DEPARTMENT OF TRANSPORTATION

Guidance for Separated/ Buffered Bike Lanes with Delineators

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Separated bicycle lanes (SBLs) are bicycle facilities that employ both paint and a vertical element as a buffer between vehicle traffic and bicycle traffic. In recent years, the installation of SBLs has increased in the U.S. as planners and engineers seek to reduce crash risk, increase safety and foster demand. In turn, public demand for these facilities has continued to grow. This project conducted a thorough literature search to identify knowledge gaps and aspects of design not addressed in depth in existing guides. In collaboration with the Local Road Research Board and MnDOT, the study identified which design elements were of the greatest local interest or missing from the guidance altogether. The identified subject areas were explored with the help of three major knowledge gathering approaches: interviews of industry professionals from local agencies currently operating SBLs, interviews with leading bicycle advocates representing the local cycling community, and an ambitious and lengthy online survey of people who cycle in Minnesota. As noted by several existing guidance documents and corroborated by the information collected and analyzed in this project, the SBL is one of the highest quality bikeway facilities available. This report adds to the existing guidance regarding the planning and operation of SBLs by refining the discussion and taking into account individual aspects of separate design elements and their implementation alternatives, as well as their influence and limitations on maintenance needs, especially in winter. The guidance identifies multiple considerations for each of the selected structural elements and maintenance considerations to inform the choices made during the design process.

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GUIDANCE FOR SEPARATED/BUFFERED BIKE LANES WITH DELINEATORS

FINAL REPORT

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EXECUTIVE SUMMARY

Separated bicycle lanes (SBLs) are bicycle facilities that employ both paint and a vertical element as a buffer between vehicle traffic and bicycle traffic. In recent years, the installation of SBLs has increased in the U.S. as planners and engineers seek to reduce crash risk, increase safety and foster demand. In turn, public demand for these facilities has continued to grow. Several organizations have published useful guides for designing SBLs. The design recommendations in these guides vary both by topic and depth but do not address all challenges encountered in practice. This project conducted a thorough literature search, described in Chapter 2, to identify knowledge gaps and aspects of design not addressed in depth in existing guides. Assisted by the Technical Advisory Panel (TAP) assembled by the Local Road Research Board and MnDOT, the study identified which design elements were of greatest interest or missing from the guidance altogether. Specifically, this study focused on the following six subjects pertaining to SBL design:

1. Buffer design
2. Mixing zone design
3. Bus stops on SBLs
4. Winter maintenance
5. Summer maintenance
6. Relative costs and benefits of design alternatives

In addition, the TAP emphasized an overarching lack of clarity in the existing guidelines regarding the *Need for Separation*. Indeed, the current guidelines approach the *Need for Separation* mainly from an engineering point of view of managing risk and safety, practically reducing it to a two-dimensional relationship between motor vehicle demand (ADT) and 85% vehicular speed. Although the guides also list several other factors involved in “refining” the selection of bikeway type, few, if any, take into consideration the differences in preferences and priorities of the separate types of people who cycle and who the facility will serve or aims to attract. Specifically, most guides do not differentiate designs preferred by experienced, confident riders and people with less experience who may be less confident about riding in traffic. For this reason, the issues pertaining to the aforementioned subject areas were explored with the help of three major knowledge gathering approaches: interviews of industry professionals from local agencies currently operating SBLs, interviews with leading bicycle advocates representing the local cycling community, and an ambitious and lengthy online survey of people who cycle in Minnesota.

The interviews, collectively referred to as Key Informant Interviews (KII), were lengthy but focused conversations with members of groups who could provide representative perspectives and feedback. In addition to these groups, the interviews also included discussions with Twin Cities parking and transportation services professionals as well as transit drivers. The KIIs with design agencies focused on guidance used and issues faced in implementing and maintaining SBLs. The Bicycle Advocacy group KIIs focused on user experience, and the bus driver interviews focused on the specific issues SBLs present to bus drivers. The user group survey was developed to examine perceptions of the safety and comfort of different designs of SBLs, including mixing zones (intersections) and bus stop designs. Since winter riding

and winter maintenance were identified as key areas of missing guidance, the survey also included sections on factors influencing winter riding behavior as well as a visual preference survey section to determine rider preferences for cleared width and pavement conditions.

During the interviews and later confirmed by the user survey results, it became clear that people who cycle are not a monolithic group. “Strong and Fearless” and “Enthused and Confident” cyclists have very different preferences than people who cycle and can be identified as “Interested but Concerned.” Therefore, design considerations need to take into account all types of people who ride bicycles and cater to the least experienced and most concerned whenever possible, especially from the perspective of fostering demand.

The interviewees in general highlighted a link among maintenance practices, the acquisition of maintenance equipment, the costs of construction and maintenance, and the overall design of facilities. The mechanisms of interaction between these linked components of SBLs appear to vary between agencies. When asked about their main sources of uncertainty for design or maintenance, many interviewees brought up the difficulties of designing SBLs at intersections – particularly two-way SBLs. Driveways and alleys were also identified as design challenges by multiple agencies – particularly regarding the fact that protection is dropped at every driveway or alley. From interviews with bicycle advocates, the consensus was that, although less undesirable than complete lack of bicycle facilities, transitions between separated/protected and non-separated bike lanes reduced the overall feeling of safety and comfort provided by the SBL. That is, they preferred to minimize interactions with traffic between origin and destination. At this time, however, avoiding traffic is not feasible when many cities struggle to have a connected network of bike lanes and designated routes, much less a network of SBLs. Nevertheless, a priority should be given in selecting routes that allow for the longest uninterrupted sections of SBLs.

Following the guidance offered in the *FHWA Bikeway Selection Guide* (44), the study focused on the collection of additional evidence in respect to the identified three guiding principles: safety, comfort, and connectivity. During the course of the study, the overarching goal evolved to the refinement of guidance on the aforementioned three structural design elements (buffer, mixing zone, and bus stop) in respect to their tradeoffs and general relationships with safety, comfort, and their likelihood to affect the choice of bicycle as mode of transportation. The latter serves as a surrogate of the core essence to affect the connectivity principle. The user survey explored the relationships between different alternatives of the structural design elements and the three guiding principles. The study explored how these relationships were affected by age group, gender, and classification of people who cycle.

Highlighting the issues involved with SBL use during winter, icy roads were, by far, the reason cited most often by survey respondents (45%) for not riding in winter. Furthermore, as indicated by the analysis, ice was even a bigger concern than fresh unpacked snow. The implication of these findings was that the priority of maintenance crews should be to clear the SBL before the snow compacts, solidifies, and turns to ice. Analyses of the survey results provided strong evidence that people who cycle strongly prefer to ride on clear and dry pavement; their likelihood of rating SLBs as safe and comfortable increased significantly as the width of the clear pavement increased. This finding suggested that prioritizing lane clearance during winter could be the most important maintenance practice if increasing SBL use during the winter season was an objective. This maintenance priority cannot be “regulated” (just as winter maintenance of roadways designated for vehicles is not regulated), but public works and transportation agencies can prioritize snow removal as part of best practices.

As noted by several existing guidance documents and corroborated by the information collected and analyzed in this project, the SBL is one of the highest quality bikeway facilities available. This report adds to existing guidance regarding the planning and operation of SBLs by refining the discussion and taking into account individual aspects of separate design elements and their implementation alternatives, as well as their influence and limitations on maintenance needs, especially in winter.

TAP members stressed the importance of context in design of SBLs and the need to consider tradeoffs in the design process. A fundamental principle underlying the guidance presented in the following matrixes is that the process of designing a SBL is context specific, involves exercise of professional judgment to match design goals and objectives with physical context, and may vary in response to other relevant circumstances such as the availability of funding. To elaborate, multiple design options exist for nearly every context, and the design objective is to identify the options that best balance objectives such as reducing risk and increasing safety, inducing demand, and minimizing costs, within the broader community or societal goals. Hence, the guidance presented here does not identify “preferred” options for any structural element or maintenance activity. Instead, consistent with the TAP emphases on highlighting tradeoffs, the guidance identifies multiple considerations for each of the selected structural elements and maintenance considerations to inform the choices made in the design process. Chapter 8 and Chapter 9 deliver the developed guidance in a systematic and organized way summarized in four visual tools called tradeoff matrixes. For completeness, the matrixes contained in Chapter 9 are also repeated in this summary.

TRADEOFF MATRIX FOR SEPARATION BUFFER DESIGN

Table ES-1 Considerations and Tradeoffs for Four Buffer Designs

Buffer Design Considerations	Solid Barrier	Intermittent Barrier	Curb and Intermittent Barrier	Grade Separation
Variants and Variant combinations	Concrete barrier Concrete planters	On-Street Parking Flexposts Bollards	On-Street Parking Cast in-place curb Parking stops	On-Street Parking Cycletrack; Shared use path Boulevard
Context Dependent Feasibility				
Restriping only	Planters	Most applicable	Removable curb	Never
Restriping as part of regularly scheduled overlay maintenance activities.	Planters		Most applicable	Never
Redesign or reconfiguration	Concrete barrier with no foundation			Limited to pre-existing Sidewalk level area.
Full Reconstruction	Most applicable			Most applicable
Objective Indicators of Safety				
Protection from vehicles				
Interface with Mixing zone				Not Applicable
Perceived clarity of action				
Interactions with pedestrians				
Interactions with stopped vehicles		Depends on delineator spacing		
Relative Tradeoffs and Implicit Costs				
Degree of vehicle intrusion allowed				Not Applicable
On-street parking	Not Advised			Not Applicable
Effect on drainage				Not Applicable

Table ES-1 Considerations and Tradeoffs for Four Buffer Designs (Cont.)

Buffer Design Considerations	Solid Barrier	Intermittent Barrier	Curb and Intermittent Barrier	Grade Separation
Installation requirements:				
Street or lane modifications	$$	$	$$	Not Applicable
Buffer width requirement (*1)	>3ft	>6ft	3ft to 6ft	Shared use path
Requires construction (i.e., grade separation, barrier)	$-$$$	$	$$	$$ + land
Curb edge *(*2)*				Not Applicable
• Area of painting				
○ Barrier proper	$	$$$	$	Not Applicable
○ Driveways *(*4)*	$	$-$$	$	$
○ Accessible parking spaces *(*5)*	$$	$	$	$$
○ Loading zones *(*5)*	$$	$	$	$
Extra cost per opening to allow access to adjacent properties	*(*3)*		flexposts, curb bumper	Driveway maintenance
Shy distance/buffer zone (minimum required in addition to barrier)	Vehicle side: 1ft SBL side: 6in	Part of buffer	Vehicle side: 2ft SBL side: 0	3ft from curb
Maintenance Considerations				
Frequency for Repairs of the Barrier	$	$$$	$	Not Applicable
Cost of Repairs of the Barrier	$$$	$$	$$	boulevard
Frequency/area of re-painting	$	$$	$$	$
Summer:				
• Difficulty of sweeping *(*6)*	$$	$	$$	$
• Effect on debris accumulation				Not Applicable
• **Winter**:				
Difficulty of plowing	$$$	$	$$	$
Snow Storage availability	Needs hauling	Store in buffer	Buffer	Design dependent
Specialized equipment	Depends on width		Depends on width	Sidewalk level
Effect on snow accumulation by plowing of driving lanes				Design dependent

Table ES-1 Considerations and Tradeoffs for Four Buffer Designs (Cont.)

Buffer Design Considerations	Solid Barrier	Intermittent Barrier	Curb and Intermittent Barrier	Grade Separation
General Considerations in Design				
• **ADA compliance:**				
Visually impaired users	Trapped pedestrians *(*7)*			Requires tactile directional treatments
Mobility impaired users	*(*8)*		*(*8)*	
• Consistency of design		Common, depends on quality of maintenance		Design dependent
• Continuation of path trajectory		Common, depends on quality of maintenance		Design dependent

(*1) Greater than 2 feet of buffer space or physical separation is preferred for cyclist comfort. At least 3ft of cleared width is preferred at all times, whether from debris in the summer or snow and ice in winter

(*2) Careful consideration should be given to the placement of asphalt joint lines and concrete expansion joints along the SBL and to rail crossings. This is typically a problem on SBLs that are on the left side of the curb line. The bicycle tire can become trapped within the joint, causing the cyclists to crash. Minimal curb apron width should be constructed or frequent maintenance conducted to keep the asphalt-to-concrete joint filled. Similar considerations can be made regarding pavement maintenance (potholes, uneven surface, cracking, etc.)

(*3) SB is most likely to be used in SBLs adjacent to driving lanes with higher speed limits. On all roads with speed limits higher than 25mph, crash attenuation devices must be installed on all edges of the solid barrier. Therefore, the more openings provided, the higher the cost of the barrier construction and maintenance.

(*4) Driveways represent an interruption in the barrier. Green paint is used to warn all users about the potential of conflicts at each the driveway. In addition, depending on the presence of on-street parking, additional areas are marked with paint to preserve the sight distance for vehicles that exit the driveway. This cost increases with the width of the SBL and the width of the buffer.

(*5) Green paint is used along areas where mobility impaired pedestrians or delivery operators cross over the SBL to access the sidewalk.

(*6) Although IB SBLs provide more space for sweeping, debris often accumulate in the middle of the buffer because it is difficult to sweep between the delineators. The comparatively less desirable conditions of the SB stem from the fact that windblown debris will accumulate faster along a wall.

(*7) Visually impaired people can potentially be trapped inside the SBL if they confuse a mid-block location as an unmarked crossing.

(*8) Implementation of accessible parking spots require a break in the SB or CIB introducing issues and complications similar to driveways.

TRADEOFF MATRIX FOR THE DESIGN OF MIXING ZONES

Table ES-2 Considerations and Tradeoffs for Six Mixing Zone Designs

Design Considerations	Switch & Weave	Shared Lane	Partially Shared Lane	Protected Intersection	Two Stage Left Turn with Bike Box	No Mixing with Bike Signal
Context Dependent Feasibility						
Restriping only *(*1)*	Requires 1.5x right-turn only lane	Requires 1x right-turn only lane	Most applicable	Never		Most applicable
Restriping as part of regularly scheduled overlay maintenance activities. *(*1)*	Requires 1.5x right-turn only lane	Requires 1x right-turn only lane		Never	Most applicable	
Redesign or reconfiguration	Most applicable	Most applicable				
Full Reconstruction				Most applicable		
Objective Indicators of Safety						
Minimizes size/area of on-street conflict zone				Not Applicable		
Minimizes size/area of conflicts during turning movements				Similar to pedestrians		After leading green *(*2)*
Perceived clarity of action						
Understanding of ROW rules	Yield line and channelization	Channelization		Similar to pedestrians		After leading green
Relative Tradeoffs and Implicit Costs of Design						
Compatibility with contraflow lanes					Not Applicable	Not Applicable
Compatibility with Two Way SBL						

Table ES-2 Considerations and Tradeoffs for Six Mixing Zone Designs (cont.)

Design Considerations	Switch & Weave	Shared Lane	Partially Shared Lane	Protected Intersection	Two Stage Left Turn with Bike Box	No Mixing with Bike Signal
Installation requirements:						
Street or lane modifications	+1.5x Right Turn lane width	+1 Right Turn lane	Paint	Not Applicable	Paint	Paint
Requires construction (i.e., grade separation, barrier)	none	none	none	$$	none	none
Requires changes in signalization	none	none	none	$$ (optional)	$ ($$ if actuated)	$$$
• New signage						
○ For cyclists	$$	$$	$	$	$$$	Not Applicable
○ For drivers	$	$$	$	$$ *(*3)*	$	Not Applicable
Area of painting (**4*)	$$$$	$$$	$	$-$$	$$$	$
Maintenance Considerations						
Need for bollard replacement	$$$$	$$$	$$	context specific	$	$
Frequency/area of re-painting *(*5)*	$$$	$$$	$$	$-$$	$$$$	$
Summer:						
• Difficulty of sweeping	Flexposts	Flexposts		Shared use path		
• Effect on debris accumulation						
Winter:						
Difficulty of plowing	Multiple passes and bollards	Multiple passes		Shared use path		
Snow Storage availability	Interface zone	Interface zone	buffer	boulevard	buffer	buffer
Specialized equipment						

Table ES-2 Considerations and Tradeoffs for Six Mixing Zone Designs (cont.)

Design Considerations	Switch & Weave	Shared Lane	Partially Shared Lane	Protected Intersection	Two Stage Left Turn with Bike Box	No Mixing with Bike Signal
Other Considerations in Design						
ADA compliance:						
Visually impaired users				Sidewalk level	Irregular crosswalk	
Mobility impaired users (*6)	Not Applicable	Not Applicable	Not Applicable	Bend-Out	Not Applicable	Not Applicable
Consistency of design	rare	frequent	common		Very rare	
Continuation of path trajectory				Bend-Out		

(*1) It is important to note that spatially the "Switch & Weave" design requires a width of 1.5 lanes of the roadway to be dedicated to vehicle right turns and bicycles going through. Similarly, the "Shared Lane" design requires the rightmost lane to be right-turn-only. Especially in the case of the S&W, implementation on an existing roadway will require the complete removal and reapplication of all lane markings. Not just the lane markings next to the SBL.

(*2) The reduced safety (increased conflict potential) rating applies only in cases of leading bicycle only signal phase implementations and for the period after the end of the bicycle only signal green. When vehicles and bicycles have green, not only the benefits of the bike signal are gone but the complete lack of an actual mixing zone can result in dangerous sideswipes by right turning vehicles. Serious consideration must be given on the expected volume of bicycles to ensure that all queued up bicycles are given adequate green time to clear the first half of the intersection during the leading green phase. If bicycle arrival is random and the SBL allows high bicycle speeds, then a protected bike only phase should be considered.

(*3) If a Bend-Out is used in the transition zone, additional signs are advised to warn drivers. i.e., "Turning vehicles yield to bikes."

(*4) Although not usually shown in the existing design manuals the PSL mixing zone also requires a Green Paint zone marking the through movement of bicycles inside the intersection. Similarly, a Green Paint zone must accompany the PI design if the bicycles are not using the regular pedestrian crosswalk to cross the intersection.

(*5) Mixing zones that incorporate road markings and especially green paint zones at locations where vehicles often travel require frequent repainting due to the increased wear from the tires. Bike Boxes are especially susceptible to this since they are located over the vehicle high acceleration spot downstream of the crosswalk.

(*6) Mixing zones that utilize only the roadway have no effect on mobility impaired pedestrians. PI Mixing zones, especially when they involve a Bend-Out require additional ADA pads and ramps or require the SBL to be raised at the sidewalk level. Regardless, planners must include "acceptable" sidewalk width between the PI SBL and the start of the crosswalk (15), where acceptable width may vary according to municipal policy and practice.

TRADEOFFS RELATED TO COMBINATIONS BETWEEN BARRIER AND MIXING ZONE DESIGNS.

Table ES-3 Recommendations and areas of concern related to combinations between Barrier types and Mixing Zone designs.

	Solid Barrier	**Intermittent Barrier *(*1)***	**Curb and Intermittent Barrier**	**Grade Separation**
Switch & Weave	Transition area of Average length. *(*2)* Height of the barrier increases severity of conflicts. *(*3)*	Average mixing zone length Highest probability of damage to the delineators by vehicles and snowplows	Needs a Short curb-less transition section. *(*4)* Conflicts safer than SB. Reduced probability of damage to the delineators by vehicles and snowplows.	Feasible with Bend-In. Not advisable
Shared Lane	Transition area of Long length. (*2) Height of the barrier increases severity of conflicts. *(*3)*	Long mixing zone length Highest probability of damage to the delineators by vehicles and snowplows	Needs a Short curb-less transition section. *(*4)* Conflicts safer than SB. Reduced probability of damage to the delineators by vehicles and snowplows.	Feasible with Bend-In. Not advisable
Partially Shared Lane	Transition area of Short length. *(*2)* Height of the barrier increases severity of conflicts. *(*3)*	Most traditional design. Short mixing zone length Highest probability of damage to the delineators by vehicles and snowplows	Needs a Long curb-less transition section. *(*4)* Conflicts safer than SB. High probability of damage to the delineators by vehicles and snowplows.	Feasible with Bend-In. Not advisable

Table ES-3 Recommendations and areas of concern related to combinations between Barrier types and Mixing Zone designs. (cont.)

	Solid Barrier	**Intermittent Barrier (1)**	**Curb and Intermittent Barrier**	**Grade Separation**
Protected Intersection	Feasible with Bend-Out	Feasible with Bend-Out *(*5)*	Feasible with Bend-Out *(*5)*	Best Combination by default.
Two Stage Left Turn with Bike Box	Feasible combination Transition section not advised. High conflict probability	Feasible combination Low conflict probability High probability of damage to the delineators by vehicles and snowplows	Feasible combination Average conflict probability Extends barrier protection all the way to the stop line.	Not Applicable
No mixing, with Bike Signal	Best Combination assuming good cyclist compliance with bike signal.	Good combination Possible average compliance with the bike signal.	Feasible combination Possible low compliance with the bike signal.	Not Applicable

(*1) This type of barrier offers the least amount of protection to cyclists. This does not translate to the transition zone length since the danger there is the same on all barrier types such section is advised and depends on the length of that section.

(*2) Given the possible lack of visibility over/through the barrier, a section similar to the Intermittent Barrier is necessary between the Solid Barrier and the beginning of the mixing zone. The length of this transition section depends on the height of the barrier and the type of the mixing zone.

(*3) As the barrier height increases, the visibility of the cyclist from the vehicle reduces. This could result in collisions if the vehicles making the switch don't yield to the cyclist because they are not aware of its presence. To counter this potential problem an intermittent barrier transition section is needed. The higher the barrier the longer the transition section must be.

(*4) There is still need for a very short section where the raised curb is removed but at least one bollard is present. This would avoid vehicles turning right too soon and hitting the corner of the raised curb.

(*5) Implementing a PI mixing zone with the midblock separation of the SBL being IB or CIB involves the construction of more complicated transitions between the SBL and the mixing zone (Bend-Out). This not only increases construction costs due to the higher required amounts of concrete for larger curbs and islands but also increases maintenance costs given the more involved (curvy) path alignment.

TRADEOFF MATRIX FOR THE DESIGN OF BUS STOPS

Table ES-4 Considerations and Tradeoffs for Six Bus Stop Designs

Design Considerations	Curbside Bus Stop, One-Way Street-Level Protected Bike Lane	Curbside Bus Stop, One-Way Raised Cycletrack	In-Street Bus Stop, Shared Street-Level Protected Bike Lane	Floating Island Bus Stop, Two-Way Street-Level Protected Bike Lane	Curbside Bus Stop, Two-Way Street-Level Protected Bike Lane	Curbside Bus Stop, Two-Way Raised Cycletrack
Context Dependent Feasibility						
Restriping only	Most applicable	Never		Never	Most applicable	Never
Restriping as part of regularly scheduled overlay maintenance activities.			Most applicable	Pre-cast platform		
Redesign or reconfiguration		Most applicable				Most applicable
Full Reconstruction				Most applicable		
Objective Indicator of Safety to cyclists						
Minimizes probability of bus/bicycle collision.	*(*1)*				*(*1)*	
Minimizes probability of vehicle/bicycle collision. *(*2)*						
Objective Indicator of Safety to Transit users						
Minimizes probability of collision during boarding				Not Applicable		
Minimizes probability of collision during alighting		*(*3)*	*(*3)*	Not Applicable		*(*3)*

Table ES-4 Considerations and Tradeoffs for Six Bus Stop Designs. (cont.)

Design Considerations	Curbside Bus Stop, One-Way Street-Level Protected Bike Lane	Curbside Bus Stop, One-Way Raised Cycletrack	In-Street Bus Stop, Shared Street-Level Protected Bike Lane	Floating Island Bus Stop, Two-Way Street-Level Protected Bike Lane	Curbside Bus Stop, Two-Way Street-Level Protected Bike Lane	Curbside Bus Stop, Two-Way Raised Cycletrack
Perceived clarity of action						
Yield to XXX and wait	Bus	Peds	Peds	Peds	Bus	55% Peds
Pass bus from the left		Not Applicable		Not Applicable		4%
Ride on the sidewalk (right)	Not Applicable		Not Applicable	Not Applicable	Not Applicable	8%
Keep riding and mix with peds	Not Applicable			Not Applicable	Not Applicable	33%
Relative Tradeoffs and Implicit Costs						
Compatibility with Two Way SBL						
Installation requirements:						
• Additional width requirements	None	None		+1 lane		None
• Street or lane modifications	$	$	$$	$$	$	$
• Requires construction (i.e., grade separation, barrier)	$	$$	$	$$$	$	$$
Maintenance Considerations						
Frequency of Repairs of the Barrier	$$	$	$$$	$$	$$	$
Cost of Repairs of the Barrier	$$	$	$$	$$$	$$	$
Frequency/area of re-painting	$$$	$	$$	$	$$$	$
Summer:						
• Difficulty of sweeping	$	Raised	$$	$	$	Raised
• Effect on debris accumulation						

Table ES-4 Considerations and Tradeoffs for Six Bus Stop Designs. (cont.)

Design Considerations	Curbside Bus Stop, One-Way Street-Level Protected Bike Lane	Curbside Bus Stop, One-Way Raised Cycletrack	In-Street Bus Stop, Shared Street-Level Protected Bike Lane	Floating Island Bus Stop, Two-Way Street-Level Protected Bike Lane	Curbside Bus Stop, Two-Way Street-Level Protected Bike Lane	Curbside Bus Stop, Two-Way Raised Cycletrack
• **Winter:**						
• Difficulty of plowing	$	Raised	$$	multipass	$	
• Snow storage availability	Buffer if IB	Sidewalk	Buffer	Parking lane	Buffer if IB	Sidewalk
• Specialized equipment	Depends on Width	Raised	Depends on Width	Parking lane	none	Raised
General Considerations in Design						
Ease of ADA compliance						
• Serving visually impaired		*(*4)*	*(*4)*			*(*4)*
• Serving mobility impaired		*(*5)*	*(*5)*			*(*5)*
Consistency of design			Rare			
Continuation of path trajectory						

(*1) Buses have a large tail swing. This implies a wider trajectory during their approach to the curb. As reported by bus drivers, cyclists are often get trapped between the bus and the curb. Transition areas similar to the ones between Solid Barriers and Shared Lane Mixing Zones are required for the cyclists to notice the bus before it's too late.

(*2) Conflicts with right turning vehicles when bus is not present.

(*3) There is very little visibility between alighting transit users and cyclists. The transit agency should consider a mechanically deployable warning sign similar to the one used on school busses but on the rear back corner of the bus. The sign can be activated along with the bus rear door to warn cyclists that a transit user is about to step out the door.

(*4) The farther the bus shelter/pole is from the bus lane the harder it is for visually impaired people to detect bus arrival through sound. They can miss flagging the bus to stop.

(*5) Special considerations are required to make sure the barrier does not conflict with wheelchair lift. In the case of the raised cycletrack there should not be a raised curb at the edge of the SBL since this will also affect the lift operation.

CHAPTER 1: INTRODUCTION

Separated bicycle lanes (SBLs) are a bicycle facility that employs both paint and a vertical element as a buffer between vehicle traffic and bicycle traffic. In recent years, the installation of SBLs has increased in the U.S., and public demand for these facilities continues to grow. For instance, in 2016, Minneapolis increased the total mileage of on-street separated bike lanes in the city from 5.4 to 9.4 miles (12) and planned to increase that to 30 miles by 2020. Despite the spike in installation of SBLs throughout the U.S., research on SBLs has not kept pace. Existing guidelines for the design and installation of SBLs are numerous; however, there is no widespread consensus on the criteria presented in existing guidelines. Several organizations have published guides for designing SBLs, but the design recommendations contained in these guides vary both by topic and depth. Such variations create concerns for the safety of SBLs since several gaps in existing research — such as the effects of SBLs on vehicle traffic, the preferred speed and volume thresholds, and the differences in safety between one- and two-way SBLs — have been identified by the Federal Highway Administration's (FHWA) *Separated Bike Lane Planning and Design Guide* (13). The FHWA's guide also lists cost as a gap in knowledge about SBLs, saying "few benchmarks exist for separated bike lane costs, which vary extensively due to the wide variety of treatments and materials used."

This project focused on how to best fill in the missing information and guidance for SBLs. To do so, a literature review of the existing guidance for the design elements identified in the available SBL design guides was conducted to identify knowledge gaps and prioritize areas of study. Industry professionals were consulted as to which design elements were of the greatest interest or missing from the guidance altogether. Key Informant Interviews (KII) were conducted with design agencies, bicycle advocates and bus drivers in the Twin Cities to collect their thoughts about SBLs. The KIIs with design agencies focused on guidance used and issues faced in implementing and maintaining SBLs. The bicycle advocacy KIIs focused on user experience, and the bus driver interview focused on the specific issues SBLs present to bus drivers, such as tailswing. A user group survey was developed to examine the safety and comfort of different designs of SBLs, including mixing zones and bus stop designs. Because winter riding and winter maintenance were identified as key areas of missing guidance, the survey also included sections on factors influencing winter riding behavior as well as a visual preference survey section to determine rider preferences for cleared width and pavement conditions. The literature review, KII and survey results were compiled here to present professionals with guidance currently missing from bikeway design guides, specifically to help them decide which type of SBL, including buffer, mixing zone and bus stop, would be appropriate to implement in various project settings.

The remainder of this report is organized in the following manner. A detailed literature review of the available guidance, highlighting knowledge gaps is presented in Chapter 2. Also included in Chapter 2 is a summary of the three study design elements of Key Informant Interviews (KII), field data collection, and user group survey. The method and outcomes of the KIIs are presented in Chapter 3, followed by a brief description of field data collection efforts in Chapter 4. Chapter 5 describes the development of the user group survey followed by the analysis of the collected results in Chapter 6 and Chapter 7. The latter focuses specifically on winter design and maintenance considerations based on the information collected from the survey. Chapter 8 presents the foundational definitions and assumptions followed in this study, preparing the reader for the main product of this effort, the design and operational guidance for elements of SBLs presented in Chapter 9. The report wraps up with conclusions in Chapter 10.

Throughout this document we prioritize the use of people-centered language such as “people who cycle” rather than cyclists in most contexts to emphasize that the purpose of better design is to make travel safer for people. We note that the definition of a cyclist is a person who cycles and, similarly, the definition of a driver is a person who drives a vehicle. In some sections of the report, where we think clarity is enhanced by minimizing words, we use the terms drivers and cyclists.

CHAPTER 2: LITERATURE REVIEW AND STUDY DESIGN

To begin, the definition and criteria for a Separated Bike Lane (SBL) for the purposes of this study was determined by reviewing established guidance documents from national, state and local agencies. Following this, guidance documents and other literature were reviewed for specific design elements. Once the 84 major design elements of an SBL were identified by the research team, the literature was again reviewed for specific guidelines or recommendations, or at least mentions of those topics. The identified knowledge gaps among those 84 major design elements were then presented to the Technical Advisory Panel, ranked, and used to design the rest of the study.

2.1 ESTABLISHING SEPARATED BIKE LANE CRITERIA

Given the inconsistencies between guidelines for SBLs and the need to establish a set of criteria that could be analyzed, the research team reviewed the definitions used by the major organizations involved with SBLs: American Association of State Highway and Transportation Officials (AASHTO), National Association of City Transportation Officials (NACTO), Federal Highway Administration (FHWA), Massachusetts Department of Transportation (MassDOT), City of Minneapolis, Minnesota Department of Transportation (MnDOT), and City of Portland.

The AASHTO Guide for the Development of Bicycle Facilities (4th edition) does not include Separated Bike Lanes, but a draft of the 5th edition yet to be published does include guidance regarding bikeway design selection. At the time of the literature review in this effort, the MnDOT Bikeway Facility Design Manual did not include SBLs; this document was updated in early 2020 with MN specific exceptions, additions and clarifications to the FHWA Separated Bike Lane Planning and Design Guide, which have been included in this revised literature review (13). The 2009 Manual of Uniform Traffic Control Devices (MUTCD) does not discuss SBLs. Table 2-1 summarizes the criteria comprising each organization's definition of an SBL – separation from motor vehicle traffic, location relative to the roadway, and the exclusivity to people who cycle.

Table 2-1 Summary of the criteria used to define SBLs by organization (updated September 2020)

Facility Requirements	NACTO	FHWA	MassDOT	MnDOT	Minneapolis	Portland
Physically separated from motor traffic with vertical element only		X		X		
Physically separated from motor traffic with vertical element or difference in elevation	X		X		X	X
In roadway only		X				
In or along roadway only	X		X	X		X
In, along, or separate from roadway					X	
Exclusive to people who cycle (not shared with pedestrians)	X	X	X	X	X	X

The relevant criteria to the definition of SBLs from each organization, identified by the research team, is whether or not a SBL must be physically separated from motor traffic with only a vertical element or with a difference in elevation as well; and whether or not an SBL must be only in roadways; along or in roadways; in, along or separate from roadways, and exclusive to people who cycle, that is, not shared with pedestrians. To the FHWA, SBLs must be physically separated from motor traffic with a vertical element only; to the NACTO, the MassDOT, the City of Minneapolis and the City of Portland, SBLs must be physically separated from motor traffic with a vertical element or difference in elevation. To the FHWA, SBLs must be only in roadways; to the NACTO, the MassDot and the City of Portland, SBLs can be in or along roadways; to the City of Minneapolis, SBLs can be in, along or separate from roadways. To all organizations, SBLs must be exclusive to people who cycle.

The FHWA has the most limited definition of an SBL and does not include facilities that are adjacent to and/or at a different elevation than the roadway. However, the FHWA does not specifically prohibit such facilities. Minneapolis, on the other hand, has the broadest definition which goes so far as to include bike paths that are not associated with a roadway. Note that NACTO uses the term “cycle track” and the City of Minneapolis uses the term “protected bikeway.” Therefore, the final set of criteria for SBL defined for this project uses the general consensus between all the organizations.

2.1.1 Project Definition of an SBL

To be considered an SBL for the purposes of this project, a facility must be:

1. separated from motor vehicles by some sort of physical barrier (flex posts, planters, curbs, etc.) and/or a difference in elevation (bike lane is at sidewalk height);
2. along or within the roadway;
3. designated as exclusively for people who cycle.

These criteria intentionally exclude shared-use paths, bike trails, and sidewalks.

2.2 APPROACH AND METHODS

The approach to the literature review included four steps:

1. Google Scholar and other database searches using a broad set of keywords;
2. Retrieval, assessment, and screening of publications for relevance to the project;
3. Review of publication references and additional document retrieval;
4. Screening and information extraction, including design elements and findings.

Search keywords used in Step 1 included: "biking", "cycling", "facilities", “separated bike lane”, “grade separation”, “rail separation”, “buffer separation”, “bicycle mixing zones”, “bus stops along bike lanes”, "amenities", "policy", "guideline", "manual", and "design solution." Due to the need to establish criteria defining separated bike lanes, general manuals and guidance documents from federal and state sources were included. In Step 2, guidance documents were examined for redundancy. Research focusing on bicycle lane conflicts, buffer types, mixing zones, bus stops, costs and benefits, and seasonal maintenance was included. Searches were limited to English language studies. Step 3 was an effort to expand the literature review by including relevant documents that were referenced and mentioned in the articles retained following the Step 2 assessment, and Step 4 involved the selection of documents for information extraction. Based on relevance to the project scope and other criteria, 20 design manuals and guidance documents (Table 2.1.1) were included in this literature review. An additional 130 documents were reviewed by the research team.

2.2.1 Guidance Documents Included in the Literature Review

The following manuals and guidance documents were included in the projects literature review, as abbreviated in Table 2-2.

Table 2-2 Guidance Documents identified during the Literature Review

Abbreviation in Table 2-4	Agency (Year) Title
NACTO (15)	National Association of City Transportation Officials (2012) Urban Bikeway Design Guide.
MassDOT (16)	Massachusetts Department of Transportation (2016) Separated Bike Lane Planning & Design Guide. https://www.mass.gov/lists/separated-bike-lane-planning-design-guide
FHWA1 (17)	Federal Highway Administration (2015) Separated Bike Lane Planning and Design Guide.
FHWA2 (18)	Federal Highway Administration (2017) Achieving Multimodal Networks: Applying Design Flexibility and Reducing Conflicts.
FHWA3 (19)	Federal Highway Administration (2017) Accessible Shared Streets: Notable Practices and Considerations for Accommodating Pedestrians with Vision Disabilities.
PROWAG (20)	United States Access Board (2011) Proposed Guidelines for Pedestrian Facilities in the Public Right-of-Way.
Portland1 (21)	City of Portland (2010) Portland Bicycle Plan for 2030 - Appendix D (Bikeway Facility Design: Survey of Best Practices).
Portland2 (22)	City of Portland (2018) Portland Protected Bicycle Lane Planning and Design Guide.
Vancouver (23)	City of Vancouver (2017) Transportation Design guidelines: All ages and abilities cycling routes.
Austroads (24)	Austroads (2017) Cycling Aspects of Austroads Guides.
NYCDOT (25)	New York City (2015) Street Design Manual.
Redmond (26)	City of Redmond (2016) Bicycle Design Manual.
ODOT (27)	Oregon Department of Transportation (2011) Bicycle and Pedestrian Design Guide.
OTM (28)	Ministry of Transportation of Ontario (MTO) (2013) Ontario Traffic Manual (Book 18).
Alta1 (29)	Alta Planning and Design (2014) Winter Bike Lane Maintenance: A Review of National and International Best Practices.
Denmark (30)	Cycling Embassy of Denmark (2012) Collection of Cycling Concepts 2012.
Alta2 (31)	Alta Planning and Design (2009) Cycle Tracks: Lessons Learned.
CiLA (32)	City of Los Angeles (2014) City of Los Angeles Mobility Plan - Ch. 9 (Complete Streets Manual).
Chicago1 (33)	City of Chicago (2012) Chicago Streets for Cycling Plan 2020.
Chicago2 (34)	City of Chicago (2013) Complete Streets Chicago.

The aforementioned guidance documents are what was available during the time period this part of the project was performed, with the most recent being from 2017. During the course of the project, additional guidance documents became available and influenced the final project deliverable. The following table lists guidance documents not involved in the initial literature review but still utilized and referenced in this report. Most importantly, these newer documents provide useful guidance on the need for separation, a topic that is relevant to but not the primary focus of this report.

Table 2-3 Guidance Documents considered in project deliverable

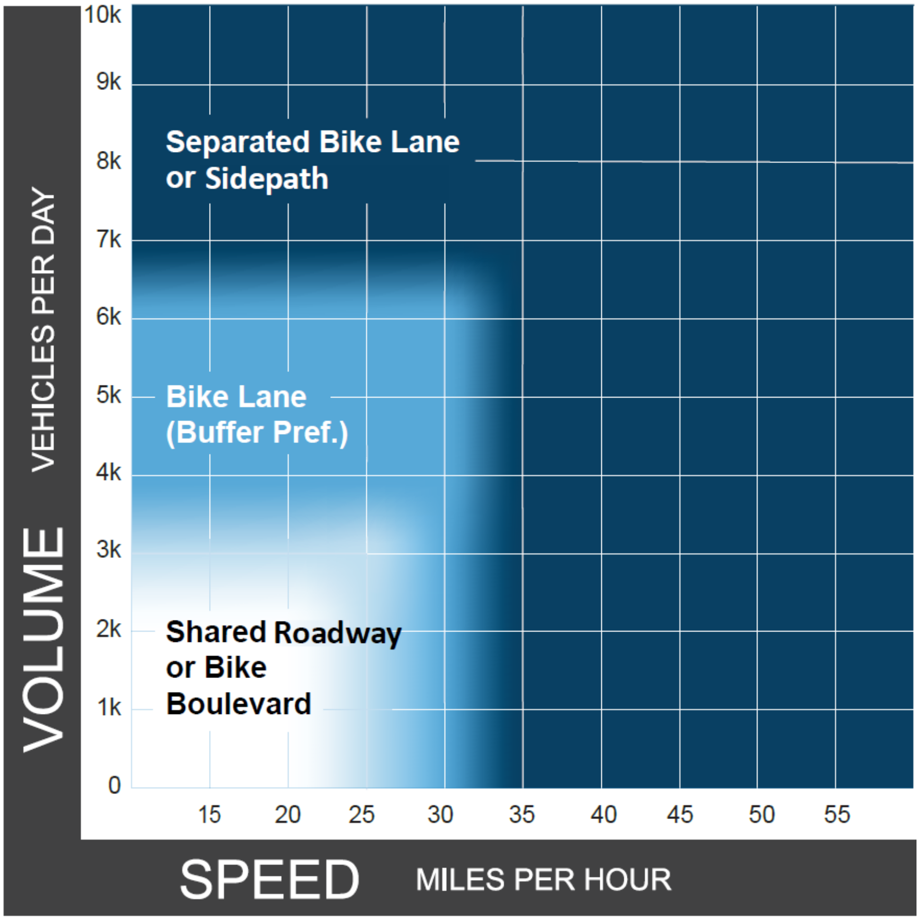
Agency	Title (Year)
FHWA (44)	Bikeway Selection Guide (2019)
NZTA (45)	Factors Affecting Cycling Levels of Service (2019)
MnDOT (14)	Bicycle Facility Design Manual (2020)
NCHRP (46)	Bicyclist Facility Preferences and Effects on Increasing Bicycle Trips (2020)
Auckland (47)	Evaluating Quality of Service for Auckland Cycle Facilities: A Practitioner's Guide (2016)
FHWA(48)	On-Street Motor Vehicle Parking and the Bikeway Selection Process (2021)
FHWA (49)	Traffic Analysis and Intersection Considerations to Inform Bikeway Selection (2021)
NITC (50)	Contextual Guidance at Intersections for Protected Bicycle Lanes(2019)
NITC (51)	Evaluation of Bus/Bicycle and Bus/Right-Turn Traffic Delays and Conflicts (2019)

2.3 NEED FOR SEPARATION

Engineers and planners typically consider an array of factors when assessing the need for separation of bikeways. These factors may include traffic-related and structural factors associated with risk and safety and demand-related factors such as target population of people who cycle, including whether a design objective is to increase cycling among people who cycle infrequently. Although not available during the time this project's literature review was performed, the FHWA Bikeway Selection Guide (44) is the most current and comprehensive guidance at the time of the writing of this report. This guide refers to existing national resources and outlines a process for balancing trade-offs by identifying the preferred bicycle facility type, assessing and refining potential options, and evaluating feasibility. Figure 2.1 shows the preferred bicycle facility type for Urban, Urban Core, Suburban and Rural Town contexts, using two important factors related to risk and safety: motor vehicle demand and speed. Separated bicycle facilities are recommended when vehicle operating speeds exceed 30 mph and volumes exceed 6,000 ADT. The guide also lists several other factors involved in "refining" the selection of bikeway. These factors, which are not integrated into the graph, include:

- Unusual motor vehicle peak hour volumes
- Traffic vehicle mix
- Parking turnover and curbside activity
- Driveway and intersection frequency
- Direction of operation
- Vulnerable populations
- Network connectivity gaps

- Transit considerations for selecting bikeways



Source: FHWA Bikeway Selection Guide

Figure 2.1 Preferred Bikeway type for Urban, Urban Core, Suburban, and Rural Town contexts (FHWA, 2019)

In addition, the FHWA Bikeway Selection Guide, introduces the seven principles of bicycle network design: Safety, Comfort, Connectivity, Directness, Cohesion, Attractiveness, and Unbroken Flow. Of these seven principles, three have particular importance in guiding bikeway selection:

- Safety: Roadway and bikeway designs should be selected to reduce the frequency and severity of crashes and minimize conflicts between users.
- Comfort: Bikeway facilities should be selected to minimize stress, anxiety, and safety concerns for the target design user. Comfort and safety are closely related.
- Connectivity: Trips within a bicycle network should be direct and convenient and offer access to all destinations served by the roadway network. Transitions between roadways and bikeways should be seamless and clear.

Studies have consistently found that people prefer bike facilities that are separated from traffic, such as off-street paths and protected bike lanes (39, 40, 13), with physical separation such as a post or curb providing increased comfort (41, 39, 42, 43). The preference for these separated facilities appears to be greater amongst those who ride primarily for recreation (as opposed to for transportation) and among those who cycle less often (43), as well as among the subset of potential people who would cycle who are classified as interested in cycling for transportation but concerned about safety and other issues (39, 41). These results suggest two things. First, that providing comfortable designs may be vital to expanding the bicycling population beyond current riders. Second that the population of people who cycle is not monolithic in their preferences and priorities.

The criteria for bikeway selection do not offer quantifiable metrics to factually compare SBLs with the rest of the bikeway types but they do suggest the use of the Level of Traffic Stress (LTS) to quantify comfort. LTS methodology was developed by Mekuria, Furth, and Nixon (38) to address deficiencies in the Bicycle LOS method which does not allow evaluation of shared use paths, separated bike lanes, or buffered bike lanes. The LTS is a method of classifying road segments and bikeway networks based on how comfortable people who cycle with different levels of confidence would feel using them. Based on Dutch roadway standards, LTS is structured to reflect the four types of people who cycle identified by past researchers: No Way, No How (approximately 33% of the population); Interested but Concerned (60%); Enthused and Confident (7%); and Strong and Fearless (1%) (38). The ‘‘No Way, No How’’ class is ignored within the LTS hierarchy, while the ‘‘Interested but Concerned’’ class is split into two: one for children and one for adults. The four levels of LTS are supposed to define the maximum tolerance for traffic stress for each type of bicyclist. LTS 1 is tolerable to children who cycle; LTS 2 is tolerable to ‘‘Interested but Concerned’’ adults who cycle; LTS 3 is tolerable to ‘‘Enthused and Confident’’ people who cycle; and LTS 4 is tolerable to ‘‘Strong and Fearless’’ people who cycle. Furthermore, LTS requires relatively little data input, accounting for only vehicle speeds, vehicle volumes, presence of bike lanes, number of thru lanes, presence of on-street parking, and bike lane widths. LTS rankings are then easily determined using simple tables.

The LTS is popular with practitioners and researchers and its simplicity has allowed several states, regions, and cities to adopt it to analyze bike networks. However, it still lacks metrics and criteria that specifically highlight SBLs and SBL design element alternatives. The following sections attempt to refine the design elements that separate SBLs from other bikeway types and elaborates on the available guidance.

2.4 DESIGN ELEMENTS

Design elements identified during the literature review include general design elements, curbside activity, maintenance, and facility zones (including buffer zones and mixing zones).

2.4.1 General Elements

The guidance on the general elements comes from a mix of guides that, although provide adequate instructions on the need for separation, give little to no specific instruction on the decision to design a one- or two-way facility, the side (or sides) of the road the facility will be located on, or the best practices for storm water management.

The most widely agreed upon factors for SBLs' regulation are those regarding the need for separation, that is, the conditions that warrant such adaptation (i.e. bicycle volumes, vehicle volumes, vehicle speeds, etc.); those that influence the decision to have one-way or two-way SBL; and those that determine which side(s) of the road will have an SBL as well as consideration of center-running facilities (SBLs on or along the median).

Other less standard factors include visibility elements and storm water management. Visibility elements consist of factors such as striping and signage (the use of signs and pavement markings to delineate the facility), lighting (type of street light and recommended light intensity), and considerations regarding increasing the safety of the facility to those who are visually impaired. Elements related to storm water management include: drainage pattern options for routing storm water away from or across the facility (which may be done via the placement of catch basins and sewer grates); the placement of sewer grates located along the facility (so that they do not pose a hazard to people who cycle or people in wheelchairs); and finally, bio-swales (which provide options for retention and infiltration of storm water in the buffer zones).

2.4.2 Curbside Activity

Guidance on curbside activity comes mainly from the NACTO, MassDOT, and FHWA SBL design guides, with very little additional specific guidance coming from the other guides. Activities taken into consideration were those happening in loading zones, driveways and alleys and bus stops. Though identified during Key Informant Interviews as an area of concern (i.e., delivery drivers blocking SBL while completing deliveries), little guidance exists.

Loading zone activities are numerous and serve different purposes, therefore requiring different adaptations. In general, striping and signage on loadings zones can be used to delineate the area through signs and pavement markings, as previously described for general elements. Some activities require a SBL to have design options and considerations for on-street loading zones that require the bicycle lane to deviate away from the centerline in order to make room via bike lane bend-outs.

Specific activities require more specific adaptations. Commercial and freight activities are normally related to the delivery of goods or mail and, therefore, call for design options that facilitate these processes on loading zones. Passenger activities demand design considerations for on-street pedestrian pick-up/drop-off areas that can be used by both able bodied individuals and people with disabilities. The ability to perform trash collection must also be taken into account when designing SBLs.

Driveways and alleys have a more restricted number of possible activities, making recommendations for the design of SBLs more objective. One of the main considerations is ensuring that people who drive crossing the facility have clear sight distance to see approaching traffic and people who cycle; such adaptation can be achieved through, for instance, parking restrictions near driveways and alleys to ameliorate sight distance. In addition, adaptations for people who drive exiting a driveway or alley should also be considered. One recommended adjustment is set-back crossings. Designing crossings where the SBL is set back from the edge of the roadway creates sufficient space between the bicycle lane and the edge of the roadway for a vehicle exiting the driveway or alley to dwell there while crossing the bicycle lane. Another adjustment to consider is on the turn radius since decreasing the curb's radius will slow down people who drive exiting into the SBL. A different approach would be to adapt the density of driveways and alleys, reducing the number of passageways crossing the bicycle lane in a block - which includes the possibility of combining driveways. As before, a more general recommendation is striping and signage through signs and pavement markings to mark locations where the SBL intersects with a driveway or alley.

Similarly to driveways and alleys, bus stop activities are fairly restricted and therefore more objective; however, there are more ways to approach this type of accommodation. The recommendations focus on three main approaches: the design of the bus stop, the SBL's accessibility to pedestrians, and the design of the SBL.

Considerations focusing on the bus stop's design are: floating or constrained; near-side, far-side or mid-block; inline or offline. Floating bus stops are located between the SBL and the roadway thus only requiring passengers to cross the SBL when they need to get between the sidewalk and the bus stop. Constrained bus stops, on the other hand, are located on the sidewalk making passengers cross the SBL to get between the bus and the bus stop. Near-side, far-side and midblock design adaptations refer to the location of the bus stop in relation to the intersection. Near-side bus stops are located on the near (or "upstream") side of an intersection and include considerations regarding parking restrictions, mixing zones, and sight distances. Far-side bus stops are located on the far (or "downstream") side of an intersection and include considerations regarding parking restrictions and sight distances. Midblock bus stops are located between two intersections and only include considerations for parking restrictions. Finally, in-line and offline adaptations are about designing a bus stop in the vehicle lanes (in-line) or between the vehicle lanes and the SBL (offline).

The pedestrian-focused approach to designing bus stops includes sidewalk-level crosswalk and channelized pedestrian crossings. Sidewalk-level crossing modifications involve designing a crossing between a floating bus stop and the curb where the crossing is raised to the same height as the curb. The benefits of doing so include reducing the space required to make the stop ADA accessible and drawing the attention of those who cycle to the crossing. A drawback of channelized pedestrian crossings is the limitation of the number of locations on a floating bus stop where pedestrians can cross the SBL to get to or from the sidewalk.

Lastly, the suggested SBL-focused approach includes shy distance and bike lane bend-out. Shy distance modifies the amount of clear space between the bicycle lane and the nearest vertical feature on the bus stop (i.e. railings, bus shelter, benches, etc.), while bike lane bend-out design options require the bicycle lane to deviate away from the centerline to make room.

2.4.3 Maintenance

Only four of the 20 guides reviewed and included in this literature review have specific guidance regarding SBL maintenance, which is divided into facility monitoring, winter maintenance and debris clearance. The report by Alta Planning and Design is the primary source of options and guidance on snow and debris maintenance. Guidance on facility monitoring and inspection is given by The Austroads design guide.

Winter maintenance has several aspects to it, such as: recommendations for the snow removal and clearance itself, means to facilitate clearance, ice removal and ice prevention. Approaches to snow clearance involve recommendations and considerations for clearing snow from the bicycle lane. This includes considerations for delineators in winter (remove delineators, remove snow, plow it around, plow it over, etc.) Another approach is the use of vehicles to clear snow from the bicycle lane; these could be specialized smaller vehicles as well as modified plows and pickup trucks. Alternatively, snow removal can be facilitated by providing sufficient snow storage capacity along the facility, primarily in the street and sidewalk buffer zones. The snow removed could also be hauled from the facility to a secondary storage site. Snow clearance can also be made easier with the installation of flex posts on curbs as guides for plows and other snow clearance vehicles; and with a system of route prioritization in a jurisdiction. Lastly, ice accumulation must be addressed. There are suggestions of anti-icing/de-icing initiatives such as preventing ice accumulation, removing accumulated ice, and increasing traction on accumulated ice. These include options that can be performed with salt or sand application as well as without.

Debris clearance did not receive an innovative list of recommendations, but it is necessary and relevant to mention. The only recommendation for this task is sweeping and clearing debris from the bicycle lane, which can also be done with sweeping vehicle types - including specialized sweepers and designs to accommodate traditional sweepers.

Monitoring the facilities is just as important to ensure their state and proper functioning. There are two recommendations for monitoring: safety audits and asset management. Safety audits monitor various aspects of the facility once it is built, while asset management tracks the state of the facility.

2.4.4 Facility Zones

Recommendations and suggestions for facility zones are divided into six groups: bike lane zones, street buffer zones, street zones, sidewalk buffer zones, sidewalk zones and mixing zones. Overall, guidance on certain elements is more limited than others. For instance, considerations regarding total clear width of the bicycle lane, the spacing of delineators, the characteristics of the street zone, or the design of mixing zones are much more limited. On the other hand, guidance on the width of the facility is provided by most of the guides reviewed, but it is not consistent.

Bike lane zone considerations relate to the design of SBLs and interactions with people who drive, people who cycle and pedestrians. One of the most discussed recommendations is the width of the SBL, which is measured from the outer edge of the street buffer zone to the inner edge of the sidewalk buffer zone. This includes factors such as the number of bicycle lanes, the average and peak hourly bicycle volumes, the grade of the SBL, and the type of separation. The total clear width is also relevant as it refers to the minimum width between the nearest vertical element in the street buffer zone and the nearest vertical element in the sidewalk buffer zone. This width impacts emergency and maintenance vehicle access as well as comfort for people who cycle.

Non-width related factors that should also be taken into account are the shy distance, the SBL's elevation, the curb and surface type and railroad interactions. The determination of the shy distance is based on the amount of clear space between the bicycle lane and the nearest vertical feature in either buffer zone via delineators, vegetation, parked vehicles, benches, railings, etc. The SBL's elevation in relation to the street and sidewalks should also be discussed when designing a facility. Note that the NACTO guide refers to bicycle lanes with elevations above that of the street as "raised cycle tracks." In some cases, differing elevation is the main form of separation. Variations in the design of SBLs will exist and may require different curb types. For instance, raised SBLs might have a type of curb on the left side of the lane that may be different from that on the right side. Another consideration is regarding the surface of SBLs, which includes deliberations on the use of permeable pavement, the quality of the pavement, and the type of pavement or paver. SBLs that interact with railroad crossings must also receive special safety considerations in their design.

In addition to width, street buffer zone recommendations take into consideration vertical delineator types, delineator spacing and on-street bicycle parking. While the bike lane zones' width is measured from the outer edge of the street buffer zone to the inner edge of the sidewalk buffer zone, the street buffer zone's width is measured from the outer edge of the street zone (if applicable, the street zone includes the parking lane) to the inner edge of the bicycle lane zone. This includes factors such as the presence of parking, the width of the outermost lane in the street, the amount of snow storage needed, and the type of separation in the street buffer zone. In street buffer zones, the type of vertical delineator to be used must be discussed as some guides allow for the use of parked vehicles without additional physical separation. In addition, the space between delineators will depend on, among other factors, the type of delineators used, likelihood of encroachment, and the presence of parking. Lastly, on-street bicycle parking is also an option and it can be located in the street buffer and/or the vehicle parking lane.

Sidewalk buffer zones considerations given relate to the same conditions: width, vertical delineator type and off-street bicycle parking. The width of the buffer between the sidewalk and the bicycle lane is measured from the outer edge of the bicycle lane to the inner edge of the walkable portion of the sidewalk. This includes factors such as the presence of vegetation, benches, the amount of snow storage needed, and the type of separation in the sidewalk buffer zone. Again, the type of vertical delineator, if any, must be debated as well as bicycle parking located in the sidewalk buffer.

Recommendations for street zones are slightly different given concerns regarding the vehicles' speed, number of lanes and street type (one-way or two-way). As before, width must be taken into account and, in this case, width refers to the distance between buffer zones on opposite sides of the roadway. This measurement includes consideration of the lane width, presence of parking, AADT, and design speed of the street. As with bike lane zones, the amount of shy distance (i.e., the clear space between the bicycle lane and the nearest vertical feature in a street buffer zone) is generally noted with delineators in street zones. The posted speed limit of the street is often determined in conjunction with the decision to include an SBL. Other vehicle-specific concerns are parking - which can be located in the outermost lane of the street - and accessible parking - which can also be designed in the outermost lane of the street, but with the necessary adjustments so it can be utilized by people with disabilities. These parking spaces are similar in most regards to accessible pedestrian loading zones. In addition, there are also options and considerations for designing SBLs on streets with one-way or two-way vehicular traffic. The number of vehicle lanes in a road must also be taken into account (including three-lane roads resulting from road diets). Finally, these adaptations can be guided by the designed Annual Average Daily Traffic (AADT) of the street, which is often determined in conjunction with the decision to include an SBL in the first place.

Guidance on sidewalk zones focus on width, cross-slope, and mixing zone considerations. In terms of width, the minimum walkable distance must be established, while cross-slopes in the sidewalk should also be considered - including accessibility and drainage. The length of a mixing zone is measured from the edge of the intersection to the beginning of the taper or parking restrictions along the bicycle lane. Mixing zone adaptations include its total length, parking restrictions, vehicle and SBL interactions, and striping and signage. When it comes to parking restrictions, a minimum distance from the intersection that vehicles may park must be designated. This decision is largely determined by the type of mixing zone and the visibility of people who cycle in the bicycle lane and people who drive on the cross street.

In terms of vehicle and SBL interactions, a main concern is the level of mixing between the two. One of the mixing zone options is the design of a shared turn lane, where drivers turning right and people who cycle mix in a shared right lane. On the other side of the mixing spectrum, a possible design is of an intersection approach where people who cycle do not mix with vehicular traffic, but instead are brought closer to the vehicle lanes in an effort to make it easier for people who drive to see them. In cases where parking is allowed along the street buffer, parking should be restricted near the intersection so that the parked vehicles do not obstruct the view from the roadway of people who cycle. Bend-ins can be used in conjunction with corner refuge islands. Corner refuge islands are similar to curb extensions, but they have cut-outs to allow bicycle and pedestrian traffic to continue through them. Other applications suggest the design of through, right or left bike boxes intersection approaches, which allow people who cycle to wait ahead of the stop line for vehicles. For instance, left-turn or right-turn bike boxes can be designed for left-turning or right-turning people who cycle on a designated lane or box between the vehicles' left and through/right lanes. In both cases, the area that people who cycle may way in is generally outlined or filled with paint.

Other suggestions take into account traffic elements such as contraflow lanes, roundabouts, striping and signage. In facilities where bicycle traffic is traveling in the opposite direction of vehicle traffic, one should consider the design of contraflow facilities. This can arise in cases where there is a dedicated contraflow SBL on a one-way street or when there is a two-way SBL on any road. Roundabouts are another traffic element to be considered when it comes to the design of approaches and mixing zones. Lastly, the use of striping and signage such as signs and pavement markings to delineate mixing zones are recommended.

2.5 COMPILATION OF AVAILABLE DESIGN GUIDANCE

As previously mentioned, the design of SBLs is a rapidly evolving topic in the United States and the guidance available is limited and has not been condensed into a single document. Several organizations have published guides for designing SBLs, but the design recommendations covered by those guides vary both by topic and by depth. Figure 2.2 compiles the 84 design element topics covered by each of the 20 design manuals and guidance documents (2.1.1) reviewed by the research team. Cells with a "G" (colored green) signify that the guide listed in that column contains specific guidance on the design element listed in that row. For example, PROWAG contains specific guidance on determining the need for physical separation between vehicles and people who cycle on a road. Similarly, cells with an "M" (colored yellow) signify that the guide listed in that column mentions the design element listed in that row but does not give specific guidance. The number of guides that at least mention a design element is tallied in the column labeled "Mention" while the number of guides that actually provide specific guidance on a design element is tallied in the column labeled "Guidance."

Table 2.2 provides an estimate of the degree of guidance that exists for each design element and aided in identifying gaps in the guidance. The most commonly mentioned elements, as well as the most amount of guidance provided for, were width of the bike lane, street buffer, and sidewalk buffer zone; bus stops were the least mentioned and had the least guidance presented.

			Totals		Major Guides								Minor Guides											
		Design Elements	Mention	Guidance	NACTO	MassDOT	FHWA1	FHWA2	FHWA3	PROWAG	Portland1	Portland2	Vancouve	Austroads	NYCDOT	Redmond	ODOT	OTM	Alta1	Alta2	Denmark	CiLA	Chicago1	Chicago2
General	SBL Basics	Need for separation	8	6	G		M			G							G	G		M	G		G	
		One- vs two-way	5	0	M		M							M		M							M	
		Running side	1	1			G																	
	Visibility	Striping and signage	7	7	G	G	G									G	G	G				G		
		Lighting	6	3		G							M		G	M		G				M		
		Visual impairment	1	1						G														
	Stormwater	Drainage pattern	6	1	M	G		M				M		M	M									
		Sewer grates	4	2								M					G	G			M			
		Bioswales	3	2		G											M					G		
Curbside Activity	Loading zones	Commercial/freight	3	2		G	G								M									
		Passenger (any)	4	1	M	G	M								M									
		Passenger (accessible)	4	2	M	G	M			G														
		Trash collection	2	1		M						G												
		Parking lane only	2	2		G	G																	
		Bike lane bend-out	2	2		G	G																	
		Striping and signage	2	2		G	G																	
	Driveways & Alleys	Clear sight distance	4	3	G	G	G							M										
		Parking restrictions	4	3	G	G	G							M										
		Approach ramp	2	2		G										G								
		Set-back crossing	2	2		G															G			
		Turn radius	2	0	M											M								
		Density	2	0										M								M		
		Striping and signage	5	4	G	G	G									G				M				
	Bus Stops	Floating	4	3	M	G	G				G													
		Constrained	1	1		G																		
		Near-side	2	1		G															M			
		Far-side	1	1		G																		
		Midblock	3	2	M	G	G																	
		Inline	4	2	M	G	G							M										
		Offline	3	2		G	G							M										
		Sidewalk-level crosswalk	2	0	M	M																		
		Channelized ped crossing	3	2		G	G				M													
		Shy distance	1	1		G																		
		Bike lane bend-out	3	2	M	G	G																	
Maintenance	Snow & Debris	Snow clearance	6	3	M	G	M								M			G	G					
		Snow clearance vehicle types	1	1															G					
		Flexposts as guides for plows	1	1															G					
		Prioritization of routes	1	1															G					
		Anti-icing/de-icing	3	1	M	M													G					
		Snow storage	3	1	M	M													G					
		Snow removal	2	0	M														M					
		Sweeping	6	1	M	M	M							M	M			G						
		Sweeping vehicle types	0	0																				
	Monitoring	Safety audits	3	2										G				M			G			
		Asset management	1	1										G										

Figure 2.2 Tabulation of SBL guidance by design element

			Totals		Major Guides								Minor Guides											
		Design Elements	Mention	Guidance	NACTO	MassDOT	FHWA1	FHWA2	FHWA3	PROWAG	Portland1	Portland2	Vancouve	Austroads	NYCDOT	Redmond	ODOT	OTM	Alta1	Alta2	Denmark	CiLA	Chicago1	Chicago2
Facility Zones	Bike Lane Zone	Width	18	16	G	G	G	M			G	G	G	G	G	G	G	G	G	G	G	G	M	G
		Shy distance	5	2		G						G	M	M				M						
		Elevation	9	3	G	G		G						M	M	M		M		M		M		
		Total clear width	3	3	G							G							G					
		Curb type	6	3	G	G		G	M					M		M								
		Grade	4	2			M						G			M					G			
		Cross slope	2	1		G										M								
		Surface	9	3		M						M	M	M	M	M	G	G			G			
		Railroad crossings	2	2													G	G						
	Street Buffer Zone	Width	11	9	G	G	M				G			M		G		G	G		G	G		G
		Vertical delineator type	9	6	G	G	G					G		M	M	G					G	M		
		Delineator spacing	3	2		M						G				G								
		On-street bicycle parking	4	4		G								G			G					G		
	Sidewalk Buffer Zone	Width	11	10		G		G		G		G					G	M	G	G	G	G		G
		Vertical delineator type	9	3	M					M	G	G	M		M	M					M	G		
		Off-street bicycle parking	7	7										G	G	G	G	G			G	G		
	Street Zone	Width	3	3				G														G		G
		Shy distance	1	1								G												
		Speed limit	4	4		G							G									G		G
		Conventional vehicle parking	9	3	M	G	M				M	G		M		M						G		M
		Accessible parking	5	3	M	G	G					M										G		
		One-way	8	6	G	G	G					G	G	M		G						M		
		Two-way	9	8	G	G	G					G	G	G	M	G						G		
		Number of lanes	1	1	G																			
		AADT	5	2	M	M	M						G					G						
	Sidewalk Zone	Width	7	6		G			G	G				M			G					G		G
		Cross slope	4	3					G	G							G					M		
	Mixing Zone	Length	6	2	M	M	M				M					G		G						
		Parking restrictions	5	4	G	G	G				M	G												
		Switch/weave	6	4	M	G	G						M			G		G						
		Shared turn lane	8	4	M	G	G				M		M			G		G					M	
		Bike lane bend-in	4	1	M	G					M							M						
		Corner refuge island	2	2		G										G								
		No mixing zone	6	3	M		G									G		G				M	M	
		Through/right bike box	7	4	M		G				G					G		G				M	M	
		Left turn bike box	3	2												G	M	G						
		Contraflow facilities	3	1	M	G												M						
		Roundabouts	3	3		G												G			G			
		Striping and signage	5	5	G	G	G									G		G						

Figure 2.2 Tabulation of SBL guidance by design element (cont.)

To assess the prevalence of the various options for each design element in Minnesota, the research team also conducted a preliminary inventory of SBL facilities in the state. This inventory can be found in Appendix A.

Because of limits of time and budget, this list of 84 design elements needed to be pared down to priority topics. The design elements were presented to the TAP; the TAP then ranked priority areas of study, which guided the rest of the project and are presented in Section 2.3.

2.6 STUDY DESIGN

The research team used the knowledge gaps identified in the literature review, the TAP's feedback on research priorities and design elements, as well as the inventory of SBLs in Minnesota to create a set of 21 priority design elements for study.

1. Need for separation: The factors or conditions that warrant separation (i.e. bicycle volumes, vehicle volumes, vehicle speeds, etc.).
2. Visual impairment: Considerations to ensure that the facility will not create a hazard for people with visual impairments.
3. Snow clearance: Recommendations and considerations for clearing snow from the bicycle lane. This includes considerations for delineators in winter (remove, plow around, plow over, etc.)
4. Snow clearance vehicle types: Options and specifications for vehicles to be used to clear snow from the bicycle lane. This includes specialized smaller vehicles as well as modified plows and pickup trucks.
5. Flexposts as guides for plows: Recommendations for using vertical delineators on curbs as a guide for snow clearance vehicles
6. Prioritization of routes: Options and considerations for a system for prioritizing snow clearance on various routes in a jurisdiction
7. Anti-icing/de-icing: Options and considerations for preventing ice accumulation, removing accumulated ice, and increasing traction on accumulated ice. This includes options that include salt application as well as those that do not.
8. Snow storage: Options and considerations for providing sufficient snow storage capacity along the facility, primarily in the street and sidewalk buffer zones.
9. Snow removal: Options and considerations for removing snow from the facility and hauling it to a secondary storage site.
10. Sweeping: Recommendations and considerations for sweeping and clearing debris from the bicycle lane.
11. Sweeping vehicle types: Options and specifications for vehicles to be used to clear debris from the bicycle lane. This includes specialized sweepers and designs to accommodate traditional sweepers.
12. Snow removal agreements/contracts with other agencies: Options for sharing costs and/or responsibility for SBLs between agencies.
13. Vertical delineator type: Options and considerations for the type or types of delineator to be used. Some guides allow for the use of parked vehicles without additional physical separation.

14. Delineator spacing: Recommendations and considerations for the spacing between delineators. Among other factors, this depends on the type of delineators used, likelihood of encroachment, and the presence of parking.
15. Shy distance: Considerations and recommendations for the amount of clear space between the bicycle lane and the nearest vertical feature in a street buffer zone (generally delineators).
16. Switch/weave mixing zones: Recommendations and considerations for the design of mixing zones where drivers turning right merge across the bicycle lane upstream of the intersection and queue in a dedicated right turn lane between the bicycle lane and the curb.
17. Bus stops: General consideration for the impacts of bus stops located on roads with SBLs
18. Repair/replacement of delineators: Recommendations and considerations for repair and/or replacement of damaged or missing delineators.
19. Re-painting: Recommendations and considerations for re-painting worn lane markings on SBLs.
20. Costs of designs and maintenance: Cost estimates of the different SBL midblock designs and associated maintenance.
21. Benefits and drawbacks of SBLs: Generic benefits and drawbacks of installing SBLs instead of other bicycle facilities that do not have physical separation from vehicle traffic (as identified in existing literature).

From these 21 priority design elements, six sub-studies were created to guide the remainder of this project:

1. Winter maintenance
2. Summer maintenance
3. Costs and Benefits
4. Buffer design
5. Mixing zone design
6. Bus stops on SBLs

Each topic was initially approached in the same four step manner:

1. Formulate a research question to address the specific topic.
2. Identify existing guidance or research on a similar topic.
3. Determine if the relationships identified in related research can be transferred to the research question. If not, examine the changes to those relationships when transferred.
4. Develop new guidelines for the topic selected.

Specific methodology to investigate each of the six sub-topics is laid out in Table 2-4. Methods to investigate the design elements in addition to any information gleaned during the Literature Review included:

2.6.1 Key Informant Interviews

Key Informant Interviews (KII) were lengthy but focused conversations with members of groups that could provide representative perspectives and feedback. The effort necessary to conduct KII consisted of designing interview questions and planned analysis methods, arranging and conducting interviews, processing recordings, and analyzing the transcribed dialogue to draw key inferences. Groups included bicycle advocates, parking and transportation services, transit drivers, and design agencies around the Twin Cities Metro Area. KIIs are discussed in the following chapter.

2.6.2 Field Data

Field data collection consisted of both site visits to SBLs around the Twin Cities Metro Area as well as observations at sites in the field to record information on events or conditions of interest. The effort necessary to conduct field observations of events consisted of selecting sites for observation, applying for any permits necessary, installing the necessary measurement devices (i.e. cameras), retrieving the measurement devices, and processing the data recorded (i.e. watching video of events and recording data of interest or aggregating tube counter data). The MTO deployed camera equipment at two sites and also obtained video of a third site from Parking and Transportation Services at the University of Minnesota. After analyzing this sample footage, it was determined the cost to collect and process enough footage for a significant sample size would be too much for this project. Chapter 4 discusses the field data collected both by researchers' site visits as well as video data collection.

2.6.3 User Group Survey

Initially visualized as short, standardized lists of questions for road users, the user survey developed into a lengthy survey targeted at people who cycle in the Twin Cities and around the state of MN. The survey included cyclist behaviors, buffer design, mixing zone design, bus stop design, and winter riding behaviors, factors and satisfaction. The effort necessary to conduct user surveys consisted of survey design, sampling method design, survey administration, and multi-level analysis of responses. The development and distribution of the user group survey is discussed in Chapter 5. Chapter 6 discusses analysis of results.

Table 2-4 Data collection method per topic

Topic	Key Informant Interviews	Field Data	Survey
Buffer Design			
- Design concerns	x		
- Safety, comfort and understanding			x
Mixing Zone Design			
- Design concerns	x		
- Safety, comfort and understanding			x
Bus Stops on SBLs			
- Design concerns	x	x	
- Safety, comfort and understanding		x	x
Summer Maintenance	x		
Costs and Benefits	x		x
Winter Maintenance			
- Costs and practicalities	x		
- Desired level of service			x

CHAPTER 3: KEY INFORMANT INTERVIEWS

This chapter discusses why and how Key Informant Interviews (KII) were performed. The KII were an invaluable source of experiential guidance on Separated Bike Lanes (SBLs), as well as pointing out gaps in guidance and knowledge from the perspective of designers, people who cycle and bus driver user groups.

3.1 INTERVIEW METHODOLOGY

The MTO interviewed stakeholders at all levels of involvement with SBLs: from planners, to designers, to operations and maintenance and user groups. Planners and designers need to know what will attract hesitant users or enhance the cycling experience for users already utilizing facilities; additionally, as explored in the literature review, guidance on SBLs is disparate and sometimes contradictory. It was critical for the project to understand what current industry professionals are looking toward for guidelines and recommendations when designing and implementing SBLs, and why. It was also important to understand the gaps between planning, design and implementation; for example, planners may recommend a certain type SBL but Right of Way (ROW) constraints might prevent that. The MTO wanted to understand how design and implementation of SBLs changed from idea to application.

Operations and Maintenance personnel are also vital to the ongoing usage and success of SBL facilities; the TAP specifically mentioned summer and winter maintenance topics as areas for further study. Interviewing these personnel helped to establish what is feasible for operations and maintenances' year-round level of service provided to SBLs.

Finally, user groups were important to interview because they experience the SBL practically. People who cycle were given the opportunity to discuss preferences and issues with SBL design elements unique to their experience as riders. These cyclist advocacy groups were sought out due to their expertise and experience in riding in the Twin Cities Metro Area. The advocacy groups were able to give more succinct answers to complex questions the MTO asked; general opinions and experiences with design elements were sought out with the user group survey, discussed in Chapter 6.

Bus drivers had particular concerns that were not addressed in the literature review of available guidance, including dealing with people who use transit and people who cycle competing for space and ROW at stops along SBLs, accounting for tailswing when attempting to turn across or merge into SBLs, and winter maintenance standards exacerbating issues of ROW. The conflicts mentioned by bus drivers went on to drive the development of the bus stop section in the user group survey.

Overall, the KII focused on understanding the needs and priorities of stakeholders, which led to questions about what users prefer in SBLs, and find safe or comfortable. This led to the creation of the user group survey to hear more directly about the needs and experiences of roadway users.

3.2 INTERVIEWEES

The research team used the inventory of facilities in Minnesota (Appendix B) to identify 11 agencies in Minnesota that have been responsible for the design, operation, and/or maintenance of SBLs. Personnel from seven of those agencies (marked with an asterisk) were interviewed in-person.

1. Glenwood
2. Hopkins
3. Hennepin County*
4. Metro Transit*
5. Minneapolis*
6. MnDOT*
7. Richfield
8. Rochester
9. St. Louis Park*
10. St. Paul*
11. U of M Parking and Transit Services*

The SBL in Hopkins was only brought to the research team's attention during an interview with a different city, so no interview was arranged. Glenwood was not approached for an interview because the SBL in Glenwood is in MnDOT's ROW. Rochester was not approached for an interview because it does not have any built SBLs and, unlike the agencies that were interviewed, is geographically distant from the MTO, making any potential field data collection more difficult than with other agencies. Richfield was approached for an interview but never responded to the research team's requests.

The research team emailed at least one designer or planner from each of the seven agencies an explanation of the project and a list of the topics being addressed by the project and asked if they would be willing to be interviewed. The personnel contacted were encouraged to pass the invitation along to any colleagues with responsibilities in the set of topics provided. Table 3-1 shows the agency, role, and name of each of the interviewees. Care was taken to include designers, planners, and maintenance supervisors so that the responses would represent as many perspectives as possible. In cases where one of those three groups was not represented at the interview, their input was either relayed by other personnel or was solicited via email after the interview.

Additionally, bicycle advocacy groups and transit drivers were approached for interviews. The following groups participated.

1. Bicycle Alliance of MN (BikeMN)
2. Our Streets MPLS
3. Twin Cities Bicycling Club
4. First Transit Drivers

Table 3-1 Interviewees' agencies, roles, and names

Agency	Role(s)	Name
University of MN	Planning, operations	Steve Sanders
St. Paul	Operations	Joe Spah
St. Paul	Maintenance	Matthew Morreim
St. Paul	Design	Nick Peterson
St. Paul	Planning	Reuben Collins
St Louis Park	Design	Ben Manibog Jr
St Louis Park	Design, Planning	Debra Heiser
St Louis Park	Design	Joe Shamla
MnDOT	Design, Planning	Hannah Pritchard
MnDOT	Planning	Mackenzie Turner Bargen
MnDOT	Design, Planning	Sonja Piper
Metro Transit	Planning, Design	Katie Roth
Minneapolis	Planning	Matthew Dyerdahl
Minneapolis	Construction, Design	Mike Kennedy
Minneapolis	Planning	Simon Blenski
Minneapolis	Construction, Maintenance	Steve Collin
Minneapolis	Construction, Maintenance	Tom Dailey
Hennepin Co	Planning	Jordan Kocak
Hennepin Co	Operations	Maury Hooper
Hennepin Co	Design	Nathan Ellingson
Hennepin Co	Design	Ryan Allers

3.3 INTERVIEW METHODOLOGY

Following the identification of interviewees, the research team designed a set of questions to help guide discussions about the research topics identified. The research team then met with the interviewees and recorded their responses to the questions. As needed, the research team asked probing questions designed to help guide the focus of the conversation about each question. Interviewees were also asked to review the list of facilities for their jurisdiction to help identify any errors or omissions. Following each interview, the research team summarized the conversation and sent the summary to the interviewees for review and – in some cases – to ask further questions or ask for materials discussed during the interview.

