Transportation Association of Canada

APPENDICES

Safety Performance of Bicycle Infrastructure in Canada

November 2020

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Appendix A: Literature review

The primary objective of the literature review is to understand the safety performance of bicycle infrastructure (including both bicycle facilities along roadways and bicycle intersection treatments) in terms of both actual safety and perceived safety. Specifically, the review attempts to understand: (1) best practices for measuring safety performance of bicycle facilities; (2) related data requirements and safety performance heuristics; (3) bicycle crash trends; and (4) the actual and perceived safety performance of bicycle infrastructure. This section outlines the scope and approach of the literature review.

The Transportation Research Information Database (TRID) was used to conduct a comprehensive search for relevant literature published internationally in the last 10 years. TRID is a database of research and studies that includes the Transportation Research Information Services (TRIS) Database and the Office of Economic Cooperation and Development (OECD) Joint Transport Research Centre's International Transport Research Documentation (ITRD) Database. TRID contains over one million records of transportation research worldwide. Results from this search identified approximately 438 documents using broad search criteria. These documents are sourced from: (1) engineering and scientific periodicals and journals; (2) conference proceedings; and (3) readily available government and industry reports.

The abstracts of the initial 438 search documents were reviewed for relevancy and 153 were selected for further review and potential inclusion in this literature review summary document. Almost three quarters of the literature were published in per-review journals while others were typically conference proceedings and reports. Almost half of the literature were conducted in the U.S., over one-quarter were conducted in Canada and over 10% were conducted in Europe.

A.1 Safety and perceived safety of bicycle infrastructure

This section presents literature findings on the safety and perceived safety of bicycle infrastructure. In general, bicycle infrastructure is implemented to improve bicyclist safety and addresses one or more of the following (DiGioia et al., 2017):

- Increasing separation between bicycles and vehicles in separation along routes and timing at intersections where conflict points are unavoidable
- Increasing conspicuity or visibility of bicyclists
- Improving site lines of all roadway users to improve expectancy and reaction times
- Reducing conflicts (e.g. reduction of vehicle traffic volumes) and conflict points (e.g. reduction of driveways) between bicycles, vehicles and pedestrians
- Reducing vehicle speeds

This section summarizes safety and safety perception research specific to each bicycle facility and bicycle intersection treatment identified in the scope (Section 1.5).

A.1.1 Bicycle facilities

A.1.1.1 Off-road bicycle pathway

These are off-road bicycle pathways that are physically separated from motor vehicles and provide sufficient width and supporting facilities to be used for bicycling only. These pathways can be paved with concrete, asphalt or may be surfaced with stone, dust, fine limestone or gravel screenings.

Key findings from the literature regarding the safety performance of off-road bicycle pathways are presented in Table A-1. Overall, the literature indicates that off-road bicycle pathways reduce both severe and less severe crashes with bicyclists compared to no facility and they reduce the risk of bicyclist injury when compared to off-road multi-use pathways and major streets with parked cars and no bicycle infrastructure, but the results are not statistically significant.

Table A-1: Key safety findings for off-road bicycle pathways

Key literature findings	Study method	Safety data source	Safety measure	Safety outcome *
Kaplan et al. (2015) developed a multivariate Poisson-lognormal model based on a sample of 5,349 bicyclist/motorist crashes that occurred in Copenhagen between 2009 and 2013. Bicycle pathways were found to reduce both more severe and less severe crashes. Thus, the design of bicycle infrastructure should not only consider bicycle lanes but focus on bicycle pathways where the number of conflicts and the stress of sharing the road are highly reduced.	Regression cross-section	Police records	Crash frequency and severity	○
Teschke et al. (2012) found that paved off-road bicycle pathways reduce the risk of injury for bicyclists (OR = 0.54; 95% CI = 0.20, 1.45; n = 21) compared to major streets with parked cars and no bicycle infrastructure, but the difference was not significant.	Case-crossover	Hospital records	Injury rate	○
Teschke et al. (2012) found that off-road multi-use pathways (adjusted OR = 0.79; 95% CI = 0.43, 1.48) present a higher risk of bicyclist injury than off-road bicycle pathways (adjusted OR = 0.59; 95% CI = 0.20, 1.76) but the difference is not significant.	Case-crossover	Hospital records	Injury rate	○
Daniels et al. (2009) analyzed 90 roundabouts in Flanders, Belgium consisting of four types of bicycle facilities that include sharrows, painted bicycle lanes, protected bicycle lanes, and off-road bicycle pathways/separated bicycle pathways. The authors found that:	Before and after study	Government database	Injury rate	○
• Roundabouts with off-street bicycle pathways seem to decrease all injury frequency.				

Key literature findings	Study method	Safety data source	Safety measure	Safety outcome *
• Roundabouts with off-street bicycle pathways seem to increase fatal and serious injury frequency.				□
Reynolds et al. (2009) reviewed 23 papers for the impact of transportation infrastructure on bicyclist safety. The author suggests that bicycle only facilities, such as bicycle lanes, off-road bicycle pathways, and protected bicycle lanes at roundabouts reduce the risk of crashes and injuries compared to bicycling on-road with traffic or off-road with pedestrians.	Literature review	#N/A	#N/A	○
* Safety outcome: ○ positive outcome ● statistically significant positive outcome (p < 0.05) □ negative outcome ■ statistically significant negative outcome (p < 0.05) Table acronyms: OR – odds ratio, CI – confidence interval				

Key literature findings regarding the safety perception of off-road bicycle pathways are presented in Table A-2. In general, the literature indicates that providing physical separation between bicycles, vehicles, and pedestrians significantly increases bicyclists perception of comfort both along roadways and at intersections. In North America, results from Vancouver and Michigan bicyclists also indicate that bicyclist perception of safety is positive on off-road bicycle pathways; however, the results were not statistically significant.

Table A-2: Key safety perception findings for off-road bicycle pathways

Key literature findings	Study method	Safety data source	Safety measure	Safety outcome *
Bai et al. (2017) surveyed 471 people and studied 30 bicycle lanes in Nanjing, China, and found the presence of physical separation between the motorized, bicycle and pedestrian lanes significantly increased the level of comfort perception of bicyclists (OR=0.277, P<0.001).	Survey Analysis	Survey	Perception of safety	●
Ng et al. (2017) surveyed 264 bicyclists in Queensland, Australia on perceived safety at unsignalized intersections and found that off-road bicycle pathways and off-road multi-use pathways were perceived by Queensland bicyclists to be the safest bicycling infrastructure at un-signalized intersections.	Survey Analysis	Survey	Perception of safety	●
Sanders et al. (2018) surveyed 351 people in Michigan and found that when an off-road bicycle pathway is present 80% of respondents indicated they were comfortable bicycling with kids and 95% were comfortable bicycling on their own.	Survey Analysis	Survey	Perception of safety	○

Key literature findings	Study method	Safety data source	Safety measure	Safety outcome *
Winters et al. (2011) surveyed 1402 adult current and potential bicyclists from Metro Vancouver regarding the relative importance of 73 potential motivators and deterrents to bicycling. Results indicate that bicyclists prefer routes with beautiful scenery and routes separated from traffic.	Survey Analysis	Survey	Perception of safety	○
Winters et al. (2010) surveyed 1402 adult current and potential bicyclists from Metro Vancouver regarding their preference to bicycle on 16 different route types. In general, off-street (71% - 85%) and separated paths (71%) were the most favored route types, followed by residential routes (48%-65%). The least favoured route types were rural roads (21%-49%) and major streets (16%-52%).	Survey Analysis	Survey	Perception of safety	○

* Safety outcome:

○ positive outcome ● statistically significant positive outcome ($p < 0.05$)

□ negative outcome ■ statistically significant negative outcome ($p < 0.05$)

Table acronyms: OR – odds ratio, CI – confidence interval

A.1.1.2 Off-road multi-use pathway

Off-road multi-use – Pathways that are physically separated from motor vehicles and provide sufficient width and supporting facilities to be used for bicycling and walking. These pathways can be paved with concrete, asphalt or may be surfaced with stone dust, fine limestone or gravel screenings.

Key findings from the literature regarding the safety performance of off-road multi-use pathways are presented in Table A-3. Overall, the literature indicates that off-road multi-use pathways reduce crashes by 25% on urban six-lane divided highways compared to no treatment and reduce the risk of bicyclist injury compared to major streets with parked cars and no bicycle infrastructure. Regarding injury severity, literature finds that the severity of bicycle crashes is higher when bicycling on off-road multi-use pathways than on major streets; bicycling on the sidewalk has a higher injury severity than bicycling on off-road multi-use pathways. Overall, when compared to no bicycle facility, off-road multi-use pathways seem to reduce bicycle crash frequency but increase the risk of a more severe injury in the event of a bicycle crash as compared to a major street.

