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# Contextual Guidance at Intersections for Protected Bicycle Lanes

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NATIONAL INSTITUTE FOR TRANSPORTATION AND COMMUNITIES nitc-utc.net

# CONTEXTUAL GUIDANCE AT INTERSECTIONS FOR PROTECTED BICYCLE LANES

## Final Report

## NITC-RR-987

by

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16. Abstract

Improved bicycle infrastructure has become increasingly common in the United States as cities seek to attract new riders, including the demographics of people who do not feel comfortable riding with motor vehicle traffic. A key tool is separated or protected bicycle lanes, and intersections are critical links in a low-stress network. This report presents an analysis of the perceived level of comfort of current and potential bicyclists from 277 survey respondents who rated 26 first-person video clips of a bicyclist riding through mixing zones, lateral shifts, bend-in, bend-out and protected intersection designs. A total of 7,166 ratings were obtained from surveys conducted at four locations in Oregon, Minnesota and Maryland, including urban and suburban locations. Survey respondents were categorized into three groups based on their response to attitudes and bicycling behavior by a cluster analysis. Descriptive analysis and regression modeling results find that designs that minimize interactions with motorists, such as fully separated signal phases and protected intersections, are rated as most comfortable (72% of respondents rated them as very comfortable or somewhat comfortable). Mean comfort drops off significantly for other designs and interactions with turning vehicles result in lower comfort ratings, though there are differences for each design. Importantly, as the exposure distance, measured as the distance a person on a bicycle is exposed to traffic, increases the comfort decreases. For each of the designs, the expected frequency with which cyclists would encounter turning motorists based on expected bicycle volume and expected right-turn volume was established using microsimulation. These estimated interactions were combined with the survey results to produce guidance for design selection based on comfort.

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# EXECUTIVE SUMMARY

Protected, or separated, bike lanes have become increasingly common around the United States. Studies have consistently found that people prefer bike facilities that are separated from traffic, such as off-street paths and protected bike lanes, with physical separation such as a post or curb providing increased comfort. The preference for these separated facilities appears to be greater amongst cyclists who ride primarily for recreation (as opposed to for transportation) and among those who cycle less, as well as among the subset of potential bicyclists who are classified as interested in cycling for transportation but concerned about safety and other issues. These results suggest that providing comfortable designs may be vital to expanding the bicycling population beyond current riders. However, these studies of bicyclists' sense of safety and comfort have generally focused on segments, rather than intersection locations. This report, *Contextual Guidance at Intersections for Protected Bicycle Lanes*, summarizes a research effort that used a combination of in-person surveys to define user comfort and microsimulations to estimate expected bicyclist and turning-vehicle interactions to estimate bicyclist comfort based on design type and volumes. Findings suggest that protected intersections and bike signals provide the best expected rider comfort, rated by two-thirds of all respondents rated them as very comfortable or somewhat comfortable.

**Background:** Cities around the United States are increasingly seeking to modernize and enhance their bicycling infrastructure with the aim of safely accommodating an increasing number of cyclists and attracting new cyclists. As a key component of this effort, cities are employing protected (separated) bike lanes. Generally, protected bike lanes assign bicyclists and motorists their own space on the roadway, with some type of vertical separation defining the respective lanes. Intersections pose a challenge; the separation often ends and people riding often must move through areas with cross traffic or turning traffic. Design approaches for protected bike-lane intersections have focused on two main philosophies: 1) reduce separation prior to the intersection by channeling bicyclists toward motor vehicle traffic, and 2) maintain separation at intersections. This research assesses a selection of design approaches for comfort and expected interactions with motorists based on bicycle and turning-vehicle volumes.

**Methodology:** The research approach is guided by the assumption that cyclist comfort is a key desired design outcome. In-person video surveys are used to identify people's comfort levels while bicycling through a variety of intersection designs under defined conditions (e.g., with or without interactions with turning motorists). Video data and microsimulation models were used to inform the comparison of the design options and analyze anticipated interactions at various bicycle and vehicle volumes for each of the design options. A total of 277 respondents rated 26 video clips showing cyclists riding through a variety of intersections, for a total of 7,166 ratings. Surveys were conducted at four locations in three states, including urban and suburban locations in Oregon, Minnesota and Maryland. Simulation models were built and calibrated to the designs of bend-in, mixing zones, and bend-out (protected intersection) that were tested in the in-person survey. Bicycle and vehicle volumes varied from 50 to 250 vehicles per hour and 10 simulations pairs were run. Surrogate safety measures were extracted from the resulting 900 trajectory files using the Federal Highway Administration (FHWA) Surrogate Safety Assessment Model (SSAM) software. Comfort estimated from surveys are combined with simulated conflicts for various turning volumes to estimate the level of comfort for the designs.

**Findings:** Survey ratings demonstrated that designs that minimize interactions with motorists, such as fully separated signal phases and protected intersections, are rated as most comfortable (two-thirds of respondents rated them as very comfortable or somewhat comfortable). Comfort drops off significantly for other designs, particularly for people who are dissuaded from riding due to concerns about traffic (e.g., the *Interested but Concerned* cyclists). Designs with longer sections of exposure for bicyclists (e.g., via mix or merge areas, or long intersection crossings) were associated with decreased comfort. In general, interactions with turning vehicles caused people to rate cycling comfort lower. Non-mixing zone locations (other than protected intersections) such as bend-in and similar designs were most susceptible to eroded comfort when interacting with turning vehicles. Women and non-white respondents were generally less likely to feel comfortable than other respondents. For the bend-in, mixing zones and bend-out (protected intersection) designs, the research team simulated the expected frequency with which cyclists would encounter turning motorists as a function of through bicycle and right-turn volumes. The research identified exposure distance, measured as the end of vertical separation on one side of the intersection to the start of separation on the far side is a significant predictor of comfort.

The simulation models were calibrated to existing conditions but could not completely represent the interactions between motorists and bicycles. In general, however, as either the bicycle or right-turning vehicle volume increases, the number of simulated conflicts of all three intersection models increases. The number of conflicts per bicycle also increases as the right-turning vehicle volume increases. The simulations found that the number of interactions were highest at the bend-out design, though occurred at lower speeds (the speeds of the turning vehicles were calibrated to each location tested). Due to the number of assumptions required, it is not recommended that the results from the microsimulation be extended outside the context used in this research for weighting the comfort scores.

**Guidance:** Contextual guidance on selecting intersection design treatments based on estimated cyclist comfort was developed by combining the survey comfort ratings with the simulated frequency with which cyclists would encounter turning motorists. This guidance is provided for both more experienced and tolerant to traffic stress (*Bike Inclined*) and those less tolerant to traffic stress and sensitive to comfort (*Interested but Concerned*). The estimated order of comfort for both groups, from least to most comfortable, was mixing zones, lateral shifts, bend-in, and maintain separation, signal and protected intersections. Importantly, comfort scores for the *Interested but Concerned* groups suggest only the  bicycle signal phase separation (3.7 comfort score out of 5 and 65% comfortable) and protected intersection (3.7-3.8 score out of 5 and 67% to 70% comfortable) as recommended designs.

# 1.0 INTRODUCTION

As cities strive to make streets safe and comfortable for bicycling, facilities that provide separation from motor vehicle traffic on the roadway have become increasingly common. As of 2019, there were 519 reported protected bike lanes totaling 393 lane miles around the United States, according to one tally - the Green Lanes Project's Protected Bike Lanes Inventory, up from less than one mile in 2007 (*PeopleForBikes, 2019*). While this is an important source to represent trends, this inventory does not represent all facilities that have been constructed. Generally, protected bike lanes assign bicyclists and motorists their own space on the roadway, with some type of vertical separation defining the respective lanes. At intersections, design options for protected bike-lane transitions can be in one of three categories: 1) designs that maintain separation between bicycles and motorists up to the intersection (e.g., straight or maintain separation, bend-in, bend-out, and protected intersection); 2) designs where bicyclists mix with or cross the path of turning motorists (e.g., mixing zones and lateral shift); and 3) designs that use bicycle signals to fully separate the conflicting movements between bicycles and motorists in time (*Federal Highway Administration, 2015*). The selection of the design is often challenged by space constraints and the need to accommodate turning vehicles. Safety (in terms of reported crashes and observed conflicts) is an essential consideration in the selection of a design. However, the perceived comfort of various intersection designs is also a key consideration for cities attempting to build connected, low-stress networks, given the link between perceived comfort and ridership (*Dill & Carr, 2003*).

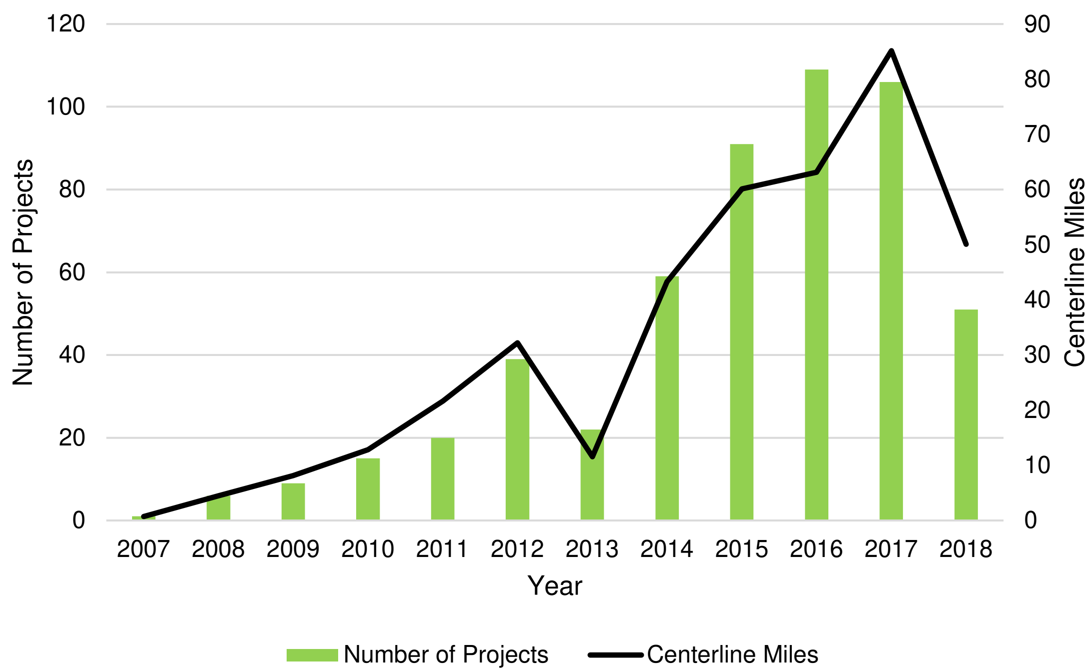



**Figure 1-1 Project Count and Centerline Mileage of Protected Bike Lanes by Installation Date, Source: Green Lanes Project, Inventory of Protected Bike Lanes**

## 1.1 RESEARCH OBJECTIVES

The research objectives were:

- To establish the contexts in which various intersection treatments for protected bike lanes should be employed, which includes analysis of intersection geometry, existing and expected traffic, turning movements, and interactions with other types of traffic.
- To establish "comfort" ratings of each design using in-person video surveys, similar to those used to create the level of service measures for bicycle facilities to identify cyclists' comfort levels in a variety of intersection designs under defined conditions (e.g., with or without turning motorists present).
- To develop calibrated microsimulation models for each of the design options to obtain estimates of the number of interactions between motorists and bicycles at intersections.
- To develop recommendations and guidance for the selection of intersection designs for protected or separated bicycle lanes based on the above results.

## 1.2 ORGANIZATION OF REPORT

The report is organized as follows. Chapter 2 provides a brief background for the project, reviewing the relevant literature and design guidance. Chapter 3 presents the research methods. The next three chapters present the research results. Chapter 4 summarizes the analysis of the survey respondents. Chapter 5 describes the intersection ratings for comfort. Chapter 6 describes the results of the microsimulation. Chapter 7 presents the guidance for using the results of this research in practice. Finally, Chapter 8 presents conclusions, limitations, and recommendations for future research.

# 2.0 BACKGROUND

Studies have consistently found that people prefer bike facilities that are separated from traffic, such as off-street paths and protected bike lanes *(McNeil, Monsere, & Dill, 2015; Sanders, 2016; Tilahun, Levinson, & Krizek, 2007; Winters, Davidson, Kao, & Teschke, 2011*), with physical separation such as a post or curb providing increased comfort (*Dill & McNeil, 2016; McNeil et al., 2015; Sanders, 2016; Sanders & Judelman, 2018*). The preference for these separated facilities appears to be greater amongst cyclists who ride primarily for recreation (as opposed to for transportation) and among those who cycle less often *(Sanders & Judelman, 2018*), as well as among the subset of potential bicyclists who are classified as interested in cycling for transportation but concerned about safety and other issues *(Dill & McNeil, 2016; McNeil et al., 2015*). These results suggest that providing comfortable designs may be vital to expanding the bicycling population beyond current riders. However, these studies of bicyclists' sense of safety and comfort have generally focused on segments, rather than intersection locations.

Recent studies of the safety of protected bike lanes have tended to be positive overall. A study examining 13 years of crash data across 12 U.S. cities found that higher concentrations of separated bike facilities were strongly associated with better safety outcomes *(Marshall & Ferenchak, 2019*). Another review of crash data noted overall trends toward decreases in bicyclist crashes along protected bike lanes (*Rothenberg, Goodman, & Sundstrom, 2016*). Studies in Toronto and Vancouver, Canada, used data from interviews with nearly 700 injured cyclists identified through hospital records to investigate the likelihood of injury along with various street types. In both studies, even though the number of protected facilities in each city was relatively small, they were found to be significantly less likely to be associated with a crash than all other facility types (*Harris et al., 2013; Teschke et al., 2012*). Another study of cycle tracks in Montreal and New York found an overall crash rate of 2.3 crashes per bicycle km/year lower than reference rates calculated for on-street cycling in multiple studies *(A. C. Lusk et al., 2011; A. Lusk, Morency, Miranda-Moreno, Willett, & Dennerlein, 2013*).

Safety data shows that most bicyclist crashes happen at intersections; for example, Metro's State of Safety Report found that 73% of bike-involved crashes occurred at intersections, much higher than the 46% of auto-only crashes or 53% of pedestrian-involved crashes (*Metro, pg. 75, 2018*). The effect of protected or separated bike lanes on bicyclist safety at intersections is somewhat unclear. The Rothenberg et al. (*2016*) review of crash data found an increased number of bicycle crashes at intersections along separated bike lanes. However, a study examining cyclist and motor-vehicle interactions at intersections along separated bike lane routes and control locations found the separated bike-lane intersections to be safer, in general, with higher through bicycle traffic being associated with increased safety and higher right-turn motorist traffic being associated with decreased safety (*Zangenehpour, Strauss, Miranda-Moreno, & Saunier, 2016).*

In September 2018, the New York City Department of Transportation released a report entitled *Cycling at a Crossroads: The Design Future of New York City Intersections* that focused on assessing a set of intersection designs for protected bike lanes. Design options assessed include a short mixing zone design, a full bike signal, a delayed turn signal (i.e., a leading interval), and an offset crossing that employs paint and plastic posts to approximate a protected intersection design. Of note, the protected intersection-style design fared better than other designs in terms of stated comfort (based on an intercept survey of cyclists), with 93% of cyclists saying they felt safe riding through them, compared to about 65% on the mixing zone and delayed turn designs.

## 2.1 INTERSECTION DESIGN GUIDANCE

Official guidance on the design and operations of protected bike lanes in the United Stated context was largely absent prior to the 2011 release of the NACTO *Urban Bikeway Design Guide*. Several resources have come online since the NACTO guide release, including a second edition of the NACTO guide in 2012, the 2015 FHWA *Separated Bike Lane Planning and Design Guide*, the 2015 Massachusetts Department of Transportation *Separated Bike Lane Planning and Design Guide*, the 2019 NACTO *Don't Give Up at the Intersection Guide*, the 2019 FHWA *Bikeway Selection Guide*.

To aid in the discussion of the approaches and designs, graphics from FHWA's Separated Bike Lane Planning and Design Guide (2015) are included below:

- A signalized intersection (Figure 2-1), wherein motor vehicle traffic and bicycle traffic have separate traffic signals that separate out their movements in time.
- A bend-in approach (Figure 2-2) shifts the bike lane in toward the motor vehicle lanes, which can increase visibility and awareness of bicyclists and motorists of one another.
- A bend-out approach (Figure 2-3) shifts the bike lane away from the motor vehicle traffic, which results in turning motorists having exited the through travel lane prior to crossing the bike lane, slowing their speed and approaching the crossing at closer to a 90 degree angle. A protected intersection is a type of bend-out design.
- A lateral shift design (Figure 2-4) moves the bicyclist out and provides a crossing area for turning-motorists to shift into a turn lane, with their paths crossing before the bike lane is reestablished to the inside of the turn lane.
- A mixing zone design (Figure 2-5) establishes a right turn lane and ends the bike lane, creating a mixing area for bicyclists and turning motorists. Although not shown, another design approach is to keep the bike lane separated up to the intersection, without any bend in or out.

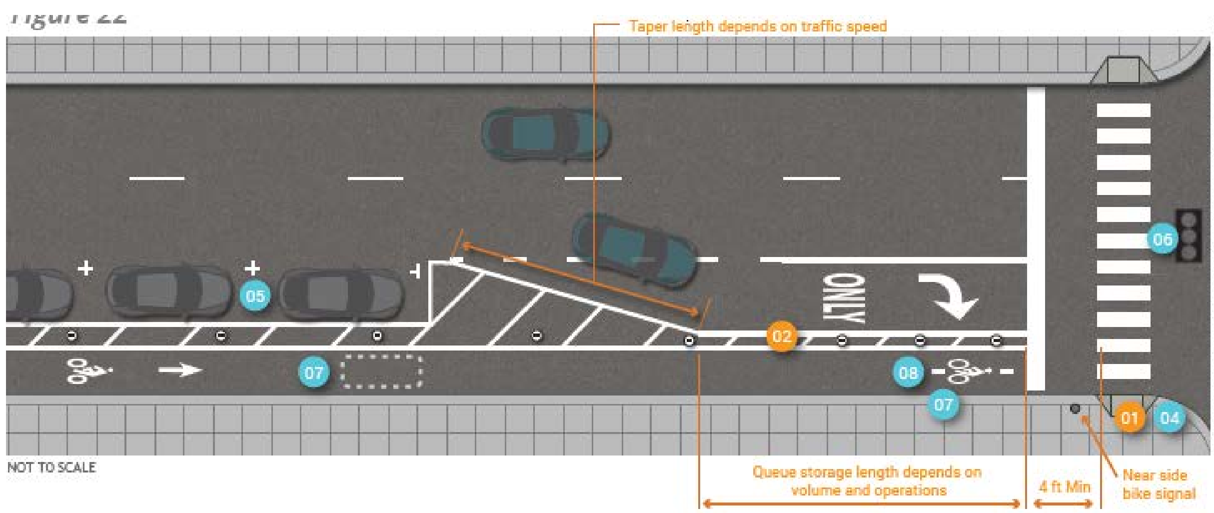



**Figure 2-1 Bicycle Signal Design (FHWA 2015, page 109)**

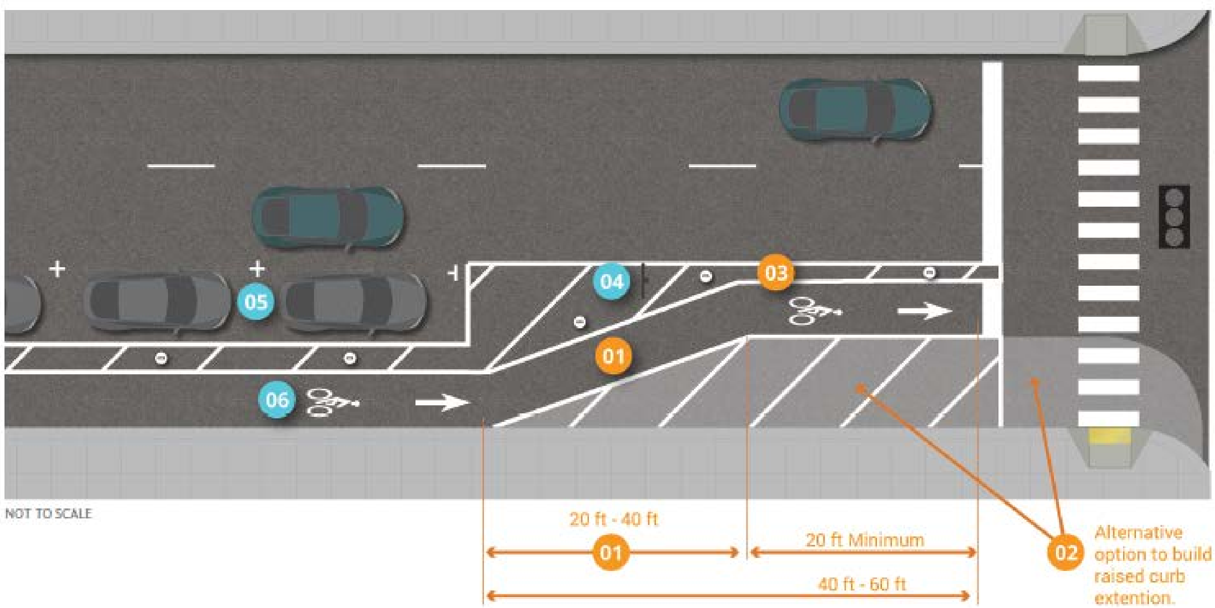



**Figure 2-2 Bend-in Design (FHWA 2015, page 108)**

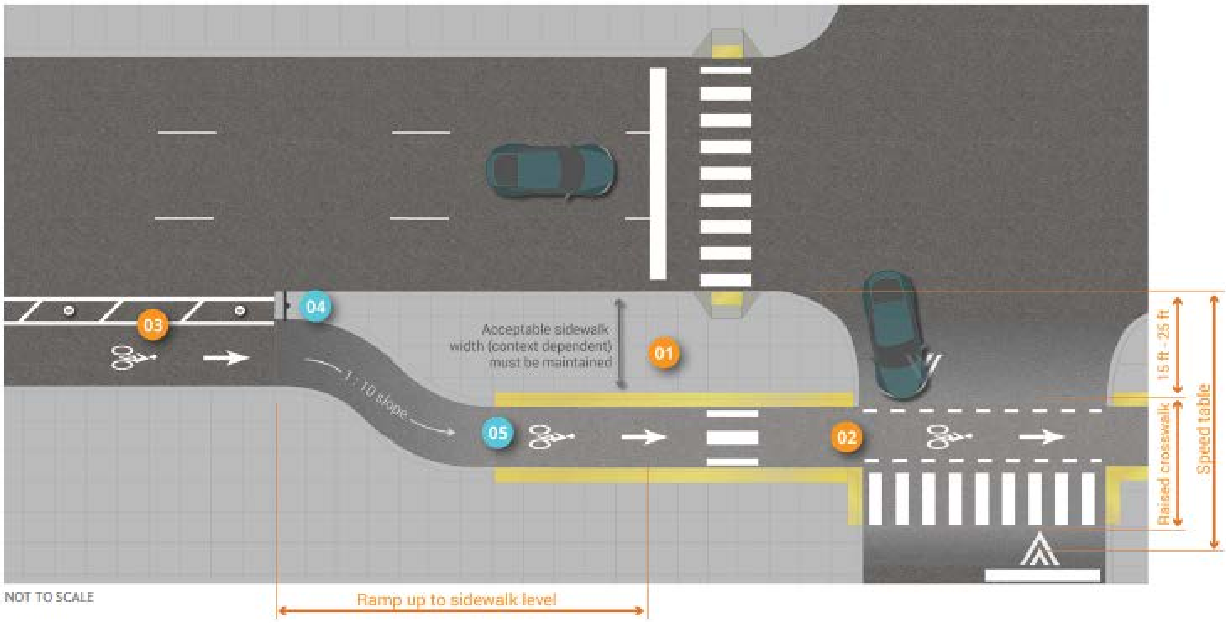



**Figure 2-3 Bend-Out Design (FHWA 2015, page 109)**

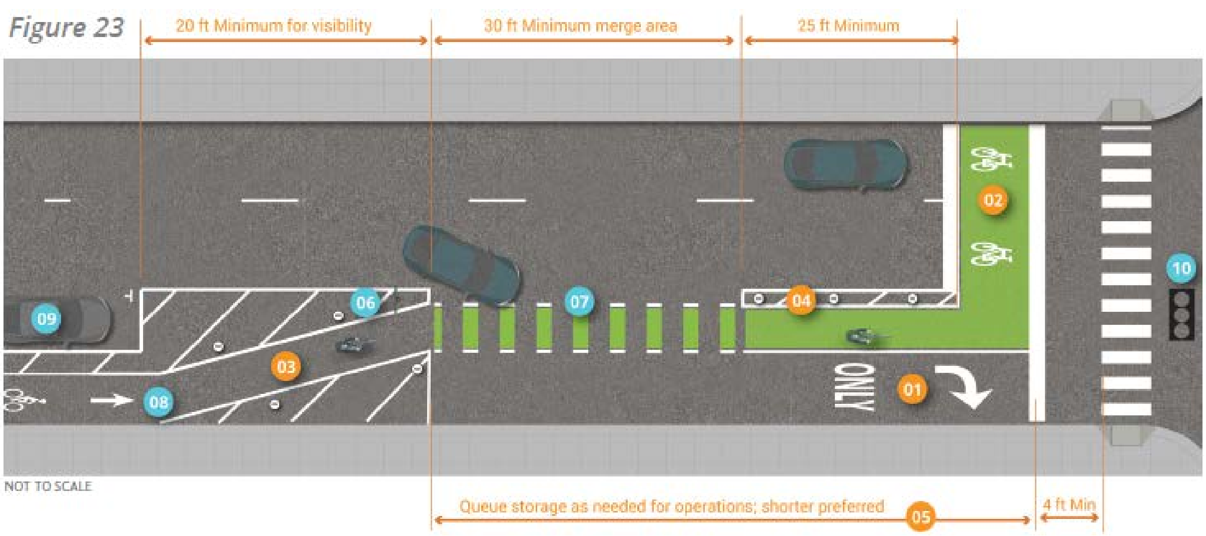



**Figure 2-4 Lateral Shift Design (FHWA 2015, page 105)**

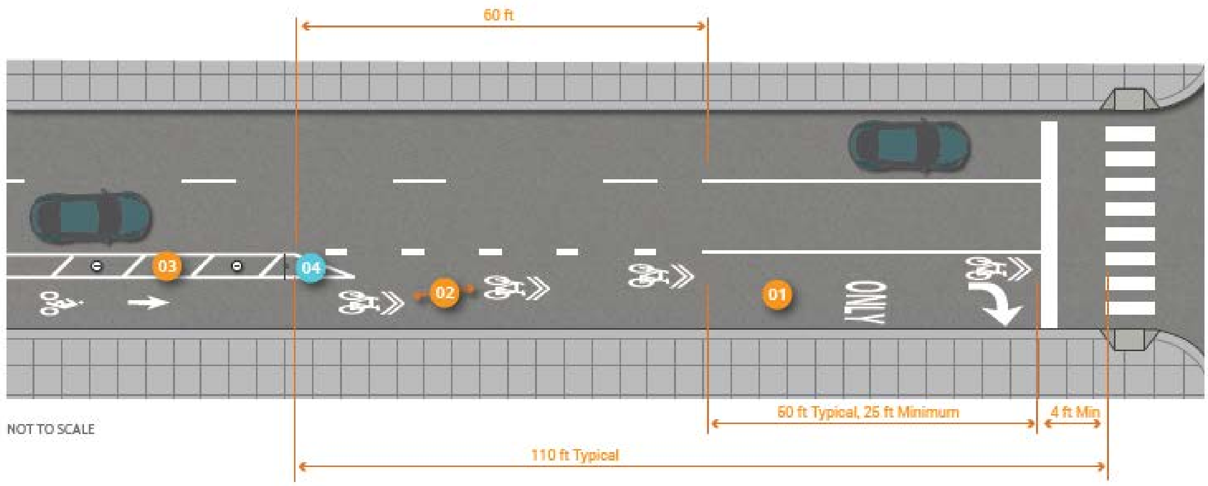



**Figure 2-5 Mixing Zone Design (FHWA 2015, page 107)**

These designs were used to guide the types of intersections that should be included in the research. In the following sections, key considerations for designing intersections for protected bike lanes are roughly summarized from some of the primary available design guidance documents on the subject.

### 2.1.1 FHWA: *Separated Bike Lane Planning and Design Guide*

The FHWA's *Separated Bike Lane Planning and Design Guide* "outlines planning considerations for separated bike lanes and provides a menu of design options covering typical one and two-way scenarios." It also "provides detailed intersection design information covering topics such as turning movement operations, signalization, signage, and on-road markings." Pages 102-126 discuss intersection design. Table 2-1 shows how the FHWA guide presents the benefits and drawbacks of various intersection design strategies.

**Table 2-1 Pros and Cons of Intersection Design Strategies (Replicated from FHWA, Table 3, p. 103)**

| Approach | Design | Pros | Cons |
|---|---|---|---|
| Maintain Separation | Signals: separate through and turning movements in time | Potential elimination of turn conflict | Increased signal cycle length, possibly with increased wait times |
| | Bend-in: position cyclists closer to turning vehicles to increase visibility | Greater sense of comfort / less traffic stress | Turning vehicle conflicts at intersections |
| | Bend-out: provide space for right-turning vehicles to turn before encountering bicycle conflicts; provide space for queueing | | |
| Shift Bicycles Across Turning Vehicles | Lateral Shift: vehicles cross high-visibility bike lane; clear responsibility for yielding | Organize conflicts; reduce right-hook risk | Greater traffic stress |
| | Mixing Zone: shared lane, requires less space | | |

The FHWA guide further elaborates on each of the intersection design strategies as follows:

- Signalization may be appropriate at "intersections with high volumes of right-turning automobiles, or on one-way streets with left turning automobiles and a left-side running separated bike lane, and where the signal phasing and cycle length can accommodate a bicycle signal phase" (pg. 103).
- Lateral shifts move turning vehicles to the outside of bike-through traffic, and require the two types of users to shift across each other. The guide notes that this "places the responsibility for yielding clearly on drivers turning right, and brings bicyclists into a highly visible position" and moves potential conflicts up before the intersection. "A lateral shift treatment is effective for intersections where a separate bicycle signal and signal phasing is not feasible, because bicyclists can proceed in the same signal phase as through and right-turning vehicles" (pg. 105).
- Mixing zones have bicyclists and turning vehicles merge into one lane. They "may provide the best option in locations without on-street parking and/or with a constrained right of way where the roadway width will not accommodate both a bicycle lane and a right-turn lane at the intersection" (page 107).
- Bend-in and bend-out options are discussed in pages 109-112. Table 2-2 replicates FHWA's Table 4 (Page 110), discussing the advantages and disadvantages of each.

**Table 2-2 Pros and Cons of Bend-In and Bend-Out Designs (Replicated from FHWA, Table 4, p. 110)**

| Design | Advantages | Disadvantages |
|---|---|---|
| Bend-in | • Motorists on a side street can see bicycles and vehicles in a similar field of vision<br>• Requires less space than bending out | • Parking spaces close the intersection may be lost<br>• Bicyclists may perceive less separation due to proximity of through vehicles |
| Bend-out | • Allows vehicle traffic turning across separated bike lane to queue out of the way of through traffic and before the separated bike lane<br>• Allows a queueing location for cyclists wanting to turn left<br>• Raised crossing provides traffic calming for automobiles and can also slow bicyclists | • Adequate sight distance may be difficult for vehicles approaching on the side street. |

### 2.1.2 Massachusetts Department of Transportation: *Separated Bike Lane Planning and Design Guide*

The Massachusetts Department of Transportation's (MassDOT) *Separated Bike Lane Planning and Design Guide* provides detailed design dimensions and considerations for reference when designing separated bike lanes. The MassDOT guide complements the FHWA guide by providing additional detail for design dimensions and important considerations. Chapter 4 specifically addresses intersection design and discusses factors that should be considered during design. The chapter details contextual factors that influence intersection design (Section 4.1, page 52), which include user volumes; user delay; design speed; bike lane operation (including whether or not there is a contraflow bike lane); presence and location of bus stops; terrain; on-street parking; land use; street buffers; available right-of-way; and type of project. It then discusses design principles that should be applied to all intersection projects with separated bike lanes (Section 4.2, pg. 54), which include minimizing exposure to conflicts; reducing speeds at conflict points, which can be done by minimizing curb radii, potentially including the use of mountable truck aprons and raised crossings; communicating right-of-way priority; and providing adequate sight distance, including adequate approach clear space for a "recognition zone," "decision zone" and "yield/stop zone." Section 4.3 discusses common intersection design treatments including key elements of protected intersections (such as corner refuge islands, bicycle queuing areas, motorist yield zones, pedestrian crossing islands, provision of pedestrian crossing over separated bike lanes, and pedestrian curb ramps); strategies for constrained locations (such as the bend-in and bend-out approaches); and mixing zone transitions.

### 2.1.3 NACTO: *Urban Bikeway Design Guide*

NACTO's *Urban Bikeway Design Guide* provides a broad overview of the different types of bikeways in use in urban areas, with a section specifically on cycle track intersection approach design. The guide suggests that a typical treatment is removing the separation and shifting the bike lane closer to the motor vehicle lane, and may involve a combined bike and turn lane. Signalization is also stated as a possible approach.

### 2.1.4 CROW: *Design Manual for Bicycle Traffic*

The Dutch Crow *Design Manual for Bicycle Traffic* (2017) includes a chapter on intersection design (Chapter 6, pg. 183). The manual notes that grade separation eliminates conflicts but is generally not viable. Given the potential for conflicts, the ability to "observe the intersection in good time (driving visibility)" is a minimal requirement, as is "a good view of the traffic flow to be crossed (approach visibility)" (pg. 187). Intersections with fewer crossing movements, such as T or Y intersections, are generally preferred. The manual elaborates that "for the safety of cyclists on an intersection it is extremely important that they are noticed by the other traffic" (pg. 188). To accomplish this, they recommend bending in cycle tracks 20 to 30 meters prior to the intersection. Other key guiding goals include reducing speed at conflict points (pg. 188), limiting the number of types of designs to ensure that road users understand what is expected of them when they encounter that type of intersection (pg. 188-189), and uniformity in application of roadway right-of-way rules, signage, marking and design principles (pg. 189). Comfort requirements listed in the manual include a smooth road surface, the ability to proceed unhindered, and minimizing the amount of other traffic the cyclist must encounter or stop and wait for (189-191). In terms of specific design approaches, the bend-in (starting 20 to 30 meters prior to the intersection) is suggested if the maximum speed is less than 60 kph (pg. 196). For roads with greater than 60 kph speeds, a bend-out is recommended with five to seven meters of clearance for a vehicle to turn and yield (pg. 196).

