – 50 years old	1.4%	3.1%	1.7%	-2.6%	-3.7%
51 years old and older	1.5%	3.4%	1.9%	-2.8%	-4.0%
Gender					
Male	0.6%	1.3%	0.7%	-1.1%	-1.5%

a – Baseline: 3-way intersection with/without traffic signals; 4-way intersection with/without traffic signals; Complicated intersection with traffic signals.
b – Baseline: No green space; Grass borders along the road; Trees on the sidewalk; Trees behind the sidewalk; Trees on the sidewalk, as well as behind the sidewalk.
c – Baseline: 18– 25 years old.

Table 17: Predictors of Separate PBIS Models

	Main	Males	Females	Novice	Intermediate	Advanced
Types of intersections & Traffic signal controls						
3-way intersection with traffic signals		√	√	√	√	
Complicated intersection (≥5 ways) without traffic signals	√	√	√	√	√	√
Roundabout with traffic signals	√	√	√	√	√	√
Roundabout without traffic signals	√	√	√	√	√	√
Road traffic						
Number of through auto lanes	√	√	√	√	√	√
Main traffic volume	√		√	√	√	√
Left turning lane			√	√		
One-way crossing lanes	√	√		√		√
Intersection treatments						
Marked or unmarked crosswalk	√	√		√	√	
Number of marked bicycle crossings	√		√			
Number of marked bicycle crossings^2	√		√			
Two-stage turn box	√	√	√		√	√
Bike box	√	√	√	√	√	√
Intersect crossing markings	√	√	√	√	√	√
Through median refuge island	√	√		√		√
Crossing median refuge island	√	√	√	√	√	√
Cycle tracks						
Two-way cycle tracks	√	√	√	√	√	√
One-way cycle tracks	√	√	√	√	√	√
Traffic diverters						
Traffic-calming circle	√	√		√		√
Forced turning islands	√	√	√		√	√
Sidewalk						
Two-side sidewalk	√	√	√	√	√	√
Curb ramp	√		√	√	√	
Clear curb extension	√	√	√	√	√	√
Pave shoulder	√	√	√	√	√	√
Surroundings						
Light rail passing	√	√	√	√	√	
Visible highway crossing	√		√	√		

Table 17 (continued): Predictors of Separate PBIS Models

	Main	**Males**	**Females**	**Novice**	**Intermediate**	**Advanced**
Green space						
Grass borders and trees along the road	√	√	√	√	√	√
Grass borders along the road, as well as trees behind the sidewalk	√	√	√	√	√	√
Grass borders with trees along the road, as well as trees behind the sidewalk	√	√	√	√	√	√
Trees on the sidewalk, as well as behind the sidewalk	√	√				
Heavy set of forest	√	√	√	√	√	√
Visible active travelers						
Presence of cyclists	√		√	√	√	√
More than 2 visible pedestrians	√	√	√	√		√
Demographics and bicycling experiences						
26 years old – 35 years old	√		√	√		√
36 years old – 50 years old	√	√	√	√	√	√
51 years old and older	√	√	√		√	√
Male	√				√	√
Novice rider		√				
Intermediate cyclist	√	√	√			
Advanced, confident cyclist	√	√	√			