Table A-3: Key safety findings for off-road multi-use pathways

Key literature findings	Study method	Safety data source	Safety measure	Safety outcome *
Raihan et al. (2017) completed a cross-sectional analysis for the Florida Department of Transportation (FDOT) to develop crash modification factors for bicycle crashes. Safety data was provided by FDOT's Crash Analysis Reporting (CAR) repository and bicycle data was determined using bicycling activity data from the Strava smart phone app. It was determined that the presence of a multi-use pathways resulted in a crash modification factor of 0.75 for urban 6 lane divided highways (statistically significant with 80% confidence interval).	Regression cross-section	Government database	Crash Modification Factor	●
Cripton et al. (2015) used multiple logistic regression to examine associations with personal, trip, route and crash characteristics on bicyclist injury severity. The data is based on interviews with 683 adult bicyclists that were admitted to hospital due to a crash in Toronto and Vancouver. The following four crash outcomes were used to classify injury severity (1) did not continue trip by bicycle; (2) transported to hospital by ambulance; (3) admitted to hospital; and (4) Canadian Triage and Acuity Scale (CTAS). The authors found that compared to bicycling on a major street, off-road multi-use pathways were significantly associated with an increased risk of being admitted to hospital as a result of a crash (OR = 7.56; 95% CI = 1.43, 40.0; n=60; p < 0.05).	Case-crossover	Hospital interviews	Injury severity	■
Romonow et al. (2012) completed a case-control study based on 274 injury sites (151 in Edmonton and 123 in Calgary) identified through interviews with hospitalized bicyclists that were involved in a crash with a motorized vehicle or with serious injury (cases) and matched to those that were not involved in a crash with a motor vehicle or discharged from the emergency department. Significantly lower odds of severe injury were observed for locations with off-road multi-use pathways compared with sidewalks (matched OR=0.24, 95% CI: 0.08, 0.77).	Case-Control	Multiple	Injury rate	●
Teschke et al. (2012) found that paved off-road multi-use pathways reduce the risk of injury for bicyclists (OR = 0.75; 95% CI = 0.42, 1.34) compared to major streets with parked cars and no bicycle infrastructure but the difference was not significant.	Case-crossover	Hospital records	Injury rate	○
Teschke et al. (2012) found that multi-use pathways (OR = 0.79; 95% CI = 0.43, 1.48) present a higher risk of bicyclist injury than bicycle pathways (OR = 0.59; 95% CI = 0.20, 1.76) but the difference is not significant.	Case-crossover	Hospital records	Injury rate	□

Key literature findings	Study method	Safety data source	Safety measure	Safety outcome *
De Rome et al. (2014) interviewed 202 adult bicyclists from emergency departments in the Australian Capital Territory who had crashed in transportation related areas. It was found that 39.1% of participants had crashed in traffic, 7.9% had crashed in painted bicycle lanes, and 36.1% had crashed on off-road multi-use pathways.	Cross-Section	Hospital records	Crash frequency and severity	☐
De Rome et al. (2014) interviewed 202 adult bicyclists from emergency departments in the Australian Capital Territory who had crashed in transportation related areas. It was found that bicyclists who crashed on off-road multi-use pathways or in traffic had higher injury severity scores compared to those in bicycle lanes.	Cross-Section	Hospital records	Crash frequency and severity	☐
Reynolds et al. (2009) reviewed 23 papers for the impact of transportation infrastructure on bicyclist safety. The authors suggest that bicycle only facilities, such as bicycle lanes, off-road bicycle pathways, and protected bicycle lanes at roundabouts, reduce the risk of crashes and injuries compared to bicycling on-road with traffic or off-road multi-use pathways with pedestrians.	Literature review	#N/A	#N/A	○

* Safety outcome:

○ positive outcome ● statistically significant positive outcome (p < 0.05)

☐ negative outcome ■ statistically significant negative outcome (p < 0.05)

Table acronyms: OR – odds ratio, CI – confidence interval

Key findings from the literature regarding the safety perception of off-road multi-use pathways are presented in Table A-4. The literature indicates that bicyclists perceive off-road multi-use pathways to be safe and comfortable when compared to other bicycle facilities (e.g. protected bicycle lanes, painted bicycle lanes and shared lanes) and roadways with no bicycle facilities.

Table A-4: Key safety perception findings for off-road multi-use pathways

Key literature findings	Study method	Safety data source	Safety measure	Safety outcome *
Bai et al. (2017) surveyed 471 people and studied 30 bicycle lanes in Nanjing, China. The authors found the presence of physical separation between the motorized, bicycle and pedestrian lanes significantly increased the level of comfort perception of bicyclists (OR=0.277, P<0.001).	Survey Analysis	Survey	Perception of safety	●
Ng et al. (2017) surveyed 264 bicyclists in Queensland, Australia on perceived safety at unsignalized intersections and found, off-road bicycle pathways and off-road multi-use pathways were perceived by Queensland bicyclists to be the safest bicycling infrastructure at un-signalized intersections (p<0.05). Respondents perceived off-road bicycle pathways and off-road multi-use pathways to be safer than protected bicycle lanes, painted bicycle lanes and shared lanes.	Survey Analysis	Survey	Perception of safety	●
Winters et al. (2011) surveyed 1402 adult current and potential bicyclists from Metro Vancouver regarding the relative importance of 73 potential motivators and deterrents to bicycling. Results indicate that bicyclists prefer routes with beautiful scenery and routes separated from traffic.	Survey Analysis	Survey	Perception of safety	○
Winters et al. (2010) surveyed 1402 adult current and potential bicyclists from Metro Vancouver regarding their preference to bicycle on 16 different route types. In general, off-street (71% - 85%) and separated paths (71%) were the most favored route types, followed by residential routes (48%-65%). The least favoured route types were rural roads (21%-49%) and major streets (16%-52%).	Survey Analysis	Survey	Perception of safety	○

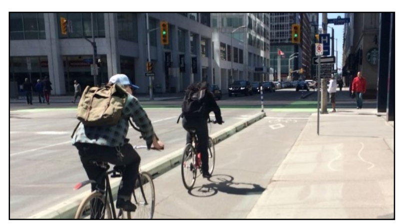
* Safety outcome:

○ positive outcome ● statistically significant positive outcome (p < 0.05)

□ negative outcome ■ statistically significant negative outcome (p < 0.05)

Table acronyms: OR – odds ratio, CI – confidence interval

A.1.1.3 Protected bicycle lanes



Protected bicycle lanes or bicycle tracks are located within the road right-of-way, but are physically separated from motor vehicle travel lanes by concrete curbs, planters, etc. They can be designed to provide both uni-directional and bi-directional travel.

Key findings from the literature regarding the safety performance of protected bicycle lanes are presented in Table A-5. Overall, the literature indicates that along roadway segments, one-way protected bicycle lanes have significantly lower risk of bicyclist crash compared to roadways without bicycle facilities. Two-way protected bicycle lanes with parking separation also reduce bicyclist crash risk along road segments and at intersections; however, two-way protected bicycle lanes *without* parking separation tend to increase bicyclist crash risk at intersections. Conversely, injury risk may increase for bicyclists involved in a crash riding on a protected bicycle facility through an intersection compared to no bicycle facility.

Automated video analysis is improving to the point where researchers are able to monitor potential bicyclist-vehicle conflicts and calculate new safety surrogate measures like time-to-crash (TTC) and post encroachment time (PET). These measures provide a more detailed understanding of potential bicycling safety issues without the need for crashes to occur. A pilot test completed in Montreal found that TTC and PET values were higher, indicating an improvement in safety, at intersections with approaching protected bicycle lanes than those with painted bicycle lanes.