## 2.2 MICROSIMULATION FOR SAFETY ANALYSIS

Microsimulation of traffic is mature and widely used tool to analyze a variety of situations. Traditional applications include operational and performance of intersections, freeways, and interchanges where the dynamic and congested nature of traffic make deterministic procedures less useful. Simulations allow a variety of alternative designs to be explored. Their use to study safety-related performance measures is a more recent extension of the model's capabilities.

Young (*Young & Archer, 2009*) used a microsimulation model to study the safety impacts of an incident reduction function into a vehicle-actuated traffic signal controller. Three safety indicators, TTC, red light violations and required braking rates, were used to investigate the effects of incident reduction function. The result reveals that incident reduction function has a small positive influence on the safety of the intersection. The study provides support for the usage of the microsimulation model on traffic safety evaluation.

Saccomanno (*Saccomanno, Cunto, Guido, & Vitale, 2008*) investigated the safety implications of adopting roundabouts in place of signalized intersections. The microsimulation model was used to compare the pattern of traffic conflicts at roundabouts and signalized intersections. TTC, deceleration rate and crash potential index were used as indicators to identify simulated conflicts. Twelve combinations of geometric design, traffic volume and pavement surface were simulated. The result showed that roundabouts have fewer rear-end conflicts and vehicles involved in the conflicts than signalized intersections.

Many other indicators, such as PET (*Tan, Alhajyaseen, Asano, & Nakamura, 2012*), deceleration rate (*Fang & Elefteriadou, 2005*), and Modified TTC (*Ozbay, Yang, Bartin, & Mudigonda, 2008*) were also used as surrogate measures in the studies. Even though they have been widely used in safety assessment, microsimulation models are limited in their ability to capture complex driver behaviors in the real world that lead to safety issues. The fundamental behaviors simulated in the models are based on car-following algorithms. There are many input parameters in simulation software that may be adjusted to best represent real world behaviors. However, these values can be difficult to measure in the field. Since they impact the model's performance, model calibration is a significant and essential process. Park *(Park & Qi, 2005*) developed a procedure for the calibration to achieve high fidelity and credibility for traffic simulation models. The procedure includes six steps: identification of calibration parameters; experimental design; multiple runs; feasibility test; statistical plots; and analysis of variance. A genetic algorithm was used to look for the best value of parameters. The validity of the proposed calibration procedure was demonstrated by a case study at a signalized intersection. The results showed that the calibrated parameters generated representative performance of the field conditions.

Cunto (*Cunto & Saccomanno, 2008*) presented a calibration and validation process for a microscopic model of safety performance. The calibration procedure involves four steps: heuristic selection of initial model inputs, statistical screening using a Plackett-Burnman design, fractional factorial analysis, and genetic algorithm procedure for obtaining best estimate values. The presented calibration procedure can effectively estimate model parameters that the simulated conflicts closely matched the observed crash data.

Some other researchers (*Fan, Yu, Liu, & Wang, 2013; Huang, Liu, Yu, & Wang, 2013; Park & Schneeberger, 2003; Zhou, Li, Sun, & Han, 2010*) proposed their calibration process as well and they all highly recommended to make calibration of parameters in simulation models in order to get meaningful results. Besides the calibration process, another important problem is the transferability of calibrated microsimulation model parameters. Essa (*Essa & Sayed, 2015*) examined whether the calibrated parameters can give reasonable results when applied to other sites. A total of 83 hours of video data from two signalized intersection in Surrey, British Columbia, were used in the study. The parameters were calibrated with observed conflicts at one intersection and then were used at the second intersection and predicted the number of conflicts by simulated model. The results were compared with results of models with a default parameter value and calibrated with second-intersection video value. The results showed that the parameters are generally transferable between the two intersections.

Even with the calibration parameters, microsimulation models are still questioned if they have a close relationship to the observed conflict or historical crash data. Dijkstra et al. (*2010*) conducted a study to investigate the relationship between simulated conflicts and crash data. In the west Netherlands, 300 $km^2$ areas were covered in the study. Researchers built up simulation models in S-PARAMICS and peak period traffic were used for calibration. TTC value were used to identify conflicts. The conflicts were categorized into three severity levels based on a different TTC threshold. Generalized linear model, log-linear model and Pearson's chi-square test were applied in the validation process. The results showed a quantitative relationship between the number of conflicts and observed crash data. The work of Shahdah (*Shahdah, Saccomanno, & Persaud, 2015*), Wang (*Wang & Stamatiadis, 2014*), Gettman(*Gettman & Head, 2003*) also provided strong evidence to support the validity of microsimulation models in safety assessment (for motor vehicles).

# 3.0 METHODS

The scope of this research is limited to one-way configurations of protected, or separated, bike lanes with a focus on the right-turning interaction. The right-turning interaction was identified as one of the important variables for the different design considerations. The research approach was guided by the assumption that cyclist comfort is the desired design outcome.

The research consisted of two primary tasks:

- Survey of users to establish "comfort" ratings of each design: In-person video surveys, similar to those used to create the level of service measures for bicycle facilities were used to identify cyclists' comfort levels in a variety of intersection designs under defined conditions (e.g., with or without turning motorists present).
- Microsimulation models that were developed and calibrated to the observed video parameters for each of the design options. Once satisfied with the base model performance, we varied bicycle and vehicle volume to obtain estimates of the number of interactions between motorists and bicycles at intersections.

Taken together, these components provide a basis for understanding intersection design considerations that affect cyclist comfort and the potential for conflict with turning vehicles.

## 3.1 SURVEY OF USER COMFORT

The study team conducted in-person surveys consisting of respondents recruited from busy locations such as farmer's markets and shopping malls. People were asked to watch video clips of places where people might ride a bicycle – primarily intersections along protected bike lane routes – and rate how comfortable they would be riding in each place. Several other sections asked respondents about why they preferred certain designs, about their bicycling behavior and opinions, and general questions about their travel and demographic background. The following section details the survey development and implementation.

### 3.1.1 Survey design

The goal of the survey was to understand people's reactions to a variety of potential designs for protected bike-lane intersections along with an understanding of how different interactions with turning motorists influenced those reactions. We sought to survey people regardless of whether they ride a bicycle or not, and comfort was used as the primary measure of the respondent's reaction to each clip.

The design and implementation of the survey involved trade-offs. Some studies evaluating preferences for different facilities and designs have used an adaptive stated preference approach that presents respondents with pairs of choices (often including factors such as facility options and cost, either in time or money), with the pairs changing depending on selections made (e.g., *Tilahun, Levinson and Krizek, 2007*). This approach could have been done using an online survey, though is very difficult in person or with a group due to the need to adapt the pairs based on selections. Other studies, particularly those examining bicycle level-of-service have presented images or video clips in person to groups of respondents (e.g., *Foster et al., 2015* and *Petritsch et al., 2010*). This approach better enables the researchers to control factors such as screen/image size, audio quality and volume, among other factors. We opted to employ the latter approach for the video clips comfort ratings. However, in recognition of the potential value gained through the comparison of pairs of options, we included two pairs of intersection choices to identify a preferred design (from this limited palette), along with a third pair – the comparison of the two selected options against one another. We also asked that the respondents provide a brief explanation of each of their choices to better understand what factors were motivating for them.

The first section of the survey involved watching a series of video clips taken from the perspective of a bicyclist riding, generally through an intersection, and then marking how comfortable they would feel if they were riding a bicycle in that place. The rating scale included 1 for "Very Uncomfortable", 2 for "Somewhat Uncomfortable," 3 for "Neither Uncomfortable nor Comfortable", 4 for "Somewhat Comfortable," and 5 for "Very Comfortable." Each clip was shown at least two times, after which the respondent was presented with a screen asking them to rate the clip. Several clips were shown a third time, and respondents were asked if they would ride (yes or no) in that location with a 10-year-old child.

Ratings were marked by circling the appropriate comfort rating (or willingness to ride with a child) on a rating sheet. The rating sheet included the full comfort scale written out across the top of the sheet with instructions. Twenty-six clips were shown, with each having a spot on the survey sheet to provide a rating. On the bottom of the page, we provided space to respond to the question "Is there anything you would like to explain about your ratings?" Outside of reviewing the video clips, respondents were asked to complete three other pages of questions, which were attached to the rating sheet.

The second page of the survey presented two pairs of images of intersection treatments, and asked the respondent to indicate which they would prefer to ride through as a cyclist and to briefly explain their choice. After completing the exercise for both sets of intersection images, they were asked to indicate which of the two prior selections they would prefer (e.g., which of the four) and to explain why. The first two images (see Figure 3-1) were of designs that mixed or crossed right-turning vehicles across bicycle traffic prior to the intersection (i.e., moving the potential conflict area upstream from the intersection location). Image A was of a mixing zone with a right-turn arrow and shark teeth yield markings indicating where turning traffic should shift into the mixing area. Image B was of a crossing design wherein the bike lane shifted out to the left of the right-turn lane, with green skip-striping showing the area where motorists would cross.

The second two images (see Figure 3-2) were of designs wherein the separation and/or protection continued up to the intersection. Image C was of a location with a protected intersection design, consisting of a curb and planter barrier to the left of the bike lane, and a curb island serving as a curb extension, shortening the exposed crossing distance. The bike lane shifts to the right, away from the through travel lane, as the bicyclist reaches the intersection. Image D was of a location with a painted buffer with plastic flexible bollards, or flexposts, extending up to the intersection. The bike lane shifts to the left, in the direction of the through lane, as the bicyclist reaches the intersection.

Would you prefer to ride through intersection A or B on a bicycle? *Circle your response* A / B

*Briefly explain your choice*:


**Figure 3-1 Survey Preference Pair A (Mixing Zone) - B (Lateral Shift)**

Would you prefer to ride through intersection C or D on a bicycle? *Circle your response* C / D

*Briefly explain your choice*:


**Figure 3-2 Survey Preference Pair C (Bend-out/Protected Intersection) – D Bend-in**

The third page of the survey asked questions about the respondent and bicycling, including how often they ride a bike, if they ride for recreation and/or transportation, and if they have ridden on certain types of facilities in the past year, such as on a path or trail separate from the street, on a quiet residential street, on a busy street (specified as "with speeds up to 30 mph") with a bike lane, a similar street without a bike lane, and a similar street with a physically protected bike lane.

Following these questions on bicycling behavior were a series of statements about bicycling, asking the respondent to indicate their level of agreement with each statement (response options included strongly disagree, disagree, agree, and strongly agree). A middle or neutral option was not provided in an effort to force respondents to fall on one side or the other of each statement. Statements included intentions to ride, barriers to riding, observations about who rides, and perceptions about how bicycling affects their neighborhood or city:

- I would like to ride a bicycle more than I currently do
- Traffic on streets keeps me from riding a bike (or riding more)
- Many places I need to go are within a reasonable biking distance
- I often see people riding bikes in my neighborhood
- I often see people like me riding bikes in my neighborhood
- I prefer to get around by modes other than by riding a bicycle
- Bike lanes make it harder to get around my neighborhood
- I usually have to transport things or people when I travel
- I would like my city/town to invest in projects (such as bike lanes) that make riding bikes safer and easier

The final page of the survey asks some general transportation and demographic questions. Transportation questions included how they travelled in the past week (no trips, some trips, or most trips by each of the following – car, car share, taxi/ Uber / Lyft, public transit, walking, personal bike, bike share, or other), and if they have a driver's license, bicycle, transit pass, or car. Other demographic questions include employment and student status, gender identity, education, age, race/ethnicity, home zip code, household size and income.

### 3.1.2 Video collection

Video collection for the survey clips was done in the summer and fall of 2017. Clips were collected using helmet-mounted GoPro cameras with wind-shield covers. Collection cities were chosen based on locations that had unique designs representing key differences in design approach. Preference for cities with multiple potential suitable intersections were chosen to improve the variety of locations and opportunities for usable clips. Locations and video collection dates are shown below:

- Salt Lake City, UT – July 31-August 1, 2017. Intersections along the 300s/Broadway protected bike lane.
- Denver, CO – August 2-3, 2017. Intersections along the Lawrence, Arapahoe, and West 14th Avenue protected bike lanes.

- Seattle, WA – August 29, 2017. Intersections along the Roosevelt NE and Dexter North protected bike lanes.
- Portland, OR – Various dates, fall 2017. Intersections along the NE Multnomah protected bike lane, as well as several control locations.

The researchers collected the video via several approaches. The first approach was to ride through corridors containing targeted intersection locations, and then to review the video collected for usable clips. In order to capture more potentially usable clips of turning vehicles and interactions with motorists, the researchers would wait upstream of target intersections and being travelling at times that would increase the chances of observing turning vehicles at the intersection. In several cases, one researcher drove the turning vehicle in order to simulate specific interactions, such as a vehicle turning in front of the cyclist or alternatively yielding to the cyclist. Locations of intersections included in the video clips are listed in Table 3-1.

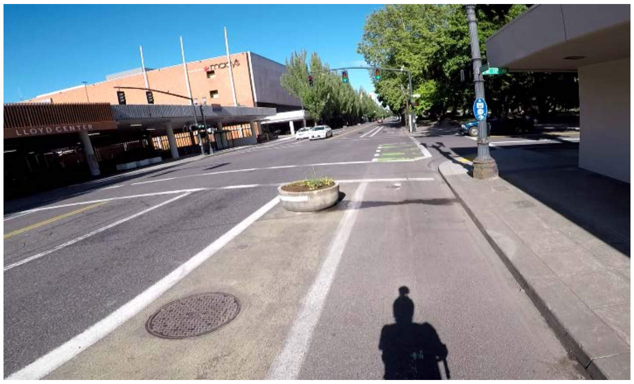
**Table 3-1 Intersection Locations**

| Location | City | Design Type | Bend (ft.) | Mix/merge length (ft.) | Crossing distance (ft.) | Exposure distance[1] (ft.) | Total # lanes |
|---|---|---|---|---|---|---|---|
| NE Multnomah at 11th EB | Portland, OR | Maintain separation | - | - | 42 | 54 | 3 |
| NE Multnomah at 9th WB | Portland, OR | Mixing zone | - | 95 | 50 | 162 | 4 |
| 200W at 300S NB | Salt Lake City, UT | Bend-out/ protected intersection | 12 | - | 15 + 25[2] | 15 + 25[2] | 3 |
| 300S at 200E EB | Salt Lake City, UT | Mixing zone | - | 30 | 99 | 145 | 4 |
| Lawrence at 19th | Denver, CO | Lateral shift | 15 | 110 | 60 | 190 | 4 |
| Roosevelt at 50th SB | Seattle, WA | Lateral shift | 10 | 55 | 46 | 140 | 3 |
| Dexter at Harrison NB | Seattle, WA | Mixing zone | - | 40 | 50 | 102 | 4 |
| 14th at Delaware EB | Denver, CO | Bend-in | 8 | - | 50 | 65 | 2 |
| 300S at 300E EB | Salt Lake City, UT | Bend-in | 12 | 45 | 104 | 199 | 3 |
| Arapahoe at 18th WB | Denver, CO | Bike signal | - | - | 60 | 78 | 3 |

[1] loss of buffer/protection to the far side of the street

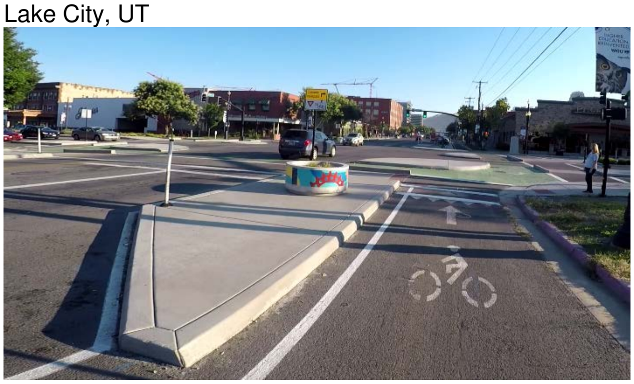
[2] The protected intersection location crossing had a median, thus breaking the crossing distance into two sections of 15 feet and then 25 feet.

NE Multnomah at 11th EB (Maintain Separation), Portland, OR



NE Multnomah at 9th WB (Mixing Zone), Portland, OR

200W at 300S NB (Bend-out/Protected Intersection, Salt Lake City, UT



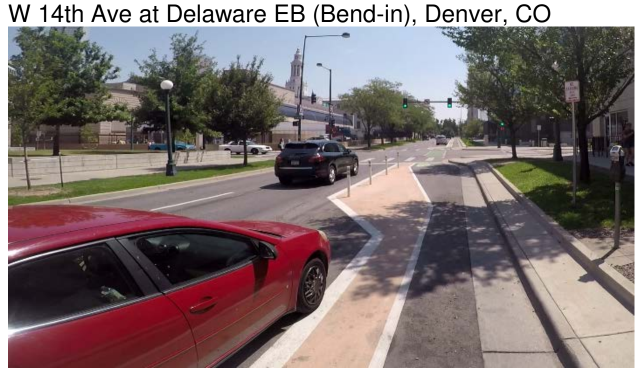
300S at 200E EB (Mixing Zone), Salt Lake City, UT

Lawrence at 19th Street (Lateral Shift), Denver, CO

Roosevelt NE at 50th Avenue (Lateral Shift), Seattle, WA

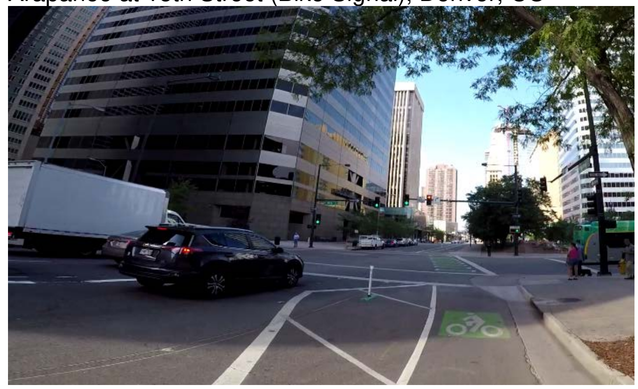
Dexter at Harrison (Mixing Zone), Seattle, WA

W 14th Ave at Delaware EB (Bend-in), Denver, CO



300S at 300E EB (Bend-in, dashed bike lane), Salt Lake City, UT

Arapahoe at 18th Street (Bike Signal), Denver, CO



Springwater Corridor Trail (Control – trail), Portland, OR

Barbur Blvd Bike Lane (Control – bike lane), Portland, OR

NE Multnomah protected bike lane (Control – protected bike lane segment), Portland, OR

**Figure 3-3 Images of Clip Locations**

### 3.1.3 Clip curation and selection

The research team collected over 500 clips from the perspective of cyclists riding through protected bike-lane intersections across the four cities. This includes videos at the location in Table 3-1 as well as at other intersection locations. Clips were categorized as either showing no turning vehicles, having a turning vehicle visible in the clip (but not having any interactions with the vehicle), and having a negotiated turn between the bicyclist and motorist. Negotiated turn could involve either party yielding, merging, crossing, or otherwise interacting at the intersection. Videos were selected based on an effort to include a variety of intersection designs, to include at least two clips for each selected location that would demonstrate a variety of potential situations and interactions, and that minimized the number of extraneous events or situations that could be potentially confounding for analysis efforts. Every attempt was made to make the level of negotiated turn as comparable as possible in the curated final selection of videos. In order to include more locations, clips without any turning vehicles were not selected for the final catalogue of videos presented to survey respondents.

**Table 3-2 Survey Video Clips**

| Clip | Location | MV Turn | Video |
|---|---|---|---|
| 1 | NE Multnomah at 11th EB | Negotiated | https://youtu.be/Q4V7ORHZzU8 |
| 2 | Lawrence at 19th | Turn visible | https://youtu.be/VlXdqtYTD74 |
| 3 | 200W at 300S NB | Turn visible | https://youtu.be/SS3mU8EQ2ZU |
| 4 | Roosevelt NE at 50th SB | Turn visible | https://youtu.be/DSeV06ezbtw |
| 5 | Arapahoe at 18th WB | No Turn | https://youtu.be/vRI9CShR53U |
| 6 | Lawrence at 19th | Negotiated | https://youtu.be/p2j4OU90sgA |
| 7 | NE Multnomah at 11th EB | Negotiated | https://youtu.be/UKgx_trKx7w |
| 8 | Dexter at Harrison NB | Negotiated | https://youtu.be/g3rG_o2trAI |
| 9 | 300S at 300E EB | Negotiated | https://youtu.be/SPYMDKeXd2I |
| 10 | NE Multnomah at 9th WB | Turn visible | https://youtu.be/g4FjKiA2BxU |
| 11 | 300S at 200E EB | Turn visible | https://youtu.be/0uvKOx96vdI |
| 12 | 300S at 200E EB | Turn visible | https://youtu.be/2dq0MxMVPC8 |
| 13 | W 14th Ave at Delaware EB | Turn visible | https://youtu.be/ONUwFDADf-Y |
| 14 | 300S at 200E EB | Negotiated | https://youtu.be/t1omEI4FY-U |
| 15 | Springwater Corridor Trail | No Turn | https://youtu.be/uWnQ9YWVCv4 |
| 16 | Barbur Blvd Bike Lane | No Turn | https://youtu.be/tQ_WXq3pPyA |
| 17 | NE Multnomah at 9th WB | Negotiated | https://youtu.be/LykYy-3UEMs |
| 18 | NE Multnomah PBL | No Turn | https://youtu.be/nmy-bGqfhrA |
| 19 | W 14th Ave at Delaware EB | Negotiated | https://youtu.be/vxik7y8Blz0 |
| 20 | NE Multnomah at 11th EB | Turn visible | https://youtu.be/gVFDvTSYCys |
| 21 | 300S at 300E EB | Turn visible | https://youtu.be/SQD_L3QaQVc |
| 22 | NE Multnomah at 9th WB | Negotiated | https://youtu.be/Cvbbxo46puQ |
| 23 | 200W at 300S NB | Negotiated | https://youtu.be/xT_qS2FJRPc |
| 24 | Roosevelt NE at 50th SB | Negotiated | https://youtu.be/U5zJi4NQ8x0 |
| 25 | 200W at 300S NB | Negotiated | https://youtu.be/VrFGqoBrgaA |
| 26 | Dexter at Harrison NB | Turn visible | https://youtu.be/AcWLpz-JQeg |

### 3.1.4 Survey sites

Surveys were conducted in person by intercepting people at locations with high volumes of foot traffic, and inviting them to take the survey. Locations included farmer’s markets in Portland, OR, and Takoma Park, MD, and shopping centers in Minneapolis, MN, and Woodburn, OR. The survey locations, dates, times and number of responses are provided in Table 3-3. While this approach was designed to reach a diverse group of participants, it is not designed to be representative of a national sample.

**Table 3-3 Survey Dates, Times, and Number of Responses**

| Location | Day and Time | Responses |
|---|---|---|
| Portland Farmers Market at Portland State University, Portland, OR | Saturday, May 14, 2018 9 a.m.-2 p.m. | 101 |
| Woodburn Premium Outlets, Woodburn, OR | Saturday, July 14, 2018, 12-5 p.m. | 42 |
| Calhoun Square, Minneapolis, MN | Sunday June 24, 2018, 11 a.m. to 4 p.m. | 57 |
| Takoma Park Farmers Market, Takoma Park, MD | Sunday, July 1st, 2018, 9:30 a.m. to 2:30 p.m. | 77 |
| **Total** | | **277** |

In Portland, we surveyed on Saturday, May 14th, 2018, at the Portland Farmers Market (a major attractor for people from across the city) on the Portland State University campus between the hours of 9 a.m. and 2 p.m. Market shoppers were handed flyers and invited to take the survey in an adjacent university building, the Smith Memorial Student Union. Upon entering the building, participants had an informed consent form explained to them, and were given instructions on taking the survey, after which they entered a meeting room (shown in Figure 3-4) to view the video clips and take the survey. All respondents were compensated with a $5 token, good for use at any Portland Farmers Market stall. We received a total of 101 completed surveys.

**Figure 3-4 Survey Takers and Setup at the Portland Farmers Market**

The Woodburn Premium Outlets are an outlet shopping mall in the town of Woodburn, OR, located halfway between Portland and Salem. We surveyed in Woodburn on July 14th, 2018, between noon and 5 p.m. Shoppers walking down a mall concourse were invited to take the survey, and interested parties were directed to an adjacent empty retail space that had been converted for the day. As they entered the space, they received the informed consent and survey instructions, and then were directed behind the greeting table to watch the video clips and complete the survey. Everyone who took the survey was offered a cold sparkling water and given a $5 gift card to their choice of several mall food merchants, including Starbucks, Subway, and Jamba Juice. We received a total of 42 completed surveys. The mall concourse and retail space with video viewing area are shown in Figure 3-5.


**Figure 3-5 Surveying at the Woodburn Premium Outlets, in Woodburn, OR**

In Minneapolis, MN, we surveyed on Sunday, June 24th, 2018, at Calhoun Square, a shopping center in Uptown Minneapolis. We surveyed between the hours of 11 a.m. and 4 p.m. Shoppers were handed flyers and invited to take the survey in the mall. Upon entering the room, participants had informed consent form explained to them and they were given instructions on taking the survey, after which they went to the back of the room to view the video clips and take the survey. We received 57 completed surveys. All respondents were compensated with a $5 gourmet coffee gift card.

In Takoma Park, MD, we surveyed on Sunday, July 1st, 2018, at the Takoma Park Farmers Market in downtown Takoma Park. We surveyed between the hours of 9:30 a.m. and 2:30 p.m. Market shoppers were handed flyers and invited to take the survey in a building across the street. Upon entering the building participants were directed to the room, where informed consent was explained to them and they were given instructions on taking the survey. They then entered a meeting room to view the video clips and take the survey. We received 77 completed surveys. All respondents were compensated with their choice of a $5 gourmet coffee gift card or a token, the latter of which was good for use at any Takoma Park Farmers Market stall.

### 3.1.5 Survey administration

In all locations, potential respondents were asked if they would be interested in taking a transportation survey, with the opportunity to get a $5 gift card. We also provided a flyer providing some basic details about the survey and the study in general. If asked, recruiters specified that the survey would ask them how comfortable they would be riding a bicycle in different situations, and that we were interested in both people who do and do not ride bicycles. However, it is likely that people who were more interested in bicycling were more likely to decide to take the survey.

For those who indicated that they would take the survey, the recruiter pointed the interested party to the survey welcome area and the potential participant had an informed consent form explained to them. Upon signing the consent form, we read a consistent script to the respondents giving them instructions on what they were being asked to do. Respondents were then directed to the video viewing area to view the video clips and complete the survey. The 26 video clips played on a continuous loop, and respondents could start at any point in the loop. Each clip played two times, after which the respondent was instructed to rate the clip for how comfortable they would feel if they were riding a bicycle in that location. Six clips repeated a third time, asking the respondent to indicate if they would ride in that location with a child.

## 3.2 MICROSIMULATION

One of the key questions facing designers is at what is the performance level of the various designs as the turning vehicle and through bicycle volumes vary. With newer bicycling infrastructure such as the ones considered in this research, there are a limited number of sites to study. In addition, the various designs are typically selected based on the turning-vehicle volumes and bicycle counts. For these reasons, we elected to use microsimulation to explore the likelihood that people on bikes would interact with turning motorists under varying conditions of motor vehicle volumes and intersection designs. This was carried out as a complementary element to the survey-derived data on expected comfort of people biking on protected bike lanes through various intersection designs (with and without turning motorists present). We developed, calibrated and analyzed simulation models for three of the designs (bend-in, bend-out, and mixing zones) derived from three intersections, as shown in Table 3-4. We assume that the interactions (from a simulation perspective) of lateral shift are similar to the mixing zone and that straight path/maintain is represented by the bend-in design.

**Table 3-4 Microsimulation Intersections Used as Base Models**

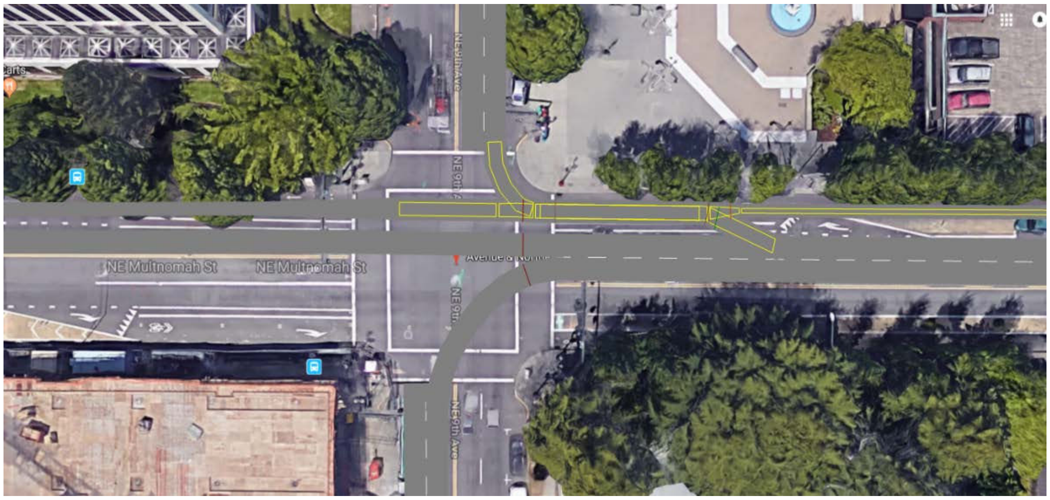
| Type of Bikeway Design | Intersection | Approach | City |
|---|---|---|---|
| Bend-in | 300 E and 300 S | Westbound | Salt Lake City, UT |
| Bend-out/protected intersection | 300 S and 200 W | Southbound | Salt Lake City, UT |
| Mixing zone | NE 9$^{th}$ Ave &NE Multnomah St | Westbound | Portland, OR |

### 3.2.1 Model development and calibration

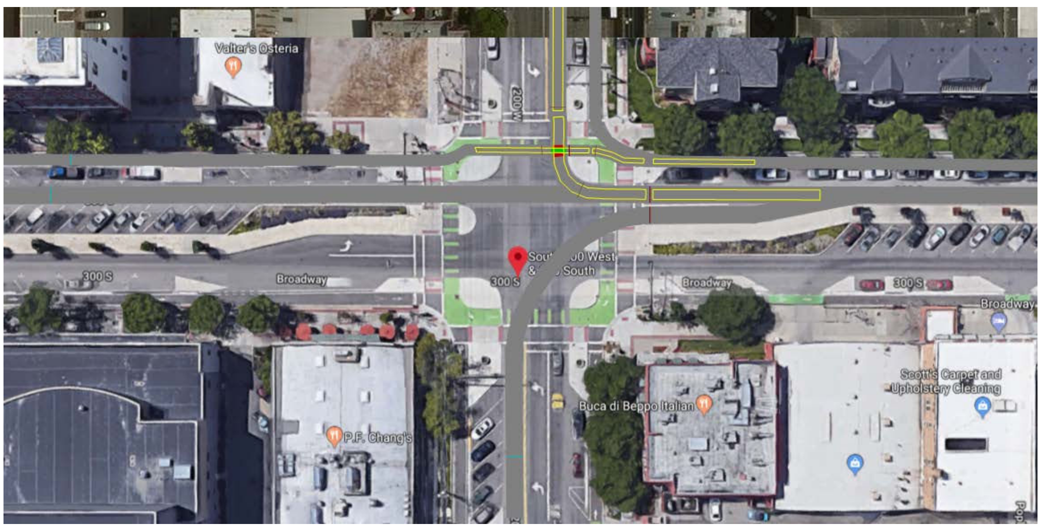
VISSIM was used as microsimulation software in this research. To build the models, we used the geometric designs of the roadway, matched to the existing configuration, by using satellite photos as the base map. Figure 3-6 shows the screenshot of simulation models of different intersection designs. For simplicity in reducing the trajectory output, we only loaded vehicles on the network. We assumed that 95% of vehicle flows were cars and 5% of the flow were HGVs (heavy goods vehicles). For the purposes of the model, 40km/h, 30km/h and 12km/h were set as the desired speed distribution on the road segment for cars, HGVs and bicycles. Reduced-speed areas, being used for short sections or connectors where different speed characteristics were present, were set for vehicles and bicycles when approaching the intersection. These values were derived from observations of video taken of the intersections. The yellow squares in Figure 3-6 were reduced-speed areas set in intersection simulation models. Signal timing can play an important role in the arrival and platooning of vehicles at intersections. However, exploring the effect of signal timing was not possible within the project budget. We elected to set the total cycle length to 60 seconds and equally split to each bound that each direction has 27s green phases and 3s yellow phases. There was no bicycle-only phase is in the models.

After setting up the simulation models, calibration was needed in order to make the simulation models match the behavior of vehicles and bicycles in reality. Cameras were set up at the corner of the selected approach and 48 hours of traffic video, including both peak hours and non-peak hours, were collected. A subset of these hours were used for calibration. At the bend-in location, six hours per day and two days of video data were used for calibration. At the bend-out intersection we used three days and seven hours per day of video data, and at the mixing zone intersection we used three days and six hours per day of video data. The number of right-turning vehicles and through bicycles were counted per hour. Table 3-6 shows the counts of bicycles and right-turning vehicles of three intersections. In addition, the length of road segments for right-turning vehicles and through bicycles were measured in Google Maps, and the duration of time each vehicle or bicycle driving in those segments was recorded. Then the average speed across these segments for each vehicle and bicycle was calculated. We then applied these speed distributions to the reduced-speed area in the simulation model.