3.3.1 Questions

The questions asked during the interviews were designed to focus the conversation on specific topic without overly constraining the responses. When applicable, the questions focusing on maintenance practices were designed to spark conversation on the design implications of those maintenance practices. Covering several large topics in the space of an hour or an hour and a half proved difficult during some interviews, especially those involving multiple interviewees. As such, the list of questions started with the most general topics and ended with the most specific topics and/or those that could be most easily followed up on via email. In addition to the questions listed below, probing questions to steer conversation toward topics that might otherwise have been neglected were employed as needed. The following is the full list of questions asked at the interviews:

1. Do you have bicycle counts for the SBL facilities in your jurisdiction?
2. How do you determine the need for a Separated Bike Lane (SBL)?
3. How do you design SBL buffers? What factors influence your designs in different locations?
4. What road users (drivers, buses, pedestrians, people with disabilities, freight, scooters, etc.) do you design for? How do you design for them?
5. How do you handle maintenance of SBLs in winter? What types of maintenance are undertaken? Are those maintenance activities a consideration in your designs?
6. What other types of maintenance are undertaken? Are those maintenance activities a consideration in your designs?
7. How do you design mixing zones at intersections? What factors influence your designs?
8. How do you design bus stops on SBLs? What factors influence your designs?
9. Do you have costs or cost estimates for different designs and maintenance practices?
10. What else about design of separated bike lanes do we need to know? If you could have guidance on one particular thing, what would it be?

Metro Transit's interaction with SBLs is somewhat different than that of a city or county; Metro Transit is generally a prominent stakeholder that reviews plans and contributes to design decisions but does not design parts of the facility other than the transit stop itself. The questions focused on maintenance activities and the impacts of design decisions and maintenance activities on transit operations. The following is the full list of questions asked at the interview with Metro Transit:

1. What parts of the design of SBLs is your agency involved in? What guidance do you refer to? What influences your designs?
2. How do different SBL buffer designs impact transit operations?
3. How do you handle maintenance of transit facilities on SBLs in winter? How does winter maintenance impact transit operations?
4. What other types of maintenance are undertaken? How does that maintenance impact transit operations?
5. How do different SBL intersection mixing zone designs impact transit operations?
6. How are transit stops on SBLs designed? How do different designs impact transit operations?
7. Do you have costs or cost estimates for different designs and maintenance practices?
8. What else about design, maintenance, or use of separated bike lanes do we need to know? If you could have guidance on one particular thing, what would it be?

Similarly, bicycle advocacy groups and transit drivers interact with SBLs but do not play a role in design. Those groups were asked:

1. What designs or design elements are most beneficial to improving users' access across and along SBLs? Which are the least beneficial?
2. What are the impacts of maintenance activities (or lack thereof) on your interactions with SBLs in winter? For example, snow clearance or deicing.
3. What are the impacts of maintenance activities (or lack thereof) on your interactions with SBLs in the warmer months? For example, sweeping or pavement repair.

4. What designs or design elements for the buffer between the vehicle lanes and the bicycle lane (e.g. buffer width, delineator type, delineator spacing, etc.) are most beneficial for your interactions with SBLs? Which are the least beneficial?
5. What designs or design elements for the regions directly upstream of intersections where motor vehicle and bicycle traffic interact/mix are most beneficial for your interactions with SBLs? Which are the least beneficial?
6. What designs or design elements for bus stops on roads with SBLs are most beneficial for your interactions with SBLs? Which are the least beneficial?

3.3.2 Interview Procedure

The interviews were led by one member of the research team and lasted between one and two hours. The research team member took notes during the interviews but also made an audio recording for later reference. Each interview started with a standardized introduction to the project and an explanation of the purpose of the interviews. Interviewees were then given the latest list of SBL facilities in Minnesota and pictures of the options for delineators, mixing zones, and transit stops included in the Massachusetts DOT (MassDOT) and Federal Highway Administration (FHWA) SBL design guides. Interviewees were asked to review the list of facilities and point out any errors or omissions.

3.3.3 Interview Follow-up

After each interview, a summary of the meeting was written using the notes and audio recordings. That summary was then sent to the interviewees so that they could review the summary and point out any missing or misinterpreted parts of the conversation as well as follow up on any unresolved matters. This also provided an opportunity to get documents – particularly cost estimates – from the interviewees.

In the case of Metro Transit, the interviewee, who works in planning and design, referred to “institutional knowledge” from the operations department as a major source of guidance for the agency and suggested that the research team talk to someone from operations. Other agencies also referenced knowledge and/or internal documents that would contain answers sought by the research team. The research team followed up with each agency as necessary; Hennepin County returned useful cost estimates and maintenance research.

3.4 SUMMARY OF RESPONSES

Using the summaries of each design agency’s responses to the standard set of questions, two tables were created: one to split the responses by question (Table 3-2) and a second to further split the responses by agency (Table 3-3). A third table (Table 3-4) was created to present Metro Transit’s responses to the alternate set of questions. A fourth table (Table 3-5) presents bicycle advocacy groups and transit drivers’ responses. Note that “ND” means “Not Discussed” – i.e. the interviewees did not have anything to add on the topic.

Some common themes include designing facilities when ROW is limited, the observation that many design decisions are heavily context-sensitive, the presence of driveways and alleys, uncertainty regarding mixing zone and bus stop designs, maintenance vehicle width as a design constraint, differing designs for retrofits vs reconstructs, and the tradeoff between flexposts' low cost and the need to replace those that were hit over the winter.

The FHWA SBL design guide and the NACTO SBL design guide and All Ages, All Abilities (AAAA) addendum were the most commonly cited sources of guidance with some interviewees also pointing to existing bicycle network master plans as a major contributor.

The interviewees' responses highlight a link between maintenance practices, the acquisition of maintenance equipment, the costs of construction and maintenance, and the overall design of facilities. The mechanisms of interaction between these linked components of SBLs appears to vary between agencies. When asked about their main sources of uncertainty for design or maintenance, many interviewees brought up the difficulties of designing SBLs at intersections – particularly two-way SBLs. Driveways and alleys were also brought up by multiple agencies – particularly regarding the fact that protection is dropped at every driveway or alley.

These perspectives – particularly those that highlight industry practitioners' uncertainties – confirm some of the available guidance but also highlight gaps in the guidance. The inferences drawn from the interviews were used to help shape the next stages of data collection through design of the user group survey and video collection.

Table 3-2 Summary of all unique responses to the standard questions by question

Do you have bicycle counts for the SBL facilities in your jurisdiction?	
Counts	• Yes
How do you determine the need for a Separated Bike Lane (SBL)?	
Considerations	• Site-specific context • Vehicle volumes • Bicycle volumes • Speed limit • Road geometry • ROW availability • Types of vehicle traffic (trucks, transit, etc.) • Number and type of intersections • Opportunity to include with existing project • Retrofit vs reconstruct • Recommendations of existing bike plans and policies • Local stakeholder feedback • Site-specific context • Rural vs urban/suburban • Maintenance responsibility • Prioritize direct routes between origins and destinations • Crash history • Budget • Demographics of adjacent parcels
Guidance Used	• NACTO Urban Streets Design guide • NACTO AAAA Addendum • NACTO Transit Streets Design Guide • FHWA SBL Design Guide • FHWA Bikeway Selection Guide • FHWA Small Town and Rural Multimodal Networks guide • Minnesota State Aid Manual • MassDOT SBL Design Guide • Local and regional plans and policies • Existing projects
Departures from Guidance	• If intersections can't be handled according to guidelines • If cost of doing things by guidelines is too high • ROW constraints • If scope or budget don't include SBL • If maintenance won't be provided • Politics • If road has extra space • Beautification • Temporary stand-in for trail • If facility is in underserved community ○ Underserved including areas lacking bike lanes or trails, rural areas, areas undergoing reconstruction for other reasons (i.e., not just to fix or add a bike lane)

Table 3.2 Summary of all unique responses to the standard questions by question (Continued)

<table>
<tr><th colspan="2">How do you design SBL buffers?
What factors influence your designs in different locations?</th></tr>
<tr><td>Considerations</td><td>• Intersecting driveways and alleys
• Parking
• Disability access to the curb
• Maintenance vehicle width
• Winter maintenance
• Snow storage
• Cost
• Delineator spacing
• Available sight distances
• Crashworthiness of delineators
• Retrofit vs reconstruct
• ROW availability
• Midblock access
• Existing pavement quality
• Adjacent land use
• Traffic volumes and speeds
• Space for signage
• Users with visual impairments
• Drainage
• Aesthetics</td></tr>
<tr><td>Pros and Cons of Options</td><td>• Flexposts
○ Inexpensive
○ Provide sense of separation but not actual separation
○ 30 to 50% hit by plows in winter
○ Damage snow blowers if hit
○ Not aesthetically pleasing to some people
○ Most common for retrofits
• Raised curb
○ Can use standard curb-paving equipment
○ Can cause lateral drainage issues
○ Windrows need to be removed to allow meltwater to drain
○ Limit midblock access for cyclists
○ Present barrier to people crossing to or from parked cars
• Planters
○ Crashworthiness may be an issue
• Bollards
○ Crashworthiness may be an issue
• Concrete barriers
○ Crashworthy (often used on bridges)
○ Can cause lateral drainage issues
• Sidewalk level facility with mountable curb
○ Allows midblock access for bikes
○ Can be plowed with wing on standard plow
• Sidewalk-level two-way SBL
○ May still need facilities on both sides of road to reduce need for cyclists to cross major road
○ Can be maintained using pickup and standard sweeping equipment</td></tr>
</table>

Table 3.2 Summary of all unique responses to the standard questions by question (Continued)

What road users (drivers, buses, pedestrians, people with disabilities, freight, scooters, etc.) do you design for? How do you design for them?	
Users	• Interested but concerned cyclists • People with mobility impairments • People with vision impairments • Freight • Buses • Parking vehicles • Door-to-door mobility services • Scooters • Roller blades • Ebikes • Pedestrians
Design Implications	• ADA access to bus islands and parking • Avoid roads with many conflicting user groups • Small turn radii or narrow lanes may pose problems for trucks and buses • Truncated domes included at ends of facilities • Detectable directional bar tiles used along sidewalk buffer • Unclear how to service door-to-door mobility customers • People on scooters and rollerblades are very sensitive to road surface irregularities • Scooters and Ebikes may reach speeds much higher than those of conventional bikes • Space should be provided for queuing pedestrians
What types of maintenance are undertaken on SBLs in winter? Are those maintenance activities a consideration in your designs?	
Activities Undertaken	• Snow clearance • Coordinate activities with other jurisdictions • Salt only if needed • Salt while plowing • Brine before snowfall • Sand only if needed
Equipment Used	• Pickup truck with plow or brush • Bobcat, maintenance tractor, or skid steer (can use bucket, brush, or blower) • Wing from plow • Dump trucks for hauling
Design Implications	• Snow storage or hauling is needed • Facility must be wide enough to be cleared by pickup truck with plow • Installation of SBL may change distribution of accessible snow storage • If SBL is part of a designated ADA clear path, it is a much higher priority • Heavier equipment may necessitate stronger pavement • Parking may hinder snow removal • Furniture and transit stops complicate snow clearance • Trees and signs may reduce clearance for equipment • Landowners may push snow into SBL • SBLs generally require at least two passes with equipment

Table 3.2 Summary of all unique responses to the standard questions by question (Continued)

What other types of maintenance are undertaken? Are those maintenance activities a consideration in your designs?	
Activities Undertaken	• Sweeping (twice per year and if needed) • Painting • Replacing/reinstalling flexposts • Patching/pavement repair • Mowing
Equipment Used	• Walk-behind striping machine if space is limited • Standard street sweeper for wide facilities • Narrow lane sweeper or broom and pan on skid steer • Painting on vehicle side of buffer is done with standard striper • Painting on bike side of buffer is done by hand or not at all • Small patches are done by hand • Full pavement overlays difficult with current equipment
Design Implications	• Sweeping SBLs with flexposts can cause "windrow" of debris in buffer • Sweeping is especially important in spring • Cyclists are especially sensitive to poor road surfaces • Can't use ground-in striping if pavement is too damaged • May need to include overlay as part of retrofit designs • Facility must be wide enough for equipment • Once raised curb is poured, lines in bike lane are much harder to repaint (currently looking into more durable MMA paint)
How do you design mixing zones at intersections? What factors influence your designs?	
Considerations	• One- vs two-way SBLs • Visibility • Angle of conflicts • Highlight conflict areas where cyclists are losing protection • Snow clearance • Snow storage • Sweeping • ROW constraints • Bike left turns • Detection of cyclists • Balancing maintaining protection and allowing access into or across lane • Additional signage and striping • Queuing pedestrians • Bicycle and vehicle turning volumes • Facilities on cross street

Pros and Cons of Options	• Adding median or delineators to road requires additional passes (and potentially additional equipment) for sweeping and snow clearance
	• Not much snow storage
	• Not sure how to transition between one-way, both sides to two-way, one side
	• Difficult to deal with bike turning movements (especially contraflow)
	• Two-phase turn boxes may not be used by all cyclists
	• Shared turn lane
	  ○ Commonly used (especially when ROW is constrained)
	  ○ Sharrows easy to paint with stencil
	• Switch and weave require more paint and signage

Table 3.2 Summary of all unique responses to the standard questions by question (Continued)

How do you design bus stops on SBLs? What factors influence your designs?	
Considerations	• ROW availability • Pedestrian cross-traffic • Same-grade disability access to island • Drainage for retrofits • Bus frequency, occupancy, and dwell time • ADA requirements • Post vs shelter • Size of shelter • Additional signage and/or striping warning cyclists of crossing pedestrians • Rider queuing space • Snow storage

Pros and Cons of Options	• Islands require at grade pedestrian crossing which may cause drainage issues
	• Islands require additional ROW
	• Constrained stops
	  ○ Simple to maintain
	  ○ Fit in most situations
	  ○ Requires consideration for bikes behind bus
	• Unclear where space for dwelling buses should come from if there aren't parking lanes

Do you have costs or cost estimates for different designs and maintenance practices?	
Construction Costs	• Construction costs for various types of facilities are presented at the end of this chapter
Maintenance Costs	• Maintenance costs for various types of facilities • Maintenance costs for various levels of clearance during the winter, ranging from basic maintenance to enhanced • Maintenance cost estimates varied greatly from agency to agency and level of desired winter maintenance
What else about design of separated bike lanes do we need to know? If you could have guidance on one particular thing, what would it be?	
Further Questions	• Number and volumes of driveways and alleys ○ Effect on buffer choice (i.e., intermittent v. continuous to allow entry/exit of driveways) • Intersection treatments (especially turning movements) • Strengths and weaknesses of different delineator types • Trade-offs between safety and facility performance when vertical element is added to painted buffer • Bike volume forecasting for SBLs • Mixing zones for two-way SBLs • Getting drivers to recognize SBL as a lane of the road (ex. Don't creep into bike lane while searching for a gap at a stop sign) • Maximum number of flexposts that can be lost while still maintaining sufficient effectiveness • Is mountable curb enough separation between road and bike lane? • Economic impact of and SBL • Special considerations for rural bike lanes • Coordination of snow clearance with transit schedule • Striping and patching on narrow bike lanes with raised curb • Making room for bus stops when ROW is limited and parking is prohibited

Table 3-3 Summary of responses to the Metro Transit questions by question

What parts of the design of SBLs is your agency involved in? What guidance do you refer to? What influences your designs?	
Role in Design	• Usually, a stakeholder and reviewer • Sometimes a full designer • Scoping of projects is generally handled by other agencies
Guidance Used	• NACTO Urban Streets Design guide • NACTO Transit Streets Design Guide • Institutional knowledge
Considerations	• Design for current conditions but make sure design will be compatible with future plans
How do different SBL buffer designs impact transit operations?	
Role in Design	• ND
How do you handle maintenance of transit facilities on SBLs in winter? How does winter maintenance impact transit operations?	
Activities Undertaken	• Coordinate activities with other jurisdictions • Snow clearance (at stop/station) • Salting (at stop/station)
Equipment Used	• Pickup truck with plow • Front-end loader with brush and scoop
Design Implications	• BRT platform clear zone is designed for pickup truck with plow or front-end loader with brush and scoop • Temporary snow storage in taper zones (dependent on site, can be removed later)
Operations Implications	• ND

Table 3.3 Summary of responses to the Metro Transit questions by question (Cont.)

What other types of maintenance are undertaken? How does that maintenance impact transit operations?	
Activities Undertaken	• Most maintenance is handled by other jurisdictions • Maintenance of pavement in front of stop in special cases (ex. BRT stop)
Equipment Used	• ND
Design Implications	• ND
Operations Implications	• ND
How do different SBL intersection mixing zone designs impact transit operations?	
Operations Implications	• Need 5' x 8' clear area for ADA access to bus door • Bus must be able to dwell next to curb
How are transit stops on SBLs designed? How do different designs impact transit operations?	
Considerations	• Site-specific context • ROW availability • ADA access to bus • Bus access to curb • Rider queuing space • In-line vs off-line
Design Implications	• Need 5' x 8' clear area for ADA access to bus door for all buses – local and BRT • Bus must be able to dwell next to curb • Need 6 ft. of clear space for queuing by the doors for BRT
Operations Implications	• ND

Table 3.3 Summary of responses to the Metro Transit questions by question (Cont.)

Do you have costs or cost estimates for different designs and maintenance practices?	
Construction Costs	• Main costs come from systems (electrical, heat, light, data, etc.) • Remaining costs (concrete, shelter, etc.) are fairly easy to estimate
Maintenance Costs	• ND
What else about design of separated bike lanes do we need to know? If you could have guidance on one particular thing, what would it be?	
Further Questions	• Not enough literature on sequencing of snow clearance activities • Not enough guidance on lane markings, signage, and user instructions

Questions regarding costs and benefits were included as part of the key informant interviews, but little information was gathered from the participating agencies. Requests for costs of specialized maintenance equipment and equipment deployment were made. The research team gathered information on construction and maintenance costs from Minneapolis, MnDOT, and Hennepin County, discussed in detail in Section 3.5.

Table 3-4 Summary of responses to the standard questions by question and agency

Do you have bicycle counts for the SBL facilities in your jurisdiction?						
	U of M Parking & Transit	**City of St. Paul**	**City of St. Louis Park**	**MnDOT**	**City of Minneapolis**	**Hennepin County**
Counts	• Yes	• Yes	• ND	• Yes	• Yes	• Yes

How do you determine the need for a Separated Bike Lane (SBL)?						
	U of M Parking & Transit	**City of St. Paul**	**City of St. Louis Park**	**MnDOT**	**City of Minneapolis**	**Hennepin County**
Considerations	• Site-specific context • Vehicle volumes • Vehicle types • Vehicle speeds • Bicycle volumes • Existing road geometry • ROW availability • Number and type of intersections	• Opportunity to include with existing project • ROW availability • Retrofit vs reconstruct	• Existing facilities • ROW availability • Existing traffic conditions • Reconstruct vs retrofit • Number and type of intersections	• Recommendations of existing bike plans and policies • Local stakeholder feedback • Site-specific context • Rural vs urban/suburban • ROW availability • Maintenance responsibility	• Recommendations of existing bike plans and policies • Site-specific context • Connectivity between origins and destinations • Bicycle volumes • Vehicle volumes • Crash rates	• Site-specific context • Public input • Budget • Crash rates • ROW availability • Maintenance responsibility • Demographics of adjacent parcels • Level of traffic stress (LTS)
Guidance Used	• NACTO guides help narrow down options	• FHWA guides • MassDOT SBL guide • NACTO guides	• Minnesota State Aid Manual • NACTO AAAA Addendum • Existing projects	• FHWA bikeway selection guide • MnDOT bicycle design manual drafts	• FHWA SBL guide • NACTO AAAA Addendum • Minneapolis bicycle master plan (and SBL addendum) • Minneapolis climate action plan	• NACTO guides • FHWA Small Town and Rural Multimodal Networks guide • FHWA SBL guide • AASHTO bike guide • Minnesota State Aid • Road to Zero • Hennepin County Mobility 2040 Plan
Departures from Guidance	• If intersections can't be handled properly • If cost of doing things properly is too high	• If road has extra space • Beautification • Temporary link in trail system	• Number and type of intersections • ROW constraints	• ROW constraints • Local agency wishes	• If scope/budget don't include SBL • Politics • Opportunity to upgrade a low priority route arises	• If maintenance won't be provided by municipality • ROW constraints • Facility is in an underserved community

Table 3.4 Summary of responses to the standard questions by question and agency (Continued)

How do you design SBL buffers? What factors influence your designs in different locations?						
	U of M Parking & Transit	**City of St. Paul**	**City of St. Louis Park**	**MnDOT**	**City of Minneapolis**	**Hennepin County**
Considerations	• Intersecting driveways • Parking • Disability access to the curb • Winter maintenance	• Cost • Delineator spacing • Parking • Sight distance • Crashworthiness • Snow storage • Retrofit vs reconstruct • Bolt-in flexposts vs butyl pad	• Feedback from user groups • ROW availability • Midblock cyclist access • Maintenance access • Existing pavement quality	• ROW availability • Land use • Traffic volumes and speeds • Snow storage • Space for large signage • Midblock access vs maintaining protection • Users with visual impairments • Crashworthiness	• Cost • ROW availability • Retrofit vs reconstruct • Delineator spacing • Bolt-in vs butyl pad • Poured vs prefab curb • Drainage • Midblock access • Crashworthiness • Aesthetics • Winter maintenance	• Retrofit vs reconstruct • ROW availability • Maintenance vehicle width • Crashworthiness • Aesthetics

Pros and Cons of Options	• Flexposts
	  ○ Low cost
	  ○ Look cheap and temporary
	  ○ Often hit by plows
	• Raised curb
	  ○ Good option if access across bike lane is not an issue
		• Flexposts
		  ○ Often hit by plows (can be reused)
		  ○ Damage pavement if bolted in
		  ○ Generally reserved for retrofit
		• Bollards and planters
		  ○ May damage cars or plows if hit
		• Raised curb
		  ○ Hinders maintenance the least
		  ○ Requires substantial roadwork to accommodate
			• Sidewalk level facility with mountable curb
			  ○ Allows midblock access for bikes
			  ○ Can be plowed with wing on standard plow
			  ○ Permanent
				• Flexposts
				  ○ Only used in temporary cases
				  ○ Need to be replaced each spring
				• Sidewalk-level two-way SBL
				  ○ Most common for MnDOT
				  ○ May still need facilities on both sides of road to reduce need for cyclists to cross major road
				  ○ Can be maintained using pickup and standard sweeping equipment
					• Flexposts
					  ○ Inexpensive
					  ○ Provide sense of separation but not actual separation
					  ○ 30 to 50% hit by plows in winter
					• Raised curb
					  ○ Prefab costs more than poured
					  ○ Use standard curb-paving equipment
					  ○ Can cause lateral drainage issues
					  ○ Prevent entry or crossing of SBL
					• Concrete barriers
					  ○ Crashworthy (often used on bridges)
					  ○ Can cause lateral drainage issues
					• Planters
					  ○ Still in pilot phase
						• Flexposts
						  ○ Most common for retrofits
						  ○ Not aesthetically pleasing
						  ○ "Porous" to vehicles
						  ○ At least some need to be replaced each spring
						• Sidewalk-level facility
						  ○ Most common for full reconstructs

Guidance Used	• ND	• ND	• NACTO AAAA Addendum • Existing projects	• ND	• ND	• ND

Table 3.4 Summary of responses to the standard questions by question and agency (Continued)

What road users (drivers, buses, pedestrians, people with disabilities, freight, scooters, etc.) do you design for? How do you design for them?						
	U of M Parking & Transit	**City of St. Paul**	**City of St. Louis Park**	**MnDOT**	**City of Minneapolis**	**Hennepin County**

Users	• Interested but concerned cyclists • People with impaired mobility	• Cyclists • Freight • Buses • People with disabilities	• User priority decreases with vulnerability • Still make sure designs work for high priority groups	• People with disabilities • Freight • Parking vehicles • Door-to-door mobility services	• Scooters • Rollerblades • Ebikes	• Freight • Other large vehicles • Pedestrians • Parking vehicles
Design Implications	• ADA access to bus islands	• Avoid roads with many conflicting user groups • Small turn radii may pose problems for trucks and buses	• ND	• ADA requirements must always be satisfied • Truncated domes included at ends of facilities • Detectable directional bar tiles used along sidewalk buffer • Parking must be accessible from curb • Turning radii must be larger or have truck aprons • Unclear how to service door-to-door mobility customers	• Tempting to have other users (freight, buses, etc.) share bike lane • People on scooters and rollerblades are very sensitive to road surface irregularities • Scooters and Ebikes may reach speeds much higher than those of conventional bikes	• Large vehicles need large turning radii or truck aprons • Most large vehicles may require access to curb • Large vehicles require wide lanes • Sidewalk buffer may need to be enhanced to delineate border • Pushbuttons must be ADA compliant and should not hinder cyclists • Space should be provided for queuing pedestrians

Table 3.4 Summary of responses to the standard questions by question and agency (Continued)

What types of maintenance are undertaken on SBLs in winter? Are those maintenance activities a consideration in your designs?						
	U of M Parking & Transit	**City of St. Paul**	**City of St. Louis Park**	**MnDOT**	**City of Minneapolis**	**Hennepin County**
Activities Undertaken	• Snow clearance • Coordinate activities with other jurisdictions	• Snow clearance • Coordinate activities with other jurisdictions • Salt only if needed	• Snow clearance	• Snow clearance • De-icing • Coordination of activities with other jurisdictions	• Snow clearance • Salt • Brine before snowfall • Sand only if needed • Coordination of activities with other jurisdictions	• Winter maintenance is generally carried out by cities
Equipment Used	• Pickup truck with plow or brush	• Pickup truck with plow	• Pickup with plow • Wing from plow • May purchase additional equipment	• Equipment used depends on responsible party • Equipment needs to be roadworthy to drive from garage to facility	• Pickup with plow • Bobcat, maintenance tractor, or skid steer (can use bucket, brush, or blower) • Dump trucks for hauling	• ND
Design Implications	• Buffers need to include snow storage or plans should be made to remove snow	• Facility must be wide enough to be cleared by pickup truck with plow • Installation of SBL may change distribution of accessible snow storage	• Street-adjacent facilities that run adjacent to sidewalk will be cleared using pickup with plow • Street-adjacent facilities with mountable curb will be plowed with standard plow wing	• If SBL is part of a designated ADA clear path, it is a much higher priority • Heavier equipment may necessitate stronger pavement • Facility must be wide enough for equipment	• Parking may hinder snow removal • Furniture and transit stops complicate snow clearance • Trees and signs may reduce clearance for equipment • Landowners may push snow into SBL • SBLs generally require at least two passes with equipment • Buffers need to include snow storage or plans should be made to remove snow	• SBLs must be wide enough for snow clearance equipment • Snow storage is desired but often not possible due to ROW constraints

Table 3.4 Summary of responses to the standard questions by question and agency (Continued)

What other types of maintenance are undertaken? Are those maintenance activities a consideration in your designs?						
	U of M Parking & Transit	**City of St. Paul**	**City of St. Louis Park**	**MnDOT**	**City of Minneapolis**	**Hennepin County**
Activities Undertaken	• Sweeping (twice per year and if needed) • Painting	• Sweeping • Replacing/reinstalling flexposts	• Sweeping • Pavement repair	• Sweeping • Painting • Patching • Mowing	• Sweeping • Painting • Patching • Replacing/reinstalling flexposts	• Maintenance is usually handled by cities
Equipment Used	• Walk-behind striping machine if space is limited	• Standard street sweeper	• May buy additional equipment for sweeping	• Equipment used depends on responsible party • Equipment used by MnDOT needs to be roadworthy to drive from garage to facility	• Narrow lane sweeper or broom and pan on skid steer • Painting on vehicle side of buffer is done with standard striper • Painting on bike side of buffer is done by hand or not at all • Small patches are done by hand • Current paver requires 8 feet of clearance to do overlay	• ND
Design Implications	• ND	• Sweeping SBLS with flexposts can cause "windrow" of debris in buffer	• Sweeping is especially important in spring • Cyclists are especially sensitive to poor road surfaces • Can't use ground-in striping if pavement is too damaged • May need to include overlay as part of retrofit designs	• Facility must be wide enough for equipment	• Once raised curb is poured, lines in bike lane are much harder to repaint (currently looking into more durable MMA paint) • Mill and overlay of lanes less than 8 feet wide is not possible using current equipment • Need sufficient width for snow clearance and sweeping vehicles	• ND

Table 3.4 Summary of responses to the standard questions by question and agency (Continued)

How do you design mixing zones at intersections? What factors influence your designs?						
	U of M Parking & Transit	**City of St. Paul**	**City of St. Louis Park**	**MnDOT**	**City of Minneapolis**	**Hennepin County**
Considerations	• Avoid mixing zones with two-way SBLs • Visibility • Angle of conflicts • Highlight conflict areas where cyclists are losing protection	• Snow clearance • Sweeping	• One- vs two-way • Retrofits may not include intersections	• One- vs two-way • Visibility • ROW constraints • Bike left turns • Detection of cyclists • Balancing maintaining protection and allowing access into or across lane	• ROW availability • Maintenance • Snow storage	• Additional signage and striping • Queuing pedestrians • Bicycle and vehicle turning volumes • Facilities on cross street

Pros and Cons of Options	• ND	• Adding median or delineators to road requires additional passes (and potentially additional equipment) for sweeping and snow clearance	• Not sure how to transition between one-way, both sides to two-way, one side
			• Difficult to deal with bike turning movements (especially contraflow)
				• Contraflow lanes may necessitate additional signage and striping to direct drivers and cyclists
				• Two-phase turn boxes may not be used by all cyclists
					• Bike lane bend in/out with refuge island
					  ○ Additional features complicate maintenance
					  ○ Not much snow storage
						• Shared turn lane
						  ○ Commonly used
						  ○ Sharrows easy to paint with stencil
						  ○ Works well when ROW is constrained
						• Switch and weave
						  ○ Commonly used
						  ○ Requires some additional paint and signage
						  ○ Green stripes need to be more durable (thermo)

Guidance Used	• ND	• ND	• ND	• ND	• ND	• ND

Table 3.4 Summary of responses to the standard questions by question and agency (Continued)

How do you design bus stops on SBLs? What factors influence your designs?						
	U of M Parking & Transit	**City of St. Paul**	**City of St. Louis Park**	**MnDOT**	**City of Minneapolis**	**Hennepin County**
Considerations	• ROW availability • Pedestrian cross-traffic • Same-grade disability access to island • Drainage for retrofits • Bus frequency	• ADA requirements	• Pedestrian cross-traffic • Total width of facility (snow clearance)	• ND	• Post vs shelter • ROW availability	• Rider queuing space • Size of shelter • Additional signage and/or striping warning cyclists of crossing pedestrians • ROW availability • Rider volume • Queuing space • Bus dwell time
Pros and Cons of Options	• Islands require at grade pedestrian crossing which may cause drainage issues • Islands require additional ROW • Constrained design requires consideration for bikes behind bus	• ND	• ND	• ND	• Constrained stops ○ Simple to maintain ○ Fit in most situations	• Modified constrained off-line stop ○ Most common ○ Roads don't generally have parking lane for bus to dwell in ○ Unclear where space for dwelling buses should come from
Guidance Used	• ND	• ND	• ND	• ND	• ND	• ND

Table 3.4 Summary of responses to the standard questions by question and agency (Continued)

Do you have costs or cost estimates for different designs and maintenance practices?						
	U of M Parking & Transit	**City of St. Paul**	**City of St. Louis Park**	**MnDOT**	**City of Minneapolis**	**Hennepin County**
Construction Costs	• Construction of SBL was included with campus construction project	• Two sets of bids for retrofits	• Construction costs for various types of facilities	• District bike plans include high level costs	• Construction costs are hard to separate • Retrofit costs may be available	• Construction costs for facility type varies
Maintenance Costs	• ND	• One estimate of maintenance costs	• ND	• ND	• Maintenance costs for various types of facilities	• Maintenance costs for facility type varies
What else about design of separated bike lanes do we need to know? If you could have guidance on one particular thing, what would it be?						
	U of M Parking & Transit	**City of St. Paul**	**City of St. Louis Park**	**MnDOT**	**City of Minneapolis**	**Hennepin County**
Further Questions	• Effect of alleys and driveways • Intersection treatments (especially turning movements)	• Strengths and weaknesses of different delineator types • Trade-offs between safety and facility performance when vertical element is added to painted buffer	• Effects of number and volumes of driveways and alleys • Bike volume forecasting for SBLs • Mixing zones for two-way SBLs • Getting drivers to recognize SBL as a lane of the road (ex. Don't wait in bike lane at stop sign)	• Maximum number of flexposts that can be lost while still maintaining sufficient effectiveness • Is mountable curb enough separation between road and bike lane? • Economic impact of and SBL • Special considerations for rural bike lanes Effects of number and volumes of driveways and alleys	• Coordination of snow clearance with transit schedule • Striping and patching on narrow bike lanes with raised curb	• Making room for bus stops when ROW is limited and parking is prohibited • Striping and patching on narrow bike lanes with raised curb

Table 3-5 Bicycle Advocacy Groups and Transit Drivers summarized

	Bicycle Advocacy Groups (BikeMN, Our Streets MPLS, TCBC)	First Transit Drivers
Access	• connected network of SBLs is needed to encourage more people to ride • intersections must be included in design of network • network should be safe and comfortable	• transit needs to have access as well
Design	• one-way preferred for "consistency" • contraflow lanes can be confusing and dangerous • two-way lanes may use ROW effectively but make turns difficult	• prefer no mixing at all with traffic lane • intersections must be designed with tailswing in mind to avoid bus/bike collision
Barriers	• flexposts preferred, as solid barriers can prevent passing/avoiding obstacles • flexposts offer less safety against intrusions to/from driving lanes • solid barriers midblock can help reduce pedestrian/cyclist conflicts • more buffer space (>2') or physical separation is preferred for cyclist comfort	• flexposts get knocked over by tailswing • separating bike lane from pedestrian drop off is important to avoid collisions • prefer complete separation where possible
Summer maintenance	• lack of summer maintenance is an issue: dirt, debris clogs the lane • flexposts are difficult to sweep around, resulting in more debris in the bike lane • solid barriers have less dirt/debris • regular sweeping or spraying down of lanes is preferred • quality of pavement should be considered as maintenance	• ND
Winter maintenance	• salt leads to damage to bicycles, is not preferred • sand is preferred for traction but doesn't melt ice • sand also accumulates and has to be cleared at the end of the season • plowing and sweeping where possible is preferred to avoid snow compacting into ice • plows push snow past flexposts and bollards into the bike lane • plows not clearing entire width of parking leads to cars parking in the SBL • costs of maintenance must be factored in at the time of construction	• too much snow at bus stop leads to issues dropping off passengers as usual • bike lanes blocked with snow force cyclists into the traffic lane • narrowing streets due to snow encroachment creates a problem for everyone
Level of Service	• timely and passable service is required for bike lanes • ideally at least 3 ft. of cleared width • policy for priority network of bike lanes to be cleared first, just like highway/snow emergency routes	• cleared drop off areas • cleared curbs to avoid encroachment

Table 3.5 Bicycle Advocacy Groups and Transit Drivers summarized (cont.)

	Bicycle Advocacy Groups (BikeMN, Our Streets MPLS, TCBC)	First Transit Drivers
Bus stop design	• floating stop is preferred to slow cyclists and separate bus traffic and pedestrians from bike lane • constrained stop: bike lane between pedestrian waiting area and bus leads to conflict • waiting behind a bus is not comfortable • ADA inclusivity is an important consideration • designs routing cyclists around the bus and loading area are ideal	• any design completely separating drop off and cyclists is preferred
Mixing zones	• most drivers and cyclists don't understand mixing zones • clear markings and education necessary for success • delivery vehicles have a need for "mixing zones" in delivery locations w/SBL	• mixing zones must account for tailswing

3.5 CONSTRUCTION AND MAINTENANCE COSTS

The following sections describe construction and maintenance costs that were provided by agencies after Key Informant Interviews.

3.5.1 Construction Costs

Construction cost estimates for SBLs cover a large range of possibilities of site-specific context influencing the scope of placement. The FHWA estimates the cost of installing a basic, unseparated bike lane can be anywhere from $5,000 to $50,000 per mile, depending on "the condition of the pavement, the extent of removing and repainting of lane lines, the need to adjust signalization and other factors." In Minnesota, those other factors include winter, leading to higher estimates due to special paint required to withstand plowing as well as type of delineator or flexposts installed along routes that would allow for snow removal. Additional factors include the scope of reconstruction necessary to include the SBL, from lane reconfiguration to lane reconstruction.

The following construction costs are Minnesota specific and are costs per mile of lane. As seen in Table 3-6 construction estimates vary a lot from agency to agency, which makes providing an exact per mile estimate per type of SBL unfeasible.

Table 3-6 Cost estimates of construction per mile of bikeways

	Minneapolis Bikeway Plan (2011)	District 3 Bicycle Plan (2019)	Hennepin County 2040 Plan (2013)
Bike lanes (unseparated)	$30,000 to $50,000	$14,000 to $20,000	$63,200 to $101,100
Bicycle Boulevards	$100,000 to $500,000	X	$14,800
Off-Street Trails	$3 million	$250,000 to $360,000	$196,700 to $491,600
Paint-Buffered Bicycle Lane	X	$17,000 to $25,000	$101,100 to $153,900
Delineator-Separated Bicycle Lane (Protected Bike Lane)	X	$25,000 to $36,000	$101,100 to $153,900
Curb-Separated Bicycle Lane (Cycle Track)	X	$1.9M to $2.7M	$137,500 to $194,200

3.5.2 Maintenance Costs

MnDOT estimates that for "routine maintenance" (activities listed in Table 3-7), approximately $1,000 to $2,500 should be budgeted annually per mile of facility (MnDOT Bicycle Facility manual, 2020). MnDOT does not provide what type of facility they consider with that estimate.

Table 3-7 Routine maintenance standards defined by MnDOT (2020 Bikeway Facility Guide)

Routine Maintenance	Function	Frequency
Sweeping shared use paths	Keep paved surfaces debris free.	Spring, after snow melt and as needed. Fall during leaf drop
Litter and trash removal	Keep bicycle facility clean and of consistent quality.	Annually, or as needed.
Mowing shared use path shoulders	Increases the operating width of the shared use path if bordered by grasses. Also helps limit weed encroachment	As needed during the growing season.
Tree/ brush trimming	Eliminate encroachments into bicycle facility to open up sight lines.	Annually, or as needed.
Weed abatement	Manage existence and/or spread of noxious weeds, if present.	Annually
Snow removal	Keep bicycle facility clear and usable year round.	As needed
Sign, pavement marking and other amenity inspections	Identify and replace damaged infrastructure	Annually
Crack sealing and surface repair	Seal cracks in bituminous surfacing to reduce long-term damage	Annually
Vacuuming permeable pavements	Removes debris and keeps pavement permeable	Depending on surrounding vegetation or presence of sand.

The City of Minneapolis provides maintenance estimates per type of bike lane, including SBL, with clearing snow and sweeping weekly (Table 3-8). These estimates come from the Minneapolis Protected Bikeway Update (2015) to the Bicycle Master Plan (2011). As Minneapolis describes, "The sample size [for a two-way protected bike lane] is fairly small based on limited experience with 1st Avenue N protected bike lanes. The unit costs for protected bikeways are based on this limited experience." Therefore, these numbers may be higher than truly required.

Table 3-8 Minneapolis Protected Bikeway Update Maintenance Cost Estimates

	Per linear foot	Per mile
Trail	$2.00	$10,560
One-way protected bike lane (single direction)	$6.50	$34,320
Two-way protected bike lane on one side	$10.00	$52,800

Hennepin County provides estimates of specific maintenance activities per mile (2016), and in the case of winter maintenance, per mile per snow event. These per mile figures can be used to estimate the cost of maintaining SBLs, and various estimates of level of maintenance can be produced.

Table 3-9 Estimates of annual pavement upkeep activities

Activity	Source*	Cost/Mile
Crack Sealing	Contractor	$3,860
2" Bituminous Overlay	Contractor	$65,960
Microsurfacing	Contractor	$21,808
Fog Seal	Contractor	$4,002
Pavement Markings	Contractor	$528
Reconstruction	Contractor	$550,616
Replace Concrete Walk	Contractor	$319,984
Add 3" Aggregate to Limestone Trails	Contractor	$24,127
* Agency cost data for pavement preservation treatment activities is limited. Contractor data for snow removal activities is also limited. Recommend adding more background cost data before using those values.		

Table 3-10 Estimates of Winter Maintenance Activities per mile per snow event

Activity	Source (Contractor or Agency)	Cost/Mile/Event
Anti-Icing Pretreatment	Agency	$107
Snow Removal, less than 8' wide	Agency	$285
Snow Removal, 8-12' wide	Agency	$428
Snow Removal, over 12' wide**	Agency	$856
Protected Bikeway Snow Removal	Agency	$1,855
**Agencies didn't have detailed cost data for snow removal over 12' wide - value used is 2 times 8-12' wide, reflecting need for additional pass(es) for wider lanes		

For example, a "basic" maintenance scenario may include crack sealing, reconstruction, and replacement of concrete and addition of aggregate to limestone trails over a 40-year period. This estimate does not include any winter maintenance on bike routes. The average annual pavement preservation cost comes to $694 per mile. On the opposite end of the spectrum, an "enhanced" maintenance scenario may include all of the activities listed in Table 3-7 for the entire bikeway, leading to a total average annual maintenance cost of $10,240.5 per mile. Designating a portion of the bikeway as “priority” routes to be cleared for snow events is a way to reduce cost while ensuring people who cycle during the winter can still get around the system. If 30% of the bikeways in Hennepin County were designated as priority routes for clearance, the maintenance cost comes to approximately $2,600 per mile. This is slightly higher than MnDOT’s $2,500 per mile estimate, but close.

Important to note in Hennepin’s estimates, the cost of snow removal on protected bike lanes includes “costs for plowing snow toward the curb from a 6’ wide street level bikeway that is protected by flexible delineator posts, within 24 hours of the end of a snowfall” as well as “clearing windrows at intersections within 48 hours after the end of a snowfall. Quote also includes as a separate line item all costs associated with removing and hauling away snow from between delineator posts, within 72 hours of the end of a snowfall." The extra passes with snow removal equipment contribute to the much higher cost to remove snow from protected bike lanes as opposed to unprotected bike lanes.

CHAPTER 4: FIELD DATA COLLECTION

To gather additional data about people who cycle, pedestrian and bus interactions at separated bike lane transit stops, an MTO researcher biked to bus stops located on SBLs around the Twin Cities Metro Area. The MTO also deployed camera equipment to two sites and collected additional video from Parking and Transportation Services at the University of MN.

4.1 PURPOSE OF VIDEO DATA COLLECTION

During key informant interviews, several potential interactions between people who cycle, pedestrians and busses were discussed. These interactions needed to be examined through video collection, as in-person observation likely wouldn't capture enough events in enough detail for analysis.

- Tailswing – the amount the back of the bus sticks out as drivers make a turning or lane changing maneuver
    - During the First Transit interview, drivers identified tailswing as a concern. People who cycle may not be aware of tailswing of a turning or merging bus and collide. Also, tailswing can damage SBL infrastructure like flexposts.
- Pedestrians waiting for the bus blocking the SBL
    - Depending on the design of the lane, pedestrians have little space to wait for the bus outside of the SBL.
- Pedestrians getting off the bus onto an SBL
    - The First Transit drivers said when an SBL abuts the bus drop off location, they must look for people who cycle before opening the door to avoid collisions between people who cycle and pedestrians.
- ADA compliance of bus stop design
    - Is the bus stop ADA accessible? Is the user forced into the SBL by design of the bus stop?

Ultimately due to budget constraints and issues with field video data collection described in this chapter, the exploration of bus stops on SBLs was limited to the user group survey.

4.2 FIELD VISITS TO SBLS

MTO Researcher Peter Dirks visited 105 bus stops located on SBLs around the Twin Cities Metro Area to catalogue them and collect video and observations. These SBLs locations were prioritized due to differing separation and buffer types as well as geometry of the bus stops (
Figure 4.1). Images from Dirks' video footage were used in the user group survey (Chapter 6) as examples of different types of separation that users might encounter.

Dirks also collected video during winter rides to examine maintenance standards. Stills from the video footage were used in the user group survey, to examine rider preferences for pavement condition and clearance. An image captured from Dirks' video footage altered and used for the winter image section can be seen in Figure 7.6.

Figure 4.1 Video capture showing Metro Transit stop with pedestrian rest area along SBL

Though not fully analyzed in this project, this video record serves to capture real world conditions of bus stops along SBLs and is a valuable resource for future study.

4.3 VIDEO DATA COLLECTION

To examine these types of interactions as well as look for others, three bus stops along SBLs were chosen for video deployment.

4.3.1 12th Ave S and E 28th St

The site of 12th Ave S and 28th Street has a grade-level SBL delineated by an intermittent barrier. The bike lane is a two-way bike lane running on a one-way street. This site was chosen as it does not have a dedicated bench or shelter for pedestrians to wait. During the day, the parking lot near the transit stop is full, causing many pedestrians to wait in the SBL for the bus (Figure 4.2).

Two cameras were deployed at this site, one in the south east corner facing the doors of the bus (Figure 4.2a) and one in the northwest corner to capture interactions potentially blocked by a bus as it arrives on the other camera (Figure 4.2b).

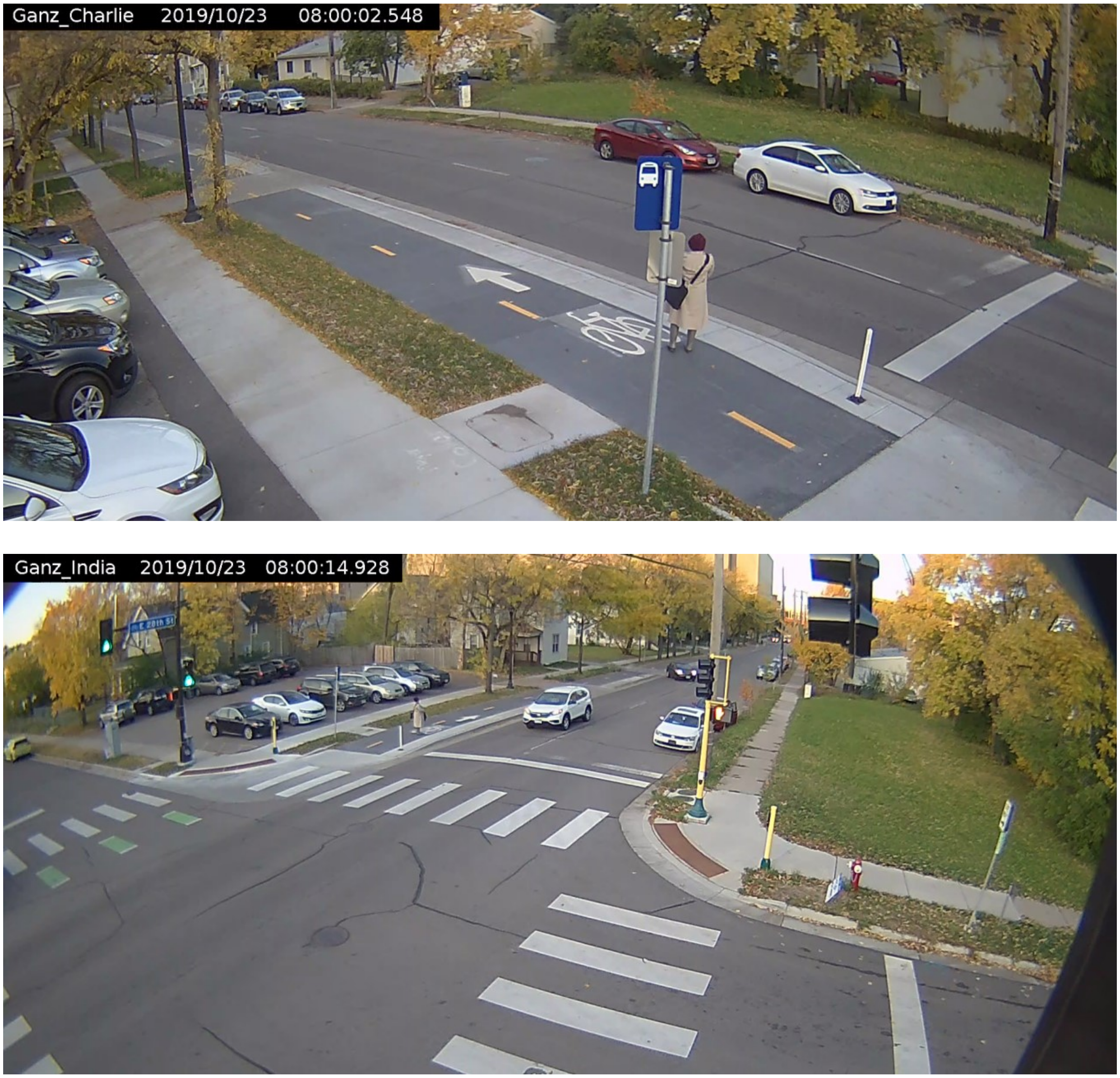


Figure 4.2. Video camera views of 12th Ave S and E 28th Street from the south east corner (a) and northwest corner (b)

The cameras were portable, mountable and powered by car batteries. See Figure 4.3 for an example of the camera equipment used at this site.

Figure 4.3. Camera attached to southeast signal pole

Six and a half days of video were recorded at this site. Due to weather conditions and lack of street lighting some hours were difficult to see.

Metro Transit Route 27 runs through this site. At some point before the research team visited the site, the route was switched from a standard 40-foot bus to a 25-foot, 22 passenger bus. The route only operates every 40 minutes, so between the length of the bus and the infrequency of the stops, not many interactions were ultimately captured.

4.3.2 Fremont Ave N and N 26th Ave

Fremont Ave N and N 26th Ave has a grade-separated SBL. It is a two-way SBL running along a two-way street. The SBL is not buffered from the pedestrian walking space by anything other than differentiated pavement, as seen in Fig. Two cameras were also deployed at this intersection, one in the south west and one in the north east. This allowed for the entire scope of a conflict to be captured when an arriving bus partially blocked one camera. Figure 4.4 shows the views from each camera.

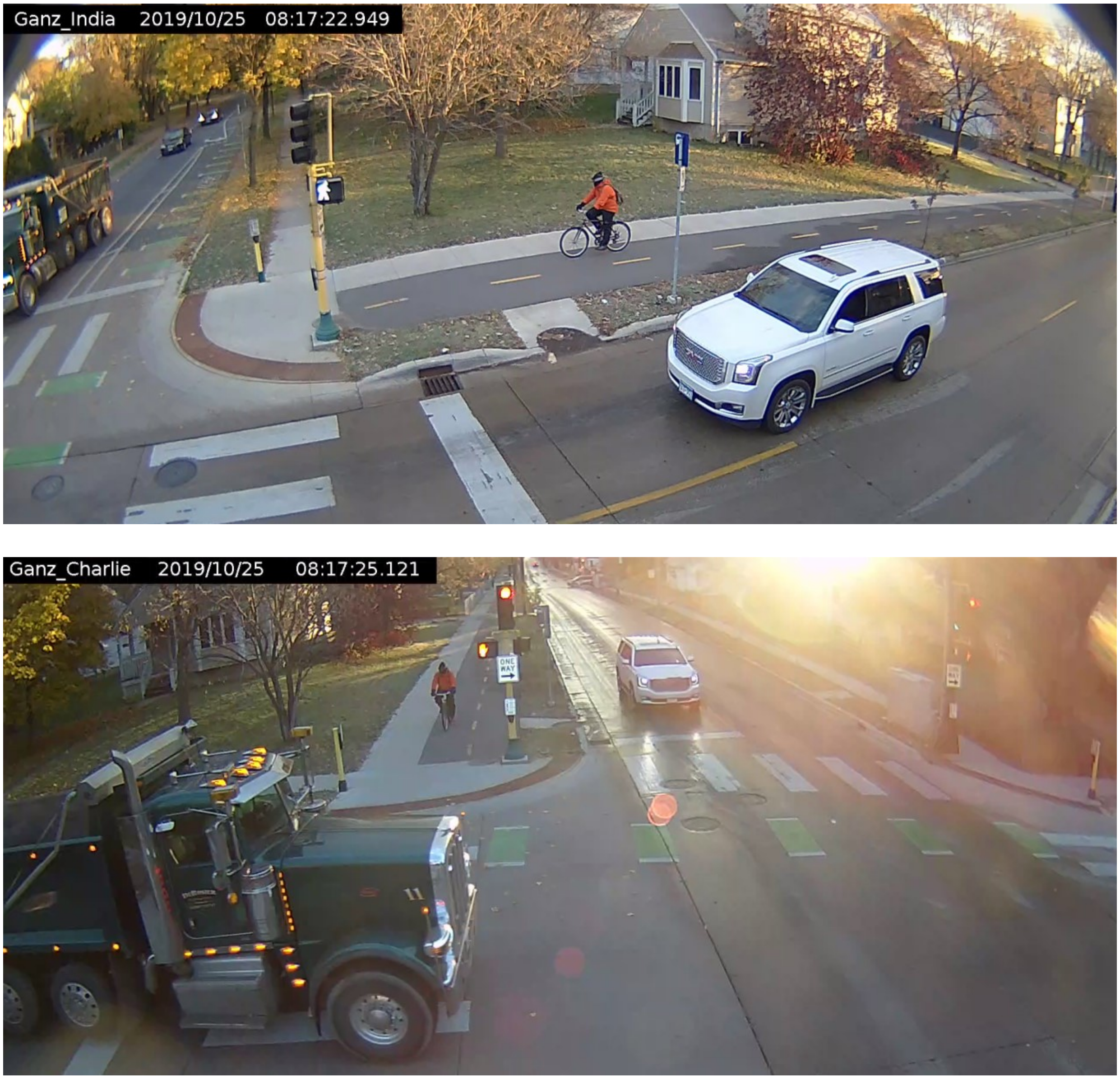


Figure 4.4. Video camera views of Fremont Ave N and N 26th Ave from the south west corner (a) and north east corner (b)

As with 12th Ave S and E 28th St, there is not a dedicated space for pedestrians to wait to board the bus, resulting in pedestrians standing in the SBL. Metro Transit Route 5 runs on this route. Route 5 is a standard sized 40-foot bus that runs approximately every 10 minutes. A full week of footage was captured at this site.

4.3.3 SE Oak St and Delaware St SE

The MTO contacted the City of Minneapolis to request footage from the SE Oak St and Delaware St SE site. Through the data request, Parking and Transportation Services (PTS) on the University of Minnesota campus was requested to pull footage from the pan-tilt-zoom (PTZ) camera at the site. Footage from September and October (40 days) were given to the MTO for analysis.

This site has a two way SBL separated by a concrete island near the transit stop, and intermittent barriers the rest of the length. Pedestrians do have a dedicated space to wait for the bus on the concrete island.

Figure 4.5 View from SE Oak St and Delaware St SE PTZ camera

On the southbound lane, both standard-sized and 25-foot sized 122 Campus Connector UMN buses run during weeknights and weekends. All hours of the day were watched for counts of people who cycle, and for notable interactions. An exception to this schedule fell on Saturday October 26, 2019, when all busses normally running on SE Washington Ave were re-routed through SE Oak St and Delaware St SE due to construction.

4.3.4 Additional Video

The MTO put in a data request to the City of Minneapolis to retrieve camera footage from the intersection of Blaisdell Ave and Lake St, but did not receive an answer as to who owns the cameras there. City video data is also only held 10 days, and the MTO was trying to secure footage from earlier in the year before the weather turned cold.

4.4 VIDEO DATA REDUCTION

Undergraduate Research Assistants (UGRA) were tasked with reducing the video collected at all sites. This was done in two passes. The first pass was a general count of people cycling with the time they passed the transit stop recorded. Additionally, the UGRA recorded if there was a pedestrian and/or bus present at the time the cyclist approached the transit stop, and any extra comments about the interaction. Table 4-1 shows an example from the beginning of October 17, 2019.

Table 4-1 Example of video reduction process (first pass)

1st Pass			
General			
Bike Arrival Time	Ped Present?	Bus Present?	Comments
[HHMMSS]	[0 or 1]	[0 or 1]	[ ]
73956	0	0	started at SBL then cut into lane
74516	0	0	
74722	0	0	
74829	0	0	
75608	0	0	
75928	0	0	
82036	0	0	scooter started on bike lane then moved to sidewalk

The second more detailed pass was only done in the event of an interaction. This pass includes:

- where the bicycle was located at the beginning and end of the event
    - bike lane, road or sidewalk
- the type of interaction
    - none, stop, decelerate, avoid or swerve
- The location of the interaction
    - None, corner cross, stop to sidewalk, bike lane, or pedestrian space
- Bicycle delay
    - Yes or no if the bicycle experienced delay
- Bicycle overtake
    - Yes or no if the bicycle overtook the bus

Interactions where people who cycle were captured with a pedestrian and/or bus present were manually reviewed by an MTO engineer due to low counts of interactions.

4.5 RESULTS OF VIDEO DATA ANALYSIS

Only 12th Ave S and E 28th St and Fremont have had all footage reduced at the time of reporting. Both sites had 91 hours of footage reduced, taking roughly 20 hours of UGRA time each. Out of 620 recorded people cycling at 12th Ave S and E 28th St, only two (0.3%) interactions took place between a person cycling and a bus. Of those, neither had an actual interactions. Sixteen (2.5%) people cycling interacted with a pedestrian, but none at the time of a bus approaching the stop. At Fremont, of 109 recorded people cycling only one interacted with a bus (less than 1%) and four (3.7%) interacted with a pedestrian outside of a bus approaching the stop.

68 hours of footage was reduced at Oak and Delaware out of the several months given to the MTO by PTS. Five out of 3,925 (<1%) people who cycle passed through the facility while a bus was present; all five cases also had pedestrians present. However, no interactions were observed, as in each case the pedestrians were waiting safely on or disembarking the bus to the floating bus island. 202 (5%) cases of a person who cycles interacting with a pedestrian were recorded. Figure 4.6 shows a snapshot of an event where a person cycling and bus were recorded as both being present, but no interaction occurred during disembarking.

Figure 4.6 Cyclist and bus at Oak and Delaware, no interaction

The cost to watch enough video to build a library of interactions between cyclists, busses and pedestrians would be high, and was out of the scope of the budget for this project. Future work could be done with video collection at bus stops on SBLs, especially during winter months.

CHAPTER 5: DEVELOPMENT OF SURVEY OF USER GROUPS

The user group survey was designed to capture people who cycle experiences and perspectives on existing bicycle infrastructure, specific to the topics identified by the TAP. A description of the survey can be found in Appendix B.

5.1 SURVEY OVERVIEW

The survey was developed based on knowledge gaps identified in the literature review (Section 2.5) and Key Informant Interviews (Section 3.4). The goal of the survey was to capture the user experience as well as preferences and issues on SBLs as they were implemented at the time of the survey. The survey also addressed critical issues of perception of safety, comfort, understanding and delay caused by different design elements of SBLs, determined to be lacking by the literature review and KII. The survey was structured as follows:

1. Behaviors and Perspectives
    a. Cycling frequency by season
    b. Level of comfort on different roadways or bicycle facilities
2. Buffer Design
    a. Rail
    b. Intermittent Barrier
    c. Curb and Intermittent Barrier
    d. Grade Separated
3. Mixing Zone Design
    a. Switch and Weave
    b. Shared Lane
    c. Partially Shared Lane
    d. Protected Intersection
    e. No Mixing (two stage left turn)
    f. No Mixing, No Box (bike signal)
4. Bus Stop Design
    a. Curbside Bus Stop, One-Way Street-Level Protected Bike Lane
    b. Curbside Bus Stop, One-Way Raised Cycletrack
    c. In-Street Bus Stop, Shared Street-Level Protected Bike Lane/Sidewalk
    d. Floating Island Bus Stop, Two-Way Street-Level Protected Bike Lane
    e. Curbside Bus Stop, Two-Way Street-Level Protected Bike Lane
    f. Curbside Bus Stop, Two-Way Raised Cycletrack
5. Winter Biking*
    a. Factors that influence winter cycling behavior
    b. Importance of and satisfaction with winter maintenance
6. Winter Images Section*
7. Demographics

Section 1 of the survey allowed the MTO to use a set of measures created by Jennifer Dill (35) to determine which of the four types of cyclist the respondent falls into: "No Way No How", "Interested but Concerned", "Enthused and Confident", and "Strong and Fearless." The Facility Comfort section provides a variety of different scenarios, such as "A path or trail separate from the street", or "A major urban street" and asks the participant to rate their comfort level with each facility.

People who cycle were also asked if they were primarily commuters, recreational riders or both, and if they had interest in riding more both in the summer and winter.

Sections 2 through 4 of the survey were developed based on knowledge gaps identified in the literature review (Section 2.5) and Key Informant Interviews (Section 3.4). The type, density and height of separation and buffers, design of mixing zones at intersections, and design of bus stops were all identified as areas requiring further guidance than available in current design manuals (Table 2.2). In each section, respondents were asked to rate safety and comfort of presented designs; Section 2 also asked respondents to rate safety and comfort by season, while Sections 3 and 4 also asked respondents about potential and experienced conflicts on the roadway.

Section 4's bus stop designs were representative of real-world bus stops on SBLs around the Twin Cities. This section was based on stakeholders' desire for the safest type of stop that would deliver the least amount of delay for people who cycle. The types of safety issues and conflicts experienced at bus stops on SBLs were discovered during KII with cyclist advocacy groups and bus drivers. These two competing user groups are not owners of the roadway, nor typically consulted during the design process, so capturing their experience through KIIs and the survey was critical to expand guidance as well as ensure owners are aware of the real-world issues taking place at stops.

Only respondents who indicated in section 1 that they cycle during the winter received sections 5 and 6. Section 5 asked respondents about different factors that weigh into their decision to bike during the winter, and the importance of and their satisfaction with those factors. The desire for information on winter maintenance drove the development of both Section 5 and Section 6. Specifically, Section 6 was a visual preference survey described in detail in Chapter 7.

Section 7 as well as the level of classification determined in Section 1 were used to compare the MTO's respondent demographics to people who cycle across Minnesota. The level of classification also allowed for a deeper look at different opinions by people who cycle opinions, as people who cycle are not a monolithic group.

The survey was mechanically tested through the use of dummy data in Qualtrics as well as volunteer respondents. The survey was distributed starting in May 2020, and responses were collected through August 2020.

5.2 SURVEY DISTRIBUTION

Because the survey was designed to gather information from people who cycle specifically, the MTO planned a purposeful sample of people who cycle and "snowballed" from initial distribution to reach additional respondents. The MTO did not use a random population because the proportion of individuals in the general population who cycle frequently, especially in the winter, is relatively small, and the costs to obtain a sample of people who cycle large enough to analyze given the project's objectives were prohibitively large. Because of the snowballing technique (i.e., members of organizations shared the survey), it is not possible to determine the number of individuals who had the opportunity to respond. A limitation of this sampling method is that results reflect self-selection – the results reflect the opinions of those whom the topic is the most salient. In this case, from the general population of people who cycle, those who responded are mostly likely to be those with the greatest interest in use of separated bicycle lanes. This fact means the responses are not representative of and cannot be generalized to the general population. However, for the purposes of the project, which are more analogous to those of a user satisfaction survey, the response are indicators of those who cycle who are most interested in use of SBLs.

The MTO initially worked with the Bicycle Alliance of MN (BikeMN) to distribute the survey to their email list of 30,000 participants. BikeMN is a cyclist advocacy group serving the entire state of MN. BikeMN works closely with other agencies and organizations around the state including MN Safe Routes to School State Network, Complete Streets, and more. After receiving fewer survey responses than anticipated in the initial distribution, the MTO reached out to District Councils in the Twin Cities to present the project background and survey at Transportation Committee Council (TCC) Meetings. Specifically, the survey was distributed in St. Paul to the following district TCCs:

- District 1 (Southeast Community Organization)
- District 2 (Greater Eastside)
- District 9 (West 7th/ Fort Road Federation)
- District 10 (Como Park)
- District 11 (Hamline Midway Coalition)
- District 13 (Union Park)
- District 14 (Macalester-Groveland)
- District 15 (Highland District Council)

The third wave of survey distribution in late June 2020 took place over social media. The following blogs, cities, community organizations, museums, nonprofits, bicycle repair shops and student groups were contacted for distribution:

- MN Bike Trail Navigator
- Cities of Duluth, Minneapolis, St. Paul and St. Cloud
- Midtown Greenway Coalition
- Minneapolis Bike Love
- St Paul Bike Coalition
- Twin Cities/MN Bicycle Advice and Discussion
- Move Minnesota
- Move Minneapolis
- Rosemount Cycling Club
- Cycling Museum of MN
- MidMN Cycling Club

- Hub Bike Co-Op
- Michael's Cycles - Prior Lake
- MN Cycling Federation
- Humphrey School of Public Affairs Students
- Master of Urban and Regional Planning Students

The Minnesota Pollution Control Agency (MPCA) also contacted the research team for permission to distribute the survey internally and to additional outside contacts.

Although specific demographic information was not collected from the district TCCs or MPCA, the geographic breadth and availability of cycling amenities in the districts participating helped to ensure against any additional bias in the responses, outside of the expected bias toward people who actively cycle.

5.3 SURVEY COMPLETION

340 responses were deemed complete enough to include in the results. The criteria for completeness included completing Section 1, so the respondent could be sorted into a classification category. Factors influencing the number of responses might include the global pandemic, state events and unrest, the survey being too long to complete comfortably in one sitting, and some confusion reported by respondents in certain sections of the survey.

Several respondents reached out to the research team with questions or suggestions for the survey; as permitted by Qualtrics, suggestions (such as changing the question "Did you have a paying job last week?" to "Did you have a paying job for the greater part of last year?") were implemented immediately and any reports of glitches or errors with the Qualtrics system were investigated. The survey was closed for responses in August 2020.

CHAPTER 6: SURVEY RESULTS AND ANALYSIS

This chapter begins with a discussion of classification methodology as, discussed in the Key Informant Interviews and supported by the survey results, people who cycle are not a monolithic group. The analysis of survey results was framed partially by level of comfort: “Interested but Concerned”, “Enthused and Confident”, and “Strong and Fearless.” Each level of comfort and the process to assign respondents is discussed first. These levels of comfort can help inform the best designs for a given bike lane dependent on the type of people who cycle that are using the infrastructure, or type of people who cycle that design agencies want to attract.

Next, each of the primary design features presented in the survey are discussed: Buffer Design, Mixing Zone Design and Bus Stop Design. Each section begins with a description and image of types of designs presented to respondents in the survey. Implicit goals and implications of design options are discussed as well, to frame how the research team approached each design option and formed recommendations informed by the survey results. Then, visualizations of survey results regarding respondent perspectives for each design option are presented.

Visualizations include bar graphs showing the scale of responses from “strongly disagree” to “strongly agree.” For ease of comparisons, a box plot is also presented for each perception question showing the mean agreement score on a scale from zero to four, where a score of two or above indicates “agree” or “strongly agree.” Binary agree-disagree visualizations were also created by combining the “strongly agree” and “agree” responses for “agree” and the rest of responses as “disagree.” These visualizations are presented by age, by gender, and by cyclist classification. In the Mixing Zone and Bus Stop sections, perceptions of potential for conflicts are also presented. For Mixing Zones, respondents who indicated familiarity with the design were also asked to report experienced conflicts; summary graphs showing how often people who cycle experienced these reported conflicts per design on a scale from “almost always” to “never” are presented in that subsection.

The chapter closes with a real-world image of a bus stop showing a person cycling approaching the bus stop while pedestrians occupy the bike lane while alighting. Respondents were asked what they would do in this situation, to help tie the abstract illustrations of bus stops presented throughout the bus stop section to a concrete, real-world scenario.

The Winter Design and Maintenance portion of the survey is presented in the following chapter due to the complexities of analysis and recommendations. Full recommendations based on the survey responses for Buffer Design, Mixing Zones and Bus Stops are presented in Chapter 9.

6.1 CLASSIFICATION METHODOLOGY

For in-depth analysis of preferences, classifying people who cycle by behavior and frequency of travel is critical to ensure bicycle infrastructure and maintenance are meeting the needs of those users who are using it the most, or would use it if it exists.

Classification of responses was done by adapting the methodology by Dill et. al (35), adapted to the survey designed by the MTO. Dill in turn based her methodology off Geller's "Four Types of Cyclists" proposal (36). The goal of classification is to sort respondents into one of four categories: "Strong and Fearless", "Enthused and Confident", "Interested but Concerned", and "No Way No How." These classifications can then be used for further analysis, with "Strong and Fearless" people who cycle needing no special right of way accommodations, "Enthused and Confident" being generally comfortable riding alongside motor vehicles but preferring to operate on their own facilities, "Interested but Concerned" generally requiring comfortable facilities separated somehow from traffic, and "No Way No How" people who cycle unwilling to ride even in the safest, most comfortable roadway conditions.

6.1.1 MTO Classification Methodology

The classification methodology that the MTO followed to sort respondents is outlined in a flowchart in Figure 6.1. This methodology follows Dill's, with differences noted in the next section.

First, respondents who indicated they had not ridden in the last year and were physically unable to ride at the time of the survey were moved to the No Way No How category. Then two additional variables were generated: commuter and recreational. Anyone who responded that they commuted in at least one or more of the categories of: to work, to school, for work, or for groceries was classified as a "commuter." Anyone who indicated that they traveled for recreation or to recreational destinations was classified as "recreational." Respondents who only fell into "recreational" were classified as "Interested but Concerned"; respondents who were commuter only or commuter and recreational continued through the classification flowchart. The remaining respondents were classified based on their responses to questions about comfort level on non-residential streets with and without bicycle infrastructure, quiet residential streets with and without bicycle infrastructure, and separated paths or trails. The scores were generated by averaging responses to each category of infrastructure and traffic on a one to four scale of "very uncomfortable" to "comfortable", as in Dill's methodology. Respondents rating their average comfort as 3.5 or greater (i.e., very comfortable) on non-residential streets without bicycle infrastructure were classified as "Strong and Fearless." Respondents rating 3.5 or higher on streets with bicycle infrastructure were classified as "Enthused and Confident." Respondents rating 3.5 or lower (i.e., uncomfortable) on streets with bicycle infrastructure were classified as "Interested but Concerned."

Additionally, respondents who rated comfort on separated trails or paths as 1.5 or lower (i.e., very uncomfortable) would be classified as "No Way No How." There were no respondents from this pathway that ranked 1.5 or lower on separated trails or paths. Figure 6.2 shows the breakdown of responses into these classifications by percentage of respondents as compared to Dill's Portland and National numbers.

As expected by targeting people who actively cycle for distribution, the MTO population has significantly higher proportions of "Strong and Fearless" as well as "Enthused and Confident" groups, and lower "Interested but Concerned" and "No Way No How" groups.

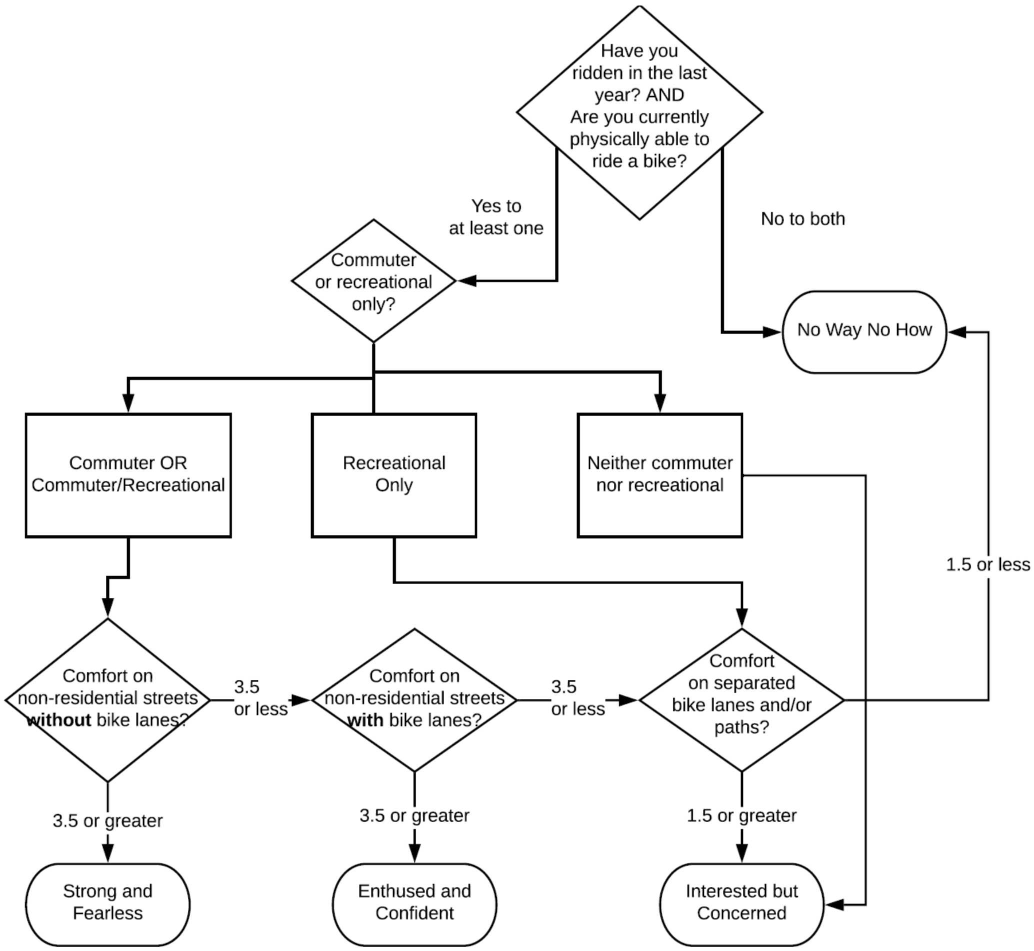


Figure 6.1 Flowchart of MTO Classification Methodology

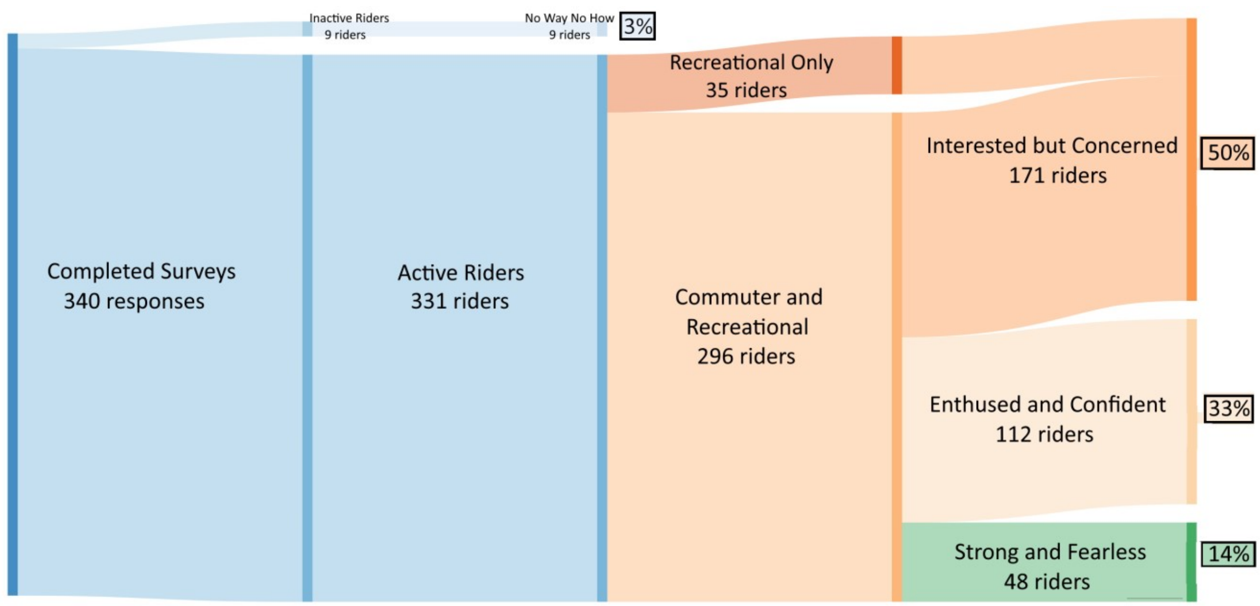


Figure 6.2 Sankey Diagram of Classification Counts

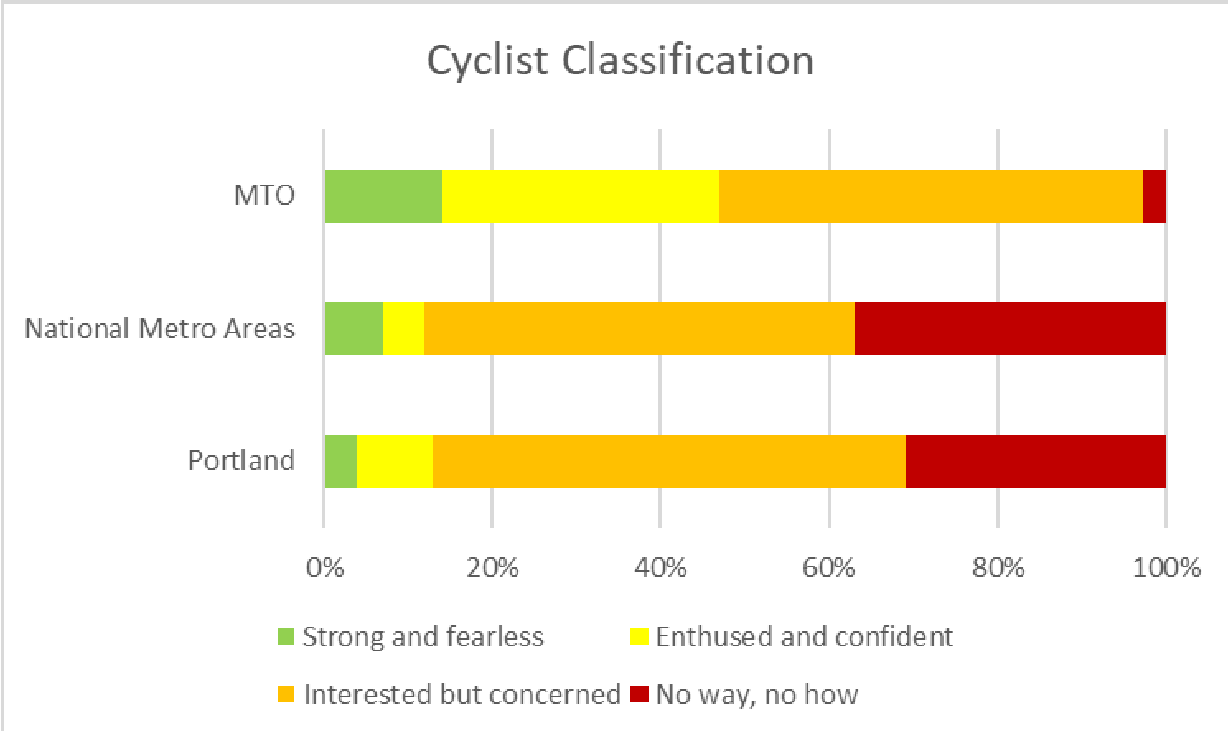


Figure 6.3 Cyclist Classification survey representation comparison between this and past studies.