Table A-5: Key safety findings for protected bicycle lanes

Key literature findings	Study method	Safety data source	Safety measure	Safety outcome *
Harris et al. (2013) studied 683 adult bicyclists who were injured in Toronto and Vancouver in a case-crossover study. The authors found that bicyclist injury risk was significantly lower on protected bicycle lanes compared to roadways without bicycle facilities (adjusted OR 0.05, 95% CI 0.01 to 0.59).	Case-crossover	Hospital records	Crash frequency	●
Teschke et al. (2012) found that bicycle tracks (one-way protected bicycle lane) had significantly lower bicycling risk (OR = 0.11; 95% CI = 0.02, 0.54) when compared to bicycling on major streets with parked cars and no bicycle infrastructure and adjusted for 13 other bicycle route types. One-way protected bicycle lanes were found to have the lowest risk of bicycling injury of all 14 bicycle routes types studied.	Case-crossover	Hospital records	Crash frequency	●
Marques et al. (2017) completed a before and after study in Seville, Spain using bicycle volume data factored to annual average by bicycle share usage data and bicyclist injury from motor-vehicle crashes as reported by traffic police from 2000-2013. The authors found evidence of a clear drop in the risk of bicyclists being injured in a bicycle/motor-vehicle crash with the implementation of a protected bicycle lane network.	Before-after study	Police records	Crash rate	○
Wall et al. (2016) analyzed data collected from 839 injured bicyclists who collided with motorized vehicles in New York City. Results showed proximity to a physically protected path was associated with 66% increases in the log-odds of having more than a mild injury (OR=1.66; 95% CI: 0.85, 3.22; p=0.136).	Regression cross-section	Hospital records	Injury severity	□
Nosal et al. (2012) studied eleven two-way protected bicycle lanes and four painted bicycle lanes, along with nine control streets in Montreal, Quebec. The study expanded short-	Cross-Section	Hospital records	Injury rate	○

Key literature findings	Study method	Safety data source	Safety measure	Safety outcome *
duration bicycle counts into estimates of annual average daily bicycle volumes using continuous bicycle count data. Injury data was provided by the Department of Public Health for which an ambulance was sent. The authors found that the overall average relative risk values show that bicyclist injury rates along roads with bicycle facilities (two-way protected bicycle lanes and painted bicycle lanes) were considerably lower than on the roads without bicycle facilities. Findings include:				
• *Along roadways*, the range in relative risk (RR) values between *two-way protected bicycle lanes with parking* and control streets is 0.05 – 0.80 with an average RR of 0.27. This indicates that two-way protected bicycle lanes with parking may reduce crash risk along roadways relative to streets without bicycle facilities.				○
• *At intersections*, the range in relative risk (RR) values between *two-way protected bicycle lanes with parking* and control streets is 0.06 – 0.71 with an average RR of 0.41. This indicates that two-way protected bicycle lanes with parking may reduce crash risk at intersections relative to intersections without bicycle facilities.				○
• *At intersections*, the range in relative risk (RR) values between *two-way protected bicycle lanes **without** parking* and control streets is 0.22 – 3.52 with an average RR of 1.57. This indicates that two-way protected bicycle lanes without parking separation may increase crash risk at intersections relative to intersections without bicycle facilities.				□
Zangenehpour et al. (2015) completed a pilot test of video analysis software to assess bicyclist safety at an intersection with a protected bicycle lane and one with a painted bicycle lane in Montreal. The time-to-crash (TTC) measure as well as the post-encroachment-time (PET) were used as surrogate measures of safety. Results indicate that the intersection with a protected bicycle lane is safer than the one with a painted bicycle lane.	Case Study	Observations /video	Time to Crash	○
Lusk et al. (2013) collected bicycle volume and crash data from 19 protected bicycle lanes located throughout the United States. The authors found the overall crash rate on protected bicycle lanes was 2.3 per million bicycle kilometers travelled (95% CI = 1.7, 3.0) and conclude that the crash rate is lower than published crash rates for roadways.	Case study	Hospital, police and insurance records	Crash rate	○

Key literature findings	Study method	Safety data source	Safety measure	Safety outcome *
* Safety outcome: ○ positive outcome ● statistically significant positive outcome ($p < 0.05$) □ negative outcome ■ statistically significant negative outcome ($p < 0.05$) Table acronyms: OR – odds ratio, CI – confidence interval				

Key findings regarding the safety perception of protected bicycle lanes are presented in Table A-6. Overall, the literature indicates that protected bicycle lanes increase a bicyclists perception of safety both at intersections, along roadways. The difference in bicyclist safety perception between protected bicycle lanes and buffered bicycle lanes with vertical deflection (i.e. flexible bollards) was found to be minimal. At intersections in Ohio, bicyclists perceived two-way protected bicycle lane approaches to be slightly more safe than one-way protected bicycle lane approaches; however, all two-way bicycle facilities also have bicycle signals at intersections which may have influenced the perception of safety.

Table A-6: Key safety perception findings for protected bicycle lanes

Key literature findings	Study method	Safety data source	Safety measure	Safety outcome *
Wang et al. (2018) conducted an empirical analysis of perceived bicyclist intersection safety based on data collected from a visual online survey on the main campus of Ohio State University, with responses from 1376 people. It was found that the presence of bicycle tracks reflects the increase in bicyclists' perceptions of safety at intersections. In addition, a slight increase in bicyclist safety at intersections was observed for two-way protected bicycle facilities as opposed to one-way protected bicycle facilities (not statistically significant). It should be noted that all two-way protected bicycle lanes had bicycle signals at intersections which may have influenced the results.	Regression cross-section	Survey	Perception of safety	●
Bai et al. (2017) surveyed 471 people and studied 30 bicycle lanes in Nanjing, China. The authors found bicyclists have higher levels of comfort in mid-block bicycle lanes with a barrier than in mid-block bicycle lanes without a barrier (OR=0.53, $P<0.001$).	Survey Analysis	Survey	Perception of safety	●
McNeil et al. (2015) surveyed 1,111 bicyclists and 2,283 residents from five American cities with newly constructed separated bicycle lanes (includes both protected and buffered bicycle lanes) to examine the influence of various hypothetical and actual separated bicycle lane designs. Results suggest that both bicyclists and non-cyclists would feel comfortable riding on a busy commercial street if there was a separated bicycle lane. The addition of some type of vertical physical separation (e.g. flexible bollard or curb) increase the perception of bicyclist	Survey Analysis	Survey	Perception of safety	○

Key literature findings	Study method	Safety data source	Safety measure	Safety outcome *
safety, particularly among the interested but concerned group. Subsequently, the high stated comfort levels of 2-3 foot painted buffers with plastic flexible bollards indicate that the desired increase in bicyclist safety perception may be achieved by relatively affordable separation options (i.e. flexible bollards verses concrete curbs).				
Sanders (2013) surveyed 579 people (including only those that drive) in the San Francisco Bay Area. The authors determined those who drive feel more comfortable with greater separation from bicyclists and those who bicycle feel overwhelmingly more comfortable with greater separation from drivers (i.e. physical separation vs no separation). Overall, at least 80% of every group felt at least moderately comfortable bicycling and driving on roadways with protected bicycle lanes than any other roadways.	Survey Analysis	Survey	Perception of safety	○
Sanders et al. (2018) surveyed 351 people in Michigan and found that when a one-way protected bicycle lane is present 70% of respondents are comfortable bicycling with kids and 95% are comfortable bicycling on their own.	Survey analysis	Survey	Perception of safety	○
* Safety outcome: ○ positive outcome ● statistically significant positive outcome ($p < 0.05$) □ negative outcome ■ statistically significant negative outcome ($p < 0.05$) Table acronyms: OR – odds ratio, CI – confidence interval				

A.1.1.4 Buffered bicycle lane

Buffered bicycle lanes provide more protected space for bicycling than a painted bicycle lane, typically through a painted buffer or "shy" zones on one or both sides of bicyclists. Plastic posts can be used to delineate the lanes. These lanes can be further separated from traffic by a parking lane.

Few studies exist regarding the safety of buffered bicycle lanes. One study by Goodno et al. (2013) analyzed crashes on two, two-way buffered bicycle lanes (one located in the median and one curbside) in Washington, DC before and after implementation. The authors found that bicyclist crash frequency increased after the implementation of the bicycle facilities at both sites. However, bicycle crash rate remained constant for the curbside facility. Bicycle crash rate increased for the median facility but mainly due to illegal U-turn activity by motorists.

Key findings regarding the safety perception of buffered bicycle lanes are presented in Table A-7. Overall, the literature indicates that buffered bicycle lanes are perceived to be safer for bicycling than roadways with no bicycle facilities. When considering perceived safety of child bicyclists, buffered bicycle lanes are perceived to be less safe than separated bicycle facilities but more safe than painted bicycle lanes on four-lane roadways. The difference in bicyclist safety perception between protected bicycle lanes and buffered bicycle lanes with vertical deflection (i.e. flexible bollards) is minimal.

Subsequently, the high stated comfort levels of 2- to 3-foot painted buffers with plastic flexible bollards indicate that the desired increase in bicyclist safety perception may be achieved by relatively affordable treatments (i.e. flexible bollards verses concrete curbs).