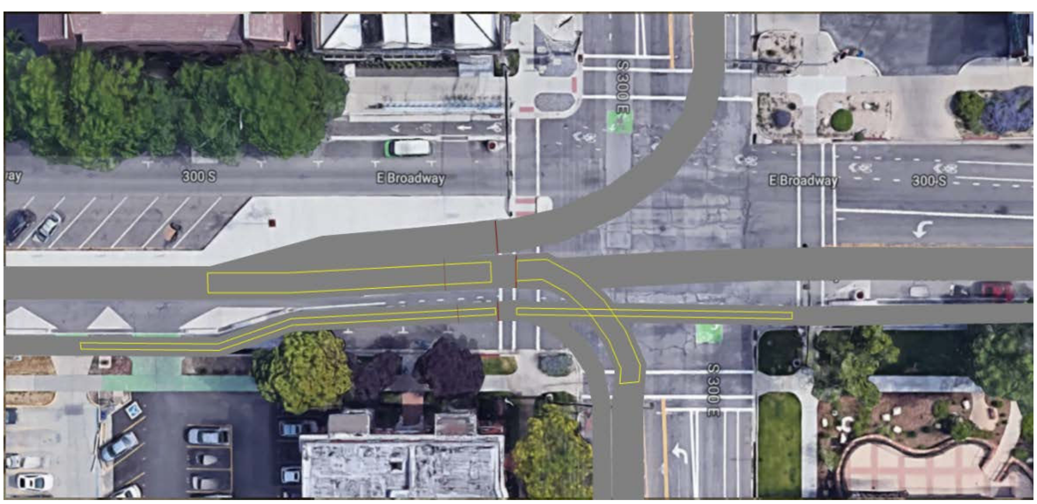
Table 3-5 describes the speed distribution of right-turning vehicles and through bicycles extracted from the videos and used in the reduced-speed area of three intersection models. The values in the table are presented in kilometers per hour. Figure 3-8 shows a plot of the median speeds in miles per hour. As shown, the bend-out design has the lowest speeds for both vehicles in the conflict area. The vehicle speed is highest for the bend-in design, followed by the mixing zone design.




a) Mixing zone intersection base model




b) Bend-out intersection base model




c) Bend-in intersection base model

**Figure 3-6 Base Models for Simulation Models in VISSIM**

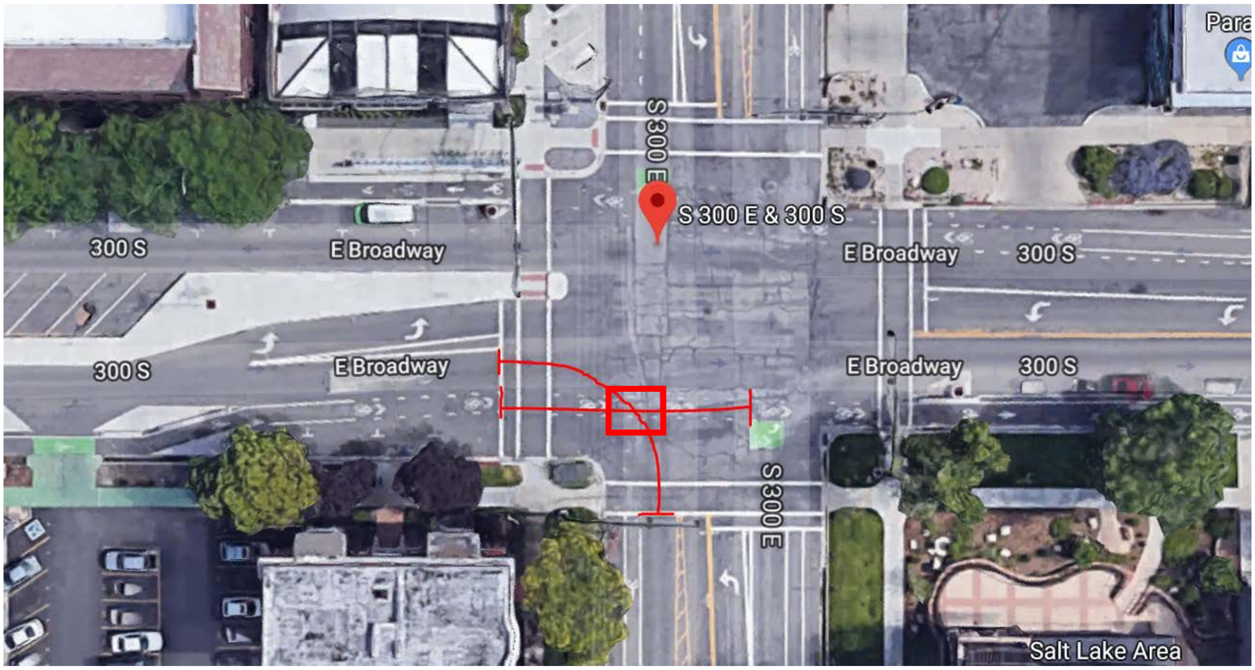



**Figure 3-7 Example of the Measured Area in Bend-In Intersection**

**Table 3-5 Average Speed Distribution in Reduced Speed Area (km/h)**

| **Quantile** | **Bend-in** | | **Bend-out** | | **Mixing zone** | |
|---|---|---|---|---|---|---|
| | **Through Bicycles** | **Right-turning Vehicles** | **Through Bicycles** | **Right-turning Vehicles** | **Through Bicycles** | **Right-turning Vehicles** |
| Lower bound | 4.7 | 3.4 | 2.2 | 2.8 | 7.4 | 4.4 |
| 10% | 12.2 | 9.7 | 6.8 | 7.1 | 9.6 | 7.9 |
| 20% | 12.2 | 13.6 | 8.3 | 9.8 | 10.9 | 9.1 |
| 50% | 14.0 | 17.0 | 10.6 | 12.2 | 13.8 | 15.1 |
| 70% | 16.2 | 22.5 | 15.2 | 14.2 | 15.4 | 18.1 |
| 90% | 24.5 | 22.5 | 16.8 | 18.0 | 18.0 | 21.8 |
| Higher bound | 28.0 | 34.0 | 19.0 | 24.4 | 19.5 | 32.5 |
| Number of observations | 141 | 721 | 109 | 450 | 411 | 1830 |

**Table 3-6 Average Bicycle and Right-Turning Vehicle Counts**

| Time | Bend-in Bicycles | Right-turning vehicles | Time | Bend-out Bicycles | Right-turning vehicles | Time | Mixing zone Bicycles | Right-turning vehicles |
|---|---|---|---|---|---|---|---|---|
| 8:00-9:00 | 6.5 | 57 | 8:00-9:00 | 2.7 | 9.3 | 7:45-8:45 | 50 | 112.3 |
| 12:00-13:00 | 6.5 | 56 | 11:00-12:00 | 1.7 | 17.7 | 8:45-9:45 | 18.3 | 94.3 |
| 13:00-14:00 | 10.5 | 49.5 | 12:00-13:00 | 2.3 | 18 | 9:45-10:45 | 10 | 73.7 |
| 15:00-16:00 | 10 | 52.5 | 16:00-17:00 | 4.7 | 19.3 | 15:45-16:45 | 13 | 94 |
| 16:00-17:00 | 12 | 56.5 | 17:00-18:00 | 8.7 | 33.7 | 16:45-17:45 | 23.3 | 120.3 |
| 17:00-18:00 | 25 | 89 | 18:00-19:00 | 8 | 24 | 17:45-18:45 | 22.3 | 115.3 |
| | | | 19:00-20:00 | 8.3 | 28 | | | |

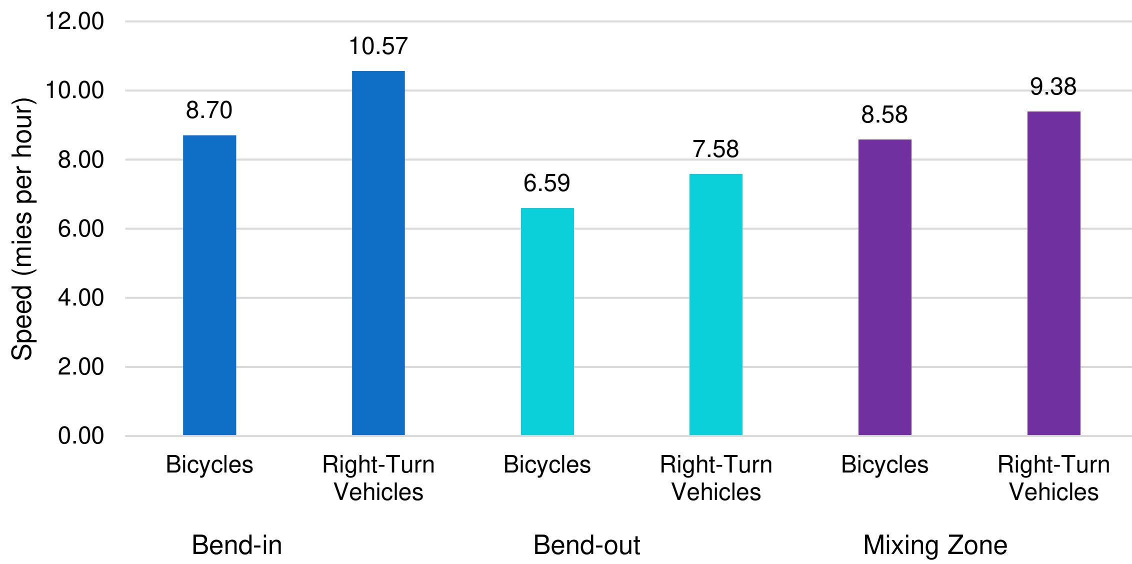



**Figure 3-8 Median Speeds of Vehicles in the Reduced Speed Area (Miles Per Hour)**

### 3.2.2 Establishing priority rules

Priority rules need to be created to control the conflict traffic flows from different links or connectors that are not controlled by signals. In this study, we set priority rules in the simulation at the conflict area between right-turning vehicles and through bicycles in the intersections. To match the road users' behavior in reality, we tried to create the rules that bicycles have the priority to pass the conflict are  first. Motorists will wait for bicycles before the conflict marker until there is sufficient distance to pass the conflict area. VISSIM generates realistic conflicts with this rule in mixing zone intersections. The number of conflicts vary when bicycle and vehicle volume vary. However, the number of conflicts remains very low and almost the same when bicycle and vehicle volume vary in bend-in and bend-out intersections. By inspection of the simulation animations, right-turning motorists will always wait for bicycles before entering the conflict area, which does not match the observed user behaviors.

In mixing zone intersections, the rear-end conflicts between right-turning vehicles and bicycles in the mixing lane are not influenced by the priority rule, thus the number of conflicts vary as the volumes vary. Since this priority rule did not generate realistic simulation results, we changed the rule to “undetermined,” which means “here is no right of way, as vehicles simply remain in their original sequence” in the VISSIM manual. To keep three intersections consistent, the priority rule in mixing zone intersections was also changed to “undetermined” in this study.

### 3.2.3 Extracting observed conflicts from video

In this study, the conflicts between bicycles and vehicles in videos were observed and counted by trained researchers on the project team. The potential conflict area in the intersection was determined based on the trajectory of right-turning vehicles and through bicycles in the video. A conflict in the video is defined as an interaction that the time interval between a bicycle and a vehicle entering the conflict area is less than 3s. Figure 3-7 used a bend-in intersection as an example to show which area is measured in Google Maps in the calibration process. The red square in Figure 3-7 is the potential conflict area defined in the bend-in intersection.

### 3.2.4 Extracting simulated conflicts (interactions) using SSAM

The Surrogate Safety Assessment Model (SSAM), a technique for outputting traffic safety measures, was used to extract conflicts from the microsimulation results in this research. SSAM was proposed by a research team in SIEMENS and sponsored by the FHWA (*Gettman, Douglas et al., 2008*). SSAM was developed to make traffic conflict analysis by using trajectory files generated by microsimulation models, including VISSIM, PARAMICS, AIMSUN and TEXAS. SSAM used several algorithms to identify simulated conflicts and output their types, severity and other features. Time to collision (TTC), post-encroachment time (PET), DR (deceleration rate), MaxS (maximum speed), the speed differential and conflict angles can be extracted from SSAM.

In this calibration effort, default threshold values of PET (3 seconds) and TTC (1.5 seconds) were used as the threshold to identify the simulated conflicts. TTC is one of the most commonly used indicators in surrogate safety measures analysis. It is defined by Hayward (*1978*) that TTC is the time until collision between the vehicles could occur if they continued on their present course at the present rates. Allen et al. (*1978*) introduced the post-encroachment time, another commonly used indicator, to help describe traffic conflicts adequately. PET is a definition of near misses and indicated the extent to which the two road users missed each other.

Since SSAM produced conflicts on all the links of the road network, we filtered for conflicts between right-turning vehicles and through bicycles using filter tools in SSAM. Conflicts occurring on the links related to the target conflict area in the intersection were filtered out and the detailed information of these conflicts, such as PET, TTC and maximum deceleration, were extracted. Figure 3-9 shows the filters applied in SSAM for the bend-in intersection simulation model.

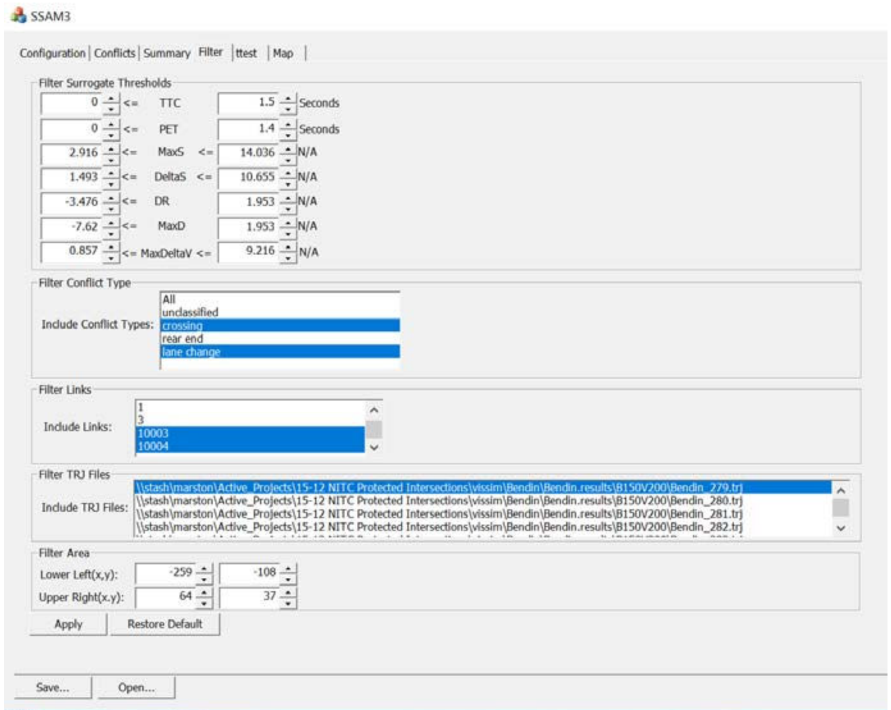



**Figure 3-9 Filters Applied in SSAM for Bend-In Intersection**

### 3.2.5 Comparing observed to expected conflicts

The simulation model was run 10 times with the vehicle and bicycle volumes matching the observed video for each hour. Output files of simulation models were SSAM trajectory files and compared to the number of interactions/conflicts observed in the video. The number of simulated conflicts extracted by SSAM was used to compare with the number of observed conflicts from the videos. Table 3-7 shows the comparison between the average number of conflicts from traffic video and simulation model results. Figure 3-10, Figure 3-11 and Figure 3-12 show the plots of the table. By inspection, it is clear that the simulation results were similar to the reality.

**Table 3-7 Average Number of Observed Conflicts and Simulated Conflicts**

| Bend-in intersection | | | Bend-out intersection | | | Mixing zone intersection | | |
|---|---|---|---|---|---|---|---|---|
| **Time** | **Video** | **VISSIM** | **Time** | **Video** | **VISSIM** | **Time** | **Video** | **VISSIM** |
| 8:00-9:00 | 1 | 0.2 | 8:00-9:00 | 0 | 0 | 7:45-8:45 | 7.7 | 12 |
| 12:00-13:00 | 0.5 | 0 | 11:00-12:00 | 0 | 0 | 8:45-9:45 | 3.7 | 3.4 |
| 13:00-14:00 | 0.5 | 0 | 12:00-13:00 | 0.3 | 0 | 9:45-10:45 | 1 | 1.8 |
| 15:00-16:00 | 1.5 | 0 | 16:00-17:00 | 0.3 | 0.7 | 15:45-16:45 | 1.7 | 2.2 |
| 16:00-17:00 | 2 | 1 | 17:00-18:00 | 1 | 1.1 | 16:45-17:45 | 6 | 5.2 |
| 17:00-18:00 | 2 | 0.2 | 18:00-19:00 | 1 | 1.4 | 17:45-18:45 | 7.3 | 5 |
| | | | 19:00-20:00 | 0.3 | 1.1 | | | |

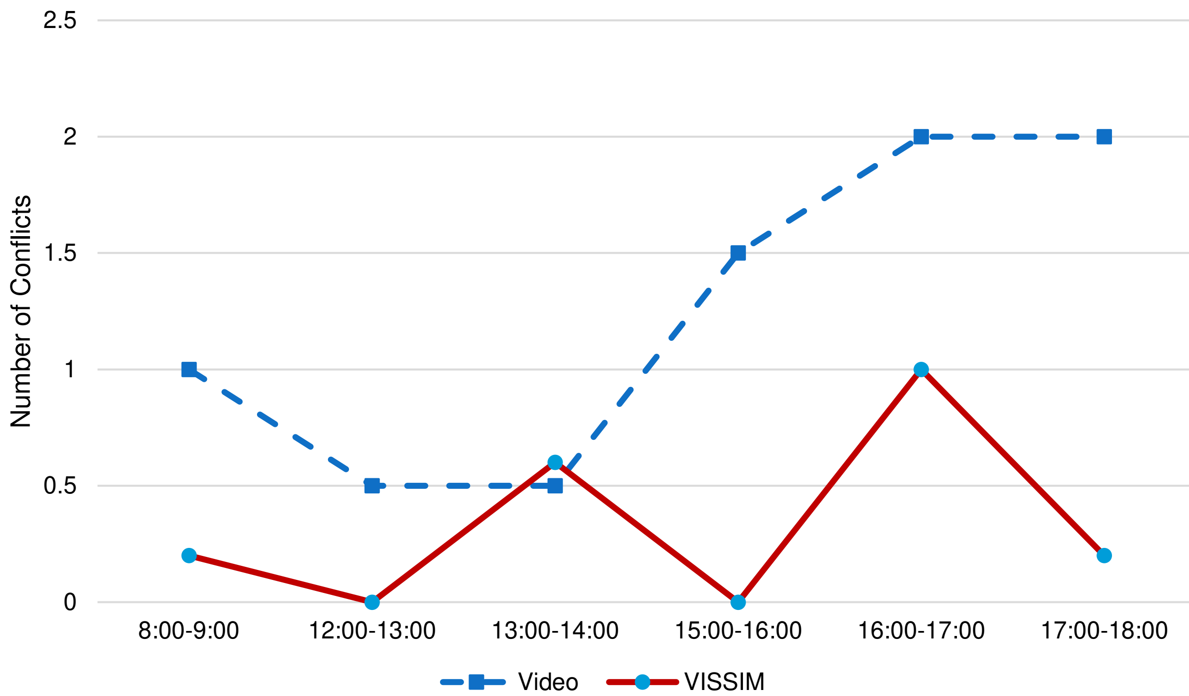



**Figure 3-10 Calibration Results for Bend-In Intersection**

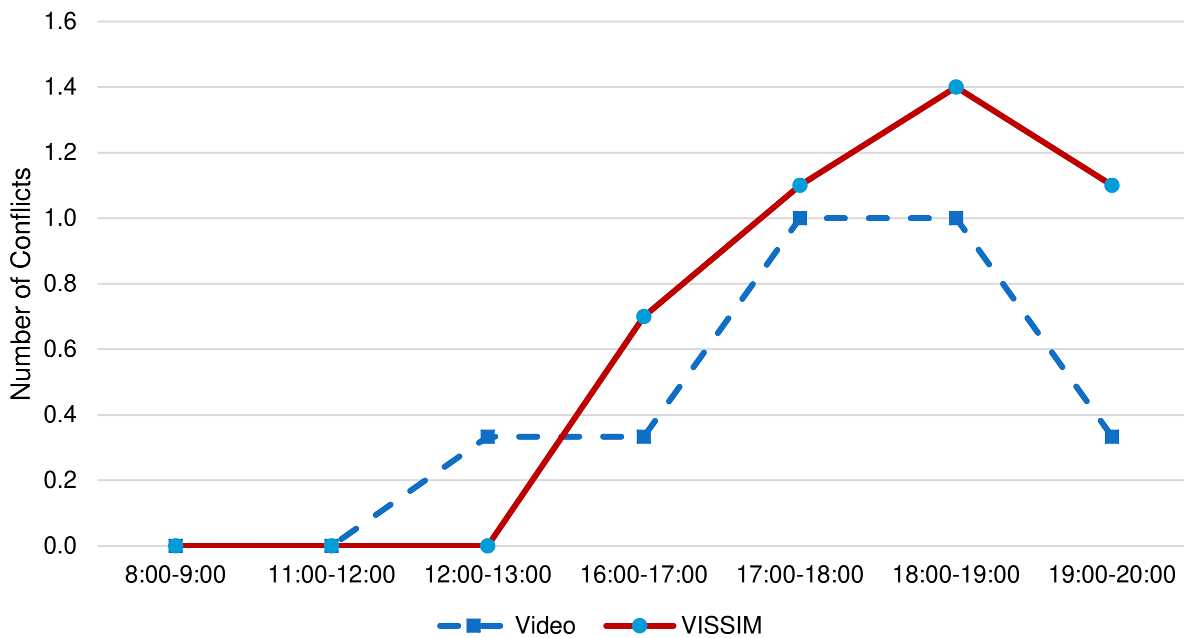



**Figure 3-11 Calibration Results for Bend-Out Intersection**

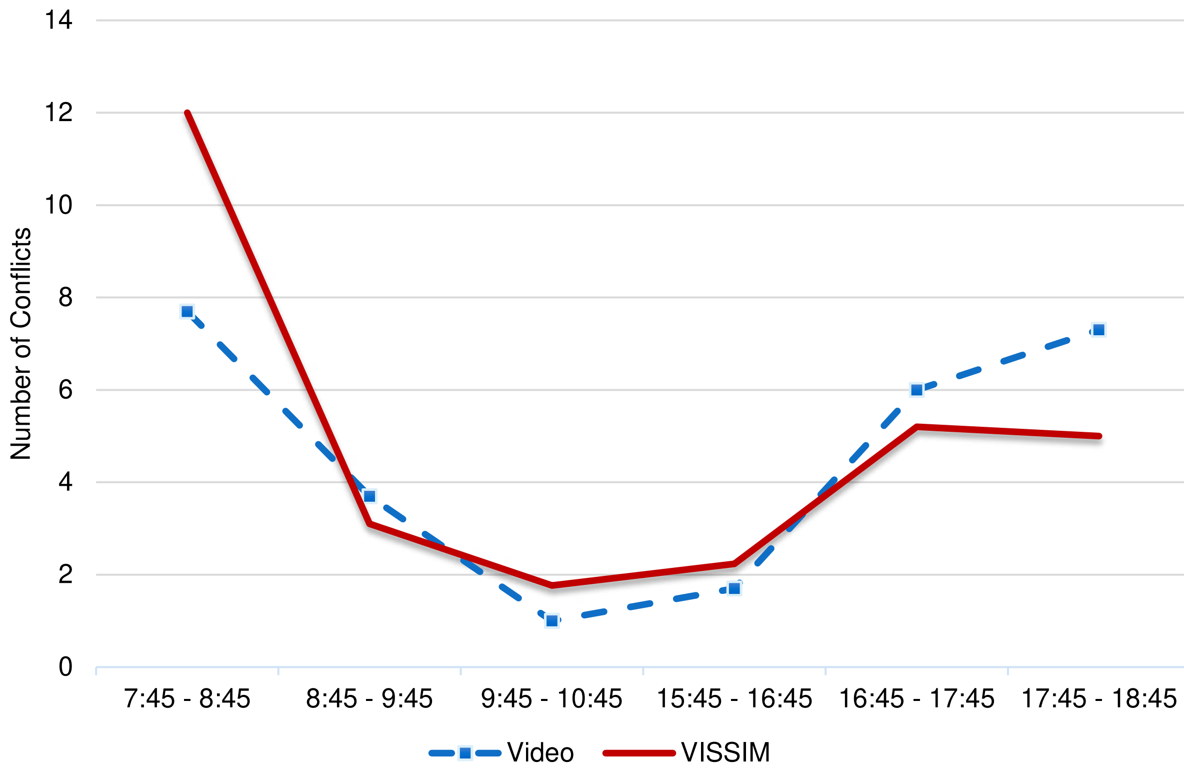



**Figure 3-12 Calibration Results for Mixing Zone Intersection**

# 4.0 RESULTS: SURVEY RESPONDENTS

This chapter summarizes the demographics and travel behaviors of the survey respondents.

## 4.1 DEMOGRAPHICS AND TRAVEL BY SURVEY SITE

Although not a random sample of Americans, the overall group of respondents represents a good mix on a number of measures when considered as a whole across the four sites. However, some individual sites reflected over-samples of certain populations. See Appendix A for a comparison of survey respondents to ACS 5-year data for each city in which surveys were administered. Across all sites, the sample was just about split evenly between age groups of 18 to 24, 25 to 34, 35 to 54, and 55 and above (between 23% and 28% across each group), and 56% female – see Table 4-1. Respondents in Woodburn, OR, and Minneapolis, MN, were skewed younger, while the Maryland respondents were somewhat older. Across all sites, respondents were 65% non-Hispanic white, 9% Hispanic or Latino, 11% Asian, 5% black or African American, and 1% American Indian or Alaska Native. The Woodburn site included 60% of respondents who were non-white and/or Hispanic, while other sites ranged from 16% to 28%. In general, when considering race and ethnicity in this report, the non-white and/or Hispanic respondents were grouped to have a large enough sample for analysis.

**Table 4-1 Survey Respondents – Age, Gender Identity, and Race/Ethnic Information**

| Category | Portland, OR | Woodburn, OR | Minneapolis, MN | Takoma Park, MD | Total |
|---|---|---|---|---|---|
| **Age** | | | | | |
| 18 to 24 | 16%$_a$ | 41%$_b$ | 39%$_b$ | 11%$_a$ | 23% |
| 25 to 34 | 33%$_{ab}$ | 21%$_{bc}$ | 42%$_a$ | 13%$_c$ | 28% |
| 35 to 54 | 22%$_{abc}$ | 33%$_c$ | 12%$_b$ | 33%$_{ac}$ | 25% |
| 55 + | 29%$_a$ | 5%$_b$ | 7%$_b$ | 43%$_a$ | 25% |
| n | 97 | 39 | 57 | 75 | 268 |
| **Gender Identity** | | | | | |
| female | 57% | 48% | 54% | 58% | 56% |
| male | 43% | 52% | 46% | 42% | 44% |
| n | 96 | 42 | 57 | 77 | 272 |
| **Race and Ethnicity** | | | | | |
| White, non-Hispanic | 66%$_a$ | 31%$_b$ | 81%$_a$ | 72%$_a$ | 65% |
| Hispanic or non-white | 28%$_a$ | 60%$_b$ | 16%$_a$ | 17%$_a$ | 27% |
| Hispanic, Latino, or Spanish origin | 7%$_a$ | 26%$_b$ | 7%$_a$ | 4%$_a$ | 9% |
| American Indian or Alaska Native | 1% | 2% | 0% | 0% | 1% |
| Asian | 13%$_{ab}$ | 26%$_b$ | 9%$_a$ | 1%$_c$ | 11% |
| Black or African American | 5%$_{ab}$ | 5%$_{ab}$ | 0%$_b$ | 9%$_a$ | 5% |
| n | 97 | 42 | 57 | 76 | 272 |

*a, b, c: Each subscript letter denotes a subset whose column proportions do not differ significantly from each other at the .05 level. (Chi-square with posthoc Z-test)*

Table 4-2 provides information on respondents' employment and student status, along with educational attainment. Just about two-thirds of respondents work full time, ranging from a low of 49% in Portland to a high of 77% in Minneapolis. Eighteen percent of respondents were fulltime students, along with 5% who were part-time students. In terms of educational attainment, 31% had less than a bachelor's degree, 31% had a bachelor's degree, and 39% had a graduate or professional degree, including 65% of the Maryland respondents.

**Table 4-2 Survey Respondents – Employment, Student and Education Information**

| Category | Portland, OR | Woodburn, OR | Minneapolis, MN | Takoma Park, MD | Total |
|---|---|---|---|---|---|
| **Employment Status** | | | | | |
| full time | $49\%_{a}$ | $76\%_{b}$ | $77\%_{b}$ | $72\%_{b}$ | 65% |
| part time | $25\%_{a}$ | $12\%_{ab}$ | $18\%_{ab}$ | $12\%_{b}$ | 18% |
| not employed | 11% | 10% | 5% | 5% | 8% |
| retired | $14\%_{a}$ | $2\%_{bc}$ | $0\%_{c}$ | $11\%_{ab}$ | 9% |
| n | 97 | 41 | 56 | 74 | 268 |
| **Student Status** | | | | | |
| full time | $16\%_{a}$ | $17\%_{a}$ | $42\%_{b}$ | $4\%_{c}$ | 18% |
| part time | 8% | 5% | 2% | 4% | 5% |
| not a student | $75\%_{a}$ | $79\%_{a}$ | $56\%_{b}$ | $92\%_{c}$ | 76% |
| n | 97 | 42 | 57 | 75 | 271 |
| **Education** | | | | | |
| less than high school | 0% | 2% | 0% | 0% | 0% |
| high school diploma / GED | $7\%_{a}$ | $31\%_{b}$ | $9\%_{a}$ | $3\%_{a}$ | 10% |
| some college or associate's degree | $26\%_{a}$ | $21\%_{ab}$ | $26\%_{a}$ | $9\%_{b}$ | 21% |
| bachelor's degree | $35\%_{ab}$ | $14\%_{c}$ | $44\%_{b}$ | $23\%_{ac}$ | 31% |
| graduate or professional degree | $31\%_{a}$ | $31\%_{a}$ | $21\%_{a}$ | $65\%_{b}$ | 39% |
| n | 99 | 42 | 57 | 77 | 275 |

*a, b, c: Each subscript letter denotes a subset whose column proportions do not differ significantly from each other at the .05 level. (Chi-square with posthoc Z-test)*

Household size, travel options and certain categories of travel behavior are shown in Table 4-3. A fifth of respondents lived in single-person households, while 42% were in two-person households and 37% were in households of three or more. Just 16% of respondents had children age 16 or younger living the household.

Nine out of 10 respondents had a driver's license, while 58% had a working bicycle, 45% had a transit pass, and 57% had a car or truck. The bicycle and transit pass questions yielded the most variety between survey sites, with Minneapolis on the high end in terms of bicycle ownership at 74%, and Woodburn on the low end with only half that number – 37% – having a bicycle. Woodburn also had the lowest rate of respondents with a transit pass, at 12%, compared to Takoma Park with a high of 77%. Woodburn and Minneapolis respondents were much more likely to travel primarily by car, while Portland and Maryland respondents were most likely to travel primarily by transit.

**Table 4-3 Survey Respondents – Household and Travel Information**

| Category | | Portland, OR | Woodburn, OR | Minneapolis, MN | Takoma Park, MD | Total |
|---|---|---|---|---|---|---|
| **Number of People in Household** | | | | | | |
| | 1 | 30%$_a$ | 5%$_b$ | 26%$_{ac}$ | 12%$_{bc}$ | 20% |
| | 2 | 42% | 34% | 40% | 49% | 42% |
| | 3+ | 28%$_a$ | 61%$_b$ | 33%$_a$ | 38%$_a$ | 37% |
| | n | 96 | 41 | 57 | 76 | 270 |
| Has children under 16 years of age in the household | | 7%$_a$ | 33%$_b$ | 15%$_{ac}$ | 19%$_{bc}$ | 16% |
| | n | 85 | 39 | 54 | 68 | 246 |
| **Travel Options** | | | | | | |
| Have driver's license | | 83%$_a$ | 93%$_{ab}$ | 96%$_a$ | 95%$_a$ | 90% |
| Have a working bicycle | | 56%$_a$ | 37%$_b$ | 74%$_c$ | 60%$_{ac}$ | 58% |
| Have a transit pass | | 42%$_a$ | 12%$_b$ | 32%$_a$ | 77%$_c$ | 45% |
| Have a car or truck | | 48%$_a$ | 54%$_a$ | 74%$_b$ | 57%$_a$ | 57% |
| n | | 98 | 41 | 57 | 77 | 273 |
| **Travel Behavior (assigned categories based on frequency of trips by mode)** | | | | | | |
| Primarily car | | 9%$_a$ | 33%$_b$ | 28%$_b$ | 6%$_a$ | 16% |
| Mostly car, but some multimodal | | 20%$_a$ | 40%$_b$ | 33%$_{ab}$ | 36%$_b$ | 31% |
| Mix | | 29% | 14% | 18% | 18% | 21% |
| Primarily transit | | 27%$_a$ | 5%$_b$ | 7%$_b$ | 30%$_a$ | 20% |
| Primarily bike | | 14% | 7% | 14% | 9% | 12% |
| N | | 99 | 42 | 57 | 77 | 275 |

*a, b, c: Each subscript letter denotes a subset whose column proportions do not differ significantly from each other at the .05 level. (Chi-square with posthoc Z-test)*

In terms of bicycling experience (Table 4-4), just under half of respondents had ridden a bicycle in the past month for fun or recreation, while just over a third had ridden for transportation. Just over three-quarters of respondents told us that they had ridden in the past year on a trail or path or on a quiet residential street. Higher percentages of respondents had ridden recently for recreation, as opposed to for transportation purposes – for example, 56% of Woodburn respondents had ridden a bicycle in the past year for recreation, while only 27% had done so for transportation. About half (53%) had ridden on a bike lane on a busy street and 41% had ridden on a busy road without a bike lane, with the same percentage having ridden in a protected bike lane on such a street.

**Table 4-4 Bicycling Experience by Survey Site**

| When was the most recent time you rode a bicycle … | | Portland, OR | Woodburn, OR | Minneapolis, MN | Takoma Park, MD | Total |
|---|---|---|---|---|---|---|
| **Primarily for fun or exercise?** | In the last month | 42%$_{a}$ | 32%$_{a}$ | 64%$_{b}$ | 45%$_{a}$ | 46% |
| | In the last year | 27% | 24% | 27% | 31% | 28% |
| | In the last five years | 14% | 15% | 4% | 13% | 12% |
| | More than five years ago | 13%$_{ab}$ | 22%$_{b}$ | 4%$_{a}$ | 9%$_{ab}$ | 11% |
| | Never | 5% | 7% | 2% | 1% | 4% |
| | n | 96 | 41 | 55 | 77 | 269 |
| **Primarily for transportation?** | In the last month | 37%$_{a}$ | 10%$_{b}$ | 50%$_{a}$ | 36%$_{a}$ | 35% |
| | In the last year | 16% | 17% | 10% | 9% | 13% |
| | In the last five years | 16% | 17% | 13% | 13% | 15% |
| | More than five years ago | 10% | 10% | 10% | 12% | 10% |
| | Never | 20%$_{a}$ | 46%$_{b}$ | 17%$_{a}$ | 30%$_{ab}$ | 26% |
| | n | 91 | 41 | 52 | 67 | 251 |
| **In the past year, have you ridden a bicycle on… (percent responding "yes")** | | | | | | |
| a path or trail separate from the street | | 75% | 71% | 80% | 79% | 76% |
| a quiet residential street | | 74% | 71% | 85% | 77% | 77% |
| a busy street with speeds up to 30 mph, WITH a striped bike lane | | 59% | 44% | 58% | 45% | 53% |
| a busy street with speeds up to 30 mph, WITHOUT a striped bike lane | | 41%$_{ab}$ | 27%$_{b}$ | 53%$_{a}$ | 38%$_{ab}$ | 41% |
| a busy street with speeds up to 30 mph, with a physically-separated bike lane (e.g. with a curb, posts or planter boxes) | | 54%$_{a}$ | 23%$_{b}$ | 42%$_{ac}$ | 35%$_{bc}$ | 41% |

*a, b, c: Each subscript letter denotes a subset whose column proportions do not differ significantly from each other at the .05 level. (Chi-square with posthoc Z-test)*

Table 4-5 compares the overall survey sample to Census numbers for the United States as a whole, as well as for "urban" areas, as defined by the U.S. Census. The survey sample is skewed younger, in general, that the U.S. Survey respondents were a bit more likely to be white or Asian, while Latinx and Black respondents were underrepresented. Respondents were also more likely to be employed full time, or to be students, that the U.S. in general. They were also considerably more educated sample than the United States as a whole. Average household size for the sample was skewed toward smaller household sizes, and were less likely to have children in the household. In terms of transportation, survey respondents were less likely to have access to a car or truck (57% in the survey compared to 91% of Americans). Finally, survey respondents were more multi-modal than Americans overall; however, it is worth noting that the survey asked about how they got around generally, while Census data specifies commute mode.