6.1.2 MTO Respondent Demographics

Table 6-1 presents demographic data for the entire MTO sample, broken down by classification. These numbers are only reported for respondents that completed the demographic section; "prefer not to say" or blank answers were omitted. In lieu of age, generation of respondent is reported in this table. Generational breakdowns at the time of publication are: Gen Z are 5-25 years old; Millennials are 26-40 years old; Gen X are 41-55 years old; Baby Boomers are 56-76 years old, and Silent Generation are older than 76 years.

In general, MTO respondents tended to under-represent younger people who cycle and slightly over-represent female people who cycle (Table 6-1). The MTO respondents were also wealthier and concentrated in the Metro Area (based on optionally reported zip codes).

Specifically looking at the demographic characteristics amongst the classification levels (Table 6-2), Generation Z and Silent Generation people who cycle are much underrepresented; there is a larger number of responses from Millennial and Baby Boomer people who cycle. Amongst the classification levels, however, the percentages of age distributions are consistent, meaning that no one classification group was made of younger or older people who cycle than the others.

Table 6-1 MTO Demographics by Cyclist Classification (Bolded figures discussed in text)

	Classification					
	No Way No How	*Interested but Concerned*	*Enthused and Confident*	*Strong and Fearless*	*Total*	*Sample size*
	%	%	%	%	%	N
Sample size	4	112	63	24	203	
Reported Generation						
Gen Z	0.0	1.8	4.8	8.3	3.4	**7**
Millennials	25.0	39.3	33.3	37.5	36.9	75
Gen X	0.0	25.0	23.8	20.8	23.6	48
Baby Boomers	75.0	31.3	34.9	33.3	33.5	68
Silent Generation	0.0	2.7	3.2	0.0	2.5	**5**
Total	100.0	100.0	100.0	100.0	100.0	203
Reported Gender						
Male	25.0	54.5	58.7	70.8	57.1	116
Female	50.0	40.2	39.7	**29.2**	**38.9**	79
Other	25.0	5.4	1.6	0.0	3.9	**8**
Total	100.0	100.0	100.0	100.0	100.0	203
Relation to Median MN Income ($75K)						
Below Median Inc.	50.0	21.4	19.0	**12.5**	20.2	41
Median Inc. to $100K	25.0	25.0	23.8	29.2	25.1	51
$100K+	25.0	53.6	57.1	58.3	54.7	**111**
Total	100.0	100.0	100.0	100.0	100.0	203
Reported Race						
White	100.0	92.0	93.7	95.8	93.1	**189**
Black-African American	0.0	1.8	0.0	0.0	1.0	2
Asian Pacific Islander	0.0	0.0	0.0	4.2	0.5	1
No dominant	0.0	3.6	0.0	0.0	2.0	4
Other	0.0	0.9	1.6	0.0	1.0	2
Multiracial	0.0	1.8	4.8	0.0	2.5	5
Total	100.0	100.0	100.0	100.0	100.0	203

In general, female people who cycle are about as represented in MTO respondents as they were in MN in 2015 (38.9% us v ~40% in 2015). However, they are underrepresented in the “Strong and Fearless” group. Additionally, below median income people who cycle are also underrepresented in “Strong and Fearless” riders. Unfortunately, the MTO respondents were overwhelmingly White, as were the 2015 MN respondents, so it is difficult to draw conclusions based on reported race.

Note that throughout this report, for the sake of analysis, only “male” and “female” respondents will be included, as “other” gendered respondents were very few and insufficient for meaningful statistical analysis. For the same reason, “Age not disclosed” respondents are dropped from the age-based perception results throughout.

Table 6-2 Comparison of MTO Demographics to MN State Cyclists Demographics (2015)

Demographic Category	MN State Survey (2015)	MTO Survey
Age: 25 to 34	25%	17%
Age: 25 to 44	45%	41%
Gender: Male	60%	52%
Race: White	90%	91%
Race: Non-White	10%	9%
Income: $20,000 or less	4%	2%
Income: $45,000 or greater	70%	90%
Income: $75,000 or greater	46%	79%
Income: not reported	11%	12%
Location: Metro area	61%	100%*

*of reported zip codes

The following section discusses the differences between Dill's methodology and the MTO's methodology for classifying respondents more in-depth.

6.1.2.1 Dill Methodology v. MTO Methodology

The purpose of Dill's survey projects was to determine the levels of comfort among a random sampling of respondents, both people who actively cycle and who do not actively cycle, in Portland (35) and later across major metropolitan areas in the US (41). The MTO decided to focus distribution on people who cycle located primarily in the Twin Cities Metro Area specifically, rather than a random sampling of respondents across the state, to better reflect the purpose of this project: guidelines for designing separated bike lanes. By focusing specifically on people who cycle, the MTO would receive useful feedback specific to bicycle infrastructure from users familiar with its implementation; most of the bicycle infrastructure in Minnesota is concentrated in the Twin Cities Metro Area, so distributing to people who cycle familiar with the challenges of bicycling in the Twin Cities also helped to ensure usable feedback from the survey. This approach, combined with the snowball method of distribution beyond initial distribution points, results in a sample biased towards people who actively cycle.

Also different was the MTO's mode of distribution. Dill's surveys were phone-based where researchers called random samplings of populations and held a roughly 20-minute live interview. The MTO created the survey in Qualtrics, targeting an average completion time of 30 minutes, especially for people who indicated they cycle during winter. This survey was then emailed out and later distributed on social media to cyclist groups based in Minnesota, in addition to the original distribution to BikeMN. The survey was also presented during Transportation Committee Meetings in several St. Paul District Councils. Task 5 has a specific list of distribution efforts among social media and District Councils.

Dill's original survey asked respondents to rate their comfort only on a variety of non-residential streets. Because of Minneapolis and St. Paul's propensity toward quiet residential streets with bicycle infrastructure, the MTO's survey asked respondents to rate their comfort both on non-residential streets and quiet residential streets with various levels of bicycle infrastructure. This difference and subsequent classification is reflected in Figure 6.1.

Dill asked specifically about trip purpose (“bicycling for transportation”) in the last 30 days. To better understand the MTO respondents’ specific cycling behaviors, a classification for commuter or recreational cyclist was created based on cycling behaviors within the last year.

“No Way No How” people who cycle were defined as those who were unable to ride a bike at the time of the survey and had not ridden in the last year; otherwise, a default interest in cycling was assumed due to the respondent proceeding through the survey, and the minimum level of comfort a respondent would be classified as was “Interested but Concerned.” The difference between all four classification levels in the MTO study and Dill’s Portland and National studies can be seen in Figure 6.3.

Another difference between Dill’s classification architecture and the MTO’s is the use of “interest in cycling more” as a marker for assigning Level of Comfort (LOC). Because the MTO’s sample specifically targeted people who cycled actively, the concern was that respondents wouldn’t indicate interest in cycling *more* as they already cycled as a primary mode of transportation. Additionally, the MTO captured interest in cycling more during both the summer and winter months rather than in general, shown in Table 6-3.

Overall, only 11% of the MTO’s survey respondents indicated interest in biking more during the non-winter seasons, but 45% indicated interest in biking more during the winter. This suggests there is interest across cycling groups in cycling more during winter, but cyclists' needs are not being met. The MTO study was designed to look at winter maintenance as well as preferred infrastructure for winter biking to meet this gap between interest in and actual cycling behavior.

Table 6-3 Interest in Cycling More during winter and Non-Winter Seasons

	LOC					*Sample size*
	No Way No How	*Interested but Concerned*	*Enthused and Confident*	*Strong and Fearless*	*Total*	
	%	%	%	%	%	N
Interest in Winter?						
No	0.0	47.4	65.2	66.7	54.7	186
Yes	100.0	52.6	34.8	33.3	45.3	154
Total	100.0	100.0	100.0	100.0	100.0	340
Interest in other seasons?						
No	0.0	88.9	95.5	87.5	88.5	301
Yes	100.0	11.1	4.5	12.5	11.5	39
Total	100.0	100.0	100.0	100.0	100.0	340
Sample size	9	171	112	48	340	

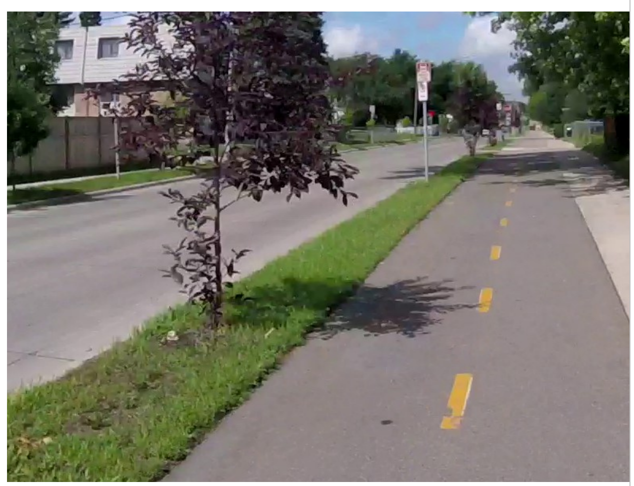
6.2 BUFFER DESIGN OPTIONS

The discussion in this section focuses on user perspectives on the design options for the barriers that act as the buffer separating the driving lanes and the SBL. The context is the uninterrupted mid-block sections of lanes. Intersections and access points with high vehicle volumes are covered later in the mixing zone section.

Buffer 1: Wall or Tall Barrier (impenetrable)

Buffer 2: Intermittent Barrier

Buffer 3: Curb and Intermittent Barrier



Buffer 4: Grade Separation

Figure 6.4 Types of Buffers presented to users

6.2.1 Buffer Design Perspectives from the User Survey

Respondents were presented with four types of buffers: solid barrier, intermittent barrier, curb and intermittent barrier, and grade separation (Figure 6.4). For each design option, respondents were asked to indicate their perception of safety and comfort separately during summer and winter months. Respondents were asked to indicate their level of agreement scale of zero (strongly disagree) to four (strongly for each measure or question about each design. Means for each question were calculated; because there was a middle category, mean values at or above two indicate more agreement than disagreement. Both the mean ratings and the percentages of respondents that agreed are reported in summary charts for all four measures. In addition, box plots and other charts are presented to provide additional detail about the variability in responses to each measure. Figure 6.5 is a scatterplot that summarizes the mean agreement scores for both the "I would feel safe on this type of design" and "I would feel comfortable on this type of design" questions, with safety on the y axis and comfort on the x axis. Scores over 2 indicate respondents agree with those statements on average. In the case of Figure 5, respondents generally agreed they feel safe and comfortable on all designs in all seasons, but the gradient of responses provides insight to which barrier type is the safest and the most comfortable in each season.

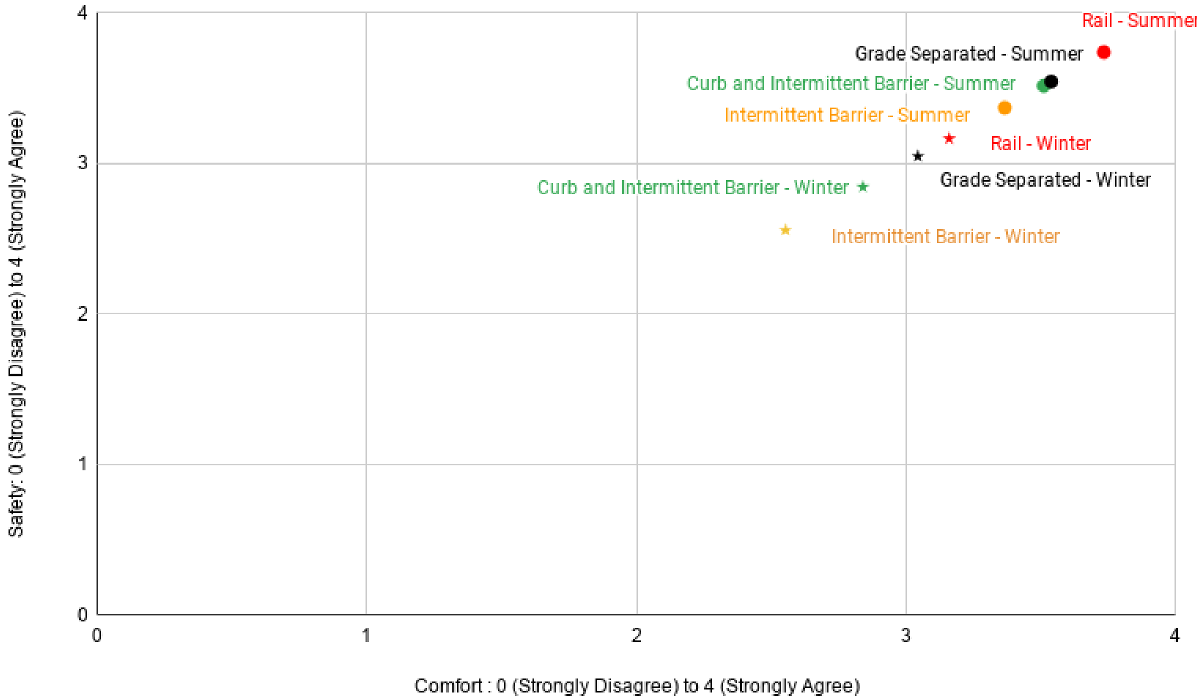


Figure 6.5 Buffer Safety and Comfort during Winter and Summer (mean scores, n = 298)

For additional insight, results also are presented in bar graphs and box-plots; each visualization allows for a different kind of understanding.

Two observations can be drawn from the box-plots in Figure 6.6 and Figure 6.7. First, the people who cycle generally perceived all buffer types as safe (i.e., mean ratings of comfort and safety were above two). Second, people who cycle were more unified in their perceptions of comfort and safety associated with solid barriers. This conclusion is based on the variability in responses across buffer types, with greater variability in responses for the three other buffer types. Specifically, from a safety perspective, respondents indicated they felt safer on SB and GS buffers in both summer and winter (Figure 6.6 and Figure 6.7). Findings for comfort for both summer and winter (Figure 6.8 and Figure 6.9) were similar. That is, respondents felt safest on SB and GS buffers in both summer and winter, although they felt less safe in winter. In general, intermittent barriers, which allow vehicular penetration into the lanes, were perceived as least safe.

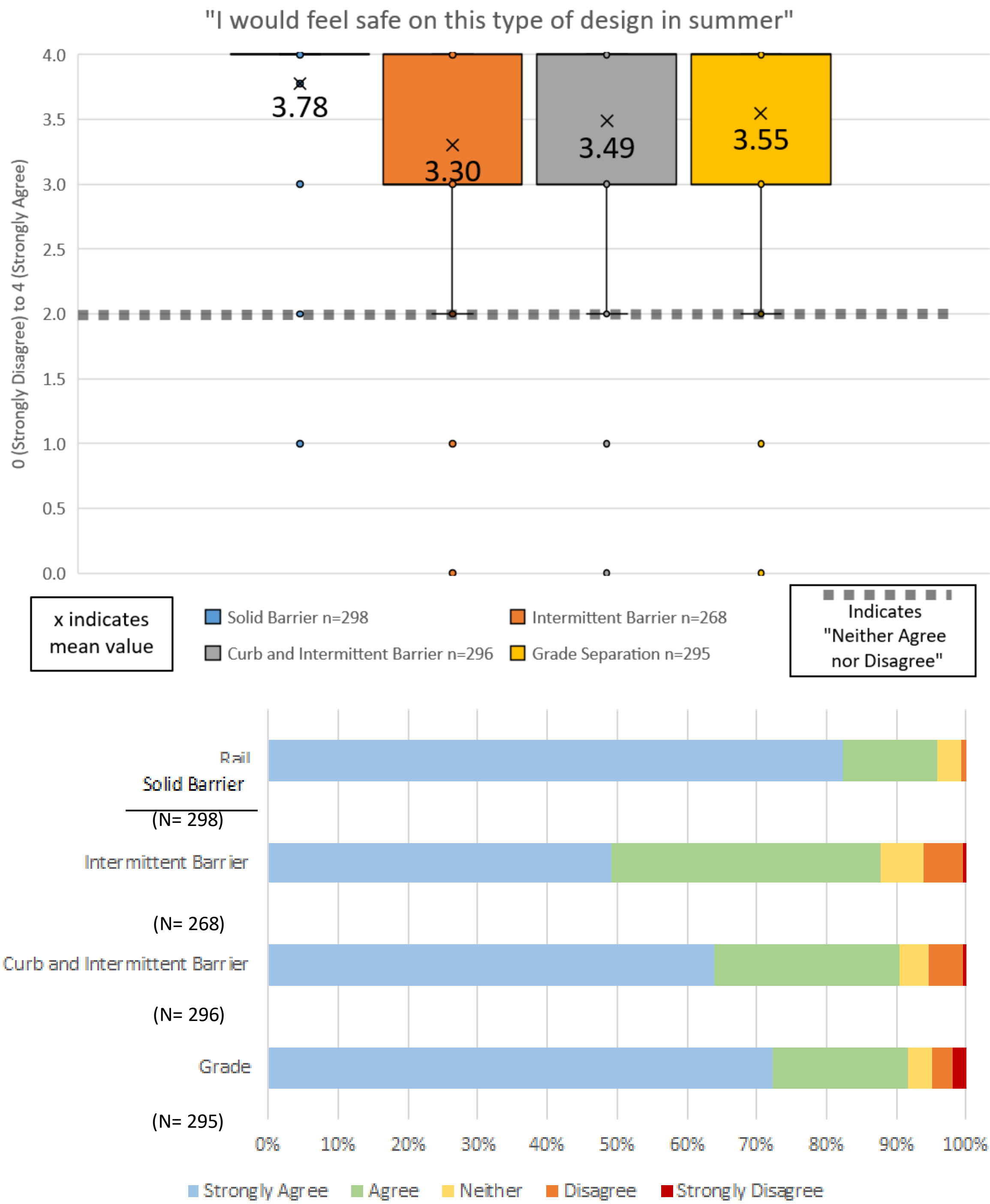
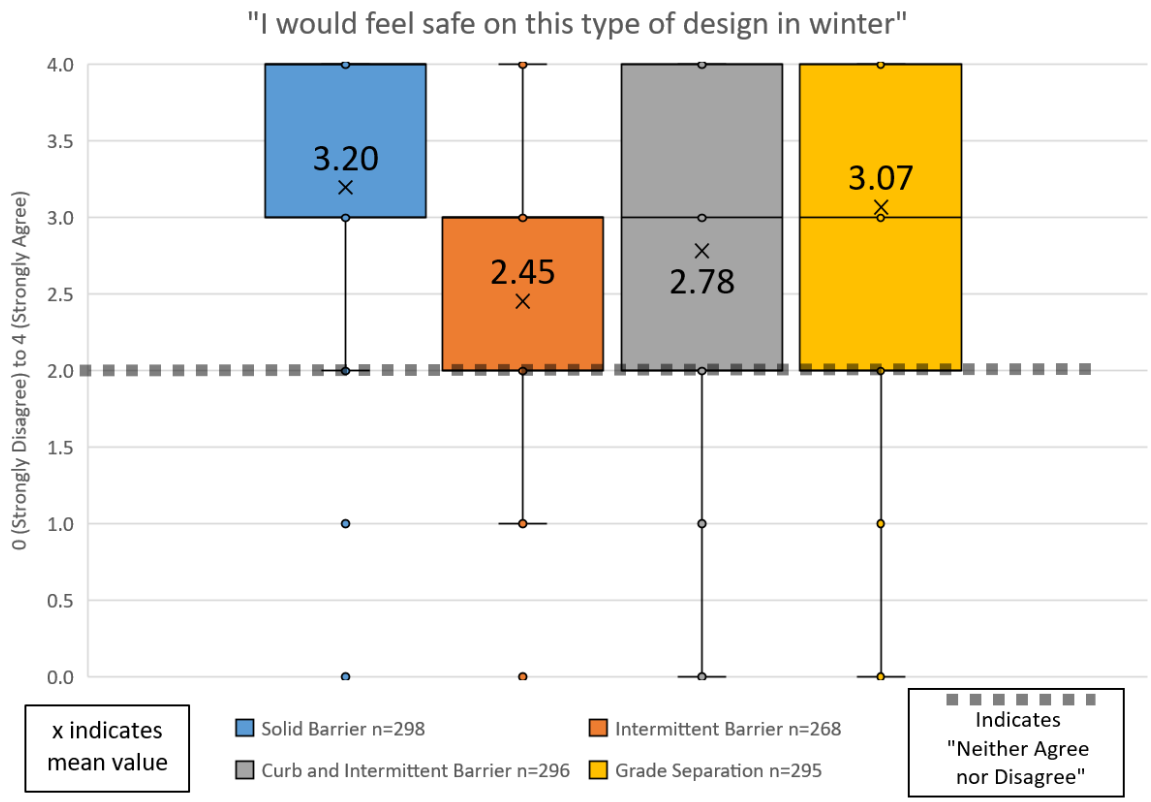


Figure 6.6 User perceptions of safety on types of barriers in summer



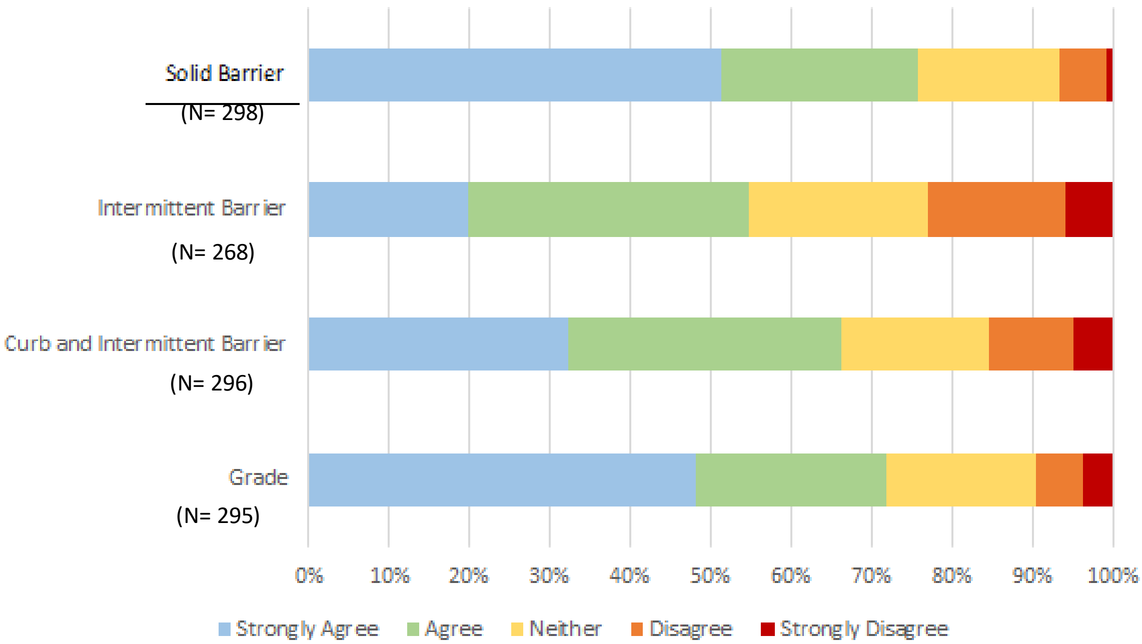


Figure 6.7 User perceptions of safety on types of barriers in winter

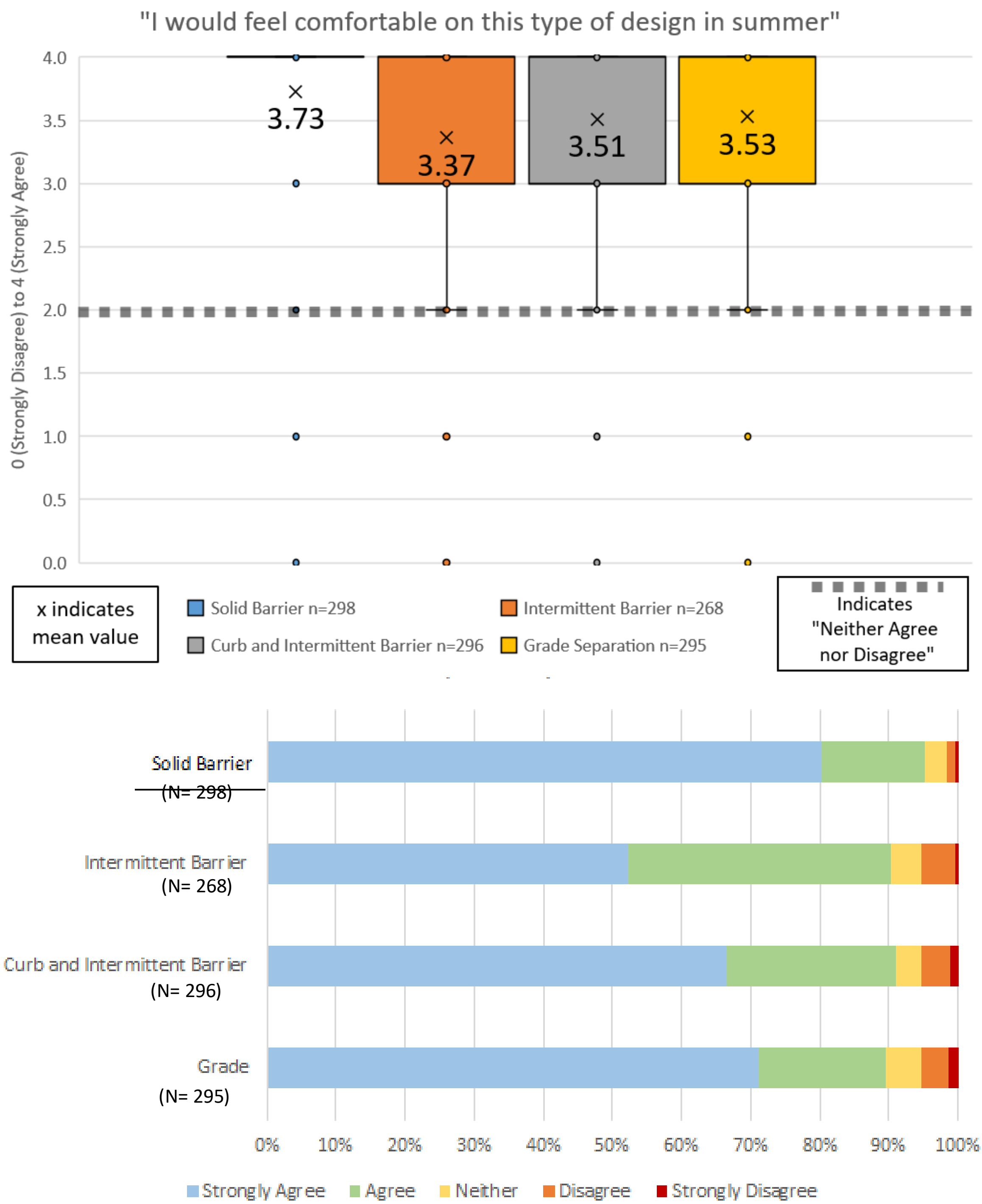


Figure 6.8 User perceptions of comfort on types of barriers in summer

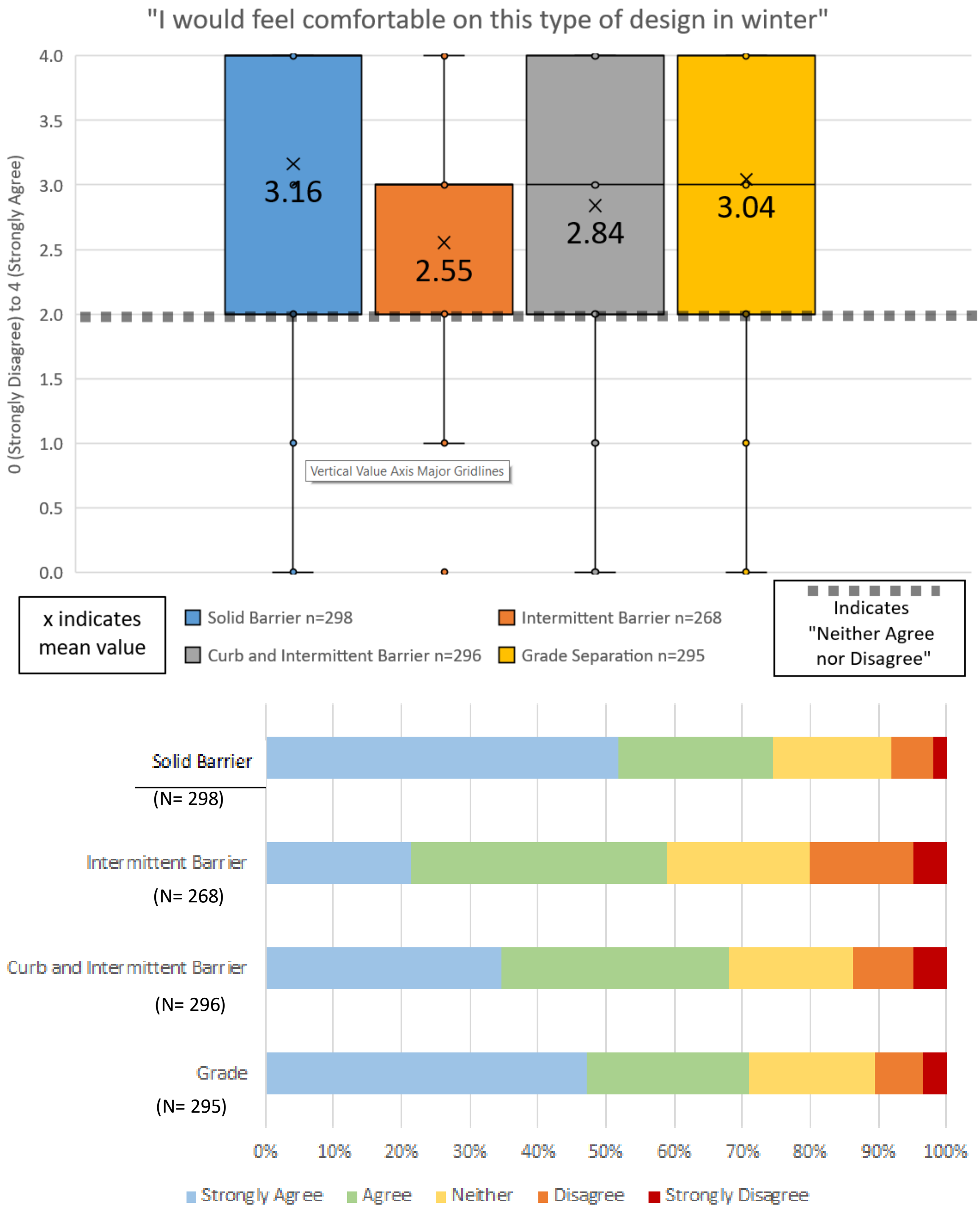


Figure 6.9 User perceptions of comfort on types of barriers in winter

6.2.1.1 Differentiation by Gender and Age Group

Males in general rated all buffer designs higher in both safety and comfort than females. Specifically, for IB, which is the most common type of separation, the gender gap is largest. The result suggests that the opportunity to reduce the gender gap is greatest with shifting from IB to any other barrier type. As indicated previously, ratings of comfort and safety are consistent across seasons, so we present only Winter figures here (all figures can be found in the Appendix C).

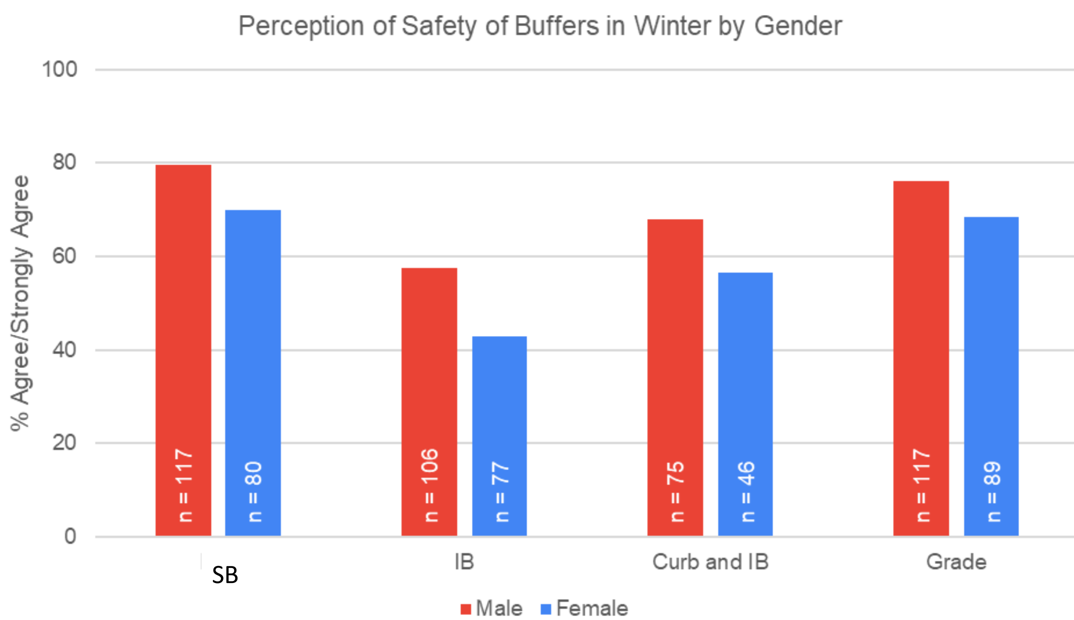


Figure 6.10 Perception of Safety of Buffer Type in Winter by Gender

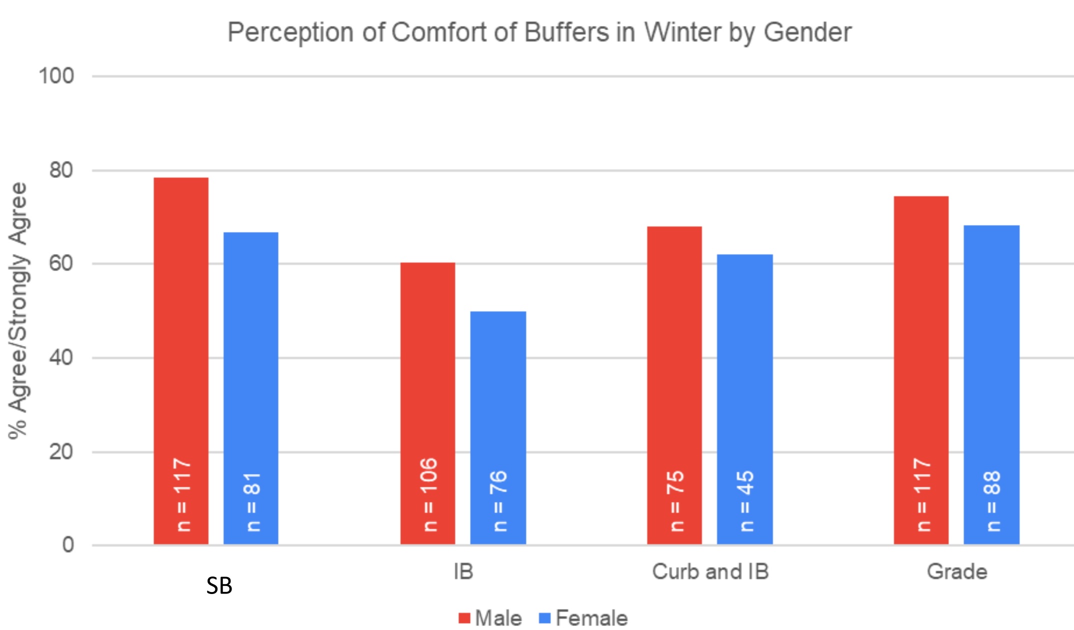


Figure 6.11 Perception of Comfort of Buffer Type in Winter by Gender

With respect to the perspectives of different age groups, the oldest and youngest generations of people who cycle had very small sample sizes and so were combined with other generations to create three age groups: younger, middle age, and older. In the summer season, middle aged (i.e., Generation X) people who cycle mostly felt less safe (Figure 6.12) and less comfortable (Figure 6.13) than people who cycle of other ages. Also in the summer, younger people who cycle (i.e., Millennials) felt less safe and comfortable with an Intermittent Barrier as compared to other types while older people who cycle (i.e., Baby Boomers) were much less influenced by the barrier type feeling similarly about all of them, especially in regards to safety.

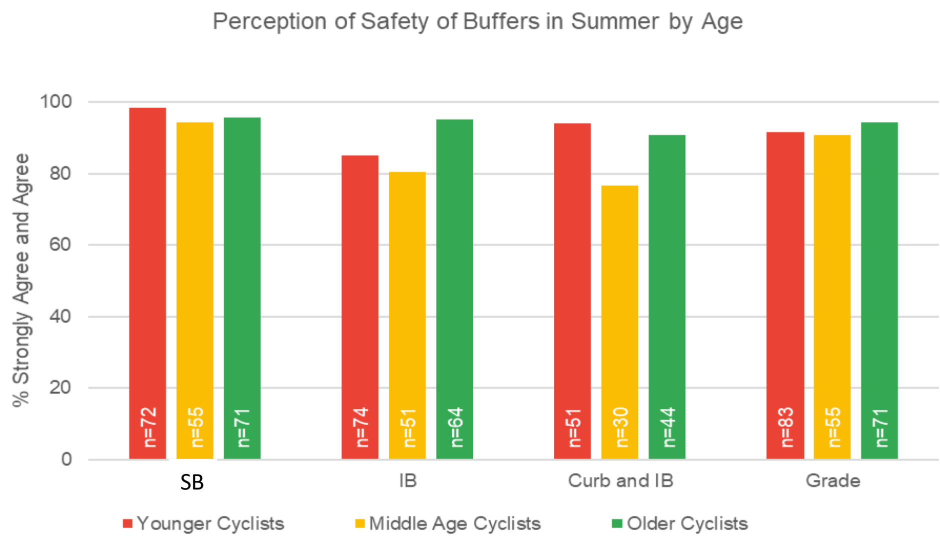


Figure 6.12 Perception of Safety of Buffer Type in Summer by Age Group

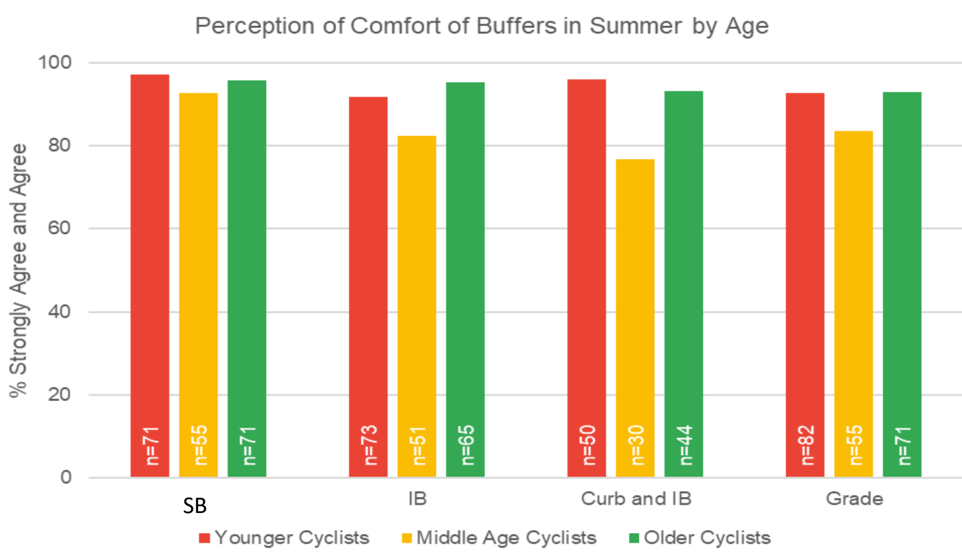


Figure 6.13 Perception of Comfort of Buffer Type in Summer by Age Group

In the winter in general, safety (Figure 6.14) and comfort (Figure 6.15) decreased with age regardless of buffer type. Feelings of safety and comfort in the winter decreased overall in the following order: Solid Barrier, Grade, Curb and IB, IB only. Older people who cycle present the greatest influence from season in their reduction of perceived safety and comfort, with the IB suffering from the greatest comparative drop. The intermittent barrier alone was rated the least safe and least comfortable option for all age groups. Comparatively speaking, the IB had the largest drop in preference between summer and winter, for all age groups except middle aged people who cycle. Specifically, in terms of safety, younger people who cycle (i.e., Millennial) felt more safe or comfortable than middle age people who cycle on all types except in the IB case where they felt less safe/comfortable than middle age and about par with older people who cycle. Overall, after setting apart the GS design, SB is the design that seems to retain the preference of two out of three age groups on the younger side.

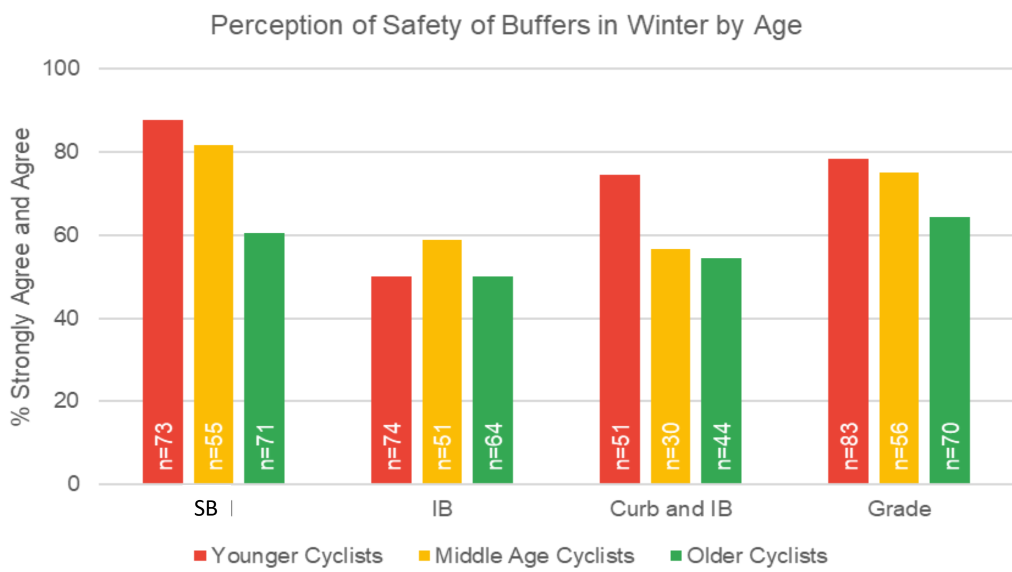


Figure 6.14 Perception of Safety of Buffer Type in Winter by Age Group

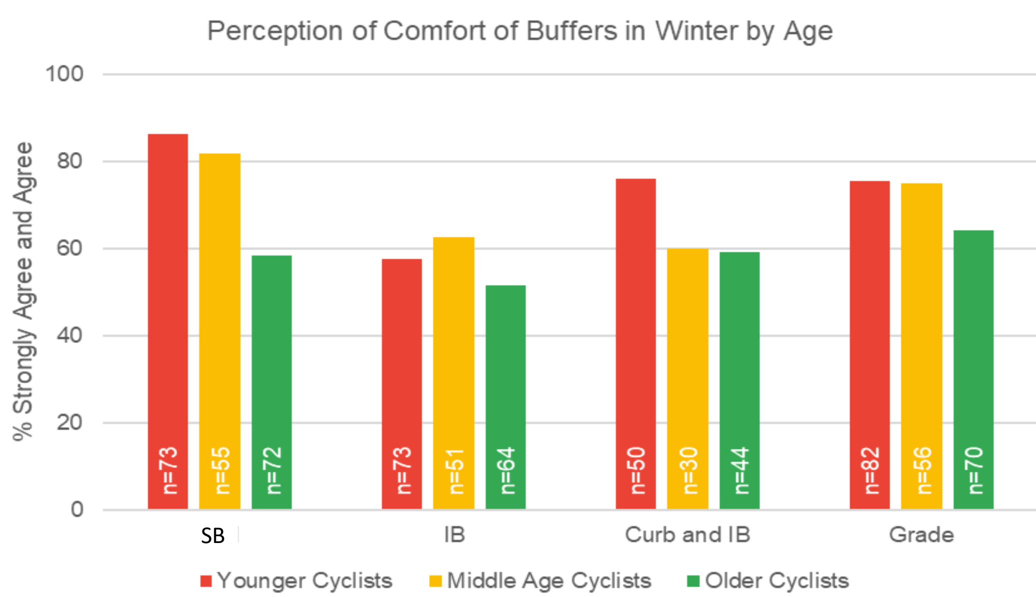


Figure 6.15 Perception of Comfort of Buffer Type in Winter by Age Group

6.2.1.2 Differentiation by Cyclist Classification

Similar to ratings when analyzed by age group, both Safety (Figure 6.16) and Comfort (Figure 6.18) were more highly rated by all cyclist classification groups in summer than winter. “Enthused and Confident” feel almost 100% safe and comfortable in the summer regardless of the type of barrier, with Grade Separation coming slightly less in both aspects as compared to the rest of the types. “Interested but Concerned” follow the pattern of Rail, Grade, Curb, and IB in degrees of reduced safety and comfort, but still with small overall variations. Interestingly, “Strong and Fearless” people who cycle showed the most variability and rated grade separation—the furthest physical spacing option-- the lowest of the buffer types in both safety and comfort. In a pattern reversal, the same class, rated the IB as the safest type. This somewhat corroborates the anecdotal evidence collected during the in-person interviews where the designs that prohibit riding inside the buffer were regarded less favorably.

Safety and comfort were over all rated lower during winter months for all cyclist groups. At the same time, winter season results exhibit much larger differences between groups on the same buffer type and in a lesser degree overall across buffer types.

Specifically, the “Interested but Concerned” feels less safe and less comfortable on an IB separated SBL in winter, most safe on SB and Grade designs, and moderately safe (i.e., in the middle) for the Curb + IB. A plausible hypothesis for this result is that this group feels the least certain in controlling the bicycle on a slippery surface therefore appreciate the complete separation offered by these buffers from the driving lanes. In contrast, “Enthused and Confident”, with the exception of the IB they rated all other types safer and more comfortable as compared to the “Strong and Fearless” people who cycle.

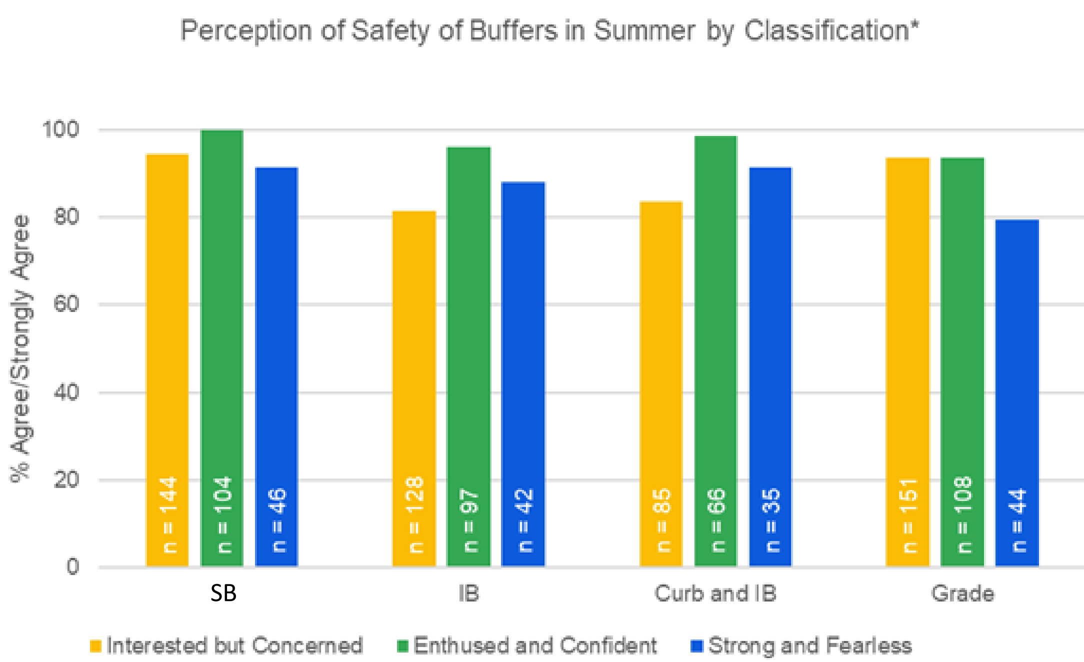


Figure 6.16 Cyclist class perception of safety during summer per buffer type.

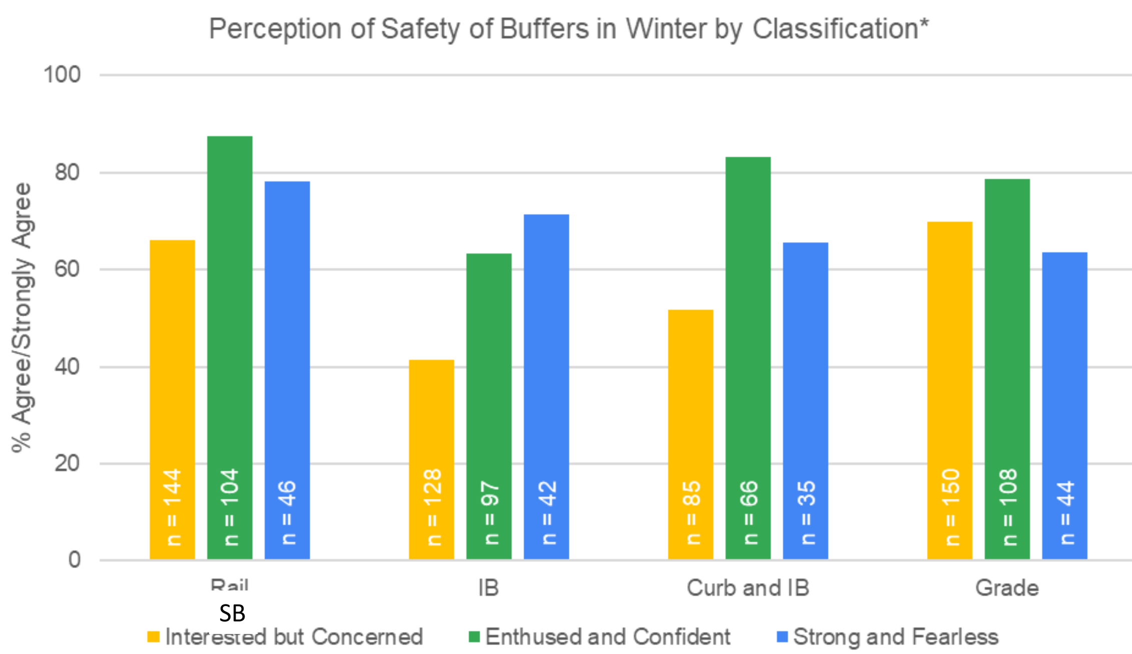


Figure 6.17 Cyclist class perception of safety during winter per buffer type.

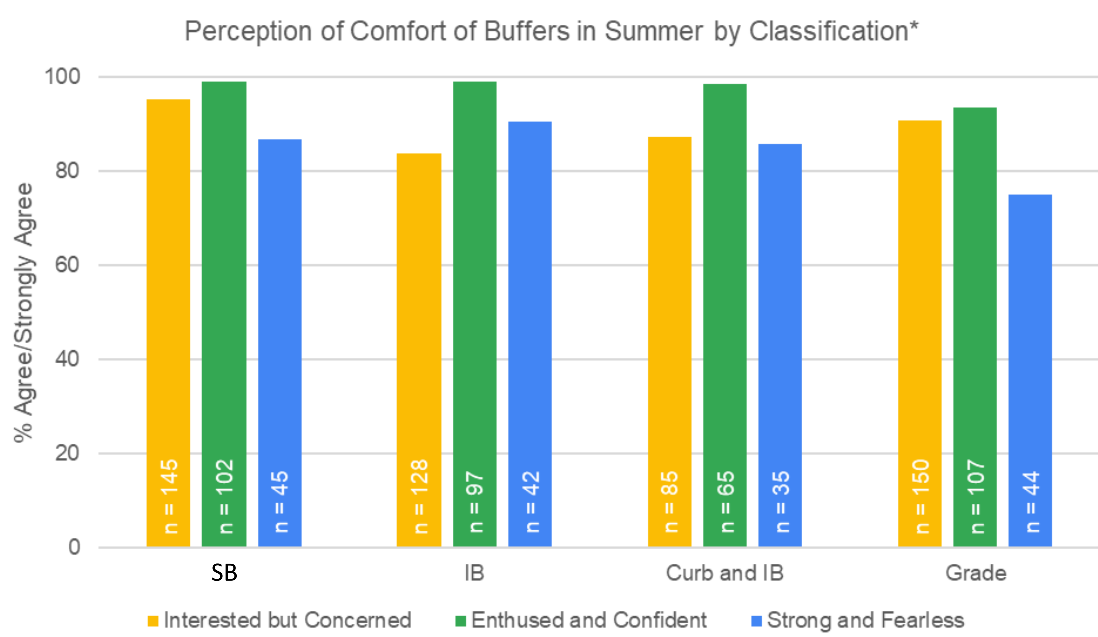


Figure 6.18 Cyclist class perception of comfort during summer per buffer type.

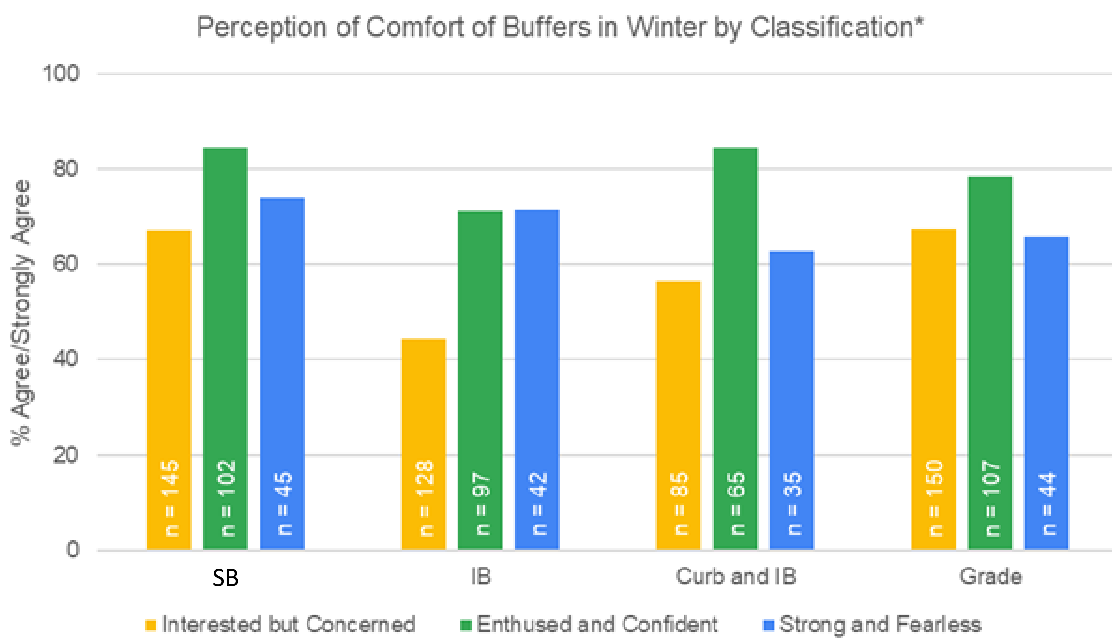
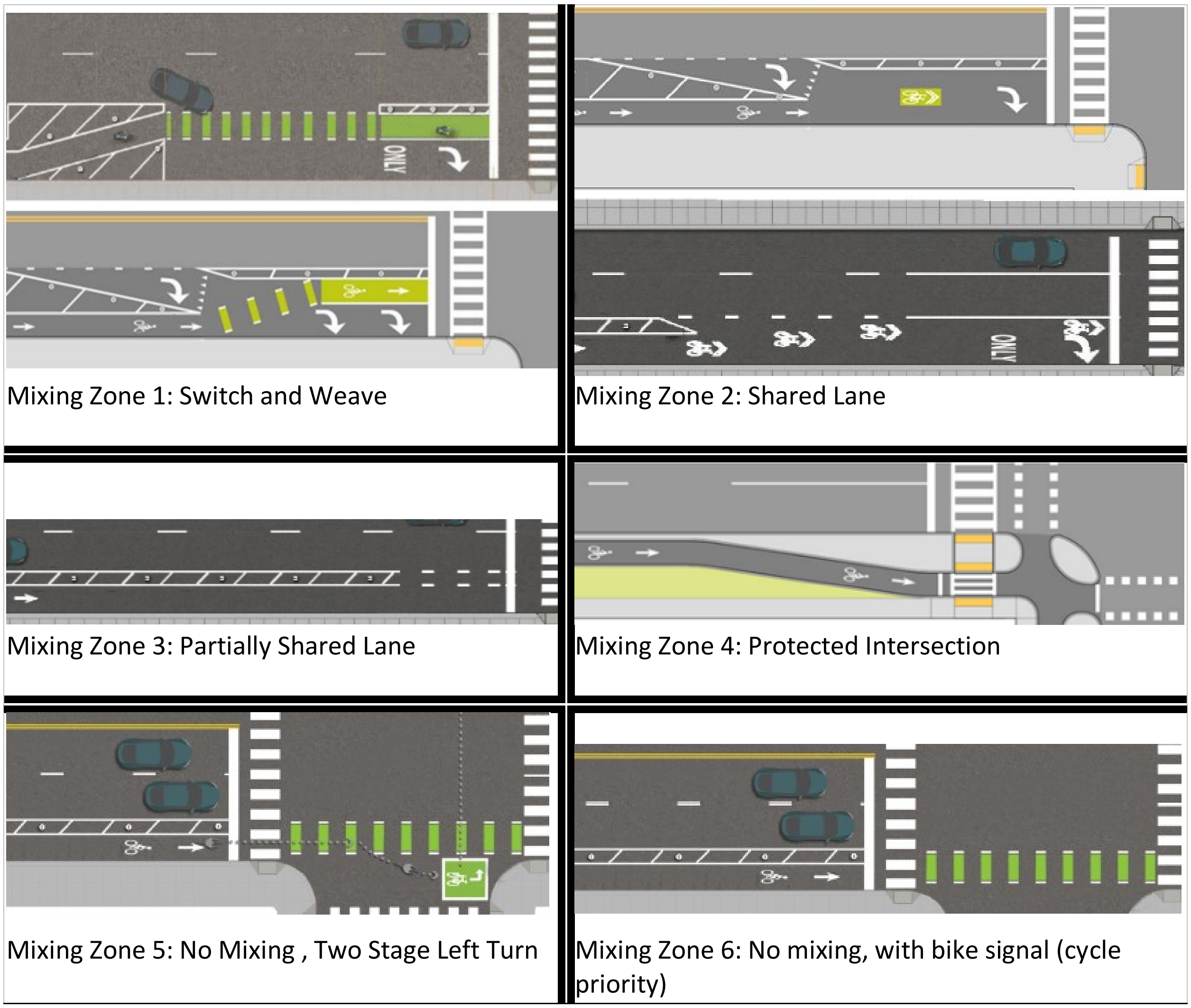


Figure 6.19 Cyclist class perception of comfort during winter per buffer type.

6.3 MIXING ZONE DESIGN OPTIONS

Six different types of mixing zones were presented to respondents (Figure 6.20): Switch and Weave (SW), Shared Lane (SL), Partially Shared Lane (PSL), Protected Intersection (PI), No Mixing with a Two-Stage Left Turn “Box” (TSLT), and No Mixing with no box but a Bike Signal (NMBS) present. Images were adapted from the MassDOT and FHWA guidance. Respondents were asked to rate their perceptions of safety and comfort as well as how well they understood how the mixing zone design is intended to be used.



Mixing Zone 1: Switch and Weave

Mixing Zone 2: Shared Lane

Mixing Zone 3: Partially Shared Lane

Mixing Zone 4: Protected Intersection

Mixing Zone 5: No Mixing , Two Stage Left Turn

Mixing Zone 6: No mixing, with bike signal (cycle priority)

Figure 6.20 Types of Mixing Zones presented to users

6.3.1 Mixing Zone Perspectives from the User Survey

In addition to perceptions of safety and comfort of different mixing zone designs, respondents were asked about their understanding of the designs and whether cycling through a particular design would result in additional delay. This section summarizes responses from all four measures (i.e., safety, comfort, understanding of design, and additional delay). Respondents were asked to indicate their level of agreement scale of zero (strongly disagree) to four (strongly for each measure or question about each design. Means for each question were calculated; because there was a middle category, mean values at or above two indicate more agreement than disagreement. Both the mean ratings and the percentages of respondents that agreed are reported in summary charts for all four measures. In addition, box plots and other charts are presented to provide additional detail about the variability in responses to each measure. Figure 6.21 and Figure 6.22 present mean ratings and the percentages of respondents, respectively, that agreed with statements about each of the four measures. These results indicate:

- The majority of respondents agreed they understood the design were intended to work, and they were most likely to agree they understood the Partially Shared lane design.
- With the exception of the No Mixing Bike Signal Design (NMBS), a majority of respondents agreed that each of the other five designs would not cause additional delays. Fewer than half the respondents agreed that the NMBS would not cause additional delays.
- Respondents have varied perceptions of safety of each design, with a majority of respondents agreeing that they would feel safe on only four of the designs: Switch and Weave; No Mixing, Two-Stage; No Mixing, Bike Signal; and Protected Intersection. Fewer than half of respondents agreed they would feel safe on Shared Lanes or Partially Shared Lanes.
- A majority of respondents agreed they would feel comfortable on each design. The highest proportions of respondents agreed they would feel comfortable on the No Mixing, Two-Stage Left Turn, and the Protected Intersection.

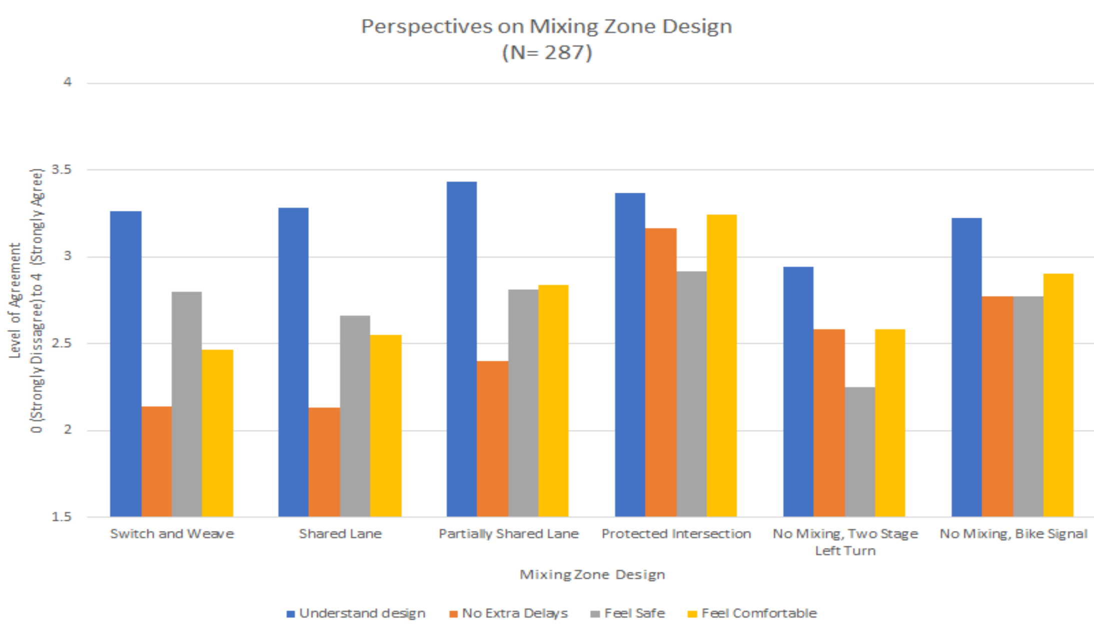


Figure 6.21 Average user level of agreement for perception of safety, comfort, understanding and extra delay per type of Mixing Zone

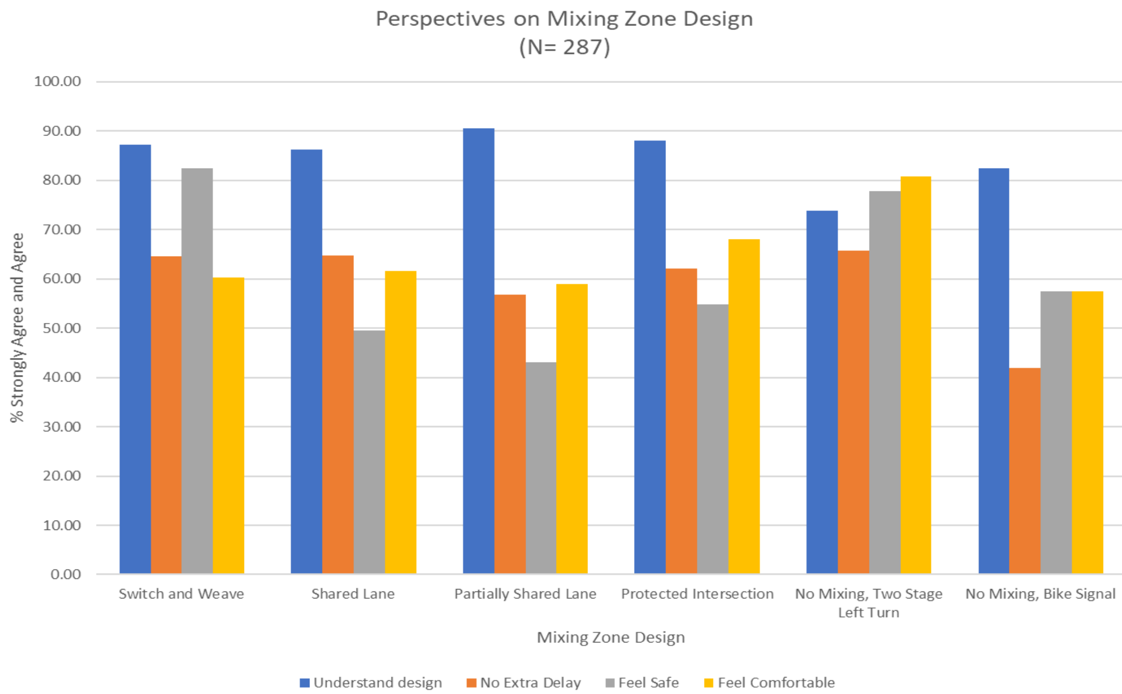


Figure 6.22 Percent of Strongly Agree and Agree responses for perception of safety, comfort, understanding and no extra delay per type of Mixing Zone

Figure 6.23 is a scatterplot of mean safety and comfort ratings for each design. This plot can be used to infer a type of preferences ordering among people who cycle given their perceptions of safety and comfort. Although the responses are bunched fairly close together in the scatterplot, the Protected Intersection dominates other alternatives: it has the highest mean levels of agreement for both safety and comfort. This design is distinctive in that it completely separates people who drive and people who cycle. Among the five designs that retain features with require mixing, the next highest rated designs based on safety and comfort are the No Mixing with Bike Signal and Partially Shared Lane designs. These outcomes seem consistent and may be because these designs do not force mixing of the two modes, have a very straight forward set of road markings and, at least in theory due to the bike signal, control the conflicts between people who cycle and drivers turning right.

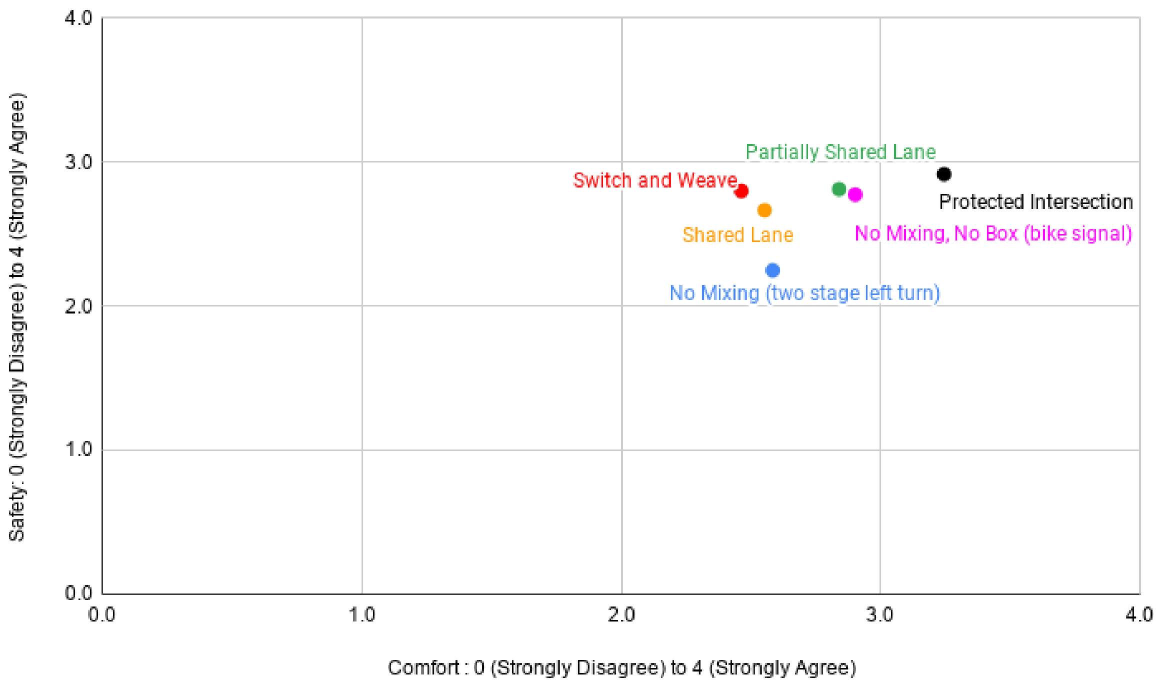


Figure 6.23 Mixing Zone Safety and Comfort (n=287)

A limitation of the scatterplot (Figure 6.23) is that it is based on mean ratings. The following box plots and stacked, horizontal bar charts, illustrate variability in responses for each the four measures (i.e., safety, comfort, understandability, and delay). In these figures, Protected Intersection is ranked the highest but given its full separation it cannot really be compared to the rest of the designs so the following discussion excludes it from comparative statements.

While a majority of respondents agree they understand all designs and would feel comfortable on them, their relative perceptions of safety vary as do their perceptions of whether facilities would result in additional delays (Figure 6.21 and Figure 6.22). The variations in responses across design alternatives imply preferences among them. For example, while respondents indicated the most understandable designs were Switch and Weave and Shared Lane, they also indicated they would feel least safe (Figure 6.24) and least comfortable (Figure 6.25) on those same designs. Their perceptions of safety are likely due to the lack of true separation at these mixing zone designs.

Respondents varied little in their understanding of five of the six designs (Figure 6.26), with the exception being the No-Mixing, Two-Stage Left Turn Design. This design is both lowest ranked and exhibits the greatest variability in assessment.

Among the six designs, the largest proportion of respondents felt that the No Mixing, Two Stage Left Turn zone would cause the most extra delay to trips out of the possible designs (Figure 6.27). This design is both lowest ranked and exhibits the greatest variability in assessment.