Table A-7: Key safety perception findings for buffered bicycle lanes

Key literature findings	Study method	Safety data source	Safety measure	Safety outcome *
McNeil et al. (2015) surveyed 1,111 bicyclists and 2,283 residents from five American cities with newly constructed separated bicycle lanes (includes both protected and buffered bicycle lanes) to examine the influence of various hypothetical and actual separated bicycle lane designs. It was found that in general the addition of buffered bicycle lanes can increase the perceived safety and comfort of bicycling for both current and potential bicyclists. The addition of some type of vertical physical separation (e.g. flexible bollard or curb) increases the perception of bicyclist safety, particularly among the interested but concerned group. Subsequently, the high stated comfort levels of 2-3 foot painted buffers with plastic flexible bollards indicate that the desired increase in bicyclist safety perception may be achieved by relatively affordable separation options (i.e. flexible bollards verses concrete curbs).	Survey analysis	Survey	Perception of safety	○
Sanders et al. (2018) surveyed 351 people (drivers and bicyclists) in Michigan and found that when a buffered bicycle lane is present 40% of respondents are comfortable bicycling with kids, and 80% are comfortable bicycling on their own. The results indicate that there isn't a significant difference between the perceived safety of different bicycle facilities; however, when children are considered buffered bicycle lanes were perceived to be less safe than separated bicycle facilities but more safe than painted bicycle lanes on four-lane roadways. All bicycle facilities were perceived to be safer for bicycling than roadways with no bicycle facilities.	Survey analysis	Survey	Perception of safety	○
Goodno et al. (2013) surveyed 351 bicyclists and 633 residents regarding their perception of safety of two newly constructed two-way buffered bicycle lanes in Washington, DC. The authors found that the majority of all road users had a positive perception of the buffered bicycle lanes.	Survey analysis	Survey	Perception of safety	○

* Safety outcome:
○ positive outcome ● statistically significant positive outcome ($p < 0.05$)
□ negative outcome ■ statistically significant negative outcome ($p < 0.05$)
Table acronyms: OR – odds ratio, CI – confidence interval

A.1.1.5 Painted bicycle lane

Painted bicycle lanes are separated lanes that are designated exclusively for bicycle travel and include pavement markings.

Key findings from the literature regarding the safety performance of painted bicycle lanes are presented in Table A-8. Overall, the literature indicates that painted bicycle lanes reduce bicycle injury and crash frequency when compared to roadways without bicycle facilities. This result is supported by research investigating the impact of vehicle encroachment which indicates that painted bicycle lanes increase the distance between overtaking vehicles and bicyclists. However, painted bicycle lanes increase crash risk when implemented on 2-lane divided highways but decrease crash risk when implemented on 4-lane divided highways.

Compared to major streets with parking, the bicycle crash rate decreases with the presence of a painted bicycle lane and significantly decreases if the major street has no parking and a painted bicycle lane. At intersections, crash rate decreases with the presence of approaching painted bicycle lanes.

Findings regarding bicyclist injury severity on painted bicycle lanes are mixed. Painted bicycle lanes seem to increase the risk of bicyclists experiencing major or fatal injury but decrease the risk of minor injury.

Table A-8: Key safety findings for painted bicycle lanes

Key literature findings	Study method	Safety data source	Safety measure	Safety outcome *
Raihan et al. (2017) completed a cross-sectional analysis for the Florida Department of Transportation (FDOT) to develop crash modification factors for bicycle crashes. Safety data was provided by FDOT's Crash Analysis Reporting (CAR) repository and bicycle data was determined using bicycling activity data from Strava smart phone app. Statistically significant results within 80% confidence interval are	Regression cross-section	Government database	Crash modification fFactor	
• the presence of painted bicycle lane resulted in a crash modification factor of 1.69 for urban 2 lane divided roadways.				■
• the presence of painted bicycle lane resulted in a crash modification factor of 0.86 for urban 4-lane divided roadways.				●
Bhatia et al. (2016) completed a before and after study on 7 installed painted bicycle lanes in Toronto, Ontario based on 329 crashes that occurred between 1991 and 2010. The authors found that:	Before-after study	Police records		
• painted bicycle lanes did not have a significant change on safety based on the incident rate ratios (IRR), however a 19% reduction in frequency of bicyclist crashes per month was observed (IRR = 0.82, 95% CI: 0.65, 1.03).			Crash frequency	○

Key literature findings	Study method	Safety data source	Safety measure	Safety outcome *
• no statistically significant differences in frequency of crashes that resulted in minor injuries (IRR =0.84, 95% CI: 0.59, 1.20)			Minor injuries	○
• no statistically significant differences in frequency of crashes that resulted in major/fatal injuries (IRR=0.72, 50% CI: 0.51, 1.01).			Major/ fatal injury	○
• significant increase in the frequency of crashes that resulted in no injury (IRR = 5.00; 95% CI 1.44, 17.28).			No injury	■
Mehta et al. (2015) recorded 5,227 passing events in the Kitchener-Waterloo area and found that:	Cross-section	Instrumented Probe Bicycle (IPB)	Vehicle encroachment	
• on a 2-lane road with no bicycle facility 12% (82/680) of passing maneuvers were unsafe passing events, while on a 2-lane road with a painted bicycle lane, 0.2% (1/515) of passing maneuvers were unsafe.				○
• on a 4-lane road with no bicycle facility 5.9% (111/1895) of passing maneuvers were unsafe passing events, while on a 4-lane road with a painted bicycle lane, 0.5% (11/2137) of passing maneuvers were unsafe				○
Chapman (2015) observed over 1,151 overtaking maneuvers on rural roads in Wisconsin and found a bicycle lane on a rural road appears to reduce the likelihood of a vehicle encroaching into oncoming traffic (crossing a solid centerline) by over 50%, and constrains the likely range in which a driver alters the forward path of their vehicle.	Before-after study	Observations /video	Vehicle encroachment	○
Pulugurtha et al. (2015) Completed a cross-sectional study on 72 roadway segments (36 with bicycle lanes, 36 without) in Charlotte, North Carolina and found that bicyclists are three to four times at higher risk (based on traffic conditions) on segments without painted bicycle lanes than when compared to segments with painted bicycle lanes.	Cross-Section	Police records	Crash rate	○
Park et al. (2015) conducted both a cross sectional study and a before and after study using empirical Bayes methods to calculate crash modification factors for painted bicycle lanes in Florida. The models considered roadway characteristics, socio-economic characteristics, financial projections, and crash data between 2003 and 2012. In general, the authors found	Regression cross-section	Hospital records	Crash frequency	

Key literature findings	Study method	Safety data source	Safety measure	Safety outcome *
that the safety effects of painted bicycle lanes were higher for the roadways with (1) low AADT per lane, (2) narrow median width, (3) narrow lane width, and (4) 4–5ft width of bicycle lane. Based on the findings in this study, it is recommended to use 4–8ft width for a bicycle lane and add a bicycle lane at the sites with narrower median (where traffic volume and speed limit are potentially lower). These treatments are likely to increase the effect of bicycle lanes in reducing crashes. The authors found that both models indicate that painted bicycle lanes reduce all crashes and bicycle crashes on urban arterials. Specifically, statistically significant CMF and standard error (S.E.) results from the cross-sectional study are:				
• 0.680 (S.E. = 0.083) for all crashes including property damage only and 0.726 (S.E. = 0.089) for all crashes excluding property damage only. • 0.422 (S.E. = 0.096) for bicycle crashes including property damage only and 0.398 (S.E. = 0.093) for bicycle crashes excluding property damage only.				●
Teschke et al. (2012) found that major streets without parked cars and a painted bicycle lane had significantly lower bicycling risk (OR = 0.47; 95% CI = 0.26, 0.83; $p < 0.05$) when compared to bicycling on major streets with parked cars and no bicycle infrastructure.	Case-crossover	Hospital records	Injury rate	●
Similarly, the authors found that painted bicycle lanes reduced the risk of injury for bicyclists (OR = 0.53; 95% CI = 0.26, 1.07; n = 25) on major streets with parked cars but the difference was not significant.				○
Wall et al. (2016) analyzed data collected from 839 injured bicyclists who collided with motorized vehicles in New York City. Results showed proximity to painted bicycle lanes was associated with having 52% increases in the log-odds of having more than a mild injury. (OR=1.52; 95% CI: 0.85-2.71, p=0.159)	Regression cross-section	Hospital records	Injury severity	■
Nosal et al. (2012) studied eleven two-way protected bicycle lanes and four painted bicycle lanes, along with nine control streets in Montreal, Quebec. The study expanded short-duration bicycle counts into estimates of annual average daily bicycle volumes using continuous bicycle count data and injury data provided by the Department of Public Health for which an ambulance was sent. The authors found that at intersections, the range in relative risk (RR) values	Cross-Section	Hospital records	Injury rate	○