**Table 4-5 Survey respondents compared to U.S. census data**

| Category | Survey | U.S. Percentage | U.S. Source | Urban Areas Percentage | Urban Areas Source |
|---|---|---|---|---|---|
| **Age** | | | | | |
| 18 to 24 | 23% | 9.7% | 2017 ACS 5 yr | 9.8% | 2017 ACS 5 yr |
| 25 to 34 | 28% | 13.7% | | 14.1% | |
| 35 to 54 | 25% | 26.1% | | 26.3% | |
| 55 + | 25% | 27.6% | | 26.8% | |
| n | 268 | | | | |
| **Gender Identity** | | | | | |
| female | 56% | 50.8% | ACS 2018 1 yr | 50.9% | 2017 ACS 5 yr |
| male | 44% | 49.2% | | 49.1% | |
| n | 272 | | | | |
| **Race and Ethnicity** | | | | | |
| White, non-Hispanic | 65% | 62% | 2017 ACS 5 yr | 56.3% | 2017 ACS 5 yr |
| Hispanic or non-white | 27% | 38% | | 43.7% | |
| Hispanic, Latino, or Spanish origin | 9% | 17.6% | | 20.2% | |
| American Indian or Alaska Native | 1% | 0.8% | | 0.6% | |
| Asian | 11% | 5.4% | | 6.3% | |
| Black or African American | 5% | 12.7% | | 14.2% | |
| n | 272 | | | | |
| **Employment Status** | | | | | |
| full time | 65% | 58.3% | 2017 ACS 5 yr, 16 to 64 | 58.4% | 2017 ACS 5 yr, 16 to 64 |
| part time | 18% | 17.5% | | 17.9% | |
| not employed | 8% | 24.2% | | 23.7% | |
| retired | 9% | | | | |
| n | 268 | | | | |
| **Student Status** | | | | | |
| full time | 18% | 10.0% | 2017 ACS 1 yr, adults 18 and older) | 10.7% | 2017 ACS 1 yr, adults 18 and older) |
| part time | 5% | | | | |
| not a student | 76% | 90.0% | | 89.3% | |
| n | 271 | | | | |
| **Education** | | | | | |
| less than high school | 0% | 12.6% | 2017 ACS 5 yr, adults 25 and older) | 12.4% | 2017 ACS 5 yr, adults 25 and older) |
| high school diploma / GED | 10% | 27.3% | | 25.9% | |
| some college or associate's degree | 21% | 29.1% | | 28.8% | |
| bachelor's degree | 31% | 19% | | 20.2% | |
| graduate or professional degree | 39% | 12% | | 12.6% | |
| n | 275 | | | | |
| **Number of People in Household** | | | | | |
| 1 | 20% | 10.1% | 2017 ACS 5 yr | 10.0% | 2017 ACS 5 yr |
| 2 | 42% | 24.5% | | 22.6% | |
| 3+ | 37% | 64.4% | | 68.4% | |
| n | 270 | | | | |
| Has children under 16 years of age in the household | 16% | 31.7% | 2017 ACS 5 yr (HH with children <18) | 32.2% | 2017 ACS 5 yr (HH with children <18) |
| n | 246 | | | | |

| Category | Survey | U.S. | | Urban Areas | |
|---|---|---|---|---|---|
| | | Percentage | Source | Percentage | Source |
| **Travel Options** | | | | | |
| Have driver's license | 90% | 88% | FHWA Highway Statistics 2017, 16 and over | n/a | |
| Have a working bicycle | 58% | | | n/a | |
| Have a transit pass | 45% | | | n/a | |
| Have a car or truck | 57% | 91.2% | Available in HH. 2017 ACS 5yr | 90.1% | Available in HH. 2017 ACS 5yr |
| n | 273 | | | | |
| **Travel Behavior** | | | | | |
| Primarily car | 16% | 85.6% | 2017 ACS 5yr, 16 and older | 84.4% | 2017 ACS 5yr |
| Mostly car, but some multimodal | 31% | | | n/a | |
| Mix | 21% | | | n/a | |
| Primarily transit | 20% | 5.1% | 2017 ACS 5yr, 16 and older | 6.1% | 2017 ACS 5yr |
| Primarily bike | 12% | 0.6% | | n/a | |
| n | 275 | | | | |

## 4.2 ATTITUDES AND BARRIERS TO BIKING

Respondents were asked to indicate their level of agreement with a set of statements about bicycling, including some potential barriers. The percentage of respondents agreeing (either somewhat or strongly) with each statement are shown broken down by select demographic factors (Table 4-6). Nine in 10 respondents agreed that they would like to ride a bicycle more than they do now. However, 66% indicated that traffic on streets keeps them from riding or from riding more. Women were more likely to strongly agree with the statement about traffic on streets keeping them from riding or riding more. Nearly 80% felt that there were places they needed to travel to within a bikeable distance, though this percentage was somewhat lower for non-white respondents (66% compared to 82%). Eighty-three percent indicated that they see people riding bikes in their neighborhood, though only 62% agreed that they saw people *like them* riding in their neighborhood. Non-white respondents were less likely to agree with the latter statement (43% compared to 70%).

About 63% agreed that they prefer to get around by modes other than riding a bicycle. Women were more likely to agree with this statement. Only 13% thought that bike lanes made it harder to get around their neighborhood, while 72% indicated that they usually have to transport things or people when they travel. Non-white respondents were more likely to agree with both of these statements. Finally, 94% agreed that they would like to see their city or town invest in projects that make riding bikes safer and easier. Women were much more likely to strongly agree with this statement, with 69% strongly agreeing compared to 51% of men.

**Table 4-6 Agreement with Statements about Biking**

| Statement | Gender Identity | | Race / Ethnicity | | Age Group | | | | Total |
|---|---|---|---|---|---|---|---|---|---|
| | Women | Men | White, non-Hispanic | Hispanic or non-white | 18 to 24 | 25 to 34 | 35 to 54 | 55 + | |
| I would like to ride a bicycle more than I currently do | 89% | 91% | 90% | 92% | $92\%_{ab}$ | $97\%_{b}$ | $89\%_{ab}$ | $83\%_{a}$ | 90% |
| Traffic on streets keeps me from riding a bike (or riding more) | **71%*** | **59%** | 66% | 69% | 63% | 70% | 58% | 69% | 66% |
| Many places I need to go are within a reasonable biking distance | 76% | 82% | **82%*** | **66%** | 77% | 82% | 80% | 79% | 79% |
| I often see people riding bikes in my neighborhood | 82% | 83% | 85% | 77% | 82% | 81% | 88% | 83% | 83% |
| I often see people like me riding bikes in my neighborhood | 58% | 67% | **70%*** | **43%** | 61% | 64% | 68% | 56% | 62% |
| I prefer to get around by modes other than by riding a bicycle | **70%*** | **56%** | 60% | 73% | 73% | 59% | 57% | 63% | 63% |
| Bike lanes make it harder to get around my neighborhood | 14% | 11% | **9%*** | **20%** | 17% | 14% | 9% | 11% | 13% |
| I usually have to transport things or people when I travel | 76% | 68% | **68%*** | **81%** | 72% | 76% | 74% | 64% | 72% |
| I would like my city/town to invest in projects (such as bike lanes) that make riding bikes safer and easier | 97% | 92% | 96% | 95% | 93% | 97% | 92% | 94% | 94% |
| n | 146 to 149 | 118 to 120 | 173 to 176 | 73 to 74 | 60 to 61 | 73 to 74 | 64 to 65 | 63 to 65 | 270 to 273 |

***bold**** *equals significantly different from comparison group (p <.05); a, b, c: Each subscript letter denotes a subset whose column proportions do not differ significantly from each other at the .05 level. (Chi-square with posthoc Z-test)*

## 4.3 SUMMARY

As discussed above, the survey sample does have some important differences from the United States overall, most notably being younger, more highly educated, and less reliant on cars for transportation. Non-white and/or Hispanic respondents were also under sampled overall. The overall mix of respondents across all locations still provides a mix of people to draw from in the analysis in terms of age, gender and race/ethnicity. The sample also provides a good mix of current travel behaviors and bicycling experience, including some people who don't ride at all (particularly for transportation purposes), some who have not ridden in the past year, and some who ride regularly. While most of the respondents would like to ride a bicycle more than they currently do, many limit their riding due to traffic safety concerns.

# 5.0 RESULTS: INTERSECTION RATINGS

As described in the methodology section, respondents were asked to rate each clip ("How comfortable would you feel riding a bicycle in this place?") on a scale from 1 being "very uncomfortable" to 5 being "very comfortable." This chapter presents the analysis of these ratings.

## 5.1 OVERALL RATINGS

Mean comfort ratings by intersection location and by individual clip are shown in Table 5-1 and Table 5-2, respectively (See Figure 3-3 for pictures of site locations). Non-intersection locations are shown with a grey background. The segment riding locations of the separated trail and protected bike lane were rated much higher than other locations for comfort, with over 90% of respondents indicating that they would be either somewhat or very comfortable riding a bike in those locations. There is a significant dropoff in ratings after that, suggesting that for each of the intersection locations, at least a third of respondents wouldn't feel comfortable riding a bike there.

The top-rated intersection locations were the phase-separated bike signal location and the protected intersection location. There was only one clip of the bike signal location (in part due to the relative consistency of the expected interactions at the location (i.e., motorists and cyclists should not be negotiating or interacting in the space if both are following the signal indicators). However, the protected intersection location was shown three times, with two of those clips involving interaction with turning vehicles. The fact that the ratings are similar between the two designs suggests that even with interactions, most people are comfortable riding through a protected intersection.

On the opposite end of the comfort spectrum were the long mixing zone and lateral shift design, each of which leaves the cyclist exposed to motor vehicle traffic for a considerable distance (approximately 95 feet in the case of the mixing zone, and 110 feet in the case of the lateral shift). These were the two designs that had the longest distance between the point where the "protection" in the protected bike lane ceased and the intersection began.

**Table 5-1 Mean Rating and Percentage Comfortable by Location**

| Location ID | | Rating | Percentage rating comfortable |
|---|---|---|---|
| Springwater Corridor Trail | Mean | 4.77 | 95% |
| https://goo.gl/maps/wYkGC92RUM62 | n | 276 | 276 |
| | Std. Deviation | 0.628 | 0.220 |
| NE Multnomah protected bike lane | Mean | 4.54 | 91% |
| https://goo.gl/maps/SZ6FeF1nQaR2 | n | 276 | 276 |
| | Std. Deviation | 0.735 | 0.282 |
| Arapahoe at 18th WB | Mean | 3.77 | 67% |
| (bike signal) | n | 275 | 275 |
| https://goo.gl/maps/3yEsSCYD9Wy | Std. Deviation | 1.154 | 0.473 |
| 200W at 300S NB | Mean | 3.78 | 66% |
| (bend-out/protected intersection) | n | 828 | 828 |
| https://goo.gl/maps/KgHhkGFgkJy | Std. Deviation | 1.099 | 0.473 |
| 14th at Delaware EB | Mean | 3.56 | 58% |
| (bend-in, maintain separation) | n | 553 | 553 |
| https://goo.gl/maps/ZDxx2Hj2qU92 | Std. Deviation | 1.084 | 0.495 |
| Dexter at Harrison NB | Mean | 3.44 | 51% |
| (short mixing zone) | n | 551 | 551 |
| https://goo.gl/maps/VQuf1VQ2JQR2 | Std. Deviation | 1.049 | 0.500 |
| NE Multnomah at 11th EB | Mean | 3.22 | 43% |
| (straight path, maintain separation) | n | 822 | 822 |
| https://goo.gl/maps/TTnFn52iHPL2 | Std. Deviation | 1.128 | 0.495 |
| Roosevelt at 50th SB | Mean | 3.20 | 43% |
| (lateral shift, post-delineated) | n | 551 | 551 |
| https://goo.gl/maps/K7KEzwM3vyj | Std. Deviation | 1.071 | 0.496 |
| 300S at 200E EB | Mean | 3.10 | 38% |
| (short mixing zone) | n | 829 | 829 |
| https://goo.gl/maps/iDy6rW49VzF2 | Std. Deviation | 1.081 | 0.486 |
| 300S at 300E EB | Mean | 3.03 | 35% |
| (bend-in, dashed bike lane) | n | 552 | 552 |
| https://goo.gl/maps/SakstuHAPEM2 | Std. Deviation | 1.066 | 0.478 |
| Barbur Blvd Bike Lane | Mean | 2.76 | 33% |
| (control – bike lane, 35mph 3 lane) | n | 276 | 276 |
| https://goo.gl/maps/K7JBuxP1j882 | Std. Deviation | 1.264 | 0.472 |
| Lawrence at 19th | Mean | 2.74 | 29% |
| (lateral shift) | n | 550 | 550 |
| https://goo.gl/maps/BYPwr7zmCyQ2 | Std. Deviation | 1.205 | 0.455 |
| NE Multnomah at 9th WB | Mean | 2.70 | 26% |
| (long mixing zone) | n | 827 | 827 |
| https://goo.gl/maps/i3zyKNvUL442 | Std. Deviation | 1.121 | 0.440 |
| Total | Mean | 3.31 | 48% |
| | n | 7166 | 7166 |
| | Std. Deviation | 1.203 | 0.500 |

*Grey shading indicates a control (non-intersection) location.

**Table 5-2 Mean Rating and Percentage Comfortable by Clip**

| Location ID | Clip # | MV Turn | Mean | Std. Deviation | n |
|---|---|---|---|---|---|
| NE Multnomah at 11th EB (straight path, maintain separation) | 1 (view) | Negotiated | 3.12 | 1.121 | 277 |
| | 7 (view) | Negotiated | 2.89 | 1.144 | 276 |
| | 20 (view) | Turn visible | 3.63 | 0.987 | 277 |
| NE Multnomah at 9th WB (long mixing zone) | 10 (view) | Turn visible | 2.47 | 1.085 | 274 |
| | 17 (view) | Negotiated | 2.73 | 1.055 | 275 |
| | 22 (view) | Negotiated | 2.91 | 1.179 | 275 |
| 200W at 300S NB (bend-out/protected intersection) | 3 (view) | Turn visible | 3.95 | 0.984 | 276 |
| | 23 (view) | Negotiated | 3.78 | 1.120 | 276 |
| | 25 (view) | Negotiated | 3.62 | 1.166 | 275 |
| 300S at 200E EB (short mixing zone) | 11 (view) | Turn visible | 3.00 | 1.060 | 275 |
| | 12 (view) | Turn visible | 3.03 | 1.078 | 275 |
| | 14 (view) | Negotiated | 3.28 | 1.088 | 275 |
| Lawrence at 19th (lateral shift) | 2 (view) | Turn visible | 3.07 | 1.170 | 276 |
| | 6 (view) | Negotiated | 2.41 | 1.154 | 276 |
| Roosevelt at 50th SB (lateral shift, post-delineated) | 4 (view) | Turn visible | 3.21 | 1.073 | 275 |
| | 24 (view) | Negotiated | 3.18 | 1.072 | 277 |
| Dexter at Harrison NB (short mixing zone) | 8 (view) | Negotiated | 3.25 | 1.076 | 276 |
| | 26 (view) | Turn visible | 3.62 | 0.989 | 276 |
| 14th at Delaware EB (bend-in, maintain separation) | 13 (view) | Turn visible | 3.96 | 0.937 | 273 |
| | 19 (view) | Negotiated | 3.16 | 1.076 | 275 |
| 300S at 300E EB (bend-in, dashed bike lane) | 9 (view) | Negotiated | 3.08 | 1.065 | 277 |
| | 21 (view) | Turn visible | 2.99 | 1.067 | 275 |
| Arapahoe at 18th WB (bike signal) | 5 (view) | No Turn | 3.77 | 1.154 | 276 |
| Springwater Corridor Trail segment | 15 (view) | No Turn | 4.77 | 0.628 | 276 |
| Barbur Blvd bike lane segment | 16 (view) | No Turn | 2.76 | 1.264 | 277 |
| NE Multnomah protected bike lane segment | 18 (view) | No Turn | 4.54 | 0.735 | 275 |
| | All clips | | 3.31 | 1.203 | 7166 |

*Grey shading indicates a control (non-intersection) location.

**Table 5-3 Mean Rating and Percentage of Respondents Comfortable, by Facility and Interaction with Turning Motorist**

| Bicycle Facility | No interaction | | Interaction with turning vehicle | | Total | | Number of ratings |
|---|---|---|---|---|---|---|---|
| | Mean Rating | Percentage comfortable[1] | Mean Rating | Percentage comfortable[1] | Mean Rating | Percentage comfortable[1] | |
| Bike Lane | *Not differentiated based on clip selection and / or design* | | | | 2.79 | 33% | 276 |
| Trail | | | | | 4.77 | 95% | 276 |
| Protected Bike Lane | | | | | 4.54 | 91% | 276 |
| Bicycle Signal | | | | | 3.77 | 67% | 275 |
| Bend-out/ protected Intersection* | 3.95 | 72% | 3.70 | 63% | 3.78 | 66% | 828 |
| Bend-in* | 3.47 | 54% | 3.12 | 40% | 3.30 | 47% | 1105 |
| Maintain separation / straight path* | 3.63 | 59% | 3.01 | 35% | 3.22 | 43% | 822 |
| Mixing zone | 3.03 | 37% | 3.04 | 37% | 3.04 | 37% | 2207 |
| Lateral Shift* | 3.14 | 40% | 2.80 | 32% | 2.97 | 36% | 1101 |
| Total | 3.29 | 47% | 3.12 | 41% | 3.22 | 44% | 6338 |
| n (ratings) | 2756 | | 3307 | | 6338 | | |

*Significant difference in percentage comfortable between no interaction and interaction clips (Chi-Square, p<.05).
[1]very or somewhat comfortable

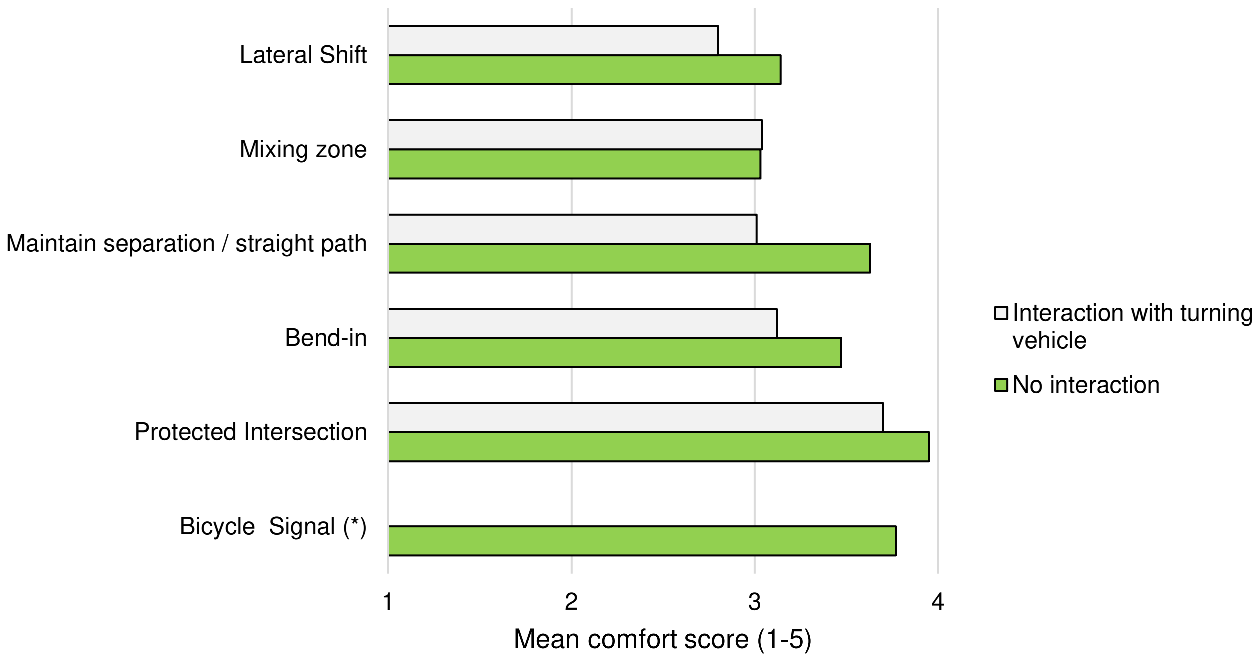



**Figure 5-1 Mean Comfort Score, Intersection Designs**

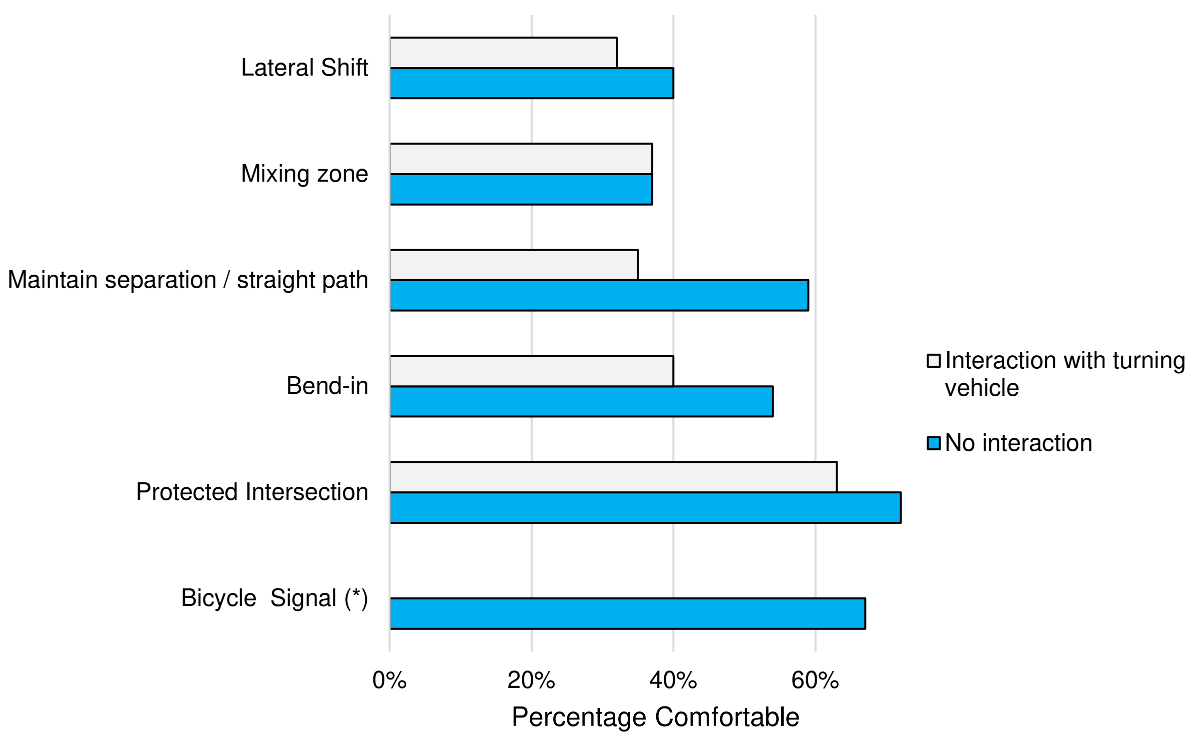



**Figure 5-2 Percentage Comfortable, Intersection Designs**

## 5.2 RATINGS BY INTERSECTION AND CLIP CHARACTERISTICS

Intersection design and related characteristics were coded and average ratings across locations and clips were examined to identify potential factors that would affect comfort ratings. While we observed a number of significant differences in comfort ratings based on design differences (see Table 5-4 and Table 5-5), it is worth noting that the descriptive analysis presented in these tables does not take into account potentially related, correlated or confounding factors. Modeling to control for these factors is presented in section 5.9/

Many of the findings related to intersection and design characteristics make intuitive sense. For example, designs that maintained physical separation up to the intersection were rated as more comfortable than those that did not (with average ratings of 3.54 out of 4 compared to 3.02). Having a bike lane dashed through an intersection was correlated with higher comfort ratings compared to having the lane go halfway through, or not at all (3.42 to 3.22 to 2.94). Higher quality pavement was associated with higher comfort ratings (3.36 for good quality, down to 2.96 for poor quality), as was having pavement colored green to denote potential conflict areas (3.37 to 3.04).

When interpreting the ratings associated with the barriers types, it is important to note that some locations had more than one type of barrier, though in most cases having one type meant the location did not have a different type. For example, locations with parked car barriers were rated as less comfortable than those without such a barrier. However, locations without a parked car barrier had some other type of barrier, as opposed to having no barrier. Locations with planter barriers had an average comfort score of 3.5, curb barriers were at 3.34, and flexpost barriers were at 3.25.

The interactions and events in the clip are also important to the average comfort rating. Table 5-5 shows average rating by a set of clip characteristics, including interactions with turning motorists, encroachment and yielding behavior of vehicles, and cyclist speed. Clips with negotiated interactions with motorists (as opposed to just seeing a turning car up ahead) were rating slightly, but significantly, lower (3.17 to 3.29). Motorist encroachment in the bike lane was associated with considerably lower comfort ratings (2.95 compared to 3.28 for other clips where this encroachment did not occur). Not surprisingly, in situations where the motorist could have yielded but did not, those were associated with much lower comfort ratings (2.85). In situations where the motorist could have yielded and did so, the comfort rating was 3.2 on average – which, when compared to the situations when motorists fail to yield, is considerably higher.

**Table 5-4 Mean Rating by Intersection and Design Characteristics**

| Design Characteristic | Group | Mean Rating | n | Std. Deviation |
|---|---|---|---|---|
| Maintain separation to intersection: | No | 3.02 | 3860 | 1.13 |
| | Yes | 3.54 | 2478 | 1.14 |
| Bike lane skip-stripe through intersection: | No | 2.94 | 2208 | 1.11 |
| | Half | 3.22 | 822 | 1.13 |
| | Yes | 3.42 | 3308 | 1.16 |
| Marking through intersection (skip-stripe, lane, etc.) condition: | Good | 3.39 | 4139 | 1.120 |
| | Moderate | 2.74 | 550 | 1.205 |
| | Poor | 3.22 | 822 | 1.128 |
| Has flexpost barrier*: | No | 3.20 | 3306 | 1.17 |
| | Yes | 3.25 | 3032 | 1.15 |
| Has parked car barrier: | No | 3.27 | 4958 | 1.15 |
| | Yes | 3.04 | 1380 | 1.18 |
| Has planter barrier: | No | 3.12 | 4688 | 1.15 |
| | Yes | 3.50 | 1650 | 1.15 |
| Has curb barrier: | No | 3.16 | 4129 | 1.17 |
| | Yes | 3.34 | 2209 | 1.14 |
| Pavement quality: | Good | 3.36 | 2482 | 1.10 |
| | Moderate | 3.27 | 2207 | 1.20 |
| | Poor | 2.96 | 1649 | 1.15 |
| Conflict zone marked with green color: | No | 3.04 | 2759 | 1.11 |
| | Yes | 3.37 | 3579 | 1.18 |
| Intersection location: | Portland, OR | 2.96 | 1649 | 1.153 |
| | Seattle, WA | 3.32 | 1102 | 1.067 |
| | Salt Lake City, UT | 3.34 | 2209 | 1.137 |
| | Denver, CO | 3.27 | 1378 | 1.229 |

*All differences significant (one-way ANOVA, p<0.05) UNLESS marked with an *asterisk

**Table 5-5 Mean Rating by Clip Characteristics**

| Clip Characteristic | Group | Mean Rating | n | Std. Deviation |
|---|---|---|---|---|
| Turning vehicles: | Turn visible | 3.29 | 2756 | 1.14 |
| | Negotiated | 3.12 | 3307 | 1.17 |
| MV encroachment in bike lane visible: | No | 3.28 | 5237 | 1.16 |
| | Yes | 2.95 | 1101 | 1.14 |
| MV fail to yield: | No | 3.30 | 5235 | 1.16 |
| | Yes | 2.85 | 1103 | 1.11 |
| MV yield*: | No | 3.23 | 4133 | 1.18 |
| | Yes | 3.20 | 2205 | 1.12 |
| Cyclist speed: | slow | 3.46 | 552 | 1.16 |
| | slow to moderate | 3.18 | 553 | 1.08 |
| | moderate | 3.18 | 4957 | 1.17 |
| | moderate to fast | 3.62 | 276 | 0.99 |
| Audible distractions*: | No | 3.23 | 4409 | 1.18 |
| | Yes | 3.21 | 1929 | 1.12 |

*All differences significant (one-way ANOVA, $p<0.05$) UNLESS marked with an *asterisk

## 5.3 RATINGS BY DESIGN AND PRESENCE OF TURNING VEHICLES

One goal of the project was to understand how the presence of (and interaction with) turning motorists affects the comfort of bicyclists riding through the various intersection designs. Table 5-3 shows the percentage of respondents who rated clips as comfortable (either very comfortable or somewhat comfortable) for each of the six intersection design types tested. Signalized and protected intersections were rated as comfortable by two-thirds of respondents, while bend-in and maintain separation designs were rated as comfortable by just under half of respondents. Mixing zones and lateral shift designs were rated as comfortable by just over a third of respondents. In situations where the bicyclists and turning motorists interacted (defined as arriving at the intersection at a similar time, necessitating an interaction such as one or the other slowing, yielding, merging, or crossing), the percentage of respondents who would be comfortable was reduced significantly – usually by around 8% to up to 24%. The exception to this was for mixing zone locations, where there was no difference in terms of the percentage of respondents indicating they would be comfortable, between clips showing interactions with turning vehicles and those without. One potential reason for this is that, in most of the cases wherein cyclists were negotiating interactions with turning vehicles, the vehicles were moving quite slowly.

## 5.4 RATING DIFFERENCES BY DEMOGRAPHIC CHARACTERISTICS

We sought to understand how comfort ratings varied depending on various demographic characteristics. Men and white respondents rated the clips as more comfortable on average, while respondents over 55 years of age rated clips as less comfortable on average than others. Respondents with kids under 16 years of age rated clips slightly lower on average. Although we did see a slight difference in average rating by survey location, those differences were not significant after considering age, gender, race, and if they have ridden a bike in the past week.

Since the survey was conducted in Portland (along with three other cities) and some of the locations were filmed in Portland, we wanted to understand if Portland respondents rated the locations differently than other respondents did, which might suggest that familiarity with the locations was having some effect on the rating. However, we found no evidence that Portland respondents were rating their local locations any differently than other respondents.

**Table 5-6 Mean Ratings by Survey Location and Select Demographic Variables**

| Category | Mean | n | Std. Deviation |
|---|---|---|---|
| **By survey site** | | | |
| Portland, OR | 3.23 | 2301 | 1.13 |
| Woodburn, OR | 3.23 | 964 | 1.19 |
| Minneapolis, MN | 3.29 | 1310 | 1.18 |
| Takoma Park MD | 3.16 | 1763 | 1.17 |
| **By gender** | | | |
| Female | 3.10 | 3459 | 1.19 |
| Male | 3.40 | 2771 | 1.10 |
| **By race / ethnicity** | | | |
| White, non-Hispanic | 3.31 | 4087 | 1.14 |
| Hispanic or non-white | 3.06 | 1686 | 1.14 |
| **Age** | | | |
| 18 to 24 | 3.21 | 1425 | 1.13 |
| 25 to 34 | 3.30 | 1693 | 1.15 |
| 35 to 54 | 3.46 | 1510 | 1.11 |
| 55 + | 2.99 | 1512 | 1.20 |
| **Has children under 16 years of age in the household** | | | |
| No kids | 3.25 | 4728 | 1.17 |
| Has kids | 3.15 | 915 | 1.11 |

*All differences significant (one-way ANOVA, $p<0.05$)

## 5.5 RATINGS BY BICYCLE BEHAVIOR AND ATTITUDES

There might be some expectation that people who ride more often, or who have positive views toward bicycling, would be more comfortable than people who don’t ride or have negative views toward bicycling. Table 5-7 to Table 5-9 show means comfort ratings broken down by some of these factors. People who only rode on paths, trails or quiet residential streets had slightly lower comfort ratings than those who indicated that they had ridden on busy streets, either with or without a bike lane or protected bike lane, in the past year. Those who indicated that they rode for transportation in the past year also had higher average comfort ratings than those who did not. Riding for fun or exercise demonstrated a similar, but not as strong of a difference.

**Table 5-7 Mean Comfort Ratings by Riding in Past Year**

| In the past year, have you ridden a bicycle on… | Yes | No |
|---|---|---|
| a path or trail separate from the street | 3.26 | 3.11 |
| a quiet residential street | 3.29 | 3.08 |
| a busy street with speeds up to 30 mph, WITH a striped bike lane | 3.43 | 3.01 |
| a busy street with speeds up to 30 mph, WITHOUT a striped bike lane | 3.49 | 3.06 |
| a busy street with speeds up to 30 mph, with a physically-separated bike lane (e.g. with a curb, posts or planter boxes) | 3.49 | 3.04 |

**all differences significant*

**Table 5-8 Mean Comfort Ratings by Most Recent Bicycle Riding and Type**

| When was the most recent time you rode a bicycle primarily for | Response | Mean comfort ratings |
|---|---|---|
| Fun or exercise? | In the last month | 3.37 |
| | In the last year | 3.16 |
| | In the last 5 years | 3.00 |
| | More than 5 years ago | 3.10 |
| | Never | 3.05 |
| | n | 269 |
| Transportation? | In the last month | 3.48 |
| | In the last year | 3.39 |
| | In the last 5 years | 3.05 |
| | More than 5 years ago | 3.03 |
| | Never | 3.03 |
| | n | 251 |

In terms of views and attitudes toward bicycling, a few interesting trends in comfort ratings emerge. In general, it appears that people with more positive views toward bicycling were likely to rate their comfort higher in the video clips. For example, those who disagreed that traffic on streets kept them from riding a bike (or riding more) had higher comfort ratings than those agreeing with the statement. Similarly, those who felt many destinations were within a bikeable distance, and that their city should invest in projects that make bicycling safer and easier, were also more likely to have higher comfort ratings.