Table 18: Measurements of Example Intersections

Intersection Features	Measurements		
	Figure 3 (Intersection 1)	Figure 4 (Intersection 2)	Figure 5 (Intersection 3)
Types of intersections & traffic signal controls			
Complicated intersection without traffic signals	0	0	0
Roundabout with traffic signals	1	0	0
Roundabout without traffic signals	0	0	0
Road traffic			
Number of through auto lanes	2	2	3
Main traffic volume (Number of moving vehicles on through auto lanes/ Number of through auto lanes)	1	1	1
One-way crossing lanes	0	0	1
Intersection treatments			
Marked or unmarked crosswalk	1	1	1
Number of marked bicycle crossings	0	0	0
Number of marked bicycle crossings[2]	0	0	0
Two-stage turn box	0	0	0
Bike box	1	1	0
Intersect crossing markings	1	1	0
Through median refuge island	0	0	0
Crossing median refuge island	1	0	0
Cycle tracks			
Two-way cycle tracks	1	0	0
One-way cycle tracks	0	0	0
Traffic diverters			
Traffic-calming circle	0	0	0
Forced turn islands	0	0	0
Sidewalk			
Presence of two-side sidewalk	1	1	1
Curb ramp	1	0	0
Clear curb extension	1	0	0
Paved shoulder	0	0	0
Surroundings			
Light rail passing	0	0	0
Visible highway crossing	0	0	0
Green space			
Grass borders with tress along the road	0	0	0
Grass borders along the road, as well as trees behind the sidewalk	0	1	0
Grass borders with trees along the road, as well as trees behind the sidewalk	0	0	0
Trees on the sidewalk, as well as behind the sidewalk	0	0	0
Heavy set of forest	0	0	0
Visible active travelers			
Presence of cyclists	1	1	0
More than 2 visible pedestrians	1	0	1

Appendix B. Figures

Figure 4-1: The intersection of Village Pkwy and Shamrock Blvd in Dublin, Ohio
(Intersection 4 – latitude: 40.10228; longitude: -83.09703)

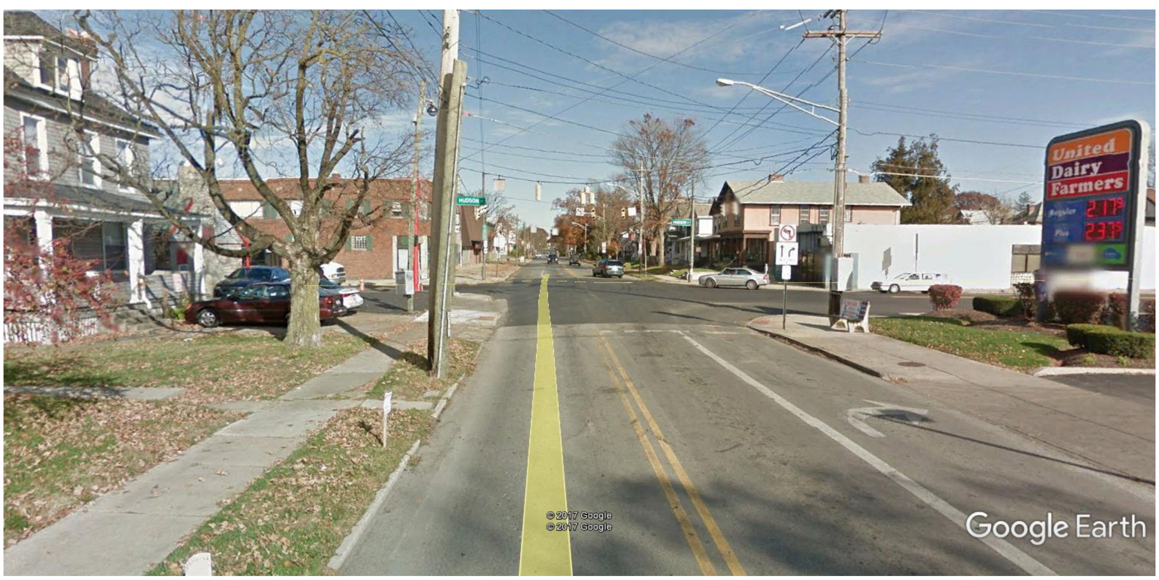

Figure 4-2: The intersection of E Hudson St and Indianola Ave in Upper Arlington, Ohio
(Intersection 5 – latitude: 40.01526; longitude: -83.0022)

Figure 4-3: The intersection of E Livingston Ave, Lancaster Ave, State Ridge Blvd and Baltimore Reynoldsburg Rd in Reynoldsburg, Ohio (Intersection 6 – latitude: 39.94576; longitude: -82.79652)