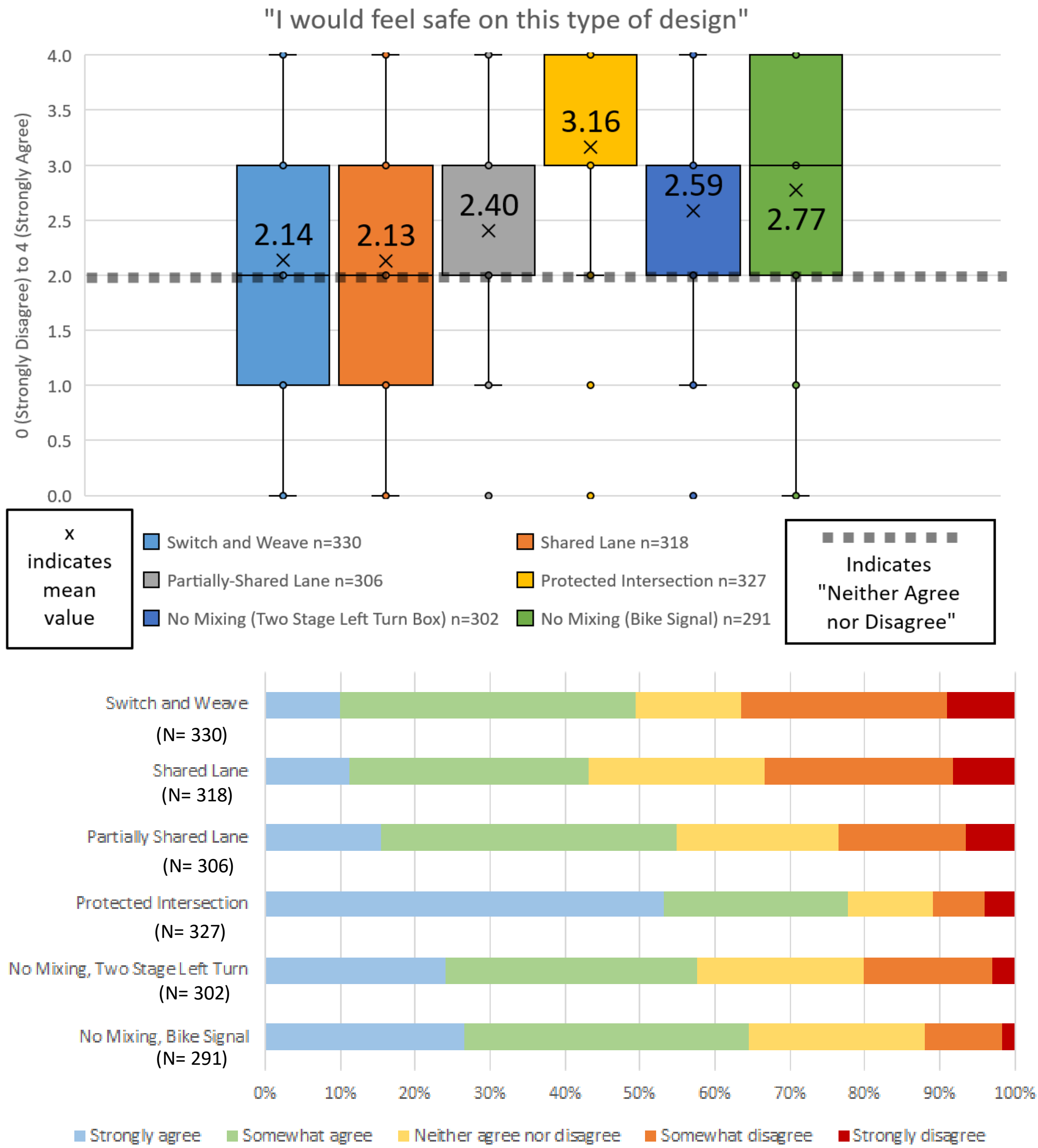


Figure 6.24 User perception of safety per Mixing Zone type

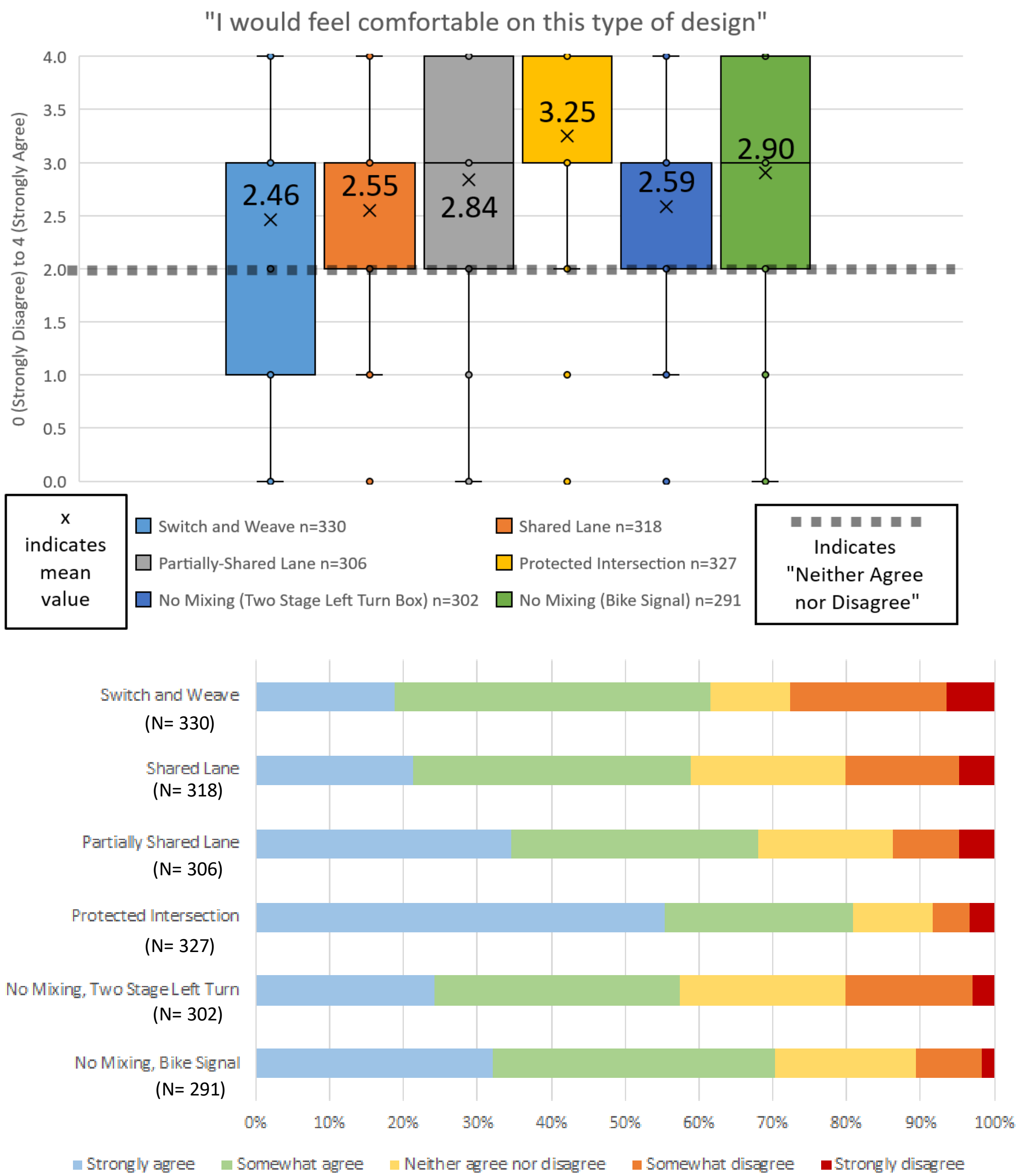


Figure 6.25 User perception of comfort per Mixing Zone type

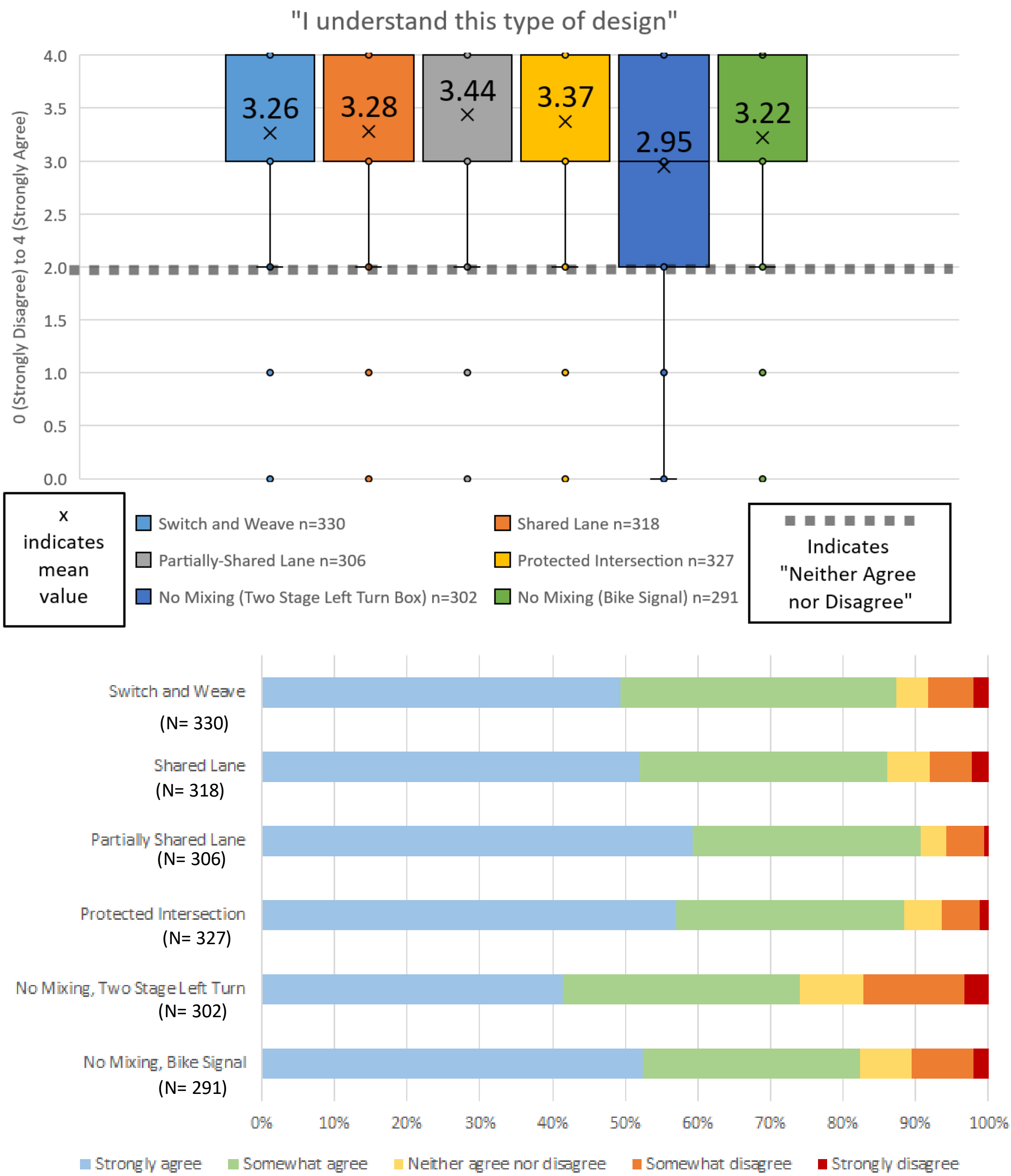


Figure 6.26 User understanding of each Mixing Zone type

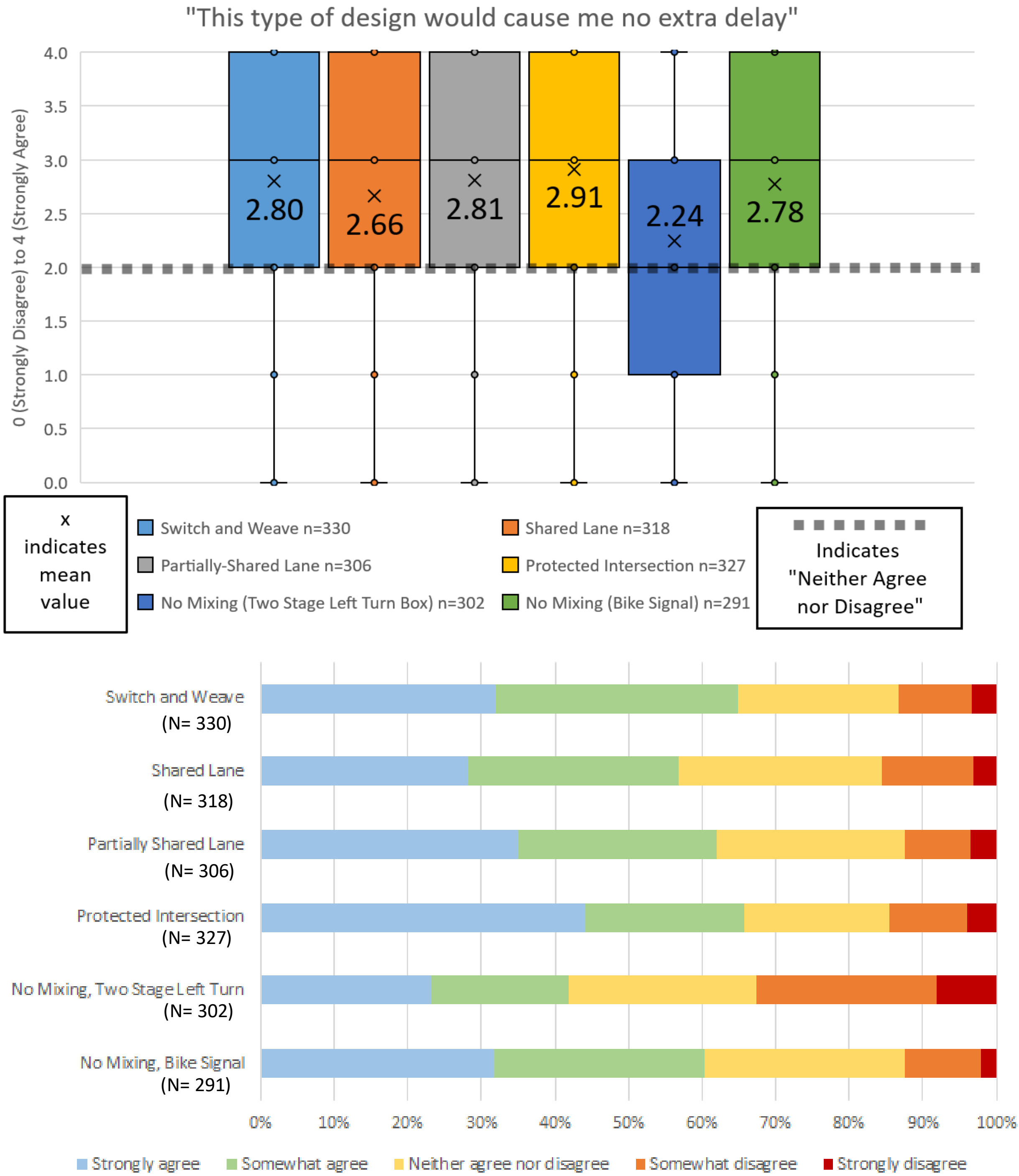


Figure 6.27 User perception of extra delay per Mixing Zone type

6.3.1.1 Ratings of Mixing Zones by Gender and Age Group

As with buffer types, males rated all mixing zones higher in both safety and comfort than females, with the exception of the No Mixing, Bike Signal design, where females rated it higher than males for safety and nearly equal for comfort. Males rated their understanding of designs higher than females; they also felt more positively that all would not cause extra delay, though the No Mixing, Two Stage Left Turn design was rated the lowest of all designs by both genders for delay. While the differences between genders were consistent across all designs, the magnitudes of the differences generally were relatively small. With the above noted exception, the combined percent of “Agree” and “Strongly Agree” the differences between genders were only about 5% to 10%. Figures that illustrate specific differences are included in the Appendix.

Results differentiated by age group also were generally consistent (graphs in Appendix C). Excluding generations with small sample sizes as previously noted, Protected Intersection is rated the highest in safety and comfort among all age groups (i.e., Millennials, Gen X, and Baby Boomers). Understanding of designs was ranked roughly equally, though the No Mixing, Two Stage Left Turn design option was rated slightly lower by Millennials. All age groups felt that all designs would cause some degree of extra delay. Among Millennials, the No Mixing, Two Stage Left Turn option was identified as causing the greatest additional delay.

6.3.1.2 Ratings of Mixing Zones by Cyclist Classification

Among the classification groups, the “Interested but Concerned” group differed substantially from the other groups, and, overall, were less likely to agree they would feel safe (Figure 6.28) or comfortable (Figure 6.29) across five of six designs. The exception was the Protected Intersection, where people who cycle classified as “Interested but Concerned” felt safer and more comfortable than “Enthused and Confident” people who cycle and “Strong and Fearless” people who cycle. The same observation holds with the designs’ potential to cause extra delay (Figure 6.30), though “Interested but Concerned” people who cycle did not feel as strongly about the Protected Intersection design.

Conversely, the “Strong and Fearless” people who cycle indicated a higher preference in terms of safety and comfort towards the Switch and Weave designs. Similar differences can be seen in the perception of extra delay. This difference in opinions poses a design objective conundrum because designs that may encourage new more casual people who cycle may be frowned upon by people who cycle that have selected cycling as a more solid transportation option.

Finally, all groups indicated a strong level of understanding (Figure 6.31) of each design, though No Mixing, Two Stage Left Turn was rated lower by “Interested but Concerned” and “Enthused and Confident” people who cycle.

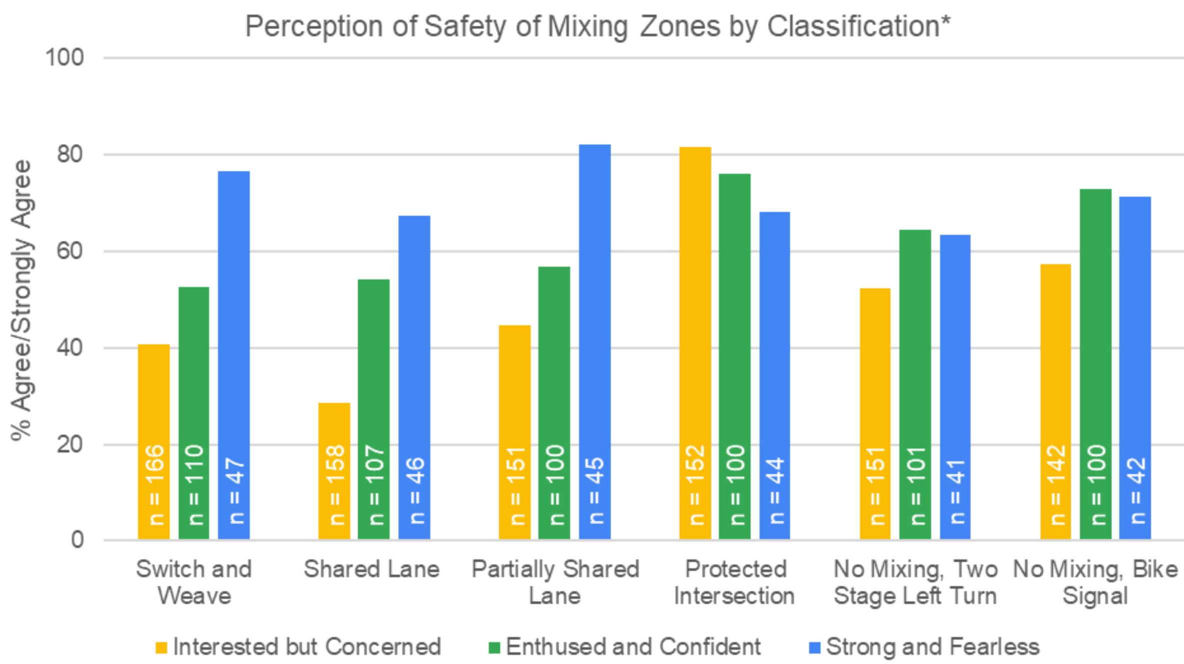


Figure 6.28 Cyclist class perception of safety per Mixing Zone type

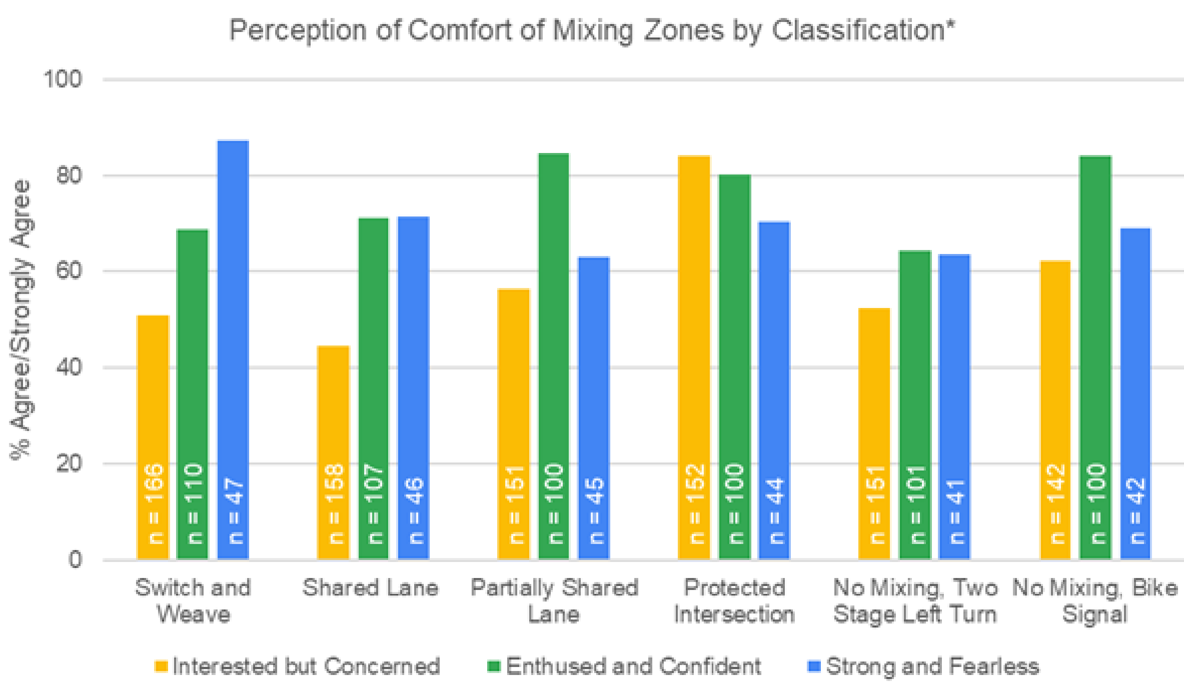


Figure 6.29 Cyclist class perception of comfort per Mixing Zone type

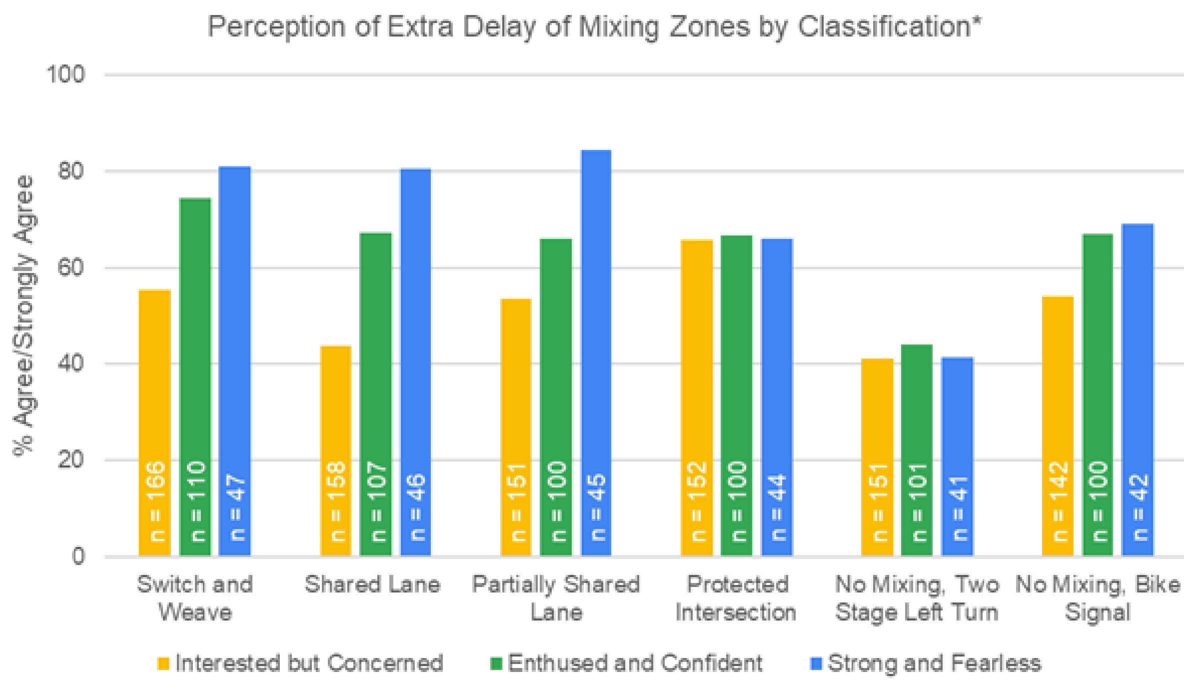


Figure 6.30 Cyclist class perception of extra delay per Mixing Zone type (lower = higher perceived delay)

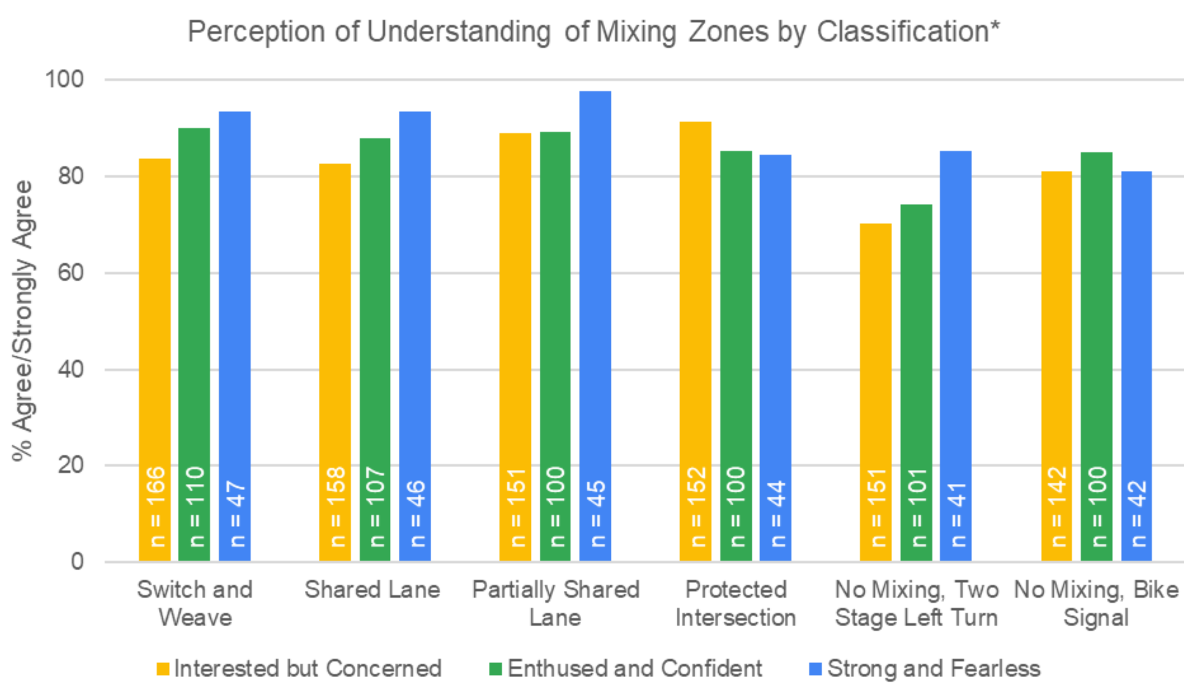


Figure 6.31 Cyclist class understanding of each Mixing Zone type

6.3.2 Mixing Zone Conflicts

Users who indicated familiarity with the mixing zone design were presented with the opportunity to report frequency of various types of conflicts encountered at the particular mixing zone. These conflicts varied with mixing zone design type due to certain conflicts only being possible with certain geometries of mixing zone design. Only users who indicated familiarity with the design received this question, and sample size (N) is reported in each graph below.

The conflicts the respondents reported with the highest frequency were vehicle blockage ("A vehicle did not fully enter the turn lane and blocked my path") and right turn ("A vehicle entering the turn lane cut me off") conflicts at Switch and Weave designs (Figure 6.32). Vehicle blockage and vehicle passing ("A vehicle passed between me and the curb while I was waiting for the light to change") were the most frequent conflicts reported in Shared Lanes (Figure 6.33) Right turn conflicts were reported most frequently for Partially Shared lanes (Figure 6.34), and "I was unable to make a left turn" was reported most frequently for Protected Intersections (Figure 6.35). Left turns were also the most frequent conflict at No Mixing, Two Stage Left Turn designs (Figure 6.36) and right turns were the most frequent conflict at No Mixing with Bike Signal designs (Figure 6.37).

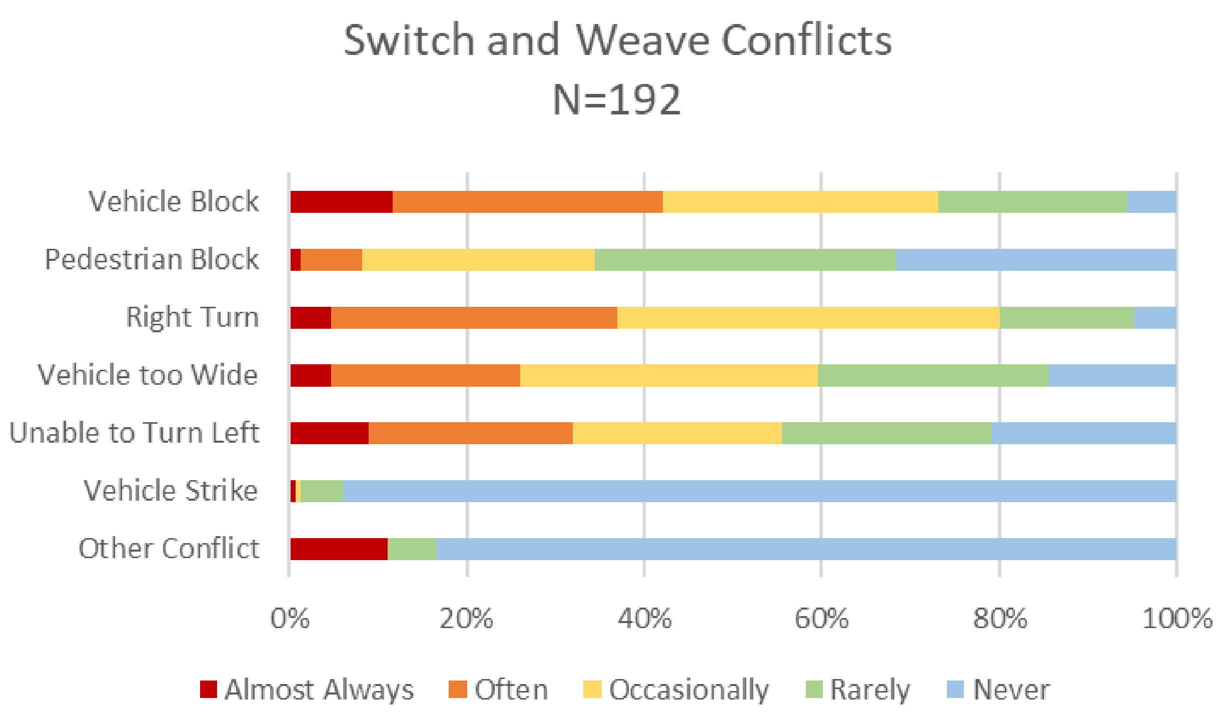


Figure 6.32 Reported conflicts at Switch and Weave Mixing Zones

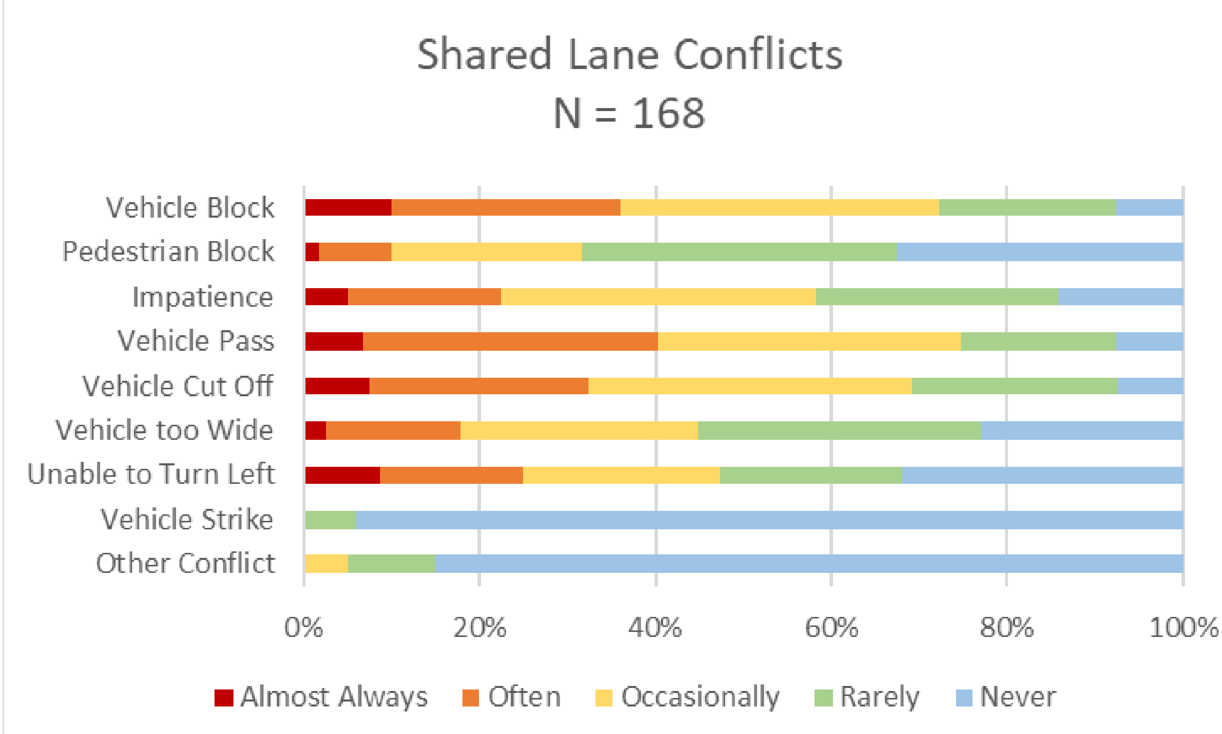


Figure 6.33 Reported conflicts at Shared Lane Mixing Zones

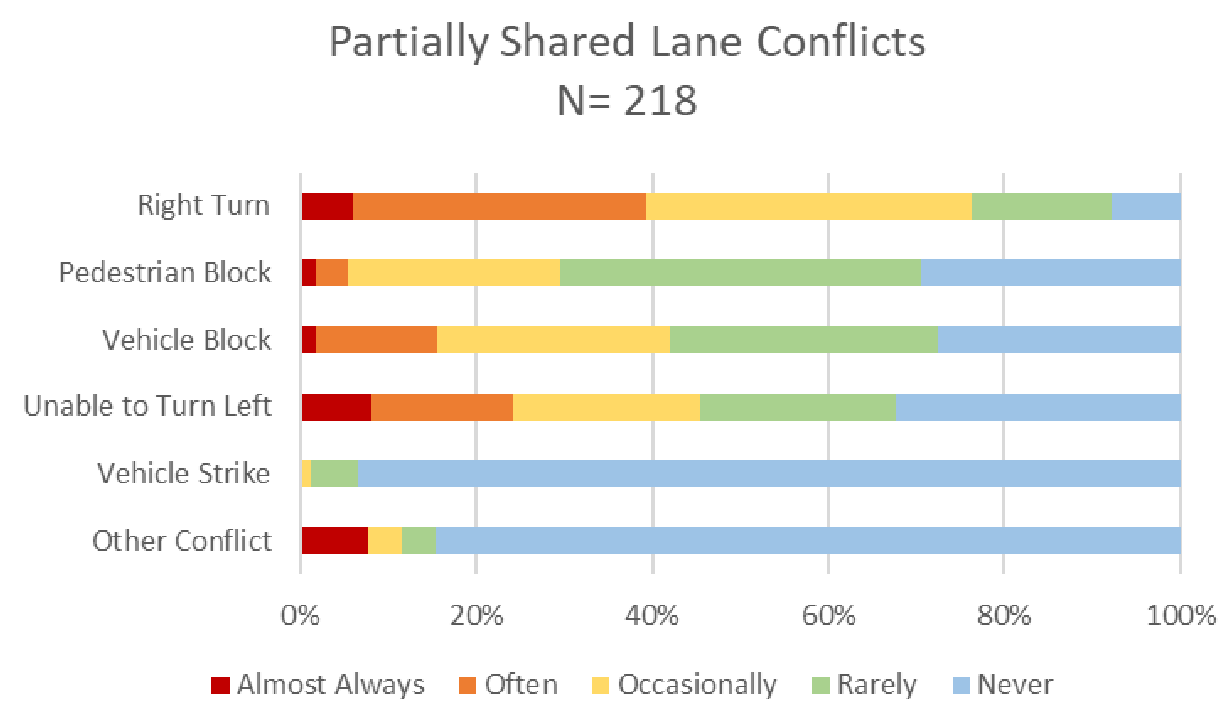


Figure 6.34 Reported conflicts at Partially Shared Lane Mixing Zones

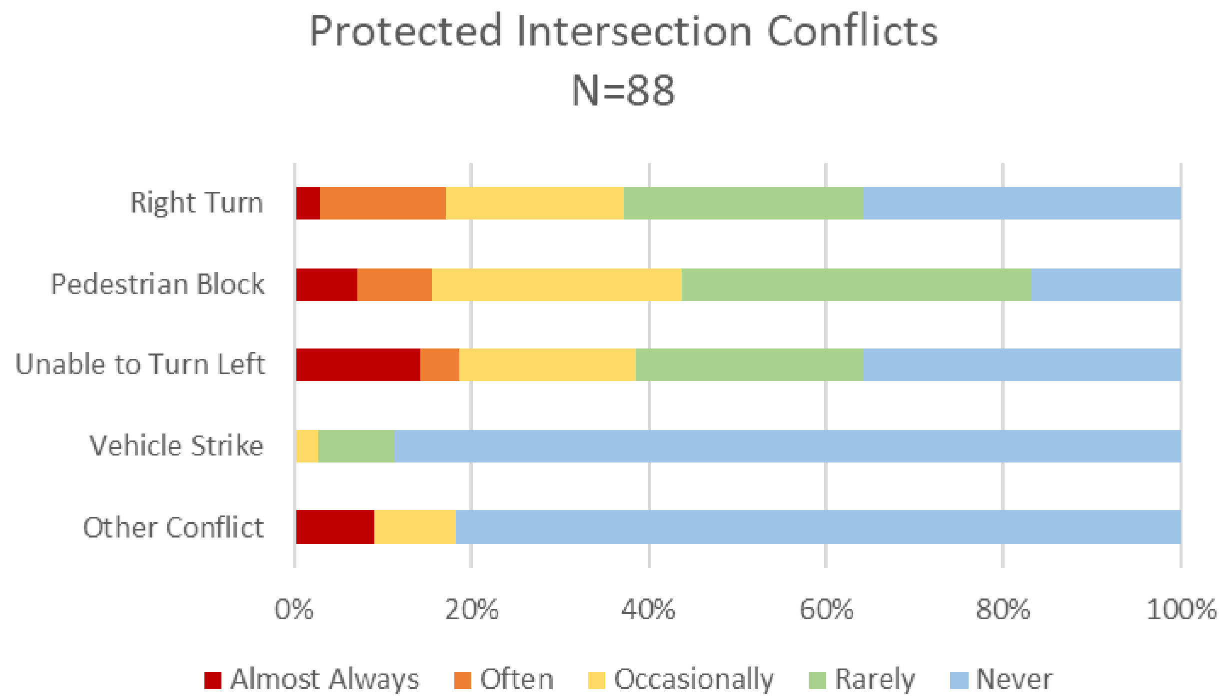


Figure 6.35 Reported conflicts at Protected Intersection Mixing Zones

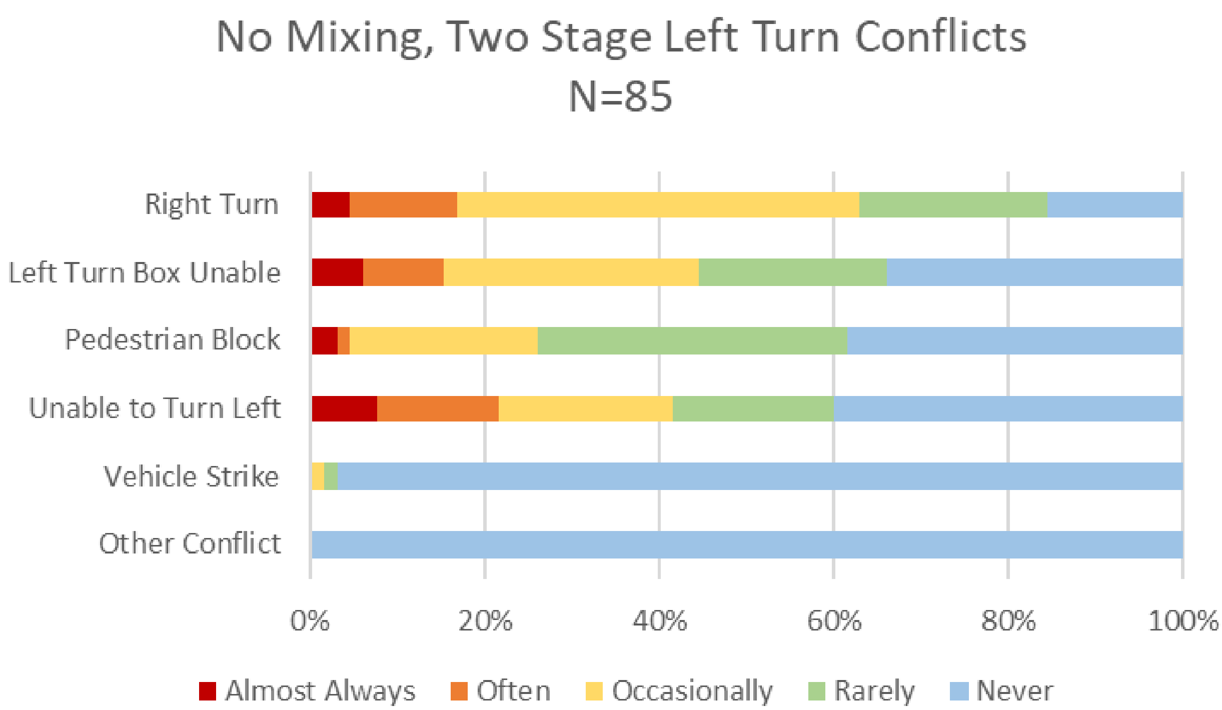


Figure 6.36 Reported conflicts at No Mixing, Two Stage Left Turn Mixing Zones

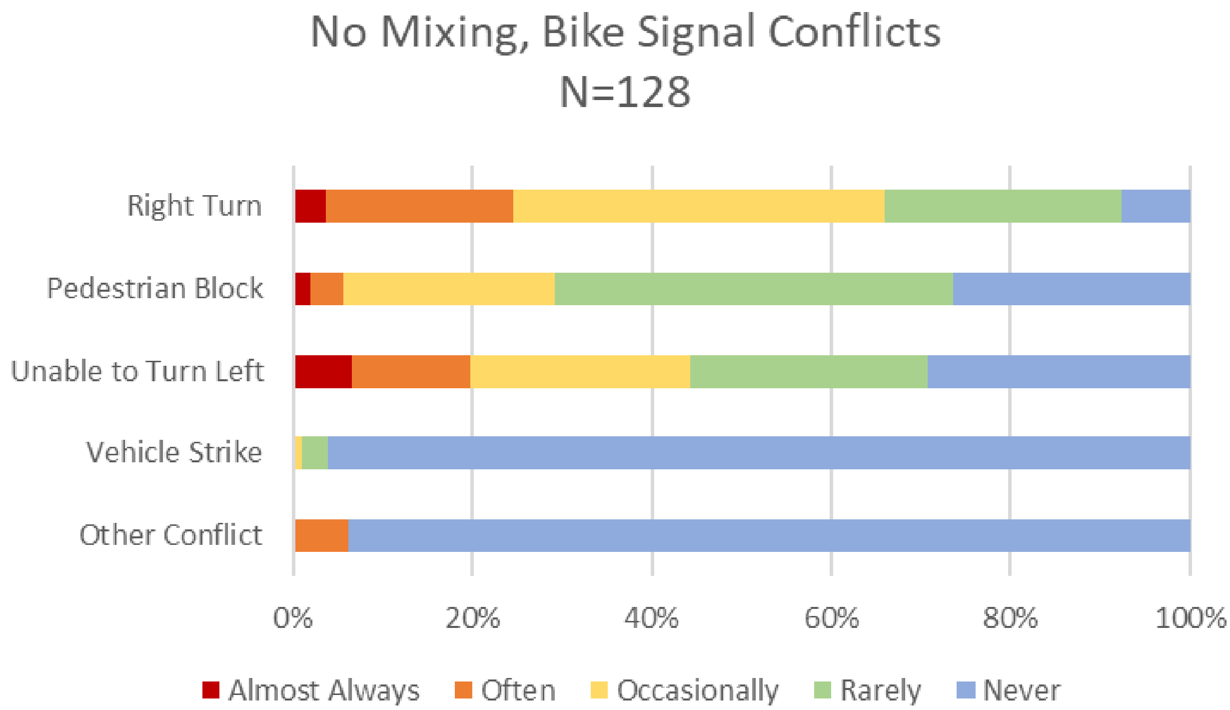


Figure 6.37 Reported conflicts at No Mixing with Bike Signal Mixing Zones

6.3.3 Summary of User preferences on Mixing Zone design

The Protected Intersection design clearly is favored by people who cycle: it ranks highest in perceived safety, comfort, and efficiency, and is one of the two highest in terms of clarity – the measure of how well people who cycle understand how the design is to be used. The problem with the Protected Intersection mentioned most frequently by people who cycle was the inability to make a left turn. This design helps to minimize conflict areas within the street. With respect to tradeoffs, the Protected Intersection has higher installation costs because of the need to install medians and, potentially, new signalization. This design also may have higher maintenance costs because of the need to work around concrete separators when sweeping streets or plowing snow.

The Switch and Weave design and the No Mixing, Two-Stage Left Turn design were perceived least favorably by people who cycle overall, with the Switch and Weave design generally ranking lower on perceived safety and comfort. The Switch and Weave design requires people who drive and people who cycle to change paths, thus creating a conflict zone. People who cycle reported that people who drive frequently do not fully enter the turn lane and thus block the path of those cycling. This design has low installation costs because improvements are limited to striping and involve low maintenance costs because street sweepers and snow-plows used for streets can be used. The No Mixing, Two-Stage Left Turn has the lowest efficiency rating when measured as perceived delay or wait, likely because people who cycle have to go through two light cycles.

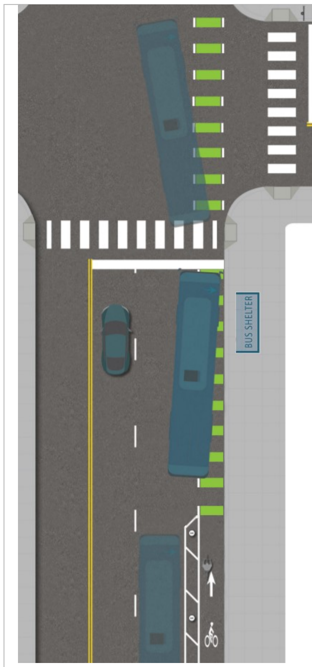
“Strong and Fearless” people who cycle preferred shared or partially shared mixing zones. This outcome illustrates the complexity of considering the preferences of cyclist subgroups in design. This outcome suggests that at intersections where most use is by the “Strong and Fearless” (e.g., perhaps commuters on high volume arterials), shared lanes may be sufficient. Conversely, this design would reduce potential to increase use by the “Enthused and Confident” or the “Interested but Concerned.” Thus, if an objective is to maximize perceived safety and comfort for all people who cycle, the preferences of the “Strong and Fearless” may not be prioritized.

Shared Lanes, Partially Shared Lanes, and No-Mixing, with Bike Signal were assessed comparably by people who cycle in terms of safety, comfort, clarity, and efficiency. People who cycle rated Partially Shared Lanes as the easiest to understand. The most commonly reported problem with both Partially Shared Lanes as well as No Mixing, with Bike Signal was the potential for a right-hook conflict, specifically, that a driver making a right turn might cut off a person who cycles. The Shared Lane design requires people who drive and people who cycle to cross paths, thus creating potential for conflict. As with the Switch and Weave, people who cycle reported people who drive frequently block the shared lane, thereby impeding people who cycle. A frequently reported critique of the No Mixing, with Bike Signal design was the inability to make a left turn.

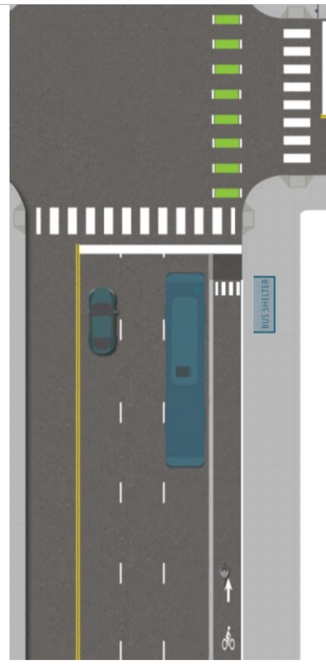
An interesting outcome is the differences in perceptions between the Protected Intersection and the Two-Stage, with Box designs. These two designs function similarly and place similar limitations on the ability of people who cycle to make left-hand turns. Their principal difference is the degree of protection provided to people who cycle when waiting at an intersection. This outcome, which likely is related to the preferences of people who cycle for impermeable dividers for buffer zones, may reflect their preferences to maximize separation.

6.4 BUS STOP DESIGN OPTIONS

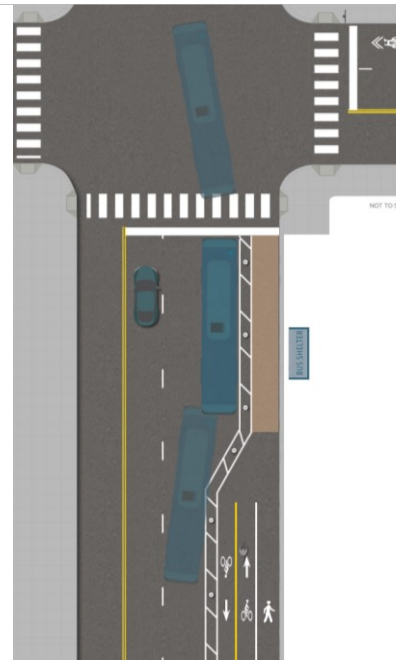
Six types of bus stop designs were shown to respondents (Figure 6.38).



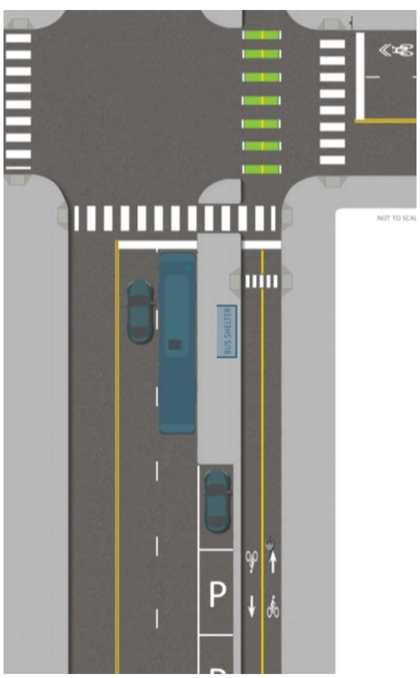
Bus 1: Curbside Bus Stop, One-Way Street-Level Protected Bike Lane



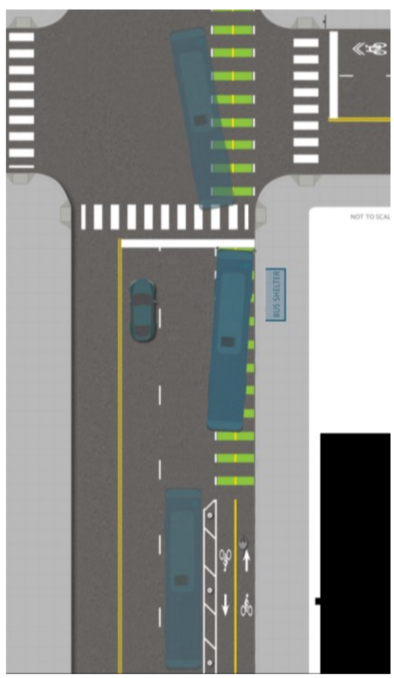
Bus 2: Curbside Bus Stop, One-Way Raised Cycletrack



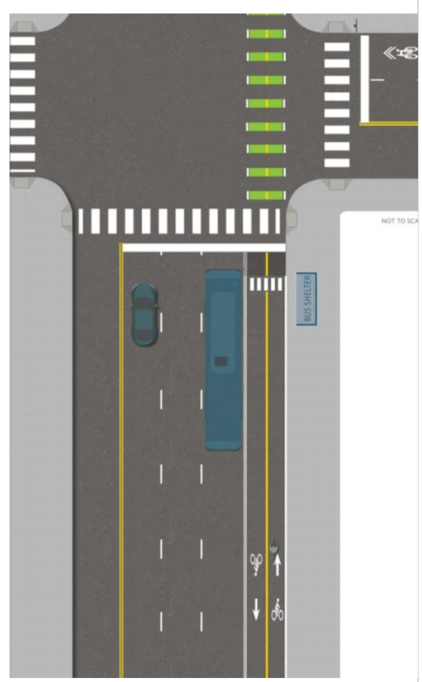
Bus 3: In-Street Bus Stop, Shared Street-Level Protected Bike Lane



Bus 4: Floating Island Bus Stop, Two-Way Street-Level Protected Bike Lane



Bus 5: Curbside Bus Stop, Two-Way Street-Level Protected Bike Lane



Bus 6: Curbside Bus Stop, Two-Way Raised Cycletrack

Figure 6.38 Types of bus stop designs presented to users

Six standard bus stop designs were shown to respondents for assessments of the potential for conflict, safety, comfort and delay. The six designs were: (1)Curbside Bus Stop, One-Way Street-Level Protected Bike Lane; (2) Curbside Bus Stop, One-Way Raised Cycletrack; (3) In-Street Bus Stop, Shared Street-Level Protected Bike Lane/Sidewalk; (4) Floating Island Bus Stop, Two-Way Street-Level Protected Bike Lane; (5) Curbside Bus Stop, Two-Way Street-Level Protected Bike Lane; and (6) Curbside Bus Stop, Two-Way Raised Cycletrack (Figure 6.38). Design images were adapted from FHWA guidance and altered to better show bus and car traffic.

6.4.1 Bus Stop Perspectives

Respondent ratings of safety, comfort, and delay are summarized in Figure 6.39, Figure 6.40, and Figure 6.41. As noted in previous sections, a useful feature of the box plots is that they present mean values and show variability around the means. Inspection of these plots shows that one design – the Floating Island Bus Stop Design – clearly dominates the others. Respondents were more likely to agree this design would be safe, comfortable, and cause no delays, the mean agreement ratings were highest, and there was least variability among responses for all bus stop design alternatives. This result likely is because this design maximizes separation, which, as will be discussed in subsequent chapters, requires more space and may be applicable in fewer situations.

Conversely, Curbside Street Level (both one way and two way) had the largest proportion of respondents disagreeing with the statements about safety, comfort, extra delay and, as will be discussed in a later section, the highest perceived potential conflict with any vehicle type.

The other designs (i.e., Curbside Bus Stop, One-Way Street-Level Protected Bike Lane and the Curbside Bus Stop, Two-Way Street-Level Protected Bike Lane) were rated similarly by people who cycle with respect to the core measures of safety and comfort. This is understandable because the common aspect between these two designs, which also differentiates them from others, is the conflict between the bus as a vehicle and the flow of people who cycle. Because of this mixing of modes, the protection of the buffer is removed to allow the bus to reach the curb. These two designs thus involve the highest level of perceived delay by people who cycle, although with the majority stating indifference rather than strong stated preference.

From the remaining designs, which all involve conflicts only with transit users and retain the bike lane protection with the buffer separation, the Curbside Bus Stop, One-Way Raised Cycletrack and the Curbside Bus Stop, Two-Way Raised Cycletrack rank approximately equally in terms of perceived safety and delay. Between these two, the one-way version presents a little higher variability in terms of comfort. A hypothetical explanation for this difference can be the additional comfort and possibility of avoidance of conflicts resulting from the wider width of the two-way bike lane.

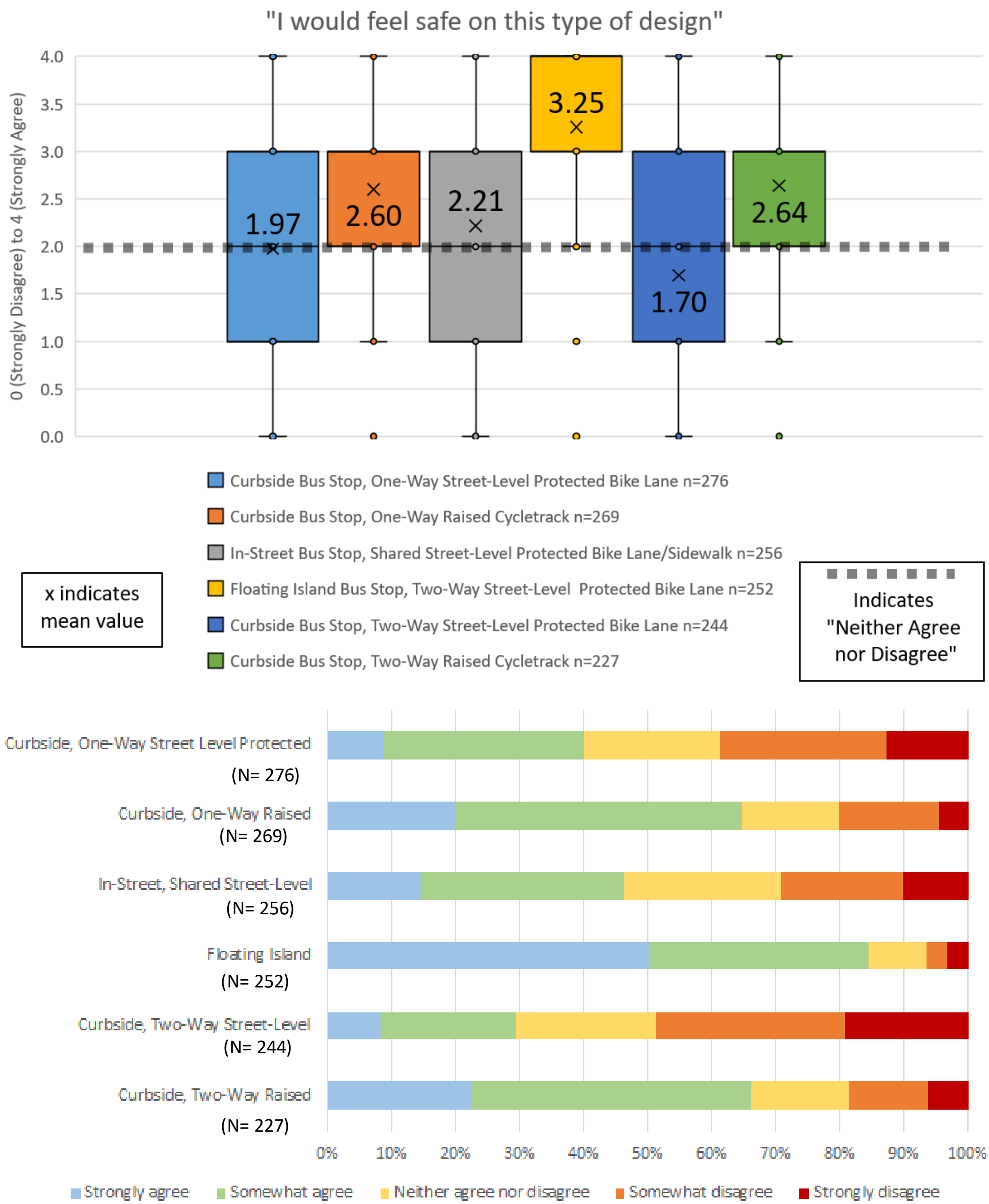


Figure 6.39 User perception of safety per types of bus stop designs

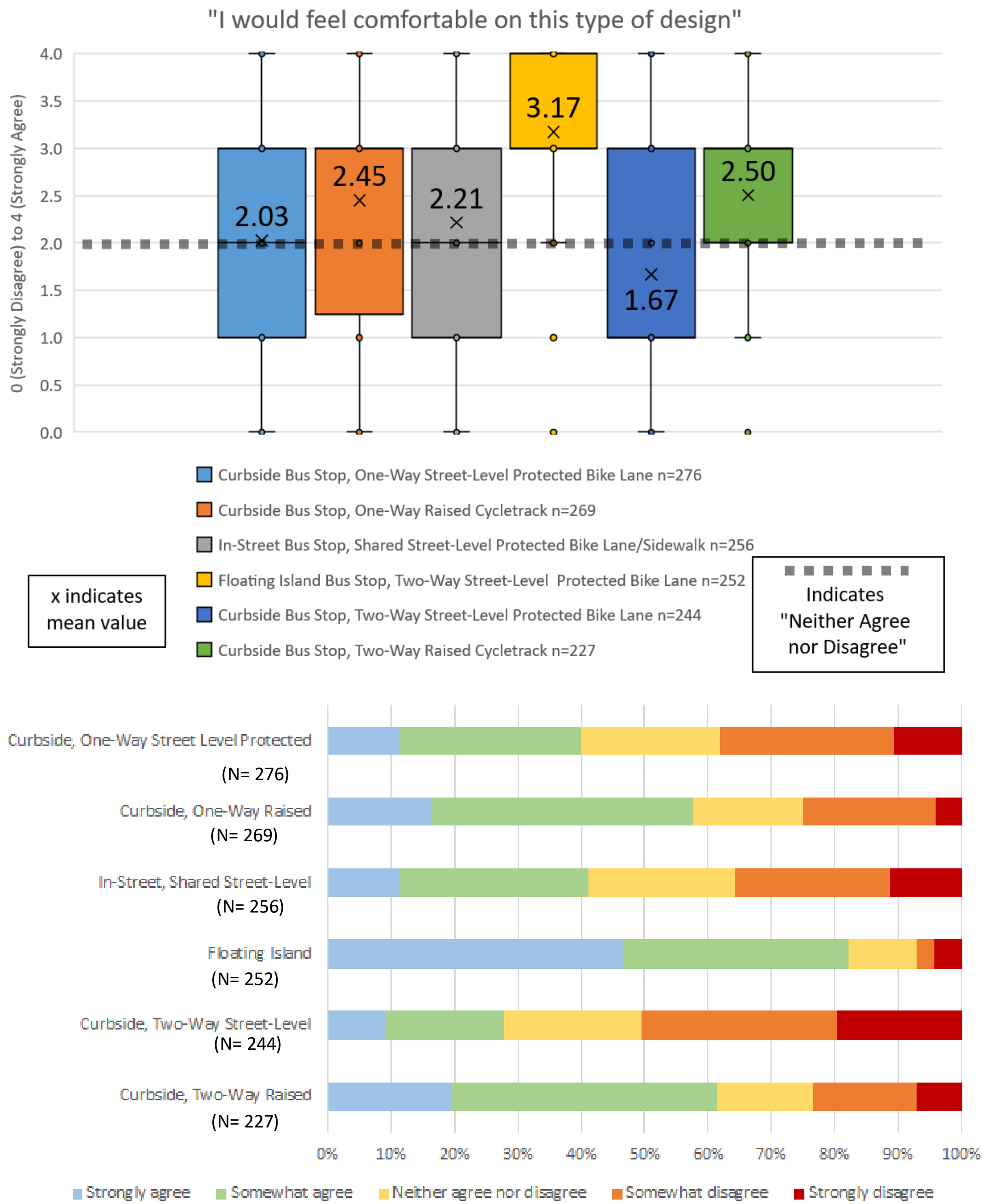


Figure 6.40 User perception of comfort per types of bus stop designs

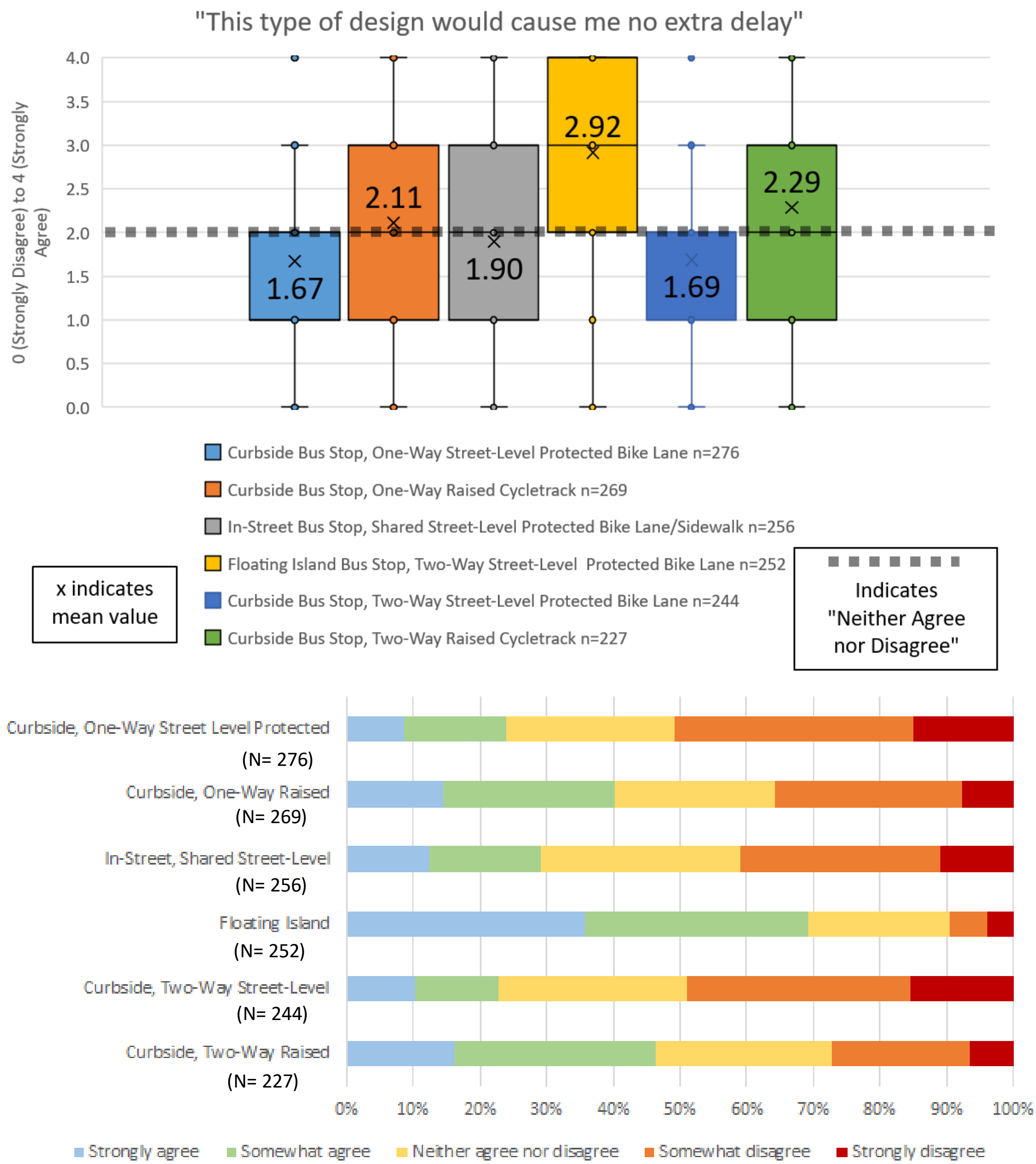


Figure 6.41 User perception of extra delay per types of bus stop designs

Figure 6.42 summarizes the respondents' perspectives on bus stop design with respect to safety, comfort, and delay. As noted previously, the Floating Island bus stop, which is the most capital-intensive design, provides the greatest separation and clearly dominates the other terms with respect to these designs. The Curbside-Two-Way Raised and the Curbside One-Way Raised designs are rated comparably and higher on all dimensions that the remaining three designs.

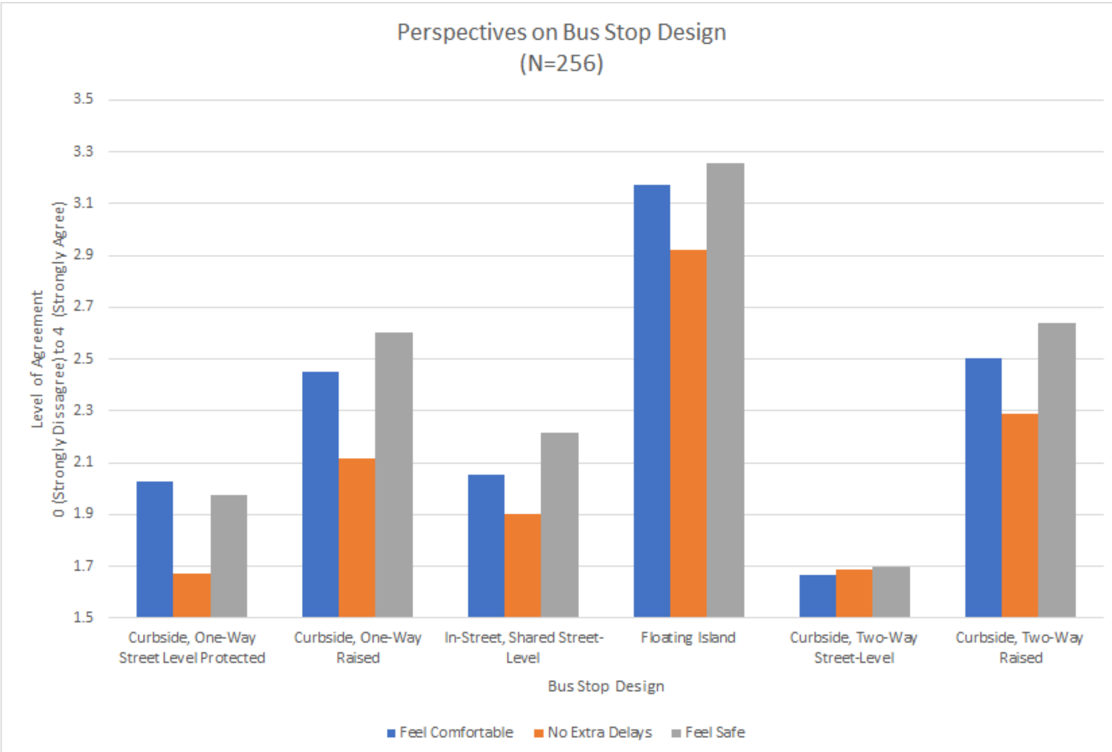


Figure 6.42 Average user level of agreement for perception of safety, comfort, and extra delay per type of stop

6.4.1.1 Ratings of Safety, Comfort, and Delay by Gender and Age Group

The ratings of safety, comfort, and potential for delay by gender and age show the same general patterns as the overall assessment. Graphs are mostly omitted for the sake of brevity and can be found in the Appendix. In general, the results reflect remarkably little difference between genders, but indicate that younger people who cycle (i.e., Millennials) are most likely to agree the designs are safe and comfortable. Specifically, both genders and all age groups agreed the Floating Island design was most safe, most comfortable, and would not cause extra delay. Their preference ordering followed the same patterns as noted in the preceding discussion. For the three top-ranked designs, the differences in responses by males and females were extremely small, with the largest differentiation shown on the subject of extra delays (Figure 6.43). While younger people who cycle (i.e. Millennials) as a group rated almost all bus stops designs as both more safe and comfortable, the highest among all age groups, the pattern did not hold for perception of potential delays. Younger people who cycle were less likely than middle and older age respondents to agree the designs would not cause delays in four of six cases (Figure 6.44).

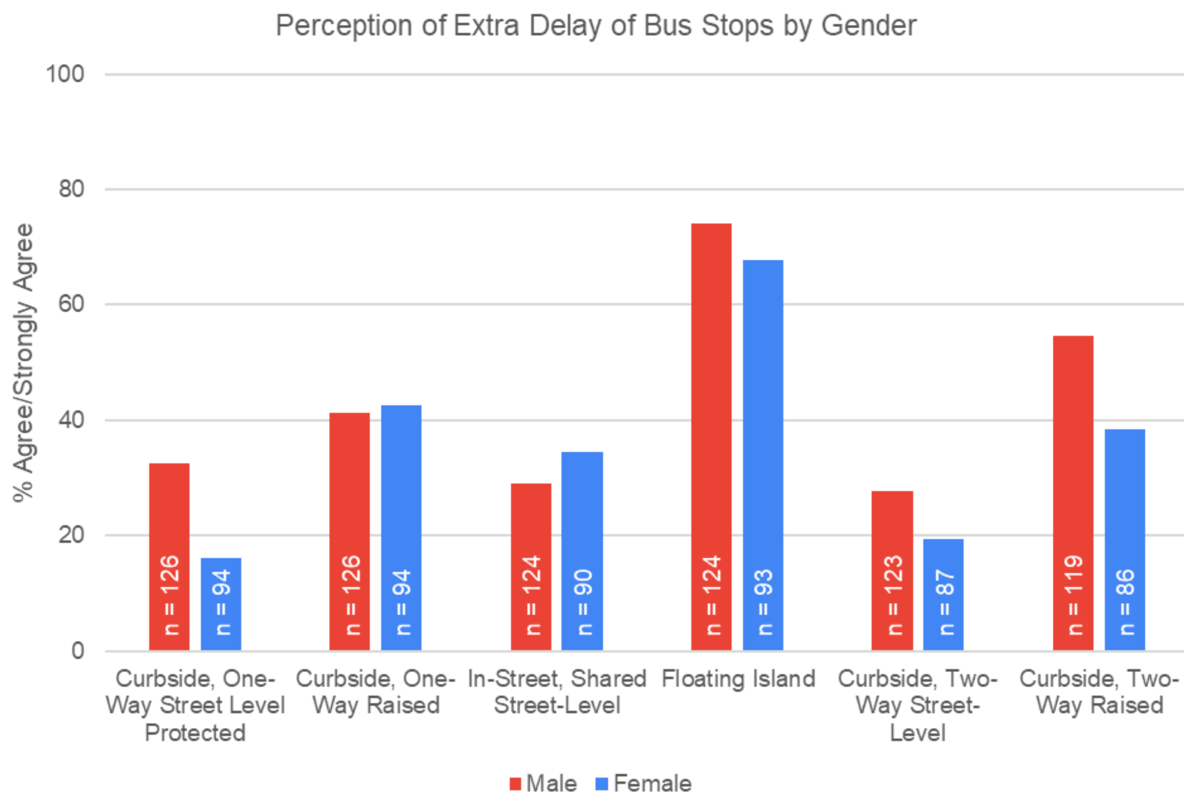


Figure 6.43 Perception of extra delay per types of bus stop designs separated by gender

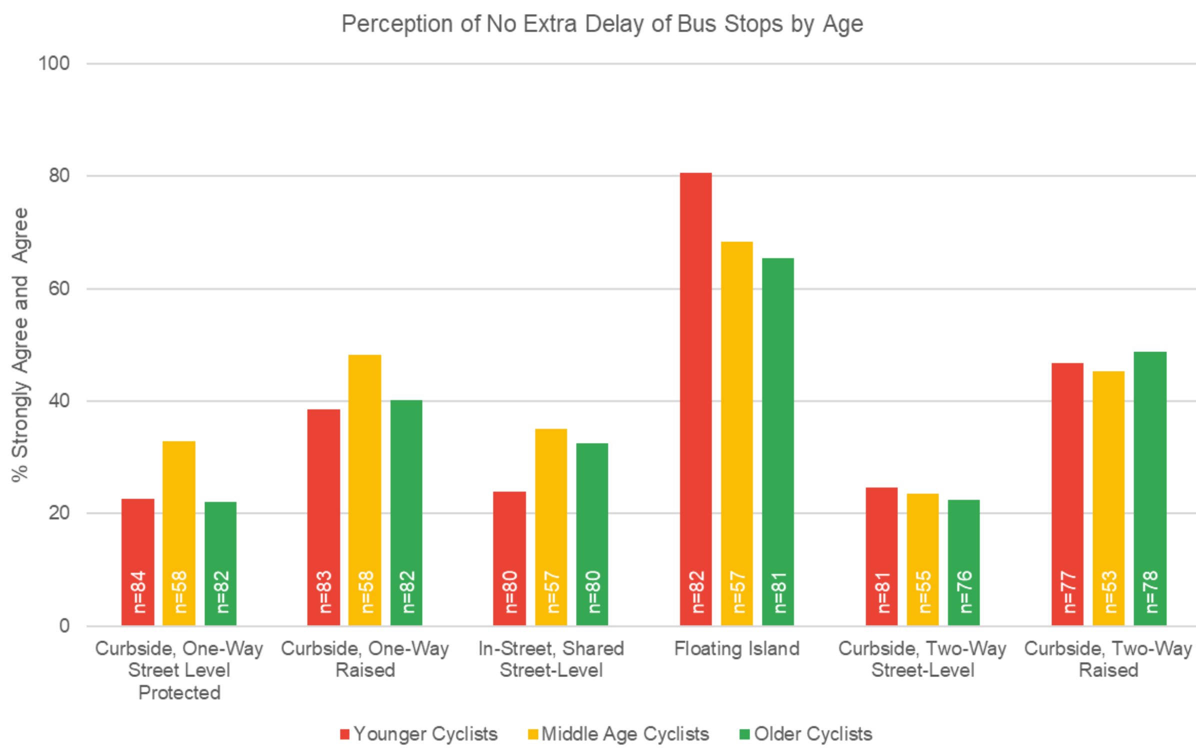


Figure 6.44 Perception of extra delay per types of bus stop designs separated by age group

6.4.1.2 Ratings Safety, Comfort, and Delay by Cyclist Classification

The ratings of safety (Figure 6.45), comfort (Figure 6.46), and potential for delay (Figure 6.47) by cyclist classification show the same general patterns as the overall assessment. Perceptions of safety and comfort were nearly identical so only one of the two graphs is included. As with buffers and mixing zones, the more separation of the design, the less the "Strong and Fearless" groups preferred it. "Interested but Concerned" as well as "Enthused and Confident" people who cycle ranked the Floating Island design as the most comfortable, safest, and least likely to cause extra delay; though Floating Island was ranked the highest by "Strong and Fearless" people who cycle, both the Curbside One- and Two-Way Raised designs were ranked nearly as safe and comfortable as Floating Island.