**Table 5-9 Mean Comfort Ratings by Agreement with Bicycle Statements**

| Statement | Strongly disagree | Disagree | Agree | Strongly agree |
|---|---|---|---|---|
| I would like to ride a bicycle more than I currently do* | 3.11 | 2.98 | 3.21 | 3.27 |
| Traffic on streets keeps me from riding a bike (or riding more) * | 3.66 | 3.50 | 3.21 | 2.85 |
| Many places I need to go are within a reasonable biking distance* | 3.10 | 3.11 | 3.22 | 3.30 |
| I often see people riding bikes in my neighborhood | 3.35 | 3.07 | 3.19 | 3.30 |
| I often see people like me riding bikes in my neighborhood* | 3.13 | 2.99 | 3.29 | 3.45 |
| I prefer to get around by modes other than by riding a bicycle* | 3.68 | 3.32 | 3.16 | 2.98 |
| Bike lanes make it harder to get around my neighborhood | 3.30 | 3.15 | 3.34 | 2.86 |
| I usually have to transport things or people when I travel | 3.28 | 3.20 | 3.23 | 3.21 |
| I would like my city/town to invest in projects (such as bike lanes) that make riding bikes safer and easier* | 2.93 | 3.12 | 3.18 | 3.27 |

**significant difference between groups (ANOVA, p<.05)*

## 5.6 RIDING WITH CHILDREN

For a selection of clips, we asked respondents if they would consider riding in that location with a 10-year-old child. Selected locations include five types of intersections, for which each clip showed a turning car visible, but without an interaction between the cyclist and car. A sixth clip showed a segment of a protected bike lane. Table 5-10 presents the percentage indicating they would ride in that location with a child overall, and broken down by gender, race, age and presence of children in the household.

The segment (non-intersection) clip of a protected bike lane ranked the highest, with 89% of respondents indicating they would ride there with a child. Next were the bend-in location of West 14$^{th}$ Avenue and the protected intersection location, with 70% and 68%, respectively. The maintain straight path and separation location had just about half of respondents indicating they would ride with a child, while the lateral shift and mixing zone were at 31% and 25%, respectively.

We did not observe many differences based on the demographic variables examined. There were no significant differences by gender or race. Respondents 55 or older were a less likely to say they would ride in the location with children for three of the clips. Interestingly, we also did not find any statistically significant differences based on whether or not the respondent self-reported they had children. However, there were practical differences for those without children scoring higher at the bend-out / protected intersection (70% and 62%) and lateral shift designs (34% and 23%).

**Table 5-10 Would Ride with 10-Year-Old Child, by Video Clip, Overall and by Gender, Race, and Age**

| **Clip #** | 3 | 4 | 11 | 13 | 18 | 20 |
|---|---|---|---|---|---|---|
| **Location** | 200W at 300S NB | Roosevelt NE at 50th SB | 300S at 200E EB | W 14th Ave at Delaware EB | NE Multnomah PBL | NE Multnomah at 11th EB |
| **Description** | Bend-out / protected intersection | lateral shift, | Mix zone | Bend-in- | Segment - protected bike lane | Straight - maintain |
| | **Percent responding "yes", would consider riding in this location with a ten-year old child.** | | | | | |
| Total | 68% | 31% | 25% | 70% | 89% | 51% |
| Women | 63% | 31% | 21% | 67% | 87% | 48% |
| Men | 74% | 33% | 31% | 73% | 93% | 57% |
| White, non-Hispanic | 72% | 33% | 27% | 72% | 92% | 54% |
| Hispanic or non-white | 65% | 26% | 20% | 68% | 86% | 47% |
| 18 to 24 | 67% | 33% | 23% | 81% | 92% | 57% |
| 25 to 34 | 76% | 32% | 27% | 74% | 89% | 47% |
| 35 to 54 | 75% | 44% | 35% | 73% | 92% | 63% |
| 55 + | 59% | **17%*** | 17% | **49%*** | 86% | **41%**** |
| No Kids | 70% | 34% | 25% | 70% | 90% | 52% |
| Has Kids | 62% | 23% | 28% | 74% | 93% | 58% |

*Significant difference at least 0.05, Pearson chi-square, 55+ age group differs from all other groups
**Significant difference at 0.05, Pearson chi-square, 55+ age group differs 35-54 age group

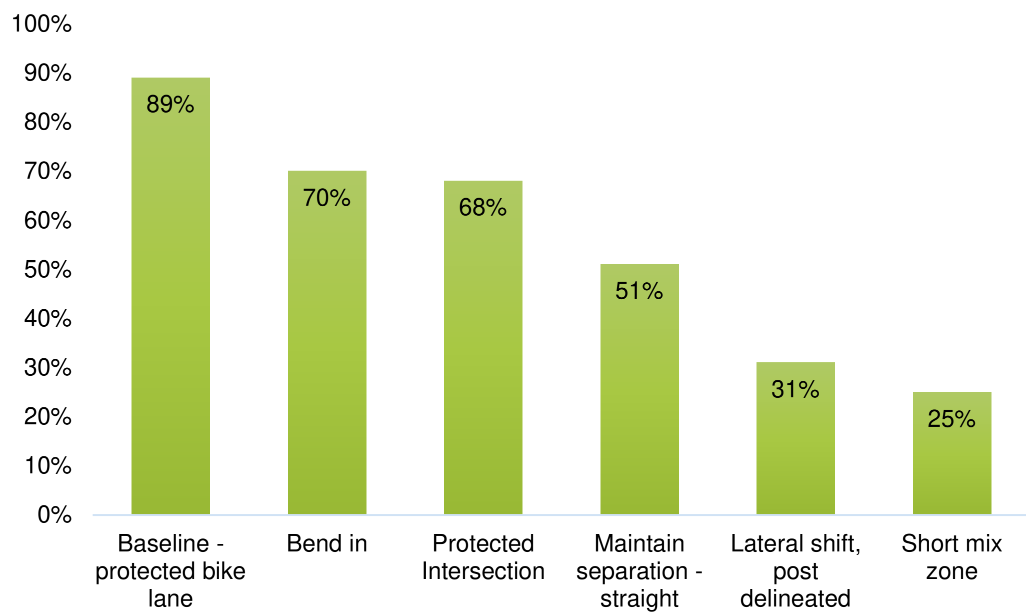



**Figure 5-3 Percentage That Would Consider Riding with a 10-Year-Old Child, by Intersection Design**

## 5.7 DESIGN PREFERENCE/CHOICE

One page of the survey showed respondents four images of intersections, each of which was featured in the video clips. The images included a long mixing zone location (image A), a lateral shift with post separation (image B), a protected intersection (image C) and a bend-in (image D). For the first two images, respondents were asked which intersection they would prefer to ride through, and to briefly explain their choice. They were asked the same questions for images C and D. Finally, they were asked to compare their selection from A/B to their selection from C/D, and to indicate which they prefer and why. Presented as Figure 3-1 and Figure 3-2 earlier in the report, the pictures in the survey are also included in Table 5-12 and Table 5-13. .

In general, respondents indicated that they preferred more defined separation from motorists, choosing the lateral shift with post separation over the mixing zone (61% to 39%), and the protected intersection overwhelmingly over the bend-in design (83% to 17%) – see Table 5-11. Between the four options, 72% selected the protected intersection design (option C), while 11% preferred the bend-in design (option D), 10% preferred the lateral shift (option B) and 6% preferred the mixing zone (option A). We did not observe many differences in preferences by gender, race or age.

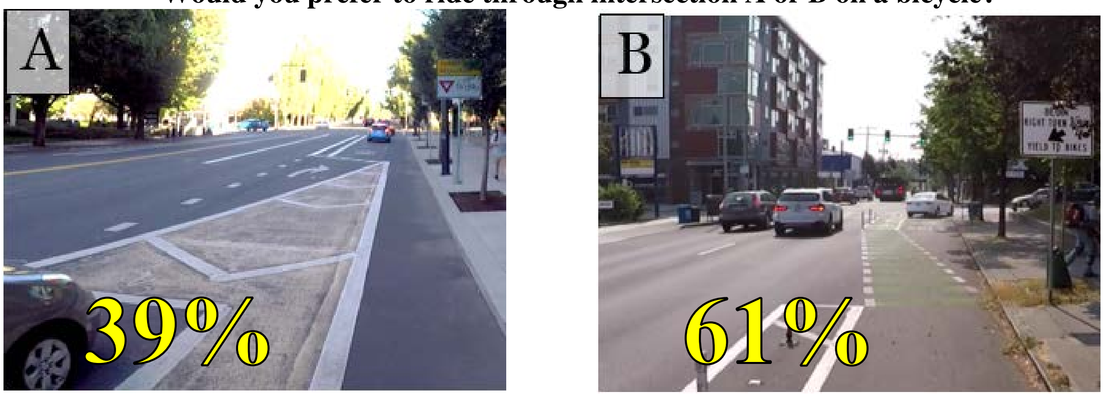
**Table 5-11 Comparative Preference of Select Designs Overall and by Gender, Race, and Age**

| | Overall | Women | Men | White, non-Hispanic | Hispanic or non-white | 18 to 24 | 25 to 34 | 35 to 54 | 55 + |
|---|---|---|---|---|---|---|---|---|---|
| **Preference for A (mixing zone) or B (lateral shift)** | | | | | | | | | |
| A | 39% | 42% | 37% | 38% | 42% | 43% | 45% | 32% | 35% |
| B | 61% | 58% | 63% | 62% | 58% | 57% | 55% | 68% | 65% |
| n | 268 | 149 | 114 | 173 | 73 | 61 | 71 | 65 | 62 |
| **Preference for C (bend-out + protected intersection) or D (bend-in + paint and plastic post buffer)** | | | | | | | | | |
| C | 83% | 84% | 81% | 86% | 79% | 75% | 84% | 83% | 89% |
| D | 17% | 16% | 19% | 14% | 21% | 25% | 16% | 17% | 11% |
| n | 264 | 147 | 112 | 170 | 72 | 61 | 69 | 65 | 61 |
| **Preference for A, B, C or D** | | | | | | | | | |
| A | 6% | 8% | 4% | 5% | 7% | 10% | 9% | 5% | 2% |
| B | 10% | 6%* | 16% | 14% | 4% | 11% | 7% | 14% | 9% |
| C | 72% | 74% | 69% | 72% | 76% | 67% | 69% | 73% | 79% |
| D | 11% | 12% | 10% | 10% | 11% | 11% | 13% | 9% | 11% |
| n | 260 | 145 | 110 | 166 | 71 | 61 | 68 | 66 | 57 |

**Significant difference at 0.05 Pearson chi-square*

We also asked respondents to briefly explain why they preferred their selected options. Open-ended responses were coded thematically. The percentage of respondents whose response touched on a theme are displayed in Figure 5-4 and Table 5-12 (Choice of A, mixing zone, or B, lateral shift), Figure 5-5 and Table 5-13 (choice of C, protected intersection, or D, bend-in), and in Table 5-14 (choice among the four options). Of those who chose A, some of the top reasons were that they preferred the yield sign/markings (19%), liked not having to cross a car lane (18%), and liked being able to stay to the right (10%). Of those who chose B, reasons included that they liked the separation from vehicles (35%) and the clear lane marking (31%), and that they liked the green color (21%) of the pavement. Of those who chose C, top reasons included that they liked the protection and separation from vehicles, including the curb separation (43%), felt the design provided improved visibility and/or a safer turning angle (34%), that it had clear markings (17%), and that the design slows down drivers and provides more time to react (13%). Of those who chose D, reasons included that they felt the design was less confusing (34%), and that it provided better visibility and made drivers more alert to the potential for bicyclists (16%).

**Would you prefer to ride through intersection A or B on a bicycle?**

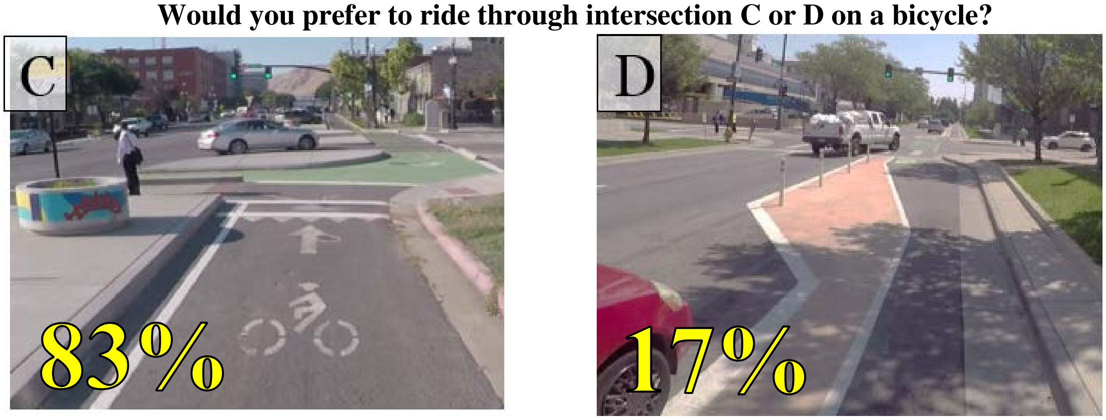



Of those who chose A, reasons include*:
Preferred the yield sign/markings (19%)
Not having to cross a car lane (18%)
Being able to stay to the right (10%)

Of those who chose B, reasons include*:
Liking the separation from vehicles (35%) and clear lane marking (31%)
Like the green color (21%)

**Figure 5-4 Preference for Mixing Zone and Lateral Shift design**

**Would you prefer to ride through intersection C or D on a bicycle?**




Of those who chose C, reasons include*:
otection and separation from vehicles (43%)
mproved visibility and turning angle (34%)
Clear markings (17%)
Slows down drivers, time to react (13%)

Of those who chose D, reasons include*:
Less confusing design (34%)
Better visibility and alertness (16%)

**Figure 5-5 Preference for Bend-out / Protected Intersection and Bend-in designs**

**Table 5-12 Preference for A (Mixing Zone) or B (Lateral Shift) – Coded Open-Ended Response**

| | A | | B | | Total |
|---|---|---|---|---|---|
| **Selected Design:** | 105 | 39% | 163 | 61% | 268 |
| **Explanation of choice** | Of those selecting the design, number and percent who mentioned each factor | | | | |
| The bike lane is clearly marked/delineated | 5 | 5% | 50 | 31% | 55 |
| Right of way is clear | 7 | 7% | 3 | 2% | 10 |
| Motorist markings are clear | 4 | 4% | 6 | 4% | 10 |
| Less confusing design | 3 | 3% | 13 | 8% | 16 |
| Like the color/green in the design. | 2 | 2% | 34 | 21% | 36 |
| Response mentioned separation, protection or more space | 13 | 12% | 57 | 35% | 70 |
| *Like the separation for bicyclists and motorists* | 5 | 5% | 30 | 18% | 35 |
| *Like the protection from motorists* | 3 | 3% | 26 | 16% | 29 |
| *Like having extra space* | 5 | 5% | 4 | 2% | 9 |
| Not having crossing vehicles in bike lane | 19 | 18% | 0 | 0% | 19 |
| Better visibility for either bicyclist or motorists | 8 | 8% | 3 | 2% | 11 |
| Design makes motorists more alert | 2 | 2% | 15 | 9% | 17 |
| Response mentioned yield sign or markings | 20 | 19% | 3 | 2% | 23 |
| *Like yield markings* | 15 | 14% | 0 | 0% | 15 |
| *Like yield sign* | 11 | 10% | 3 | 2% | 14 |
| Bike lane in B goes between two motor vehicle lanes - prefer to stay right | 11 | 10% | 2 | 1% | 13 |
| Merge zone is clear | 4 | 4% | 4 | 2% | 8 |
| Like turn restriction | 1 | 1% | 6 | 4% | 7 |
| Like that vehicles cross prior to turning | 0 | 0% | 7 | 4% | 7 |

Note multiple codings to the open-ended responses are possible; subtotal sections do not necessarily total.

**Table 5-13 Preference for C (Bend-Out + Curb) or D (Bend-In + Paint/Post) – Coded Open-Ended Responses**

| | C | | D | | Total |
|---|---|---|---|---|---|
| Selected Design: | 219 | 83% | 44 | 17% | **263** |
| **Explanation of choice** | Of those selecting the design, number and percent who mentioned each factor | | | | |
| Response mentioned design improving visibility, alertness or the benefit of the turn angle | 74 | 34% | 7 | 16% | 81 |
| *Better visibility for either bicyclist or motorist* | 51 | 23% | 5 | 11% | 56 |
| *Design makes motorists more alert* | 20 | 9% | 3 | 7% | 23 |
| *Better/safer turn angle for motorists* | 12 | 5% | | 0% | 12 |
| The bike lane is clearly marked / delineated | 38 | 17% | 2 | 5% | 40 |
| Motorist markings are clear | 4 | 2% | 1 | 2% | 5 |
| Response mentioned protection, concrete curb, separation, or having more space | 95 | 43% | 7 | 16% | 102 |
| *Like the protection from motorists* | 37 | 17% | 2 | 5% | 39 |
| *Specifically cited the curb or concrete barrier* | 37 | 17% | 1 | 2% | 38 |
| *Like the separation for bicyclists and motorists* | 32 | 15% | 4 | 9% | 36 |
| *Like having extra space* | 17 | 8% | | 0% | 17 |
| Response mentioned motorist slowed, time to react, or space to wait | 29 | 13% | | 0% | 29 |
| *Motorists must slow* | 17 | 8% | | 0% | 17 |
| *Design provides more time to react* | 12 | 5% | | 0% | 12 |
| *Design provides space to wait* | 5 | 2% | | 0% | 5 |
| Less confusing design | | 0% | 15 | 34% | 15 |
| Like the color / green in the design. | 12 | 5% | | 0% | 12 |
| Like bike lane width | 4 | 2% | | 0% | 4 |
| More direct option | | 0% | 3 | 7% | 3 |
| Easier | 2 | 1% | | 0% | 2 |

Note multiple codings to the open-ended responses are possible; subtotal sections do not necessarily total.

**Table 5-14 Preference for A, B, C or D – Coded Open-Ended Responses**

| | A | | B | | C | | D | | Grand Total |
|---|---|---|---|---|---|---|---|---|---|
| **Selected design:** | 16 | 6% | 27 | 10% | 188 | 73% | 28 | 11% | 259 |
| Explanation of choice | Of those selecting the design, number and percent who mentioned each factor | | | | | | | | |
| Mentioned either separation, not having to merge, protection, curb or extra space | 1 | 6% | 2 | 7% | 111 | 59% | 13 | 46% | 127 |
| *Like the separation for bicyclists and motorists* | 1 | 6% | 2 | 7% | 52 | 28% | 5 | 18% | 60 |
| *Like not having to merge with motorists* | | | | | 2 | 1% | 1 | 4% | 3 |
| *Like the protection from motorists* | | | | | 44 | 23% | 5 | 18% | 49 |
| *Specifically cited the curb or concrete barrier* | | | | | 48 | 26% | | | 48 |
| *Like having extra space* | | | | | 15 | 8% | 4 | 14% | 19 |
| The bike lane is clearly marked / delineated | 1 | 6% | 3 | 11% | 29 | 15% | 5 | 18% | 38 |
| Mentioned either visibility or making the driver more alert | 2 | 13% | 4 | 15% | 35 | 19% | 6 | 21% | 47 |
| *Like the visibility for either bicyclist or motorist* | | | 4 | 15% | 28 | 15% | 3 | 11% | 35 |
| *Design makes motorists more alert* | 2 | 13% | 2 | 7% | 7 | 4% | 3 | 11% | 14 |
| Like the color / green in the design. | | | | | 12 | 6% | 3 | 11% | 15 |
| Mentioned either time to react or motorists needing to slow | | | | | 21 | 11% | 1 | 4% | 22 |
| *Provide time and space to react* | | | | | 14 | 7% | 1 | 4% | 15 |
| *Motorists must slow* | | | | | 10 | 5% | | | 10 |
| Less confusing design | 1 | 6% | 5 | 19% | 4 | 2% | 5 | 18% | 15 |
| Like yield markings | 8 | 50% | | | | | | | 8 |
| Like bike lane width | | | | | 6 | 3% | 1 | 4% | 7 |
| Like that motorists cross prior to turning | | | 5 | 19% | | | | | 5 |
| More direction option | | | 2 | 7% | | | 2 | 7% | 4 |
| Right of way is clear | | | | | 4 | 2% | | | 4 |

Note multiple codings to the open-ended responses are possible; subtotal sections do not necessarily total.

## 5.8 COMFORT BY CYCLIST GROUPING

The respondent data obtained in the brief survey did not allow us to collect all the data we would want to fully understand how respondents would fit into a cyclist typology along the lines of that proposed by Geller (2007) and tested by Dill and McNeil (2014 and 2016). However, we used the data available to us from the survey responses to approximately assign these cyclist types. While not exact, they do offer a window into how a combination of bicycling behavior, interest and concern factor into facility rates.

### 5.8.1 Modified four types of cyclists

Our modified approach to recreating the typology (see Table 5-15) first identified those who are not riding a bike now and are not interested in doing so. These respondents told us they rode a bike zero days in a typical month, had not ridden for recreation or transportation in the past year, and were not interested in riding more. These people were placed into the *No Way No How* group (which might also be thought of as "not riding, not interested" as applied in our grouping). As noted below, we only had 12 respondents in this category, which limits any interpretation we can make from this group. Next, we identified infrequent riders – either those riding one to four days in a typical month, or those who don't ride in a typical month but are interested in riding more. Of this group, most were placed in the *Interested but Concerned* group (which can also be thought of as "infrequent riders" in this application; however, those who strongly disagreed that traffic keeps them from riding more were placed in the *Strong and Fearless* group. Finally, we looked at more frequent riders – those who told us they ride five or more days in a typical month. Among these respondents, we divided them based on whether they agreed with the statement that traffic keeps them from riding more. Those who agreed were placed in the *Enthused and Confident* group (or "frequent cyclists with traffic concerns") and those who disagreed were placed in the *Strong and Fearless* group (or "frequent cyclists without traffic concerns").

**Table 5-15 Method for Four Types Assignment Method**

| Current and Past bike riding | Interested in riding more | Traffic keeps them from riding more | Grouping |
|---|---|---|---|
| Zero days in typical month, zero days riding for recreations or transportation in past year | Yes | Strongly disagree | Strong and Fearless |
| | | All others | Interested but Concerned |
| | No | Any | No Way No How |
| One to four days in a typical month | Either | Strongly disagree | Strong and Fearless |
| | | Agree or disagree somewhat | Interested but Concerned |
| Five + days per month | Either | Disagree (somewhat or strongly) | Strong and Fearless |
| | | Agree | Enthused and Confident |

The resulting groups yielded 12 participants (*No Way No How*), 156 (*Interested but Concerned*), 54 (*Enthused and Confident*) and 52 (*Strong and Fearless*). Table 5-16 presents the percentage of respondents in each group who told us they would feel comfortable riding on each facility. We also present a simple comparison between the *Interested but Concerned* respondents (n=156) and the combination of *Enthused and Confident* with *Strong and Fearless* (n=106), and excluding the *No Way No How* respondents. The distribution of respondents across these groupings is not intended to be representative, and is limited due to the number of questions available in the survey upon which to assign characteristics consistent with similar past typologies. Rather, the grouping provides a rough breakdown of how people more or less comfortable riding in various conditions are likely to perceive intersection designs.

One interesting finding to emerge from this assessment was that there were few to no differences between the different group members at non-intersection locations. On the other hand, all of the intersection locations showed differences in comfort between the groups. In general, the *Strong and Fearless* group was significantly more comfortable than all or most other groups. The percentage of respondents in the *Interested but Concerned* group who indicated they would be comfortable on each intersection varied from about 19-31% less than the *Strong and Fearless* group. In some cases, the *Enthused and Confident* group resembled the *Interested but Concerned* in terms of comfort ratings (i.e., bike signal, bend-in, maintain straight path, lateral shifts, long mixing zones), while in other cases they resemble the *Strong and Fearless* group (bike signal, short mixing zone).

**Table 5-16 Percentage Comfortable by Clip Location, Modified Four Types**

| | Interested but Concerned | Enthused Confident + Strong Fearless | No Way No How | Interested but Concerned | Enthused and Confident | Strong and Fearless | Total |
|---|---|---|---|---|---|---|---|
| Mixed-use trail (Springwater Corridor) | 94% | 97% | 92% | 94% | 96% | 98% | 95% |
| Protected bike lane segment (NE Multnomah) | 89% | 95% | 92%$_{ab}$ | 89%$_{b}$ | 93%$_{ab}$ | 98%$_{b}$ | 92% |
| Bend-out/ Protected intersection (200W at 300S NB) | **61%*** | 76% | 53%$_{a}$ | 61%$_{a}$ | 70%$_{b}$ | 81%$_{c}$ | 67% |
| Bike signal (Arapahoe at 18th WB) | **60%*** | 76% | 58%$_{ab}$ | 60%$_{b}$ | 74%$_{ab}$ | 79%$_{a}$ | 67% |
| Bend-in (14th at Delaware EB) | **52%*** | 68% | 42%$_{a}$ | 52%$_{a}$ | 60%$_{a}$ | 77%$_{b}$ | 58% |
| Short mixing zone (Dexter at Harrison NB) | **45%*** | 63% | 21%$_{a}$ | 45%$_{b}$ | 61%$_{c}$ | 65%$_{c}$ | 51% |
| Maintain – straight path (NE Multnomah at 11th EB) | **36%*** | 53% | 47%$_{a}$ | 36%$_{a}$ | 40%$_{a}$ | 67%$_{b}$ | 43% |
| Lateral shift – post delineated (Roosevelt at 50th SB) | **38%*** | 52% | 29%$_{a}$ | 38%$_{a}$ | 39%$_{a}$ | 65%$_{b}$ | 43% |
| Short mixing zone (300S at 200E EB) | **34%*** | 44% | 33%$_{a}$ | 34%$_{a}$ | 36%$_{a}$ | 53%$_{b}$ | 38% |
| Bend-in / mix (300S at 300E EB) | **31%*** | 43% | 21%$_{a}$ | 31%$_{a}$ | 33%$_{a}$ | 54%$_{b}$ | 35% |
| Bike Lane segment (Barbur Blvd) | 32% | 36% | 25% | 32% | 28% | 44% | 33% |
| Lateral shift – long (Lawrence at 19th) | **23%*** | 38% | 17%$_{a}$ | 23%$_{a}$ | 28%$_{a}$ | 49%$_{b}$ | 29% |
| Long mixing zone (NE Multnomah at 9th WB) | **24%*** | 31% | 19%$_{a}$ | 24%$_{a}$ | 19%$_{a}$ | 43%$_{b}$ | 26% |
| Total | 43% | 56% | 38%$_{a}$ | 43%$_{b}$ | 47%$_{b}$ | 64%$_{c}$ | 48% |
| n | 156 | 106 | 12 | 156 | 54 | 52 | 274 |

**Significantly different at .05 level (Chi-square with post-hoc Z-test)*
*a, b, c, d: Each subscript letter denotes a subset whose column proportions do not differ significantly from each other at the .05 level. (Chi-square with post-hoc Z-test)*

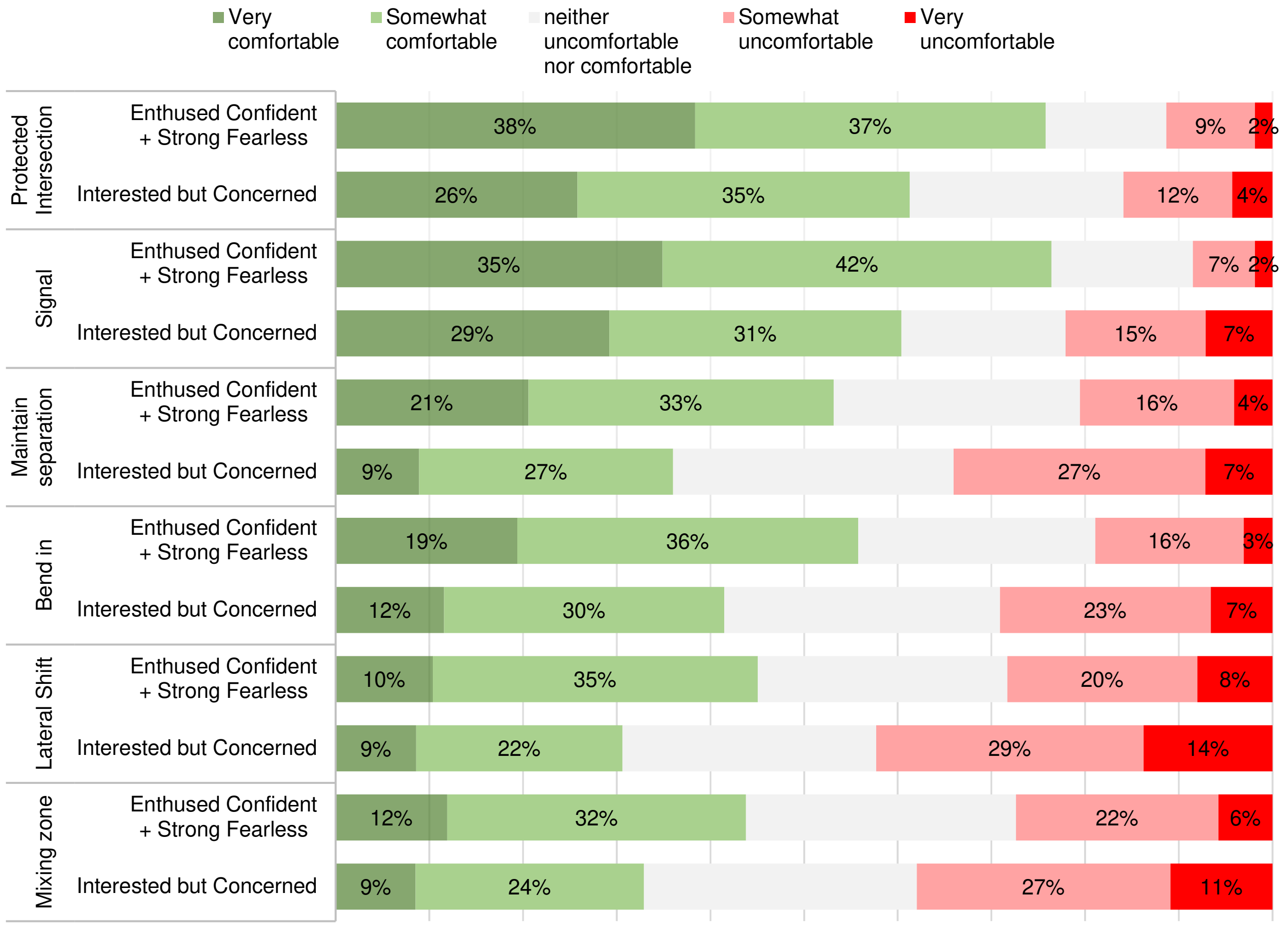



**Figure 5-6 Percentage Comfortable by Intersection Design and Cyclist Type**

**Table 5-17 Comfort at Intersection Locations by Design Type, Modified Four Types**

| Intersection Design | No Way No How | Interested but Concerned | Enthused and Confident | Strong and Fearless | Total |
|---|---|---|---|---|---|
| Bend-out/ Protected intersection | $53\%_{a}$ | $61\%_{a}$ | $70\%_{b}$ | $81\%_{c}$ | 67% |
| Signal | $58\%_{ab}$ | $60\%_{b}$ | $74\%_{ab}$ | $79\%_{a}$ | 67% |
| Bend-in | $31\%_{a}$ | $41\%_{a}$ | $47\%_{a}$ | $65\%_{b}$ | 47% |
| Maintain separation | $47\%_{a}$ | $36\%_{a}$ | $40\%_{a}$ | $67\%_{b}$ | 43% |
| Mixing zone | $25\%_{a}$ | $33\%_{ab}$ | $36\%_{b}$ | $52\%_{c}$ | 37% |
| Lateral shift | $23\%_{a}$ | $31\%_{a}$ | $33\%_{a}$ | $57\%_{b}$ | 36% |
| Total | $34\%_{a}$ | $39\%_{a}$ | $44\%_{b}$ | $62\%_{c}$ | 44% |
| n (ratings) | 276 | 3559 | 1240 | 1194 | 6269 |

*a, b, c, d: Each subscript letter denotes a subset whose column proportions do not differ significantly from each other at the .05 level. (Chi-square with post-hoc Z-test)*

We examined whether the presence of a turning vehicle made a difference in cyclist comfort, based on the cyclist type. For this exploration, we employed the *Interested but Concerned* subgroup (n=156) compared to the combination of *Enthused and Confident* with *Strong and Fearless* (n=106). Table 5-18 shows the percentage comfortable on the various design types. The comfort at the bike signal location is shown, but not tallied in the "total" column as there is generally no distinction between turning vehicles present or not (at least in the clip shown).

In general, interacting with a turning vehicle resulted in decreased comfort, regardless of whether or not the individual was in the *Interested but Concerned* or combination of *Enthused and Confident* and *Strong and Fearless* group.

**Table 5-18 Percentage Comfortable (Very or Somewhat) by Design, Vehicle Interaction, and Cyclist Type**

| | **Interested but Concerned** | | **Enthused Confident + Strong Fearless** | |
|---|---|---|---|---|
| **Intersection Design** | **No interaction** | **Interaction** | **No interaction** | **Interaction** |
| Signal | 60% | | 76% | |
| Bend-out/ Protected Intersection | 66% | 59% | 85%* | 71% |
| Bend-in | 48%* | 35% | 63%* | 49% |
| Maintain separation | 50%* | 29% | 72%* | 44% |
| Mixing zone | 32% | 34% | 45% | 43% |
| Lateral Shift | 35%* | 27% | 50%* | 40% |
| Total | 41%* | 36% | 56%* | 48% |

**Significantly different at .05 level (Chi-square with post-hoc Z-test)*

We also examine differences between the four types of cyclists on the percentage who would ride in select locations with children (Table 5-19) and preference within defined sets of facilities (Table 5-20). Fewer than a quarter of the *Interested but Concerned* would ride in one of the lateral shift or mixing zone treatments, while about two-thirds of the people in that group would ride with children through the protected intersection or bend-in location. The maintain straight path location fell in the middle, at just below 50%. The *Enthused and Confident* cyclists generally had similar ratings to the *Interested but Concerned*, while the *Strong and Fearless* were more likely to say that would ride in the various locations with children.

In terms of facility preference, there were few significant differences between the groups. At least two-thirds of any of the groups preferred the protected intersection design over the other three options. However, the strong and fearless were a bit less likely to select that option, and a bit more likely to select one of the mixing zone type options (25% did so), with most of those preferring the lateral shift design over the long mixing zone design.