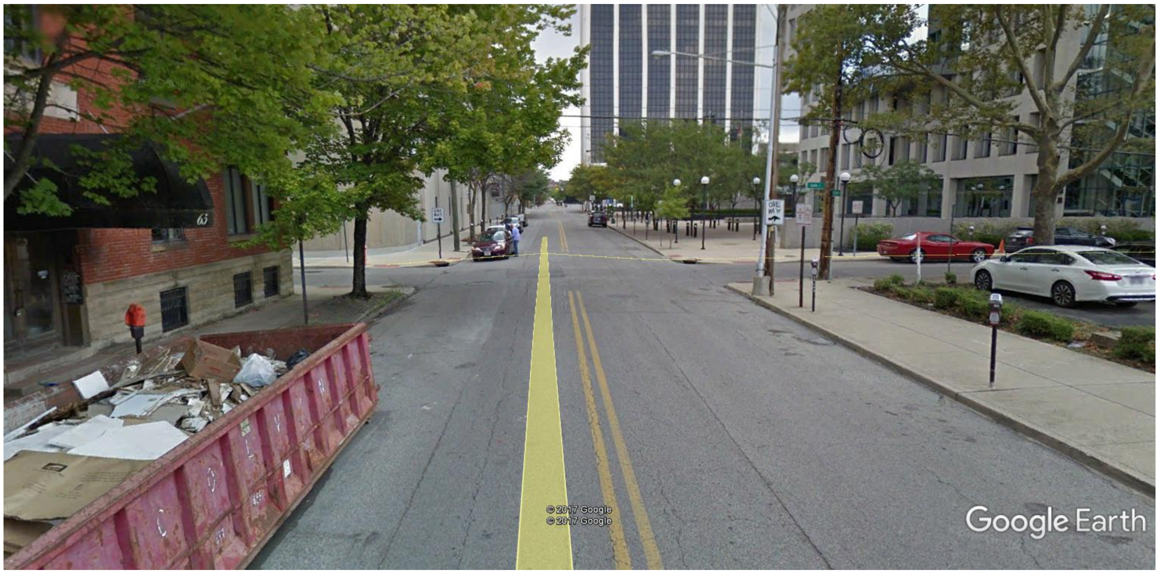

Figure 4-4: The intersection of S 5^{th} St and Oak St in Columbus, Ohio (Intersection 7 – latitude: 39.9616; longitude: -82.99412)

Figure 4-5: The intersection of Daugherty Dr and Lancaster Ave in Reynoldsburg, Ohio (Intersection 8 – latitude: 39.97366; longitude: -82.8103)

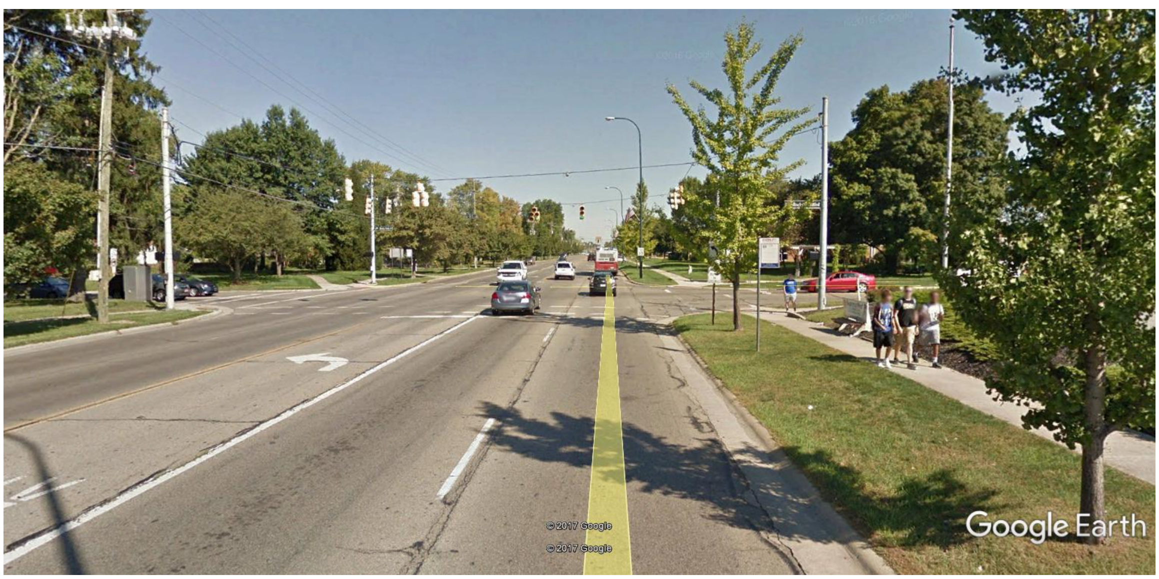

Figure 4-6: The intersection of Rocky Fork Dr N and S Hamilton Rd in Gahanna, Ohio (Intersection 9 – latitude: 40.0135; longitude: -82.86699)