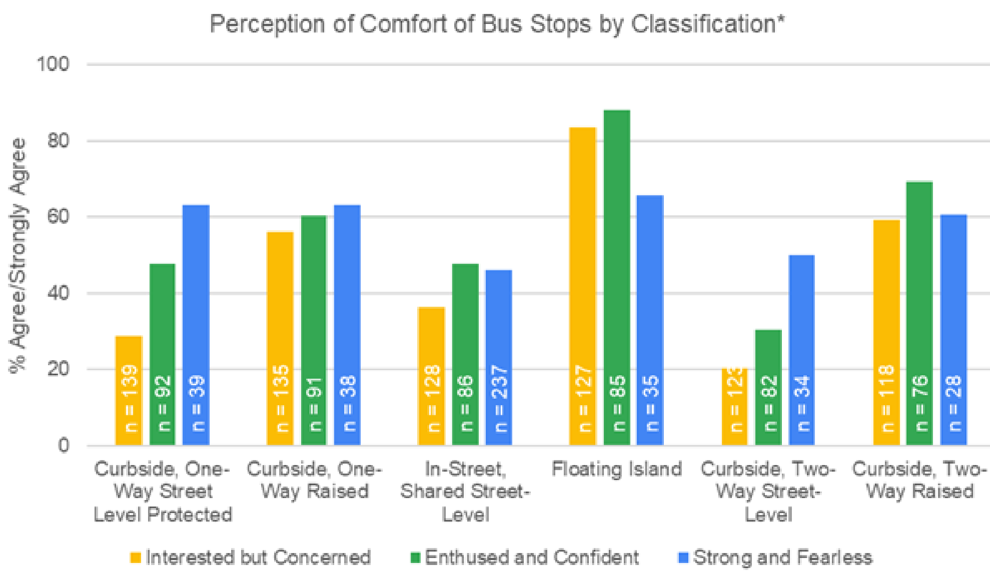


Figure 6.45 Cyclist class perception of comfort per Bus Stop design

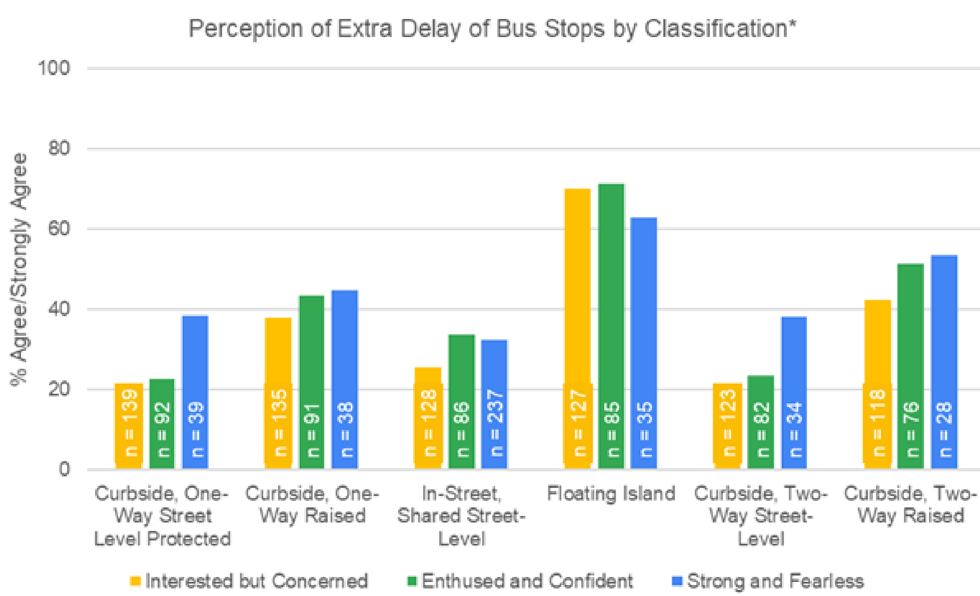


Figure 6.46 Cyclist class perception of extra delay per Bus Stop design (lower = higher perceived delay)

6.4.2 Bus Stop Conflicts

As with Mixing Zones, respondents who indicated familiarity with the design were asked to report if they had experienced conflicts at the Bus Stop designs. Those who indicated they had experienced conflicts were then asked to report which transportation modes they had conflicted with. The "Curbside, One-Way Street Level Protected Bus Stop" design by far had the most reported conflicts (N=90), with the majority of reported conflicts being between people who cycle and busses or other vehicles (Figure 6.47). Pedestrian conflicts were the largest percent of reported conflicts for Curbside One-Way and Curbside Two-Way Raised bus stop types (Figure 6.47).

All respondents received the question "Do you agree with the following statements about this bus stop design? This type of bus stop creates potential for conflicts: between cyclists and buses, between cyclists and vehicles other than buses, between cyclists and pedestrians." Figure 6.49, Figure 6.50 and Figure 6.51 show responses for the perceived level of each type of conflict at each type of bus stop. The Curbside One-Way Street Level and Curbside Two-Way Street Level designs were perceived as the most prone to bus or vehicle conflict, while the Curbside One-Way Raised design as perceived as the most prone to pedestrian conflicts.

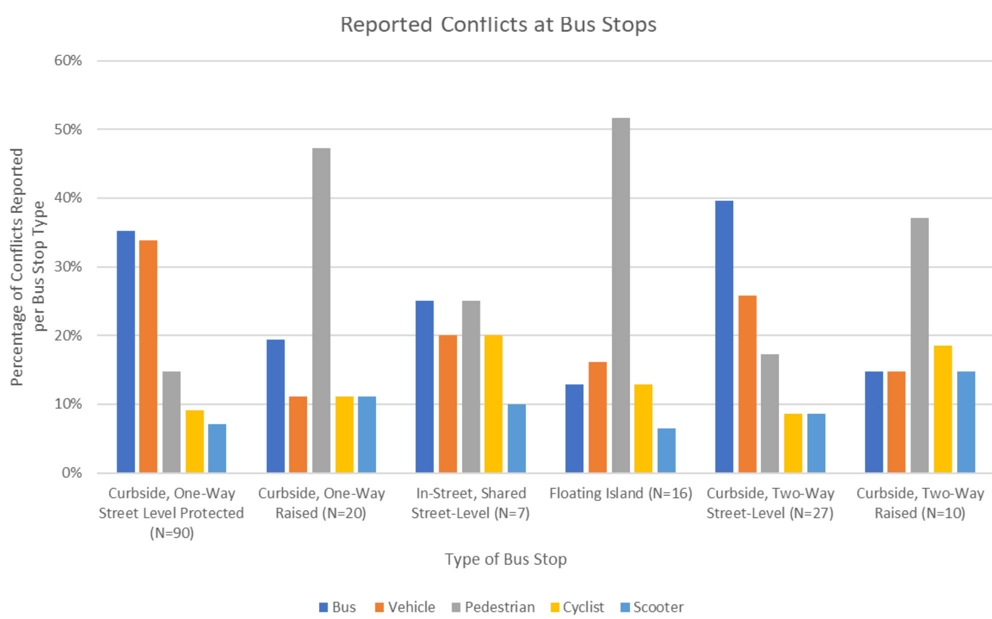


Figure 6.47 Percentage of reported conflicts per bus stop type

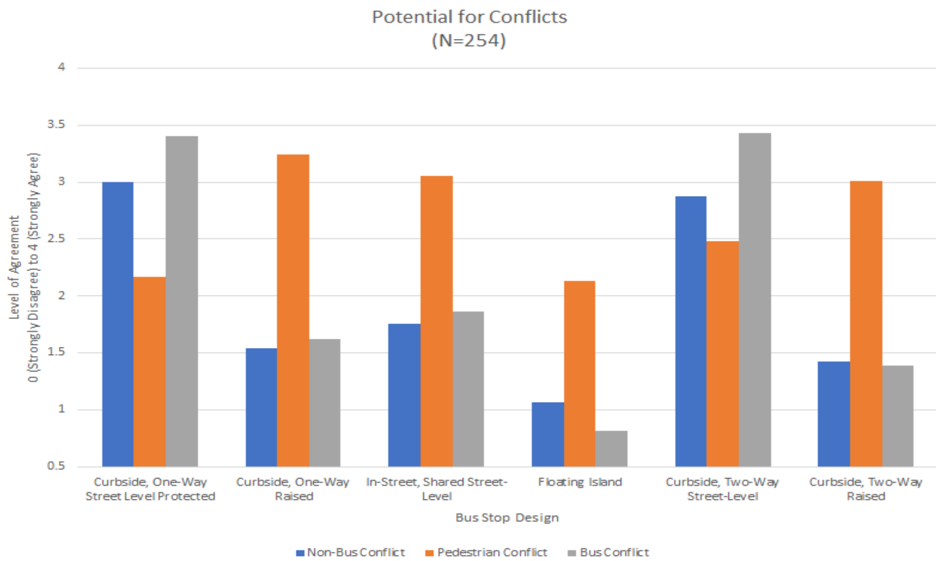


Figure 6.48 Average user level of agreement for perception of types of conflict per type of stop

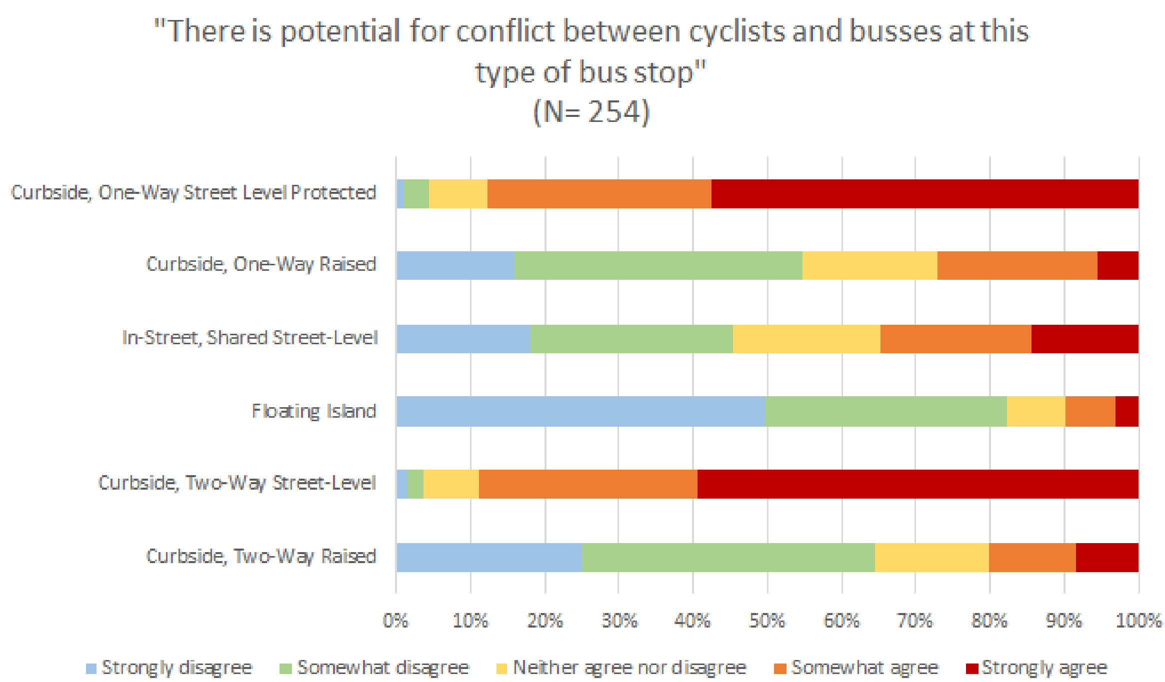


Figure 6.49 User perception of potential for conflict per types of bus stop designs between cyclists and busses

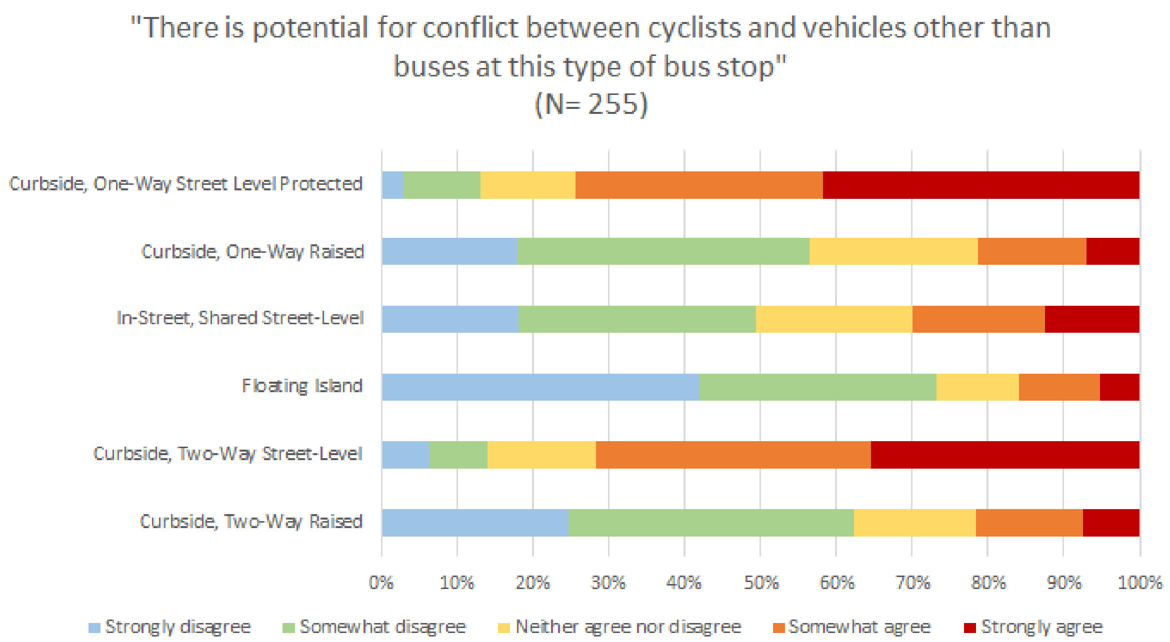


Figure 6.50 User perception of potential for conflict per types of bus stop designs between cyclists and vehicles other than busses

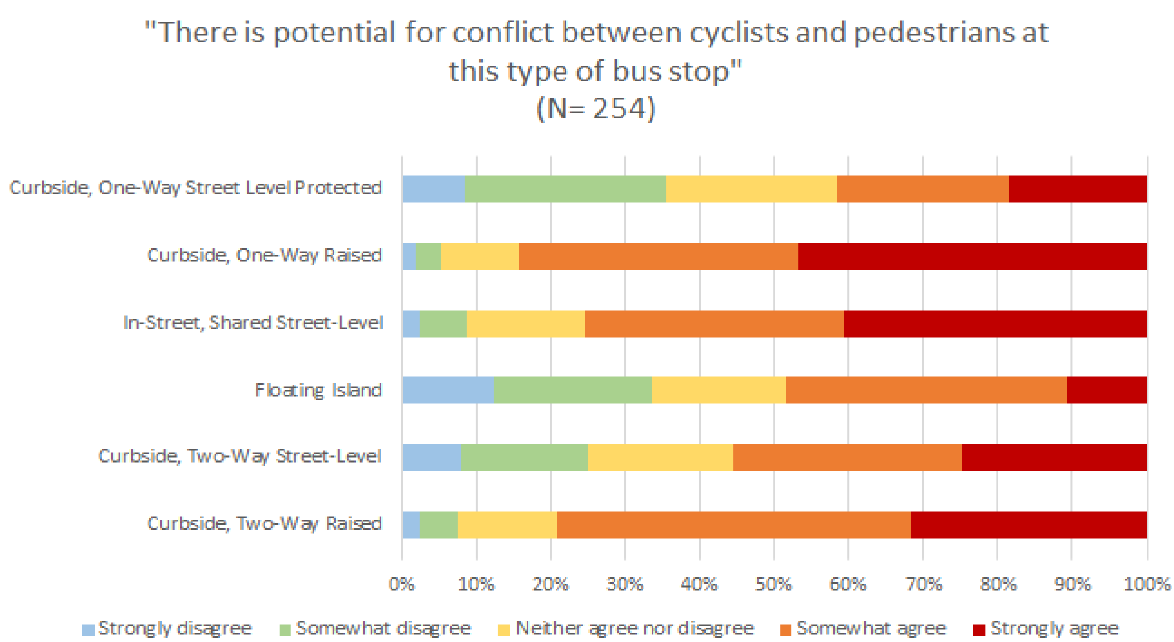


Figure 6.51 User perception of potential for conflict per types of bus stop designs between cyclists and pedestrians

6.4.3 Real World Bus Scenario

To connect the abstract illustrations of bus stops to real world scenarios, users were presented with the image in Figure 6.52. People who cycle were asked what they would do if they were the person in yellow cycling in this situation. This question was not required to be answered before proceeding, so two users did not respond. The highest proportion of respondents said they would "yield and wait", with the next highest reporting that they would "ride ahead in the bike lane" (Figure 6.53).

Figure 6.52 Generated image of bus stop conflict shown to users

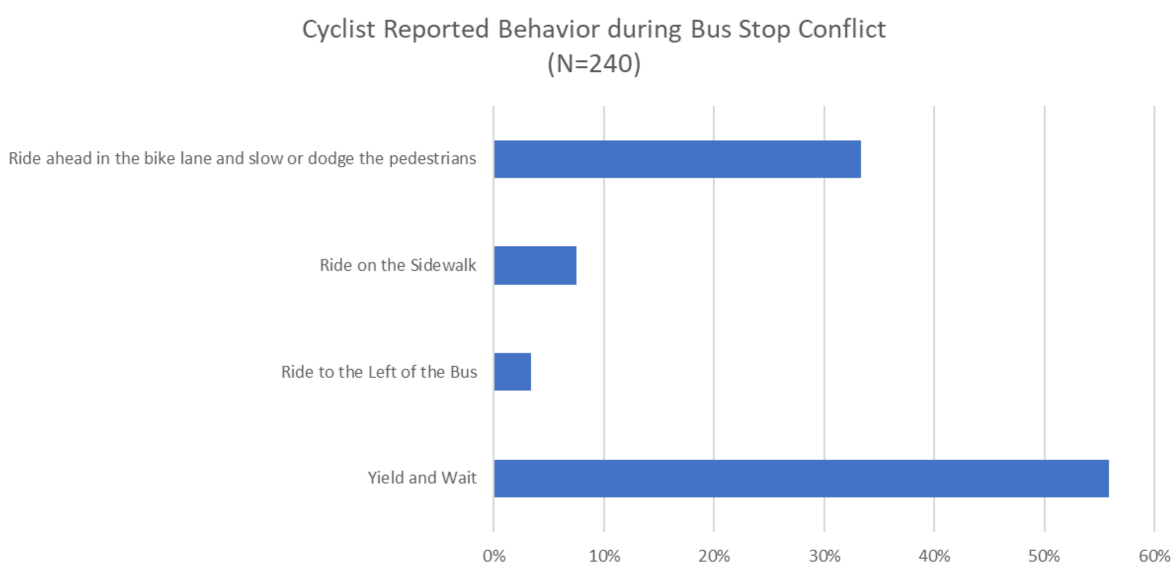


Figure 6.53 Reported user behavior during theoretical bus stop conflict

CHAPTER 7: WINTER DESIGN AND MAINTENANCE CONSIDERATIONS

One of the priority subjects identified by the TAP was the design, operation, and maintenance of SBLs for bicycle use during the winter season. Although in the earlier sections, the subject of winter conditions was approached in regards to the three main structural elements of buffer separation, mixing zones, and bus stops, the more foundational questions are, “How many people are interested in riding a bicycle in the winter?” and “What are the design and operation elements that influence the choice to ride in winter.?” This chapter presents the results collected from the user survey on the subject.

Only bikers who indicated they biked during the winter received this section. Respondents were first asked “What winter condition is most likely to cause you to cancel rides?” As seen in Figure 7.1, icy road condition was the by far greatest reason for cancelling, followed by snow depth and cold. This is an interesting piece of information because icy roads are directly related to scheduled, recurring maintenance efforts, compared to snow depth which is more related to quick response after a snowfall.

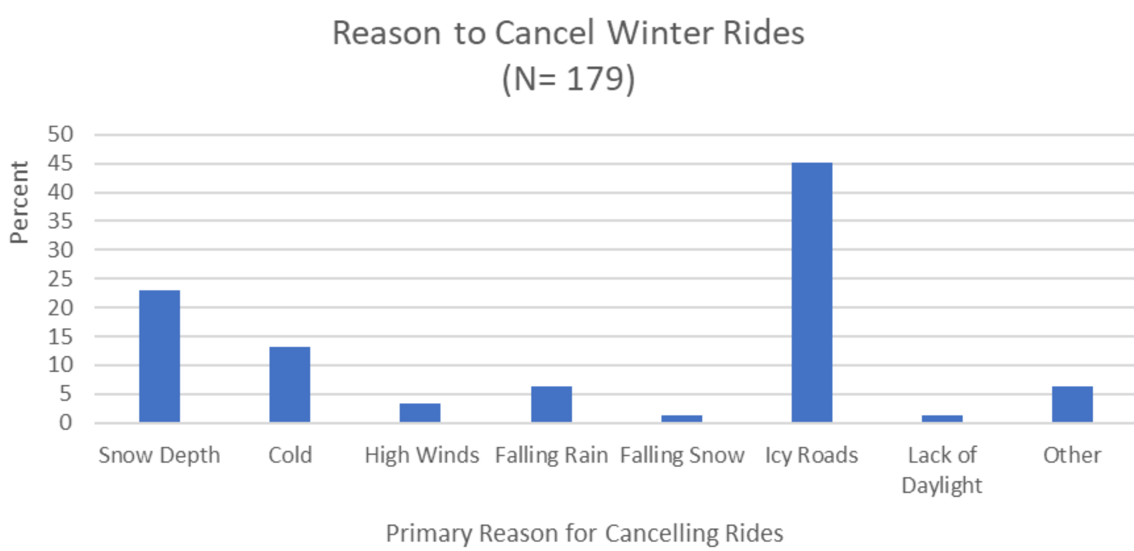


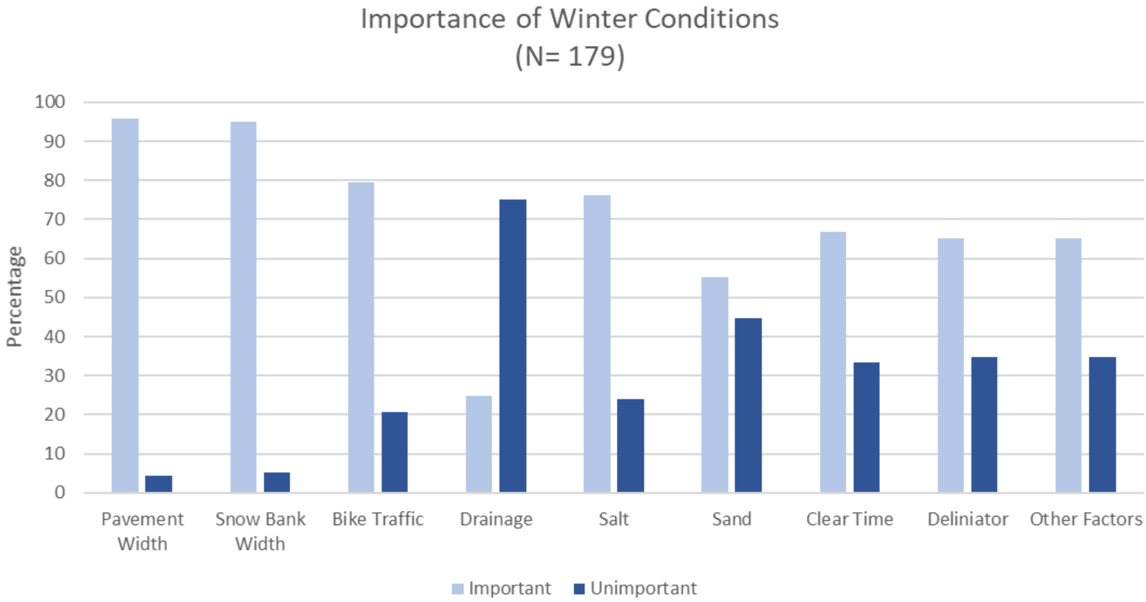
Figure 7.1 Winter conditions causing cyclists to cancel rides

Respondents were then asked to rate the importance of (Figure 7.2) and satisfaction with (Figure 7.3) winter conditions where they live. All factors except drainage were rated as “Important” by the majority of respondents, while the majority of respondents indicated they were “dissatisfied” by all factors where they live.

“Other” factors written in by respondents included:

- Snow and ice removal concerns
    - Patchiness of clearance
    - Quality of clearance
    - Clearance in intersections specifically

- Build up and mounding of snow and ice from previous weather and plowing
    - Roads are cleared but paths are not
- Debris
    - Removal of debris and broken glass
    - Salt and sand accumulation
- Potholes



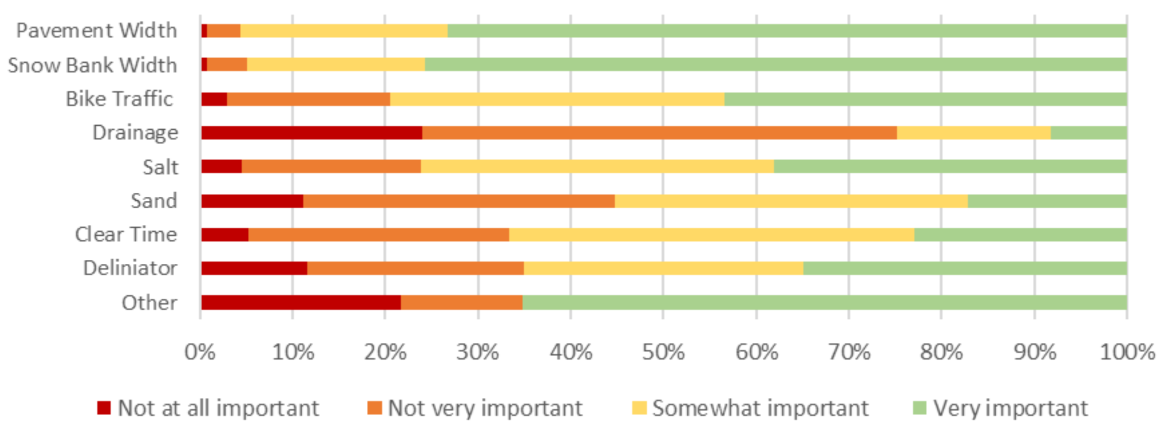


Figure 7.2 Importance of SBL Winter Conditions attribution by winter cyclists

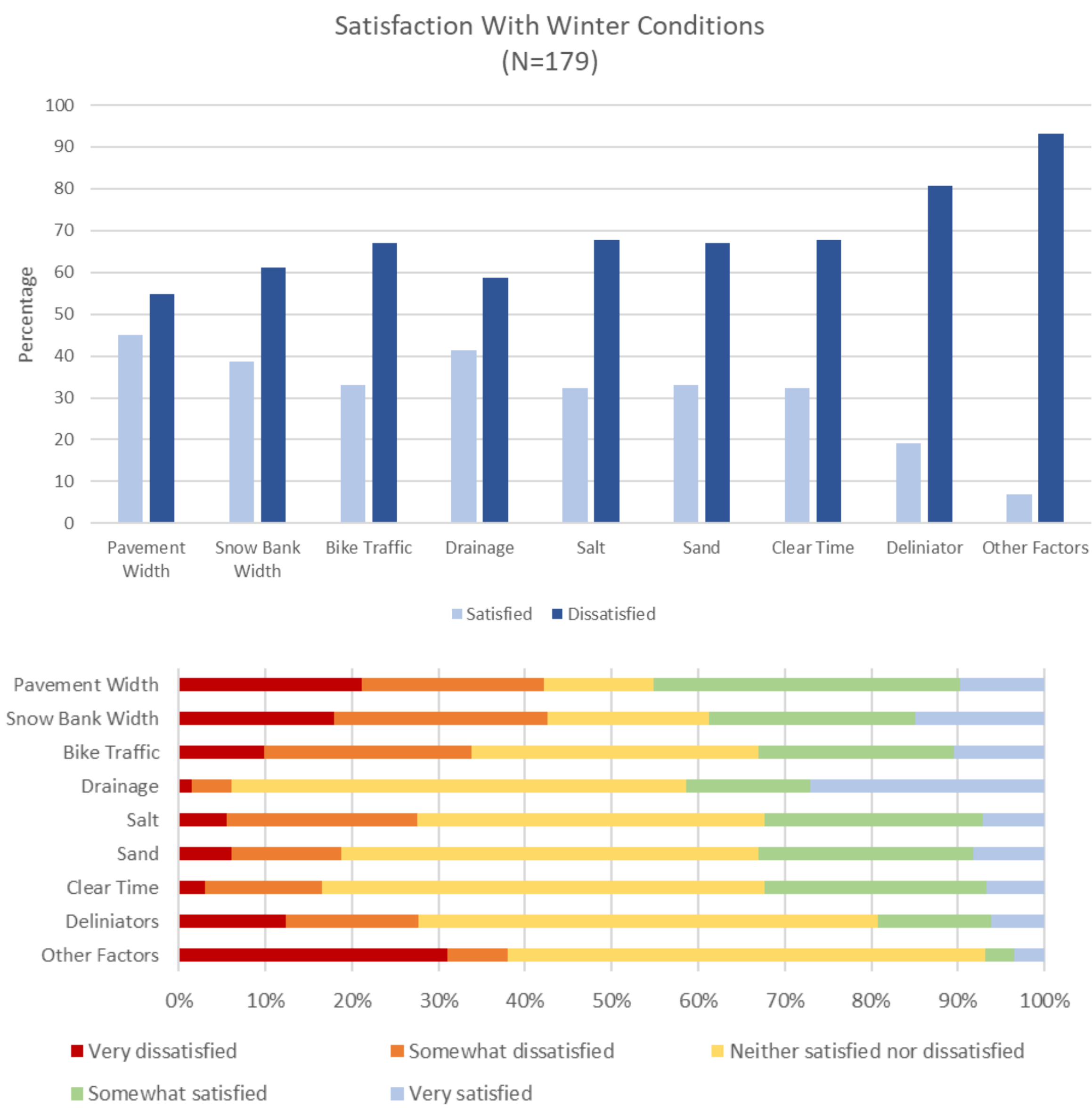


Figure 7.3 Satisfaction with experienced SBL Winter Conditions reported by winter cyclists

The ranked satisfaction and importance of each factor on a scale from zero to four (very dissatisfied to very satisfied) and zero to three (not at all important to very important) were plotted (Figure 7-3). Delineator type, other factors as listed above, and cleared pavement width were all revealed as areas to focus on.

To further explore the satisfaction and importance rankings and identify priority areas for improvement, Importance-Performance Analysis (IPA) was also performed on the winter factors. Importance-performance analysis, or IPA, is used to gauge how satisfied people are with the quality of service they have received and the relative importance of certain characteristics of a place, issue, or program. To construct IPA data plots, mean importance and satisfaction scores for identified individual attributes or an index of multiple attributes are both plotted on a two-dimensional scale grid which form a four-quadrant matrix (Figure 7.4). This matrix can be used to inform prioritization and decisions about different attributes.

Overall, it is recommended to focus on increasing the satisfaction of characteristics that have a high importance score and a low satisfaction score (items that fall into the “Concentrate Here” quadrant) and maintaining the satisfaction of items with both a high importance score and a high satisfaction score (items that fall under the “Keep Up the Good Work” quadrant). The research team wanted to see if implicit importance ratings would reveal more factors to prioritize, or underscore stated importance findings. Towards that goal, Importance and Satisfaction Indexes were generated by determining the correlation between all variables and the frequency of winter ridership (Figure 7.5).

Figure 7.4 Winter Factors Satisfaction and Importance (N=179)

The results (Figure 7.4, Figure 7.5) were consistent: both indicated the need for appropriate delineator type as well as maintain width between snowbanks.

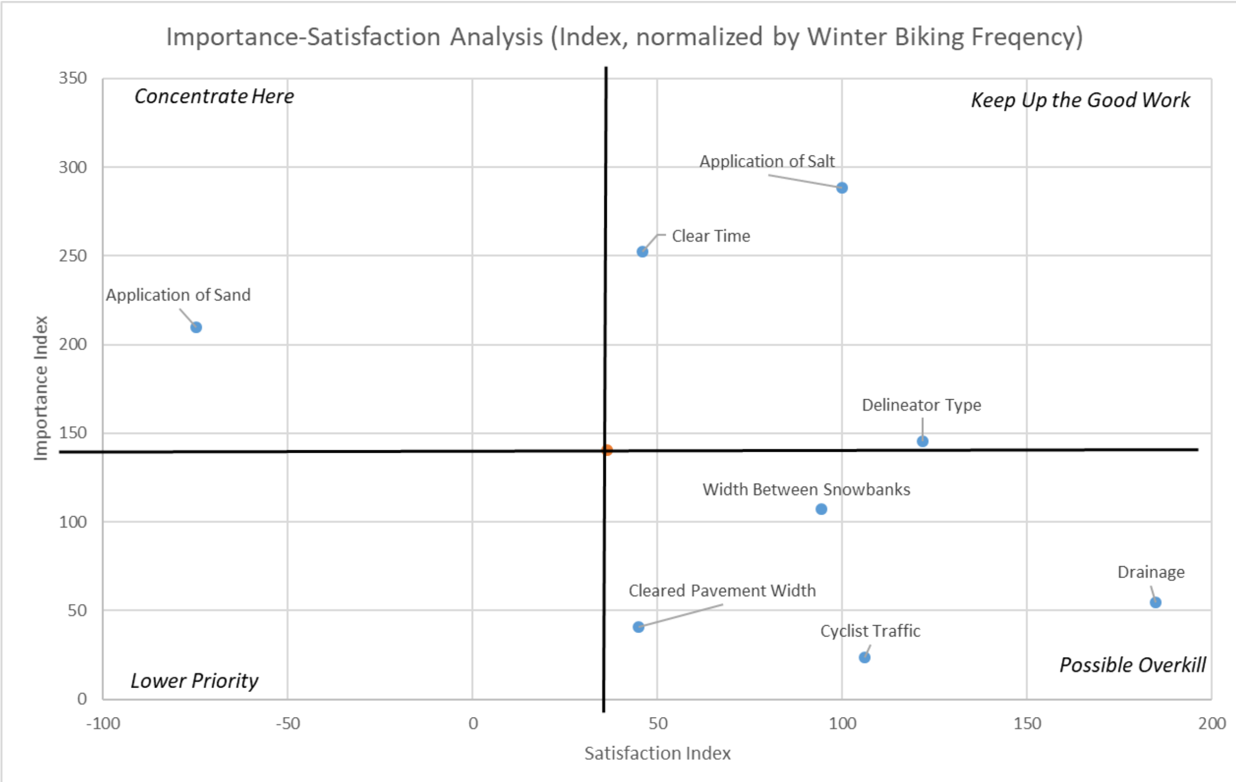


Figure 7.5 Importance Performance Matrix (n=179)

7.1 WINTER BIKE LANE MAINTENANCE SURVEY DATA ANALYSIS

The TAP also prioritized collection of information about user preferences for winter maintenance of SBLs to inform development of guidelines for design, operation, and maintenance. As mentioned previously in this report, fewer respondents cycle during the winter, but the proportion of respondents who indicated they would like to cycle more in the winter was higher than the proportion who indicated they would like to increase summertime cycling frequency. While this outcome clearly reflects the fact that fewer respondents now cycle in the winter, it is an indication there is latent demand for winter cycling.

Respondents identified icy roads, snow depth, and cold as the main reasons they do not cycle in the winter (Figure 7.1). They also identified cleared pavement width, types and spacing of delineators, and use of sand and/or salt as important maintenance considerations, and they generally indicated dissatisfaction with current levels of maintenance. Consistent with these responses, management of snow and ice on SBLs is a primary concern for winter maintenance. To provide insight into the perspectives of people who cycle with respect to winter maintenance, the research team incorporated a visual preference section within the larger survey. Visual preference surveys are surveys used by planners and engineers to assess preferences for different phenomena, including landscapes, features of the built environment, or variations in particular features of the landscape or built environment. In some cases, respondents are asked to rate images on Likert-type scales. In other applications, respondents are asked to express preferences between photographs in which particular elements of the photograph differ or have been modified. In these latter types of applications, the stated preferences of respondents are analyzed statistically and correlations with different elements in the photographs are noted. For example, respondents might be asked to state preferences for cycling along the same street with two different types of bike lanes, and their responses would be correlated with the design element of the bike lanes.

In this application, the research team prepared pairs of photographs that reflected different levels of winter maintenance and asked respondents to state their preferences between the two images. To explore preferences for winter maintenance and, specifically, preferences to which degree of cleared snow and ice from the SBL during maintenance, a randomized question block was included in the survey. Each person surveyed was asked 10 questions containing a random pairing of two images showing the same location under different riding conditions. Figure 7.6 shows the introductory page to this survey section where the important features of the images are highlighted and explained. An example of one random question is shown in Figure 7.7. Two inquiries were made, one regarding safety and the second regarding comfort.

The following image illustrates the differences to look for in each set of images: barrier type (solid or intermittent), pavement condition (clear, snowy or icy), pavement cleared width, and cyclist traffic.

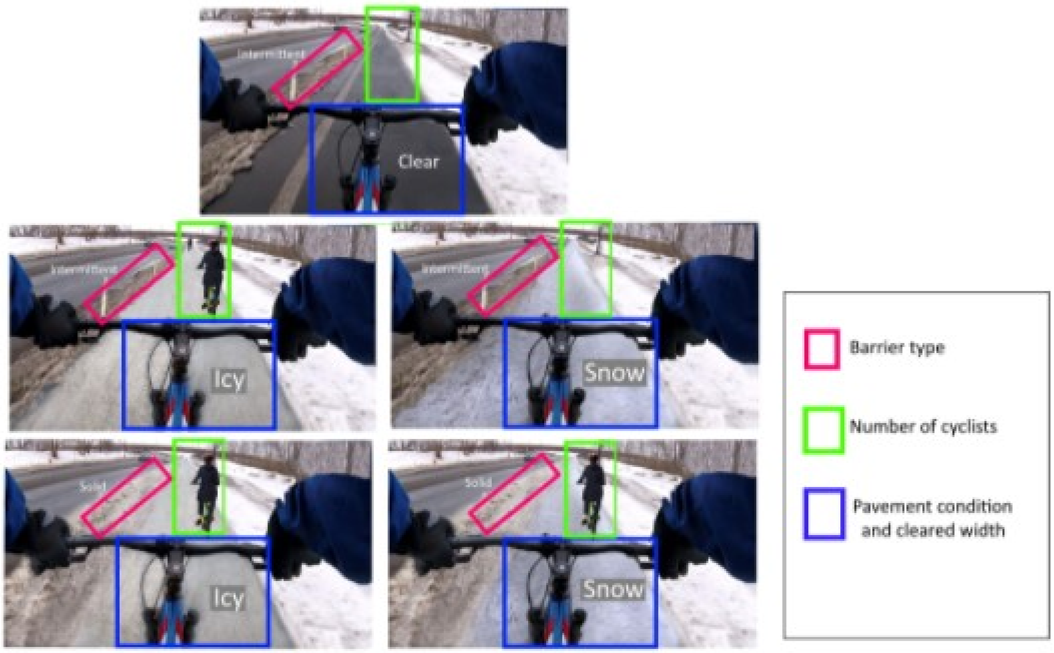


Figure 7.6 Introductory page for the winter conditions block of random questions.

The photographs were designed to explore three dimensions of winter maintenance. The first dimension is the level of coverage by ice and snow of the lane surface. This dimension was defined by the following levels: Entirely clear (i.e., all pavement; base condition), 25% Ice coverage, 50% Ice coverage, 100% Ice coverage, and 100% Snow coverage. The 100% Ice and 100% Snow images were included to differentiate between conditions where traction is severely impaired (ice or days old compacted snow) and less impaired (recently fallen snow with visible tracks). The second dimension involved the penetrability of the barrier. In all cases the location involved an intermittent buffer (IB) design, but the level and amount of snow accumulated between the barriers varied. For the base level, very little snow was stored in the buffer, while in the second level enough snow was stored to effectively function as a solid or impenetrable barrier (SB). To explore the effect of demand or congestion on safety and comfort, a third dimension with three levels was included. In the base case no other people who cycle are in view. On the second level, a single, hypothetically slower, person cycling was closely in front of the subject, implying the need for a passing maneuver. In the third level, farther ahead in the SBL, another person cycling slowly can be seen, implying that passing maneuvers will not be a rare event. The combinations generated by these three dimensions result in a pool of 30 images. These images are presented in Figure 7.8 (penetrable barrier) and Figure 7.9 (impenetrable barrier.)

Image A

Image B

Please state whether you strongly agree, agree, neither agree nor disagree, disagree, or strongly disagree with the of the following statements.

I would feel more safe riding on the lane in image A than the lane in Image B.

Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree

I would feel more comfortable riding on the lane in image A than the lane in Image B.

Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree

I would be more likely to ride my bicycle in the winter if the lanes were maintained as in Image A than Image B.

Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree

Figure 7.7 Example of one out of ten random pairing question blocks asked.

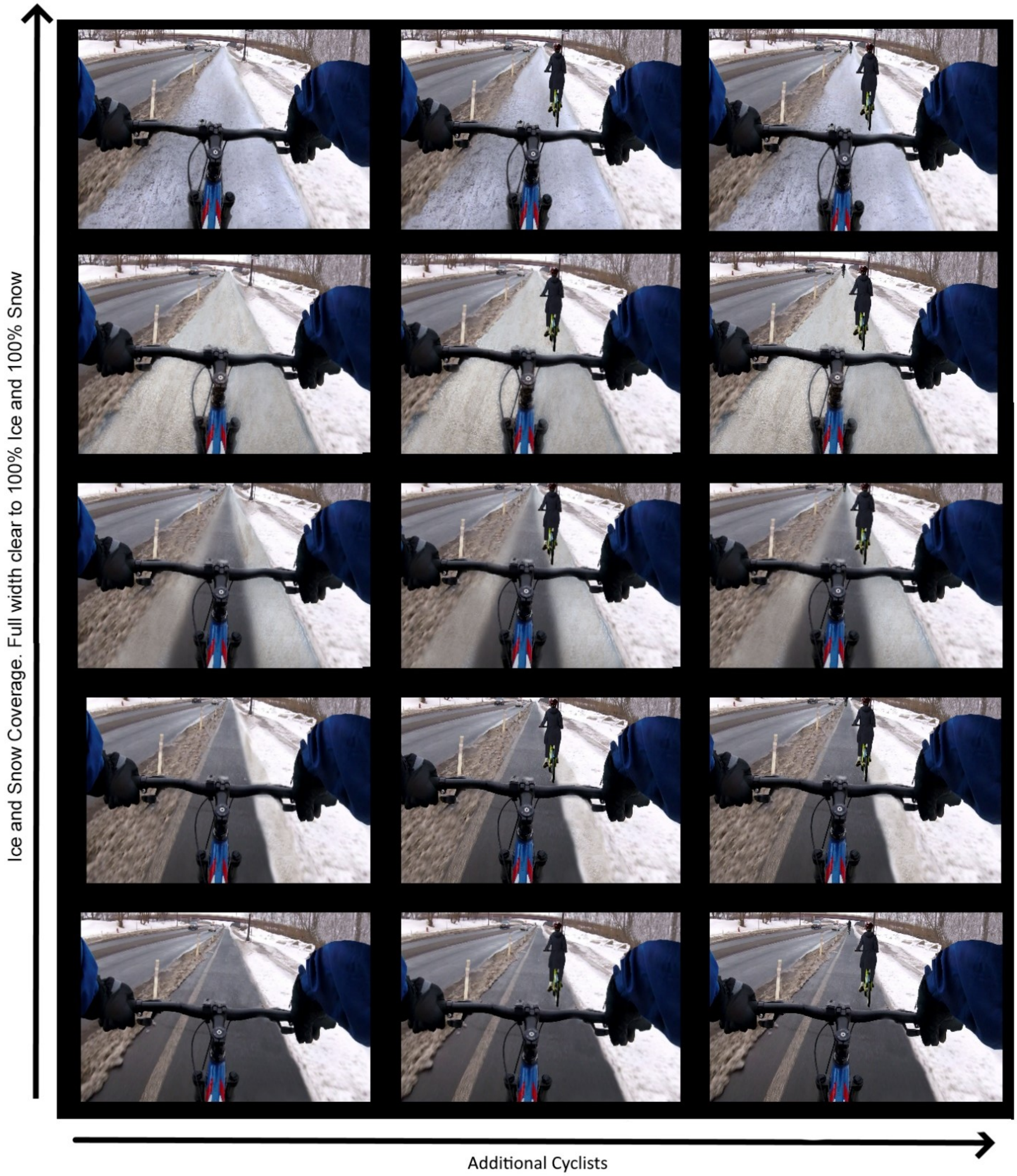


Figure 7.8 Set of 15 penetrable barrier images with varying levels of SBL coverage and cyclist demand

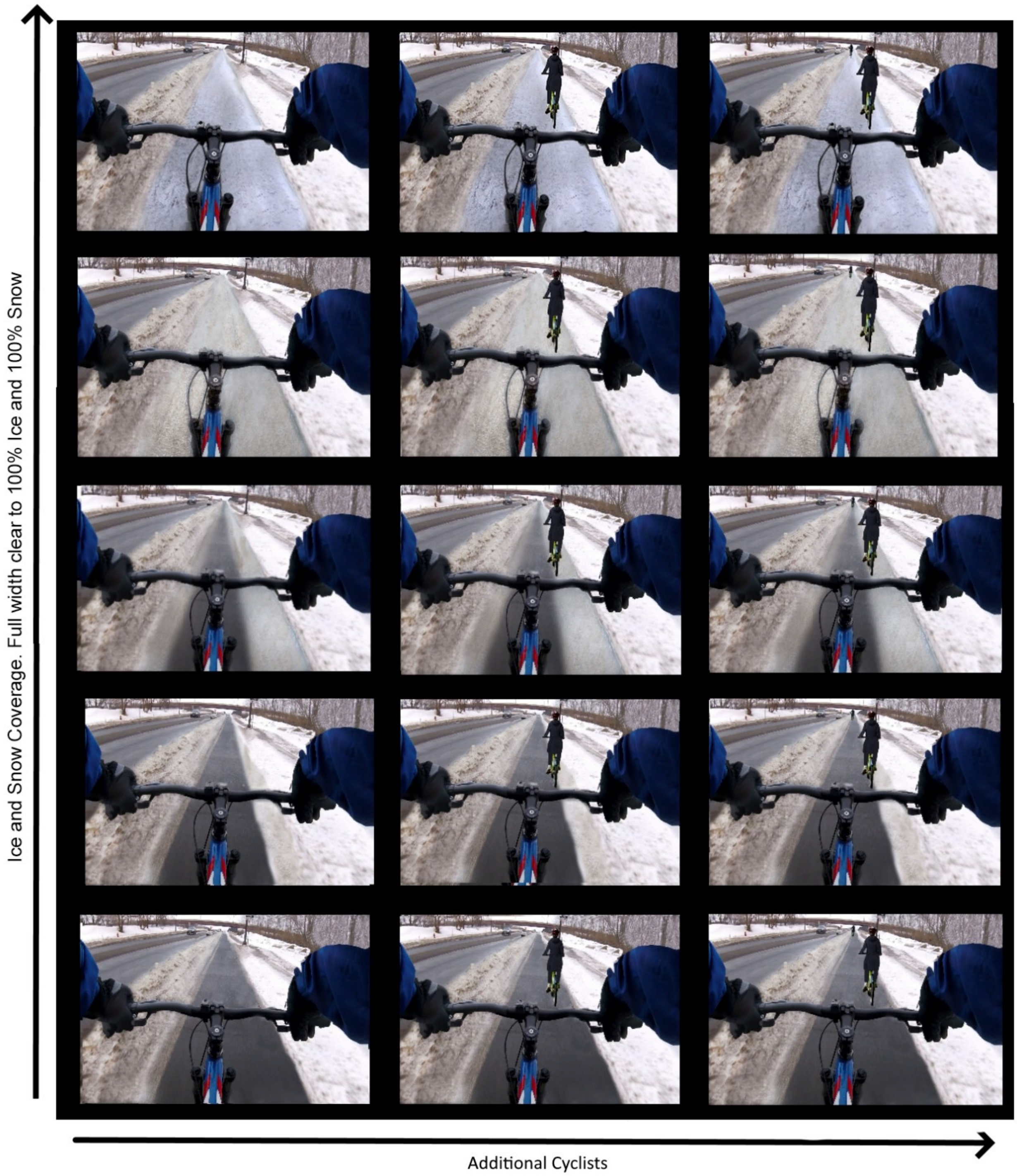


Figure 7.9 Set of 15 impenetrable barrier images with varying levels of SBL coverage and cyclist demand

The following table summarizes the independent variables that codify the conditions presented in each of the two hypothetical SBL winter riding conditions shown in the pictures. Given that each survey question represents a random pairing between hypothetical SBL riding conditions, variables describing separately each of the two images are included.

Table 7-1 Winter condition categorical variables

Variable names	Explanation
Dependent Variables	
Binary DP	This is the dependent variable coded as 1 if image A was preferred to image B. The concept is the same on all three models describing safety, comfort, and likely to ride.
Independent Variables	
A_Cover 0% 25% 50% 100% Ice 100% Snow	Categorical variable describing the SBL surface conditions shown in Image A. On each record only one of the following five levels is 1 (true) with the rest set to 0 (false)
B_ Cover 0% 25% 50% 100% Ice 100% Snow	Categorical variable describing the SBL surface conditions shown in Image B. On each record only one of the following five levels is 1 (true) with the rest set to 0 (false)
A_Barrier_Wall B_Barrier_Wall	Variables representing the two conditions of the buffer separation. Variable is set to 0 (false) if the image shows a penetrable buffer and 1 (true) if the image shows a snow “wall.”
A_Bikes B_Bikes	Variables representing the number of additional cyclists present in the lane (0, 1, or 2). These variables were explored both as a numerical as well as a categorical variable.
Barrier_Diff	Interaction variable to control for interactions. It is set as 1 (true) if the two images show different types of buffer separation. Variable is set to 0 (false) if both images show the same type of buffer separation.
Cover_Diff	Similar to above for lane conditions.
Bikes_Diff	Similar to above for number of additional cyclists present.

Respondents were provided the opportunity to express preferences on a five-point Likert-type scale. The Likert scale is a type of psychometric response scale in which responders specify their level of agreement to a statement typically in five points: (1) Strongly disagree; (2) Somewhat Disagree; (3) Neither agree nor disagree; (4) Somewhat Agree; (5) Strongly Agree. This design enables multiple approaches to statistical analyses associated with how categories of responses are analyzed. Following experimentation with different analytical approaches, a simple binary response was selected. A database was created that included each respondent’s preferences for each image in a binary, true-false variable. This binary variable was True if the response was “Strongly Agree” or “Somewhat Agree” and

False otherwise. In simple terms, if the person surveyed found the conditions in image A safer, more comfortable, or more likely to use the bicycle than the conditions in image B, the Binary DP variable was set to 1 (True). The tie “Neither Agree nor Disagree” was selected to fall in favor of image B and set the variable to 0 (False). A standard approach for analyzing binary (i.e., 0/1) variables is logistic regression. For the analyses reported here, the Stata statistical software was used to fit all logistic regression models.

A series of binary logistic regression models were then fit to assess any association between the stated comparative preference, separately in the contexts of safety, comfort, and likelihood to ride on, given the coded alternatives regarding barrier penetrability, bike lane pavement snow/ice coverage, and the density of SBL users. If P[Yi=1] denotes the probability that a survey question response (aka row) i of the data file shows preference of conditions shown in Image A over Image B, then a binary logistic model of the form

$$P[Y_i = 1] = \frac{\exp\left(\beta_0 + \sum_j \beta_j x_{i,j}\right)}{1 + \exp\left(\beta_0 + \sum_j \beta_j x_{i,j}\right)}$$

captures the associations between this probability and a set of measurable features denoted by x_{i1}, x_{i2}, …, with the coefficients β_1, β_2, … reflecting the strength and direction of those associations. If β_j=0 then feature x_{ij} has no association with the probability of preferring one of the two conditions presented in the two images, β_j >0 means an increase in x_{ij} is associated with increases in probability of preferring conditions shown in image A, and β_j <0 means an increase x_{ij} is associated with a decrease in this probability. If all coefficients including β_0 are equal to 0 then $P[Y_i=1]=P[Y_i=0]=0.5$.

The same methodology was followed separately for each of the three stated preference subjects, namely Safety, Comfort, and Likelihood to Use a Bicycle. Each subject was explored through two different modeling exercises. The first involved a straightforward regression in which the independent variables (Table 7-1) were categorical variables that captured the aforementioned dimensions included in the photographs presented to the respondents.

As it will be discussed in detail in the following sections, the initial analysis involving the variables as shown in the table above, did not provide very conclusive results. Through the analysis it was deduced that the three dimensions codified have complicated correlations. To alleviate this problem and identify more concrete relationships, a second modeling exercise was conducted. Specifically, instead of incorporating the direct, separate features for each of the two images (i.e., the variables described in Table 7-1), a set of new variables was created that codify all possible combinations of conditions between the two images.

Table 7-2 Interaction variable names and explanation.

Variable name	Variable is 1 (True) if Image A shows ___ AND Image B shows ___ Variable is 0 (False) otherwise.
I_A_BxB_B_0_0	A_Bikes==0 & B_Bikes==0
I_A_BxB_B_0_1	A_Bikes==0 & B_Bikes==1
I_A_BxB_B_0_2	A_Bikes==0 & B_Bikes==2
I_A_BxB_B_1_0	A_Bikes==1 & B_Bikes==0
I_A_BxB_B_1_1	A_Bikes==1 & B_Bikes==1
I_A_BxB_B_1_2	A_Bikes==1 & B_Bikes==2
I_A_BxB_B_2_0	A_Bikes==2 & B_Bikes==0
I_A_BxB_B_2_1	A_Bikes==2 & B_Bikes==1
I_A_BxB_B_2_2	A_Bikes==2 & B_Bikes==2
I_A_BxB_Ba_0_0	A_Barrier_Wall==0 & B_Barrier_Wall==0 *(0 indicates penetrable barrier)*
I_A_BxB_Ba_0_1	A_Barrier_Wall==0 & B_Barrier_Wall==1
I_A_BxB_Ba_1_0	A_Barrier_Wall==1 & B_Barrier_Wall==0
I_A_BxB_Ba_1_1	A_Barrier_Wall==1 & B_Barrier_Wall==1
I_A_CxB_C_0_0	A_Cover==0% & B_Cover==0%
I_A_CxB_C_0_100Ice	A_Cover==0% & B_Cover==100% Ice
I_A_CxB_C_0_100Snow	A_Cover==0% & B_Cover==100% Snow
I_A_CxB_C_0_25	A_Cover==0% & B_Cover==25%
I_A_CxB_C_0_50	A_Cover==0% & B_Cover==50%
I_A_CxB_C_100Ice_0	A_Cover==100% Ice &B_Cover==0%
I_A_CxB_C_100Ice_100Ice	A_Cover==100% Ice & B_Cover==100% Ice
I_A_CxB_C_100Ice_100Snow	A_Cover==100% Ice & B_Cover==100% Snow
I_A_CxB_C_100Ice_25	A_Cover==100% Ice & B_Cover==25%
I_A_CxB_C_100Ice_50	A_Cover==100% Ice & B_Cover==50%
I_A_CxB_C_100Snow_0	A_Cover==100% Snow & B_Cover==0%
I_A_CxB_C_100Snow_100Ice	A_Cover==100% Snow & B_Cover==100% Ice
I_A_CxB_C_100Snow_100Snow	A_Cover==100% Snow & B_Cover==100% Snow
I_A_CxB_C_100Snow_25	A_Cover==100% Snow & B_Cover==25%
I_A_CxB_C_100Snow_50	A_Cover==100% Snow & B_Cover==50%
I_A_CxB_C_25_0	A_Cover==25% & B_Cover==0%
I_A_CxB_C_25_100Ice	A_Cover==25% & B_Cover==100% Ice
I_A_CxB_C_25_100Snow	A_Cover==25% & B_Cover==100% Snow
I_A_CxB_C_25_25	A_Cover==25% & B_Cover==25%
I_A_CxB_C_25_50	A_Cover==2%5 & B_Cover==50%
I_A_CxB_C_50_0	A_Cover==50% & B_Cover==0%
I_A_CxB_C_50_100Ice	A_Cover==50% & B_Cover==100% Ice
I_A_CxB_C_50_100Snow	A_Cover==50% & B_Cover==100% Snow
I_A_CxB_C_50_25	A_Cover==50% & B_Cover==25%
I_A_CxB_C_50_50	A_Cover==50% & B_Cover==50%

7.1.1 Safety

Table 7-3 and 7.4 present some of the direct results from the logistic regression analysis in regards to the perceived safety of riding on the hypothetical SB during winter. The actual process was more involved and included estimation and assessment of many different models. For efficiency, only the more general regression results are shown in these tables; each table presents both Odds Ratios and regression coefficients. The model shown in Table 7-3 contains the constant β_0, the directly codified predictors describing the conditions shown in image A and image B separately, and three binary variables controlling for the case a given dimension is identical between the two images. The estimated value for the constant was -1.36561 and its associated standard error estimate was 0.358829. The Z-statistic for testing the hypothesis that $\beta_0=0$ was -3.81 (not shown) and the probability (P-value) of getting a Z-statistic this large or larger had it been true that $\beta_0=0$ is essentially zero, indicating that, for this data set, perceived safety between the two hypothetical conditions presented is not equally likely.

Table 7-3 Logistic regression analysis of direct variables on safety (sample size = 1,280)

	Coef.	Std. Err.	Odds Ratio	Z	P>|z|	
constant	**-1.365**	**.3588**	**0.255**	**-3.81**	**0.000**	**
A_Cover						
25%	**-0.596**	**.2230**	**0.550**	**-2.67**	**0.008**	**
50%	**-1.707**	**.2244**	**0.181**	**-7.61**	**0.000**	**
100% Ice	**-3.785**	**.2891**	**0.022**	**-13.09**	**0.000**	**
100% Snow	**-2.821**	**.2500**	**0.059**	**-11.29**	**0.000**	**
B_Cover						
25%	**1.316**	**.2661**	**3.731**	**4.95**	**0.000**	**
50%	**1.835**	**.2617**	**6.266**	**7.01**	**0.000**	**
100% Ice	**3.464**	**.2831**	**31.956**	**12.24**	**0.000**	**
100% Snow	**2.881**	**.2685**	**17.841**	**10.73**	**0.000**	**
A_Barrier_Wall	-0.224	.1483	0.798	-1.51	0.130	
B_Barrier_Wall	**0.455**	**.1489**	**1.577**	**3.06**	**0.002**	**
A_Bikes	**-0.183**	**.0912**	**0.832**	**-2.01**	**0.044**	*
B_Bikes	**0.318**	**.0910**	**1.375**	**3.5**	**0.000**	**
Barrier_Diff	**0.379**	**.1505**	**1.461**	**2.52**	**0.012**	*
Cover_Diff	0.289	.1780	1.335	1.62	0.104	
Bikes_Diff	-0.019	.1644	0.981	-0.12	0.908	

The results suggest a much stronger influence on perceived safety by the bike lane pavement conditions. As expected, the presence of ice and snow on the pavement negatively affects perceptions of safety. Specifically, the more area of the SBL is covered, the more unsafe it was rated. As seen from the table, all pavement coverage categorical variables are shown to be statistically significant. Given that the not shown, base case is 0% coverage, the negative signs on all A_Cover and positive signs on all Cover variables suggest a reduction in perceived safety as the percent of clear SBL pavement reduces. It is interesting to note that, for the extreme cases that involve comparison of 100% Ice vs 100% Snow, respondents rated 100% snow as safer. This observation corroborates the stated preference results shown in Figure 7.1 where Icy Roads was rated much higher as a condition that can cause a person who cycles to cancel a ride. It is interesting to note that the results are symmetrical in this dimension meaning that as much "aversion" is applied to Image A the same "attraction" is applied to Image B. This shows a well-behaved variable with minimal exogenous causal relationships. As expected, SBLs that were completely covered with snow or ice both were perceived as less safe than lanes with only 50% coverage. From combined results not all shown in the above table it is estimated that people who cycle perceive more than 30% safer riding on 100% snow than riding on 100% ice. In general, the differences between 25% and 50% are small implying that as long as even half of the SBL lane is clear, perceived safety is not harmed.

The estimated coefficients for the penetrability/impenetrability of the barrier shown separately on images A and B are A_Barrier_Wall=-0.224 with an associated standard error of estimate equal to 0.1483 and B_Barrier_Wall=0.455 with an associated standard error of estimate equal to 0.1489 respectively. The Z-statistic testing the hypothesis that A_Barrier_Wall =0 was -1.51 and the probability of getting a Z-statistic this large or larger if A_Barrier_Wall = is true was 0.130. The Z-statistic testing the hypothesis that B_Barrier_Wall =0 was 3.06 and the probability of getting a Z-statistic this large or larger if B_Barrier_Wall = is true was 0.002. These results indicate that this data set is consistent with no association between the type of barrier shown in image A and the perceived safety between the two conditions but it shows a strong association with the type of barrier shown in image B. Specifically, given that both of these variables are 0 when the respective image shows a penetrable barrier and 1 when it shows an impenetrable one (Wall), the positive coefficient for B_Barrier_Wall suggests that the probability of perceiving the conditions shown in image A as safer increases when the barrier shown in image B is an impenetrable one. In short, the tall solid snowbank on the SBL is perceived as a negative element in regards to safety. This not crystal-clear result suggests both that the barrier type has low importance to perceived safety compared to the rest of the dimensions describing SBL winter riding conditions and their complex interactions. Similar impressions are formed from the numerical variables describing the cyclist density on each of the two images, with a positive association between the number of people who cycle shown in image B and the probability of perceiving the conditions shown in image A as safer.

As alluded to earlier, given the comparative nature of the visual preference survey format, the probability of preferring image A over image B is not only influenced by the variables describing each of the two images but can also be influenced by the individual combination of presented conditions in the particular image pair. In the model discussed in the previous paragraphs, a rudimentary set of interaction terms were added to cover and control for cases of randomly generated image pairs that showed the exact same level of one or more condition dimensions. Although, this controls for estimation errors in the model coefficients it does not cover the variable influence different pairings have on the preference probability. To explore these interactions between specific combinations of individual predictors, the constructed interaction terms described in Table 7-2 were created and explored in separate models. An example of these results is shown in Table 7-4.

Table 7-4 Logistic regression analysis of interaction variables on safety

	Coef.	Std. Err.	Odds Ratio	z	P>|z|	
Constant	-0.655	0.4298	0.519	-1.53	0.127	
I_A_CxB_C_0_0	-0.128	0.4813	0.879	-0.27	0.79	
I_A_CxB_C_0_25	**1.704**	**0.4378**	**5.500**	**3.89**	**0**	**
I_A_CxB_C_0_50	**1.945**	**0.4747**	**6.995**	**4.1**	**0**	**
I_A_CxB_C_0_100Ice	**2.648**	**0.5260**	**14.136**	**5.04**	**0**	**
I_A_CxB_C_0_100Snow	**2.627**	**0.4867**	**13.836**	**5.4**	**0**	**
I_A_CxB_C_25_0	**-1.007**	**0.4936**	**0.365**	**-2.04**	**0.041**	*
I_A_CxB_C_25_25	0.339	0.4683	1.404	0.73	0.468	
I_A_CxB_C_25_50	**1.774**	**0.4458**	**5.896**	**3.98**	**0**	**
I_A_CxB_C_25_100Ice	**2.324**	**0.4797**	**10.224**	**4.85**	**0**	**
I_A_CxB_C_25_100Snow	**2.845**	**0.5429**	**17.207**	**5.24**	**0**	**
I_A_CxB_C_50_0	**-1.922**	**0.6189**	**0.146**	**-3.11**	**0.002**	**
I_A_CxB_C_50_25	-0.666	0.4676	0.513	-1.43	0.154	
I_A_CxB_C_50_50	-0.555	0.4830	0.573	-1.15	0.25	
I_A_CxB_C_50_100Ice	**2.728**	**0.5226**	**15.305**	**5.22**	**0**	**
I_A_CxB_C_50_100Snow	**1.234**	**0.4286**	**3.436**	**2.88**	**0.004**	**
I_A_CxB_C_100Ice_0	**-3.209**	**1.06255**	**0.040**	**-3.02**	**0.003**	**
I_A_CxB_C_100Ice_25	**-2.576**	**0.7934**	**0.076**	**-3.25**	**0.001**	**
I_A_CxB_C_100Ice_50	**-1.605**	**0.5778**	**0.200**	**-2.78**	**0.005**	**
I_A_CxB_C_100Ice_100Ice	-0.442	0.4597	0.642	-0.96	0.336	
I_A_CxB_C_100Ice_100Snow	**-1.355**	**0.5500**	**0.257**	**-2.46**	**0.014**	*
I_A_CxB_C_100Snow_0	**-1.656**	**0.5749**	**0.190**	**-2.88**	**0.004**	**
I_A_CxB_C_100Snow_25	**-1.476**	**0.5795**	**0.228**	**-2.55**	**0.011**	*
I_A_CxB_C_100Snow_50	**-1.598**	**0.5491**	**0.202**	**-2.91**	**0.004**	**
I_A_CxB_C_100Snow_100Ice	0.558	0.4478	1.747	1.25	0.213	
I_A_CxB_C_100Snow_100Snow	omitted because of collinearity					
I_A_BxB_Ba_0_0	-0.178	0.2175	0.836	-0.82	0.412	
I_A_BxB_Ba_0_1	**0.694**	**0.2174**	**2.002**	**3.19**	**0.001**	**
I_A_BxB_Ba_1_0	-0.072	0.2202	0.929	-0.33	0.741	
I_A_BxB_Ba_1_1	omitted because of collinearity					
I_A_BxB_B_0_0	-0.403	0.3375	0.667	-1.2	0.232	
I_A_BxB_B_0_1	0.113	0.3239	1.119	0.35	0.727	
I_A_BxB_B_0_2	0.445	0.3216	1.561	1.39	0.166	
I_A_BxB_B_1_0	**-0.605**	**0.3225**	**0.545**	**-1.88**	**0.061**	*
I_A_BxB_B_1_1	-0.133	0.34334	0.874	-0.39	0.697	
I_A_BxB_B_1_2	0.082	0.3269	1.086	0.25	0.801	
I_A_BxB_B_2_0	**-0.643**	**0.3384**	**0.525**	**-1.9**	**0.057**	*
I_A_BxB_B_2_1	-0.141	0.3323	0.867	-0.43	0.67	
I_A_BxB_B_2_2	omitted because of collinearity					

In addition to this second level analysis two additional modeling experiments were performed that include additional heuristic variables. The first heuristic variable is “A_Cover_Less_than_B” and it takes the value of 1 if in the particular data row the % coverage of the SBL pavement shown in image A is less or equal to the same in image B. The second heuristic variable is “A_Bikes_Less_than_B” and it takes the value of 1 if in the particular data row the number of people who cycle shown in image A is less or equal to the same in image B. In the following tables only the Odds Ratios are presented because the interest is in the comparison between specific conditions given certain constraints. An Odds Ratio >1 indicates a positive relationship between the variable and the probability, the same indication from a positive sign on the estimated coefficient. The reverse applies for OR < 1. The benefit in this case from using the ORs is that they can be shorted to facilitate quick comparisons of the effect from combinations of conditions. For example, from Table 7-5 the following statements can be formulated for survey questions where both images showed the same barrier type, penetrable (0) or impenetrable (1):

- Assuming percent of SBL cover by snow/ice is less on image A (green and black rows), higher cyclist density is associated with lower probability of perceiving conditions on image A as safer than the conditions shown on image B, regardless of the barrier type.
- In contrast, when the percent of SBL cover by snow/ice is higher on image A (red and blue rows), higher cyclist density is associated with higher lower probability of perceiving conditions on image A as safer than the conditions shown on image B, regardless of the barrier type.

Results shown in Table 7-6 can lead to similar statements assuming that barrier type is different between the two images presented. Please note that the statistical significance of the estimated OR is generally low because sample size for each individual combination is often small. Therefore, although the information is informative regarding comparative relationships and trends it is not to be used to quantify likelihood.

Table 7-5 Perception of Safety: Assuming same barrier type, relative influence from Lane cover and cyclists density.

A_Cover_<_B	A_Bikes_<_B	A_Barrier_Wall	B_Barrier_Wall	Odds Ratio	P>|z|
0	1	1	1	0.08	0
0	1	0	0	0.11	0
0	0	1	1	0.2	0
1	0	0	0	0.88	0.617
1	0	1	1	0.92	0.736
0	0	0	0	1	
1	1	0	0	1.71	0.004
1	1	1	1	2.65	0

Table 7-6 Perception of Safety: Assuming a given lane condition, relative influence from cyclist density and barrier type.

A_Cover_<_B	A_Bikes_<_B	A_Barrier_Wall	B_Barrier_Wall	Odds Ratio	P>|z|
0	1	1	0	0.13	0
0	0	0	1	0.17	0
0	0	1	0	0.19	0
0	1	0	1	0.30	0
1	0	1	0	0.86	0.587
1	1	1	0	1.75	0.001
1	0	0	1	2.05	0.01
1	1	0	1	2.3	0

In contrast to results reported in previous chapters where the Solid Barrier was perceived as safer than the Intermittent Barrier for all groups and classifications (assuming non-winter conditions), more complicated relationships are observed in this analysis. On a more general level, a weak preference towards the penetrable barrier is observed. When more detailed investigation is performed, controlling for the presence of other people who cycle and the level of coverage by ice and snow, the following are observed when looking at the information in Table 7-7 and Table 7-8.

Regardless of the difference in number of people who cycle present in each of the two images, grouped by lane coverage shown on Image B, the penetrable barrier is preferred at lane coverages of 0% (all clear) and 25%. A reverse preference is observed, favoring the impenetrable barrier, when lane coverage is 50% or higher. This is an interesting finding which implies that when people who cycle prefer a penetrable barrier when they feel safe from sliding in the bike lane due to ice and snow. These people who cycle may wish to switch to the driving lanes to turn or pass a slower cyclist. When snow or ice cover on the lane is 50% or more, the protection of the impenetrable barrier is preferred. A plausible explanation for this result is that if a person cycling loses control of their bike, the impenetrable barrier will prevent them from entering the vehicle lanes. It is also possible that this correlation has some uncontrolled relationship with ideas that people who cycle have about the conditions on the driving lanes. For example, it is conceivable that people who cycle assume similar slippery conditions on the vehicle lane as in the bike lane and therefore perceive the impenetrable barrier as safer (i.e., more likely to protect them from sliding vehicles). Regardless, the analysis suggests that during winter months, SBLs with Intermittent Barrier designs should be maintained at or below 25% level of coverage until a solid, tall snow wall is formed on the buffer. When an impenetrable barrier is formed, although winter maintenance is still important, people who cycle do not perceive it as critical. The same logic can be extended in the case of the CIB since the low curb will quickly disappear under even a small amount of snow.

The number of other people cycling present behaved in the expected way; the more bikes present, the less likely an image was to be perceived as safer. As with the barrier, the relationship is more complex. Regardless of the state of the barrier, fewer people cycling on the SBL is roughly equivalent to the change in preference levels as 25% more coverage. For example, an SBL with low cyclist demand, requiring fewer passing maneuvers with 50% coverage of ice or snow has the same level of preference as a similar SBL with more people who cycle but only 25% covered. This logically suggests that the higher the volume on the SBL the more important it is to keep it clear from ice/snow during the winter months.

Table 7-7 Combinations of presented cover alternatives and Cyclist density when Image A shows an Impenetrable snow barrier (A_Barrier_Wall =1).

A_Bikes_<_B	A_Cover	B_Cover	Odds Ratio	P>|z|
1	25%	0%	0.05	0.004
1	50%	0%	0.07	0.011
1	100% Snow	0%	0.071	0.011
0	100% Ice	0%	0.11	0.037
0	50%	0%	0.12	0.05
1	0%	0%	0.22	0.054
0	25%	0%	0.33	0.099
1	100% Snow	25%	0.07	0.013
0	100% Snow	25%	0.08	0.017
0	50%	25%	0.2	0.142
1	50%	25%	0.3	0.147
1	25%	25%	0.8	0.739
0	0%	25%	1	1
1	%0	25%	4	0.013
1	100% Ice	50%	0.2	0.003
0	100% Snow	50%	0.25	0.08
0	50%	50%	0.3	0.178
1	50%	50%	0.7	0.566
0	25%	50%	1	1
0	0%	50%	2	0.423
1	0%	50%	3.4	0.016
1	25%	50%	3.4	0.016
0	100% Ice	100% Ice	0.07	0.013
1	100% Ice	100% Ice	0.5	0.292
1	100% Snow	100% Ice	0.6	0.53
0	100% Snow	100% Ice	1	1
0	25%	100% Ice	1.5	0.53
1	50%	100% Ice	3.8	0.008
1	25%	100% Ice	5.6	0.006
0	50%	100% Ice	6	0.019
1	0%	100% Ice	6.5	0.014
0	0%	100% Ice	7	0.069
1	100% Ice	100% Snow	0.14	0.01
0	100% Snow	100% Snow	0.16	0.097
1	100% Snow	100% Snow	0.6	0.323
0	50%	100% Snow	2.3	0.22
0	25%	100% Snow	2.5	0.273
0	0%	100% Snow	4.5	0.054
1	50%	100% Snow	5.5	0.027
1	0%	100% Snow	5.7	0.001

Table 7-8 Combinations of presented cover alternatives and Cyclist density when Image A shows a Penetrable barrier (A_Barrier_Wall =0).

A_Bikes_<_B	A_Cover	B_Cover	Odds Ratio	P>|z|
0	100% Snow	0	0.07	0.011
0	25	0	0.11	0.037
1	50	0	0.117	0.004
1	100% Snow	0	0.23	0.022
1	25	0	0.36	0.083
1	0	0	1	1
0	100% Snow	25	0.2	0.142
1	100% Snow	25	0.2	0.038
0	100% Ice	25	0.22	0.054
1	50	25	0.4	0.028
0	25	25	0.7	0.706
1	0	25	1.5	0.35
1	25	25	1.8	0.292
1	100% Ice	50	0.07	0.013
0	100% Snow	50	0.09	0.022
1	50	50	0.18	0.027
0	50	50	0.2	0.038
1	100% Snow	50	0.2	0.011
0	25	50	2	0.327
0	0	50	2.6	0.147
1	25	50	4	0.013
1	0	50	11	0.022
0	100% Ice	100% Ice	0.3	0.147
1	100% Ice	100% Ice	0.5	0.258
0	100% Snow	100% Ice	0.6	0.53
1	100% Snow	100% Ice	1	1
0	25	100% Ice	3.5	0.118
1	0	100% Ice	4.3	0.022
0	0	100% Ice	9	0.037
1	25	100% Ice	17.9	0.005
0	150	100% Snow	0.12	0.05
1	100% Ice	100% Snow	0.14	0.01
0	100% Ice	100% Snow	0.4	0.273
0	50	100% Snow	0.5	0.571
1	100% Snow	100% Snow	1.1	0.796
1	50	100% Snow	1.3	0.386
0	25	100% Snow	2.5	0.273
0	0	100% Snow	7	0.069
1	0	100% Snow	9	0.003
1	25	100% Snow	10	0.002

7.1.2 Comfort

Preferences of images with respect to perceived comfort (Table 7-9) during various winter conditions are very similar to the results discussed on Safety. For this reason and in the interest of brevity, only interpretation and discussion of differences in observed relationships are included in this document.

Table 7-9 Logistic regression analysis of direct variables on comfort (sample size = 1,300)

	Coef.	Std. Err.	Odds Ratio	Z	P>|z|	
constant	**-1.413**	**0.3500**	**0.243**	**-4.04**	**0.000**	**
A_Cover						
25%	**-0.627**	**0.2214**	**0.534**	**-2.83**	**0.005**	**
50%	**-1.655**	**0.2228**	**0.191**	**-7.43**	**0.000**	**
100% Ice	**-3.536**	**0.2720**	**0.029**	**-13.00**	**0.000**	**
100% Snow	**-2.739**	**0.2452**	**0.064**	**-11.17**	**0.000**	**
B_Cover						
25%	**1.102**	**0.2535**	**3.012**	**4.35**	**0.000**	**
50%	**1.637**	**0.2493**	**5.144**	**6.57**	**0.000**	**
100% Ice	**3.241**	**0.2689**	**25.566**	**12.05**	**0.000**	**
100% Snow	**2.804**	**0.2572**	**16.514**	**10.90**	**0.000**	**
A_Barrier_Wall	-0.064	0.1449	0.937	-0.44	0.657	
B_Barrier_Wall	**0.325**	**0.1454**	**1.384**	**2.23**	**0.025**	*
A_Bikes	**-0.192**	**0.0892**	**0.824**	**-2.16**	**0.031**	*
B_Bikes	**0.321**	**0.0892**	**1.379**	**3.61**	**0.000**	**
Barrier_Diff	**0.511**	**0.1481**	**1.667**	**3.45**	**0.001**	**
Cover_Diff	**0.493**	**0.1744**	**1.638**	**2.83**	**0.005**	**
Bikes_Diff	-0.042	0.1607	0.958	-0.26	0.794	

Although respondents were more likely to perceive images with 100% snow cover as safer than images with 100% ice cover, the type of cover did not exert as great an influence in the respondents' assessments of comfort. That is, with respect to assessment of relative comfort, it did not seem to matter whether it was ice or snow that covered the SBL if the SBL was 100% covered.