**Table 5-19 Riding with Kids, Modified Four Types**

| Clip # | Description | No Way No How | Interested but Concerned | Enthused and Confident | Strong and Fearless | Total |
|---|---|---|---|---|---|---|
| 3 | Bend-out/ Protected intersection (200W at 300S NB) | 50%$_{a}$ | 64%$_{a}$ | 72%$_{ab}$ | 84%$_{b}$ | 69% |
| 4 | Lateral shift – post delineated (Roosevelt at 50th SB) | 42%$_{ab}$ | 24%$_{b}$ | 31%$_{b}$ | 50%$_{a}$ | 31% |
| 11 | Short mixing zone (300S at 200E EB) | 9%$_{ab}$ | 23%$_{b}$ | 21%$_{b}$ | 40%$_{a}$ | 25% |
| 13 | Bend-in (14th at Delaware EB) | 50%$_{a}$ | 68%$_{ab}$ | 67%$_{ab}$ | 82%$_{b}$ | 70% |
| 18 | Protected bike lane segment (NE Multnomah) | 83% | 88% | 89% | 94% | 89% |
| 20 | Maintain – straight path (NE Multnomah at 11th EB) | 45%$_{ab}$ | 47%$_{b}$ | 46%$_{b}$ | 69%$_{a}$ | 51% |

*a, b, c, d: Each subscript letter denotes a subset whose column proportions do not differ significantly from each other at the .05 level. (Chi-square with post-hoc Z-test)*

**Table 5-20 Facility Preference, Modified Four Types**

| Question | Options | No Way No How | Interested but Concerned | Enthused and Confident | Strong and Fearless | Total |
|---|---|---|---|---|---|---|
| Would you prefer to ride through intersection A or B on a bicycle? | A (long mixing zone) | 50% | 41% | 43% | 27% | 39% |
| | B (lateral shift) | 50% | 59% | 57% | 73% | 61% |
| Would you prefer to ride through intersection C or D on a bicycle? | C (protected intersection) | 92% | 86% | 79% | 78% | 84% |
| | D (bend-in) | 8% | 14% | 21% | 22% | 16% |
| Now, compare your preference from A/B to your preference from C/D. Which would you prefer to ride through on a bicycle? | A (long mixing zone) | 0% | 6% | 8% | 6% | 6% |
| | B (lateral shift) | 0% | 10% | 2% | 19% | 10% |
| | C (protected intersection) | 90% | 74% | 75% | 67% | 73% |
| | D (bend-in) | 10% | 10% | 16% | 8% | 11% |

### 5.8.2 Cluster analysis grouping

As an alternative to matching respondents to pre-identified group types, we also explored identifying clusters of respondents via a K-Means cluster analysis. Three distinct groups were identified based on clusters derived from attitude variables (see Table 5-21):

- Group one respondents (n=72) are a little less interested in bicycling, much less likely to view destinations as bikeable and see people like themselves riding in their neighborhood. They were also the least likely to have ridden a bike for transportation or to have a transit pass, and were most likely to take most trips by car. Based on home zip codes provided by respondents, they also lived in areas with lower population density. These respondents were labeled as *Indifferent to Bicycling for Transportation (shortened to "Indifferent to Bicycling"*

- Group two respondents (n=93) were least likely to say that traffic keeps them from riding a bicycle. Nearly all group two respondents felt that destinations were within bikeable distances and that they saw people like them riding in their neighborhoods. They were most likely to have biked for transport and were more likely than respondents in other groups to be male and white. These are *Bike Inclined.*
- Group three respondents (n=93) were nearly all interested in biking more but felt that traffic kept them from riding more. They were also more likely than other respondents to be female. Due to their similarity to the group identified in Geller's Types of Cyclist typology, these respondents were labeled as *Interested but Concerned*.

**Table 5-21 K-Means Cluster Groups, Characteristics**

| Group | Indifferent to Bicycling | Bike Inclined | Interested but Concerned |
|---|---|---|---|
| **Bike related opinions (basis of clusters) - Percent agree** | | | |
| I would like to ride a bicycle more than I currently do | $72\%_{a}$ | $93\%_{b}$ | $99\%_{b}$ |
| Traffic on streets keeps me from riding a bike (or riding more) | $54\%_{a}$ | $43\%_{a}$ | $98\%_{b}$ |
| Many places I need to go are within a reasonable biking distance | $40\%_{a}$ | $97\%_{b}$ | $91\%_{b}$ |
| I often see people riding bikes in my neighborhood | $62\%_{a}$ | $100\%_{b}$ | $87\%_{c}$ |
| I often see people like me riding bikes in my neighborhood | $32\%_{a}$ | $100\%_{b}$ | $51\%_{c}$ |
| I prefer to get around by modes other than by riding a bicycle | $82\%_{a}$ | $41\%_{b}$ | $73\%_{a}$ |
| Bike lanes make it harder to get around my neighborhood | $20\%_{a}$ | $3\%_{b}$ | $14\%_{a}$ |
| I usually have to transport things or people when I travel | $73\%_{ab}$ | $61\%_{b}$ | $78\%_{a}$ |
| I would like my city/town to invest in projects (such as bike lanes) that make riding bikes safer and easier | $86\%_{a}$ | $99\%_{b}$ | $97\%_{b}$ |
| **Behavior and Demographics** | | | |
| Bike for transport in past month | $15\%_{a}$ | $60\%_{b}$ | $26\%_{a}$ |
| Most trips by car (past week) | $71\%_{a}$ | $38\%_{b}$ | $62\%_{a}$ |
| Have transit pass | $27\%_{a}$ | $52\%_{b}$ | $53\%_{b}$ |
| Female | $52\%_{a}$ | $42\%_{a}$ | $70\%_{b}$ |
| White | $57\%_{a}$ | $83\%_{b}$ | $65\%_{a}$ |
| **Zip code characteristics** | | | |
| Zip code – Mean population density | $59{,}144_{a}$ | $72{,}728_{ab}$ | $84{,}766_{b}$ |
| Zip code – Mean percent white population | $73\%_{a}$ | $68\%_{ab}$ | $62\%_{b}$ |
| n | 72 | 93 | 93 |

*a, b, c: Each subscript letter denotes a subset whose column proportions do not differ significantly from each other at the .05 level. (Chi-square with posthoc Z-test or ANOVA with Tukey post-hoc*)*

Across most of the surveyed intersections (see Figure 3-3 for reference), the *Bike Inclined* respondents were the most likely to rate each as being comfortable to ride through. The *Indifferent to Bicycling* and *Interested but Concerned* groups were consistent across many locations, with a few exceptions. The *Interested but Concerned* group was less comfortable on the maintain straight path location (just 34% of the *Interested but Concerned* would be comfortable at this location, in comparison to 46% of the *Indifferent to Bicycling*). *Interested but Concerned* respondents were also less likely to be comfortable on the bike lane segment, and overall across the locations.

**Table 5-22 Percentage Comfortable by Clip Location, K-Means Cluster Groups**

| Group | Indifferent to Bicycling | Bike Inclined | Interested but Concerned | Total |
|---|---|---|---|---|
| Mixed-use trail (Springwater Corridor) | 90%$_a$ | 98%$_{ab}$ | 95%$_b$ | 95% |
| Protected bike lane segment (NE Multnomah) | 90% | 94% | 91% | 92% |
| Bend-out/ Protected intersection (200W at 300S NB) | 62%$_a$ | 75%$_b$ | 64%$_a$ | 67% |
| Bike signal (Arapahoe at 18th WB) | 61% | 73% | 65% | 66% |
| Bend-in (14th at Delaware EB) | 53%$_a$ | 68%$_b$ | 52%$_a$ | 58% |
| Short mixing zone (Dexter at Harrison NB) | 45%$_a$ | 63%$_b$ | 43%$_a$ | 51% |
| Maintain – straight path (NE Multnomah at 11th EB) | 46%$_a$ | 53%$_a$ | 34%$_b$ | 44% |
| Lateral shift – post delineated (Roosevelt at 50th SB) | 38%$_a$ | 59%$_b$ | 34%$_a$ | 44% |
| Short mixing zone (300S at 200E EB) | 34%$_a$ | 48%$_b$ | 31%$_a$ | 38% |
| Bend-in/mix (300S at 300E EB) | 34%$_a$ | 46%$_b$ | 28%$_a$ | 36% |
| Bike Lane segment (Barbur Blvd) | 38%$_a$ | 38%$_a$ | 23%$_b$ | 32% |
| Lateral shift – long (Lawrence at 19$^{th}$) | 25%$_a$ | 42%$_b$ | 20%$_a$ | 29% |
| Long mixing zone (NE Multnomah at 9th WB) | 24%$_a$ | 38%$_b$ | 18%$_a$ | 27% |
| Total | 45%$_a$ | 58%$_b$ | 41%$_c$ | 48% |
| n (respondents) | 72 | 93 | 93 | 72 |

*a, b, c: Each subscript letter denotes a subset whose column proportions do not differ significantly from each other at the .05 level. (Chi-square with post-hoc Z-test)*

The tables below show the mean rating of each intersection type for each cluster group, along with the percentage of respondents who indicated that they would feel either somewhat or very comfortable riding through that intersection, for clips with turning vehicles visible (Table 5-23), and with interactions with turning vehicles (Table 5-24). As expected, the *Bike Inclined* respondents were more comfortable in all situations, whether without or with an interaction with a turning motorist. About half of the *Interested but Concerned* respondents would be comfortable with the maintain separation/straight path design without an interaction; however, that percentage drops to just 25% with an interaction.

**Table 5-23 Mean Rating and Percentage Comfortable by Cluster Groups - No Interaction**

| | **Indifferent to Bicycling** | | **Bike Inclined** | | **Interested but Concerned** | | **Total** | |
|---|---|---|---|---|---|---|---|---|
| | Mean Rating | Percentage Comfortable | Mean Rating | Percentage Comfortable | Mean Rating | Percentage Comfortable | Mean Rating | Percentage Comfortable |
| Bike Signal | 3.65 | 61% | 3.97 | 73% | 3.65 | 65% | 3.76 | 66% |
| Bend-out/ Protected Intersection | 3.85 | $65\%_{a}$ | 4.30 | $83\%_{b}$ | 3.78 | $71\%_{ab}$ | 3.99 | 74% |
| Maintain separation | 3.66 | $60\%_{ab}$ | 3.87 | $68\%_{b}$ | 3.43 | $51\%_{a}$ | 3.65 | 59% |
| Bend in | 3.35 | $52\%_{a}$ | 3.81 | $64\%_{b}$ | 3.31 | $46\%_{a}$ | 3.50 | 54% |
| Mixing zone | 2.88 | $30\%_{a}$ | 3.32 | $47\%_{b}$ | 2.88 | $32\%_{a}$ | 3.04 | 37% |
| Lateral Shift | 2.97 | $32\%_{a}$ | 3.56 | $59\%_{b}$ | 2.90 | $30\%_{a}$ | 3.16 | 41% |
| Total | 3.17 | $41\%_{a}$ | 3.62 | $59\%_{b}$ | 3.12 | $40\%_{a}$ | 3.31 | 47% |

*a, b, c: Each subscript letter denotes a subset whose column proportions do not differ significantly from each other at the .05 level. (Chi-square with post-hoc Z-test)*

**Table 5-24 Mean Rating and Percentage Comfortable by Cluster Groups - Interaction**

| | **Indifferent to Bicycling** | | **Bike Inclined** | | **Interested but Concerned** | | **Total** | |
|---|---|---|---|---|---|---|---|---|
| | Mean Rating | Percentage Comfortable | Mean Rating | Percentage Comfortable | Mean Rating | Percentage Comfortable | Mean Rating | Percentage Comfortable |
| Signal | | | | *n/a* | | | | |
| Bend-out/ Protected Intersection | 3.58 | $61\%_{a}$ | 3.97 | $72\%_{b}$ | 3.61 | $60\%_{a}$ | 3.73 | 64% |
| Maintain separation | 2.99 | $39\%_{a}$ | 3.32 | $45\%_{a}$ | 2.76 | $25\%_{b}$ | 3.03 | 36% |
| Bend in | 3.05 | $35\%_{a}$ | 3.40 | $50\%_{b}$ | 2.92 | $33\%_{a}$ | 3.13 | 40% |
| Mixing zone | 2.99 | $37\%_{a}$ | 3.35 | $49\%_{b}$ | 2.78 | $26\%_{c}$ | 3.04 | 37% |
| Lateral Shift | 2.74 | $31\%_{a}$ | 3.15 | $42\%_{b}$ | 2.50 | $24\%_{a}$ | 2.80 | 32% |
| Total | 3.06 | $40\%_{a}$ | 3.43 | $51\%_{b}$ | 2.89 | $33\%_{c}$ | 3.13 | 41% |

*a, b, c: Each subscript letter denotes a subset whose column proportions do not differ significantly from each other at the .05 level. (Chi-square with post-hoc Z-test)*

In terms of riding with children (Table 5-25), members of group three were, in fact, more likely than those in group one to say they would ride in several locations, including through the protected intersection and through the short mixing zone. We did not see many differences in terms of facility preference (Table 5-26).

**Table 5-25 Riding with Kids, K-Means Cluster Groups**

| Clip # | Description | Indifferent to Bicycling | Bike Inclined | Interested but Concerned | Total |
|---|---|---|---|---|---|
| 3 | Protected intersection (200W at 300S NB) | 58%$_a$ | 76%$_b$ | 68%$_{ab}$ | 68% |
| 4 | Lateral shift – post delineated (Roosevelt at 50th SB) | 24%$_a$ | 45%$_b$ | 23%$_a$ | 31% |
| 11 | Short mixing zone (300S at 200E EB) | 17%$_a$ | 33%$_b$ | 23%$_{ab}$ | 25% |
| 13 | Bend-in (14th at Delaware EB) | 72% | 68% | 73% | 71% |
| 18 | Protected bike lane segment (NE Multnomah) | 84% | 94% | 89% | 89% |
| 20 | Maintain – straight path (NE Multnomah at 11th EB) | 50% | 54% | 52% | 52% |

*a, b, c: Each subscript letter denotes a subset whose column proportions do not differ significantly from each other at the .05 level. (Chi-square with post-hoc Z-test)*

**Table 5-26 Facility Preference, K-Means Cluster Groups**

| Question | Options | Indifferent to Bicycling | Bike Inclined | Interested but Concerned | Total |
|---|---|---|---|---|---|
| Would you prefer to ride through intersection A or B on a bicycle? | A (long mixing zone) | 44% | 34% | 39% | 39% |
| | B (lateral shift) | 56% | 66% | 61% | 61% |
| Would you prefer to ride through intersection C or D on a bicycle? | C (protected intersection) | 86% | 81% | 85% | 84% |
| | D (bend-in) | 14% | 19% | 15% | 16% |
| Now, compare your preference from A/B to your preference from C/D. Which would you prefer to ride through on a bicycle? | A (long mixing zone) | 1% | 7% | 8% | 6% |
| | B (lateral shift) | 7% | 15% | 6% | 10% |
| | C (protected intersection) | 78% | 68% | 76% | 74% |
| | D (bend-in) | 13% | 10% | 9% | 11% |

### 5.8.3 Comparing grouping methods

Whether basing a comparison on the four types of cyclist approach, or a cluster analysis approach, a few consistent findings emerge. First, there are a significant number of infrequent cyclists who are interested in riding more, but not comfortable with many types of bicycle facilities. These individuals fall into the *Interested but Concerned* group in the four types breakdown, and in group three of the K-means cluster analysis. They are less comfortable than the more frequent transportation cyclists (e.g., *Enthused and Confident* or *Strong and Fearless* cyclists, or group two - *Bike Inclined* in the cluster analysis) across a variety of facilities. In particular, facilities with any form of mixing before the intersection (e.g., mixing zones, lateral shift) are likely to drop these cyclists down below the point where 50% would feel comfortable riding through the facility. In general, protected facilities, in particular those with treatments designed to separate phases (i.e., bike signals) or improve visibility (bend-in design or protected intersection designs), appear to result in over half of these people feeling they would be comfortable riding bikes through these intersections.

The cluster analysis also revealed a group of individuals who don't view biking as being particularly useful for them – they are more likely to view destinations as not being within bikeable distances and preferring other modes to bicycles. There is some indication that they exhibited less sensitivity to the different designs and interactions than other respondents. For example, they didn't rate clips with interactions with turning vehicles lower than those without such interactions (while the other two groups did), and they have a narrower band of comfort ratings than those in group three (i.e., their ratings ranged from 24% for the lowest rated location to 90% for the highest, while group three ranged from 18% to 95%). This could be in part because they have fewer riding experiences, making it hard to imagine what riding in the presented situations might be like.

## 5.9 MODELING EFFECTS OF DESIGN ON COMFORT

The project team explored a number of models incorporating variables from the intersection design elements, clip characteristics, and respondent characteristics. Exposure distance emerged as the only significant design factor in comfort ratings. Figure 5-7 shows the average percentage of respondents indicating that they would be either somewhat or very comfortable compared to the distance the rider would be exposed to (the loss of physical protection in the separated bike lane to the far side of the intersection). Uncontrolled for other factors, the trend is quite clear – intersection and designs with longer exposed distances for the bicyclist, either through mixing or crossover areas prior to the intersection, or longer crossing distances were generally rated as less comfortable designs.

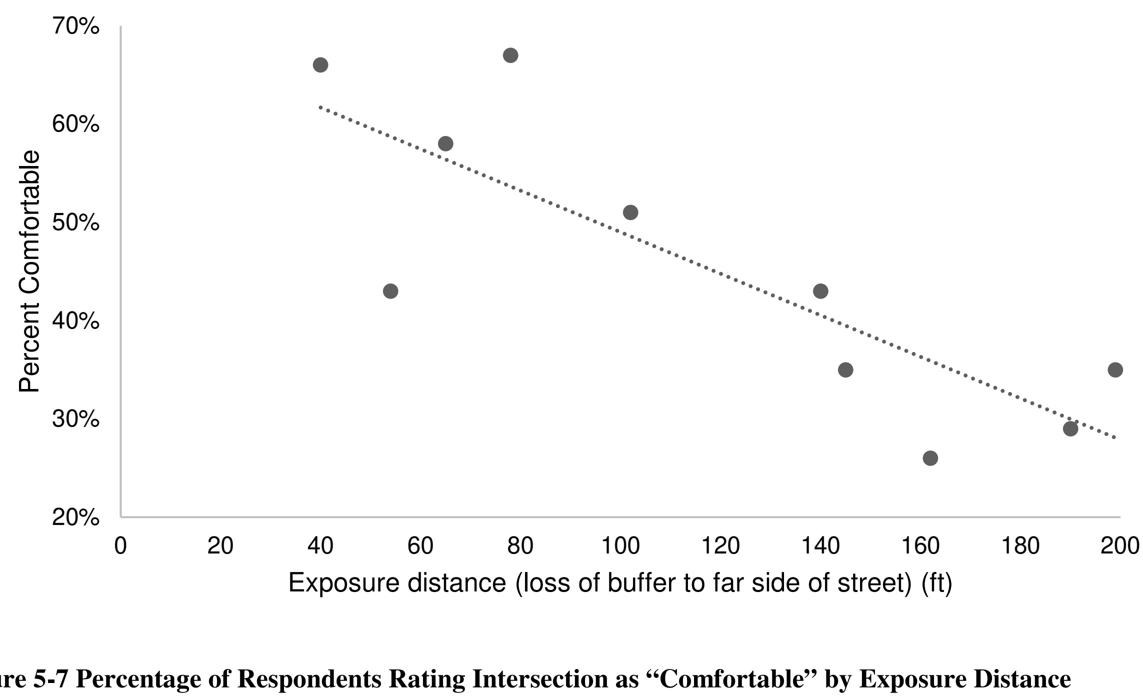



**Figure 5-7 Percentage of Respondents Rating Intersection as "Comfortable" by Exposure Distance**

Independent linear regression models were created for each cluster group to examine the effect of the exposure distance. The models included the comfort rating as the dependent variable, and the mix/merge length and crossing distance as the independent variables. While the $R^2$ values are relatively low, the models confirm that the longer the exposure distance, the lower the expected comfort, with an average effect on the comfort ratings of negative 0.011 per foot of combined exposure. As an example, an intersection with 140 feet of exposure compared to 50 feet of exposure would be one rating down one notch on our five-point comfort scale. Further, the results suggest that the mix/merge length exposure (at -0.007 per foot) is near twice the negative impact as the crossing distance (at -0.004).

With respect to the cluster group types, the *Bike Inclined* start from a higher baseline comfort level (with the constant of 4.021 roughly equating to an average rating of "somewhat comfortable"), and lose a combined 0.010 per foot of exposure. Meanwhile, the *Interested but Concerned* group starts at a lower average rating of 3.536 and loses comfort at a faster rate of 0.012 per foot of exposure. While the model values are not highly predictive, they do suggest that *Interested but Concerned* group are more sensitive to exposure.

**Table 5-27 Independent Linear Regressions of Comfort on Exposure Distance Measures**

| | **Indifferent to Bicycling** | **Bike Inclined** | **Interested but Concerned** | **Total** |
|---|---|---|---|---|
| | Model Summaries | | | |
| R* | .288 | .266 | .303 | .274 |
| R Square | 0.083 | 0.071 | 0.092 | .075 |
| Std. Error of the Estimate | 1.075 | 1.054 | 1.133 | 1.116 |
| **Unstandardized Coefficients of Predictors** | | | | |
| (Constant)* | 3.633 | 4.021 | 3.536 | 3.712 |
| Mix / merge length* | -0.007 | -0.006 | -0.009 | -0.007 |
| Crossing distance (ft.)* | -0.004 | -0.004 | -0.003 | -0.004 |

*Significant p<0.01 in each case

## 5.10 SUMMARY

When considering the expected level of comfort, protected intersections (bend-out) and bike signals were found to provide the best expected rider comfort. Designs that move bicyclists and motorists into shared space (mixing zones or lateral shifts) were viewed as least comfortable. Designs that keep a separate bike lane (bend-in, straight path) were rated as comfortable by more than half of all respondents, but were particularly sensitive to the presence of turning vehicles. This may be that without the vehicles in the video clip, the design implies separation from vehicles and is rated higher but when shown interacting with vehicles, it is more apparent to the extent cyclists must mix with traffic. There was not a difference in the comfort of mixing zone designs with or without vehicle interactions. One potential reason for this is that with mixing zones bicyclists and motorists are already primed for interaction (as opposed to separated spaces). Additionally, in most of the cases in which cyclists were negotiating interactions with turning vehicles, the vehicles were moving quite slowly.

There are a significant number of infrequent cyclists who are interested in riding more, but not comfortable with many types of bicycle facilities. These individuals fall into *Interested but*

*Concerned* group of the K-means cluster analysis. They are less comfortable than the *Bike Inclined* (who may be comparable to the *Enthused and Confident* or *Strong and Fearless* cyclists in the four types typology) across a variety of facilities. In particular, facilities with any form of mixing before the intersection (e.g., mixing zones, lateral shift) are likely to drop the *Interested but Concerned* group down below the point where even 30% would feel comfortable riding through the facility. The locations with bike signals and protected intersections resulted in about two-thirds of the *Interested but Concerned* respondents indicating they would feel comfortable riding there. The facilities with bend-in designs and maintaining separation were generally in between the two other types for the *Interested but Concerned* group (about 30 to 40% felt comfortable).

The cluster analysis also revealed a group of individuals who don't view biking as being particularly useful for them – they are more likely to view destinations as not being within bikeable distances and preferring other modes to bicycles. There is some indication that they exhibited less sensitivity to the different designs and interactions than other respondents. For example, they didn't rate clips with interactions with turning vehicles lower than those without such interactions (while the other two groups did), and they have a narrower band of comfort ratings than those in group three (i.e., their ratings ranged from 24% for the lowest-rated individual location to 90% for the highest, while the *Interested but Concerned* group ranged from 18% to 95%). The *Interested but Concerned* group, on the other hand, may be more sensitive to intersection design than the average non-cyclist. This corroborates past research finding that they tend to be the most responsive to changes in the design environments.

The survey results about riding with children provide valuable insights but should be interpreted with caution as they are each based on a single video clip, without any interaction with a turning vehicle. The bend-in design and protected intersection were the highest-rated intersection locations, while the lateral shift and mixing zone locations were the lowest.

Finally, exposure distance was found to be a significant predictor of comfort. *Interested but Concerned* respondents were particularly sensitive to the exposure distance, with the upstream exposure lowering comfort more than the crossing distance exposure. From a comfort viewpoint, shortening exposure distance is a good design objective.

# 6.0 RESULTS: MICROSIMULATION

Microsimulation models were created in VISSIM and used to identify the expected frequency of interactions between bicyclists and motorists at intersections along protected bikeways. For this analysis, only the interactions between right-turning vehicles and through bicycles were studied. For each right-turning vehicle and through bicycle volume combination, the calibrated, validated simulation models were run 10 times. Trajectory files were post-processed using SSAM to identify interactions between vehicles and bicycles and surrogate measures of safety.

There is an important limitation to note about the results in this chapter. As discussed in Section 3.2, setting up the models to more realistically represent bicycle-vehicle interactions resulted in the vast majority of the simulated conflicts filtered by SSAM to have "0" TTC or PET values. By definition, these are collisions or crashes. Efforts to refine the microsimulation models to reduce the zero TTC/PET values resulted in unrealistic yielding or interactions between the bicycles and vehicles (i.e., where a vehicle or bicycle would remain stopped in the simulation until one flow or the other allowed the stopped vehicle to proceed). There are many parameters that can be calibrated in VISSIM and while we explored most of them, we were not able to resolve this issue in a satisfactory manner. Ultimately, because our objective was to gain an understanding of how the interactions varied by design and volume, we elected to use the models that best represented interactions between motorists and bicycles even if these simulated conflicts were far more severe than we would expect in reality. Thus, the results in this chapter show the simulated number of conflicts that met the threshold for PET and TTC, but we do not report these values as we do not believe they are realistic. One surrogate measure, MaxS, is reported as it the maximum speed of any one vehicle in the conflict identified by SSAM.

## 6.1 MIXING ZONE INTERSECTION

Table 6-1 presents the average number of conflicts generated by 10 VISSIM runs of each bicycle and right-turning vehicle volume combination. The lowest number of conflicts is 0.3 per hour when bicycle volume is 25 and right-turning vehicle volume is 50 per hour. The highest number of conflicts is 32.5 per hour, when bicycle volume is 200 and vehicle volume is 250 per hour. Note only the total number of conflicts was reported, but also the number of conflicts per bicycle was calculated to examine the relationship between the conflicts counts and volume combinations.

Table 6-2 presents the average number of conflicts per bicycle in the mixing zone intersection model. The smallest number is 0.01 conflicts/bicycle which shows up at bicycle volume equals 25 and right-turning vehicle volume equals 50. The largest number of conflicts per bicycle is 0.16, with highest bicycle volume 200 and highest right-turning vehicle volume 250.

**Table 6-1 Number of Simulated Conflicts Per Hour (Mixing Zone Design)**

| Right-turning volume (veh/hr) | Bicycle volume (veh/hr) | | | | | |
|---|---|---|---|---|---|---|
| | 25 | 50 | 75 | 100 | 150 | 200 |
| 50 | 0.3 | 1 | 2.2 | 2.6 | 3 | 4.9 |
| 100 | 1.5 | 3.1 | 5.4 | 5.6 | 8.3 | 13.9 |
| 150 | 3.1 | 3.9 | 6.8 | 8.1 | 12.4 | 16.4 |
| 200 | 3.2 | 5.8 | 9.2 | 9.9 | 15.9 | 24.8 |
| 250 | 2.3 | 7.3 | 10.7 | 15.4 | 20.8 | 32.5 |

**Table 6-2 Number of Simulated Conflicts Per Bicycle (Mixing Zone Design)**

| Right-turning volume (veh/hr) | Bicycle volume (veh/hr) | | | | | |
|---|---|---|---|---|---|---|
| | 25 | 50 | 75 | 100 | 150 | 200 |
| 50 | 0.01 | 0.02 | 0.03 | 0.03 | 0.02 | 0.02 |
| 100 | 0.06 | 0.06 | 0.07 | 0.06 | 0.06 | 0.07 |
| 150 | 0.12 | 0.08 | 0.09 | 0.08 | 0.08 | 0.08 |
| 200 | 0.13 | 0.12 | 0.14 | 0.10 | 0.11 | 0.12 |
| 250 | 0.09 | 0.15 | 0.14 | 0.15 | 0.14 | 0.16 |

Figure 6-1 indicates that the number of the conflicts in mixing zone intersections generally increases as the volume, either right-turning vehicle or through bicycle, increases. This fact meets expectations as higher volume leads to more exposure. However, the total number of conflicts does not change very much when vehicle volume increases and bicycle volume holds at 25. The number of conflicts with bicycle volume equals 75 and 100 are close to each other except with the highest vehicle volume.

Figure 6-2 shows the number of conflicts per bicycle with different volume combinations in mixing zone intersections. Generally, the number of conflicts per bicycle increases as right-turning vehicle volume increases except for an unexpected drop when bicycle volume equals 25. The influence of right-turn volume is apparent, as there is little variation in the simulated conflict rate as the bicycle volume increases.

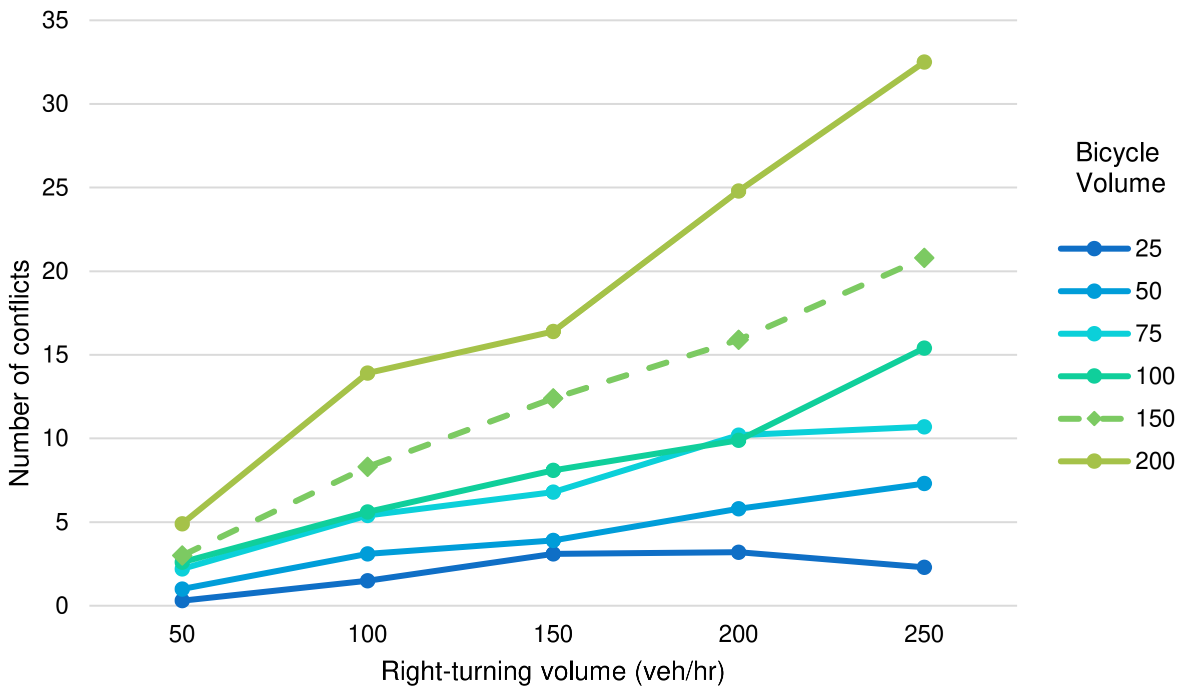



**Figure 6-1 Number of Simulated Conflicts (Mixing Zone Design)**

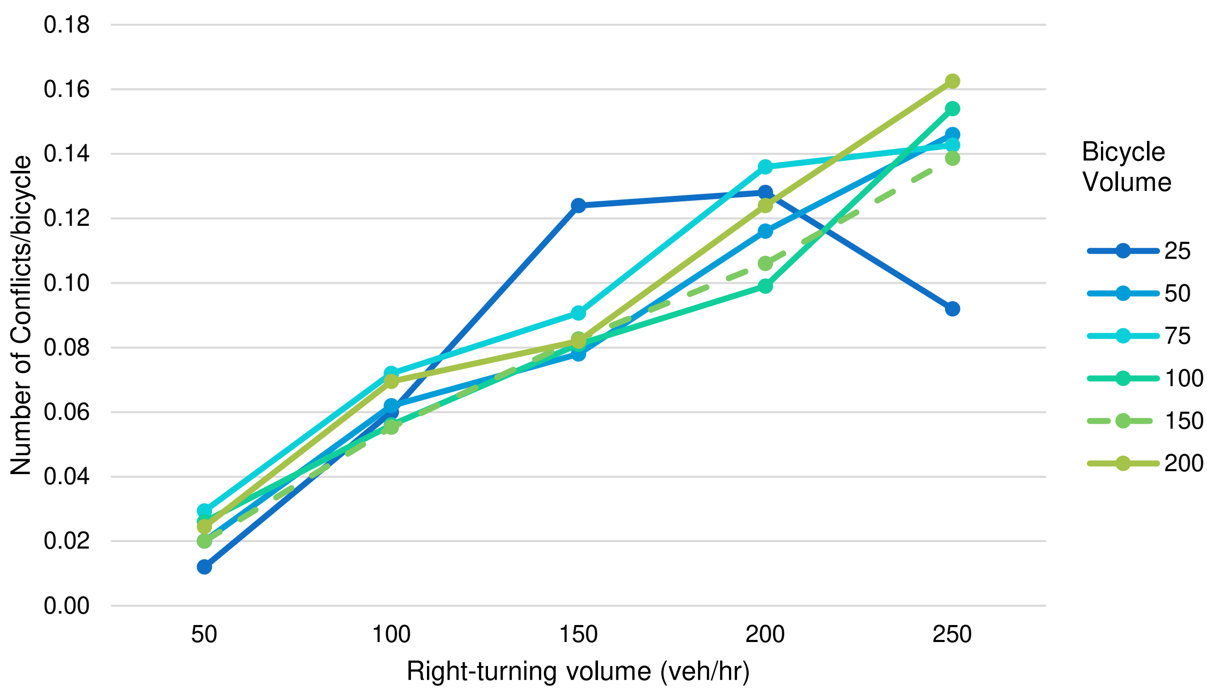


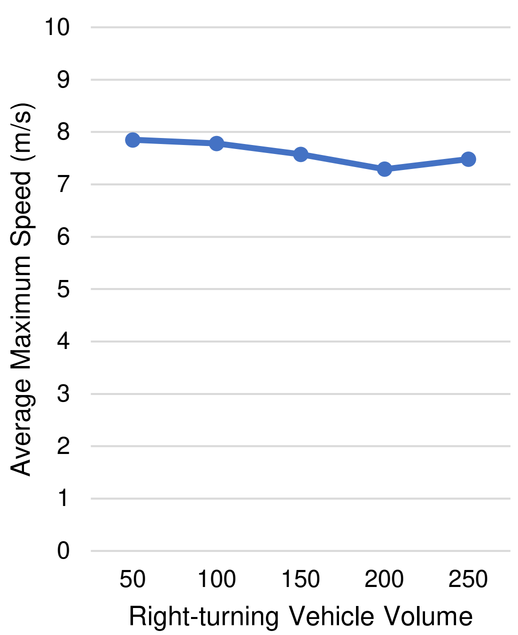

**Figure 6-2 Number of Simulated Conflicts Per Bicycle (Mixing Zone Intersection)**

Table 6-3 is the average MaxS of conflicts generated in mixing zone intersections. MaxS (maximum speed) was examined to provide information about conflicts' severity. MaxS refers to "the maximum speed of either vehicle throughout the conflicts" (*Gettman, Douglas. et al., 2008*) output of SSAM results output. Higher MaxS usually leads to more serious conflicts.