Figure 4-7: The intersection of Davidson Rd and Britton in Hilliard, Ohio
(Intersection 10 – latitude: 40.04985; longitude: -83.13375)

Figure 4-8: The intersection of Worthington Road and Olde Worthington Rd in Westerville, Ohio
(Intersection 11 – latitude: 40.14156; longitude: -82.95617)

Figure 4-9: The intersection of E Dublin Granville Rd and Ambleside Rd in Worthington, Ohio (Intersection 12 – latitude: 40.08734; longitude: -82.98112)

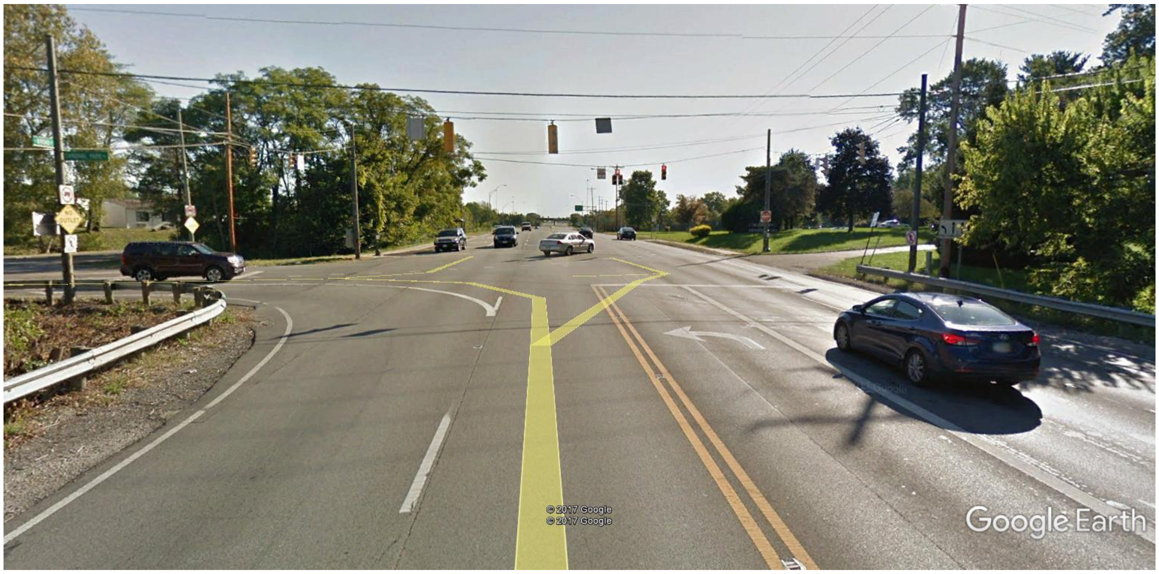

Figure 4-10: The intersection of E Broad St and Cardinal Park Dr in Whitehall, Ohio (Intersection 13 – latitude: 39.97769; longitude: -82.86079)

Appendix C. Survey Questionnaires

THE OHIO STATE UNIVERSITY

Introduction

Welcome to our survey on Perceived Bicycling Safety!

This survey is conducted by researchers from The Ohio State University's City and Regional Planning (C&RP) section. The purpose of this survey is to understand how intersection features affect perceived intersection safety from the perspective of those who are riding a bicycle. Your input is very important to us!

The questionnaire should take no more than 10 minutes to complete. Any identifying information that you provide will remain confidential. You will be asked to rate twelve intersections on a scale of "Very safe to cross" to "Very unsafe to cross". You will also be asked to provide some information about yourself and your travel preferences. Your participation in this survey is completely voluntary and your decision related to participation will not affect your relationship with the University.