7.1.3 Likely to Ride on

Results regarding likelihood to ride in winter are also very similar to the results discussed on Safety and Comfort. Most of the same observations are valid in this context. Specifically, on the subject of 100% cover by either Ice or Snow, the likelihood to ride exhibit similar pattern with safety showing a significant preference to 100% Snow cover as opposed to 100% Ice. Even from the high-level results shown in Table 7-10, a strengthening of the influence of the barrier type is observed with no change in the observed trends. In a similar way the role of additional people who cycle on the lane is weakened.

Table 7-10 Logistic regression analysis of direct variables on Likelihood to ride (sample size = 1,310)

	Coef.	Std. Err.	Odds Ratio	Z	P>|z|	
constant	**-1.595**	**0.3690**	**0.202**	**-4.32**	**0.000**	**
A_Cover						
25%	**-0.696**	**0.2186**	**0.498**	**-3.18**	**0.001**	**
50%	**-1.918**	**0.2245**	**0.146**	**-8.54**	**0.000**	**
100% Ice	**-3.884**	**0.3031**	**0.020**	**-12.81**	**0.000**	**
100% Snow	**-2.861**	**0.2526**	**0.057**	**-11.32**	**0.000**	**
B_Cover						
25%	**1.054**	**0.2701**	**2.870**	**3.90**	**0.000**	**
50%	**1.619**	**0.2648**	**5.050**	**6.11**	**0.000**	**
100% Ice	**3.146**	**0.2797**	**23.253**	**11.25**	**0.000**	**
100% Snow	**2.720**	**0.2688**	**15.189**	**10.12**	**0.000**	**
A_Barrier_Wall	**-0.349**	**0.150**	**0.705**	**-2.32**	**0.021**	*
B_Barrier_Wall	**0.410**	**0.150**	**1.507**	**2.73**	**0.006**	**
A_Bikes	-0.076	0.0919	0.926	-0.83	0.405	
B_Bikes	**0.219**	**0.0915**	**1.245**	**2.40**	**0.017**	*
Barrier_Diff	0.193	0.1512	1.213	1.28	0.202	
Cover_Diff	**0.755**	**0.1947**	**2.127**	**3.88**	**0.000**	**
Bikes_Diff	0.058	0.1649	1.060	-0.36	0.722	

From the more in-depth analysis, similar to the one related to Table 7-5 on safety, a slightly different pattern is observed; regardless of the comparative state of the SBL cover and additional cycles, the penetrable barrier is always associated with an increase in likelihood to ride.

7.2 SUMMARY OF FINDINGS

In summary, respondents were asked state preferences between pairs of photographs and identify the photograph they thought was safer, more comfortable, and would be more likely to ride on. Each photo in each pair varied in three dimensions: proportion of ice or snow cover, presence of a snow barrier/wall, and presence of other people who cycle. The effects of increasing ice or snow cover and the presence of people who cycle were consistent with a-priori hypotheses, while the effects of the presence of the snow/barrier wall were inconclusive or counterintuitive.

With respect to ice and snow cover, the higher the cover level in photo A relative to 100% clear pavement, the less likely it was to be selected as safer, comfortable, or a likely place to ride. Conversely, the higher the cover level in photo B, the more likely photo A was to be preferred in all dimensions. Each of the cover levels in both photographs was statistically significant. The lower or higher the level of cover in photos A and B respectively, the greater the odds that photo A was preferred. These results provide strong evidence that providing some clear pavement is an important goal for winter maintenance. Separately, between the extreme cases of 100% ice cover and 100% snow cover, although both less preferred than any condition that has some clear pavement, the 100% snow cover was preferred over the 100% ice. This suggest that, immediate action after a heavy snowfall is less important, but what is really important is to not let traffic compact the snow into an icy surface.

The presence of additional people cycling in photo A decreased the likelihood of photo A being preferred to photo B with respect to safety, comfort, and riding, while the presence of people cycling in photo B increased the likelihood that photo A was preferred. The effects of the snow/wall barrier were more complex and seemed to interact with degree of ice/snow cover, with respondents preferring no walls with lower levels of ice/snow cover but favoring the snow/wall barriers with higher levels of snow-ice cover.

CHAPTER 8: FOUNDATIONAL DEFINITIONS AND ASSUMPTIONS

To assist the reader and to minimize misunderstandings, it is important to frame the conversation by defining some basic terms and stating the fundamental assumptions involved in the formulation of the guidelines and recommendations presented in Chapter 9.

8.1 THE CARRIAGEWAY, THE ROADWAY, AND THE SIDEWALK LEVEL

We define "carriageway" as the space between property lines. The carriageway includes the areas where vehicles move, the areas where only pedestrians are allowed, as well as structural elements like pavement layers, curbs, storm water drains and pipes, etc. The term Right-Of-Way (ROW) is often used to denote land devoted to transportation purposes but it is mostly used in the context of land use and lacks the desired connection with above and below ground structural elements.

The term "roadway" is used to describe the part of the carriageway where people drive and park motor vehicles. In similar fashion, to describe the part of the carriageway where people are not allowed to drive motor vehicles because it is reserved for non-motorized traffic, we use the term "sidewalk level." We understand that the use of the term sidewalk may be limiting, but here it is used to simply describe that this area of the carriageway is physically separated from the roadway. In several places in this study we use grade or elevation to differentiate between the roadway and the sidewalk level because it describes the vast majority of the existing facilities but we recognize that it is not the only way of separating areas of the carriageway that have difference rules controlling use.

Specifically, on the sidewalk level, the term "shared use path" is used to define the portion of the facility where motorized vehicle traffic is prohibited and is physically separated from non-motorized vehicle traffic by either open space or a barrier. Shared use paths are generally open to any form of non-motorized travel, including but not limited to: pedestrians (walkers, joggers, and runners), people who cycle, roller skaters, wheelchair users, scooter users, and horse riders. Still, we prefer to use the term "sidewalk level" because it also encompasses nonfunctional areas like boulevards.

8.1.1 Curbs and Curb Lines

We define "curbs" as the structural elements forming the boundaries between different areas of the carriageway, specifically those that use height as a physical dimension to implement the separation or transition between areas of the carriageway. Curbs can be either independent elements separating areas of similar elevation (e.g., islands, curbs as SBL buffers) or the structural elements facilitating transitions between areas of the carriageway having different elevations (e.g., the curb separating the roadway from sidewalk). Being a vertical element, curbs affect and control drainage as well as influence maintenance needs and operations. In certain implementations of complete streets, non-structural elements, like painted concrete or grooved marker tiles, can be used to mark such boundaries. With the term "curb" we specifically refer to structural elements that use height as a physical dimension to implement the separation or transition between areas of the carriageway.

8.1.2 Traffic Conflicts

Carriageways are constructed to facilitate movements and access to locations in an efficient and safe way while minimizing traffic conflicts. They involve several explicit and implicit ways to facilitate and control all the allowed movements. Lane markings, direction of travel agreement, traffic signs, signals, sidewalks, driveways, ADA ramps, etc. are all constructs (e.g., material objects, agreements, and rules) developed for that purpose. Like all human designs, they both solve and create problems. For example, by paving a section of the ground to help vehicles move more smoothly, we disturb the natural mitigation of rain water and create the problem of storm-water management. Controlling peoples' movements (including driving) with lanes and sidewalks both generates and formalizes conflict points.

In the greater context of the carriageway there are many points where conflicts are possible. In general, we define as conflict the trajectory intersection of any object moving on the carriageway. Therefore, conflicts can arise between people who drive, bike and walk. Some of these conflicts are important to control to mitigate unsafe situations; some are traditionally left uncontrolled. For example, almost every urban intersection involves points where different sidewalks meet. Theoretically pedestrians, busy looking at their smartphones, can collide on these areas. There are, however, no formal rules controlling these conflicts nor any markings or signs are used to aid pedestrians. It is assumed that people can collectively arrange their trajectories and avoid crashing into one another and that the speed and mass of the moving parties are low enough to minimize the probability of injuries should a crash occur. Therefore, in a more general sense, designers need to control/mitigate any conflict where the actors involved may not have the time and space to adjust their trajectories to avoid collision, and the speeds and masses involved can result in damages if the conflict results in a crash. In the context of this study the main conflicts we are interested in are between, in rank of importance: people who cycle and people who drive, people who cycle and people who walk, and between people who cycle.

8.2 SEPARATED BIKE LANES

A Separated Bike Lane (SBL) is an optional part of a carriageway. The SBL is an exclusive facility for people who cycle that is located within or directly adjacent to the driving lanes and that is physically separated from motor vehicle traffic with a vertical element. SBLs are differentiated from standard and buffered bike lanes by some type of vertical element. They are differentiated from shared use paths (and sidepaths) by their more proximate relationship to the adjacent driving lanes and the fact that they are bike-only facilities. SBLs are also sometimes called "cycle tracks" or "protected bike lanes."

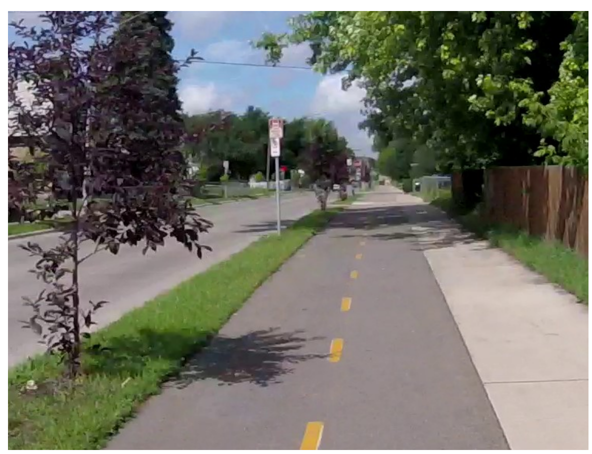
Within the common elements of SBLs – dedicated space for people who cycle that is separated from motor vehicle travel and parking lanes – practitioners have flexibility in choosing specific design elements. SBLs can operate as one-way or two-way facilities; their designs can integrate with turning automobile traffic at intersections or can be more fully separated; they can be designed at roadway level, at sidewalk level or at an intermediate one; and they can be separated from the adjacent roadway or sidewalk with a variety of treatments including but not limited to raised curbs or medians, bollards, landscaping, concrete barriers, planters, or on-street parking. Regarding the latter, in many bike lane design guides, the combination of a painted buffer and a parking lane is used to form a more solid barrier. In our considerations, we still assume that at minimum flexposts are also included in the buffer, otherwise it is not considered an SBL. In the context of this study, this assumption is important in conjunction with winter maintenance, and for snow removal in particular. In our discussions, the assumption of the existence of flexposts or other vertical elements implies limitations even if snow emergency parking restrictions are enforced.

Traffic engineers separately approach the mid-block and intersection segments in all design problems pertaining to the carriageway. Bike lanes are no exception. In this document, the buffer separation discussion involves almost exclusively mid-block segments, while intersections between the SBL and other carriageways are discussed under mixing zone design. The following sections summarize the definitions and assumptions involved in each of these segment types.

Buffer 1: Wall or Tall Barrier (impenetrable)

Buffer 2: Intermittent Barrier

Buffer 3: Curb and Intermittent Barrier



Buffer 4: Grade Separation

Figure 8.1 Types of Buffers Separation Methods

8.2.1 Mid-Block Segments

The form of separation, or "buffer" as it is often called, is the most important bike lane design problem for the mid-block segments. Strictly in the context of SBLs, the vertical elements in the buffer area are critical to SBL design. These separation types provide the comfort and safety that make SBLs attractive facilities. For people who cycle, the vertical element serves as a real or perceived barrier to keep people who drive cars from crossing into the bike lane. For people who drive the vertical elements again are real or perceived barriers to stop or limit encroachment into the bike lane. The selection of separation type(s) should be based on the presence of on-street parking, overall roadway and buffer width, cost, durability, aesthetics, traffic speeds, and maintenance. In certain circumstances, emergency vehicle access may need to be provided through low or mountable curbs or non-rigid means. In this guidance, four major categories or types of separation are considered, with variations on the vertical elements within types mentioned when tradeoffs are significant. The four general categories of separation considered are the Solid Barrier (SB), Intermittent Barrier (IB), Curb and IB (CIB), and Grade Separation (GS) (Figure 8.1). While not a barrier type on its own, parked cars can provide an additional level of protection and comfort for people who cycle. A minimum buffer width of 3 feet is required to allow for the opening of doors and other maneuvers. Additional vertical elements such as periodic delineator posts should be paired with this design. Barrier types that obstruct the opening of car doors or create tripping hazards should be avoided.

8.2.1.1 Solid Barrier (SB).

The primary goal of this type of buffer is to provide as complete as possible separation from the vehicle lanes, thereby maximizing safety. It is assumed that the barrier type is such that prevents any penetration to the bike lane by all types of vehicles moving at normal speeds. The key feature is the assurance that only in the rarest of cases a vehicle will manage to breakthrough this kind of barrier.

Concrete barriers provide the highest level of crash protection among these separation types. They can be less expensive than many of the other treatments and require little maintenance. The cost variation depends on the construction method for the barrier. The simplest method is the use of concrete blocks similar to the ones used on highway work zones, assuming the roadway surface and sublayers can accommodate the concentrated weight long term. More expensive implementations involve cast-in-place barriers that can include a foundation that both ensures the longevity of the installation as well as increases the level of impact it can withstand. This barrier type may be less attractive and may require additional drainage and service vehicle solutions. A crash attenuation device should be installed where the barrier end is exposed in all roads with speeds higher than 25mph. Given that such devices are costly, concrete wall barriers often are preferred on long uninterrupted sections of road.

Concrete Planters. This form of separation provides an aesthetic element to the streetscape, a suitable vertical barrier, and is quick to install. However, depending on the placement, this treatment is more expensive than other solutions, requires maintenance of the landscaping, and may not be as appropriate on higher speed streets given that the planters rarely are anchored in ground. One positive aspect of the planters is that they can involve gaps that solve drainage issues.

A general feature of solid barriers is that they can prevent or greatly reduce intrusion of snow during snow clearance operations from separate such efforts between the vehicle lanes and the SBL. Corollary to that is the need for snow plows big enough to push the snow farther down the road till a break in the barrier is available or the use of front loaders to scoop up snow into trucks.

8.2.1.2 Intermittent barrier (IB)

Intermittent barriers are one of the most used buffer designs. Because nothing solid separates the driving lanes from the SBL, they often result in a wider overall buffer to avoid encroachments between lanes. There are two major product categories used as vertical separation elements.

Flexible delineator posts (Flexposts) are one of the most popular types of separation elements due to their low cost, visibility, and ease of installation. Flexposts provide more of a sense of separation rather than actual separation. Their durability and aesthetic quality can present challenges and agencies may consider converting these types of buffers to a more permanent style when design and budgets allow. Delineators can be placed in the middle of the buffer area or to one side or the other as site conditions dictate (such as street sweeper width or vehicle door opening). During the project interviews, it was reported that 30% to 50% of these posts are hit and damaged by plows during the winter. It also was reported that they can damage snow blowers if the operator is not careful.

Bollards are rigid barriers that provides a strong vertical element to the buffer space. Depending on how frequently the bollards are placed, this form of separation may result in an increased cost compared to others, and may not be as appropriate on higher speed streets.

Regardless of type (i.e., flexible or bollard), when compared to SBs, IB can allow the following illegal and, in several cases, unsafe movements/situations.

1. Depending on the density of the vertical separators used, they can allow people who drive who are trying to access a driveway to penetrate the SBL. Similarly, they can allow drivers to violate and enter the SBL and use it as a parking lane. These outcomes have been observed, usually in cases of small delivery trucks and vehicle passenger pick-up and drop-offs.
2. Although debatable as to its desirability, the wider buffer space does facilitate storage of snow during the winter months. Often such situations can transform this type of barrier from penetrable to impenetrable by regularly sized vehicles.
3. Flexposts especially are most often damaged by vehicles, snow plows, or other street cleaning equipment.
4. During interviews with bicycle advocacy groups (likely “Strong and Fearless” people who cycle by positionality within an advocacy group), it was mentioned that they prefer IBs over the other three buffer designs because it allows them to ride inside the buffer to pass people who cycle slowly or to indiscriminately switch in and out between the SBL and the vehicle lanes.

As will be discussed later, this IBs require the least amount of transition from the mid-block geometry to the mixing zone part at the end of the block. All other buffer designs require a transition section of the Intermittent Barrier type before fully transitioning into the mixing zone.

In discussions with bike lane designers, a hybrid barrier category between the SB and the IB was mentioned. This intermediate category, loosely termed as Rail, can be considered as an extreme case of the IB where the bollards are at maximum density prohibiting all barrier penetrations. The principal difference between the Rail and the SB is that the Rail does not provide the same level of safety benefits for the bike lane users because it in most cases will not have the strength to stop a vehicle. This barrier type is not discussed further because the examples evaluated in the project did not include it.

8.2.1.3 Curb and Intermittent barrier (CIB)

The CIB design can be considered as an evolution of the IB design. It introduces a solid low height curb in the middle of the buffer zone. Mountable curbs are an option where emergency vehicle access may be required. There are many different variations and products for the curb element all achieving the same objective but differ greatly in terms of costs. For the purposes of this study we offer two variants, a semi-permanent and a removable one.

Concrete curbs can either be cast in place or precast. This type of buffer element is more expensive to construct and install but provides a continuous raised buffer that is attractive with little long-term maintenance required. In many cases, standard curb-paving equipment can be used but such installations will require milling part of the pavement to allow for better bonding between curb and road surface. Depending on the lengths of the curbs between interruptions as well as the formation of windrows, the possibility of detrimental effects on drainage must be considered.

Parking stops and similar low linear barriers are inexpensive buffer solutions that offer several benefits. These barriers have a high level of durability, can provide near continuous separation, and are a good solution when minimal buffer width is available. However, using the minimum width will not provide the same level of comfort and protection due to their low height and cyclists' proximity to traffic.

Regardless of the particular product implementation, the curb can help deflect a vehicle from encroaching inside the buffer and damaging the bollards. Actual evidence of deflection can be seen on the SBL on Plymouth Ave in Minneapolis, shown in Figure 8.1. When there, one can observe rubber marks on the concrete curb on the street side on spots where people who drive likely drifted inside the driving lane but their wheel was deflected by the curb. One can hypothesize that in the absence of the curb such momentary losses of control would have at least resulted in damaged bollards. Given that benefit, the overall width of the buffer can be smaller as compared to the no-curb version. A corollary to this feature is that the use of a low height curb may hypothetically reduce the cost of the damage resulting from drivers' minor loss of control.

Although it may appear similar, the CIB is different than a Rail barrier and functions differently when installed. For example, pedestrians crossing the street at an unmarked crossing would be stopped by a Rail but not by a CIB. Furthermore, although the CIB prevents people who cycle from crossing over to the driving lanes while in motion, it does not stop them if they choose to momentarily dismount and "jump" over the curb.

8.2.1.4 Grade Separation (GS)

SBLs vertically separated by the vehicle driving lanes can be considered as a design evolving from multiuse trails adapted to more urban and/ or higher volume contexts. Such SBLs can be discussed in the context sidewalk/shared space design, operation, and safety. They rarely involve the use of bollards as vertical elements, with some using a grass boulevard with trees or planters as the vertical solid elements in addition to the curb itself. Fully physically separated bicycle facilities provide a high level of comfort by creating an exclusive space for people who cycle and by minimizing bicycle lane blockage. Depending on the presence of a boulevard and in general the distance between the roadway-curb boundary and the cycle path, GS SBLs can be plowed with the addition of a wing on a standard plow.

As will be discussed later in the mixing zone design section, SBLs with this type of buffer design require special considerations for the majority of cases. This study did not explicitly investigate the implication and relationship between such SBL designs and the adjacent sidewalk pedestrian traffic. It is likely, however, this specific subject will warrant attention as bicycle speeds are rising with the introduction of electric cycles that can easily reach speeds of 20 to 25 mph. Such speeds today are largely reserved for fit and experienced people who cycle which by nature of volume as well as experience may pose the least danger to pedestrians.

8.2.1.5 Mid-Block areas of concern for SBL buffer design

Accessible Parking and Loading Zones

On-street parking can provide access for people with disabilities. Where on-street parking is designated, accessible parking spaces must be provided. The Proposed Accessibility Guidelines for Pedestrian Facilities in the Public Right-of-Way (PROWAG), published by the U.S. Access Board in 2011 (53), provide a useful framework to help public entities meet their obligations under the ADA to make their programs, services, and activities in the public rights-of-way readily accessible to and usable by individuals with disabilities. Even if designated accessible spaces are not currently available, parking spaces may be utilized by people using vans with a lift they can deploy directly onto the sidewalk. If not planned carefully, SBL installations can potentially impede access to the curb. Design guidelines on how to combine accessible parking spots with SBLs in general are available on several existing design manuals. Unfortunately, none of these manuals provide detailed instructions that cover all the possible SBL structural element alternatives. Although in this study we also do not produce detailed design plans, we do discuss the compatibility and implications involved between SBL design alternatives and accessible parking locations.

Apart from parking, freight operations, trash pick-up, and mail deliveries are some examples of additional reasons why restricting access to the sidewalk level from the roadway is a complicated issue. The term “loading zone” is used to describe the spatial design element required to satisfy these needs. In a geometrical sense, loading zones are very similar to accessible parking. For this reason, we will only emphasize important differences and operational models that are applicable specifically in the context of loading zones.

Driveways

Driveways that intersect with SBLs create a potential crash risk due to the conflict between people turning in motor vehicles and people who cycle proceeding through. The risk is increased at locations where there is poor sight distance due to parked cars, landscaping, and other obstructions, or where the design may result in unexpected movements such as the contra-flow direction of travel that occurs on two-way separated bike lanes. On the subject of driveways, the proposed recommendations emphasize specific complexities arising with the different buffer design alternatives. Some of these complexities are increased with the presence of on-street parking.

8.2.2 Intersections (Mixing Zones)

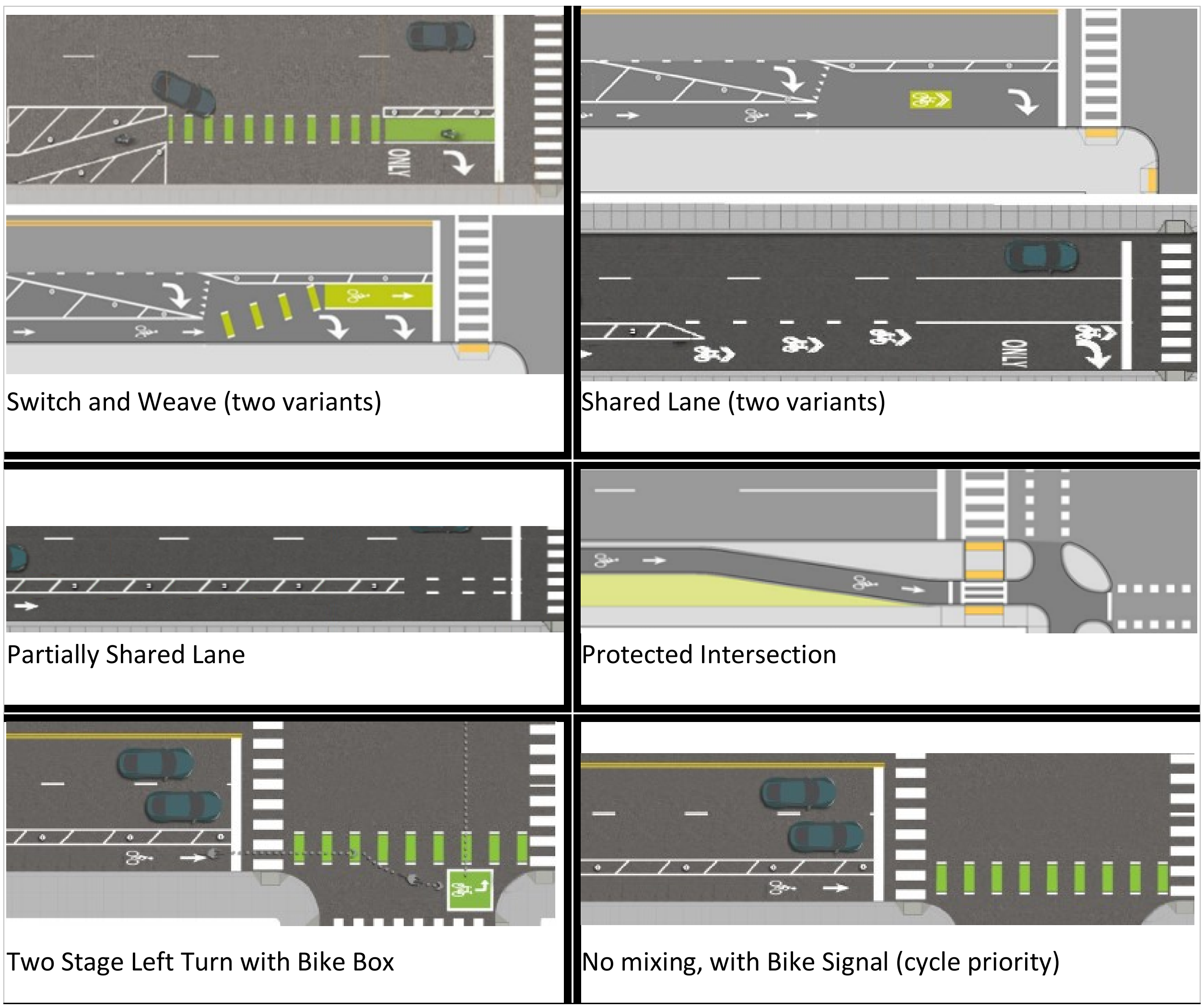
In this study we use the term "mixing zone" to define the area where the SBL meets an intersection. This term is used in some industry guides to describe specific types of treatments at those locations. We use the term in a more general way to describe all possible design alternatives for these conflict areas. Conflict areas that involve near-side transit stops are defined as "bus stops" and are not included in our definition of mixing zones and instead are discussed separately.

Six different types of mixing zones are defined in this study: Switch and Weave (SW), Shared Lane (SL), Partially Shared Lane (PSL), Protected Intersection (PI), Two-Stage Left Turn with Bike Box (TSLT), and No Mixing with Bike Signal (NMBS) Schematics of each type of mixing zone are presented in Figure 8.2 (images were adapted from the MassDOT (16) and FHWA guidance (17)).

It is important to clarify the implied goals of each mixing zone design, the different turning movements they are designed to facilitate, and which movements they do not facilitate or allow. In Table 8-1, we assume that the hypothetical approach discussed allows through, right, and left turning movements for vehicles and cycles. This assumption does not explicitly take into consideration the bike lane design, if any, on the turning movement destination section. Table 8-1 summarizes the ways each turning movement is handled on each of the six designs. Green color indicates that the movement is handled without potential conflicts, yellow indicates that the movement is possible but it involves a potential conflict between people who drive and those who cycle, and red indicates that this movement is not explicitly catered by the design as shown in Figure 8.2. The latter involves all left turns because the designs discussed involve right-side bike lanes interacting with right turning vehicles.

As mentioned above, the design examples used in this study were adapted from existing guides without changing the functional elements of each design. Although not directly stated, it is implied that the context the aforementioned guides describe the mixing zone design alternatives prioritizes on SBL continuity and not in catering movements departing from the main facility. For this reason, the SW, SL, and PSL designs, as shown, do not include traffic control elements facilitating left turn movements. On all applicable roads, people who cycle can legally use the leftmost lane to perform a left turn. If such movements were to be catered, and not simply allowed, on those designs additional traffic control elements are necessary. For example, in the aforementioned mixing zone types, the addition of a full width bike box would achieve that objective. Therefore, it is important to note that the guidance developed implies on the designs as shown, emphasizing the need for additional control elements if the goal is to explicitly manage movements not covered adequately.

Given that the in some degree all mixing zones involve a change in carriageway geometry (roadway, sidewalk level, or both) as compared to the mid-block one, we introduce the concept of the "transition area." The transition area is the required path assignment and traffic control that allows the efficient transition between the mid-block SBL geometry and the mixing zone geometry just upstream of the crosswalk or stop line. All design guides present mixing zones with selected, limited examples of mid-block buffer designs. For example, the images used in Figure 8.2 show each alternative except the PI mixing zone alternatives interfacing with an IB buffer design. In contrast, the PI mixing zone image implies that it is only applicable to a Grade Separated SBL. This generates problems when designers are required to create different kinds of combinations. Considerations regarding the required transition



Switch and Weave (two variants)

Shared Lane (two variants)

Partially Shared Lane

Protected Intersection

Two Stage Left Turn with Bike Box

No mixing, with Bike Signal (cycle priority)

Figure 8.2 Types of Mixing Zones covered in this study

Table 8-1 Turning movement accommodation and conflict handling

	Switch and Weave (SW)	Shared Lane (SL)	Partially Shared Lane (PSL)	Protected Intersection (PI)	Two-Stage Left Turn with Bike Box (TSLT)	No Mixing, Bike Signal (NMBS)	
						Bike only phase	General Phase
Through				Crosswalk + Signal			
Left Turn				Crosswalk + Signal	Indirectly		
Right Turn							

zones given a specific combination of buffer and mixing zone design is covered in the next chapter. There are two design elements that have been included in the latest design manuals albeit with no contextual connection to the buffer design. These mixing zone elements are the Bend-Out and Bend-In designs.

Bend-Out: In the schematic of the PI mixing zone in Figure 8.2, depicts a Bend-Out design. A Bend-Out design 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 Bend-Out can be used to transition from any buffer design to a PI mixing zone.

Bend-In: This design shifts the bike lane in toward the motor vehicle lanes, which can increase visibility and awareness of people who cycle and who drive of one another. Such a transition area can be used to interface GS SBLs with S&W, TSLT, and NMBS mixing zones, since all of them require the SBL to be on the roadway level. Bend-Ins are usually found in conjunction with on-street parking, IB SBLs, leading the all mixing zones except S&W and PI.

8.2.2.1 Switch and Weave (SW)

The objectives of the SW design are to facilitate and control mixed mode lane traffic (people who drive and who cycle side by side). The two SW design alternatives shown in Figure 8.2, implicitly involve right-only turn lanes, but suggest a reversal of priority rules for the potential conflicts. The main conflict point is at the left area of the zone. In Minnesota, statute 169.19 and 169.20 describe priority rules in varying degrees of clarity. Regardless, no matter what the rules describe, human behavior must be taken into account in order to prevent crashes instead of managing blame after the fact. In the absence of traffic control devices (pavement markings and signs) driving behaviors guided by habit can be expected. From the two variations of a SW mixing zone covered in this study the first design alternative includes actual yield pavement markings for people who drive while the second, as shown, has no regulatory traffic control messages, implying a more first-come first-served operation. On the latter, and assuming generalized lane change behavior by people who drive, it is reasonable to expect that the bicycle will end up yielding more often in this design. Regardless, the three movements of concern are:

- Through Movement of Cyclists.
  - No through movements by drivers of vehicles from the mixed traffic lane, only cyclists
  - Goal is to facilitate the switching of sides in the lane between drivers and cyclists turning right. Successful switching results in elimination of any potential conflicts between cyclists making through movements drivers of vehicles turning right.
- Right Movements of Drivers and Cyclists.
  - Primary goal of the design is to allow for drivers of vehicles to Turn-Right-On Red without being in conflict with cyclists who also are turning right.
  - Assumes right-turning cyclists are in queue with drivers in the lane.
  - Provides no room for cyclists to pass stopped vehicles and turn right (although people who cycle sometimes encroach into areas between vehicles and the curb).
  - Given that this design reserves lane width on the left side of the right-turn lane for through movements, it is conceivable that cyclists who are unwilling to queue behind vehicles could use that space to turn right following a bigger turning arc and end up on the left side of the perpendicular destination lane. This maneuver potentially could generate a conflict since the person cycling is on the wrong side of the vehicle.
- Left Movement of Cyclists. Does not address vehicle left movements.
  - This design does not support direct left turning movements, so cyclists need to enter the left-turn lane and queue among vehicles.
  - It is conceivable that people who cycle could turn slightly right following a bigger turn arc and jump ahead of the through movement of the cross-street. Like the Two-Stage-Left-Turn but without the added safety of a bike box.

8.2.2.2 Shared Lane (SL).

The SL is designed very similarly to the SW discussed above; therefore, we only discuss differences with the SW design. The main difference is that people who drive and people who cycle are forced to follow each other since the lane width generally is insufficient to accommodate both vehicles and bicycles, though mixing sometimes occurs. In this design, right turns are better served since there is no misunderstanding or opportunities that could lead to people cycling on the left side of the lane.

8.2.2.3 Partially Shared Lane (PSL).

The PSL design is a further evolution of the SW and SL designs. The PSL design does not involve a formal Right-Turn Only lane for the vehicles, but rather signals with the termination of the buffer and the double dashed lines that right turn vehicles can occupy this space. This feature assumes that people who drive will utilize the transition zone to move right before turning and avoid potential conflicts with cyclists going straight. In Table 8-1, we indicate this with yellow because it is conceivable that people who drive do not use the facility as intended but instead, they turn right from the driving lane. This safety concern has been emphasized in several studies (54, 55, and 55 for example). An example of another problematic situation that can occur is when several through moving cyclists are at the stop line waiting for the signal to change. This group may block any right-turning vehicles from entering the transition zone and most likely encourage them to turn from the through driving lane. This illegal maneuver gives no warning to the cyclists going through and can result in a conflict. Designs that provide proper length to the interface zone can mitigate this concern.

8.2.2.4 Protected Intersection (PI)

Protected Intersections provide physical separation between cyclists and drivers as they enter the intersection. In most of the various PI SBL design variants, the cyclists have the same available trajectories as pedestrians on the sidewalk. This fact suggests that people who cycle need to obey all pedestrian signal indicators (unlike the previously mentioned designs where people who cycle follow the same signal indicators as drivers of vehicles). Most current design manuals suggest that the physical separation forces right turning vehicles – one of the greatest threats to cyclists at intersections – to slow down before turning by narrowing the available space, adding visibility to people who cycle as they enter the intersection, and forcing people who drive to make a tighter angle turn. These design elements help slow drivers and increase visibility by distancing the approaching people on bicycles from the blind spot of a driver. All these imply a greater level of safety for the people who cycle. Given that PI mixing zones are rare and on top of that have several different design variants, increased safety for the aforementioned reasons is not guaranteed, and the safety impact has to be investigated on a case-by-case basis.

8.2.2.5 Two Stage Left Turn with Bike Box (TSLT)

The TSLT design is the only design that explicitly facilitates left turns for the bicycles. It involves a two-stage maneuver where a left turning cycle (1) travels through the intersection to the special “box” space reserved forward of the right-hand side approach crosswalk, and (2) then, when in the box, turns and proceeds in the new direction. This design can generate a number of conflicts.

- The TSLT design, as shown, does not provide any clear priority or interface zone (see PS above) between through moving cycles and right turn vehicles. This omission can potentially result in delays to right turn vehicles (similar to delays on any lane catering to more than one turning movement) as well as potential conflict hazards to through moving cycles because the advised shared space is not included forcing the vehicle to turn in front of the bicycle. The colored pavement alerts people who drive turning right that cycles have priority since cycle-crossing is offset, closer to the driving lane, than the perpendicular pedestrian crossing.
- Unless the approach with the “box” has a No-Turn-on-Red sign, the box may be illegally occupied by vehicles turning right looking for a gap during which they can turn. Such vehicles will prevent the cycle from reaching a safe spot and leave them further exposed. In a recently concluded LRRB research project, it has been shown that when, either because of a crosswalk or in this case a bike box, the distance between the stop line and the edge of the perpendicular road right-most lane increases, the percent of drivers stopping over the line and over the crosswalk increases (57).
- Potentially unsafe interactions can occur on semi-actuated signalized intersections unless specifically located cycle detectors are used at the location of the box. A limitation of the design

is that it is difficult to place a cycle phase call button where people who cycle can use it conveniently.

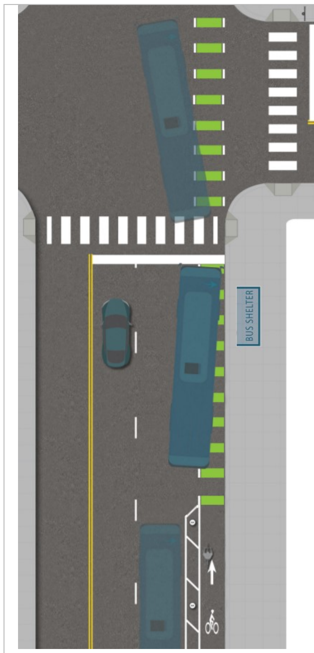
8.2.2.6 No Mixing, with Bike Signal (NMBS)

The NMBS design features a bike signal to prioritize bicycle movements and reduce conflicts. Bicycle signals, similar to pedestrian signals, provide an exclusive phase or a leading bicycle interval for people cycling through the intersection. A bicycle signal separates cyclist movements from conflicting motor vehicle or pedestrian movements. They can also simplify cyclist movements through complex intersections, with the possibility of improving overall operations and reducing conflicts for all modes. A leading bicycle interval acts similarly to a leading pedestrian interval by giving people on bicycles a head start, making them more visible and allowing them to establish position moving through the intersection. Bike signals, particularly leading bicycle interval timing, could greatly improve the level of comfort for people who cycle along the corridor. In conjunction with bicycle boxes and protected intersections (where appropriate), leading bicycle intervals have the potential to improve overall intersection operations by providing people who cycle with a queuing area which would then clear the intersection more efficiently.

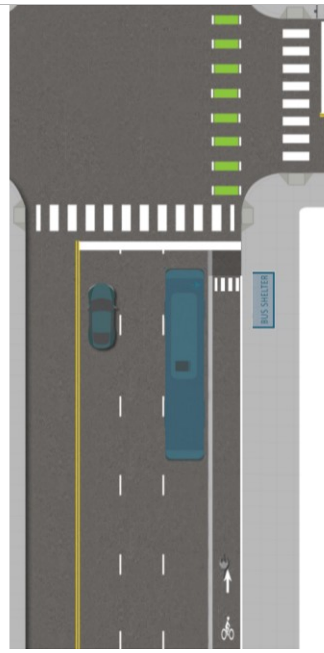
It is important to emphasize that in the case of leading bicycle interval timing implementations, the aforementioned benefits apply only during the bike only phase. However, after the lead green time is exhausted and the people driving vehicles also receive a green. This design then operates in the same way as the PSL but without the interface zone. This design may be particularly useful in cases where the majority of the SBL traffic involves a left turn connection between two perpendicular SBLs. The rationale for this application is that, because people cycling move on green while all other movements are on red, they can utilize the last period of the perpendicular road pedestrian phase and transfer to the left. In addition to this application, depending on the traffic signal timing, there also is the possibility of a cycle-only phase allowing left and through movements. This modification will increase the overall cycle length, especially on roads where cycle left turns involve crossing over many vehicle lanes, but people cycling may be able to take a more direct diagonal path in such cases.

8.2.3 Bus Stops

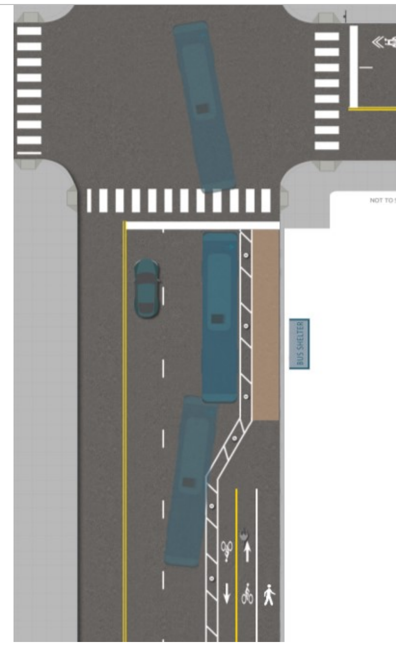
In the context of this study, the six Bus Stop design alternatives shown in Figure 8.3 were explored. All the Bus Stop designs investigated involve near-side bus stops (located immediately prior to an intersection). The corollary to this is that, by default, the bus stop is the mixing zone. Design images were adapted from FHWA guidance (17) and altered to better show bus and car traffic.



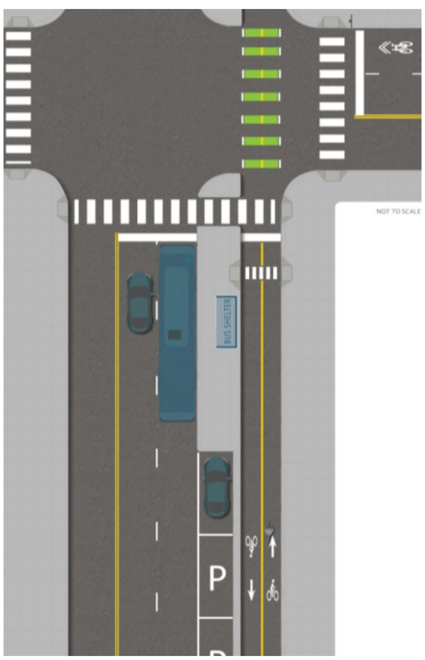
Bus 1: Curbside Bus Stop, One-Way Street-Level Protected Bike Lane



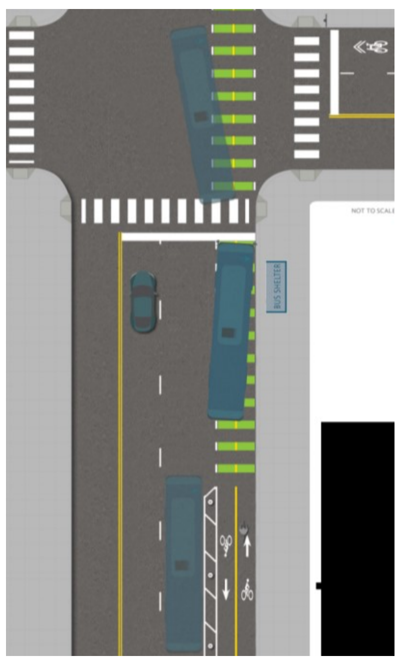
Bus 2: Curbside Bus Stop, One-Way Raised Cycletrack



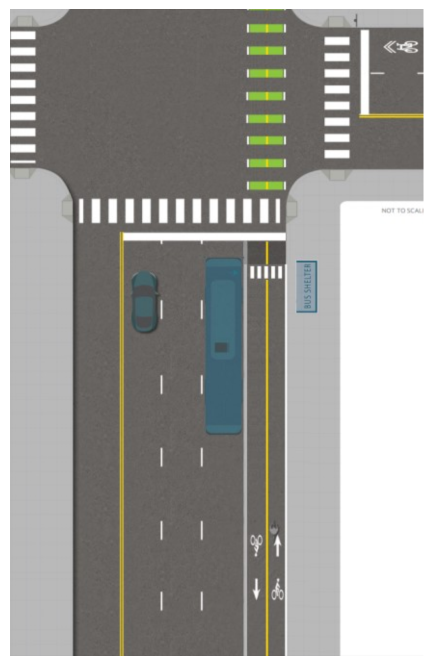
Bus 3: In-Street Bus Stop, Shared Street-Level Protected Bike Lane



Bus 4: Floating Island Bus Stop, Two-Way Street-Level Protected Bike Lane



Bus 5: Curbside Bus Stop, Two-Way Street-Level Protected Bike Lane



Bus 6: Curbside Bus Stop, Two-Way Raised Cycletrack

Figure 8.3 Types of bus stop designs covered in this study

CHAPTER 9: DESIGN AND OPERATIONAL GUIDANCE FOR ELEMENTS OF SEPARATED BICYCLE LANES

As the project title implies the principal objective of this project is to synthesize the knowledge and insight accumulated in a series of easy-to-read visualizations and recommendations for planners and engineers when they plan, design, construct, and operate Separated Bike Lanes (SBLs). This chapter does not present strict engineering guidelines nor repeat the guidance available in existing design guides (e.g., FHWA Separated Bike Lane Planning and Design Guide (2015), FHWA Bikeway Selection Guide (2019)). Instead, focusing on filling the knowledge gaps identified by the Technical Advisory Panel (TAP), it presents supplementary guidance and recommendations for planning selected elements of SBLs.

The TAP prioritized three structural elements and one operational element for detailed study. The three structural elements were: Buffer Design, Mixing Zone Design, and Bus Stop Design. The single operational consideration was Maintenance Considerations (both summer and winter). The TAP also prioritized the need for information about some specific aspects of SBL design such as the need for separation and implications for people with disabilities. Finally, the TAP specified the goal of illustrating tradeoffs in design of each structural and operational element. This chapter attempts to deliver factual and derived information in a compact, organized way.

A fundamental principle underlying the guidance presented here is that the process of designing a SBL is context specific, always involves exercise of professional judgment to match design goals and objectives to physical context, and may vary in response to other relevant circumstances such as the availability of funding. To elaborate, multiple design options exist for nearly every context, and the design objective is to identify the options that best balance objectives such as reducing risk and increasing safety, inducing demand, or minimizing costs, within the broader community or societal goals. Hence, the guidance presented here does not identify "preferred" options for any structural element or maintenance activity. Instead, consistent with the TAP emphases on highlighting tradeoffs, the guidance identifies multiple considerations for each of the selected structural elements and maintenance considerations to inform the choices made in the design process.

We summarize considerations for each of the selected elements in visualizations we call tradeoff matrixes. We first present the content and structure of the matrixes (Section 9.1), followed by a set of general guidance statements that are relevant to each selected element (Section 9.2). We then present the tradeoff matrixes for Buffer Designs (Section 9.3), Mixing Zones (Section 9.4), Combinations of Buffer Designs and Mixing Zones (Section 9.5), and Bus Stops (Section 9.6). Each of the four matrixes includes considerations for winter operation and maintenance.

9.1 STRUCTURE, CONTENT, AND DEFINITIONS USED IN TRADEOFF MATRIXES

The tradeoff matrices present in the following sections use a shaded color scale to illustrate tradeoffs. For any particular consideration (e.g., cyclists' perceptions of safety), the lightest shade of color is used to denote the most applicable design while the darkest shade of color is used to identify alternative applicable in the fewest circumstances. The color black is used in cells of the matrixes to indicate that in the context of the particular subject there is no logical or feasible relationship. To further clarify this, we also use the "Not Applicable" label. In cases where more discussion is warranted, the number in parenthesis acts as a footnote directing the reader to the information at the end of the table.

In subjects involving costs, a relative scale, **by row**, visualized in $ signs in each cell, is used. It is important to remember not to use the matrix to make inferences of cost across different rows or between matrixes. As noted, this chapter does not make specific recommendations for particular designs because site-specific designs are contingent upon planning objectives, contextual features, and site-specific engineering considerations. The summary matrices presented here are best interpreted as sets of factors to consider when designing SBLs to serve the needs of people who cycle in light of other relevant objectives such as costs. The guidance matrixes follow a structured format separating the discussion in the following subject areas that are used as subheadings to separate sections of each matrix:

1. **Variants and Variant Combinations (Buffer Design only)**
2. **Context Dependent Feasibility**
3. **Objective Indicators of Safety**
4. **Perceived Clarity of Action**
5. **Tradeoffs and Implicit Costs**
6. **Maintenance Considerations**
7. **General Considerations in Design**

- **Variants and Variant Combinations**: Where applicable, in the first row of each guidance matrix, the most common variants and variant combinations for the different design alternatives are mentioned.
- **Context Dependent Feasibility**: This section summarizes the applicability/feasibility of including the structural element design alternative being considered in construction projects of different cost levels. Even if cost reduction is not a constraint, discussing the implementation of different buffer designs in the context of influence and relation to different parts of the carriageway helps the understanding of the different alternative scopes and constraints each design introduces. The MnDOT Bicycle Facility Design Manual (14) and FHWA Incorporating Bicycle Networks in Resurfacing Projects (52) offer extensive guidance on this subject, but they do not offer details regarding the constraints introduced with the different design alternatives. Regardless, based on direction from the TAP, the following construction project levels were identified, in relation to implementing/introducing a new SBL in conjunction with:
    - <u>Restriping only</u>: These maintenance projects involve only changes in the original road markings. This is the least costly category since it takes place as part of the usual repainting of the road markings. Combining the introduction of a new SBL with a restriping project implies no changes on the road surface or any type of in-place construction other than maybe the addition of flexposts (bollards are stronger, fixed structures that require anchoring). Usually, restriping projects involve repainting the

road markings that have faded away over time. A common way to add an SBL during a restriping project is to remove existing on-street parking. In this case, minimal modification of the existing lane markings is required. If the implementation of the SBL requires realignment of lanes to reduce width it can result in substantial pavement grinding to remove all traces of old markings. If this is the case, then the following project category is more applicable.

- Restriping as part of regularly scheduled overlay maintenance activities: Roadways, especially in places like Minnesota with hot summers and very cold winters, deteriorate and require removal and replacement of the topmost asphalt or concrete layer. These types of projects do not involve any work on concrete boundary elements like the gutter/curb or median islands. When the surface of the pavement is ground down to allow for better adhesion of the new layer as well as not to change the vertical elevation of the roadway, all existing road markings are destroyed and need to be replaced. Combining the introduction of a new SBL with this road resurfacing project allows more freedom as changes on all affected lanes in terms of number, alignment, and width can be implemented. However, it is important to emphasize that, although more extensive and expensive, this projects still do not involve any changes beyond the physical boundaries of the pavement as defined by preexisting curb lines, including any such structural elements on the median. Considering these limitations, 3-lane conversions or road diet projects, as they commonly refer to, that do not involve any changes to the pavement's horizontal and vertical alignment can fall in this category and very often combine the implementation of a new bike lane, SBL or other. The key characteristic and limitation of such projects is that they do not involve any modification of curbs. Although, some structural elements like bollards and cast-in-place curbs separators can be implemented during such projects, anything that will affect the drainage of the carriageway involves cost levels covered by the next category.
- Redesign or reconfiguration: This category involves projects that expand the construction footprint to include changes of the boundaries of the carriageway like curbs, boulevards, and sidewalks as well as median elements like concrete barriers or islands. The main reason these projects are substantially more expensive and complicated is that any changes in the roadway curb lines affects drainage. Therefore, these projects involve not only changes in the carriageway surface but also changes in the foundation and storm-water management levels. Examples of such projects are road diets that include changes to curb lines and other poured structural elements that do not dramatically change the sidewalk level. How much these projects can extend into the aforementioned area separates them from the next and final project category.
- Full Reconstruction: Projects implementing complete streets or right sizing the roadway are examples of these most extensive and expensive of projects. Basically, at this level there isn't much of the old carriageway alignment left and everything can change including property lines.

In the context of pairing the implementation of a SBL with a maintenance project, the darker the shade the less compatible a given combination is. To that end, the color black represents total

incompatibility, the darkest shade of color signifies partial compatibility with limitations of the SBL design, and lighter shades indicates a compatibility with the majority of SBL design alternatives. The label “most applicable” is used to differentiate between fully compatible combinations and the one that presents simultaneously the most cost-effective combination with the least amount of limitations in the final design of the SBL. While "most applicable" indicates the most balanced combination, we encourage consideration and implementation of all options whenever possible. In the combinations where SBL implementation is feasible the labels discuss the specific design elements that allow such a combination.
It should be noted that, the guidance produced does not consider pilot or demonstration projects. Under certain conditions in such projects the SBL implementation can be based on short term solutions and designs for the sake of expediency and ease of modifications. The provided guidance, relates only to final, long term projects.

- **Objective Indicators of Safety**: This section lists the ways different kinds of conflicts or other safety concerns are handled by each structural element design alternative.
    - The colors used are to rank the different alternatives comparatively and should not be considered as a unified scale comparing safety across table rows. Labels serve as links to additional discussion sections following the matrix.
- **Perceived Clarity of Action**: This section, relevant only to mixing zones and bus stops, summarizes the information collected through the survey of people who cycle regarding their level of understanding of rules governing right-of-way and other road user actions.
- **Tradeoffs and Implicit Costs**: This section highlights differences between structural element design alternatives in terms of operation and implementation costs. The matrixes include subjects this study focuses on and therefore it should not be considered as a comprehensive listing off all possible tradeoffs and costs.
- **Maintenance Considerations**: This section lists relevant upkeep activities and costs and how each of these change based on the structural element design alternative involved. Properly maintaining SBLs involves a set of unique issues that may not be compatible with general roadway or sidewalk maintenance.
    - The maintenance needs of the buffer both in terms of the vertical element as well as the road marking, vary a lot between buffer, mixing zone, and bus stop design alternatives. The matrixes provide guidance on specific problem dimensions.
    - Seasonal maintenance is discussed separately focusing on debris removal in spring (non-winter) and SBL snow/ice clearance during the winter months.
        - When building SBLs, municipalities must consider how they will be swept in warmer months and plowed during snow events. Consideration should include an inventory of existing maintenance equipment, whether they can fit and operate in the proposed SBL, and alternative options if the equipment will not be compatible. The width of separated bike lanes relative to the width of sanitation vehicles is a particularly important issue to address during planning stages.
        - The width as well as type of separation affects options and considerations for providing sufficient snow storage capacity along the facility, primarily in the

        roadway and sidewalk levels. The need and cost for snow removal is also affected by width and type of separation. In the guidance matrixes, plowing complexity, need for specialized equipment, and snow storage availability are covered separately.

        - Operationally, common maintenance problems are the lack of coordination between planning and maintenance departments. Plowing and sweeping problems are exacerbated in many municipalities due to their separate departments for planning and maintaining SBLs. During the project interviews, both ROW owners as well as cycle advocacy groups emphasized the importance of prioritizing snow clearance on various routes both on the individual jurisdiction level as well as in regards to the overall bikeway network.

- **General Considerations in Design**: This general section lists considerations that are of a more general scope or do not fit any of the aforementioned sections.
    - **Visually impaired users:** Implications to visually impaired people with a focus on considerations to ensure that the facility will not create a hazard for people with visual impairments.
    - **Mobility impaired users:** Implications to accessible loading and unloading.
    - **Consistency of design:** Mainly relevant to mixing zones and bus stops but also under some conditions to buffer design. It expresses a combination between familiarity with the particular design and the complexity of the implicit and explicit rules governing its use. It is fundamental traffic engineering principle that roadways of a similar type and function should have a familiar "look" to road users; traffic control devices should be as uniform as possible and suggest the same behavior and ROW rules. Although this does not assure uniform reactions from road users, it at least narrows the range of behavior as users become accustomed to and familiar with the cues traffic engineers design into the system. Therefore, the guidance provided takes into consideration the degree of uniformity each design alternative has.
    - **Continuation of path trajectory:** Degree of geometric directness of the bicycle path both in the macro scale (transitions between different grade levels) as well as at the micro scale (directional adjustments around loading zones, driveways, lane sides, etc.). Bend-ins and Bend-outs for example are features that somewhat reduce path continuity while bike boxes introduce even greater discontinuity.

9.2 GENERAL GUIDANCE STATEMENTS

The following are general guidance statements and findings. The first set involves findings regarding preferences about general SBL design and operation or applications of general design principles to the case of SBLs. The second set focuses mainly on winter and summer maintenance.

- During the interviews, leading bicycle advocates emphasized the importance of a connected network of SBLs. The consensus is that, although less undesirable than complete lack of bicycle facilities, transitions between separated/protected and non-separated bike lanes reduce the overall feeling of safety and comfort provided by the SBL. The idea is that people who cycle prefer to minimize the interactions with traffic between origin and destination. Avoiding traffic is not feasible right now when many cities struggle to have a connected network of bike lanes and designated routes, much less a network of SBLs. Nevertheless, a priority should be given in selecting routes that allow for the longest uninterrupted sections of SBLs.

- One-way SBLs are preferred by people who cycle overall specifically because they provide a sense of consistency in design. Two-way lanes can generate conflicts and make turns difficult. Contraflow lanes are in general the least preferred by people who cycle because they are confusing and dangerous.
- Predictability is an important factor in reducing risk and increasing safety. A general engineering design principle is to “engineer” predictability. When applied to SBLs, this principle means that people who drive, people who cycle, and pedestrians all should be able to anticipate how the other user groups will act when using a facility. Although exceptions occur – both people who drive and people who cycle occasionally depart from lanes or run red lights- effective designs foster predictability.
- People who cycle are not a monolithic group. “Strong and Fearless” and “Enthused and Confident” people who cycle have very different preferences than “Interested but Concerned” people who cycle. Therefore, design considerations need to take into account all types of people that ride bicycles, and cater to the least experienced and most concerned whenever possible, especially from the perspective of fostering demand.
- The official guidance provided in the FHWA Bikeway Design Guide, states that ideally, SBLs will not operate along the same side of the roadway as high-frequency transit routes, either by using different sides of the street or different streets. However, on many corridors, this division between transit and bicycles is not possible. In these cases, transit stops present a challenge among interactions with people who cycle, transit vehicles, and those accessing transit stops. Where possible, separation should continue at transit stops by routing people who cycle behind the bus platform. This type of design avoids conflicts with transit vehicles but does create potential conflicts with pedestrians who must cross the separated bike lane to access the transit stop. This potential pedestrian conflict can be mitigated through design and the provision of discrete crossing locations. Visually impaired pedestrians accessing the bus stop should be directed to the crosswalk using detectable warnings.
- Icy roads were, by far, the reason cited most often by survey respondents (45%) for not riding during winter. Furthermore, as indicated by the analysis, ice is even a bigger concern than fresh unpacked snow. The implication of these findings is the priority of maintenance crews should be to clear the SBL before the snow compacts, solidifies, and turns to ice. This maintenance priority cannot be “regulated” (just as winter maintenance of roadways designated for vehicles is not regulated), but public works and transportation agencies can prioritize snow removal as part of best practices. Analyses of the survey results provide strong evidence that people who cycle strongly prefer to ride on clear and dry pavement: their likelihood of rating SLBs as safe and comfortable increased significantly as the width of the clear pavement increased. This finding suggests that prioritizing lane clearance during winter may be the most important maintenance

practice if increasing SBL use during the winter season is an objective. Because of the narrow width of most SBLs, prioritizing removal of snow to avoid subsequent accumulation of ice and to maintain clear pavement likely will require access to specialized equipment and, in some or many cases, vehicles with trailers to transport the equipment to the SBLs. Experts who were interviewed indicated in some cases the availability of specialized equipment for maintenance was a factor in design because agencies did not have funds for acquisition of additional equipment. Consultation with maintenance staff during the design process is therefore important.

9.3 CONSIDERATIONS IN THE DESIGN OF BUFFERS

This section presents the summary guidance and recommendations developed in regards to the Buffer separation design alternatives.

9.3.1 Assumptions

To assist in the comprehension of the buffer design alternatives matrix the following assumptions are clarified.

I. In the evaluation of the SBL user level of safety, we consider only situations involving average sized vehicles such as passenger cars moving at or close to the posted speed limit. Realistically, the heavier and/or faster a vehicle that loses control, the stronger and larger the barrier needs to be to prevent it from intruding into the SBL. For example, concrete planters are a method for the implementation of a solid barrier but, since they do not involve any reinforced anchor element, a fully loaded dump truck moving at 40mph could destroy them and push them into the SBL. Similarly, in a Grade Separated design, even if trees, utility poles, or other heavy street furniture are present, a heavy, fast moving vehicle will not be prevented from leaving the driving lanes and entering the sidewalk level. Such rare events are not included in our comparative ranking because it is impossible to generalize.

II. Similar assumptions are made in regards to the types of obstructions of the SBL by people who drive. For example, although a known problem, we do not cover issues arising from vehicles going over the curb to enter a GS SBL and drive or park on the sidewalk level. This explains the "Not Applicable" label in the Grade Separation column which signifies that such a concern is not comparable to more frequent forms of intrusion other designs are susceptible to.

III. We define "transition area" as the area of interface with the Mixing Zone that may be required between the mid-block section of the barrier and the area near the intersection where paths of people who drive and those who cycle intersect. In this section, the focus is on the safety impact. Similar interface areas are required in conjunction with some bus stop designs.

IV. "Shy Distance" is defined as the extra space, often marked by paint, required between the vertical element of the buffer and the bicycle path. This is the equivalent of the shoulder space reserved between the edge of the driving lane and the barrier.

9.3.2 Tradeoff Matrix for Separation Buffer Design

Table 9-1 Considerations and Tradeoffs for Four Buffer Designs

Buffer Design Considerations	Solid Barrier	Intermittent Barrier	Curb and Intermittent Barrier	Grade Separation
Variants and Variant combinations	**Concrete barrier Concrete planters**	**On-Street Parking Flexposts Bollards**	**On-Street Parking Cast in-place curb Parking stops**	**On-Street Parking Cycletrack; Shared use path Boulevard**
Context Dependent Feasibility				
Restriping only	Planters	Most applicable	Removable curb	Never
Restriping as part of regularly scheduled overlay maintenance activities.	Planters		Most applicable	Never
Redesign or reconfiguration	Concrete barrier with no foundation			Limited to pre-existing Sidewalk level area.
Full Reconstruction	Most applicable			Most applicable
Objective Indicators of Safety				
Protection from vehicles				
Interface with Mixing zone				Not Applicable
Perceived clarity of action				
Interactions with pedestrians				
Interactions with stopped vehicles		Depends on delineator spacing		
Relative Tradeoffs and Implicit Costs				
Degree of vehicle intrusion allowed				Not Applicable
On-street parking	Not Advised			Not Applicable
Effect on drainage				Not Applicable

Table 9-1 Considerations and Tradeoffs for Four Buffer Designs (Cont.)

Buffer Design Considerations	**Solid Barrier**	**Intermittent Barrier**	**Curb and Intermittent Barrier**	**Grade Separation**
Installation requirements:				
Street or lane modifications	$$	$	$$	Not Applicable
Buffer width requirement (*1*)	>3ft	>6ft	3ft to 6ft	Shared use path
Requires construction (i.e., grade separation, barrier)	$-$$$	$	$$	$$ + land
Curb edge *(*2)*				Not Applicable
• Area of painting				
○ Barrier proper	$	$$$	$	Not Applicable
○ Driveways *(*4)*	$	$-$$	$	$
○ Accessible parking spaces *(*5)*	$$	$	$	$$
○ Loading zones *(*5)*	$$	$	$	$
Extra cost per opening to allow access to adjacent properties	*(*3)*		flexposts, curb bumper	Driveway maintenance
Shy distance/buffer zone (minimum required in addition to barrier)	Vehicle side: 1ft SBL side: 6in	Part of buffer	Vehicle side: 2ft SBL side: 0	3ft from curb
Maintenance Considerations				
Frequency for Repairs of the Barrier	$	$$$	$	Not Applicable
Cost of Repairs of the Barrier	$$$	$$	$$	boulevard
Frequency/area of re-painting	$	$$	$$	$
Summer:				
• Difficulty of sweeping *(*6)*	$$	$	$$	$
• Effect on debris accumulation				Not Applicable
• **Winter**:				
Difficulty of plowing	$$$	$	$$	$
Snow Storage availability	Needs hauling	Store in buffer	Buffer	Design dependent
Specialized equipment	Depends on width		Depends on width	Sidewalk level
Effect on snow accumulation by plowing of driving lanes				Design dependent

Table 9-1 Considerations and Tradeoffs for Four Buffer Designs (Cont.)

Buffer Design Considerations	Solid Barrier	Intermittent Barrier	Curb and Intermittent Barrier	Grade Separation
General Considerations in Design				
• **ADA compliance:**				
Visually impaired users	Trapped pedestrians *(*7)*			Requires tactile directional treatments
Mobility impaired users	*(*8)*		*(*8)*	
• Consistency of design		Common, depends on quality of maintenance		Design dependent
• Continuation of path trajectory		Common, depends on quality of maintenance		Design dependent

(*1) Greater than 2 feet of buffer space or physical separation is preferred for cyclist comfort. At least 3ft of cleared width is preferred at all times, whether from debris in the summer or snow and ice in winter

(*2) Careful consideration should be given to the placement of asphalt joint lines and concrete expansion joints along the SBL and to rail crossings. This is typically a problem on SBLs that are on the left side of the curb line. The bicycle tire can become trapped within the joint, causing the cyclists to crash. Minimal curb apron width should be constructed or frequent maintenance conducted to keep the asphalt-to-concrete joint filled. Similar considerations can be made regarding pavement maintenance (potholes, uneven surface, cracking, etc.)

(*3) SB is most likely to be used in SBLs adjacent to driving lanes with higher speed limits. On all roads with speed limits higher than 25mph, crash attenuation devices must be installed on all edges of the solid barrier. Therefore the more openings provided, the higher the cost of the barrier construction and maintenance.

(*4) Driveways represent an interruption in the barrier. Green paint is used to warn all users about the potential of conflicts at each the driveway. In addition, depending on the presence of on-street parking, additional areas are marked with paint to preserve the sight distance for vehicles that exit the driveway. This cost increases with the width of the SBL and the width of the buffer.

(*5) Green paint is used along areas where mobility impaired pedestrians or delivery operators cross over the SBL to access the sidewalk.

(*6) Although IB SBLs provide more space for sweeping, debris often accumulate in the middle of the buffer because it is difficult to sweep between the delineators. The comparatively less desirable conditions of the SB stem from the fact that windblown debris will accumulate faster along a wall.

(*7) Visually impaired people can potentially be trapped inside the SBL if they confuse a mid-block location as an unmarked crossing.

(*8) Implementation of accessible parking spots require a break in the SB or CIB introducing issues and complications similar to driveways.

9.3.3 Preferences for Separation Buffer Design and SBL Mid-block Maintenance

The survey results provide evidence of the preferences of people who cycle for different buffer designs. While they generally perceived all buffer types as safe and comfortable:

- People who cycle were more unified in their perceptions of comfort and safety associated with solid barriers. Specifically, from a safety perspective, respondents indicated they felt safer on SB and GS buffers in both summer and winter.
- In general, intermittent barriers were perceived both as least safe and least comfortable during winter. This opinion was the same across age groups.
- The results suggest that the opportunity to reduce the gender gap is greatest with shifting from IB to any other barrier type.
- People who cycle expressed a preference towards the use of sand in the winter, although it is less effective over ice. In difference, they do not like salt because it causes damage to the bicycles.
- People who cycle emphasized the need for promptly clearing accumulated sand at the end of the season.

9.4 CONSIDERATIONS IN THE DESIGN OF MIXING ZONES

This section presents the summary guidance and recommendations developed in regards to mixing zones design alternatives.

9.4.1 Assumptions

To assist in the comprehension of the mixing zone design alternatives matrix the following assumptions are clarified.

I. All discussions are related to the specific area of the mixing zone and should be considered separate to equivalent subjects covered in the buffer design. For example, one-way SBLs will always require narrower equipment to sweep and plow but in the cases of the S&W and SL the area of the mixing zone, after the mid-block to intersection transition area, can be maintained with the same equipment as the driving lanes.

II. Protected intersections, as described in the user survey, are the intersection equivalent of a mid-block grade separated SBL. This is not entirely true since, with the use of Bend-Out transition area designs, any kind of mid-block SBL can connect with a PI mixing zone to traverse the intersection. Since Bend-Outs are uncommon and examples of them were not included in the user survey, guidance that considers such design variants is based on engineering judgement.

9.4.2 Tradeoff Matrix for the Design of Mixing Zones

Table 9-2 Considerations and Tradeoffs for Six Mixing Zone Designs

Design Considerations	Switch & Weave	Shared Lane	Partially Shared Lane	Protected Intersection	Two Stage Left Turn with Bike Box	No Mixing with Bike Signal
Context Dependent Feasibility						
Restriping only *(*1)*	Requires 1.5x right-turn only lane	Requires 1x right-turn only lane	Most applicable	Never		Most applicable
Restriping as part of regularly scheduled overlay maintenance activities. *(*1)*	Requires 1.5x right-turn only lane	Requires 1x right-turn only lane		Never	Most applicable	
Redesign or reconfiguration	Most applicable	Most applicable				
Full Reconstruction				Most applicable		
Objective Indicators of Safety						
Minimizes size/area of on-street conflict zone				Not Applicable		
Minimizes size/area of conflicts during turning movements				Similar to pedestrians		After leading green *(*2)*
Perceived clarity of action						
Understanding of ROW rules	Yield line and channelization	Channelization		Similar to pedestrians		After leading green
Relative Tradeoffs and Implicit Costs of Design						
Compatibility with contraflow lanes					Not Applicable	Not Applicable
Compatibility with Two Way SBL						

Table 9-2 Considerations and Tradeoffs for Six Mixing Zone Designs (cont.)

Design Considerations	Switch & Weave	Shared Lane	Partially Shared Lane	Protected Intersection	Two Stage Left Turn with Bike Box	No Mixing with Bike Signal
Installation requirements:						
Street or lane modifications	+1.5x Right Turn lane width	+1 Right Turn lane	Paint	Not Applicable	Paint	Paint
Requires construction (i.e., grade separation, barrier)	none	none	none	$$	none	none
Requires changes in signalization	none	none	none	$$ (optional)	$ ($$ if actuated)	$$$
• New signage						
○ For cyclists	$$	$$	$	$	$$$	Not Applicable
○ For drivers	$	$$	$	$$ *(*3)*	$	Not Applicable
Area of painting (**4*)	$$$$	$$$	$	$-$$	$$$	$
Maintenance Considerations						
Need for bollard replacement	$$$$	$$$	$$	context specific	$	$
Frequency/area of re-painting *(*5)*	$$$	$$$	$$	$-$$	$$$$	$
Summer:						
• Difficulty of sweeping	Flexposts	Flexposts		Shared use path		
• Effect on debris accumulation						
Winter:						
Difficulty of plowing	Multiple passes and bollards	Multiple passes		Shared use path		
Snow Storage availability	Interface zone	Interface zone	buffer	boulevard	buffer	buffer
Specialized equipment						

Table 9-2 Considerations and Tradeoffs for Six Mixing Zone Designs (cont.)

Design Considerations	**Switch & Weave**	**Shared Lane**	**Partially Shared Lane**	**Protected Intersection**	**Two Stage Left Turn with Bike Box**	**No Mixing with Bike Signal**
Other Considerations in Design						
ADA compliance:						
Visually impaired users				Sidewalk level	Irregular crosswalk	
Mobility impaired users (*6)	Not Applicable	Not Applicable	Not Applicable	Bend-Out	Not Applicable	Not Applicable
Consistency of design	rare	frequent	common		Very rare	
Continuation of path trajectory				Bend-Out		

(*1) It is important to note that spatially the “Switch & Weave” design requires a width of 1.5 lanes of the roadway to be dedicated to vehicle right turns and bicycles going through. Similarly the “Shared Lane” design requires the rightmost lane to be right-turn-only. Especially in the case of the S&W, implementation on an existing roadway will require the complete removal and reapplication of all lane markings. Not just the lane markings next to the SBL.

(*2) The reduced safety (increased conflict potential) rating applies only in cases of leading bicycle only signal phase implementations and for the period after the end of the bicycle only signal green. When vehicles and bicycles have green, not only the benefits of the bike signal are gone but the complete lack of an actual mixing zone can result in dangerous sideswipes by right turning vehicles. Serious consideration must be given on the expected volume of bicycles to ensure that all queued up bicycles are given adequate green time to clear the first half of the intersection during the leading green phase. If bicycle arrival is random and the SBL allows high bicycle speeds, then a protected bike only phase should be considered.

(*3) If a Bend-Out is used in the transition zone, additional signs are advised to warn drivers. i.e. “Turning vehicles yield to bikes.”

(*4) Although not usually shown in the existing design manuals the PSL mixing zone also requires a Green Paint zone marking the through movement of bicycles inside the intersection. Similarly, a Green Paint zone must accompany the PI design if the bicycles are not using the regular pedestrian crosswalk to cross the intersection.

(*5) Mixing zones that incorporate road markings and especially green paint zones at locations where vehicles often travel require frequent repainting due to the increased wear from the tires. Bike Boxes are especially susceptible to this since they are located over the vehicle high acceleration spot downstream of the crosswalk.

(*6) Mixing zones that utilize only the roadway have no effect on mobility impaired pedestrians. PI Mixing zones, especially when they involve a Bend-Out require additional ADA pads and ramps or require the SBL to be raised at the sidewalk level. Regardless, planners must include “acceptable” sidewalk width between the PI SBL and the start of the crosswalk (15), where acceptable width may vary according to municipal policy and practice.

9.4.3 Preferences for Mixing Zone Design

The survey results provide evidence of the preferences of people who cycle for different mixing zone designs:

- The PI design is favored on all levels (Safety, Comfort and Efficiency) by people who cycle.
- All things considered, it is important to consider how the cost attributes are influenced by the mixing zone boundary features and the requirements imposed by the SBL midblock barrier type. Similar interplay exists between the PI design for the mixing zone and a co-located bus stop. The PI design, within limits, can produce a similar geometry as a Floating Island bus stop, which as discussed earlier, is the most desired by people who cycle. If a bus stop has to be located in a mixing zone that has the real estate that allows it, implementing at the same time as a PI mixing zone design will not involve much additional cost and will combine the two most favored choices.
- The S&W design and the TSLT design were perceived least favorably overall by people who cycle.
- The S&W design requires people who drive and people who cycle to change paths, thus creating a conflict zone. People who cycle reported that people who drive frequently do not fully enter the turn lane and thus block the cycle path.
- The use of flexposts demarcating the turn lane from other lanes and using green paint to reserve the bicycle part of the lane can alleviate the reported problem. Naturally this exacerbates the issues flexposts generally have.
- A low mountable composite curb can be used instead of flexposts to preserve the bicycle part of the turn lane but this can complicate plowing.
- People who cycle categorized as “Strong and Fearless” preferred the shared or partially shared mixing zones in contrast to the preferences of the “Enthused and Confident” and the “Interested but Concerned”
    - This outcome suggests that at intersections where most use is by “Strong and Fearless” people who cycle (e.g., perhaps commuters on high volume arterials), shared space mixing zones may be sufficient.
    - Conversely, this design would reduce potential to increase use by the “Enthused and Confident” or the “Interested but Concerned.” Thus, if an objective is to maximize perceived safety and comfort for all people who cycle, the preferences of the “Strong and Fearless” may not be prioritized.

9.5 CONSIDERATIONS REGARDING COMBINATIONS OF BUFFER AND MIXING ZONE DESIGN ALTERNATIVES

This section focuses specifically on guidance and recommendations related to specific combinations between mid-block SBL buffer design and mixing zone alternatives. As discussed earlier, conceptually the most important considerations here involve the transition area between the mid-block SBL buffer design and the mixing zone proper. In some of the mixing zone designs shown in Figure 8.2, examples of such transition areas are shown. For example, the heavily striped areas on the upstream end of the S&W and SL designs represent what we define as transition area in this study.

9.5.1 Assumptions

It is important to clarify the contexts for the various guidance statements presented in the following matrix.

I. In most cases the separation between the SBL and the driving lanes in the transition area follows the Intermittent Barrier design. When this is the case, it is specifically mentioned.

II. We define three levels of transition area length: Short, Average, and Long. The length is related to the visibility between modes prior to conflict. Similarly, given the lack of strict specifications regarding the "Shared" part of the PSL, similar terms are used.

III. **Visibility prior to conflict:** Especially in the case of mixing zones like S&W or SL that involve an orchestrated crossing of paths between vehicles and bicycles, visibility between the two modes prior to the conflict is critical. This visibility depends on the mid-block barrier design and the length of the transition zone. Naturally, the more obstructive the barrier is, the longer the transition area have to be. Elements that affect the degree to which the view between the two modes is obstructed include barrier penetrability and height, as well as buffer width. SBL width also plays a role here, with two-way SBLs representing the biggest problem since the two modes are far from each other. Finally, on-street parking and its blending with the buffer design also plays a role.

IV. **Conflicts:** The provided guidance covers conflicts in the context of expectancy. Some transition zone designs involve crossing of paths, and as such conflicts are not consistent with frequent encounters road users normally experience. Such conflicts are undesirable because their rarity results in higher reaction times by people who drive.

V. Similarly to the previous section, guidance involving the Bike Signal Mixing Zone deals only with the signal phases where both the people who drive and those who cycle have green.

Table 9-3 Recommendations and areas of concern related to combinations between Barrier types and Mixing Zone designs.

	Solid Barrier	Intermittent Barrier *(*1)*	Curb and Intermittent Barrier	Grade Separation
Switch & Weave	Transition area of Average length. *(*2)* Height of the barrier increases severity of conflicts. *(*3)*	Average mixing zone length Highest probability of damage to the delineators by vehicles and snowplows	Needs a Short curb-less transition section. *(*4)* Conflicts safer than SB. Reduced probability of damage to the delineators by vehicles and snowplows.	Feasible with Bend-In. Not advisable
Shared Lane	Transition area of Long length. (*2) Height of the barrier increases severity of conflicts. *(*3)*	Long mixing zone length Highest probability of damage to the delineators by vehicles and snowplows	Needs a Short curb-less transition section. *(*4)* Conflicts safer than SB. Reduced probability of damage to the delineators by vehicles and snowplows.	Feasible with Bend-In. Not advisable
Partially Shared Lane	Transition area of Short length. *(*2)* Height of the barrier increases severity of conflicts. *(*3)*	Most traditional design. Short mixing zone length Highest probability of damage to the delineators by vehicles and snowplows	Needs a Long curb-less transition section. *(*4)* Conflicts safer than SB. High probability of damage to the delineators by vehicles and snowplows.	Feasible with Bend-In. Not advisable

Table 9-3 Recommendations and areas of concern related to combinations between Barrier types and Mixing Zone designs. (cont.)