**Table 6-3 MaxS of Conflicts in Mixing Zone Intersections (m/s)**

| Right-turning volume (veh/hr) | Bicycle volume (veh/hr) | | | | | | Average |
|---|---|---|---|---|---|---|---|
| | 25 | 50 | 75 | 100 | 150 | 200 | |
| 50 | 7.7 | 8.36 | 8.13 | 7.53 | 7.15 | 8.24 | 7.85 |
| 100 | 6.42 | 9.23 | 7.74 | 7.67 | 7.74 | 7.9 | 7.78 |
| 150 | 7.48 | 7.52 | 7.59 | 7.7 | 7.64 | 7.51 | 7.57 |
| 200 | 7.04 | 7.61 | 7.72 | 7.26 | 7.06 | 7.05 | 7.29 |
| 250 | 8.62 | 7.55 | 7.34 | 7.37 | 7.3 | 6.71 | 7.48 |
| Average | 7.45 | 8.05 | 7.70 | 7.51 | 7.38 | 7.48 | |

The average MaxS was calculated and plotted based on bicycle or right-turning vehicle volume (Figure 6-3). The average ranges from 7.45 to 8.05 meters per second (16.7 to 18.0 miles per hour). The figure indicates that the trend of MaxS decreases slightly when the volumes become higher. Even though the number of conflicts increases, the average severity level of the conflicts might decrease because the vehicles become slower when there are more vehicles on the road. However, the MaxS is a little higher than before when the intersection is very crowded (vehicle volume equals 250 and bicycle volume equals 200).



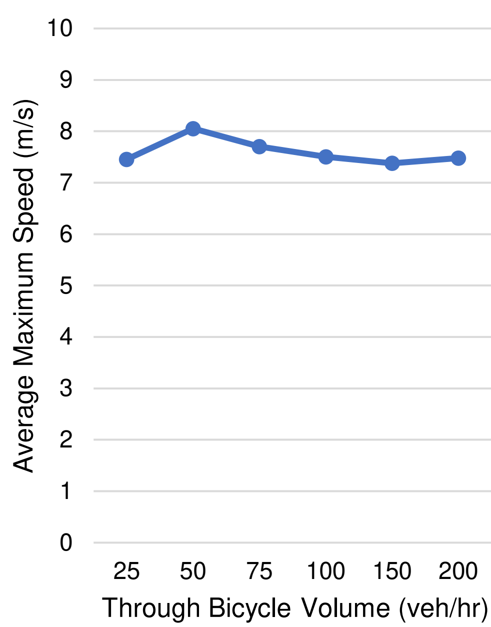




**Figure 6-3 Average MaxS of Mixing Zone Intersections (m/s)**

## 6.2 BEND-IN INTERSECTION

Table 6-4 shows the number of conflicts in bend-in intersections with different vehicle and bicycle volume combinations. The highest number of conflicts is 23.6 with the highest bicycle and vehicle volume combination, and the lowest number of conflicts is 0.6 with the lowest bicycle and vehicle volume combination. Table 6-5 presents the number of conflicts per bicycle in bend-in intersections with different volume combinations. The lowest number is 0.2, which presents four times when right-turning vehicle volume equals 50. The highest number is 0.12 and presents three times with highest right-turning vehicle volume is 250.

**Table 6-4 Number of Simulated Conflicts Per Hour (Bend-In Design)**

| Right-turning volume (veh/hr) | Bicycle volume (veh/hr) | | | | | |
|---|---|---|---|---|---|---|
| | **25** | **50** | **75** | **100** | **150** | **200** |
| 50 | 0.6 | 1.1 | 2.1 | 2.9 | 3 | 4.9 |
| 100 | 0.7 | 2.1 | 3.3 | 4.5 | 6.8 | 9.8 |
| 150 | 1.4 | 3 | 4.8 | 6.4 | 9.4 | 13.1 |
| 200 | 2.1 | 4.3 | 5.2 | 8.7 | 14.5 | 17.5 |
| 250 | 2.3 | 5.8 | 7.9 | 10.6 | 17.6 | 23.6 |

**Table 6-5 Number of Simulated Conflicts Per Bicycle (Bend-In Design)**

| Right-turning volume (veh/hr) | Bicycle volume (veh/hr) | | | | | |
|---|---|---|---|---|---|---|
| | **25** | **50** | **75** | **100** | **150** | **200** |
| 50 | 0.02 | 0.02 | 0.03 | 0.03 | 0.02 | 0.02 |
| 100 | 0.03 | 0.04 | 0.04 | 0.05 | 0.05 | 0.05 |
| 150 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.07 |
| 200 | 0.08 | 0.09 | 0.07 | 0.09 | 0.10 | 0.09 |
| 250 | 0.09 | 0.12 | 0.11 | 0.11 | 0.12 | 0.12 |

Similar to mixing zone intersections, the number of conflicts increases as the volume, either right-turning vehicles or bicycles, increases. In addition, the number of total conflicts increases faster when bicycle volume is 150 and 200 per hour than when bicycle volume is lower. Figure 6-5 indicates that the number of conflicts per bicycle increases with higher right-turning vehicle volume. However, the number of conflicts per bicycle are almost the same with different bicycle volumes when right-turning vehicle volume is constant, as in the mixing zone.

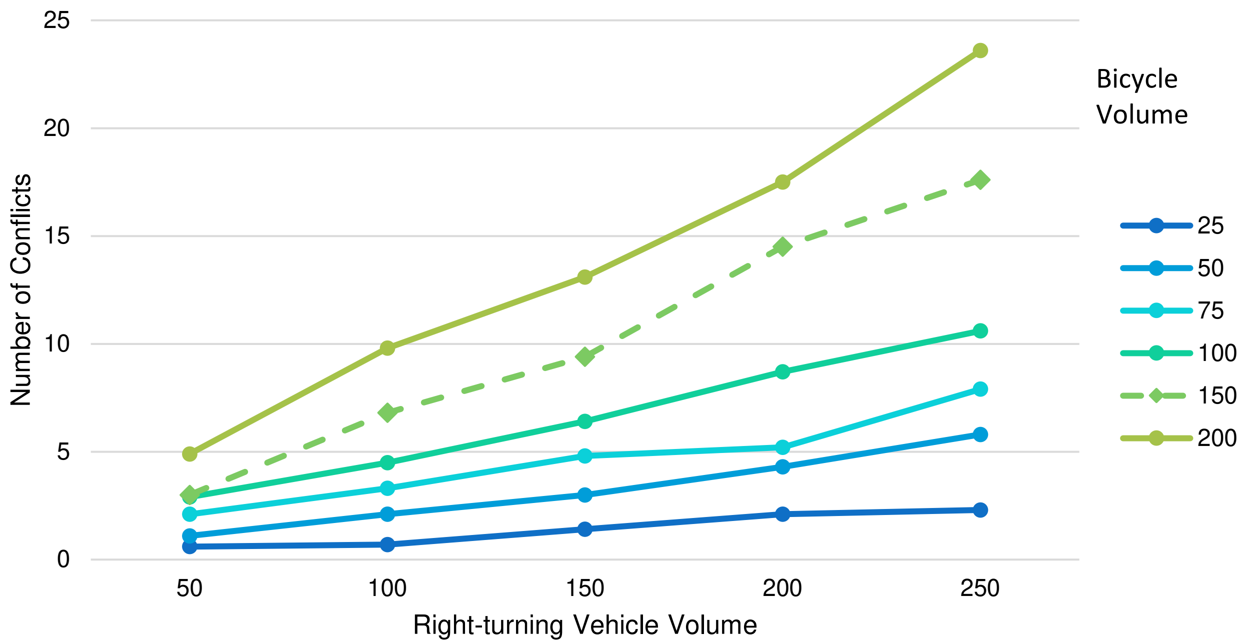



**Figure 6-4 Number of Simulated Conflicts (Bend-In Design)**

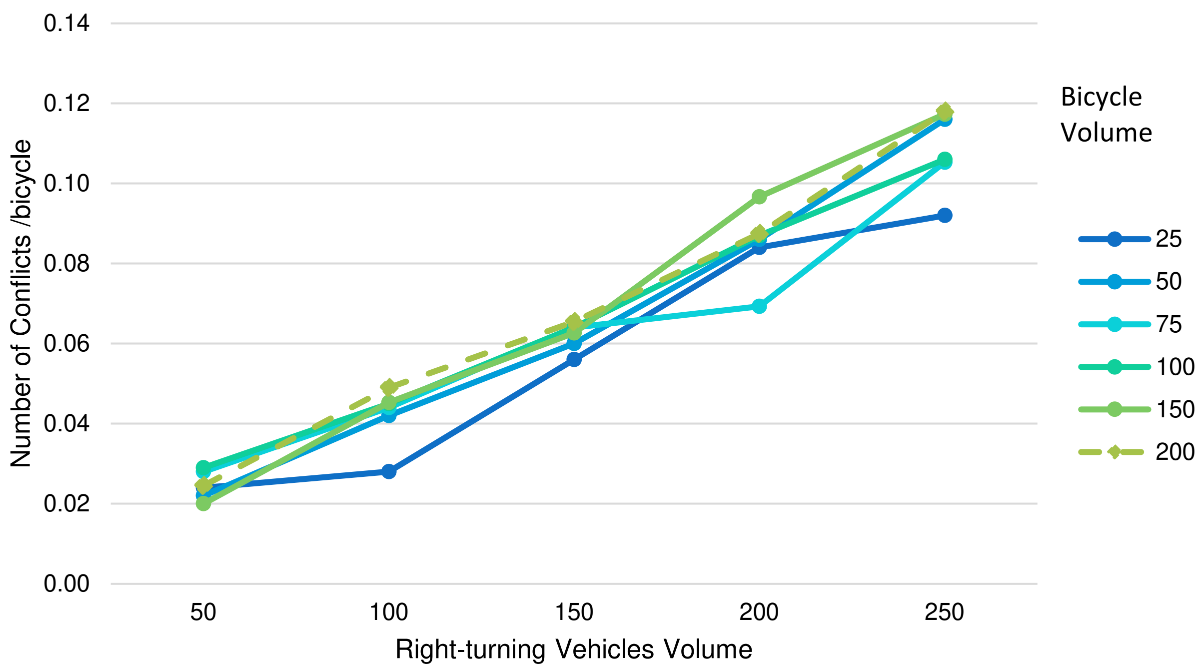



**Figure 6-5 Number of Simulated Conflicts Per Bicycle (Bend-In Design)**

Table 6-6 presents the MaxS of conflicts with different volume combination. The average ranges from 6.89 to 7.23 meters per second (15.4 to 16.2 miles per hour). The highest average MaxS occurs when bicycle volume equals 50 or right-turning vehicle volume equals 100, then the average MaxS decreases as the volumes increase. This might be because vehicle drivers usually are more careful and decrease their speed when they see other road users in the intersection. In this case, the severity levels of the conflicts decrease accordingly.

**Table 6-6 MaxS (m/s) of Simulated Conflicts (Bend-In Design)**

| Right-turning volume (veh/hr) | Bicycle volume (veh/hr) | | | | | | Average |
|---|---|---|---|---|---|---|---|
| | 25 | 50 | 75 | 100 | 150 | 200 | |
| 50 | 6.48 | 6.6 | 7.11 | 7.06 | 7.08 | 6.98 | 6.89 |
| 100 | 8.72 | 7.8 | 7.58 | 7.19 | 7.35 | 7.35 | 7.67 |
| 150 | 6.07 | 7.04 | 7.2 | 7.63 | 7.44 | 7.19 | 7.10 |
| 200 | 6.55 | 7.58 | 6.88 | 6.73 | 6.79 | 7.06 | 6.93 |
| 250 | 6.69 | 7.13 | 7.08 | 6.91 | 6.62 | 6.93 | 6.89 |
| Average | 6.90 | 7.23 | 7.17 | 7.10 | 7.06 | 7.10 | |

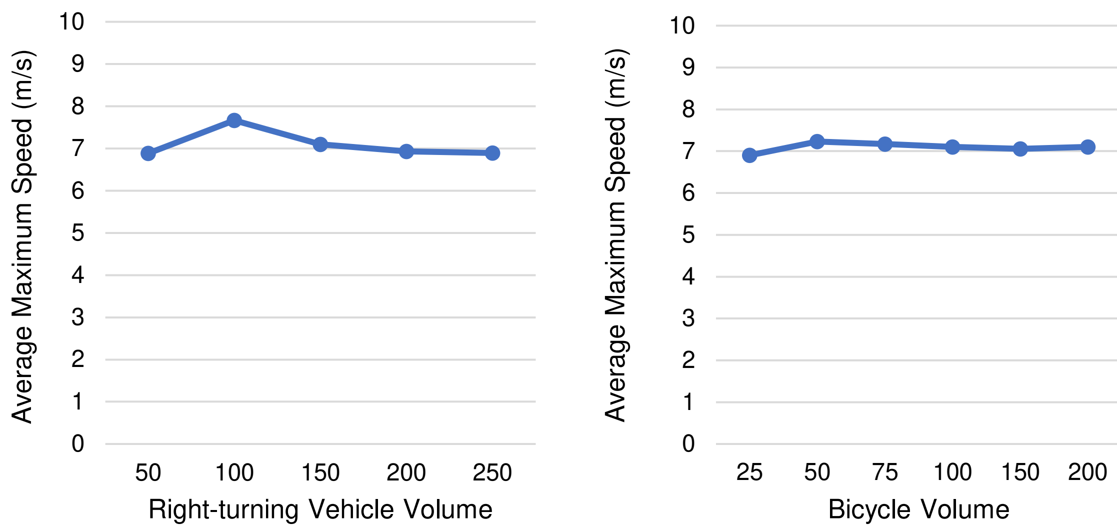



**Figure 6-6 Average MaxS (m/s) of Simulated Conflicts (Bend-In Design)**

## 6.3 BEND-OUT INTERSECTION

Table 6-7 shows the average number of conflicts of 10 simulation runs with different bicycle and vehicle volume combinations in bend-out intersections. The lowest number of conflicts is 0.8 per hour when bicycle volume equals 25 and right-turning vehicle volume equals 50 per hour. The highest number of conflicts is 62.9 per hour when bicycle volume equals 200 and right-turning vehicle volume equals 250 per hour.

Table 6-8 presents the number of conflicts per bicycle with different volume combinations. The lowest number is 0.03, which shows up with the lowest bicycle and right-turning vehicle volume combinations. The highest number is 0.31, much higher than the highest number in the other two intersections, when bicycle volume is 200 and vehicle volume is 250 per hour.

**Table 6-7 Number of Simulated Conflicts (Bend-Out Design)**

| Right-turning volume (veh/hr) | Bicycle volume (veh/hr) | | | | | |
|---|---|---|---|---|---|---|
| | **25** | **50** | **75** | **100** | **150** | **200** |
| 50 | 0.8 | 1.8 | 3.8 | 5.2 | 11.3 | 11.4 |
| 100 | 2.5 | 4.6 | 8.6 | 12.6 | 17.3 | 22.5 |
| 150 | 2.8 | 7.2 | 11.7 | 13.9 | 29 | 35.6 |
| 200 | 3.9 | 9.9 | 16 | 24.5 | 36.4 | 50.6 |
| 250 | 7.3 | 14.2 | 21.2 | 31.5 | 47 | 62.9 |

**Table 6-8 Number of Simulated Conflicts Per Bicycle (Bend-Out Design)**

| Right-turning volume (veh/hr) | Bicycle volume (veh/hr) | | | | | |
|---|---|---|---|---|---|---|
| | **25** | **50** | **75** | **100** | **150** | **200** |
| 50 | 0.03 | 0.04 | 0.05 | 0.05 | 0.08 | 0.06 |
| 100 | 0.10 | 0.09 | 0.11 | 0.13 | 0.12 | 0.11 |
| 150 | 0.11 | 0.14 | 0.16 | 0.14 | 0.19 | 0.18 |
| 200 | 0.16 | 0.20 | 0.21 | 0.25 | 0.24 | 0.25 |
| 250 | 0.29 | 0.28 | 0.28 | 0.32 | 0.31 | 0.31 |

Similar to mixing zone and bend-in intersections, the number of conflicts increases while the bicycle and vehicle volume increases, as they have more exposure on the road. The number of total conflicts increases relatively consistantly when bicycle and vehicle volume increases. Figure 6-8 indicates that the number of conflicts per bicycle increases as right-turning vehicle volume increase and, generally, the number of conflicts per bicycle with higher bicycle volume is higher than the ones with lower bicycle volume.

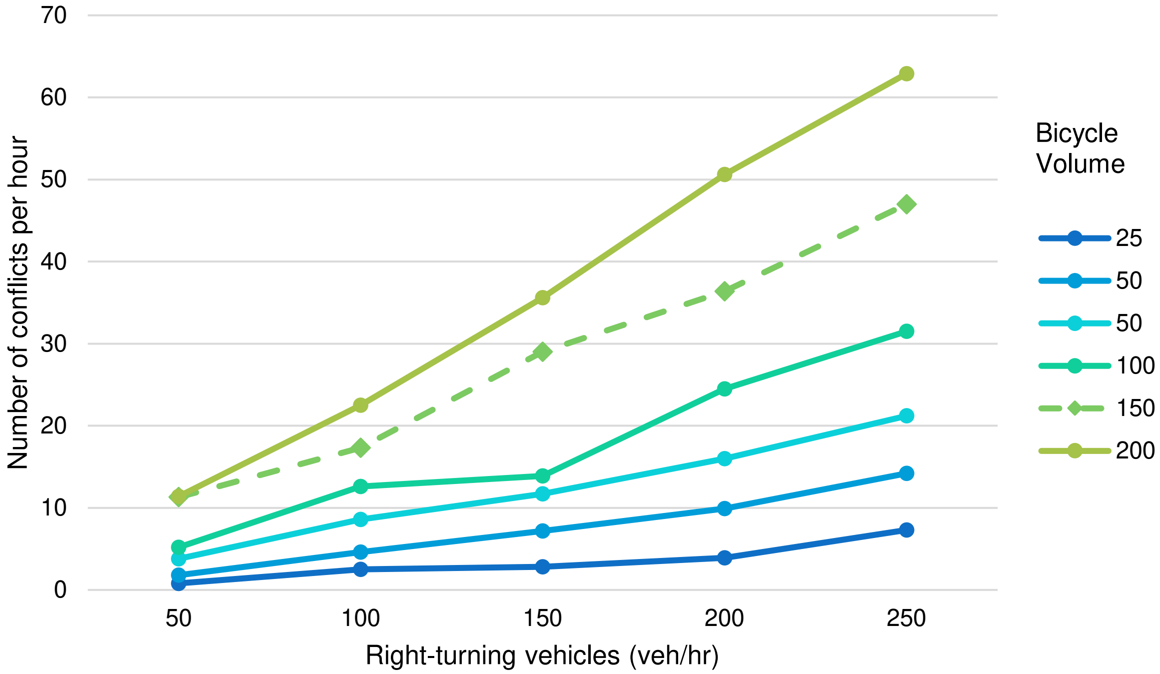



**Figure 6-7 Number of Simulated Conflicts (Bend-Out Design)**

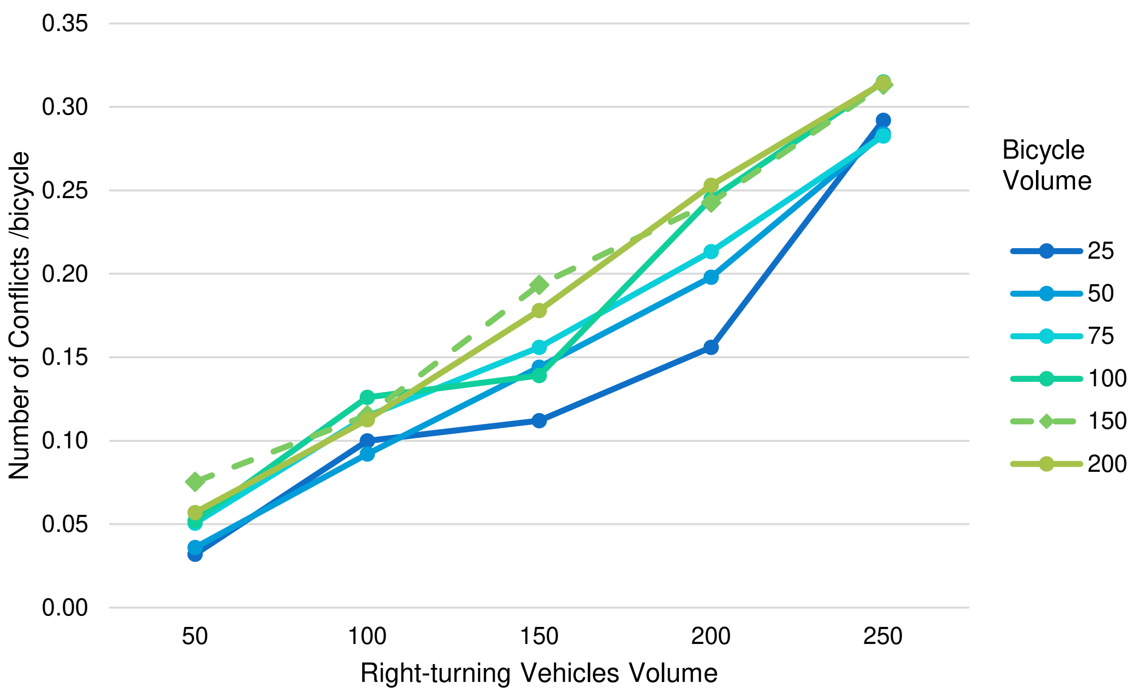



**Figure 6-8 Number of Simulated Conflicts Per Bicycle (Bend-Out Design)**

Table 6-9 presents the MaxS of conflicts in bend-out intersections. The average ranges from 3.03 to 3.61 meters per second (6.77 to 8.07 miles per hour). When the volume becomes higher the average MaxS decreases, which indicates that the severity level of the conflicts might be lower though the number of conflicts is higher. Figure 6-9 is the plot of average maximum speed of conflicts with bicycle or right-turning vehicles volume (veh/h).

**Table 6-9 MaxS of Simulated Conflicts (Bend-Out Design)**

| Right-turning volume (veh/hr) | Bicycle volume (veh/hr) | | | | | | Average |
|---|---|---|---|---|---|---|---|
| | 25 | 50 | 75 | 100 | 150 | 200 | |
| **50** | 4.06 | 3.7 | 3.65 | 3.54 | 3.3 | 3.38 | 3.61 |
| **100** | 3.28 | 3.77 | 3.33 | 3.16 | 3.39 | 3.23 | 3.36 |
| **150** | 3.67 | 3.51 | 3.29 | 3.28 | 3.24 | 3.04 | 3.34 |
| **200** | 3.43 | 3.27 | 3.2 | 3.19 | 3.13 | 2.96 | 3.20 |
| **250** | 3.28 | 3.17 | 2.95 | 2.9 | 2.93 | 2.94 | 3.03 |
| **Average** | 3.54 | 3.48 | 3.28 | 3.21 | 3.20 | 3.11 | |

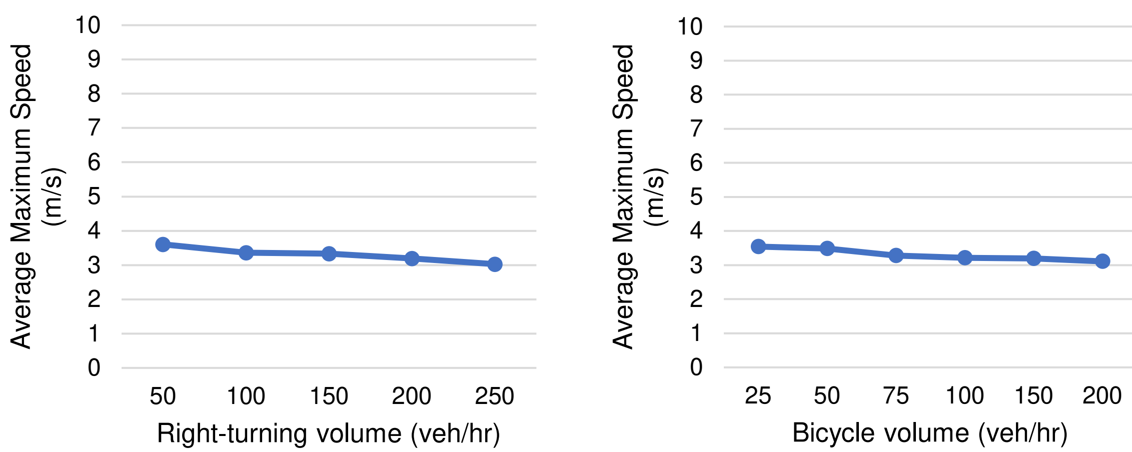



**Figure 6-9 Average MaxS (m/s) of Conflicts (Bend-Out Design)**

## 6.4 COMPARISON OF MODELS

Figure 6-10 shows the number of simulated conflicts of three intersections when bicycle volume equals 50, 100 and 200 per hour. The number of conflicts per bicycle in three intersections is almost same when right-turning vehicles volume is low, no matter how many bicycles are on the road. However, the number of conflicts per bicycle in bend-out intersections grows more rapidly when the right-turning vehicle volume increases compared to the other two intersections. This means that the number of conflicts per bicycle in bend-out intersections is more sensitive to bicycle and vehicle volumes than the other two intersections. Bend-in and mixing zone intersections had almost the same number of conflicts per bicycle when right-turning vehicle volume holds, but the number of conflicts per bicycle in mixing zone intersections grows faster when vehicle volume goes higher. The reason may be the one mentioned above, that vehicles and bicycles have more possibility to have conflicts in the whole mixing lane instead of only a conflict point in a bend-in intersection.

The MaxS of conflicts are also compared between three intersections (Figure 6-11). The conflicts that happen in a mixing zone intersection have the highest MaxS, bend-in intersection conflicts have a little bit lower MaxS and bend-out intersections have the lowest MaxS. This fact indicates that even though the number of conflicts in bend-out intersections is the highest, the severity levels of these conflicts may be the lowest of the three intersections. The reason may be that right-turning vehicles in bend-out intersections had the longest reduced speed area considering that the bend-out intersection is larger than the other two intersections.

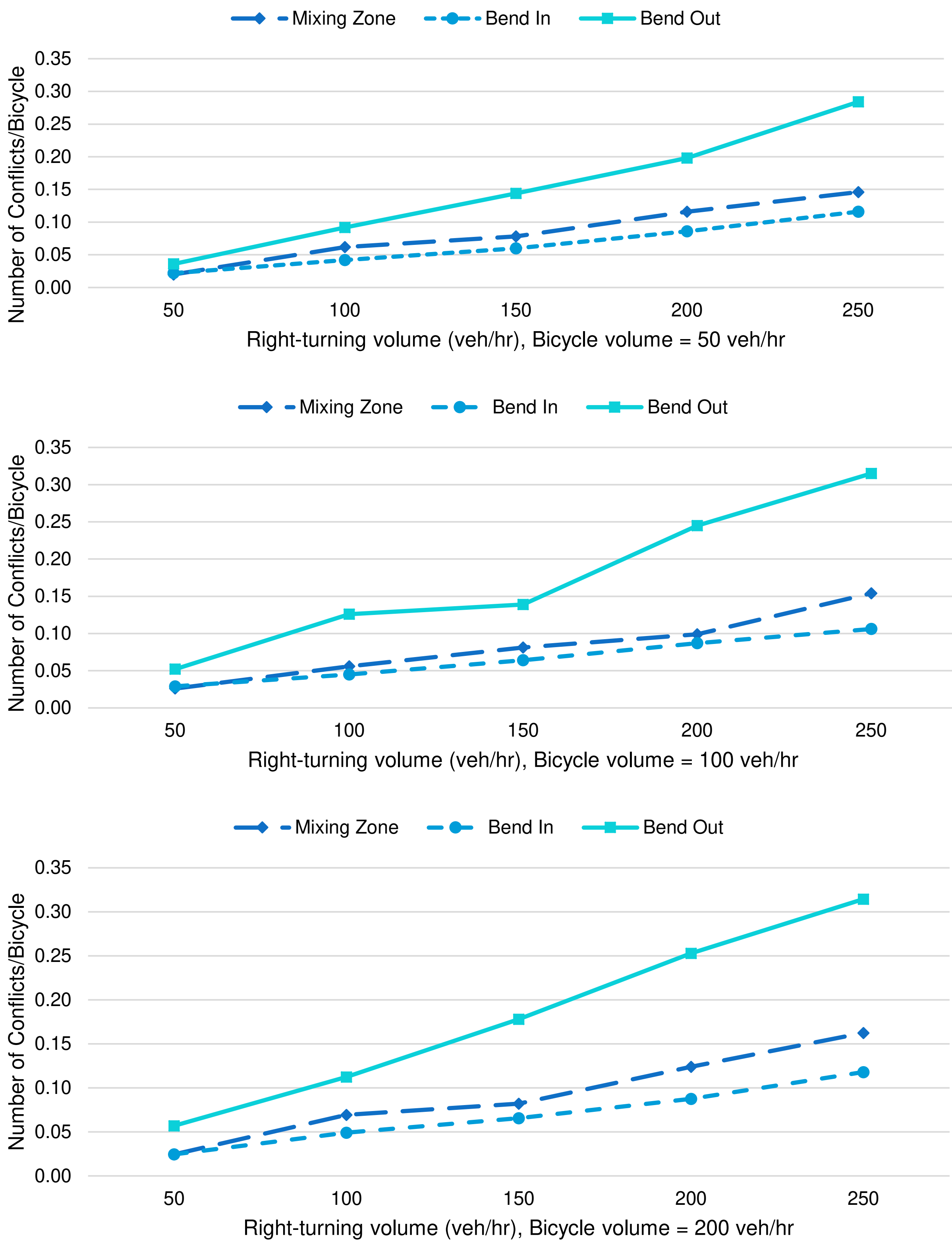



**Figure 6-10 Number of Simulated Conflicts Per Bicycle (All Designs)**

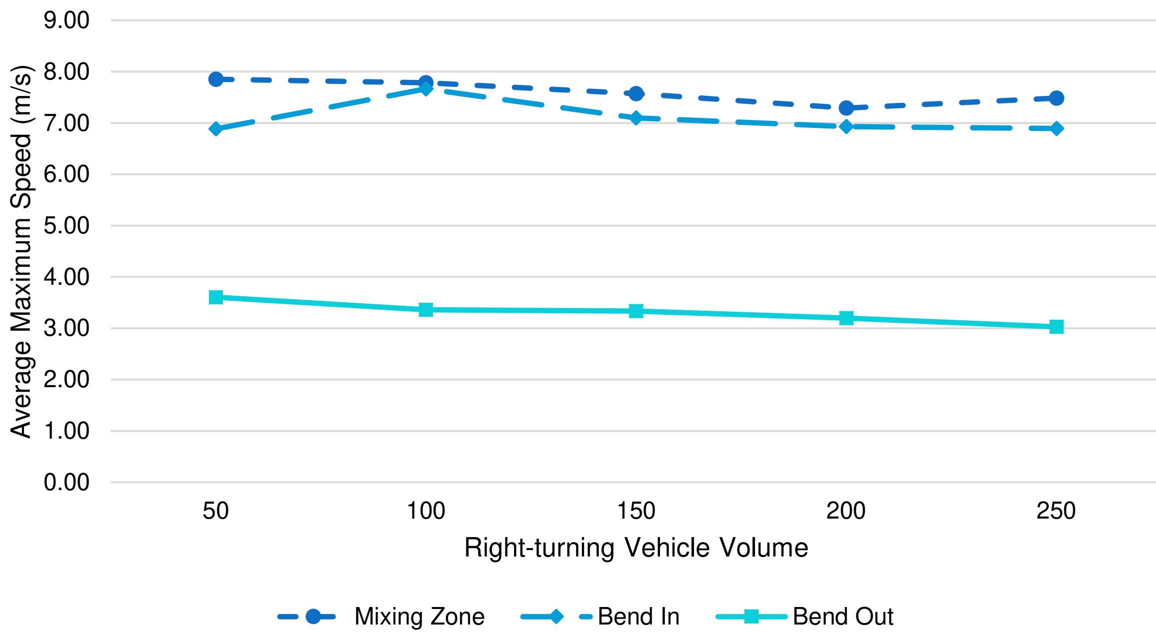



**Figure 6-11 Average MaxS of Conflict in Three Intersections**

## 6.5 SUMMARY

Microsimulation models were created in VISSIM and used to identify the expected frequency of interactions between bicyclists and motorists at intersections along protected bikeways. For this analysis, only the interactions between right-turning vehicles and through bicycles were studied. For each right-turning vehicle and through bicycle volume combination, the calibrated, validated simulation models were run 10 times. Trajectory files were post-processed using SSAM to identify interactions between vehicles and bicycles and surrogate measures of safety. There is an important limitation to note about the results in this chapter. The vast majority of the simulated conflicts filtered by SSAM have zero TTC or PET values. By definition, these are collisions or crashes. Efforts to refine the microsimulation models to reduce the zero TTC/PET values resulted in unrealistic yielding or interactions between the bicycles and vehicles (i.e., where a vehicle or bicycle would remain stopped in the simulation until one flow or the other allowed the stopped vehicle to proceed). Ultimately, because our objective was to gain an understanding of how the interactions varied by design and volume, we elected to use the models that best represented interactions between motorists and bicycles, even if the surrogate measures from these simulated conflicts were unrealistic. Thus, the results in this chapter show the simulated number of conflicts that met the threshold for PET and TTC, but we do not report these values as we do not believe they are realistic.

A brief summary of the microsimulation results:

1. As the volume, either bicycle of right-turning vehicle volume, increases the number of simulated conflicts of all three intersection models increases. The number of conflicts per bicycle also increases with right-turning vehicle volume increases.

2. With the same bicycle and right-turning vehicle volume combination, the number of conflicts in bend-out intersections is the highest and the number of conflicts in bend-in intersections is the lowest.

3. The average MaxS of conflicts in bend-out intersections is the lowest of the three types of intersections, which indicates that the conflicts in bend-out intersections may have the lowest severity level of conflicts.

These simulation models were based on the geometry of the intersections in Salt Lake City, UT, and Portland, OR. However, signal timing parameters were generalized and held constant for each model. We did not explore the effect of increasing volumes on delay of functionality (both to motorists and bicycles) as turning volumes increase. It is likely that when turning volumes are over 200 vehicles per hour, these intersections function better for all users with phase separation.

We did not expect the bend-out (protected) intersection to have the most estimated conflicts. The bend-out intersection model in Salt Lake City is based on a design that has a relatively large footprint. At the time of data collection, this was one of the only locations in the U.S. with a bend-out, protected intersection constructed. In the simulation, the right-turning vehicles and through bicycles are isolated to each other and this might be one of the reasons that bend-out intersections have the highest number of conflicts per bicycle in simulation. In a real mixing zone intersection, the conflict area is much larger than the ones in the other two intersections, as bicycles and vehicles merge to one lane when approaching the intersection. However, in the simulation model the lane following behavior required of the vehicles means these interactions are not well-captured in the simulation models.