Key literature findings	Study method	Safety data source	Safety measure	Safety outcome *
between painted bicycle lanes and control streets is 0.04 – 1.28 with an average RR of 0.41. Thus, painted bicycle lanes may reduce crash risk at intersections relative to streets without bicycle facilities.				
Hamann et al. (2013) conducted a case-control study of 147 bicycle crash locations that occurred between 2007 and 2010 compared to 147 control sites without crashes in Iowa. Results suggest that the presence of pavement markings (i.e. a painted bicycle lane or shared lane arrow (sharrow)) decreases crash risk by as much as 60% compared to roadways without on-road bicycle facilities (adjusted OR = 0.40, 95% CI = 0.09, 1.82).	Case-control	Police records	Crash frequency	○
Chen et al. (2012) completed a before-and-after study in New York on the safety performance of painted bicycle lanes (treatment group) compared to roadways without painted bicycle lanes (comparison group). Crash data was collected from police reported crashes for five-years prior and two-years after the facilities were implemented. A generalized estimating equation methodology was used to control for confounding factors. The authors found that the installation of painted bicycle lanes does not lead to an increase in crashes despite the likely increase in the number of bicyclists after the addition of the painted bicycle lanes.	Before-after study with control	Police records	Crash frequency	○

* Safety outcome:

○ positive outcome ● statistically significant positive outcome ($p < 0.05$)

□ negative outcome ■ statistically significant negative outcome ($p < 0.05$)

Table acronyms: OR – odds ratio, CI – confidence interval

Key findings regarding the safety perception of painted bicycle lanes are presented in Table A-9. Overall, the literature indicates that confident bicyclists perceive painted bicycle lanes to be comfortable when compared to no facility. However, non-cyclists do not perceive painted bicycle lanes to be comfortable.

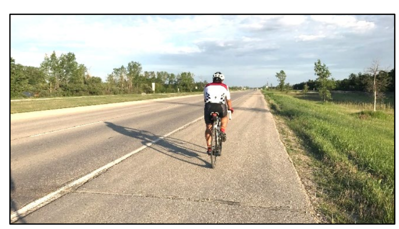
Other literature suggests that painted bicycle lanes may not operate as intended with the presence of snow on the roadway and that there is no difference in bicyclist safety perception of painted bicycle lanes that are 3.75 feet (1.1 meters) wide compared to 6.25 feet (1.9 meters) wide.

Table A-9: Key safety perception findings for painted bicycle lanes

Key literature findings	Study method	Safety data source	Safety measure	Safety outcome *
McNeil et al. (2015) surveyed residents from multiple cities with newly constructed protected bicycle lanes to examine the influence of various hypothetical and actual buffered bicycle lane designs. Current Bicyclists were fairly comfortable on streets with painted bicycle lanes while non-cyclists were not.	Survey Analysis	Survey	Perception of safety	
Sanders et al. (2018) surveyed 351 people in Michigan and found that when a painted bicycle lane is present 20% of respondents are comfortable bicycling with kids, and 77% are comfortable bicycling on their own.	Survey Analysis	Survey	Perception of safety	○
Sener et al. (2009) identified the importance of attributes influencing bicyclists' route choice preferences by surveying 1621 people in Texas. For bicyclists, no statistically significant differences in preferences between a 3.75 feet bicycle lane and a 6.25 feet bicycle lane was found	Survey Analysis	Survey	Perception of safety	
Chataway et al. (2014) surveyed 894 people in Brisbane and Copenhagen. The authors found the perceived safety of infrastructure layouts is positively related to the availability of painted bicycle lanes.	Survey Analysis	Survey	Perception of safety	○
Shirgaokar et al. (2016) interviewed 33 adult winter bicyclists in Edmonton. The results suggested the infrastructure designed for summer use, such as painted bicycle lanes and sharrows, does not operate effectively during the winter months.	Survey Analysis	Survey	Perception of safety	□

* Safety outcome:
○ positive outcome ● statistically significant positive outcome ($p < 0.05$)
□ negative outcome ■ statistically significant negative outcome ($p < 0.05$)
Table acronyms: OR – odds ratio, CI – confidence interval

A.1.1.6 Bicycle accessible shoulder



Where intended for bicyclist use, and provided sufficient width is available, paved shoulders on the edge of roadways can serve as a functional space for bicyclists in the absence of other facilities with more separation or delineation.

Key findings from the literature regarding the safety performance of bicycle accessible shoulders are presented in Table A-10. Bicycle accessible shoulders are most commonly used in rural jurisdictions along highways characterized by high vehicle speeds and low vehicle and bicycle volumes. However, there is a gap in research that studies the safety performance of bicycle accessible shoulders along rural highways.

In general, bicycle accessible shoulders in urban environments are expected to behave similar to painted bicycle lanes (discussed in the previous section) where bicycle accessible shoulders are not constrained by a curb on the roadway edge. Literature regarding vehicle encroachment as a surrogate measure of bicyclist safety indicates that vehicles travel closer to bicyclists when the bicyclists have a marked lane (i.e. painted bicycle lanes and bicycle accessible shoulders). In addition, vehicles tend to travel across a solid centre lane into on-coming traffic (two-lane roadways) more often then they travel across a dashed lane into another lane in the same travel direction (four-lane roadways). This finding indicates that vehicles may give more space to bicyclists on accessible shoulders along two-lane roadways rather than four-lane roadways.

Table A-10: Key safety findings for bicycle accessible shoulders

Key literature findings	Study method	Safety data source	Safety measure	Safety outcome *
Feng et al. (2018) studied 4,792 overtaking events in Southeast Michigan based on data from an existing naturalistic driving study that monitored driver behavior of instrumented test vehicles. The authors found that encroachment to the left-side lane, away from bicyclists, was significantly less when a painted bicycle lane or paved shoulder was present compared to only road edge or curb. This indicates that motorists pass closer to bicyclists when they have their own designated space. In addition, encroachment was significantly less for the dashed non-centreline (typically a four-lane two-way road or two-lane one-way street) compared to the solid centreline (typically a two-lane two-way road) when a painted bicycle lane or shoulder was present. However, the authors note that vehicles travelling in the inner most travel lane on four-lane roadways were not included in the study and may have influenced these results.	Naturalistic study	Video observation	Vehicle encroachment	○

* Safety outcome:

○ positive outcome ● statistically significant positive outcome ($p < 0.05$)

□ negative outcome ■ statistically significant negative outcome ($p < 0.05$)

Table acronyms: OR – odds ratio, CI – confidence interval

A.1.1.7 Major street shared lane

Shared lanes provide direct routes for experienced bicyclists along the outer travel lane of a roadway. While bicyclists mix with motor vehicle traffic, they are separate from pedestrians using the sidewalk. Sharrows are painted on the road surface to remind drivers they must share the road with bicyclists.

Key findings from the literature regarding the safety performance of major street shared lanes are presented in Table A-11. Overall, the literature indicates that major street shared lanes seem to increase bicyclist collision risk and the risk a bicyclist will experience more than a mild injury as result of a collision when compared to major streets with no bicycle facility. Compared to painted bicycle lanes, major street shared lanes significantly increase the separation between vehicles and bicyclists when vehicles are overtaking.

Despite the increase in bicycle injury rates, literature indicates that the position of the sharrow marking does influence the position of drivers and bicyclists on the roadway. Specifically, the sharrow marking may increase the operating space for bicyclists by increasing the separation of the bicyclist away from roadside hazards (i.e. parked vehicles and curbs) as well as increasing the separation distance between passing vehicles. The separation distance between bicyclists and parking is particularly important considering that the presence of parking significantly increases the risk of injury to bicyclists. The separation between bicyclists and parking is more pronounced on multi-lane roadways compared to two-lane roadways and when the sharrow marking is located in the centre of the shared lane. These studies suggest that the increase in operating space for bicyclists is a surrogate for a reduction in bicycle collision risk due to the potential decrease in collisions with passing vehicles and dooring collisions that result when a bicyclist travels to close to a vehicle door when it is opened. However, a majority of bicyclists may still travel in the “dooring zone” near parked vehicles regardless of the presence of sharrows.