	Solid Barrier	**Intermittent Barrier (1)**	**Curb and Intermittent Barrier**	**Grade Separation**
Protected Intersection	Feasible with Bend-Out	Feasible with Bend-Out *(*5)*	Feasible with Bend-Out *(*5)*	Best Combination by default.
Two Stage Left Turn with Bike Box	Feasible combination Transition section not advised. High conflict probability	Feasible combination Low conflict probability High probability of damage to the delineators by vehicles and snowplows	Feasible combination Average conflict probability Extends barrier protection all the way to the stop line.	Not Applicable
No mixing, with Bike Signal	Best Combination assuming good cyclist compliance with bike signal.	Good combination Possible average compliance with the bike signal.	Feasible combination Possible low compliance with the bike signal.	Not Applicable

(*1) This type of barrier offers the least amount of protection to cyclists. This does not translate to the transition zone length since the danger there is the same on all barrier types such section is advised and depends on the length of that section.

(*2) Given the possible lack of visibility over/through the barrier, a section similar to the Intermittent Barrier is necessary between the Solid Barrier and the beginning of the mixing zone. The length of this transition section depends on the height of the barrier and the type of the mixing zone.

(*3) As the barrier height increases, the visibility of the cyclist from the vehicle reduces. This could result in collisions if the vehicles making the switch don't yield to the cyclist because they are not aware of its presence. To counter this potential problem an intermittent barrier transition section is needed. The higher the barrier the longer the transition section must be.

(*4) There is still need for a very short section where the raised curb is removed but at least one bollard is present. This would avoid vehicles turning right too soon and hitting the corner of the raised curb.

(*5) Implementing a PI mixing zone with the midblock separation of the SBL being IB or CIB involves the construction of more complicated transitions between the SBL and the mixing zone (Bend-Out). This not only increases construction costs due to the higher required amounts of concrete for larger curbs and islands but also increases maintenance costs given the more involved (curvy) path alignment.

9.6 CONSIDERATIONS IN THE DESIGN OF BUS STOPS

This section presents the summary guidance and recommendations developed in regards to bus stop design alternatives.

9.6.1 Assumptions

To assist in the comprehension of the buffer design alternatives matrix the, following assumptions are clarified.

I. As noted in other design guides and verified during the interviews with the transit agency, each bus stop requires 90 to 100 feet of open curb space, more if longer than standard busses are involved. The reason for this is the bus large tail swing. The wider the overall SBL is (SBL + Buffer) the longer the required opening for the bus stop needs to be.

II. Transit stops occurring on the same side of the street as the separated bike lane present a challenge due to interactions among cyclists, transit vehicles, and those accessing transit stops. Therefore, conflicts between the different modes are discussed separately.

III. In regards to conflict potential, transit users are separated based on their actions in relation to the crossing of the SBL.
    a. Transit users crossing the bike path to move between the sidewalk or bus shelter and the bus door.
    b. Transit users leaving the bus from any of the available doors and stepping on the bike path.
    c. Transit users standing near the bike path in the case of a shared space facility.

IV. As discussed earlier all of the Bus Stop designs investigated involve near-side bus stops (located immediately prior to an intersection). The corollary to this is that, by default, the bus stop is the mixing zone. For each of the designs, conflicts may be different between cases where a bus is present and when there is no bus present.

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9.6.2 Tradeoff Matrix for the Design of Bus Stops

Table 9-4 Considerations and Tradeoffs for Six Bus Stop Designs

Design Considerations	Curbside Bus Stop, One-Way Street-Level Protected Bike Lane	Curbside Bus Stop, One-Way Raised Cycletrack	In-Street Bus Stop, Shared Street-Level Protected Bike Lane	Floating Island Bus Stop, Two-Way Street-Level Protected Bike Lane	Curbside Bus Stop, Two-Way Street-Level Protected Bike Lane	Curbside Bus Stop, Two-Way Raised Cycletrack
Context Dependent Feasibility						
Restriping only	Most applicable	Never		Never	Most applicable	Never
Restriping as part of regularly scheduled overlay maintenance activities.			Most applicable	Pre-cast platform		
Redesign or reconfiguration		Most applicable				Most applicable
Full Reconstruction				Most applicable		
Objective Indicator of Safety to cyclists						
Minimizes probability of bus/bicycle collision.	*(*1)*				*(*1)*	
Minimizes probability of vehicle/bicycle collision. *(*2)*						
Objective Indicator of Safety to Transit users						
Minimizes probability of collision during boarding				Not Applicable		
Minimizes probability of collision during alighting		*(*3)*	*(*3)*	Not Applicable		*(*3)*

Table 9-4 Considerations and Tradeoffs for Six Bus Stop Designs. (cont.)

Design Considerations	**Curbside Bus Stop, One-Way Street-Level Protected Bike Lane**	**Curbside Bus Stop, One-Way Raised Cycletrack**	**In-Street Bus Stop, Shared Street-Level Protected Bike Lane**	**Floating Island Bus Stop, Two-Way Street-Level Protected Bike Lane**	**Curbside Bus Stop, Two-Way Street-Level Protected Bike Lane**	**Curbside Bus Stop, Two-Way Raised Cycletrack**
Perceived clarity of action						
Yield to XXX and wait	Bus	Peds	Peds	Peds	Bus	55% Peds
Pass bus from the left		Not Applicable		Not Applicable		4%
Ride on the sidewalk (right)	Not Applicable		Not Applicable	Not Applicable	Not Applicable	8%
Keep riding and mix with peds	Not Applicable			Not Applicable	Not Applicable	33%
Relative Tradeoffs and Implicit Costs						
Compatibility with Two Way SBL						
Installation requirements:						
• Additional width requirements	None	None		+1 lane		None
• Street or lane modifications	$	$	$$	$$	$	$
• Requires construction (i.e., grade separation, barrier)	$	$$	$	$$$	$	$$
Maintenance Considerations						
Frequency of Repairs of the Barrier	$$	$	$$$	$$	$$	$
Cost of Repairs of the Barrier	$$	$	$$	$$$	$$	$
Frequency/area of re-painting	$$$	$	$$	$	$$$	$
Summer:						
• Difficulty of sweeping	$	Raised	$$	$	$	Raised
• Effect on debris accumulation						

Table 9 4 Considerations and Tradeoffs for Six Bus Stop Designs. (cont.)

Design Considerations	Curbside Bus Stop, One-Way Street-Level Protected Bike Lane	Curbside Bus Stop, One-Way Raised Cycletrack	In-Street Bus Stop, Shared Street-Level Protected Bike Lane	Floating Island Bus Stop, Two-Way Street-Level Protected Bike Lane	Curbside Bus Stop, Two-Way Street-Level Protected Bike Lane	Curbside Bus Stop, Two-Way Raised Cycletrack
• **Winter:**						
• Difficulty of plowing	$	Raised	$$	multipass	$	
• Snow storage availability	Buffer if IB	Sidewalk	Buffer	Parking lane	Buffer if IB	Sidewalk
• Specialized equipment	Depends on Width	Raised	Depends on Width	Parking lane	none	Raised
General Considerations in Design						
Ease of ADA compliance						
• Serving visually impaired		*(*4)*	*(*4)*			*(*4)*
• Serving mobility impaired		*(*5)*	*(*5)*			*(*5)*
Consistency of design			Rare			
Continuation of path trajectory						

(*1) Buses have a large tail swing. This implies a wider trajectory during their approach to the curb. As reported by bus drivers, cyclists are often get trapped between the bus and the curb. Transition areas similar to the ones between Solid Barriers and Shared Lane Mixing Zones are required for the cyclists to notice the bus before it's too late.

(*2) Conflicts with right turning vehicles when bus is not present.

(*3) There is very little visibility between alighting transit users and cyclists. The transit agency should consider a mechanically deployable warning sign similar to the one used on school busses but on the rear back corner of the bus. The sign can be activated along with the bus rear door to warn cyclists that a transit user is about to step out the door.

(*4) The farther the bus shelter/pole is from the bus lane the harder it is for visually impaired people to detect bus arrival through sound. They can miss flagging the bus to stop.

(*5) Special considerations are required to make sure the barrier does not conflict with wheelchair lift. In the case of the raised cycletrack there should not be a raised curb at the edge of the SBL since this will also affect the lift operation.

9.6.3 Preferences for Bus Stop Design

The survey results provide evidence of the preferences of people who cycle for different bus stop designs. While they generally perceived all buffer types as safe and comfortable:

- The Floating Island Bus Stop Design clearly dominates as the most preferred design. This is likely because this design maximizes separation.
- Curbside Street Level (both one way and two way) had the largest proportion of respondents disagreeing with the statements about safety, comfort, and extra delay.
- As with Buffers and Mixing Zones, the more separation of the design, the less the "Strong and Fearless" groups liked it.
- The Curbside One-Way Street Level and Curbside Two-Way Street Level designs were perceived as the most prone to bus or vehicle conflict, while the Curbside One-Way Raised design as perceived as the most prone to pedestrian conflicts.
- Space should be provided for queuing pedestrians during boarding.

CHAPTER 10: CONCLUSIONS

Separated bicycle lanes (SBLs) are a bicycle facility that employs both paint and a vertical element as a buffer between vehicle traffic and bicycle traffic. In recent years, the installation of SBLs has increased in the U.S., and public demand for these facilities continues to grow. Several organizations have published guides for designing SBLs, but the design recommendations contained in these guides vary both by topic and depth. This project focused on how to best fill in needed information and expand the available guidance for SBLs. To do so, a literature review of the existing guidance for the design elements identified in the available SBL design guides was conducted to identify knowledge gaps and prioritize areas of study. This is presented in Chapter 2. Industry professionals were consulted as to which design elements were of the greatest interest or missing from the guidance altogether. Key Informant Interviews (KII), presented in Chapter 3, were conducted with design agencies, bicycle advocates and bus drivers in the Twin Cities to collect their thoughts about SBLs. The KIIs with design agencies focused on guidance used and issues faced in implementing and maintaining SBLs. The bicycle advocacy group KIIs focused on the user experience, and the bus driver interviews focused on the specific issues SBLs present to bus drivers. A user group survey was developed to examine the safety and comfort of different designs of SBLs, including mixing zones and bus stop designs. Because winter riding and winter maintenance were identified as key areas of missing guidance, the survey also included sections on factors influencing winter riding behavior as well as a visual preference survey section to determine rider preferences for cleared width and pavement conditions.

Planners typically consider an array of factors when assessing the need for separation of bikeways. These factors may include traffic-related and structural factors associated with risk and safety and demand-related factors such as target population of people who cycle, including whether a design objective is to increase cycling among people who cycle infrequently. At an engineering level, the official guideline regarding the need for separation considers only two metrics, vehicle volume and 85% speed. These guidelines also list a number of other factors that can be considered but offer only qualitative arguments, often through anecdotal information. Regardless, this study follows the guidance offered in the *FHWA Bikeway Selection Guide* (44) and focused on the collection of additional evidence in respect to the identified three guiding principles of safety, comfort, and connectivity. These guided both the KIIs as well as the development of the user preference survey, presented in Chapter 6 and Chapter 7. Therefore, the overarching goal evolved to the refinement of guidance on specific structural design elements in respect to their tradeoffs and general relationships with safety, comfort, and likelihood to choose bicycle as the mode of transportation. The latter serves as a surrogate of the core essence of the connectivity principle.

As noted on several existing guidance documents and corroborated by the information collected and analyzed in this project, the Separated Bike Lane is one of the highest-quality bikeway facilities available. This report adds to the existing guidance regarding the planning and operation of SBLs by refining the discussion and taking into account individual aspects of separate design elements and their implementation alternatives, as well as their influence and limitations on maintenance needs, specifically in winter. Regardless, there should be continued education targeted at design practitioners to emphasize the flexibility that exists within the still evolving design guidance to create connected bicycle networks everywhere. These connected bicycle networks provide increased transportation options, enhance access to jobs, schools, and essential services, and increase the utility of our existing transportation network.

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APPENDIX A: INVENTORY OF SEPARATED BICYCLE LANES IN MINNESOTA

INVENTORY OF EXISTING SEPARATED BIKE LANES IN MINNESOTA

City	Street (start to end)	Completed	Miles	Type	Protection type	Elevation	Comments
Glenwood	Minnesota Ave E/W (2nd St SW to 2nd St NE/SE)	2018	0.3	1-way, each side	Curb and parking	Sidewalk Level	MnDOT, Pope County, and City of Glenwood
Minneapolis	11th Ave S (6th St S to West River Pkwy)	2016	0.5	1-way, each side	Flex posts	On street	
Minneapolis	18th Ave NE (Central Ave NE to Johnson Ave NE)	2018	0.5	2-way, one side	Landscaping	Sidewalk level	
Minneapolis	18th Ave NE (University Ave NE to 5th St NE)	2011	0.1	2-way, one side	Landscaping	Sidewalk level	
Minneapolis	26th Ave N (Theodore Wirth Pkwy to Pacific St N)	2017	2.0	2-way, one side	Landscaping	Sidewalk level	
Minneapolis	26th St E/W (Hiawatha Ave to Portland Ave)	2015	1.3	1-way, one side	Flex posts	On street	
Minneapolis	26th St W (Portland Ave to Hennepin Ave S)	2017	1.4	1-way, one side	Flex posts	On street	
Minneapolis	27th Ave NE (Marshall St SE to University Ave NE)	2017	0.4	1-way, each side	Flex posts	On street	
Minneapolis	28th St E/W (Longfellow Ave to 5th Ave S)	2015	1.1	1-way, one side	Flex posts	On street	
Minneapolis	28th St W (5th Ave S to Hennepin Ave S)	2017	1.4	1-way, one side	Flex posts	On street	
Minneapolis	36th Street (Richfield Rd to Dupont Ave S)	2014	0.5	2-way, one side	Flex posts	On street	Green bike lane at intersections. Bike boxes for left-turns
Minneapolis	3rd Ave NE (Main St NE to Central Ave NE)	?	0.6	2-way, one side	Landscaping and parking	Sidewalk level	
Minneapolis	3rd Ave S (1st St S to 16th St E)	2016	1.1	1-way, each side	Flex posts	On street	
Minneapolis	3rd Ave/Central Ave (1st St S to University Ave SE)	2017	0.5	1-way, each side	Flex posts	On street	
Minneapolis	5th St S (13th Ave S to 11th Ave S)	2018	0.2	2-way, one side	Landscaping and sidewalk	Sidewalk level	
Minneapolis	6th St S (11th Ave S to Chicago Ave S)	2016	0.2	2-way, one side	Landscaping and sidewalk	Sidewalk level	
Minneapolis	66th St (Xerxes Ave S to 16th Ave S)	2018	3.3	1-way, each side	Landscaping, back of curb	Sidewalk level	Hennepin County Project
Minneapolis	Blaisdell Ave S (29th St W to 40th St)	2016	1.4	1-way, one side	Flex posts	On street	

City	Street (start to end)	Completed	Miles	Type	Protection type	Elevation	Comments
Minneapolis	Broadway St NE (Stinson Blvd NE to Industrial Blvd NE)	2016	0.7	2-way, one side	Flex posts	On street	
Minneapolis	Calhoun Pkwy W (Rose Ln to Lake St W)	?	0.7	2-way, one side	Landscaping	Sidewalk level	Grand Rounds
Minneapolis	Calhoun Pkwy W (Upton Ave S to Richfield Rd)	?	0.3	2-way, one side	Landscaping	Sidewalk level	Grand Rounds
Minneapolis	Cedar Lake Pkwy (Sunset Blvd to Cedar Lake Rd)	?	1.2	2-way, one side	Landscaping	Sidewalk level	
Minneapolis	East River Pkwy (Emerald St SE to Delaware St SE)	?	2.0	2-way, one side	Landscaping	Sidewalk level	
Minneapolis	Emerson Ave N (Plymouth Ave N to 33rd Ave N)	2019	1.6	1-way, one side	Flex posts	On street	Mostly on left side of road
Minneapolis	Franklin Ave E (West River Pkwy to East River Pkwy)	2016	0.1	1-way, each side	Concrete barriers	Sidewalk level	
Minneapolis	Franklin Ave E (29th Ave S to West River Pkwy)	2016	0.5	1-way, each side	Flex posts	On street	
Minneapolis	Fremont Ave N (33rd Ave N to Plymouth Ave N)	2019	1.6	1-way, one side	Flex posts	On street	Mostly on left side of road
Minneapolis	Lake Harriet Blvd W (Lake Harriet Pkwy to Penn Ave S)	?	1.6	1-way, one side	Landscaping	Sidewalk level	Lake Harriet Bike Trail
Minneapolis	Lake Harriet Blvd W (Penn Ave S to 42nd St W)	?	1.1	1-way, one side	Landscaping	Sidewalk level	Lake Harriet Bike Trail
Minneapolis	Lake of the Isles Pkwy E (Franklin Ave W to Calhoun Pkwy W)	?	1.0	1-way, one side	Landscaping	Sidewalk level	
Minneapolis	Lake of the Isles Pkwy W (Calhoun Pkwy W to Franklin Ave W)	?	1.8	1-way, one side	Landscaping	Sidewalk level	
Minneapolis	Oak St SE (Washington Ave to East River Road)	2015	0.3	2-way, one side	Raised curb and flex posts	On street	
Minneapolis	Park Ave S (4th St S to Washington Ave S)	2016	0.1	1-way, one side	Raised curb	On street	
Minneapolis	Plymouth Ave N (Lyndale to 8th Ave NE)	2015	1.1	1-way, each side	Flex posts	On street	Green bike lane at intersections.
Minneapolis	Portland Ave S (3rd St S to 5th St S)	2016	0.1	1-way, one side	Raised curb	Sidewalk level	
Minneapolis	Theodore Wirth Pkwy (Hwy 55 to McNair Ave N)	?	1.6	2-way, one side	Landscaping	Sidewalk level	
Minneapolis	Victory Memorial Pkwy (Lowry Ave N to Humboldt Ave N)	?	2.7	2-way, one side	Landscaping	Sidewalk level	

City	Street (start to end)	Completed	Miles	Type	Protection type	Elevation	Comments
Minneapolis	Washington Ave S (Hennepin Ave to 5th Ave S)	2017	0.4	1-way, one side	Curbs, trees, planters	Sidewalk level	Early green light for bikes
Minneapolis	West River Pkwy (11th Ave S to 22nd Ave S)	?	0.7	2-way, one side	Landscaping	Sidewalk level	
Minneapolis	18th Ave SE (E Hennepin Ave to Como Ave SE)	2019	0.3	2-way, one side	Flex posts	On street	
Minneapolis	10th Ave SE/19th Ave S (Riverside Ave S to 5th St SE)	2019	1.2	2-way, one side	Flex posts	On street	
Minneapolis	15th Ave SE (Rollins Ave SE to University Ave SE)	2019	0.5	1-way, each side	Flex posts	On street	
Minneapolis	20th Ave S (4th St S to Minnehaha Ave S)	2019	0.5	2-way, one side	Flex posts	On street	
Minneapolis	Rollins Ave SE (15th Ave SE to 17th Ave SE)	2019	0.1	2-way, one side	Flex posts	On street	
Minneapolis	4th St SE (Central Ave to I-35W Bridge)	2019	0.7	1-way, one side	Flex posts	On street	Minneapolis/ MnDOT Project
St Louis Park	Cedar Lake Rd (Kentucky Ave to Park Place Blvd)	2019	1.1	1-way, each side	Raised curb and TBD	Sidewalk Level	Roundabout at Zarthan Ave.
Minneapolis/ St. Paul	West River Pkwy/Godfrey Pkwy (4th St S to Hiawatha Ave)	?	5.2	2-way, one side	Landscaping	Sidewalk level	
St. Paul	West River Rd/Pkwy (24th Ave N to Portland Ave S)	?	2.2	2-way, one side	Landscaping	Sidewalk level	
St. Paul	East Como Lake Dr (Victoria St to Lexington Pkwy)	?	0.5	1-way, one side	Landscaping	Sidewalk level	
St. Paul	East Shore Dr (Johnson Pkwy to Larpenteur Ave)	?	1.0	1-way, one side	Landscaping	Sidewalk level	
St. Paul	Jackson St (Kellogg Blvd to University Ave)	2017	1.0	2-way, one side	Landscaping	Sidewalk level	First phase of Capitol City Bikeway
St. Paul	Mississippi Blvd (Woodlawn Ave S to Hidden Falls Dr)	?	1.1	2-way, one side	Landscaping	Sidewalk level	
St. Paul	Pelham Blvd (Mississippi River Blvd to Myrtle Ave)	2017	0.8	2-way, one side	Flex posts	On street	
St. Paul	Saint Anthony Ave (Prior Ave to Pierce St)	2018	1.0	2-way, one side	Flex posts	On street	
St. Paul	Shepard Road (Randolph Ave to Eagle Pkwy)	?	1.0	2-way, one side	Landscaping	Sidewalk level	

City	Street (start to end)	Completed	Miles	Type	Protection type	Elevation	Comments
St. Paul	Wheelock Pkwy (Rice St to Edgerton St)	2016	2.0	2-way, one side	Landscaping	Sidewalk level	West end of SBL is center-running
St. Paul	Wheelock Pkwy (Victoria St to Danforth St)	2017	0.6	2-way, one side	Landscaping	Sidewalk level	
St. Paul	Wheelock Pkwy (Danforth St to Cohansey St N)	2019	1.0	2-way, one side	Landscaping	Sidewalk level	

INVENTORY OF PLANNED SEPARATED BIKE LANES IN MINNESOTA

City	Street (start to end)	Anticipated Finish	Length (Miles)	Facility type	Protection type	Elevation	Comments
Minneapolis	Glenwood Ave (Aldrich Ave N to N 7th St)	(2020)	0.6	1-way, each side	Flex posts	On street	Hennepin County Project
Minneapolis/ Richfield	Portland Ave S (E 60th St to 66th St)	(2021)	0.7	1-way, each side	Flex posts, curb	Sidewalk level & On street	Hennepin County Project
Rochester	4th St SW (1st Ave to 6th Ave SW)	(2021)	0.3	1-way, each side	Landscaping	Sidewalk level	
Rochester	Broadway Ave N (5th St NW to 13th St NW)	(2021)	0.5	1-way, each side	Landscaping	Sidewalk level	
St Louis Park	Louisiana Avenue (Oxford St to Excelsior Blvd)	(2021)	0.5	1-way, each side	Raised curb	Sidewalk Level	Green cross-bike striping at Louisiana Circle

APPENDIX B: USER GROUP SURVEY

SURVEY NARRATIVE

This section describes the survey narratively with example questions representative of the entire survey.

FILTER QUESTIONS

Survey respondents were shown a brief description of the project and Separated Bike Lanes (SBLs).

> "The Minnesota Traffic Observatory of the U of M is currently working on a study for the Local Road Research Board to produce guidance for the design and maintenance of Separated Bike Lanes ("SBLs" for short) - focusing on the midblock segments.
>
> For the purposes of this study, we have defined a Separated Bike Lane as a facility with the following characteristics:
>
> - Along or within the roadway
> - Separated from motor vehicles by some sort of physical barrier (flexposts, planters, curbs, etc.) and/or a difference in elevation (bike lane is at sidewalk height)
> - Designated as exclusively for cyclists
>
> Note that these criteria intentionally exclude shared-use paths, multi-use trails, greenways, and sidewalks.
>
> We want to gather the insights of cyclists such as yourself to make sure your needs are considered. As a cyclist - the primary user of these facilities – your perspective will be extremely helpful in shaping our next steps in this study.
>
> The first set of questions is aimed at understanding your current bicycling activities."

This introductory text was followed by two questions: "Are you currently physically able to ride a bicycle?" and "Have you ridden a bicycle in the past year?". If a respondent answered no to both questions they were taken to the end of the survey, otherwise they proceeded into the Cycling Behavior section.

Cycling Behavior

Cyclists were asked about frequency (Figure 1) and reason for biking during all seasons (Figure 2). Cyclists were also asked if they "would like to travel by bike…more than I do now" in both "summer months" and "winter months". If a respondent indicated they did not ride in summer or winter, they received a follow-up question about why they did not bike in the season (Figure 3, Figure 4) . The responses in this section and the next, Cyclist Comfort, were used to classify respondents per Dill's classification methodology.

When have you ridden a bicycle for any reason in the last year, and how often?

	Never	About once per month	Once or twice per month	Almost every day per week	Once or twice per week	More than twice per week	Don't recall
Summer (Jun 2019 - Aug 2019)	O	O	O	O	O	O	O
Fall (Sep 2019 - Nov 2019)	O	O	O	O	O	O	O
Winter (Dec 2019 - March 2020)	O	O	O	O	O	O	O
Spring (Mar 2020 - May 2020)	O	O	O	O	O	O	O

Figure 1 Filter Question about when respondents ride

How often was each of the following a reason for riding a bicycle in Spring, Summer, and/or Fall (June 1st, 2019 to November 30th, 2019; March 1st, 2020 to May 30th, 2020)?

	Most trips	Some trips	Very few trips	No trips
Commuting to or from work	O	O	O	O
Commuting to or from school	O	O	O	O
Work (ex. bike messenger or courier)	O	O	O	O
Recreation/exercise	O	O	O	O
Traveling to or from a recreation/entertainment event/location	O	O	O	O
Traveling to shop for groceries or retail items	O	O	O	O
Other (please explain)	O	O	O	O

Figure 2 Filter question about why respondents ride

If you did not ride a bicycle this summer, why not?

- I don't enjoy biking
- None of my destinations were reachable by bike
- I don't own a bike
- I don't feel safe on the bicycle facilities in the areas where I might bike
- I could not afford a bicycle
- Other (please explain)

Figure 3 Respondents' reasons for not biking in summer

If you did not bike last winter, why not?

- It was too cold outside for me
- I don't enjoy biking in general
- I feel unsafe biking on ice
- I didn't want the salt and slush to damage my bike
- Biking in snow is too strenuous for me
- Biking in snow is too slow for me
- I feel unsafe biking in the dark
- I could not afford a bicycle
- Other

Figure 4 Respondents' reasons for not biking in winter

Cyclist Comfort

Respondents were asked to rate their comfort on a scale from very uncomfortable to very comfortable while cycling in various situations such as:

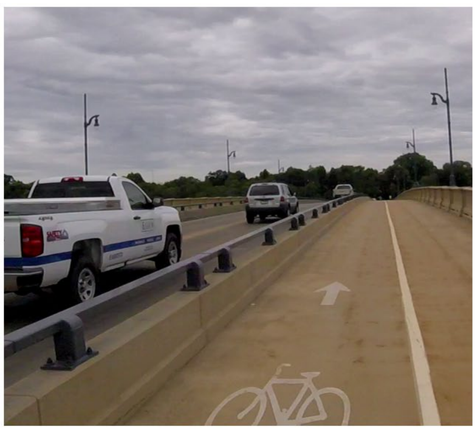
- "A path or trail separate from the street"

- “A quiet, residential street with traffic speeds of 20-25 miles per hour…”
  - “…with a 20 mile per hour speed limit, bicycle route markings, wide speed humps, and other things that slow down and discourage car traffic?”
- “A major urban or suburban street with four lanes, on-street parking, traffic speeds of 30–35 miles per hour, and no bike lane…”
  - “…with a striped bike lane?”
  - “…with a wide bike lane physically separated from traffic by a raised curb, planters, or parked cars?”

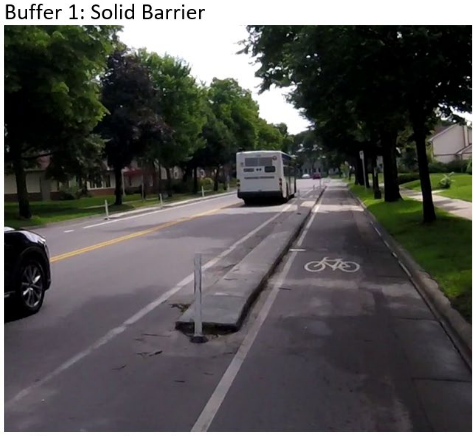
The responses were then used in conjunction with cycling frequency and cyclist behavior (recreational, commuter, or both) to classify respondents per an adapted Dill methodology (chapter reference).

BUFFER DESIGN

Respondents were first shown the differing types of buffers and separation currently available on Minnesota SBLs. Respondents were asked if they have ever ridden on an SBL like the one shown, and how safe and comfortable they perceive the design to be in both summer and winter months. Figure 3 depicts the categories of buffers and example photos of those buffers at sites around the Twin Cities Metro Area. Figure 4 and Figure 5 show the questions asked in each buffer section.


Buffer 1: Solid Barrier


Buffer 2: Intermittent Barrier


Buffer 3: Curb and Intermittent Barrier


Buffer 4: Grade Separation

Figure 5 Types of buffers presented to the user

Rate how you would feel on this type of facility during the summer.

	Strongly Agree	Agree	Neither Agree Nor Disagree	Disagree	Strongly Disagree
I would feel safe on this type of separated bike lane.	○	○	○	○	○
I would feel comfortable on this type of separated bike lane.	○	○	○	○	○

Figure 6 Questions on how safe and comfortable the rider would feel during summer months

Rate how you would feel on this type of facility during the winter.

	Strongly Agree	Agree	Neither Agree Nor Disagree	Disagree	Strongly Disagree
I would feel safe on this type of separated bike lane.	○	○	○	○	○
I would feel comfortable on this type of separated bike lane.	○	○	○	○	○

Figure 7 Questions on how safe and comfortable the rider would feel during winter months

After a respondent answered questions about buffer designs, they proceeded to the Mixing Zone section.

MIXING ZONES

Similar to the buffer design section, respondents were presented with six Mixing Zone designs that are present in the Twin Cities Metro Area (Figure 6). Respondents first were asked about their familiarity with the design. Respondents received questions about their perceived understanding of the design, comfort with the design, perceived safety of the design, and perceived delay due to the design for each type of mixing zone (Figure 7). Respondents were then asked about the frequency with which they have encountered certain types of conflicts while riding through the specified mixing zone design (Figure 8)

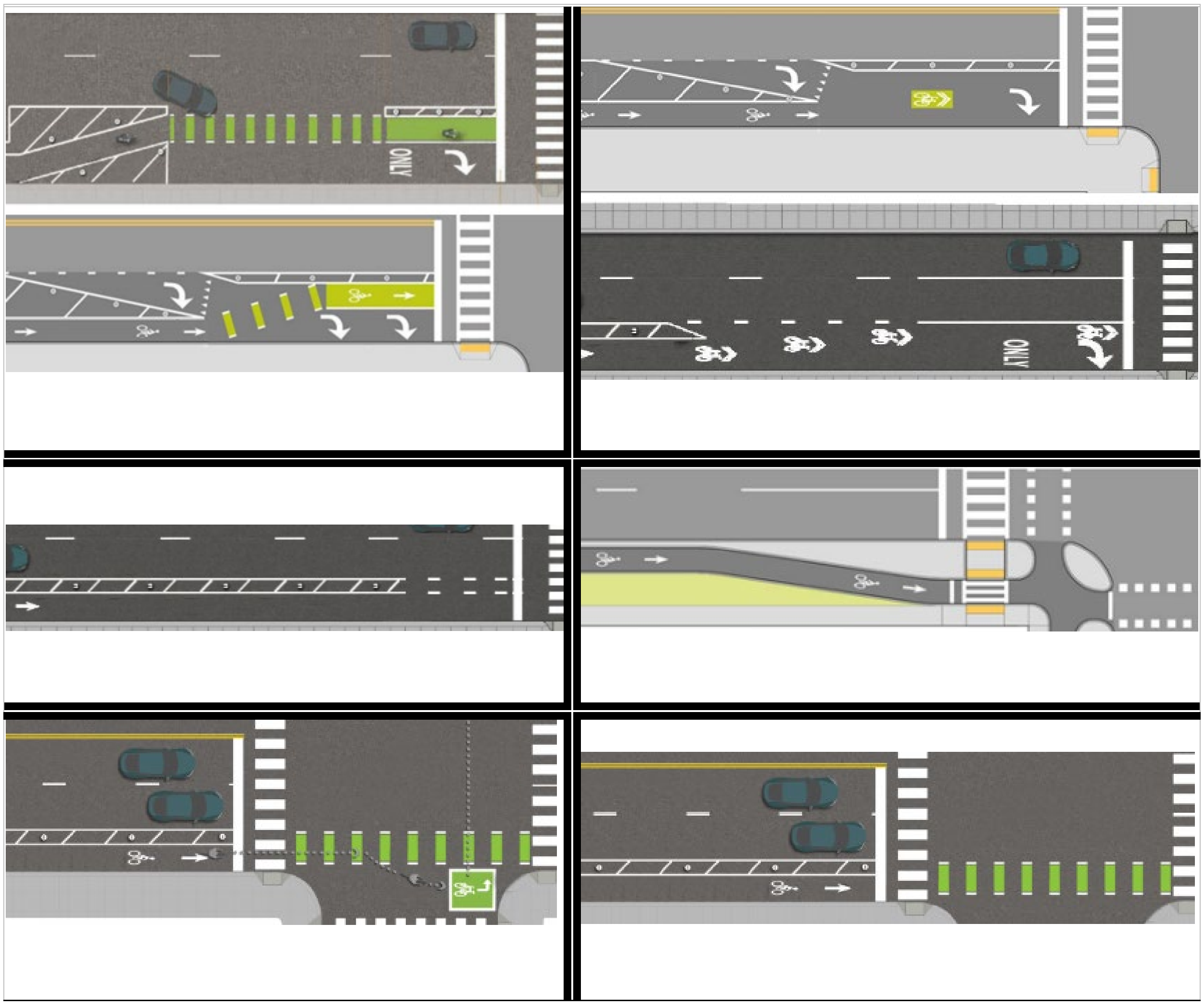


Figure 8 Types of Mixing Zones presented to users

Have you ridden on this type of mixing zone in the last year?

- ○ Yes
- ○ No
- ○ I don't recall

Do you agree or disagree with the following statements about this design?

	Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree
I understand how to use this design.	○	○	○	○	○
I would feel comfortable riding on this design.	○	○	○	○	○
I would feel safe riding on this design.	○	○	○	○	○
Riding on this design would not cause me any extra delay.	○	○	○	○	○

Figure 9 Familiarity with and comfort, safety, understanding and extra delay questions on mixing zones

Respondents who indicated they had ridden on the designs were then specifically asked about any conflicts they experienced at the mixing zone (Figure 8). The list of conflicts remained the same except where some conflicts were not possible due to the geometry of the mixing zone (i.e., “a vehicle entering the mixing zone hit me” was not presented in the “Protected Intersection” scenario, as the concrete barrier between the vehicle lane and bike lane would prevent that type of conflict except in extreme cases).

While riding on facilities with this design, how often have you experienced the following issues?

	Almost Always	Often	Occasionally	Rarely	Never
A vehicle did not fully enter the mixing zone and blocked my path	○	○	○	○	○
A pedestrian or cyclist waiting to cross the intersection blocked my path	○	○	○	○	○
A vehicle was waiting behind me and the driver honked, yelled, or otherwise indicated impatience	○	○	○	○	○
A vehicle passed between me and the curb while I was waiting for the light to change	○	○	○	○	○
A vehicle entering the mixing zone cut me off/failed to yield to me	○	○	○	○	○
A vehicle was too wide for the mixing zone and prevented me from using the facility	○	○	○	○	○
I was unable to make a left turn	○	○	○	○	○
A vehicle entering the mixing zone hit me	○	○	○	○	○
Other (please explain)	○	○	○	○	○

Figure 10 Types of conflicts

The survey then continued into bus stop designs.

BUS STOP DESIGNS

Similar to the mixing zone and buffer design sections, respondents were presented with six Bus Stop designs that are present in the Twin Cities Metro Area (Figure 9). Respondents first were asked about their familiarity with the design. Respondents received questions about their perceived safety of the design, perceived comfort with the design, and perceived delay due to the design for each type of bus stop (Figure 10) as well as potential for conflicts with other vehicles, cyclists and/or pedestrians (Figure

11). Respondents were then asked about the frequency with which they have encountered certain types of conflicts while riding through the specified bus stop design (Figure 12)

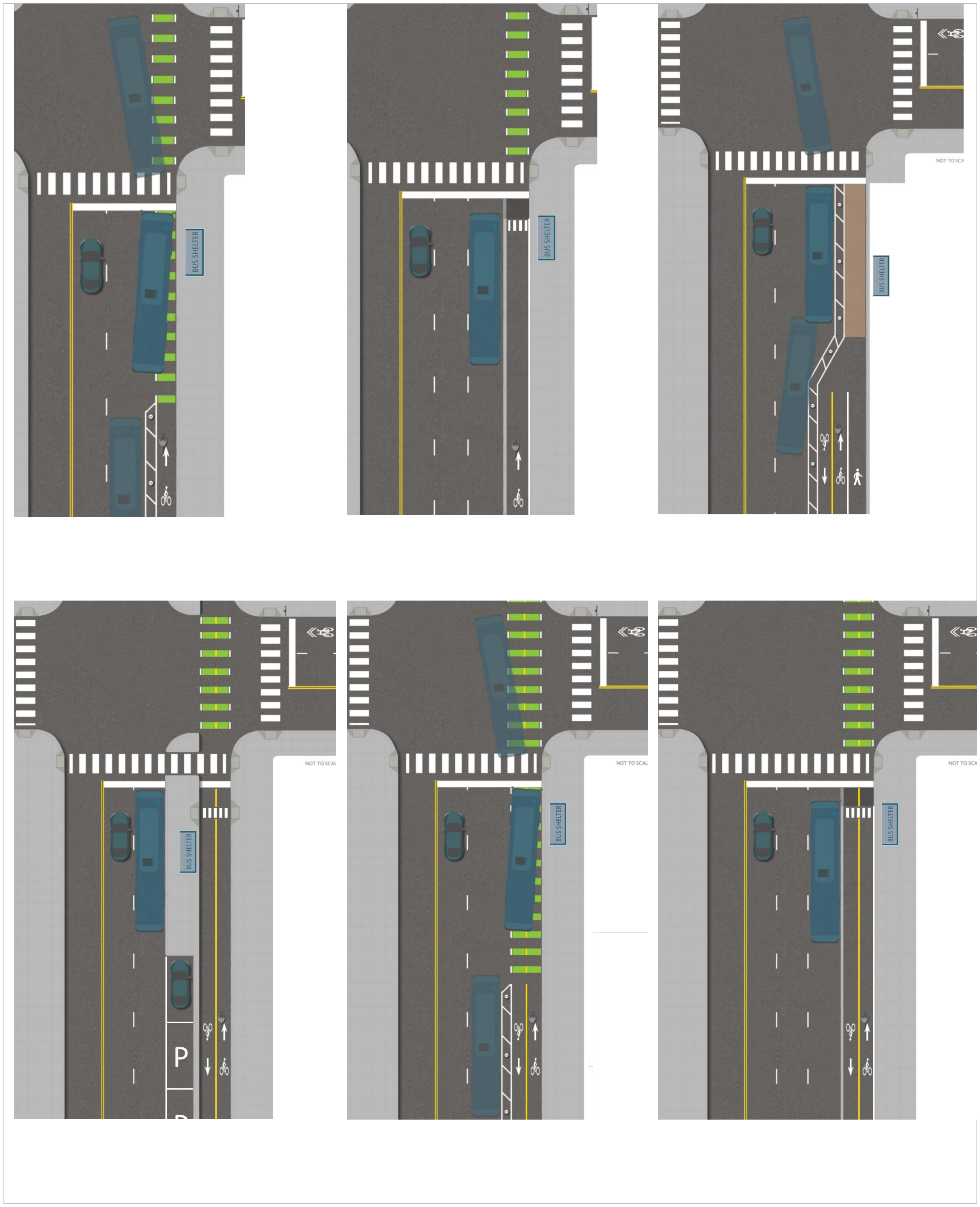


Figure 11 Types of bus stop designs presented to users

Do you agree or disagree with the following statements about this bus stop design?

	Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree
I would feel safe riding in a bike lane with this type of bus stop.	○	○	○	○	○
I would feel comfortable riding in a bike lane with this type of bus stop.	○	○	○	○	○
Riding on this design would not cause me any extra delay.	○	○	○	○	○

Figure 12 Safety, comfort and extra delay questions for bus stops

Do you agree or disagree with the following statements about this bus stop design?

This type of bus stop creates potential for conflicts...

	Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree
between cyclists and buses.	○	○	○	○	○
between cyclists and vehicles other than buses.	○	○	○	○	○
between cyclists and pedestrians.	○	○	○	○	○

Figure 13 Potential for conflicts questions for bus stops

Have you ever experienced conflict with a bus, another vehicle, a pedestrian, another bicyclist, or a scooter when riding by this type of bus stop?

- ○ Yes
- ○ No

Please identify the modes of traffic you have experienced conflicts with. (check all that apply)

- ☐ Bus
- ☐ Another vehicle
- ☐ Pedestrian
- ☐ Another cyclist
- ☐ Scooter

Figure 14 Experienced conflicts questions for bus stops

Bus Stop Real-World Scenario

To connect the abstract illustrations of bus stops to real world scenarios, users were presented with the following image (Figure 13). This image was created from video captured at 12th St and 28th St during the field video data collection. The image is an amalgamation of a cyclist, a bus at the stop, and several bus passengers embarking through the bicycle lane. The image was created because no such encounter was captured authentically on video. The research team was particularly interested in how cyclists would react to a passenger disembarking as they approached; as no one disembarked the bus at this stop in the video capture, the research team was unable to create an image grounded in real-world scenarios at this particular location.

Cyclists were asked what they would do if they were the biker in yellow in this situation (Figure 55), with the intention of determining how cyclists would interact with the pedestrians crossing the bicycle lane. In this situation, laws are nebulous, but Minnesota statue 169.222 states that bicycles should yield to pedestrians, or at least “give an audible signal…before overtaking and passing any pedestrian”.

Assume you are riding in the separated bike lane like the biker in the yellow jacket in the image above. If you encountered a situation at a bus stop like the image above, what would you do?

- ○ Yield and wait
- ○ Ride to the left of the bus
- ○ Ride on the sidewalk
- ○ Ride ahead in the bike lane and slow or dodge the pedestrians

Figure 15 Real world bus scenario image and accompanying question on rider behavior

Winter Riding - Factors

Only respondents who indicated they ride in winter received these questions. Respondents were asked about winter conditions that are likely to cause them to cancel a ride (Figure 14), and asked about various types of winter maintenance and how important they are (Figure 15) as well as how satisfied respondents have been (Figure 16) with winter maintenance along their routes.

What winter condition is most likely to cause you to cancel rides?

- Snow depth
- Cold temperatures
- High winds
- Falling rain
- Falling snow
- Icy roads
- Lack of daylight
- Other (please specify)

Figure 16 Winter conditions

Please rate the importance of the following factors in shaping your perception of a bicycling trip.

	How important is this factor to you viewing a cycling trip in winter as a positive experience?			
	Very important	Somewhat important	Not very important	Not at all important
Cleared pavement width				
Width between banks of snow				
Number of other cyclists in the lane				
Drainage				
Application of salt				
Application of sand				
Timeliness of snow and ice clearance				
Type of delineator				
Other				

Figure 17 Importance of winter conditions

Please rate your satisfaction with the current state of each factor where you live.

	How satisfied are you with the conditions you encountered?				
	Very satisfied	Somewhat satisfied	Neither satisfied nor dissatisfied	Somewhat dissatisfied	Very dissatisfied
Cleared pavement width	○	○	○	○	○
Width between banks of snow	○	○	○	○	○
Number of other cyclists in the lane	○	○	○	○	○
Drainage	○	○	○	○	○
Application of salt	○	○	○	○	○
Application of sand	○	○	○	○	○
Timeliness of snow and ice clearance	○	○	○	○	○
Type of delineator	○	○	○	○	○
Other	○	○	○	○	○

Figure 18 Satisfaction with winter conditions

Respondents were then introduced to the winter image section (Figure 17). In this section, respondents were shown two images of an SBL site experiencing various winter conditions, from cleared pavement to fresh snow to completely iced over. Additionally, levels of pedestrian and cyclist traffic are varied between images, as highlighted in the introductory image (Figure 17). These image pairs were randomly selected from a larger pool. Respondents compared how safe and comfortable they feel about each image. Figure 18 shows a sample question containing two randomized images and the subsequent questions of on which image the rider would feel safer, more comfortable and more likely to bike on.

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The next questions will each present two types of winter conditions along the same type of separated bike lane, and ask you to compare the conditions.

You will see 10 questions with pairs of images (20 images total). Due to the way these images and questions were generated, some images may appear to be repeated. Some question numbers may appear out of order due to randomization. Please treat each set of images as its own.

The following image illustrates the differences to look for in each set of images: barrier type (solid or intermittent), pavement condition (clear, snowy or icy), pavement cleared width, and cyclist traffic.

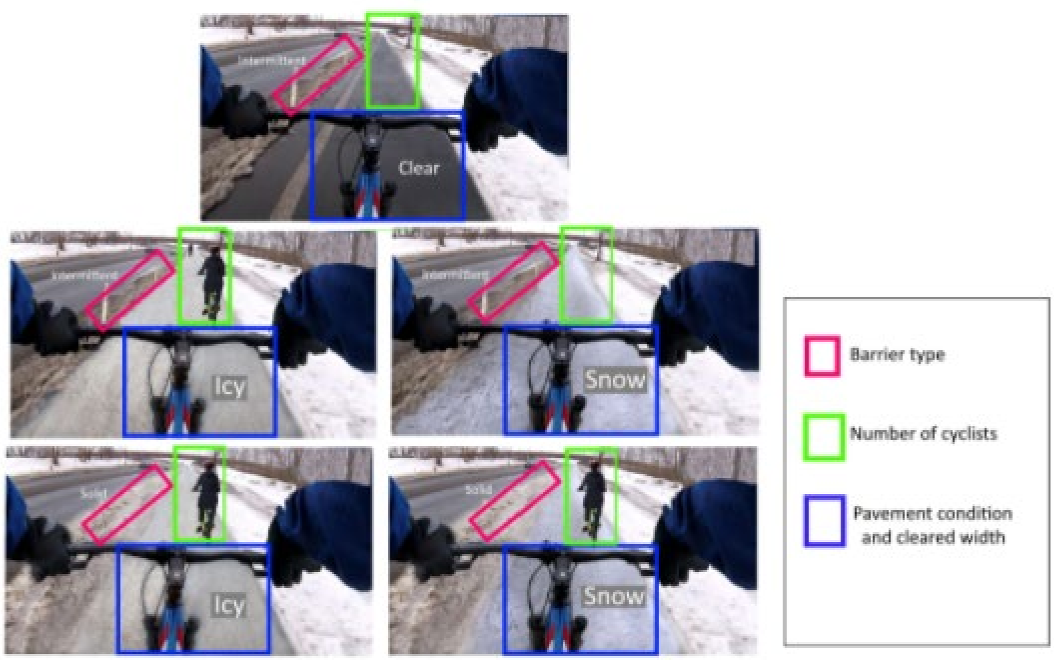

Figure 19 Introduction to the randomized image section

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Image A

Image B

Please state whether you strongly agree, agree, neither agree nor disagree, disagree, or strongly disagree with the of the following statements.

I would feel more safe riding on the lane in image A than the lane in Image B.

Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree

I would feel more comfortable riding on the lane in image A than the lane in Image B.

Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree

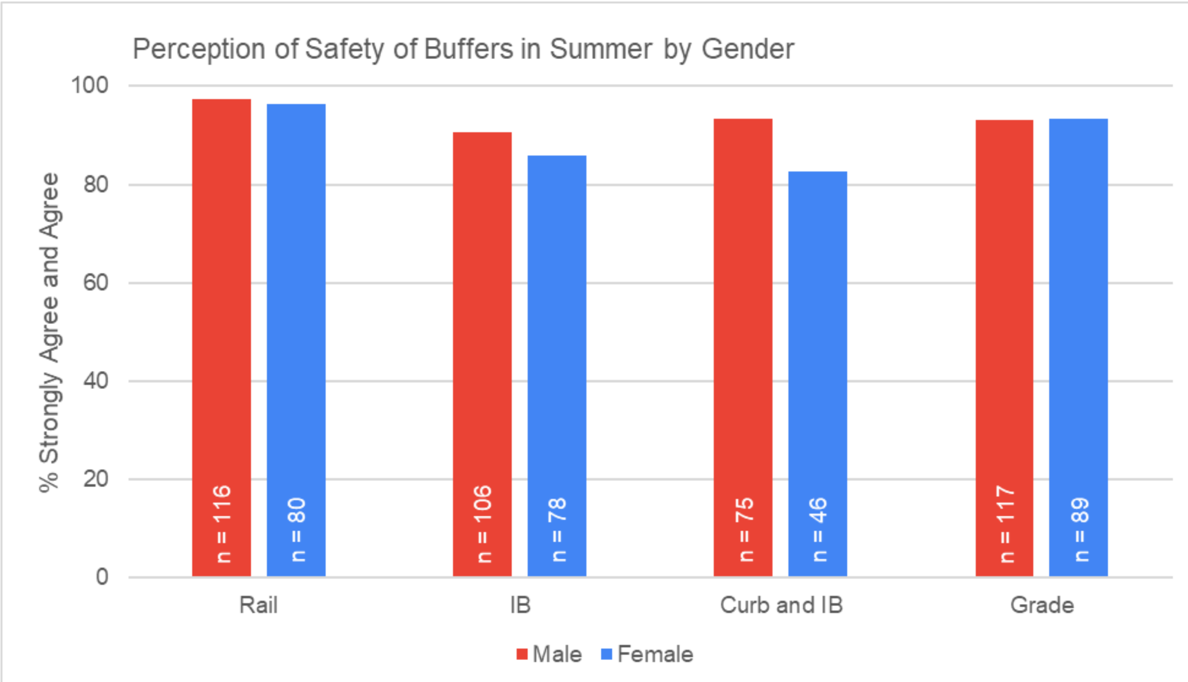
I would be more likely to ride my bicycle in the winter if the lanes were maintained as in Image A than Image B.

Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree

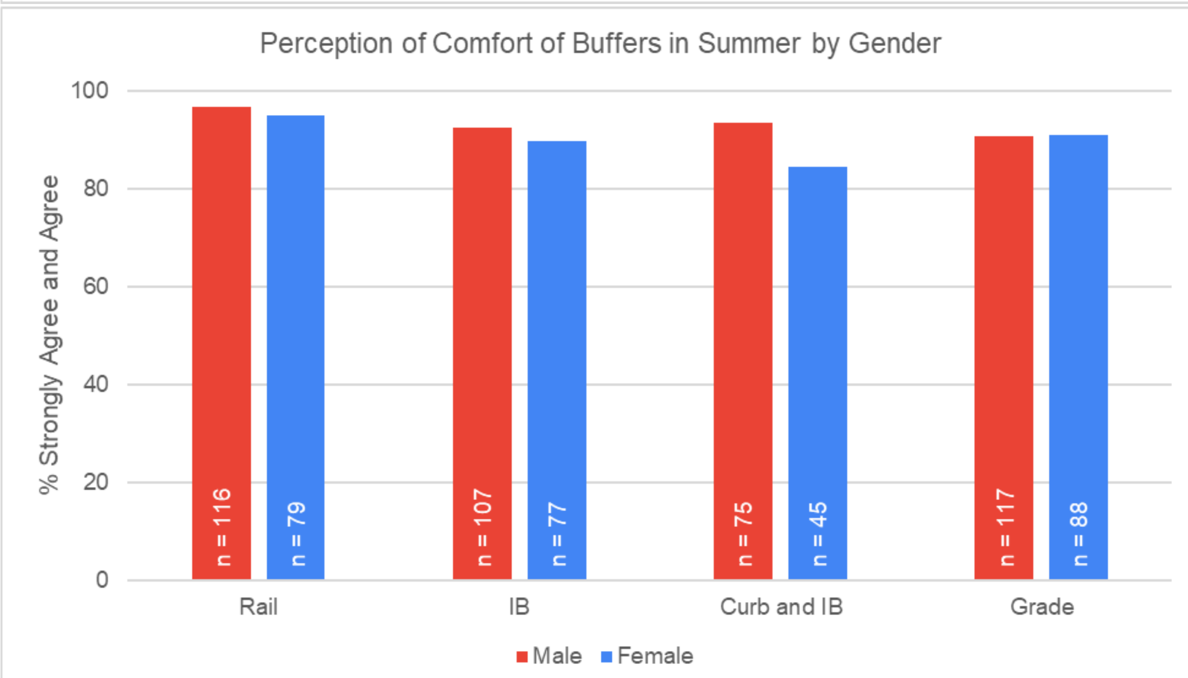
Figure 20 Example of randomized image section with two randomized images (A and B) and accompanying questions

Finally, respondents were taken to a brief demographic questionnaire before completing the survey. These demographic questions were standardized with language and categories taken from the U.S. Census. The demographic information collected was used to compare the respondent demographic to the cyclist demographic of MN as a whole, in order to point out potential bias in the sample.

APPENDIX C: ALL SURVEY ANALYSIS GRAPHS



Perception of Safety of Buffers in Summer by Gender
% Strongly Agree and Agree
100
80
60
40
20
0
n = 116
n = 80
n = 106
n = 78
n = 75
n = 46
n = 117
n = 89
Rail
IB
Curb and IB
Grade
Male
Female



Perception of Comfort of Buffers in Summer by Gender
% Strongly Agree and Agree
100
80
60
40
20
0
n = 116
n = 79
n = 107
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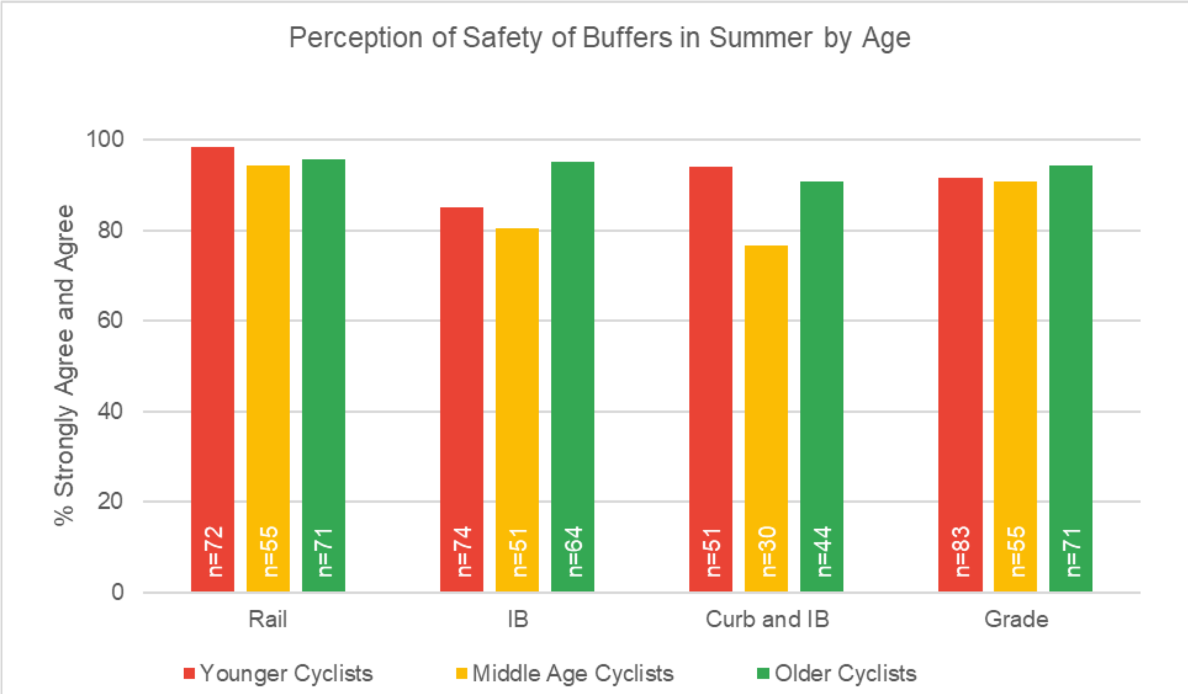
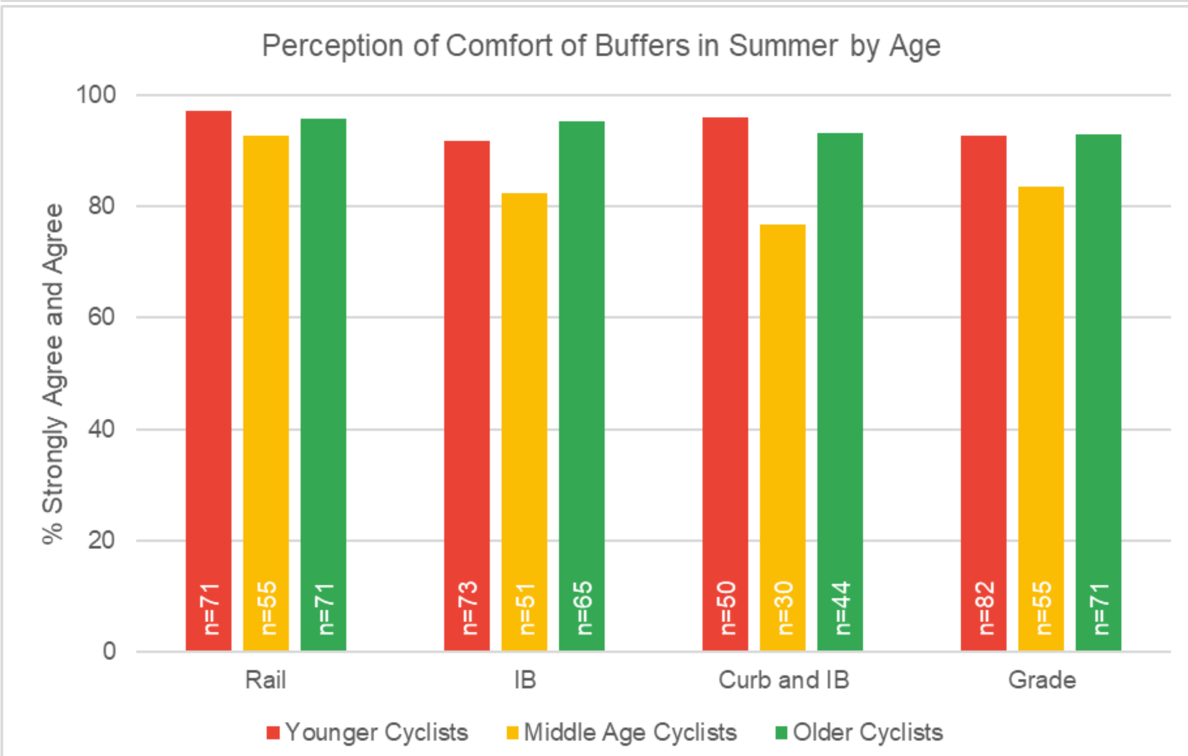
Rail
IB
Curb and IB
Grade
Male
Female


Perception of Safety of Buffers in Summer by Age
% Strongly Agree and Agree
100
80
60
40
20
0
n=72
n=55
n=71
n=74
n=51
n=64
n=51
n=30
n=44
n=83
n=55
n=71
Rail
IB
Curb and IB
Grade
Younger Cyclists
Middle Age Cyclists
Older Cyclists


Perception of Comfort of Buffers in Summer by Age
% Strongly Agree and Agree
100
80
60
40
20
0
n=71
n=55
n=71
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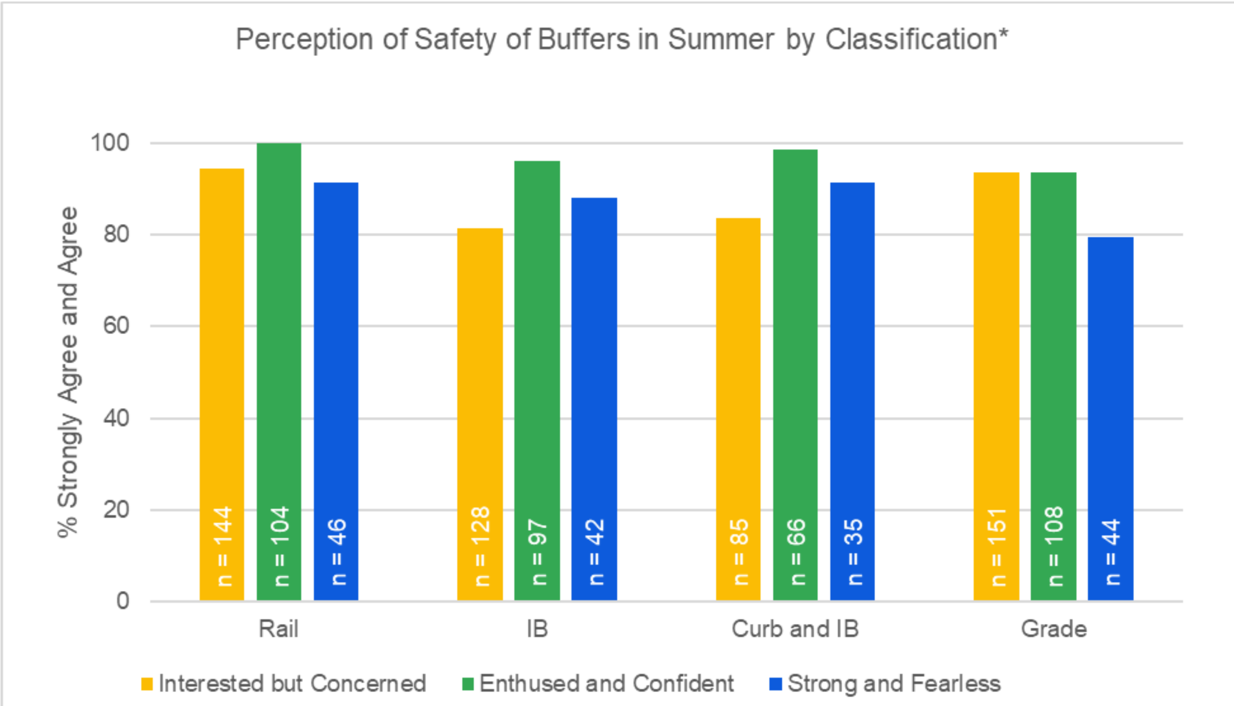
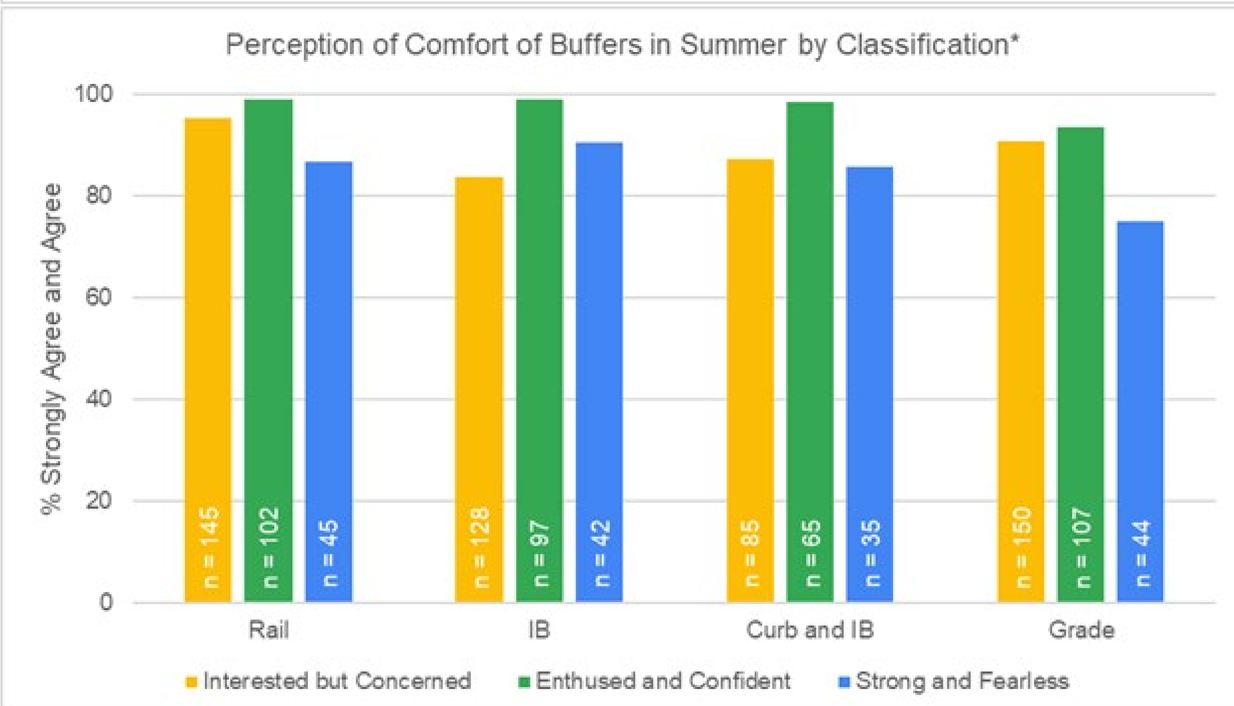
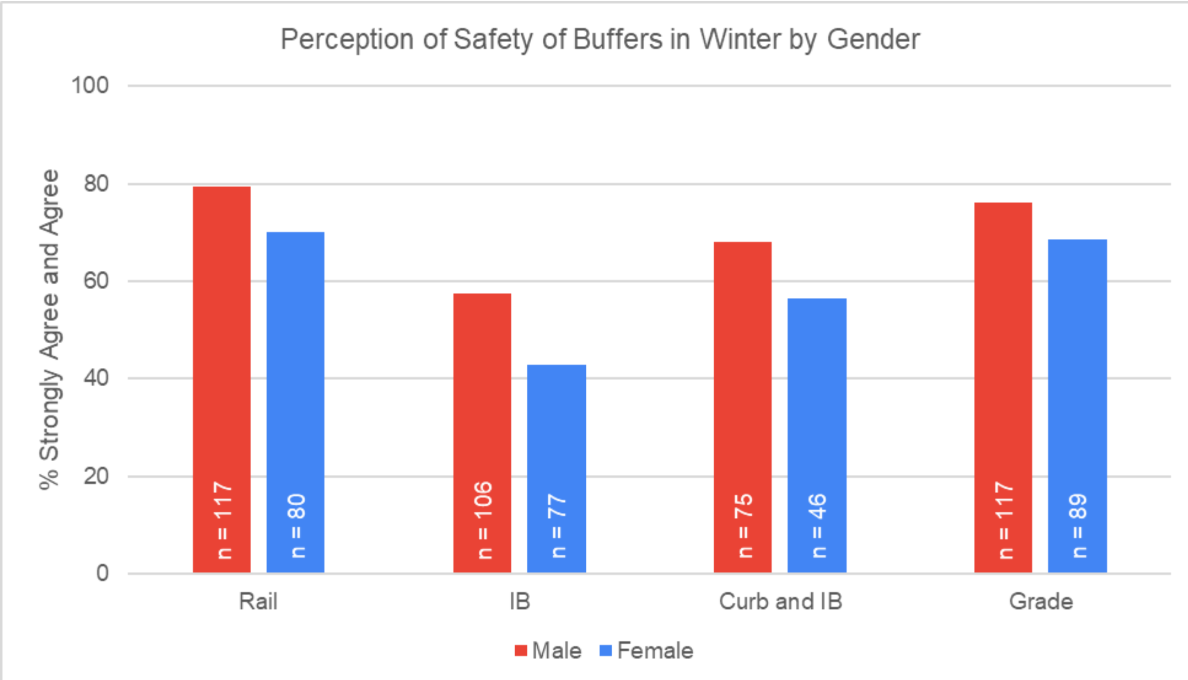
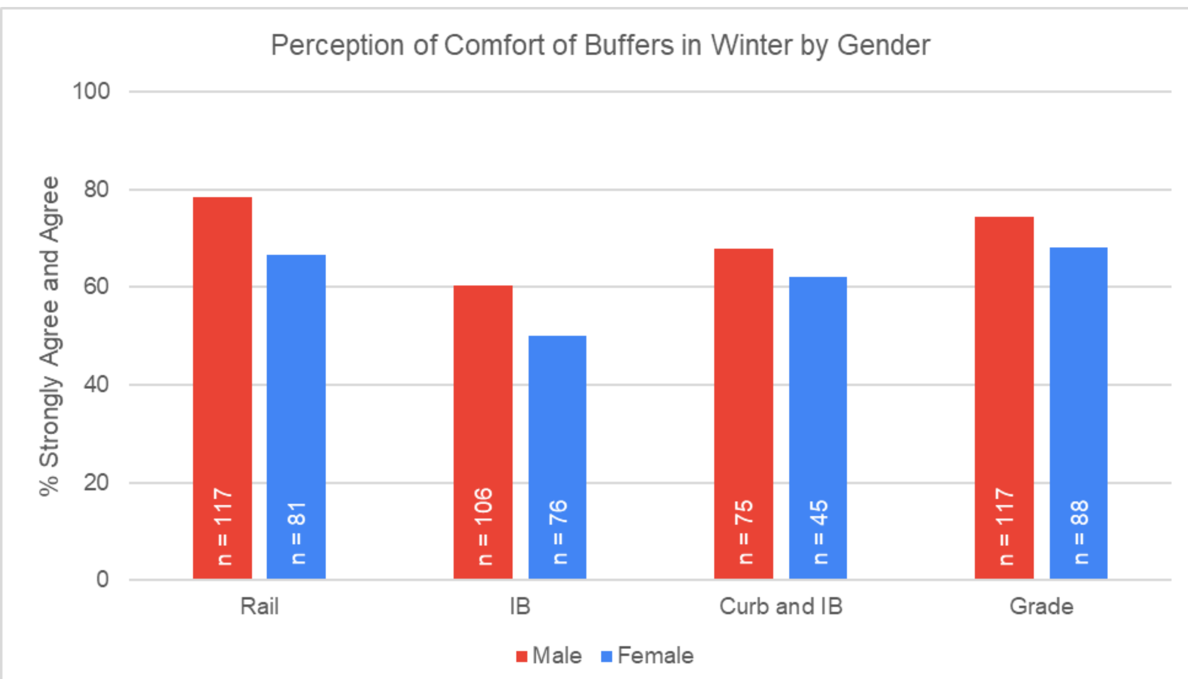
n=51
n=65
n=50
n=30
n=44
n=82
n=55
n=71
Rail
IB
Curb and IB
Grade
Younger Cyclists
Middle Age Cyclists
Older Cyclists


Perception of Safety of Buffers in Summer by Classification*
% Strongly Agree and Agree
100
80
60
40
20
0
n = 144
n = 104
n = 46
n = 128
n = 97
n = 42
n = 85
n = 66
n = 35
n = 151
n = 108
n = 44
Rail
IB
Curb and IB
Grade
Interested but Concerned
Enthused and Confident
Strong and Fearless


Perception of Comfort of Buffers in Summer by Classification*
% Strongly Agree and Agree
100
80
60
40
20
0
n = 145
n = 102
n = 45
n = 128
n = 97
n = 42
n = 85
n = 65
n = 35
n = 150
n = 107
n = 44
Rail
IB
Curb and IB
Grade
Interested but Concerned
Enthused and Confident
Strong and Fearless


Perception of Safety of Buffers in Winter by Gender
% Strongly Agree and Agree
100
80
60
40
20
0
n = 117
n = 80
n = 106
n = 77
n = 75
n = 46
n = 117
n = 89
Rail
IB
Curb and IB
Grade
Male
Female


Perception of Comfort of Buffers in Winter by Gender
% Strongly Agree and Agree
100
80
60
40
20
0
n = 117
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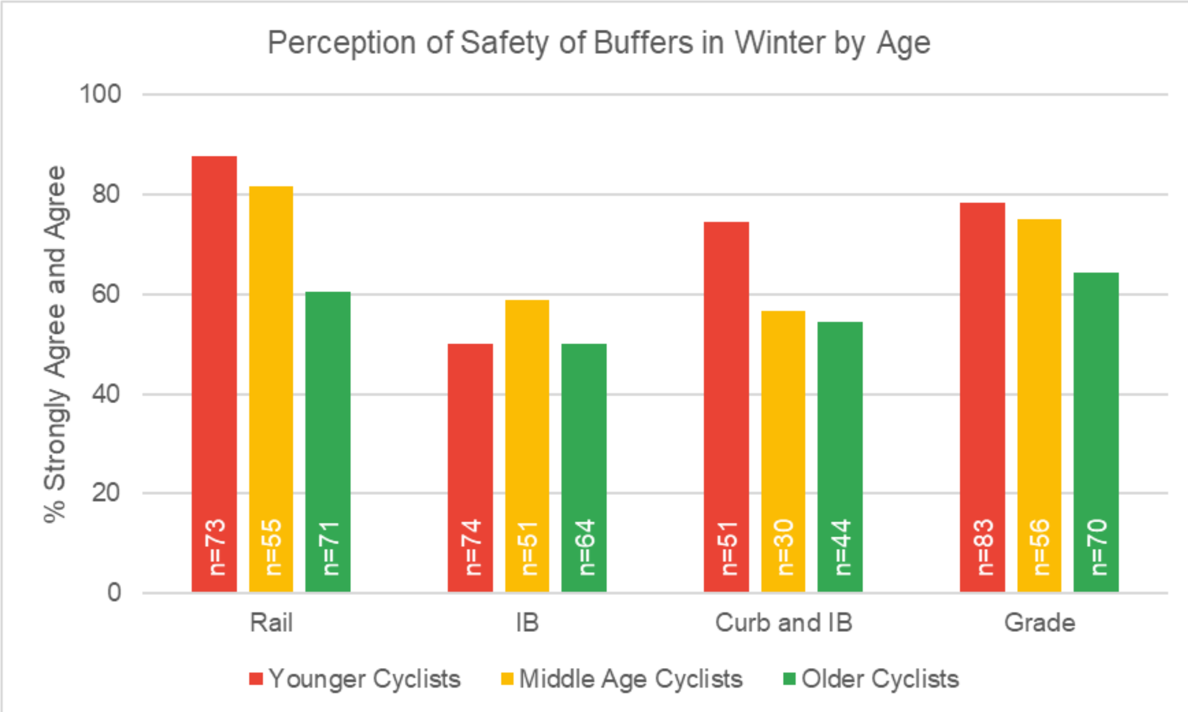
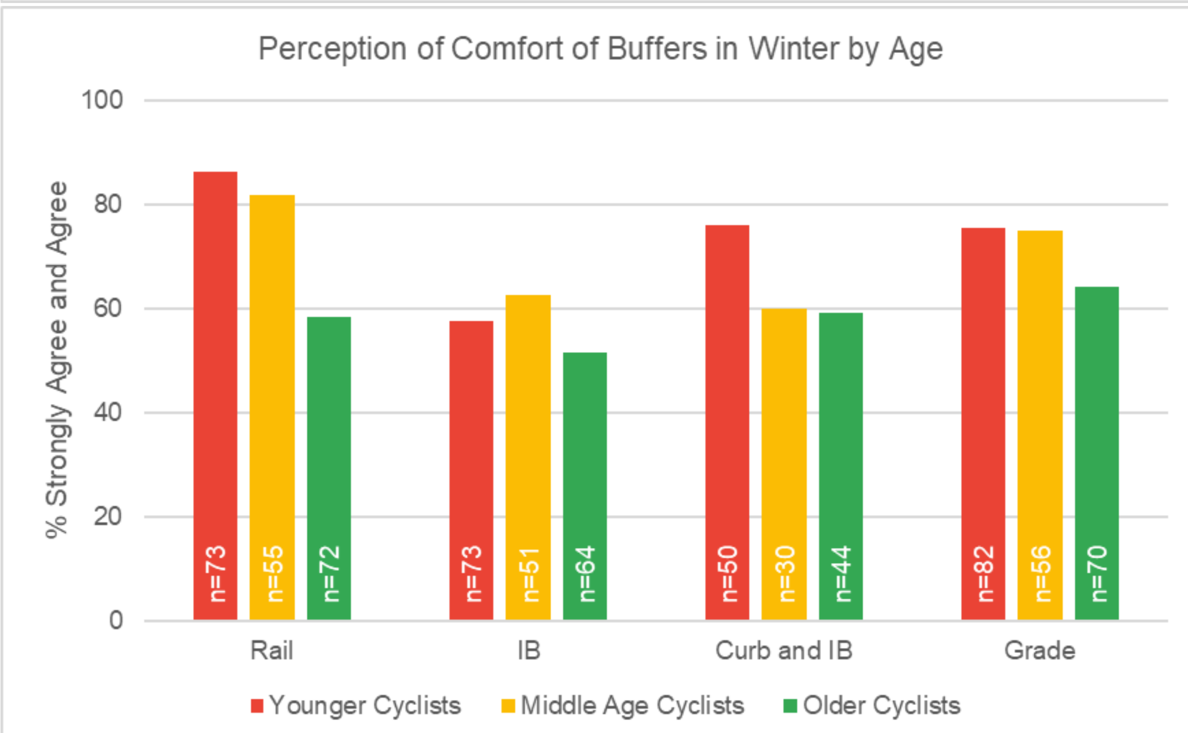
Rail
IB
Curb and IB
Grade
Male
Female