As you complete each image/section please click on the button at the bottom of the page, this will take you to the following set of questions. If you have any questions related to this survey, please contact Kailai Wang, wang.7684@osu.edu.

For questions about your rights as a participant in this study, to discuss other study-related concerns, or to lodge complaints with someone who is not part of the research team, you may contact the Office of Responsible Research Practices at 1-800-678-6251.

Thank you for participating.
Sincerely,

Kailai Wang, PhD Student
City and Regional Planning Section
Knowlton School of Architecture
The Ohio State University
275 W. Woodruff Avenue, Columbus, OH 43210
(480) 414-3171 / wang.7684@osu.edu

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What is your primary mode of transportation (How do you travel most of the time)?

Auto (driving alone)	Bicycle
Carpooling (with 1 or more people)	Bicycle & bus (in the same trip)
CABS bus	Bicycle & Auto (in the same trip)
COTA bus	Other
Walking	

What is your secondary mode of transportation?

Auto (driving alone)	Bicycle
Carpooling (with 1 or more people)	Bicycle & bus (in the same trip)
CABS bus	Bicycle & Auto (in the same trip)
COTA bus	Other
Walking	None

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When was the last time that you rode a bicycle (for any purpose)?

Within last week

Within last month

Within the last year

More than a year ago

Never

Which of these phrases best describes you as a cyclist?

I cannot ride a bicycle

A novice cyclist, I prefer to stick to bike trails and/or paths.

An intermediate cyclist who is somewhat comfortable riding in some traffic situations

An advanced, confident cyclist who is comfortable riding in most traffic situations

I don't know how to describe my bicycling skills

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Please rate the following **12 intersection images** on a scale of “Very unsafe to cross” to "Very safe to cross".

Please rate these as if you were riding a **bicycle** crossing each intersection.

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1/12

If you were riding a bicycle, how safe would you feel crossing this intersection?

Very unsafe	Unsafe	Neutral	Safe	Very safe

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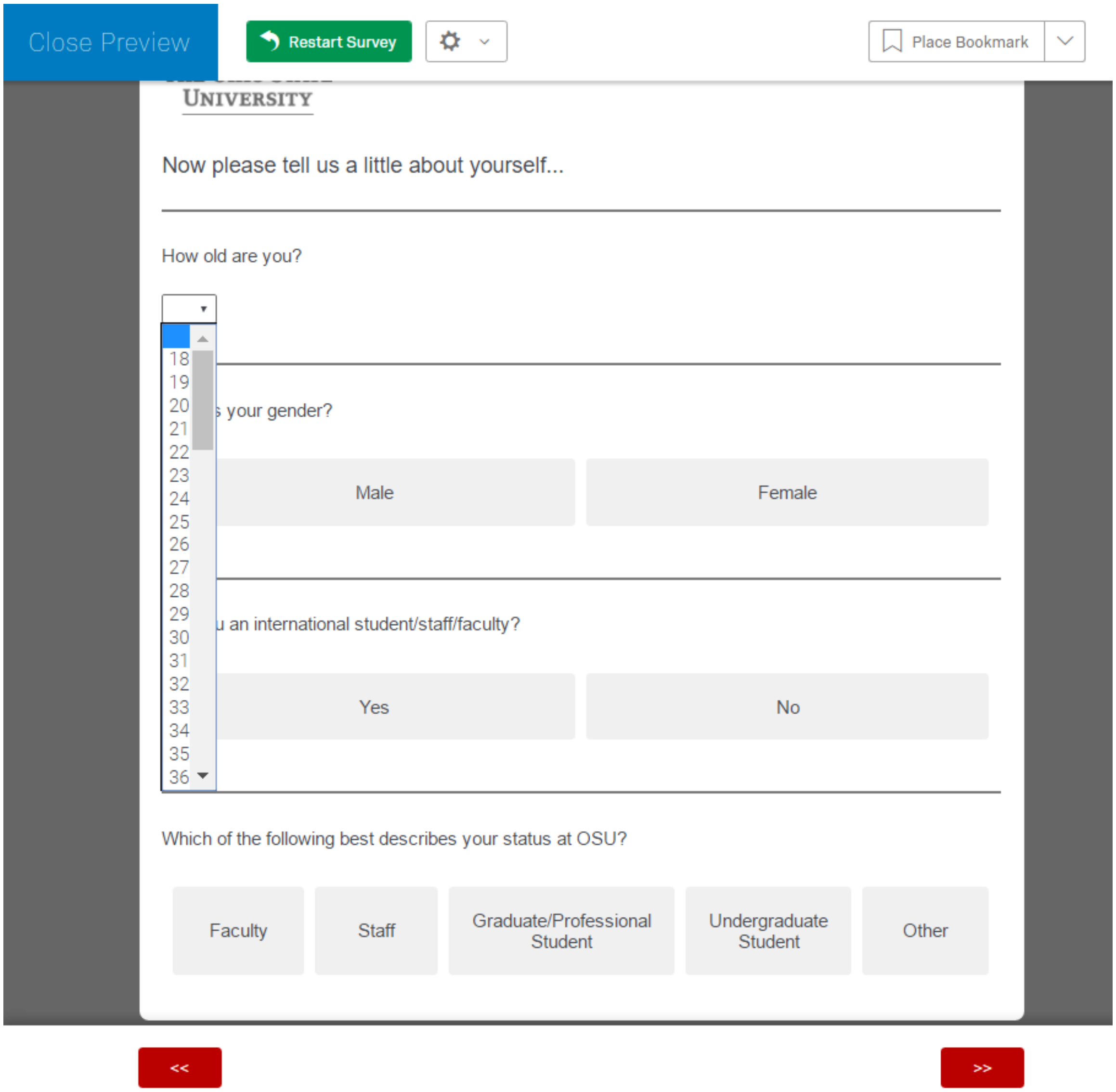