These results suggest that sharrow markings may be an effective tool to position bicyclists but when implemented as a continuous bicycle facility for major street shared lanes they tend to increase bicyclist collision risk and injury severity. The presence of sharrows are associated with a significant increase in the likelihood that a bicyclist will experience more than a mild injury as result of a crash compared to a roadway with no bicycle facility.

Table A-11: Key safety findings for major street shared lanes

Key literature findings	Study method	Safety data source	Safety measure	Safety outcome *
Ferenchak and Marshall (2019) completed a before-after regression (negative binomial) analysis of shared lanes in Chicago between 2011 and 2014 based on bicyclist injury data that specifically identifies dooring related bicyclist injuries and bicyclist commuting data to account for exposure by census block group. The authors found that, compared to blocks with no bicycle facilities, blocks with shared lanes had an increase in both total bicyclist injury rates and dooring bicyclist injury rates. The shared lanes were configured as outlines in the MUTCD with sharrow markings positioned a minimum of 4 ft from the curb with no parking lanes and 11 ft from the curb with a parking lane.	Regression before and after	Police records	Injury rate	□
Wall et al. (2016) analyzed data collected from 839 injured bicyclists who collided with motorized vehicles in New York City. Results showed that sharrows were associated with having 94% increase in log-odds of incurring more than mild injury compared to having no bicycle route available. (OR=1.94; 95% CI: 0.91, 4.15; p=0.086)	Regression cross-section	Hospital records	Injury severity	■

Key literature findings	Study method	Safety data source	Safety measure	Safety outcome *
Teschke et al. (2012) completed a case-crossover study of the bicycle infrastructure present when 690 bicyclists were injured in Toronto and Vancouver compared to randomly selected infrastructure at another point during the bicyclist's trip. The authors found:	Case-crossover	Hospital records	Injury rate	
• On major streets with parked cars, shared lane bicycle facilities reduced the risk of injury for bicyclists (OR = 0.78; 95% CI = 0.25, 2.41; n = 9) but the difference was not significant. The configuration of the shared lanes included use of on-peak parking restricted lanes and transit.				○
• Major streets without parked cars and no bicycle infrastructure had significantly lower bicycling risk (OR = 0.63; 95% CI = 0.41, 0.96; p < 0.05) when compared to bicycling on major streets with parked cars and no bicycle infrastructure and adjusted for 13 other bicycle route types.				●
Hallett et al. (2006) looked at 24 sites in Texas, which included retrofitted painted bicycle lanes and wide outside lanes with sharrows. It was found that motorists give bicyclists more room during passing maneuvers if a major street shared lane is present compared to a painted bicycle lane.	Cross-Section	Observations/ video	Vehicle encroachment	●
Fitzpatrick et al. (2011) reviewed video of vehicle and bicycle lane positioning before and after the installation of shared lane marking (sharrows) in six American cities. The authors conclude that sharrows enhance motorist awareness of bicyclists in the traffic stream and increase operating space for bicyclists.	Before-after study	Observations/ video	Vehicle encroachment	○
Schimek (2017) looked at data from across the U.S., from 1997 to 2012. It was determined that sharrows move some bicyclists away from the door zone, but a majority of bicyclists still ride within the range of car doors.	Literature review	Hospital, insurance and police records	Vehicle encroachment	
Furth et al. (2011) The lane-within-a-lane treatment (a shared lane with colour pavement) is effective in shifting bicyclist position away from right-side hazards. Stronger shifts were seen in the applications on multilane roads than on a 2-lane road.	Before-after study	Observations/ video	Vehicle encroachment	○

Key literature findings	Study method	Safety data source	Safety measure	Safety outcome *
* Safety outcome: ○ positive outcome ● statistically significant positive outcome ($p < 0.05$) □ negative outcome ■ statistically significant negative outcome ($p < 0.05$) Table acronyms: OR – odds ratio, CI – confidence interval				

Key findings regarding the safety perception of major street shared lanes are presented in Table A-12. Overall, the literature indicates that in general, bicyclists perceive major street shared lanes to be one of the least safe and comfortable bicycle facilities. Other literature indicates that major street shared lanes without parking are preferred to major street shared lanes with parking and major street shared lanes are perceived to be ineffective during months with snow cover.

Table A-12: Key safety perception findings for major street shared lanes

Key literature findings	Study method	Safety data source	Safety measure	Safety outcome *
Ng et al. (2017) surveyed 264 bicyclists in Queensland, Australia on perceived safety at unsignalized intersections. The authors found that respondents perceived protected bicycle lanes to be less safe than off-road bicycle pathways and off-road multi-use pathways but safer than painted bicycle lanes and shared lanes.	Survey Analysis	Survey	Perception of safety	□
Sanders (2013) surveyed 579 people in the San Francisco Bay Area. The authors determined that painted bicycle lanes and sharrows were considered at least moderately comfortable by only a small minority of the sample.	survey analysis	Survey	Perception of safety	□
Winters et al. (2010) surveyed 1402 adult current and potential bicyclists from Metro Vancouver regarding their preference to bicycle on 16 different route types. The least favoured bicycle facility types were major city streets with bicycle symbols (sharrows) followed by rural roads with paved shoulders (bicycle accessible shoulders). Major street shared lanes without parking were favoured over major street shared lanes with parking.	Survey Analysis	Survey	Perception of safety	□
Shirgaokar et al. (2016) interviewed 33 adult winter bicyclists in Edmonton. The results suggested the infrastructure designed for summer use, such as painted bicycle lanes and sharrows, is not effectively operational during the winter months.	Meta Analysis	Survey	Perception of safety	○

Key literature findings	Study method	Safety data source	Safety measure	Safety outcome *
Christofa et al. (2017) using simulators and questionnaires of 24 people from Massachusetts. The authors found most drivers only follow the intended use of bicycle facility markings if bicyclists are present.	Driving simulation	Driving simulator	Driver compliance and glance frequency	○

* Safety outcome:
○ positive outcome ● statistically significant positive outcome ($p < 0.05$)
□ negative outcome ■ statistically significant negative outcome ($p < 0.05$)
Table acronyms: OR – odds ratio, CI – confidence interval

A.1.1.8 Bicycle boulevards

Bicycle boulevards or neighbourhood greenways are routes on streets with low vehicle speeds and volumes, which include a range of treatments to reduce traffic volumes, slow down traffic, and improve safety for walking, bicycling and driving. A critical component of bicycle boulevards are the treatments implemented at major intersections along the facility. Treatments range from signage, bicycle signals and pavement markings to varying degrees of traffic calming (speed humps, traffic circles, etc.)

Key findings from the literature regarding the safety performance of bicycle boulevards are presented in Table A-13. These findings indicate that overall, bicyclist-vehicle crash frequency is significantly lower on bicycle boulevards than riding on arterials and the presence of bicycle-specific signage decreases injury rate. Traffic calming measures like directional diverters and traffic circles, are often implemented along bicycle boulevards to reduce vehicle speeds and volumes, making it safer for bicyclists. The use directional diverters significantly decreases bicyclist crash frequency while the use of traffic circles significantly increases bicyclist crash frequency. No research regarding the perception of bicyclists with respect to bicycle boulevards was identified or readily available.

Table A-13: Key safety findings for bicycle boulevards

Key literature findings	Study method	Safety data source	Safety measure	Safety outcome *
Harris et al. (2013) studied 683 adult bicyclists who were injured in Toronto and Vancouver in a case-crossover study. The authors found that traffic circles on local streets increased the risk of these otherwise safe intersections (adjusted OR 7.98, 95% CI 1.79 to 35.6).	Case-crossover	Hospital records	Crash frequency	■
Harris et al. (2013) studied 683 adult bicyclists who were injured in Toronto and Vancouver in a case-crossover study. The authors found that local streets with diverters that reduce vehicle traffic were associated with low bicyclist crash risk (adjusted OR 0.05, 95% CI 0.01 to 0.59).	Case-crossover	Hospital records	Crash frequency	●
Hamann et al. (2013) conducted a case-control study of 147 bicycle crash locations that occurred between 2007 and 2010 compared to 147 control sites without crashes in Iowa. Results suggest that the presence of bicycle-specific signage along a roadway decreases crash risk compared to roadways without on-road bicycle facilities or signage (OR = 0.62, 95% CI = 0.15, 2.58).	Case-control	Police records	Crash frequency	○
Minikel (2012) analyzed police-reported bicycle crash data and manually collected bicyclist count data from Berkeley California to conduct a cross-sectional safety study of 6 bicycle boulevards compared to 6 parallel arterial roadways. It was found that bicyclists are safer when riding on all studied bicycle boulevards compared to their parallel arterial routes with risk ratios ranging from 1.8 to 8.0 (a risk ratio of 2 indicates that bicyclist crash risk is double on arterials than on bicycle boulevards).	Cross-Section	Police records	Crash rate	●
Teschke et al. (2012) completed a case-crossover study of the bicycle infrastructure present when 690 bicyclists were injured in Toronto and Vancouver compared to randomly selected infrastructure at another point during the bicyclist’s trip. The authors found that local streets without parked cars and designated as a bicycle route had significantly lower bicycling risk (OR = 0.49; 95% CI = 0.26, 0.90; $p < 0.05$) compared to bicycling on major streets with parked cars and no bicycle infrastructure and adjusted for 13 other bicycle route types.	Case-crossover	Hospital records	Injury rate	●
Reynolds et al. (2009) reviewed literature on the impact of transportation infrastructure on bicyclist safety. Results suggest that bicycle facilities such as on-road bicycle routes, on-road marked bicycle lanes and off-road bicycle paths decrease crash risk at "straightaways".	Literature Review	#N/A	Injury rate and severity	○