# 7.0 CONTEXTUAL GUIDANCE

This chapter merges the survey comfort ratings with the simulated frequency with which cyclists would encounter turnings motorists as a function of though bicycle and right-turn volume to provide contextual guidance on selecting a design based on estimated cyclist comfort. This guidance is provided for both those more experienced and tolerant to traffic stress and those less tolerant to traffic stress and sensitive to comfort. This guidance does not suggest facilities be designed for a type of cyclist, rather it summarizes the results of this research so that comfort can be compared between designs and types of users.

## 7.1 COMBINING COMFORT AND SIMULATED INTERACTIONS

The mean comfort scores for the *Bike Inclined* and "*Interested but Concerned*" persons identified in by the K-means clustering exercise were combined with information from the simulated number of interactions for each design type. For each bicycle and right-turn volume combination, we can extract the number of cyclists per hour that, according to the simulations, either a) did not interact with a vehicle or b) interacted with a vehicle. We assumed for a) the comfort results for the turn-visible clips apply and for b) the comfort results for the negotiated turns are applicable. We assumed that the interactions (from a simulation perspective) of lateral shift are similar to the mixing zone and that straight path/maintain is represented by the bend-in design. The comfort scores and the percentage comfortable by type of interaction and cyclist type are presented in Table 5-23 and Table 5-24. The simulation models estimated the number of interactions and are presented in Table 6-1, Table 6-4, and Table 6-7.

The combined comfort scores and percentage comfortable were weighted by the number of interactions and calculated using the following equation:

$$CS_{t,b} = \frac{(S * C_N) + (b - S) * C_{TV}}{b}$$

Where:

$CS_{t,b}$ = weighted comfort score or percentage comfortable for turning volume (t) and bicycle volume (b)

$C_{TV}$= is the mean comfort score or percentage comfortable when a turn was visible

$C_N$ = is the mean comfort score or percentage comfortable when an interaction was present

$b$ = volume of bicycles per hour

$t$ =volume of turning vehicles per hour, rounded up to nearest integer

$S$= simulated number of conflicts.

As an example, calculation is shown for the mixing zone design for the *Bike Inclined* typology for 100 through bicycles and 100 right-turning vehicles:

$$CS_{t,b} = \frac{(6 * 3.35) + (100 - 6) * 3.32}{100} = 3.32$$

with:

$C_{TV}$= 3.32 (from Table 5-23)

$C_N$ = 3.35 (from Table 5-24)
$b$ = 100 (given)
$t$ =100 (given)
$S$= 6 (from Table 6-1, rounded to nearest integer)

While the calculations were made for the entire matrix of bicycle and right-turning vehicle volumes, the weighted comfort scores are not very sensitive to bicycle volumes. Thus, the results in Table 7-1 through Table 7-4 present the minimum weighted comfort score for the right-turn volumes for all bicycle volumes. The full matrix of the calculations is presented in the Appendix B.

There is research that supports that near misses (conflicts) have a significant impact on the perceptions of comfort for bicyclists (*Aldred, 2016*). We speculate that the interaction comfort scores should be weighted more so that the overall comfort score would decrease significantly more with increased conflicts. While we know that comfort declines with the presence of turning vehicles, we do not know the exact relationship with comfort and volume. Thus, the estimates presented here are most likely the best comfort that could be obtained.

## 7.2 GUIDANCE

The results of this research can be used to inform the selection of intersection designs for separated or protected bike lanes on the basis of comfort of the persons riding through the intersections. The results have been summarized and tabulated for two broad types of cyclists. The selection of a cyclist typology can be used to explore the comfort tradeoffs of each design. The *Interested but Concerned* is appropriate when considering an all-ages-and-ability, low-stress network and would reflect the comfort of the widest range of persons. The *Bike Inclined* typology is narrower and primarily reflects the comfort of those already willing to bicycle for transportation. To use the results of this research, the following steps can be followed:

**Step 1: Select cyclist typology**

To consider the comfort of current cyclists can use the table outputs presented for the *Bike Inclined*. As a reminder, the *Bike Inclined* respondents were least likely to say that traffic keeps them from riding a bicycle, felt that destinations were within bikeable distances and that they saw people like them riding in their neighborhoods. They were most likely to have biked for transport and were more likely than respondents in other groups to be male and white.

To consider the comfort of prospective cyclists can use the table outputs presented for the *Interested but Concerned*. As a reminder, these respondents were nearly all interested in biking more but felt that traffic kept them from riding more. They were also more likely than other respondents to be female. This typology would be appropriate when considering an all-ages-and-ability, low-stress network.

**Step 2: Select acceptable comfort thresholds**

The selection of an acceptable mean comfort score will be a context-specific decision. The survey results were developed using a five-point scale. A mean score of 3.0 is neutral, a rating of neither comfortable nor uncomfortable. The tables can be interpreted with this scale. Based on a review of the established comfort scores of those who rated clips suitable for riding with children, an all-ages-and-ability comfort score would be 4.0.

**Step 3: Consider other enhancements to the design for comfort**

These final results have been aggregated to the similar intersection designs. Analysis of the differences between intersection types and other features suggest some enhancements to the designs that likely improve overall comfort of persons riding through the intersections.

The following sections present the guidance for the types identified in Step 1.

### 7.2.1 Comfort guidance for the *Bike Inclined* typology

Table 7-1 presents the mean comfort scores for the turn-visible and interaction clips extracted from Table 5-23 and Table 5-24. The weighted comfort scores are presented by right-turning vehicles volumes as described. The designs are ordered in the table from left to right by comfort score. At the single digit rounding, there is little variation in the comfort score by volume since the weighting by the simulated conflicts does not change the rating much. Table 7-2 presents the estimated percentage comfortable for each design using the same weighting methodology.

For this typology, all designs except the mixing zones exceed a mean score of 3.5. The cells shaded grey in both tables indicate where the comfort of the design may be more impacted by turning volumes than our methodology estimates (based on further analysis of the data and judgement of the research team).

For the comfort scores for the lateral shifts, bend-in and maintain separation, the percentage comfortable drops significantly when the clips involved an interaction with a vehicle. Thus, the cells for right-turning volumes over 150 vehicles per hour are shaded grey, as it likely that these comfort scores would be lower than we have estimated. Based on cyclists' comfort, a signal separated intersection or a protected intersection (bend-out) should be considered. If other designs are chosen, enhancements such as minimizing the exposure length and providing as much separation from vehicles as possible should be considered. As stated previously, it is likely that when turning volumes are over 200 vehicles per hour, these intersections would function better for all users from a delay and functionality perspective with phase separation. Another important note is that the survey did not find a difference in the comfort of mixing zone designs with or without vehicle interactions. We suspect that mixing zone design implies interactions even when no vehicles are present.

**Table 7-1 Estimated Mean Comfort Score for Each Design, Bike Inclined**

| Comfort Score | | Mixing zone | Lateral Shift | Bend in | Maintain separation | Signal | Bend out / Protected Intersection |
|---|---|---|---|---|---|---|---|
| Turn visible | | 3.32 | 3.56 | 3.81 | 3.87 | 4.0 | 4.30 |
| Interaction | | 3.35 | 3.15 | 3.40 | 3.32 | | 3.97 |
| Right-turning volumes | 50 | 3.3 | 3.5 | 3.8 | 3.8 | 4.0 | 4.3 |
| | 100 | 3.3 | 3.5 | 3.8 | 3.8 | 4.0 | 4.3 |
| | 150 | *3.5* | *3.5* | *3.8* | *3.8* | 4.0 | 4.2 |
| | 200 | *3.3* | *3.5* | *3.8* | *3.8* | 4.0 | 4.2 |
| | 250 | *3.3* | *3.5* | *3.8* | *3.8* | 4.0 | 4.2 |

**Table 7-2 Estimated Percentage Comfortable for Each Design, Bike Inclined**

| Percentage Comfortable | | Mixing zone | Lateral Shift | Bend in | Maintain separation | Signal | Bend out / Protected Intersection |
|---|---|---|---|---|---|---|---|
| Turn visible | | 47% | 59% | 64% | 68% | 73% | 83% |
| Interaction | | 49% | 42% | 50% | 45% | | 72% |
| Right-turning volumes | 50 | 47% | 58% | 63% | 67% | 73% | 82% |
| | 100 | 47% | 58% | 63% | 67% | 73% | 82% |
| | 150 | *47%* | *56%* | *63%* | *66%* | 73% | 81% |
| | 200 | *47%* | *56%* | *62%* | *65%* | 73% | 80% |
| | 250 | *47%* | *56%* | *62%* | *65%* | 73% | 79% |

### 7.2.2 Comfort guidance for the *Interested but Concerned* typology

Table 7-3 presents the mean comfort scores for the turn-visible and interaction clips extracted from Table 5-23 and Table 5-24. Table 7-4 presents the corresponding estimated percentage comfortable. The weighted comfort scores are then presented by right-turning volumes as described. The tables reflect the comfort scores for those persons who were grouped in the *Interested but Concerned* type. As shown previously, the comfort scores are all lower than the *Bike Inclined* typology and only the signal or protected intersection designs have comfort scores that exceed 3.5. All of the designs that require the person on a bicycle to interact or mix with motorists have scores below 3.5. Similar to the *Bike Inclined* typology, there is a significant drop in the estimated comfort when there is an interaction with motorists. Given the sensitivity of this group to traffic stress, all the cells are shaded grey.

**Table 7-3 Estimated Mean Comfort Score, Interested But Concerned**

| Comfort Score | | Mixing zone | Lateral Shift | Bend in | Maintain separation | Signal | Bend out / Protected Intersection |
|---|---|---|---|---|---|---|---|
| Turn visible | | 2.88 | 2.90 | 3.31 | 3.43 | 3.7 | 3.78 |
| Interaction | | 2.78 | 2.50 | 2.92 | 2.76 | | 3.61 |
| By right-turning volumes | 50 | *2.9* | *2.9* | *3.3* | *3.4* | 3.7 | 3.8 |
| | 100 | *2.9* | *2.9* | *3.3* | *3.4* | 3.7 | 3.8 |
| | 150 | *2.9* | *2.8* | *3.3* | *3.4* | 3.7 | 3.7 |
| | 200 | *2.9* | *2.8* | *3.3* | *3.3* | 3.7 | 3.7 |
| | 250 | *2.9* | *2.8* | *3.3* | *3.3* | 3.7 | 3.7 |

**Table 7-4 Estimated Percentage Comfortable for Each Design, Interested But Concerned**

| Comfort Score | | Mixing zone | Lateral Shift | Bend in | Maintain separation | Signal | Bend out / Protected Intersection |
|---|---|---|---|---|---|---|---|
| Turn visible | | 32% | 30% | 46% | 51% | 65% | 71% |
| Interaction | | 26% | 24% | 33% | 25% | | 60% |
| By right-turning volumes | 50 | *32%* | *30%* | *45%* | *50%* | 65% | 70% |
| | 100 | *32%* | *30%* | *45%* | *49%* | 65% | 70% |
| | 150 | *31%* | *29%* | *45%* | *49%* | 65% | 69% |
| | 200 | *31%* | *29%* | *44%* | *48%* | 65% | 68% |
| | 250 | *31%* | *29%* | *44%* | *48%* | 65% | 67% |

# 8.0 CONCLUSIONS

The research approach was guided by the assumption that cyclist comfort is a key desired design outcome. In-person video surveys are used to identify people's comfort levels while bicycling through a variety of intersection designs under defined conditions (e.g., with or without interactions with turning motorists). A total of 277 respondents rated 26 video clips showing cyclists riding through a variety of intersections, for a total of 7,166 ratings. Surveys were conducted at four locations in three states, including urban and suburban locations in Oregon, Minnesota and Maryland. Simulation models were built and calibrated to the bend-in, mixing zone, and bend-out (protected intersection) designs that were tested in the in-person survey. Bicycle and vehicle volumes varied from 50 to 250 vehicles per hour and 10 simulations pairs were run. The estimated number of conflicts were extracted from the resulting 900 trajectory files using the Federal Highway Administration (FHWA) Surrogate Safety Assessment Model (SSAM) software. The results of the survey comfort data and estimated conflicts were combined to produce estimates of comfort for two groups of persons on bicycles.

The primary conclusions of this research are:

1. The survey respondents represent a mix of current travel behaviors and bicycling experience, including some people who don't ride at all (particularly for transportation purposes), some who have not ridden in the past year, and some who ride regularly. However, it may not be representative of the general U.S. urban population in the following ways: younger, more educated, less car ownership, underrepresented the non-white and/or hispanic respondents.
2. Separation from traffic matters for comfort of people on bicycles.
    - Protected intersections and bike signals were found to provide the best expected rider comfort. Two-thirds of all respondents rated them as very comfortable or somewhat comfortable.
    - Designs that keep a separate bike lane (bend-in, straight-path) were rated as comfortable by more than half of all respondents but were sensitive to the presence of turning vehicles. This may be that without the vehicles in the video clip, the design implies separation from vehicles and is rated higher but when shown interacting with vehicles, it is more apparent to the extent cyclists must mix with traffic.
    - Designs that move bicyclists and motor vehicles into shared space (mixing zones or lateral shifts) were viewed as least comfortable. There was not a difference in the comfort of mixing zone designs with or without vehicle interactions. One potential reason for this is that mixing zones cyclists and motor vehicles are already primed for interaction (as opposed to separated spaces). Additionally, in most of the cases in which cyclists were negotiating interactions with turning vehicles, the vehicles were moving quite slowly.
3. There were demographic and attitude differences in the overall comfort scores that are consistent with other research.

- Women and non-white respondents were generally less likely to feel comfortable than other respondents.

- Those who indicated that they rode for transportation in the past year also had higher average comfort ratings than those who did not.

4. Exposure distance, measured as the end of vertical separation on one side of the intersection to the start of separation on the far side is a significant predictor of comfort.

    - *Interested but Concerned* respondents were particularly sensitive to the exposure distance, with the upstream exposure lowering comfort more than that the crossing distance exposure. From a comfort viewpoint, shortening exposure distance is a good design objective.

5. When asked about locations that they would ride in with a ten-year old child, the bend-in design and protected intersection were the highest-rated intersection locations, while the lateral shift and mixing zone locations were the lowest. The survey results provide valuable insights but should be interpreted with caution as they are each based on a single video clip, without any interaction with a turning vehicle.

6. The microsimulation results found that as the volume, either bicycle or right-turning vehicle volume, increases the number of simulated conflicts increases. The number of conflicts per bicycle also increases with right-turning vehicle volume. With the same bicycle and right-turning vehicle volume combination, the number of conflicts in bend-out or protected intersections was the highest and the number of conflicts in bend-in intersections is the lowest. However, the average maximum speed of a vehicle involved in a conflict was lowest in bend-out (or protected) intersections which indicates that the conflicts in bend-out intersections may have the lowest severity level of conflicts.

7. The research estimated the level of comfort for both more experienced and tolerant to traffic stress (*Bike Inclined*) and those less tolerant to traffic stress and sensitive to comfort (*Interested but Concerned*) varied by right-turning motor vehicles and through bicycles. This was done by combining the comfort scores for interactions with turning vehicles and no interactions weighted by the estimated number of conflicts. For both types of cyclists, the order of the designs for comfort is the same, but the estimated score and percent comfortable vary.

    - For *Interested but Concerned* cyclists' comfort, only the signal phase separation (3.7 comfort score and 65% comfortable) and protected intersection (3.7-3.8 score and 67% to 70% comfortable) are recommended options.

    - For *Bike Inclined* cyclists' comfort, signal phase separation (4.0 comfort score and 73% comfortable) and protected intersection (4.2-4.3 score and 79% to 82% comfortable) are still considered the most comfortable. The maintain separation (3.8 comfort score and 65% to 67% comfortable) and bend-in (3.8 comfort score and 62% to 63% comfortable) are ranked next. The designs with the most mixing with traffic have the lowest scores: lateral shift (3.5 comfort score and 56% to

58% comfortable) and mixing zone (3.3 to 3.5 comfort score and 47% comfortable).

## 8.1 LIMITATIONS AND FUTURE WORK

This research only addresses the design objective of comfort. This research did not study the safety of these design options (either in terms of reported crashes or other surrogate measures). The safety of these designs is an area of continued research need as any design selection also needs to consider safety and other considerations. One promising method would be to explore the conflicts measured in the field at each of these designs with automated vision processing tools or other methods. The challenge of this approach is that it has been challenging to identify intersections that are consistent in design to evaluate the effect of motor vehicle turning volumes, though this will change as more separated bike lanes are constructed

While we attempted to obtain a diverse and representative sample, these scores represent the perceptions of the persons surveyed. The respondents represent a good mix of current travel behaviors and bicycling experience, including some people who don't ride at all (particularly for transportation purposes), some who have not ridden in the past year, and some who ride regularly but is not as representative on other demographic measures. In addition, while we have generalized the results to the design type, these scores are based on images and interactions at specific locations shown in the video clips. It is possible that other variables in the video clips influenced the comfort ratings even though we attempted to minimize any confounding effects. In addition, we opted to focus on selecting locations and clips that had similar streetscapes and feel. Thus, the clips that we selected are of streets that are generally wide and do not reflect the diversity of conditions that exist in all cities. While we present overall comfort scores for each design, we were not able to differentiate the aspects of the designs in determining the mean comfort scores (such as the length of the mix-merge length or the offsets for the bend-ins or bend-outs). We also were not able to establish the rate of change of comfort as interactions with vehicles increase. Finally, this research did not left-turning traffic, pedestrians, or two-way configurations. Future research could be designed to explore these open questions would be useful.

The microsimulation of bicycle-vehicle interactions has not yet been completely validated as a tool that replicates reality for bicycle-vehicle interactions. We also assumed that the interactions (from a simulation perspective) of lateral shift are similar to the mixing zone design and that straight path/maintain is represented by the bend-in design – there may be differences in these designs not captured in our recommendations. In addition, we made a number of simplifying assumptions in constructing the models and were not able to explore all possible calibration parameters. As such, it is not recommended that the results from the microsimulation be extended outside the context used in this research for weighting the comfort scores. Future work should seek to develop better validation and outputs of the surrogate safety measures by refining the calibration inputs and model settings.

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# Appendix A

**Table 9-1 Survey Respondents and 2017 Five-Year ACS**

| | Portland, OR | | Woodburn, OR | | Minneapolis, MN | | Takoma Park, MD | | Total |
|---|---|---|---|---|---|---|---|---|---|
| | **Survey** | **ACS*** | **Survey** | **ACS*** | **Survey** | **ACS*** | **Survey** | **ACS*** | |
| **Age** | | | | | | | | | |
| 18 to 24 | 16% | 10% | 41% | 12% | 39% | 17% | 11% | 9% | 23% |
| 25 to 34 | 33% | 24% | 21% | 19% | 42% | 28% | 13% | 17% | 28% |
| 35 to 54 | 22% | 37% | 33% | 32% | 12% | 31% | 33% | 41% | 25% |
| 55 + | 29% | 29% | 5% | 37% | 7% | 24% | 43% | 32% | 25% |
| n | 97 | | 39 | | 57 | | 75 | | 268 |
| **Gender Identity** | | | | | | | | | |
| female | 57% | 51% | 48% | 52% | 54% | 49% | 58% | 53% | 56% |
| male | 43% | 50% | 52% | 48% | 46% | 51% | 42% | 47% | 44% |
| n | 96 | | 42 | | 57 | | 77 | | 272 |
| **Race and Ethnicity** | | | | | | | | | |
| White, non-Hispanic | 66% | 71% | 31% | 40% | 81% | 60% | 72% | 46% | 65% |
| Hispanic or non-white | 28% | 29% | 60% | 60% | 16% | 40% | 17% | 54% | 27% |
| Hispanic, Latino, or Spanish origin | 7% | 10% | 26% | 56% | 7% | 10% | 4% | 11% | 9% |
| American Indian or Alaska Native | 1% | 1% | 2% | 0% | 0% | 0% | 0% | 0% | 1% |
| Asian | 13% | 8% | 26% | 1% | 9% | 6% | 1% | 6% | 11% |
| Black or African American | 5% | 6% | 5% | 0% | 0% | 19% | 9% | 35% | 5% |
| n | 97 | | 42 | | 57 | | 76 | | 272 |

*2017 5-year ACS

# Appendix B

## Mixing Zones

| Simulated Interactions Per Hour | | | | | | |
|---|---|---|---|---|---|---|
| Right-turning volume (veh/hr) | Bicycle volume (veh/hr) | | | | | |
| | 25 | 50 | 75 | 100 | 150 | 200 |
| 50 | 1 | 1 | 3 | 3 | 3 | 5 |
| 100 | 2 | 4 | 6 | 6 | 9 | 14 |
| 150 | 4 | 4 | 7 | 9 | 13 | 17 |
| 200 | 4 | 6 | 10 | 10 | 16 | 25 |
| 250 | 3 | 8 | 11 | 16 | 21 | 33 |

**Bike Inclined**

| Comfort Score | 3.32 | turn visible | | | | | |
|---|---|---|---|---|---|---|---|
| | 3.35 | interaction | | | | | |
| Right-turning volume (veh/hr) | Bicycle volume (veh/hr) | | | | | | Min Score |
| | 25 | 50 | 75 | 100 | 150 | 200 | |
| 50 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.32 |
| 100 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.32 |
| 150 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.32 |
| 200 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.32 |
| 250 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.32 |

| Percent Comfort | 0.47 | turn visible | | | | |
|---|---|---|---|---|---|---|
| | 0.49 | interaction | | | | |
| Bicycle volume (veh/hr) | | | | | | Min Score |
| 25 | 50 | 75 | 100 | 150 | 200 | |
| 47% | 47% | 47% | 47% | 47% | 47% | 47% |
| 47% | 47% | 47% | 47% | 47% | 47% | 47% |
| 47% | 47% | 47% | 47% | 47% | 47% | 47% |
| 47% | 47% | 47% | 47% | 47% | 47% | 47% |
| 47% | 47% | 47% | 47% | 47% | 47% | 47% |

**Interested But Concerned**

| Comfort Score | 2.88 | turn visible | | | | | |
|---|---|---|---|---|---|---|---|
| | 2.78 | interaction | | | | | |
| Right-turning volume (veh/hr) | Bicycle volume (veh/hr) | | | | | | Min Score |
| | 25 | 50 | 75 | 100 | 150 | 200 | |
| 50 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.88 |
| 100 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.87 |
| 150 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.86 |
| 200 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.86 |
| 250 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.86 |

| Percent Comfort | 0.32 | turn visible | | | | |
|---|---|---|---|---|---|---|
| | 0.26 | interaction | | | | |
| Bicycle volume (veh/hr) | | | | | | Min Score |
| 25 | 50 | 75 | 100 | 150 | 200 | |
| 32% | 32% | 32% | 32% | 32% | 32% | 32% |
| 32% | 32% | 32% | 32% | 32% | 32% | 32% |
| 31% | 32% | 31% | 31% | 31% | 31% | 31% |
| 31% | 31% | 31% | 31% | 31% | 31% | 31% |
| 31% | 31% | 31% | 31% | 31% | 31% | 31% |

## Lateral Shift

| Simulated Interactions Per Hour | | | | | | |
|---|---|---|---|---|---|---|
| Right-turning volume (veh/hr) | Bicycle volume (veh/hr) | | | | | |
| | 25 | 50 | 75 | 100 | 150 | 200 |
| 50 | 1 | 1 | 3 | 3 | 3 | 5 |
| 100 | 2 | 4 | 6 | 6 | 9 | 14 |
| 150 | 4 | 4 | 7 | 9 | 13 | 17 |
| 200 | 4 | 6 | 10 | 10 | 16 | 25 |
| 250 | 3 | 8 | 11 | 16 | 21 | 33 |

**Bike Inclined**

| Comfort Score | Comfort S | 3.56 | turn visible |
|---|---|---|---|
| | | 3.15 | interaction |

| Right-turning volume (veh/hr) | Bicycle volume (veh/hr) | | | | | | Min Score |
|---|---|---|---|---|---|---|---|
| | 25 | 50 | 75 | 100 | 150 | 200 | |
| 50 | 3.5 | 3.6 | 3.5 | 3.5 | 3.6 | 3.5 | 3.54 |
| 100 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.53 |
| 150 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.49 |
| 200 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.49 |
| 250 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.49 |

| Percent | 0.59 | turn visible |
|---|---|---|
| Comfort | 0.42 | interaction |

| Bicycle volume (veh/hr) | | | | | | Min Score |
|---|---|---|---|---|---|---|
| 25 | 50 | 75 | 100 | 150 | 200 | |
| 58% | 59% | 58% | 58% | 59% | 59% | 58% |
| 58% | 58% | 58% | 58% | 58% | 58% | 58% |
| 56% | 58% | 57% | 57% | 58% | 58% | 56% |
| 56% | 57% | 57% | 57% | 57% | 57% | 56% |
| 57% | 56% | 57% | 56% | 57% | 56% | 56% |

**Interested But Concerned**

| Comfort Score | 2.9 | turn visible |
|---|---|---|
| | 2.5 | interaction |

| Right-turning volume (veh/hr) | Bicycle volume (veh/hr) | | | | | | Min Score |
|---|---|---|---|---|---|---|---|
| | 25 | 50 | 75 | 100 | 150 | 200 | |
| 50 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.88 |
| 100 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.87 |
| 150 | 2.8 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.84 |
| 200 | 2.8 | 2.9 | 2.8 | 2.9 | 2.9 | 2.9 | 2.84 |
| 250 | 2.9 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.83 |

| Percent | 0.3 | turn visible |
|---|---|---|
| Comfort | 0.24 | interaction |

| Bicycle volume (veh/hr) | | | | | | Min Score |
|---|---|---|---|---|---|---|
| 25 | 50 | 75 | 100 | 150 | 200 | |
| 30% | 30% | 30% | 30% | 30% | 30% | 30% |
| 30% | 30% | 30% | 30% | 30% | 30% | 30% |
| 29% | 30% | 29% | 29% | 29% | 29% | 29% |
| 29% | 29% | 29% | 29% | 29% | 29% | 29% |
| 29% | 29% | 29% | 29% | 29% | 29% | 29% |

## Bend-In

| Simulated Interactions Per Hour | | | | | | |
|---|---|---|---|---|---|---|
| Right-turning volume (veh/hr) | Bicycle volume (veh/hr) | | | | | |
| | 25 | 50 | 75 | 100 | 150 | 200 |
| 50 | 1 | 2 | 3 | 3 | 3 | 5 |
| 100 | 1 | 3 | 4 | 5 | 7 | 10 |
| 150 | 2 | 3 | 5 | 7 | 10 | 14 |
| 200 | 3 | 5 | 6 | 9 | 15 | 18 |
| 250 | 3 | 6 | 8 | 11 | 18 | 24 |

**Bike Inclined**

| Comfort Score | Comfort S | 3.81 | turn visible | | | |
|---|---|---|---|---|---|---|
| | | 3.4 | interaction | | | |
| Right-turning volume (veh/hr) | Bicycle volume (veh/hr) | | | | | Min Score |
| | 25 | 50 | 75 | 100 | 150 | 200 | |
| 50 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.79 |
| 100 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.79 |
| 150 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.78 |
| 200 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.76 |
| 250 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.76 |

| Percent Comfort | 0.64 | turn visible | | | | |
|---|---|---|---|---|---|---|
| | 0.5 | interaction | | | | |
| Bicycle volume (veh/hr) | | | | | | Min Score |
| 25 | 50 | 75 | 100 | 150 | 200 | |
| 63% | 63% | 63% | 64% | 64% | 64% | 63% |
| 63% | 63% | 63% | 63% | 63% | 63% | 63% |
| 63% | 63% | 63% | 63% | 63% | 63% | 63% |
| 62% | 63% | 63% | 63% | 63% | 63% | 62% |
| 62% | 62% | 63% | 62% | 62% | 62% | 62% |

**Interested But Concerned**

| Comfort Score | | 3.31 | turn visible | | | | |
|---|---|---|---|---|---|---|---|
| | | 2.92 | interaction | | | | |
| Right-turning volume (veh/hr) | Bicycle volume (veh/hr) | | | | | | Min Score |
| | 25 | 50 | 75 | 100 | 150 | 200 | |
| 50 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.29 |
| 100 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.29 |
| 150 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.28 |
| 200 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.26 |
| 250 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.26 |

| Percent Comfort | 0.46 | turn visible | | | | |
|---|---|---|---|---|---|---|
| | 0.33 | interaction | | | | |
| Bicycle volume (veh/hr) | | | | | | Min Score |
| 25 | 50 | 75 | 100 | 150 | 200 | |
| 45% | 45% | 45% | 46% | 46% | 46% | 45% |
| 45% | 45% | 45% | 45% | 45% | 45% | 45% |
| 45% | 45% | 45% | 45% | 45% | 45% | 45% |
| 44% | 45% | 45% | 45% | 45% | 45% | 44% |
| 44% | 44% | 45% | 45% | 44% | 44% | 44% |

## Maintain Separation

| Simulated Interactions Per Hour | | | | | | |
|---|---|---|---|---|---|---|
| Right-turning volume (veh/hr) | Bicycle volume (veh/hr) | | | | | |
| | 25 | 50 | 75 | 100 | 150 | 200 |
| 50 | 1 | 2 | 3 | 3 | 3 | 5 |
| 100 | 1 | 3 | 4 | 5 | 7 | 10 |
| 150 | 2 | 3 | 5 | 7 | 10 | 14 |
| 200 | 3 | 5 | 6 | 9 | 15 | 18 |
| 250 | 3 | 6 | 8 | 11 | 18 | 24 |

**Bike Inclined**

| Comfort Score | Comfort S | 3.87 | turn visible |
|---|---|---|---|
| | | 3.32 | interaction |

| Right-turning volume (veh/hr) | Bicycle volume (veh/hr) | | | | | | Min Score |
|---|---|---|---|---|---|---|---|
| | 25 | 50 | 75 | 100 | 150 | 200 | |
| 50 | 3.8 | 3.8 | 3.8 | 3.9 | 3.9 | 3.9 | 3.85 |
| 100 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.84 |
| 150 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.83 |
| 200 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.80 |
| 250 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.80 |

| Percent Comfort | 0.68 | turn visible |
|---|---|---|
| | 0.45 | interaction |

| Bicycle volume (veh/hr) | | | | | | Min Score |
|---|---|---|---|---|---|---|
| 25 | 50 | 75 | 100 | 150 | 200 | |
| 67% | 67% | 67% | 67% | 68% | 67% | 67% |
| 67% | 67% | 67% | 67% | 67% | 67% | 67% |
| 66% | 67% | 66% | 66% | 66% | 66% | 66% |
| 65% | 66% | 66% | 66% | 66% | 66% | 65% |
| 65% | 65% | 66% | 65% | 65% | 65% | 65% |

**Interested But Concerned**

| Comfort Score | 3.43 | turn visible |
|---|---|---|
| | 2.76 | interaction |

| Right-turning volume (veh/hr) | Bicycle volume (veh/hr) | | | | | | Min Score |
|---|---|---|---|---|---|---|---|
| | 25 | 50 | 75 | 100 | 150 | 200 | |
| 50 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.40 |
| 100 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.39 |
| 150 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.38 |
| 200 | 3.3 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.35 |
| 250 | 3.3 | 3.3 | 3.4 | 3.4 | 3.3 | 3.3 | 3.35 |

| Percent Comfort | 0.51 | turn visible |
|---|---|---|
| | 0.25 | interaction |

| Bicycle volume (veh/hr) | | | | | | Min Score |
|---|---|---|---|---|---|---|
| 25 | 50 | 75 | 100 | 150 | 200 | |
| 50% | 50% | 50% | 50% | 50% | 50% | 50% |
| 50% | 49% | 50% | 50% | 50% | 50% | 49% |
| 49% | 49% | 49% | 49% | 49% | 49% | 49% |
| 48% | 48% | 49% | 49% | 48% | 49% | 48% |
| 48% | 48% | 48% | 48% | 48% | 48% | 48% |

## Bend-out (Protected Intersection)

| Simulated Interactions Per Hour | | | | | | |
|---|---|---|---|---|---|---|
| Right-turning | Bicycle volume (veh/hr) | | | | | |
| volume (veh/hr) | 25 | 50 | 75 | 100 | 150 | 200 |
| 50 | 1 | 2 | 4 | 6 | 12 | 12 |
| 100 | 3 | 5 | 9 | 13 | 18 | 23 |
| 150 | 3 | 8 | 12 | 14 | 29 | 36 |
| 200 | 4 | 10 | 16 | 25 | 37 | 51 |
| 250 | 8 | 15 | 22 | 32 | 47 | 63 |

**Bike Inclined**

| Comfort Score | Comfort S | 4.3 | turn visible | | | | |
|---|---|---|---|---|---|---|---|
| | | 3.97 | interaction | | | | |
| Right-turning | Bicycle volume (veh/hr) | | | | | | Min Score |
| volume (veh/hr) | 25 | 50 | 75 | 100 | 150 | 200 | |
| 50 | 4.3 | 4.3 | 4.3 | 4.3 | 4.3 | 4.3 | 4.27 |
| 100 | 4.3 | 4.3 | 4.3 | 4.3 | 4.3 | 4.3 | 4.26 |
| 150 | 4.3 | 4.2 | 4.2 | 4.3 | 4.2 | 4.2 | 4.24 |
| 200 | 4.2 | 4.2 | 4.2 | 4.2 | 4.2 | 4.2 | 4.22 |
| 250 | 4.2 | 4.2 | 4.2 | 4.2 | 4.2 | 4.2 | 4.19 |

| Percent Comfort | 0.83 | turn visible | | | | |
|---|---|---|---|---|---|---|
| | 0.72 | interaction | | | | |
| Bicycle volume (veh/hr) | | | | | | Min Score |
| 25 | 50 | 75 | 100 | 150 | 200 | |
| 83% | 83% | 82% | 82% | 82% | 82% | 82% |
| 82% | 82% | 82% | 82% | 82% | 82% | 82% |
| 82% | 81% | 81% | 81% | 81% | 81% | 81% |
| 81% | 81% | 81% | 80% | 80% | 80% | 80% |
| 79% | 80% | 80% | 79% | 80% | 80% | 79% |

**Interested But Concerned**

| Comfort Score | 3.78 | turn visible | | | | |
|---|---|---|---|---|---|---|
| | 3.61 | interaction | | | | |
| Right-turning | Bicycle volume (veh/hr) | | | | | | Min Score |
| volume (veh/hr) | 25 | 50 | 75 | 100 | 150 | 200 | |
| 50 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.77 |
| 100 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.76 |
| 150 | 3.8 | 3.8 | 3.8 | 3.8 | 3.7 | 3.7 | 3.75 |
| 200 | 3.8 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.74 |
| 250 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.73 |

| Percent Comfort | 0.71 | turn visible | | | | |
|---|---|---|---|---|---|---|
| | 0.6 | interaction | | | | |
| Bicycle volume (veh/hr) | | | | | | Min Score |
| 25 | 50 | 75 | 100 | 150 | 200 | |
| 71% | 71% | 70% | 70% | 70% | 70% | 70% |
| 70% | 70% | 70% | 70% | 70% | 70% | 70% |
| 70% | 69% | 69% | 69% | 69% | 69% | 69% |
| 69% | 69% | 69% | 68% | 68% | 68% | 68% |
| 67% | 68% | 68% | 67% | 68% | 68% | 67% |