Close Preview

Restart Survey

Place Bookmark

UNIVERSITY

Now please tell us a little about yourself...

How old are you?

18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36

s your gender?

Male

Female

u an international student/staff/faculty?

Yes

No

Which of the following best describes your status at OSU?

Faculty

Staff

Graduate/Professional Student

Undergraduate Student

Other

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Do you have a valid driver's license?

Yes	No	No, I am considering getting one

Do you own or have access to an auto?

Yes	No	No, I am considering purchasing one

Do you own or have access to a bicycle?

Yes	No	No, I am considering purchasing one

Are you a member of Campus Bike Sharing System?

Yes	No	No, I am considering purchasing a membership

Are you a member of CoGo Bike Sharing System?

Yes	No	No, I am considering purchasing a membership

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How important are these factors when choosing your mode of transportation (walking, bicycling, bus, auto, etc)?

	Not Important	Somewhat Important	Important	Very Important
The ability to make stops on the way to and from campus	○	○	○	○
Concern for the environment	○	○	○	○
More flexibility in when I depart from campus/home	○	○	○	○
Safety from crime	○	○	○	○
Safety in traffic	○	○	○	○
Extreme weather conditions	○	○	○	○
Shorter commute time	○	○	○	○
Cost	○	○	○	○

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How important are the following factors in your decision to bicycle?

	Not Important	Somewhat Important	Important	Very Important
More secure or covered bicycle parking	○	○	○	○
Educational classes on bicycle riding and safety	○	○	○	○
A bicycle station on campus providing repairs/ supplies	○	○	○	○
More convenient bicycle trails and pathways separated from the roadway	○	○	○	○
A campus map showing bicycle routes	○	○	○	○
Dedicated bicycle lanes on campus	○	○	○	○
More frequent police patrols to ensure safety	○	○	○	○
Dedicated bicycle lanes to/from campus	○	○	○	○
Greater enforcement of traffic laws to protect bicyclists on the road	○	○	○	○
Distance	○	○	○	○
A convenient place to shower/ change clothes	○	○	○	○
Prohibiting car traffic on some or all of the campus roads	○	○	○	○
Better lighting on/around campus	○	○	○	○
Extreme weather conditions	○	○	○	○
Worry about possible mechanical issues, such as a flat tire	○	○	○	○
Safety (crime)	○	○	○	○
Safety (crime)	○	○	○	○
The need to carry things	○	○	○	○
The need to change clothes/shower	○	○	○	○