Key literature findings	Study method	Safety data source	Safety measure	Safety outcome *

* Safety outcome:
○ positive outcome ● statistically significant positive outcome (p < 0.05)
□ negative outcome ■ statistically significant negative outcome (p < 0.05)
Table acronyms: OR – odds ratio, CI – confidence interval

A.1.1.9 Advisory bicycle lanes

Advisory bicycle lanes are used on low-volume streets that are too narrow for the installation of conventional bicycle lanes and standard-width travel lanes for motor vehicles. Dashed bicycle lanes are marked on the outside or the roadway with a single narrow two-way vehicle lane occupying the middle of the roadway. The dashed bicycle lane line permits motorists to merge into the bicycle lane to negotiate oncoming traffic when no bicyclists are present.

Key findings from the literature regarding the safety performance of advisory bicycle lanes are presented in Table A-14. Advisory bicycle lanes are relatively new devices and there is limited research that discusses their safety performance. Literature indicates that vehicles travel closer to bicyclists when bicyclists have a marked lane (i.e. painted bicycle lanes and bicycle accessible shoulders). In addition, vehicles tend to travel across a solid centre lane into on-coming traffic (typically on two-lane roadways) more often then they travel across a dashed lane into another lane in the same travel direction (typically on four-lane roadways). This may be the result of motorists being more comfortable crossing into oncoming traffic because they can easily see when they are able to do so rather than shoulder checking to cross a white dashed line into another lane in the same travel direction. This result is positively related to bicycle accessible shoulders because vehicles are required to share a centre lane with oncoming vehicles and encroach into the advisory bicycle lane to pass oncoming vehicles. No research regarding the perception of bicyclists with respect to advisory bicycle lanes was identified or readily available.

Table A-14: Key safety findings for advisory bicycle lanes

Key literature findings	Study method	Safety data source	Safety measure	Safety outcome *
Feng et al. (2018) studied 4,792 overtaking events in Southeast Michigan based on data from an existing naturalistic driving study that monitored driver behavior of instrumented test vehicles. The authors found that encroachment to the left-side lane, away from bicyclists, was significantly less when a painted bicycle lane or paved shoulder was present compared to only road edge or curb. This indicates that motorists pass closer to bicyclists when they have their own designated space. In addition, encroachment was significantly less for the dashed non-center line (typically a four-lane two-way road or two-lane one-way street) compared to the solid centerline (typically a two-lane two-way road) when a painted bicycle lane or shoulder was present. However, the authors note that vehicles travelling in the inner most travel lane on four-lane roadways were not included in the study and may have influenced these results.	Naturalistic study	Observations/ video	Vehicle encroachment	○

* Safety outcome:
○ positive outcome ● statistically significant positive outcome ($p < 0.05$)
☐ negative outcome ■ statistically significant negative outcome ($p < 0.05$)
Table acronyms: OR – odds ratio, CI – confidence interval

A.1.2 Bicycle intersection treatments

A.1.2.1 Protected intersection

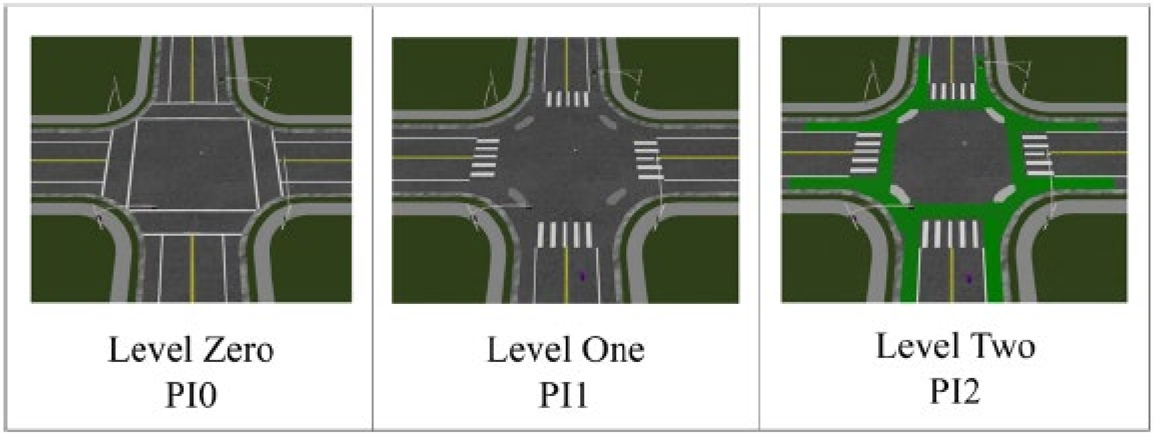
Protected intersections extend bicycle lane protection up to and through the intersection, shortening crossings and physically separating space for through and turning bicycle traffic to wait in an advanced position. Conflicts with turning motor vehicle travel are typically managed with separate signal phases or setback crossings.

Literature indicates that protected intersections with an island and/or green pavement marking show some improvements in driver performance with respect to the potential crash severity as measured by vehicle speeds in near and actual crashes.

Key literature findings

One study was found that investigates bicyclist safety performance at protected intersections. Hurwitz et al., (2015) used the Oregon State University high-fidelity driving simulator to test various bicycle infrastructure treatments to determine the treatments ability to reduce bicycle-vehicle conflict caused by right-turning vehicles. Time-to-crash data was collected for a total of 1,071 right-turn movements that were completed by 51 participants (30 male and 21 female) and field-validated using 144 hours of video review. The study investigated the three protected intersection configurations shown in Figure A-1 where level zero is a typical four-legged intersection, level one includes protected islands at each corner, and level two includes protected islands and green pavement markings (a novel design, not familiar to any driver).

Figure A-1: Experimental levels of the protected intersection treatment (Hurwitz et al., 2015)



The study found the following:

- Level One protected intersections had a positive influence on driver behavior that reduced the potential crash severity. Specifically, there was a 15 % decrease in the average vehicle speed during moderate- to high-risk crashes. However, the visual attention of the drivers was found to decrease.
- Level Two protected intersections showed no consistent change in driver behavior. However, Level Two outperformed Level One for the driver following the correct vehicle path by 3 %.

A.1.2.2 Bike box

A bike box is a designated area at the head of a traffic lane at a signalized intersection that provides bicyclists with a safe and visible way to get ahead of queuing traffic during the red signal phase.

Key literature findings regarding the safety performance of bike boxes at signalized intersections are presented in Table A-15. Overall, the literature indicates that bike boxes are effective at stopping vehicles from encroaching in the bike box and reducing the number of bicycle-vehicle conflicts at signalized intersections. In addition, left-turning bicyclist compliance with traffic signals increases with the presence of a bike box. The effectiveness of bike boxes can be improved with the addition of colour, a protected bicycle signal phase, and a “No Right Turn on Red” sign. Current research relies on video observation for the collection of surrogate safety measures that include vehicle encroachment and traffic signal compliance.