Perception of Safety of Buffers in Winter by Age
% Strongly Agree and Agree
100
80
60
40
20
0
n=73
n=55
n=71
n=74
n=51
n=64
n=51
n=30
n=44
n=83
n=56
n=70
Rail
IB
Curb and IB
Grade
Younger Cyclists
Middle Age Cyclists
Older Cyclists


Perception of Comfort of Buffers in Winter by Age
% Strongly Agree and Agree
100
80
60
40
20
0
n=73
n=55
n=72
n=73
n=51
n=64
n=50
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Rail
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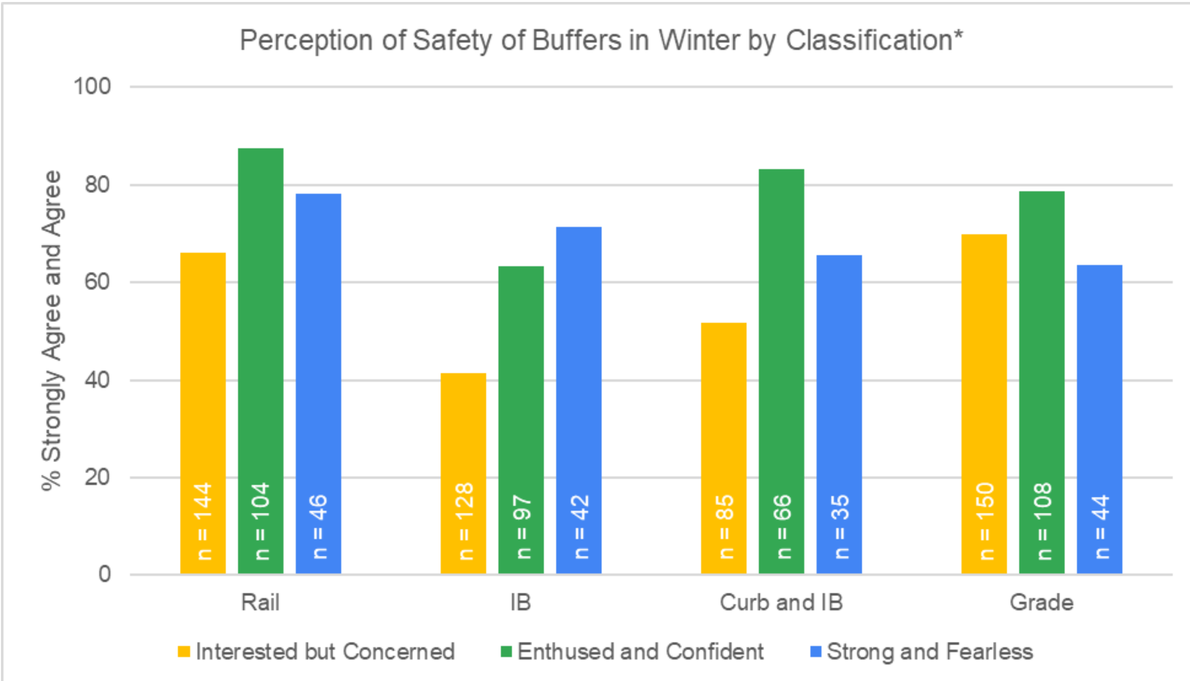
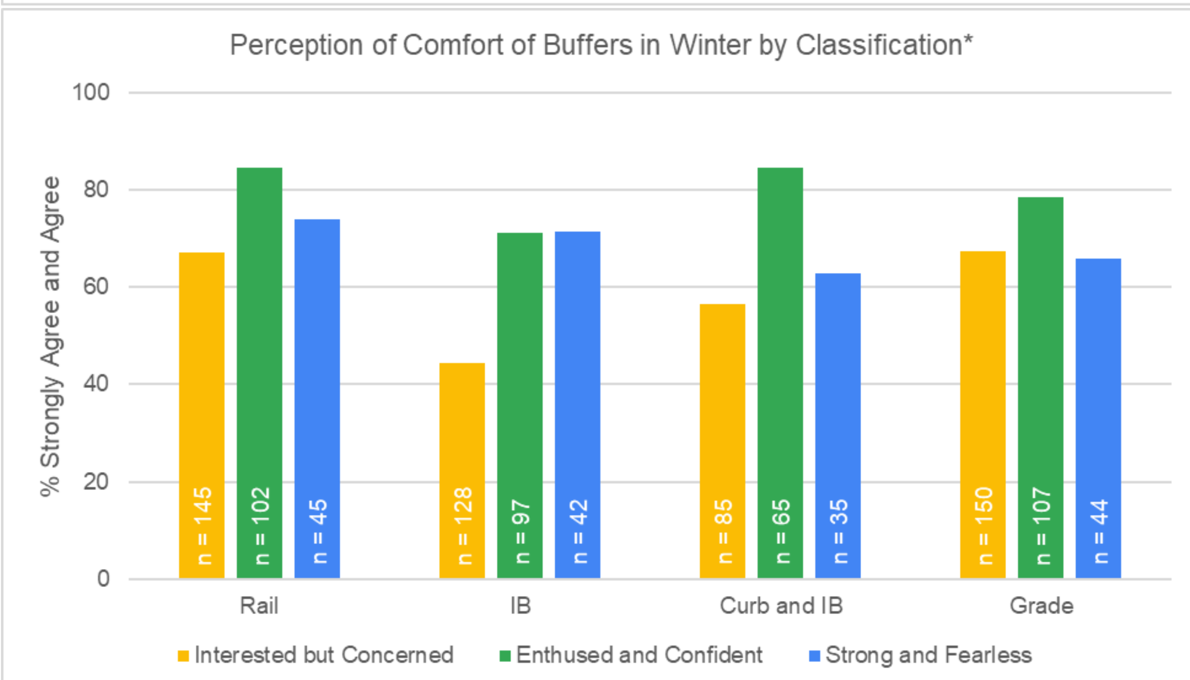
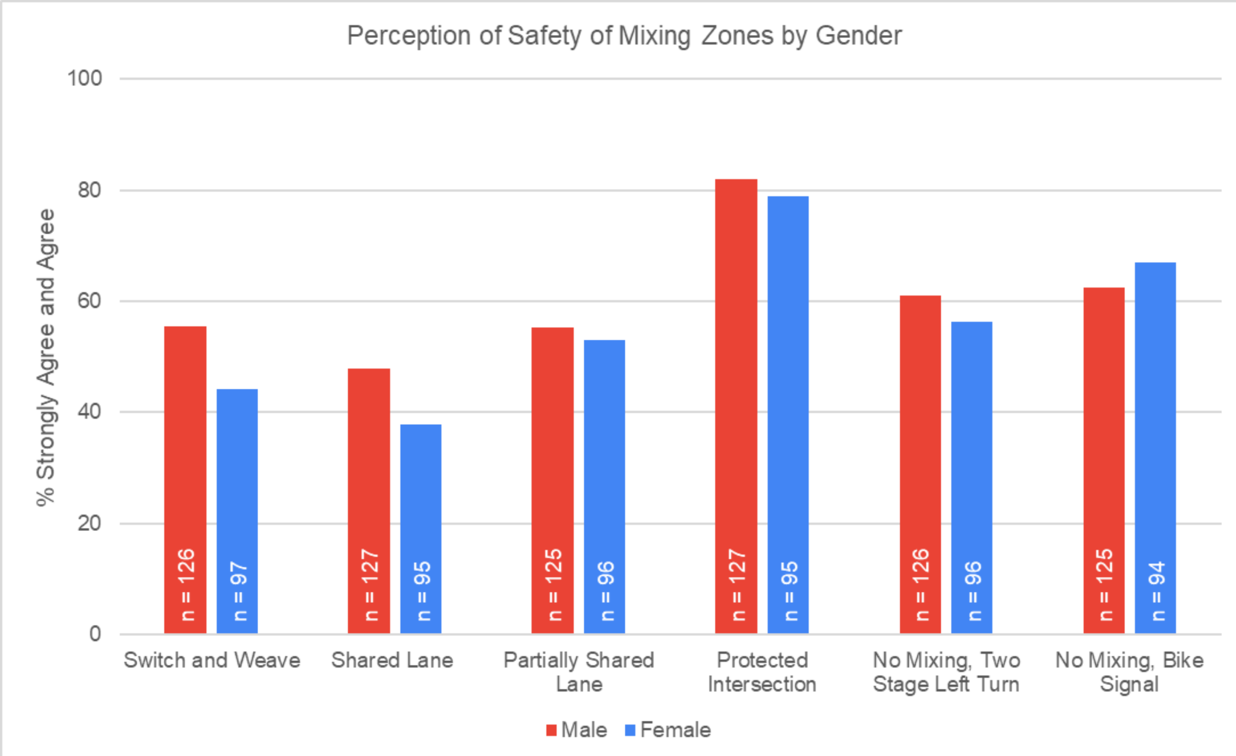
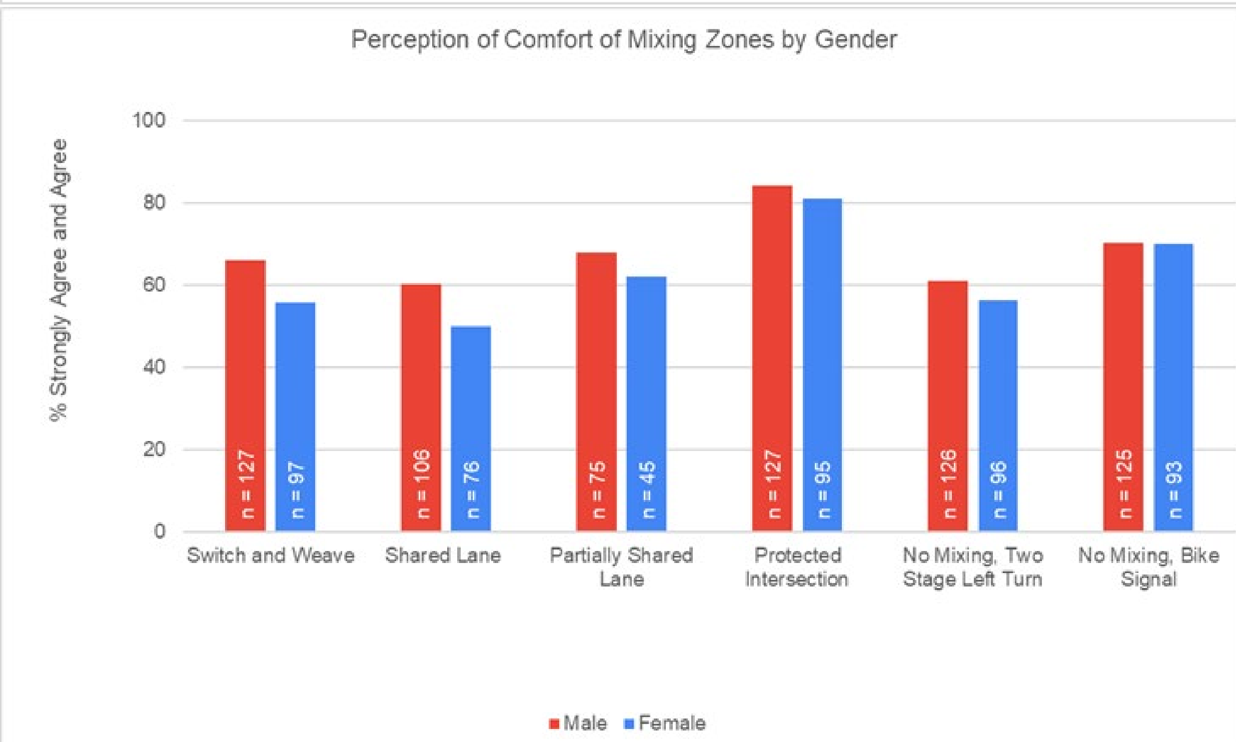
Younger Cyclists
Middle Age Cyclists
Older Cyclists

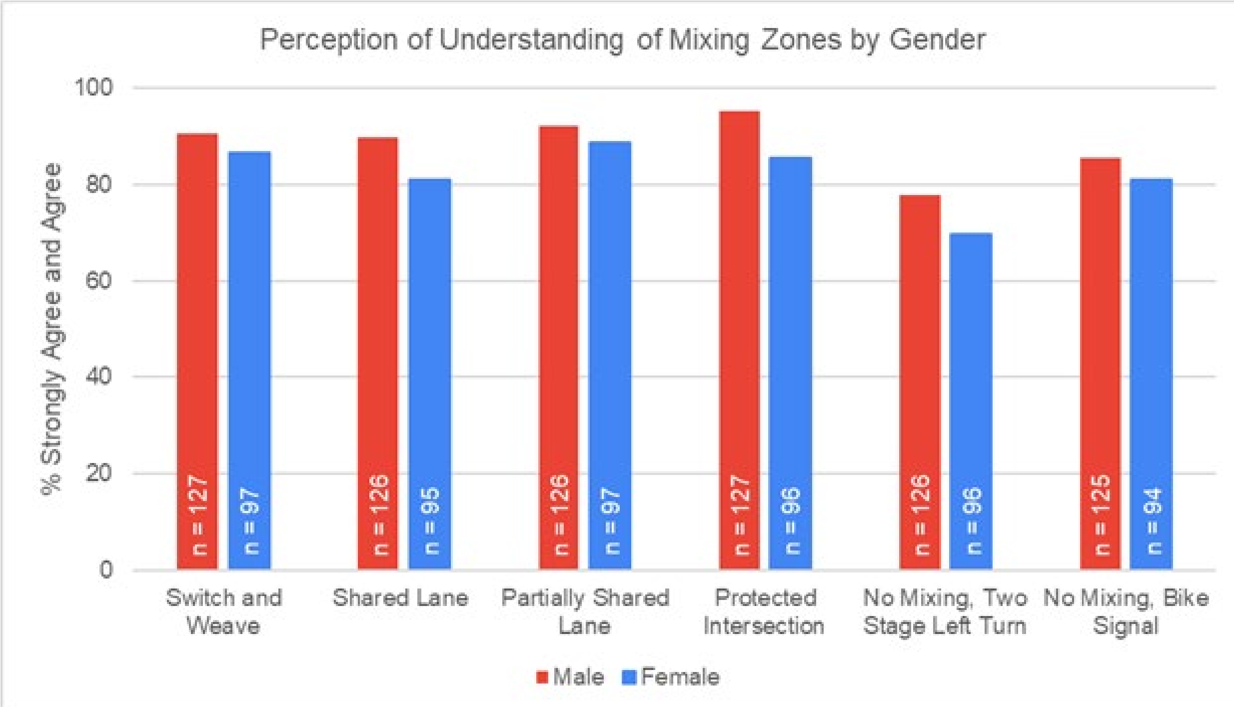


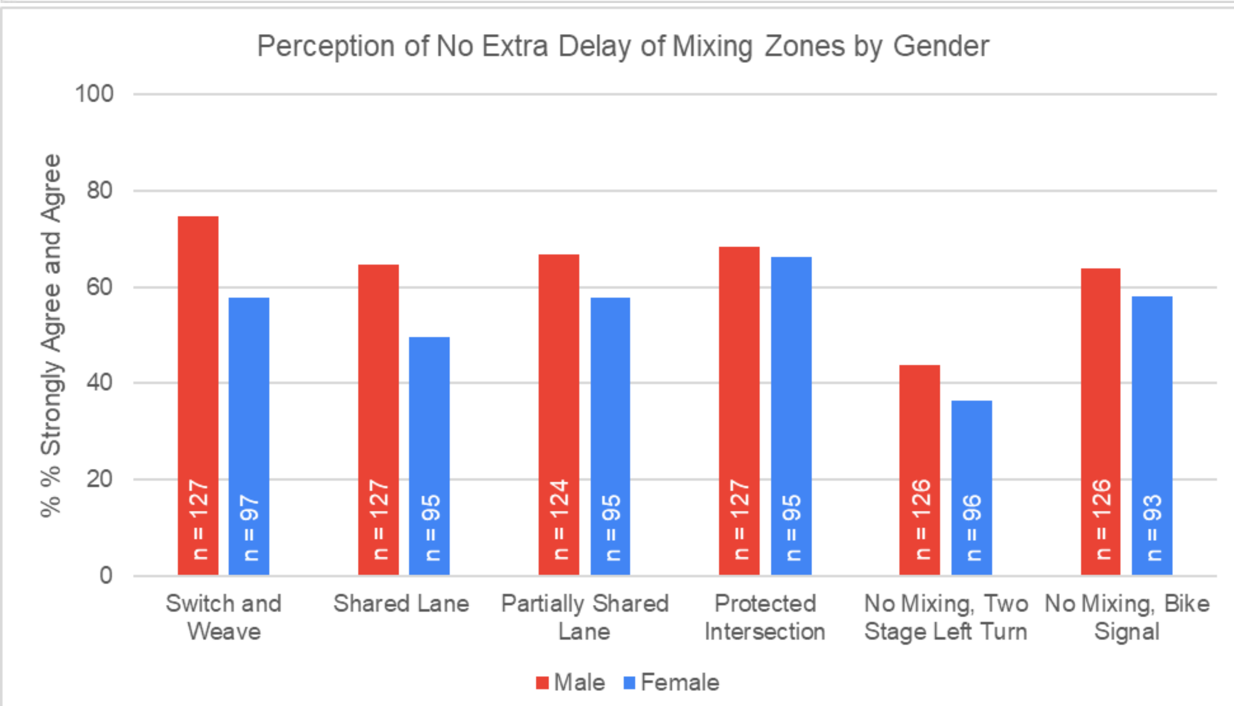


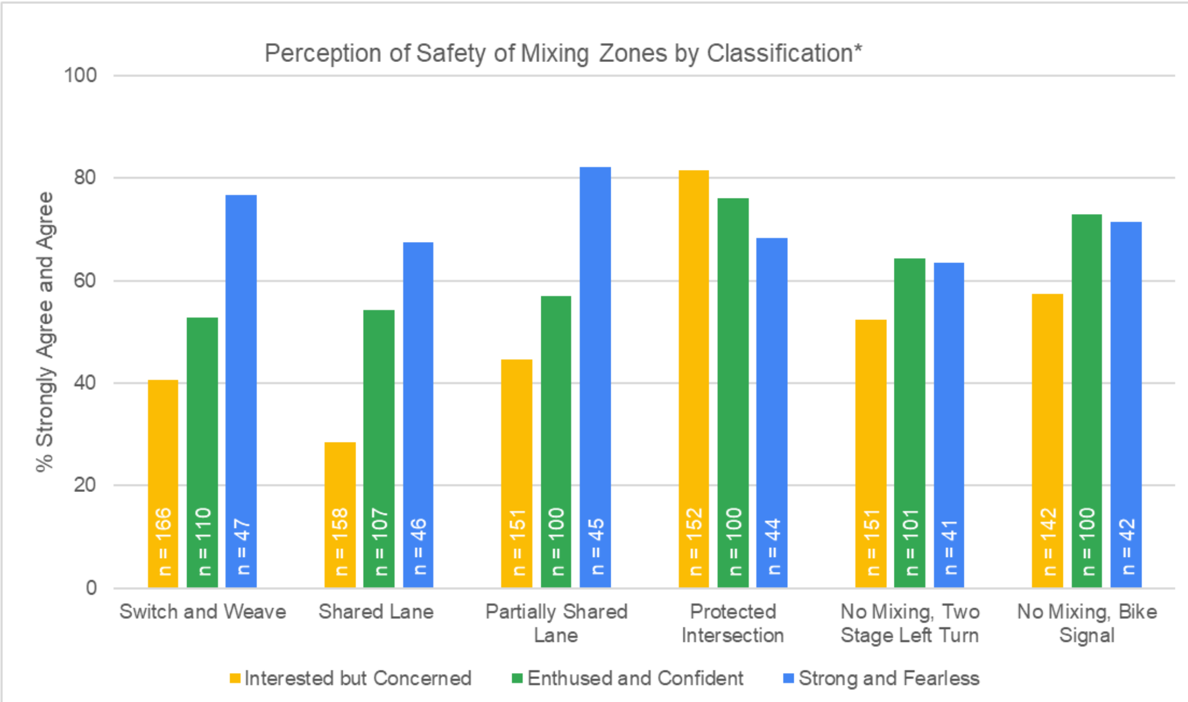
Mixing Zones


Perception of Safety of Mixing Zones by Gender
% Strongly Agree and Agree
100
80
60
40
20
0
n = 126
n = 97
n = 127
n = 95
n = 125
n = 96
n = 127
n = 95
n = 126
n = 96
n = 125
n = 94
Switch and Weave
Shared Lane
Partially Shared Lane
Protected Intersection
No Mixing, Two Stage Left Turn
No Mixing, Bike Signal
Male
Female

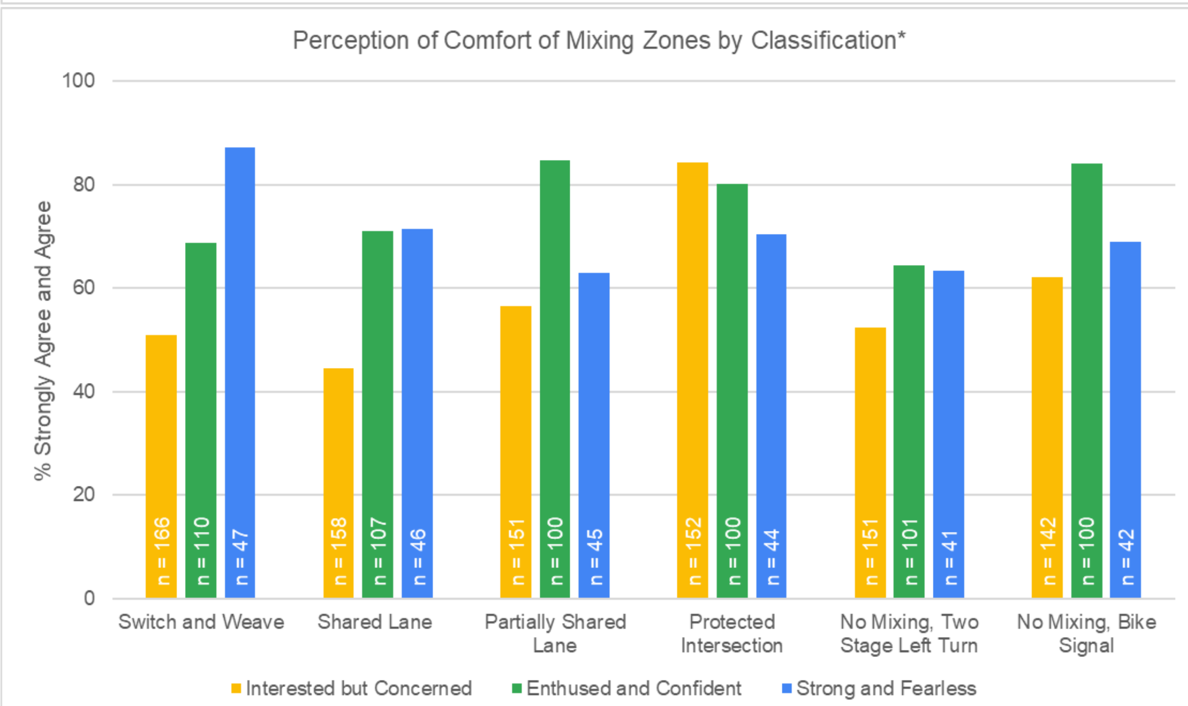

Perception of Comfort of Mixing Zones by Gender
% Strongly Agree and Agree
100
80
60
40
20
0
n = 127
n = 97
n = 106
n = 76
n = 75
n = 45
n = 127
n = 95
n = 126
n = 96
n = 125
n = 93
Switch and Weave
Shared Lane
Partially Shared Lane
Protected Intersection
No Mixing, Two Stage Left Turn
No Mixing, Bike Signal
Male
Female


Perception of Understanding of Mixing Zones by Gender
% Strongly Agree and Agree
100
80
60
40
20
0
n = 127
n = 97
n = 126
n = 95
n = 126
n = 97
n = 127
n = 96
n = 126
n = 96
n = 125
n = 94
Switch and Weave
Shared Lane
Partially Shared Lane
Protected Intersection
No Mixing, Two Stage Left Turn
No Mixing, Bike Signal
Male
Female

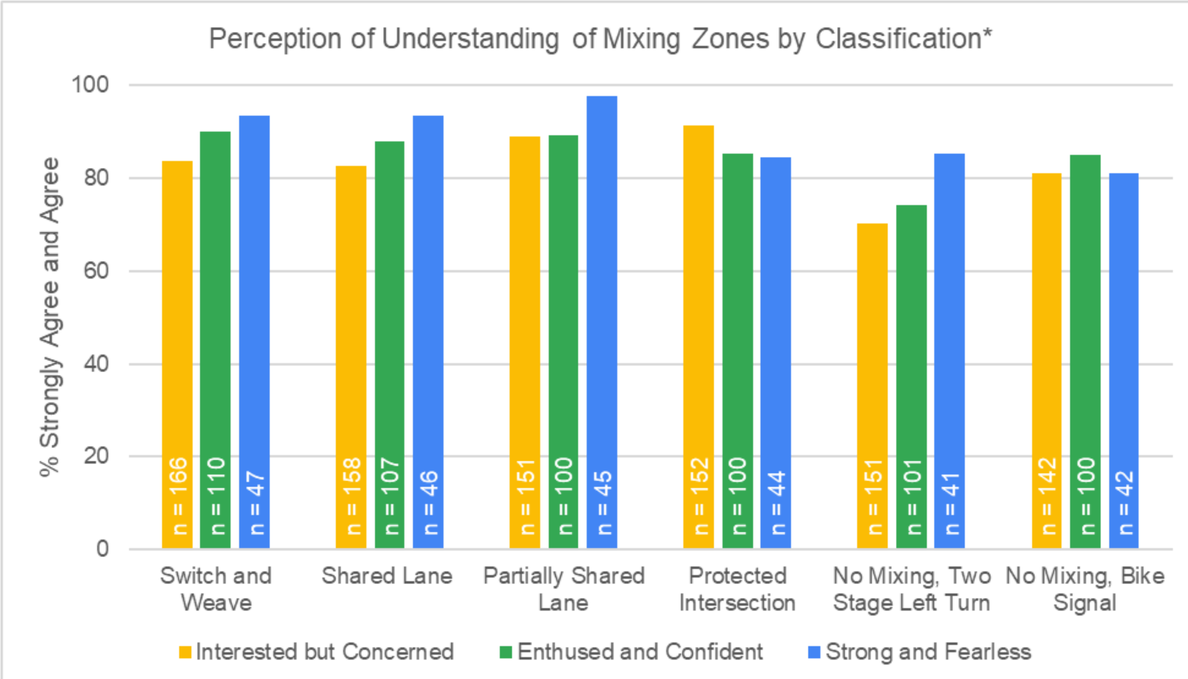

Perception of No Extra Delay of Mixing Zones by Gender
% % Strongly Agree and Agree
100
80
60
40
20
0
n = 127
n = 97
n = 127
n = 95
n = 124
n = 95
n = 127
n = 95
n = 126
n = 96
n = 126
n = 93
Switch and Weave
Shared Lane
Partially Shared Lane
Protected Intersection
No Mixing, Two Stage Left Turn
No Mixing, Bike Signal
Male
Female

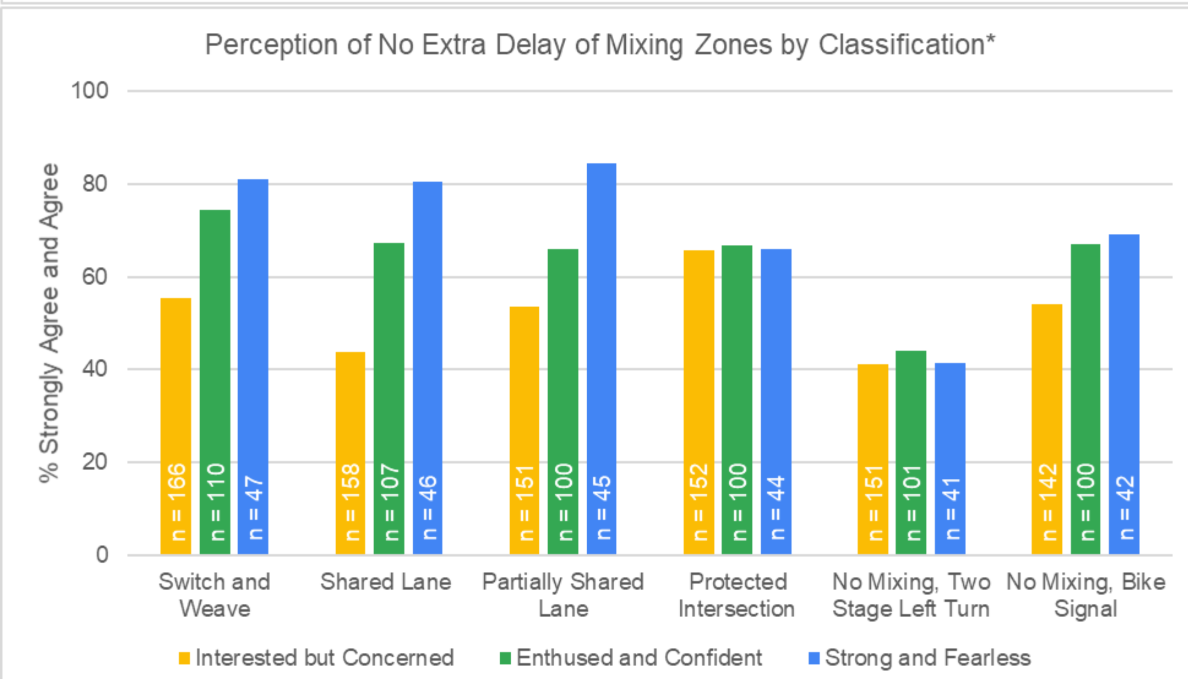


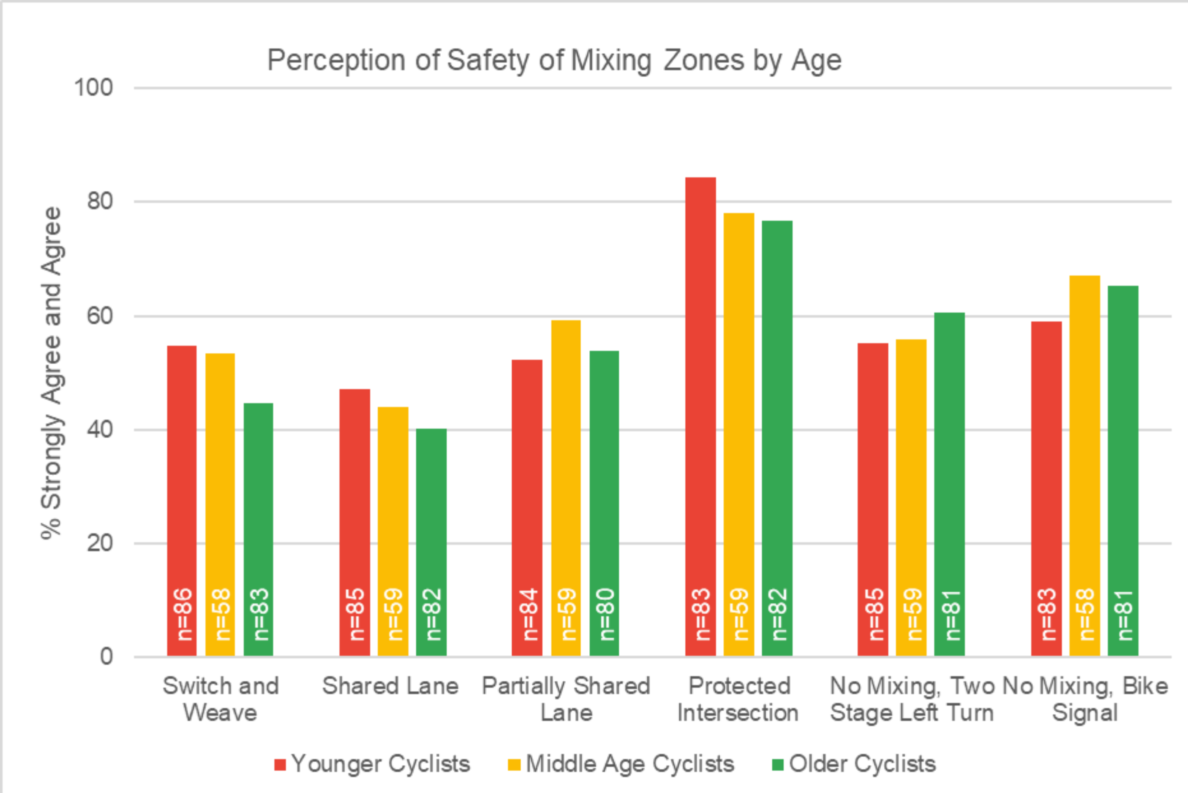
Perception of Safety of Mixing Zones by Classification*
% Strongly Agree and Agree
100
80
60
40
20
0
n = 166
n = 110
n = 47
n = 158
n = 107
n = 46
n = 151
n = 100
n = 45
n = 152
n = 100
n = 44
n = 151
n = 101
n = 41
n = 142
n = 100
n = 42
Switch and Weave
Shared Lane
Partially Shared Lane
Protected Intersection
No Mixing, Two Stage Left Turn
No Mixing, Bike Signal
Interested but Concerned
Enthused and Confident
Strong and Fearless

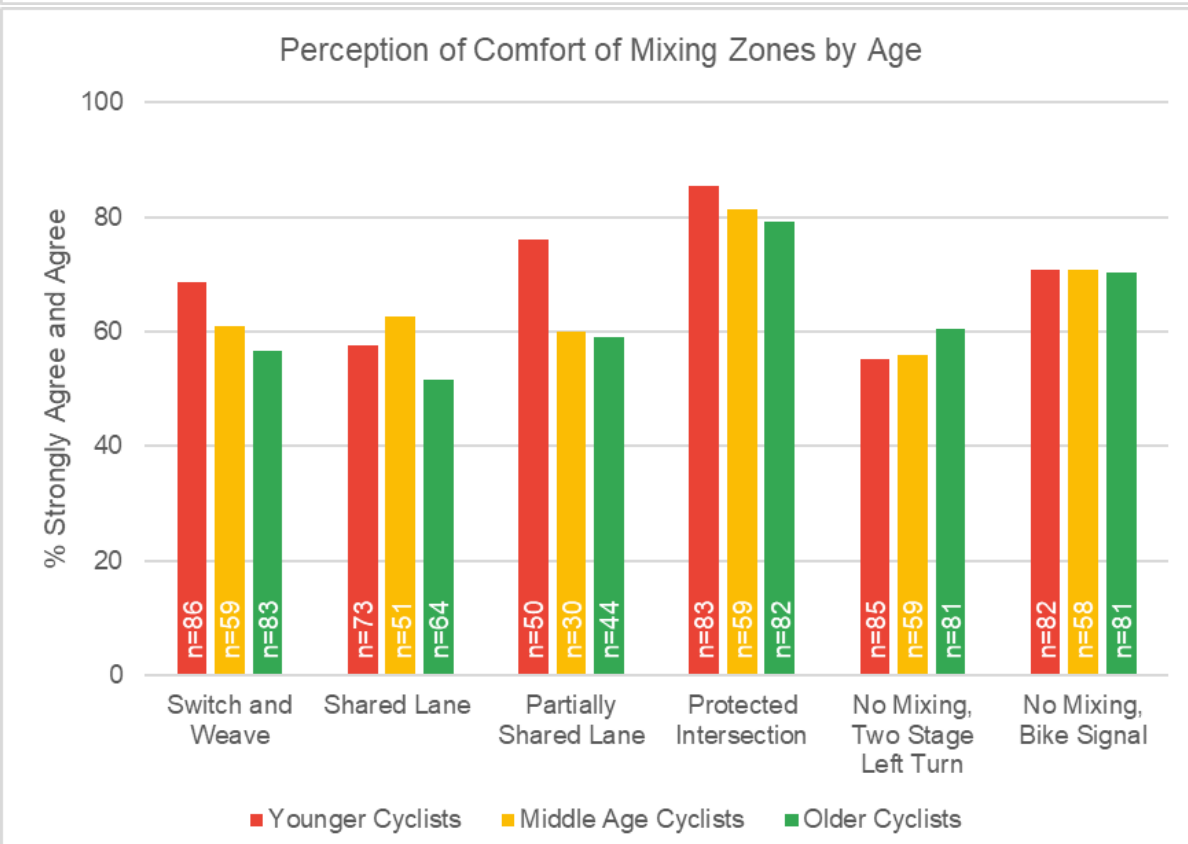


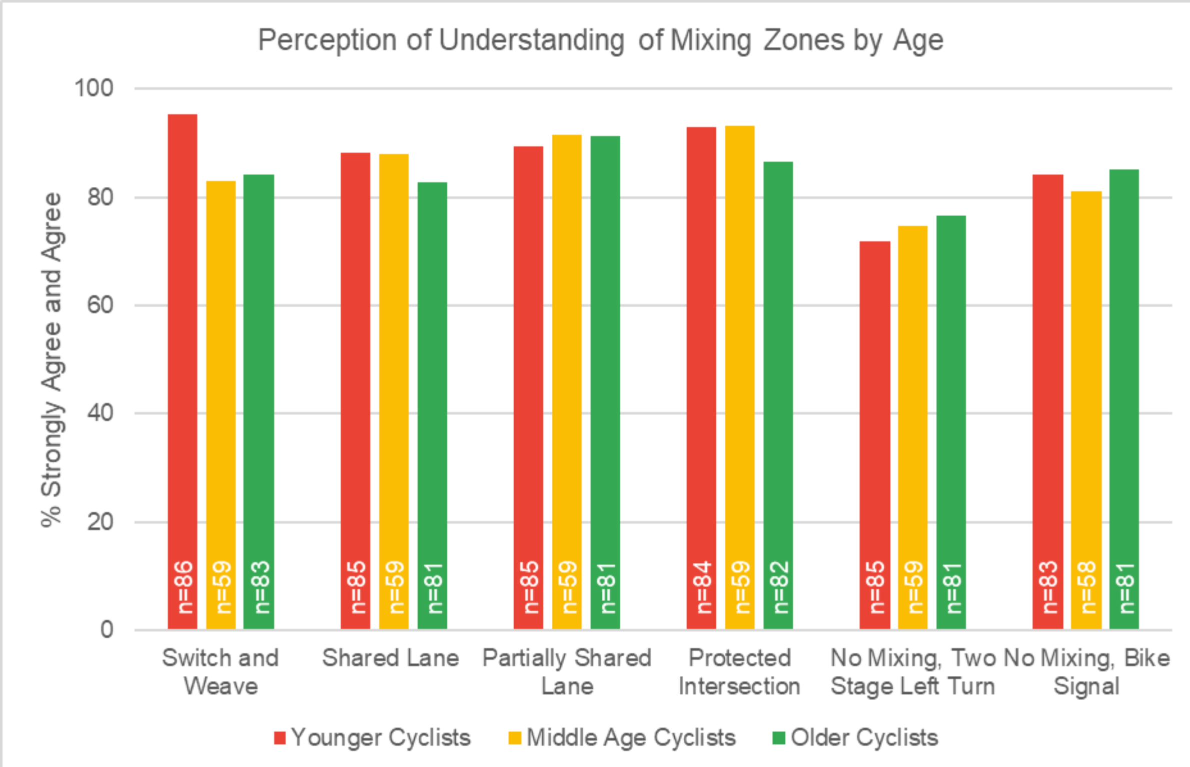
Perception of Comfort of Mixing Zones by Classification*
% Strongly Agree and Agree
100
80
60
40
20
0
n = 166
n = 110
n = 47
n = 158
n = 107
n = 46
n = 151
n = 100
n = 45
n = 152
n = 100
n = 44
n = 151
n = 101
n = 41
n = 142
n = 100
n = 42
Switch and Weave
Shared Lane
Partially Shared Lane
Protected Intersection
No Mixing, Two Stage Left Turn
No Mixing, Bike Signal
Interested but Concerned
Enthused and Confident
Strong and Fearless

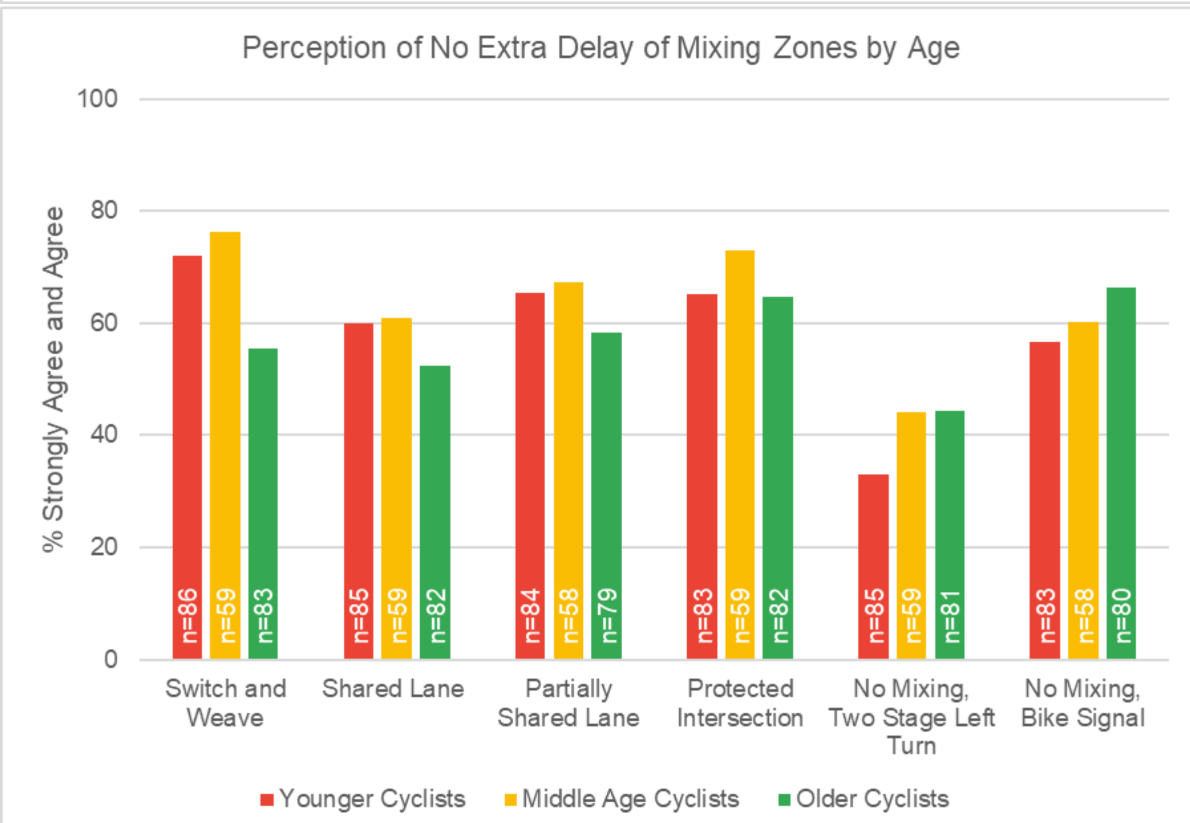

Perception of Understanding of Mixing Zones by Classification*
% Strongly Agree and Agree
100
80
60
40
20
0
n = 166
n = 110
n = 47
n = 158
n = 107
n = 46
n = 151
n = 100
n = 45
n = 152
n = 100
n = 44
n = 151
n = 101
n = 41
n = 142
n = 100
n = 42
Switch and Weave
Shared Lane
Partially Shared Lane
Protected Intersection
No Mixing, Two Stage Left Turn
No Mixing, Bike Signal
Interested but Concerned
Enthused and Confident
Strong and Fearless

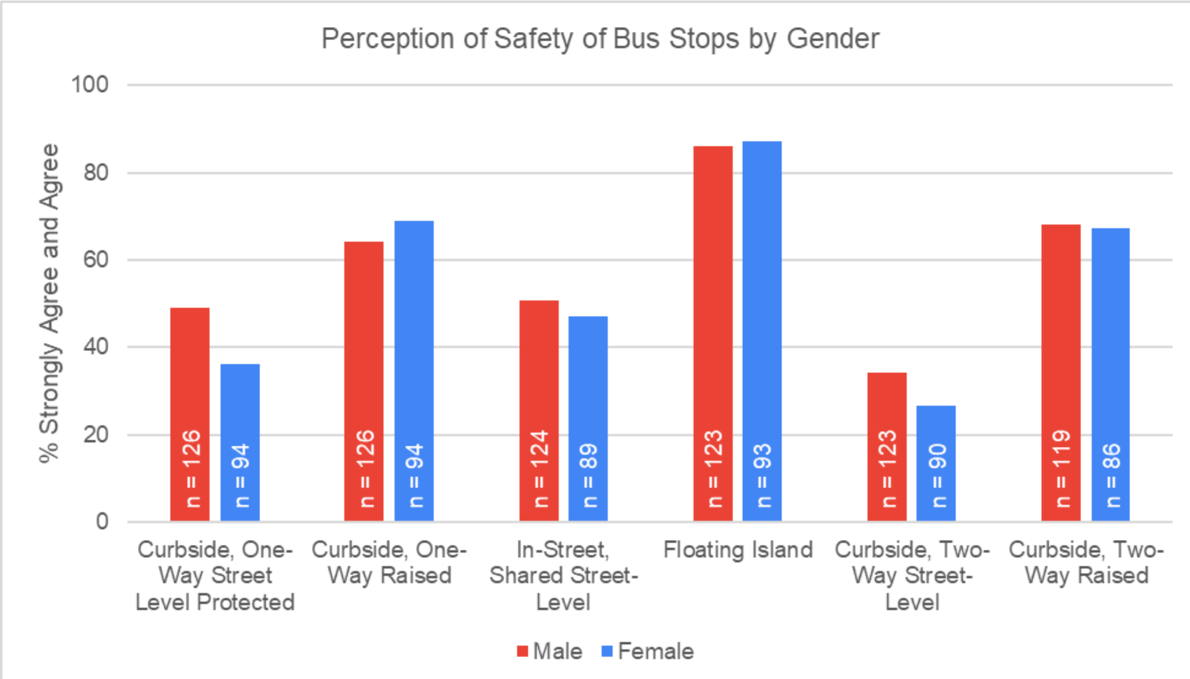

Perception of No Extra Delay of Mixing Zones by Classification*
% Strongly Agree and Agree
100
80
60
40
20
0
n = 166
n = 110
n = 47
n = 158
n = 107
n = 46
n = 151
n = 100
n = 45
n = 152
n = 100
n = 44
n = 151
n = 101
n = 41
n = 142
n = 100
n = 42
Switch and Weave
Shared Lane
Partially Shared Lane
Protected Intersection
No Mixing, Two Stage Left Turn
No Mixing, Bike Signal
Interested but Concerned
Enthused and Confident
Strong and Fearless

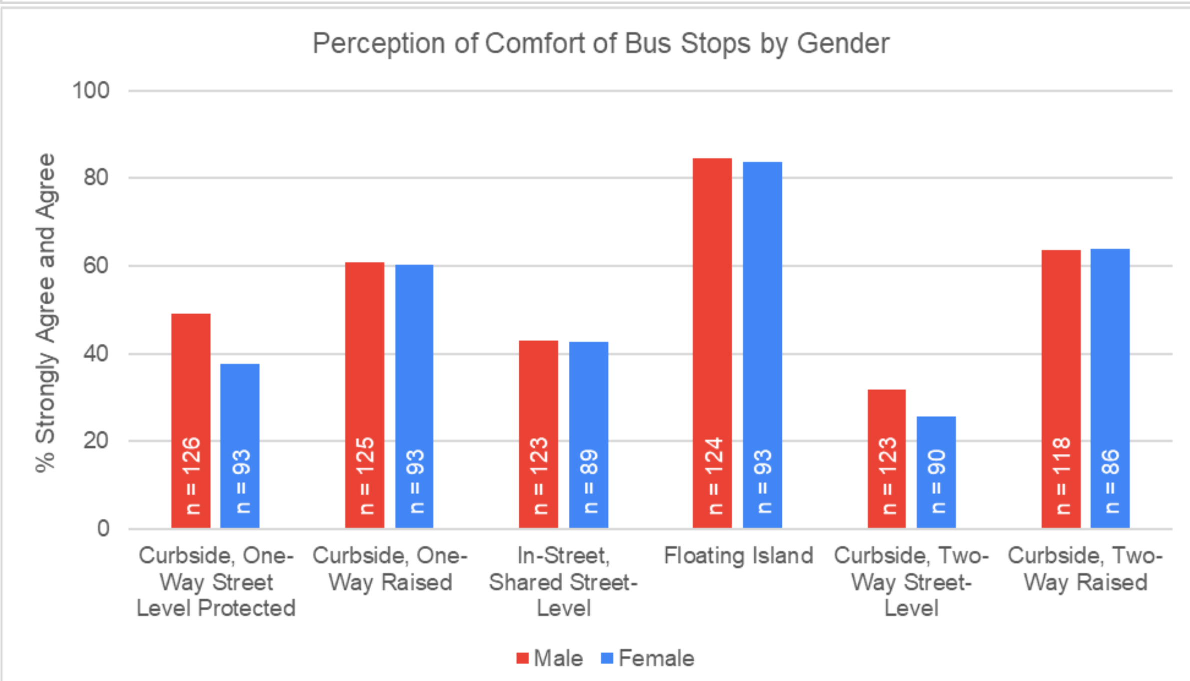

Perception of Safety of Mixing Zones by Age
% Strongly Agree and Agree
100
80
60
40
20
0
n=86
n=58
n=83
n=85
n=59
n=82
n=84
n=59
n=80
n=83
n=59
n=82
n=85
n=59
n=81
n=83
n=58
n=81
Switch and Weave
Shared Lane
Partially Shared Lane
Protected Intersection
No Mixing, Two Stage Left Turn
No Mixing, Bike Signal
Younger Cyclists
Middle Age Cyclists
Older Cyclists

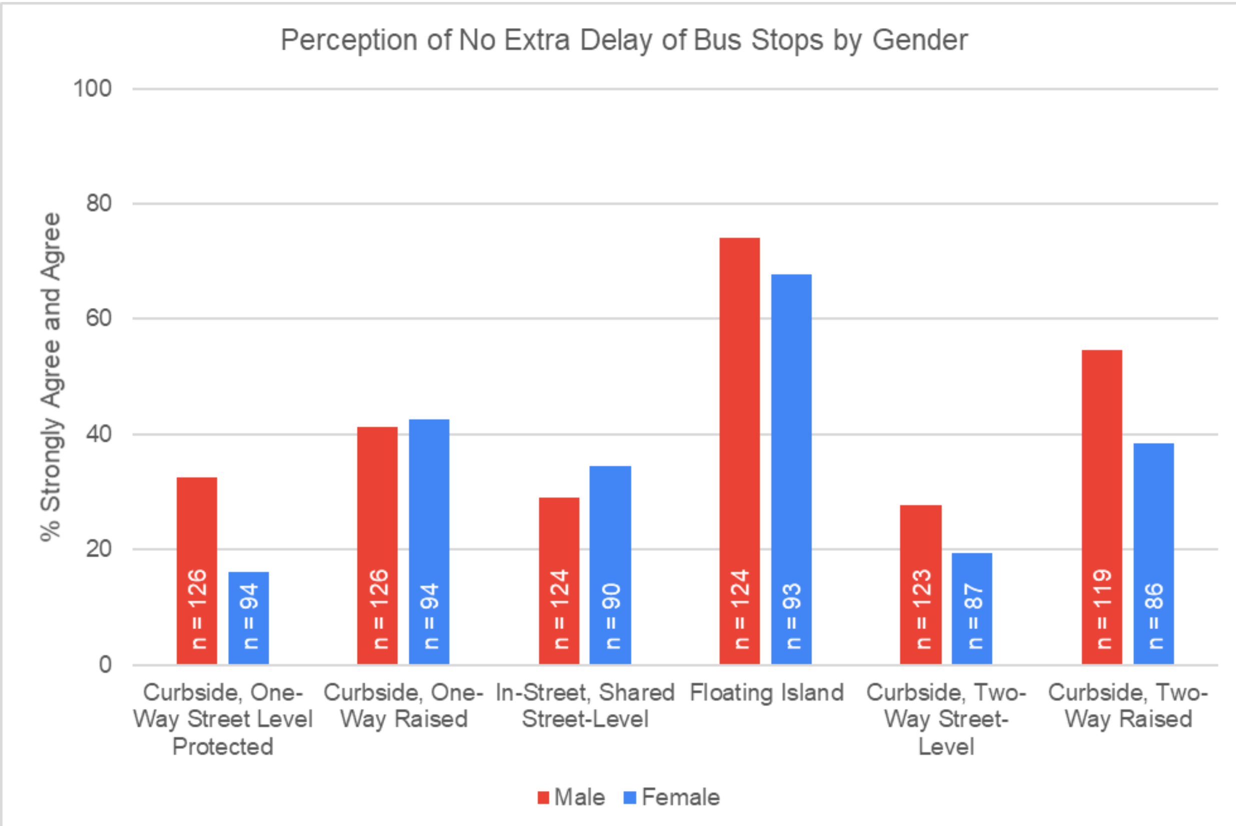

Perception of Comfort of Mixing Zones by Age
% Strongly Agree and Agree
100
80
60
40
20
0
n=86
n=59
n=83
n=73
n=51
n=64
n=50
n=30
n=44
n=83
n=59
n=82
n=85
n=59
n=81
n=82
n=58
n=81
Switch and Weave
Shared Lane
Partially Shared Lane
Protected Intersection
No Mixing, Two Stage Left Turn
No Mixing, Bike Signal
Younger Cyclists
Middle Age Cyclists
Older Cyclists

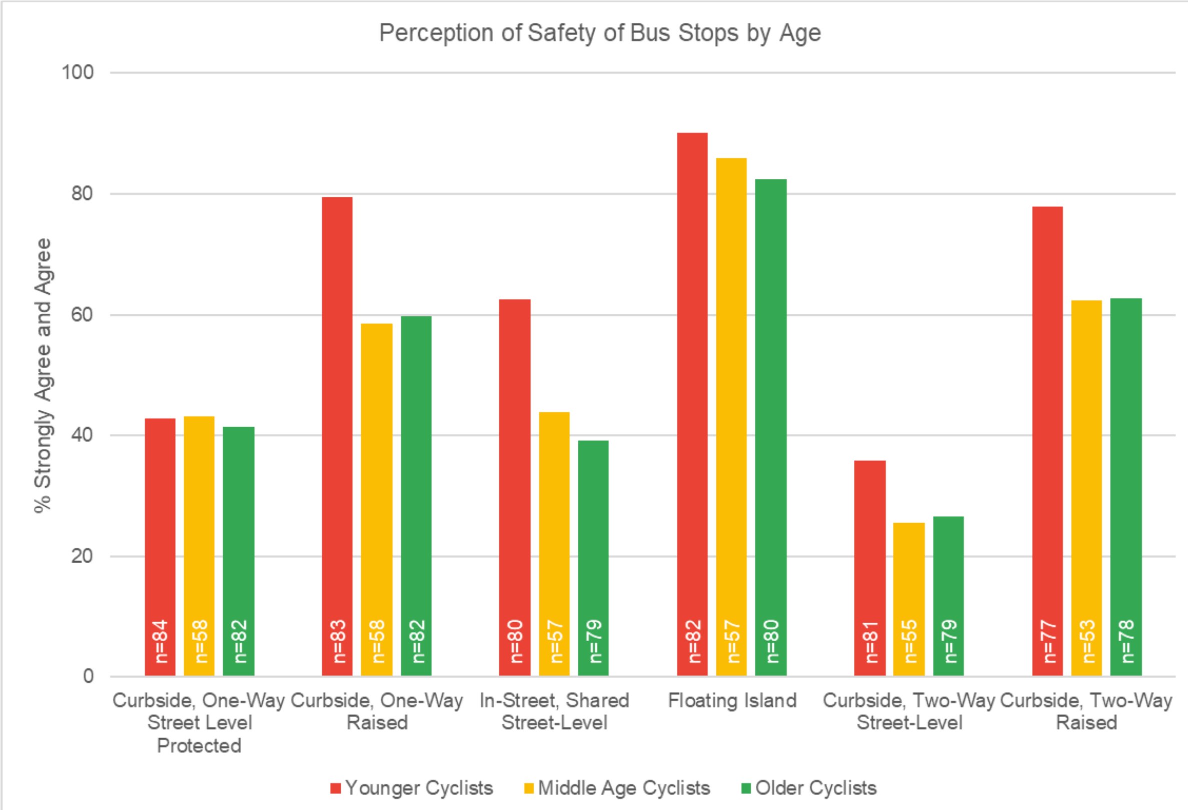

Perception of Understanding of Mixing Zones by Age
% Strongly Agree and Agree
100
80
60
40
20
0
n=86 n=59 n=83
n=85 n=59 n=81
n=85 n=59 n=81
n=84 n=59 n=82
n=85 n=59 n=81
n=83 n=58 n=81
Switch and Weave
Shared Lane
Partially Shared Lane
Protected Intersection
No Mixing, Two Stage Left Turn
No Mixing, Bike Signal
Younger Cyclists
Middle Age Cyclists
Older Cyclists

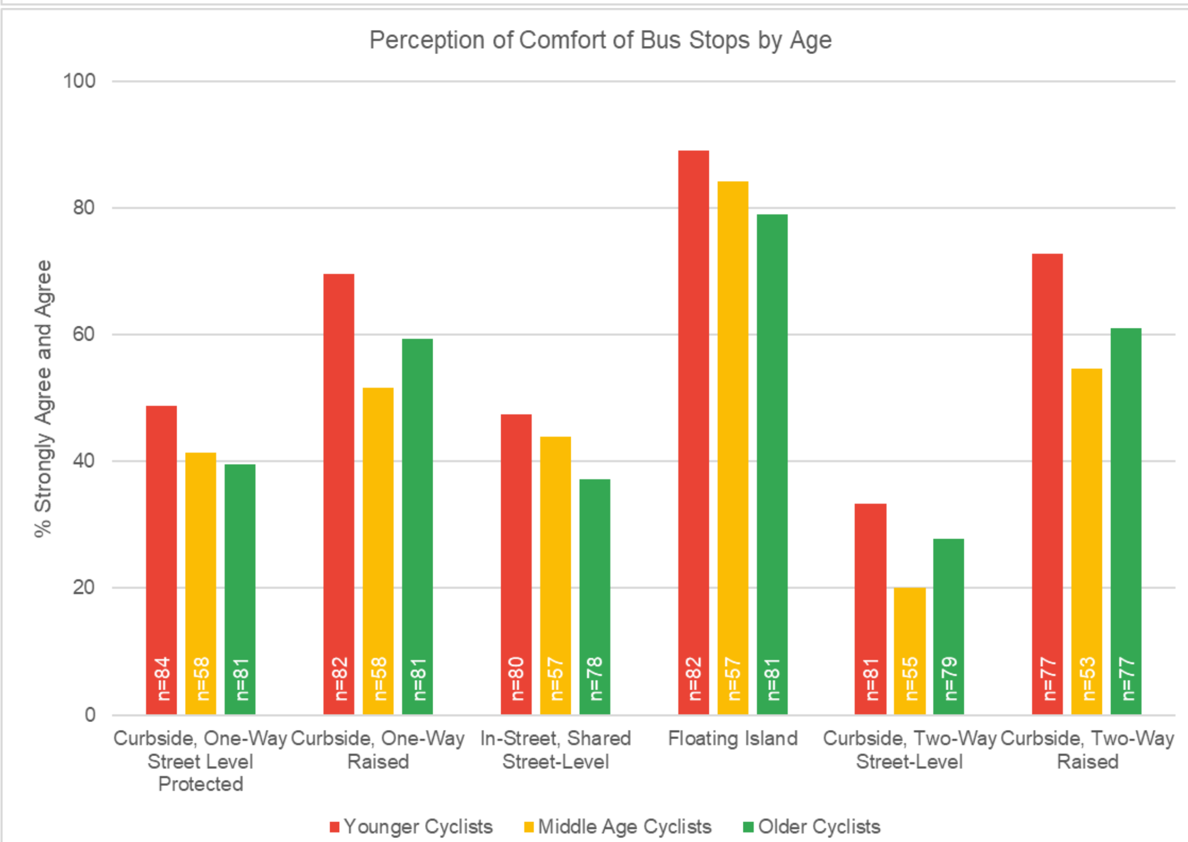

Perception of No Extra Delay of Mixing Zones by Age
% Strongly Agree and Agree
100
80
60
40
20
0
n=86 n=59 n=83
n=85 n=59 n=82
n=84 n=58 n=79
n=83 n=59 n=82
n=85 n=59 n=81
n=83 n=58 n=80
Switch and Weave
Shared Lane
Partially Shared Lane
Protected Intersection
No Mixing, Two Stage Left Turn
No Mixing, Bike Signal
Younger Cyclists
Middle Age Cyclists
Older Cyclists

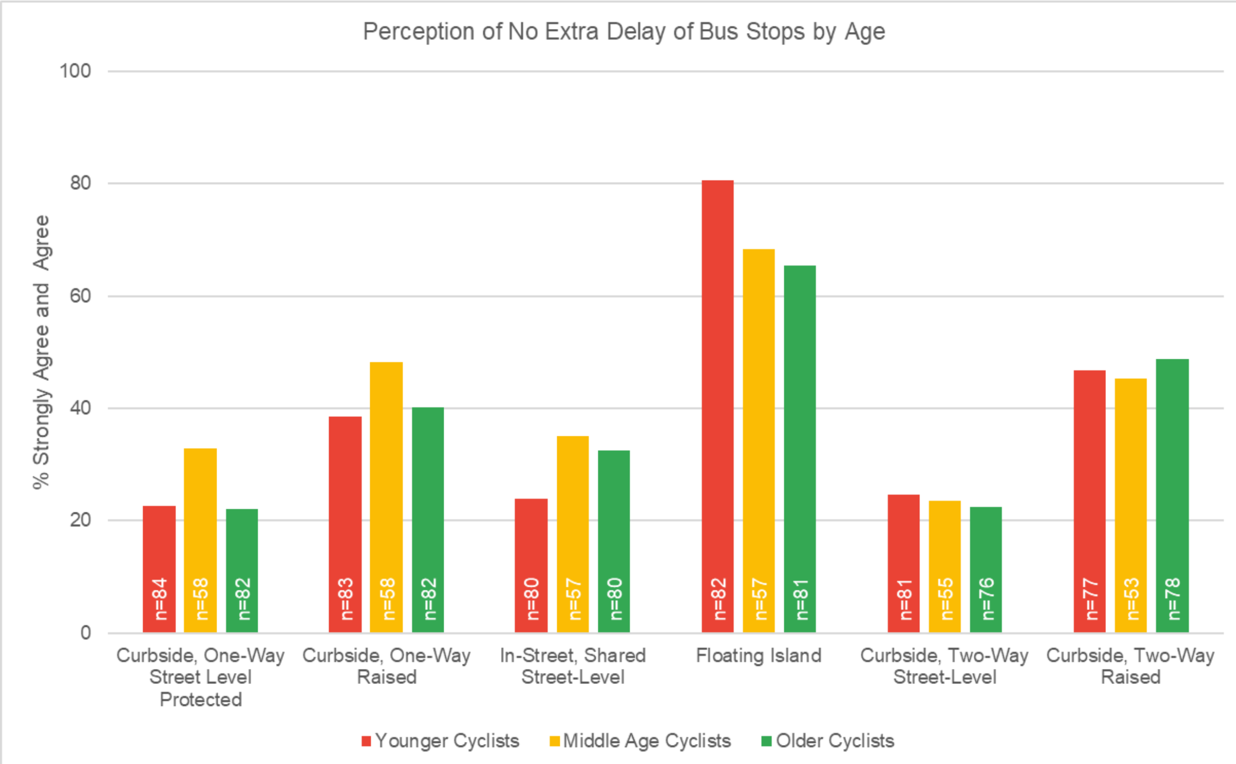

Perception of Safety of Bus Stops by Gender
% Strongly Agree and Agree
100
80
60
40
20
0
n = 126
n = 94
n = 126
n = 94
n = 124
n = 89
n = 123
n = 93
n = 123
n = 90
n = 119
n = 86
Curbside, One-Way Street Level Protected
Curbside, One-Way Raised
In-Street, Shared Street-Level
Floating Island
Curbside, Two-Way Street-Level
Curbside, Two-Way Raised
Male
Female


Perception of Comfort of Bus Stops by Gender
% Strongly Agree and Agree
100
80
60
40
20
0
n = 126
n = 93
n = 125
n = 93
n = 123
n = 89
n = 124
n = 93
n = 123
n = 90
n = 118
n = 86
Curbside, One-Way Street Level Protected
Curbside, One-Way Raised
In-Street, Shared Street-Level
Floating Island
Curbside, Two-Way Street-Level
Curbside, Two-Way Raised
Male
Female

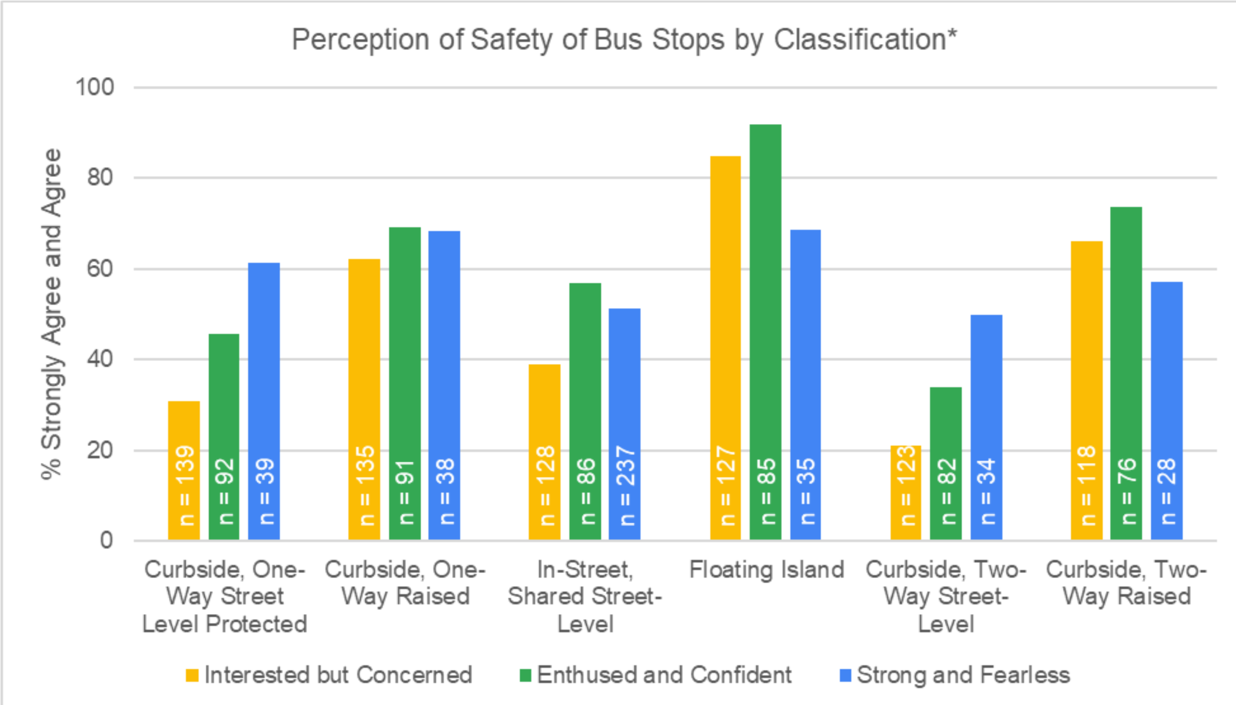

Perception of No Extra Delay of Bus Stops by Gender
% Strongly Agree and Agree
100
80
60
40
20
0
n = 126
n = 94
n = 126
n = 94
n = 124
n = 90
n = 124
n = 93
n = 123
n = 87
n = 119
n = 86
Curbside, One-Way Street Level Protected
Curbside, One-Way Raised
In-Street, Shared Street-Level
Floating Island
Curbside, Two-Way Street-Level
Curbside, Two-Way Raised
Male
Female

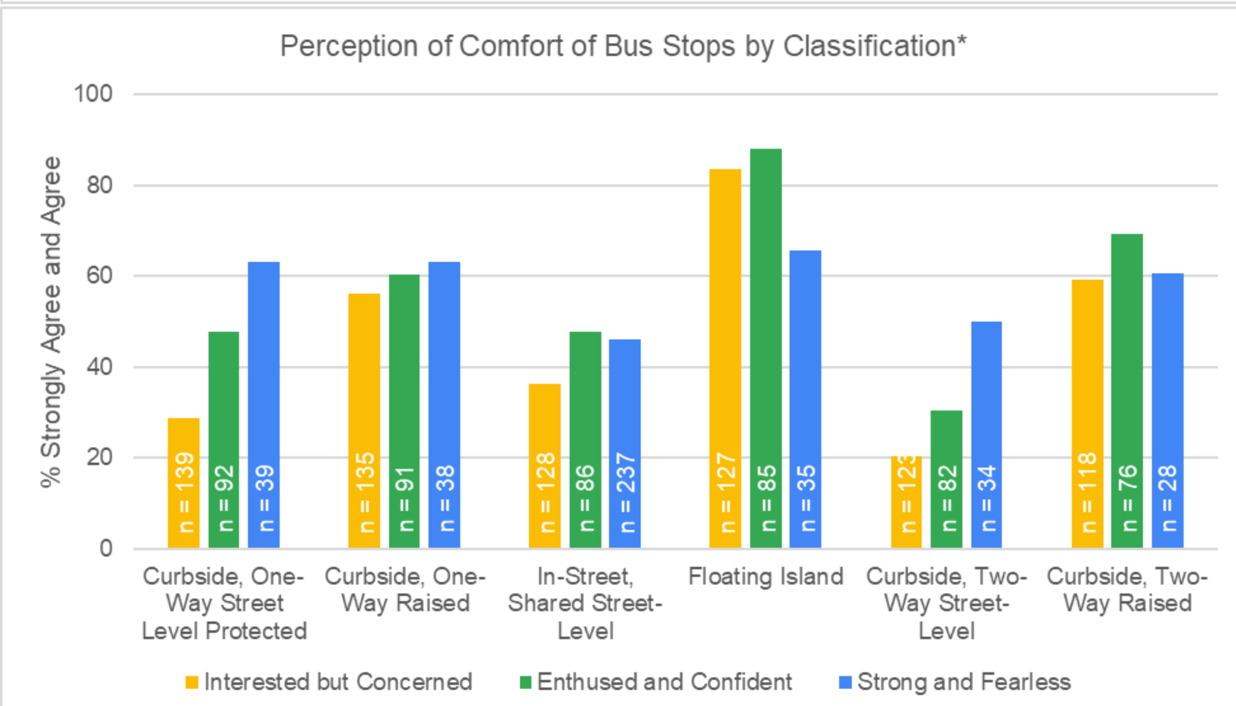

Perception of Safety of Bus Stops by Age
% Strongly Agree and Agree
0
20
40
60
80
100
n=84
n=58
n=82
n=83
n=58
n=82
n=80
n=57
n=79
n=82
n=57
n=80
n=81
n=55
n=79
n=77
n=53
n=78
Curbside, One-Way Street Level Protected
Curbside, One-Way Raised
In-Street, Shared Street-Level
Floating Island
Curbside, Two-Way Street-Level
Curbside, Two-Way Raised
Younger Cyclists
Middle Age Cyclists
Older Cyclists

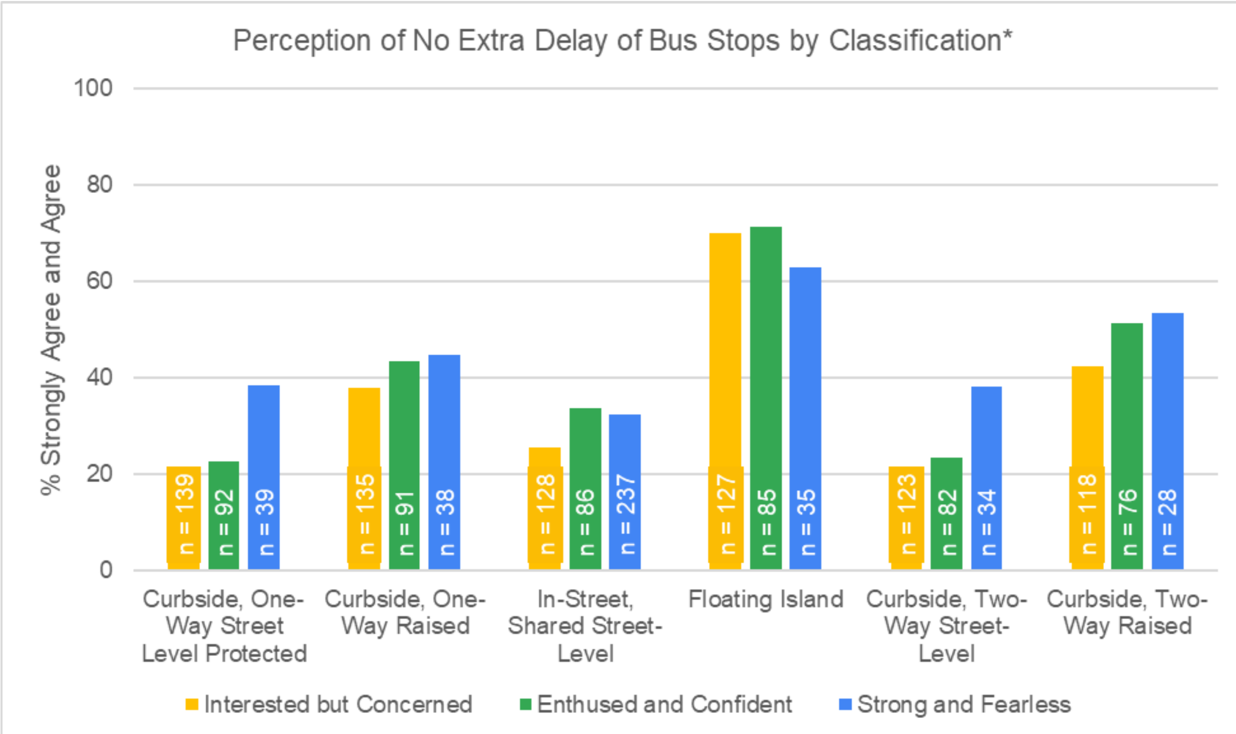

Perception of Comfort of Bus Stops by Age
% Strongly Agree and Agree
0
20
40
60
80
100
n=84
n=58
n=81
n=82
n=58
n=81
n=80
n=57
n=78
n=82
n=57
n=81
n=81
n=55
n=79
n=77
n=53
n=77
Curbside, One-Way Street Level Protected
Curbside, One-Way Raised
In-Street, Shared Street-Level
Floating Island
Curbside, Two-Way Street-Level
Curbside, Two-Way Raised
Younger Cyclists
Middle Age Cyclists
Older Cyclists



Perception of No Extra Delay of Bus Stops by Age
% Strongly Agree and Agree
100
80
60
40
20
0
n=84
n=58
n=82
n=83
n=58
n=82
n=80
n=57
n=80
n=82
n=57
n=81
n=81
n=55
n=76
n=77
n=53
n=78
Curbside, One-Way Street Level Protected
Curbside, One-Way Raised
In-Street, Shared Street-Level
Floating Island
Curbside, Two-Way Street-Level
Curbside, Two-Way Raised
Younger Cyclists
Middle Age Cyclists
Older Cyclists


Perception of Safety of Bus Stops by Classification*
% Strongly Agree and Agree
100
80
60
40
20
0
n = 139
n = 92
n = 39
n = 135
n = 91
n = 38
n = 128
n = 86
n = 237
n = 127
n = 85
n = 35
n = 123
n = 82
n = 34
n = 118
n = 76
n = 28
Curbside, One-Way Street Level Protected
Curbside, One-Way Raised
In-Street, Shared Street-Level
Floating Island
Curbside, Two-Way Street-Level
Curbside, Two-Way Raised
Interested but Concerned
Enthused and Confident
Strong and Fearless


Perception of Comfort of Bus Stops by Classification*
% Strongly Agree and Agree
100
80
60
40
20
0
n = 139
n = 92
n = 39
n = 135
n = 91
n = 38
n = 128
n = 86
n = 237
n = 127
n = 85
n = 35
n = 123
n = 82
n = 34
n = 118
n = 76
n = 28
Curbside, One-Way Street Level Protected
Curbside, One-Way Raised
In-Street, Shared Street-Level
Floating Island
Curbside, Two-Way Street-Level
Curbside, Two-Way Raised
Interested but Concerned
Enthused and Confident
Strong and Fearless



Perception of No Extra Delay of Bus Stops by Classification*
% Strongly Agree and Agree
100
80
60
40
20
0
n = 139
n = 92
n = 39
n = 135
n = 91
n = 38
n = 128
n = 86
n = 237
n = 127
n = 85
n = 35
n = 123
n = 82
n = 34
n = 118
n = 76
n = 28
Curbside, One-Way Street Level Protected
Curbside, One-Way Raised
In-Street, Shared Street-Level
Floating Island
Curbside, Two-Way Street-Level
Curbside, Two-Way Raised
Interested but Concerned
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