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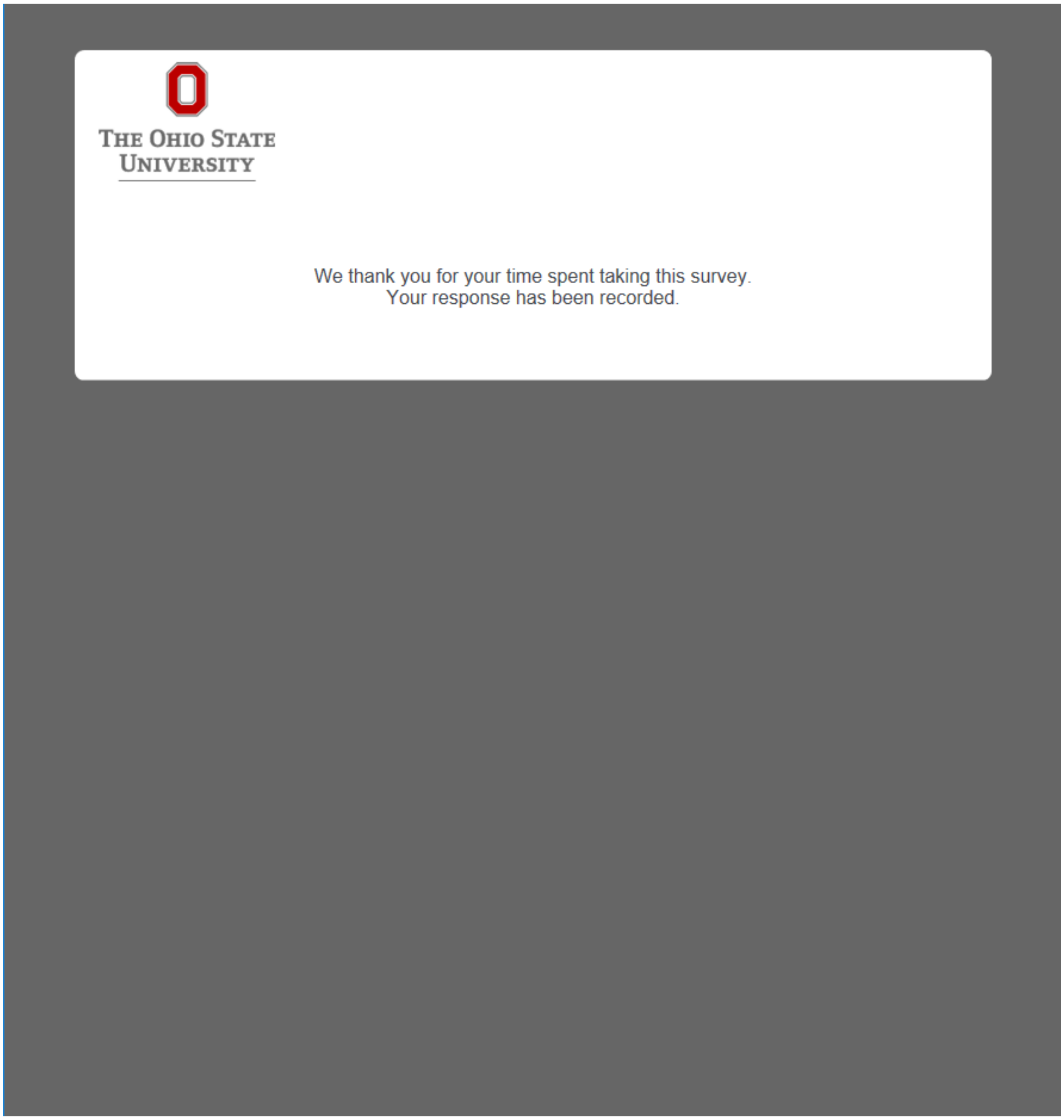
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We thank you for your time spent taking this survey.
Your response has been recorded.