Table A-15: Key safety findings for bike boxes

Key literature findings	Study method	Safety data source	Safety measure	Safety outcome *
Dill et al. (2010) completed a before and after study of 10 bike boxes at signalized intersections in Portland, Oregon compared with two control sites. Video was reviewed for vehicle encroachment as a surrogate safety measure. The authors found that 73% of the stopping motor vehicles did not encroach at all into the bike box and the number of observed conflicts at the bike box locations decreased.	Before-after study with comparison group	Video observation	Vehicle encroachment	●
Casello et al. (2017) reviewed video of 322 bicyclists completing left turns at five different intersection types in Toronto to quantify bicyclist compliance with the Highway Safety Act and the intended travel path of each intersection treatment. The intersection with the best compliance had one left-turn lane, one through-lane, one painted bicycle lane, a bike box, and an advanced green left-turn signal. Approximately 90% of all bicyclists made the left turn legally and more than 65% did so using the intended design. Based on the theory that increased bicyclist compliance results in increased bicyclist safety, the authors make a primary design recommendation to include bike boxes supplemented with advanced green signals phases whenever possible.	Cross-section	Video observation	Compliance with traffic signal	○
Loskorn et al. (2011) studied two intersections in Austin, Texas, under three conditions: no bike box, after bike box markings were installed, and after chartreuse colour was added to the bike box and approaching bicycle lane. It was found bike boxes accompanied with "No Right Turn on Red" signs can improve the safety of bicyclists and motorists at intersections. 92% of bicyclists stopped safely in front of motorists in the coloured area. The addition of colour allowed motorists to be more aware of the presence of a bicyclist, indicated by a higher percentage of bicyclists approaching the intersection in the bicycle lane and stopping within the coloured area.	Before-after study	Video observation	Vehicle encroachment	○

* Safety outcome:

○ positive outcome ● statistically significant positive outcome ($p < 0.05$)

□ negative outcome ■ statistically significant negative outcome ($p < 0.05$)

Table acronyms: OR – odds ratio, CI – confidence interval

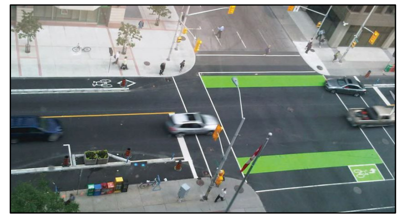
Key literature findings regarding the safety perception of bike boxes are presented in Table A-16. Overall, the literature indicates that bike boxes are perceived by bicyclists and motorists to increase the safety of signalized intersections. Bike boxes are also perceived to increase safety along roadways where bicyclists may need to wait to make a left-turn at an unsignalized intersection. When compared to two-stage turn boxes, bike boxes are perceived to be marginally safer.

Table A-16: Key safety perception findings for bike boxes

Key literature findings	Study method	Safety data source	Safety measure	Safety outcome *
Gotschi et al. (2018) surveyed 178 bicyclists immediately after they completed a left-turn at an intersection in Zurich, Switzerland before a bike box was implemented (pre-survey) and surveyed 99 bicyclists after the bike box was implemented (post-survey). Respondents were asked to rate bicyclists safety on a scale of 1 to 10, with 0 being very unsafe and 10 being very safe. Pre-survey respondents rated pictures of the intersection without a bike box an average of 4.10 and pictures of the intersection with a bike box an average of 6.84. Post-survey respondents rated the intersection without a bike box an average of 5.17 and pictures of the intersection with a bike box an average of 5.51.	Before-after study	In-situ survey and picture survey	Perception of safety	○
Dill et al. (2010) completed a before and after study of 10 bike boxes at signalized intersections in Portland, Oregon compared with 2 control sites. A survey of 468 bicyclists and 721 drivers was administered to understand their safety perception of bike boxes. The authors found over three-quarters of the surveyed bicyclists thought that bike boxes made the intersection safer while 42 % of drivers indicated the intersection was safer for driving. in addition, over half of the non-cycling drivers (52 %) thought that the boxes made drivers more aware of bicyclists generally.	Before-after study with comparison group	Survey	Perception of safety	○
Wang et al. (2018) conducted an empirical analysis of perceived bicyclist intersection safety based on data collected from a visual online survey on the main campus of Ohio State University, with responses from 1,376 people. The authors found that the presence of bike boxes can significantly increase bicyclists safety perceptions at intersections. In addition, bike boxes seem to be perceived marginally safer than two-stage turn boxes. The implementation of a bike box will increase the likelihood of a bicyclist perceiving the intersection as 'safe' and 'very safe' by 6.7 and 5.9 % respectively.	Regression cross-section	Survey	Perception of safety	○

* Safety outcome:
○ positive outcome ● statistically significant positive outcome ($p < 0.05$)
□ negative outcome ■ statistically significant negative outcome ($p < 0.05$)
Table acronyms: OR – odds ratio, CI – confidence interval

A.1.2.3 Two-stage turn queue box



Two-stage turn queue boxes offer bicyclists a safe way to make left turns at multi-lane signalized intersections from a right-side bicycle track or bicycle lane, or right turns from a left side bicycle track or bicycle lane.

Few studies have been conducted regarding bicyclist safety using two-stage queue boxes. Two-stage turn queue boxes seem to encourage bicyclists to comply with traffic signals but are not as effective as bike boxes. Bicylists also seem to percieve bike boxes to be safer than two-stage turn queue boxes.

Key literature findings

Casello et al. (2017), studied the influence of various intersection designs on bicyclist compliance with traffic signals as a surrogate for bicyclist safety (i.e. compliance with traffic signals will reduce bicyclist crash risk) in Toronto. The authors found that nearly 70% of bicyclists made the left turn legally and approximately 54% of bicyclists followed the intended design for an intersection with a left-turn lane, a through lane, a protected bicycle lane, and a two-stage turn queue box. For compirson, a similar intersection configuration with a bike box and advanced green left-turn signal rather than a two-stage turn box resulted in 90% of all bicyclists making the turn legally and more than 65% followed the intended design.

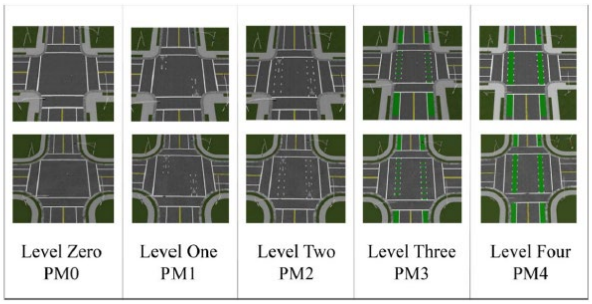
In terms of bicyclist safety perception, Wang et al. (2018) also found that bike boxes seem to be perceived marginally safer than two-stage turn boxes. Specifically, the implementation of a two-stage turn box was found to increase the likelihood of a bicyclist perceiving the intersection as ‘safe’ and ‘very safe’ by 3.9% and 3.5% respectively.

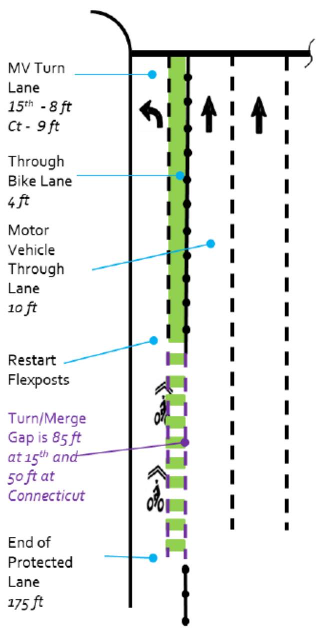
A.1.2.4 Intersection crossing markings

Intersection crossing markings indicate the intended path of bicyclists. They guide bicyclists on a safe and direct path through intersections, including driveways and ramps. They provide a clear boundary between the paths of through bicyclists and either through or crossing motor vehicles in the adjacent lane.

Key findings are mixed regarding the safety performance of intersection crossing markings are presented in Table A-17. Results indicate that intersection crossing markings improve crash avoidance of drivers at intersections with two bicycle crossings. A crossing with full green bicycle lanes and dotted white outline through the entire intersection is the most effective. However, intersections with more than one blue crossing marking (blue is used rather then green in some jurisdictions) increase total crashes and injuries of all modes; although increases in rear-end vehicle crashes and red-light running crashes played a primary role in the increase.

Table A-17: Key safety findings for intersection crossing markings

Key literature findings	Study method	Safety data source	Safety measure	Safety outcome *
Hurwitz et al. (2015) used the Oregon State University high-fidelity driving simulator to test various bicycle infrastructure treatments to determine their ability to reduce bicycle-vehicle conflict caused by right-turning vehicles. Time-to-crash data was collected for a total of 1,071 right-turn movements that were completed by 51 participants (30 male and 21 female) and field validated using 144 hours of video review. The following designs were tested:  Results indicate that: • PM1 treatments which comprise a single or double, dotted white line with bicycle stencil pavement marking at the start of the intersection improved driver's performance in crash avoidance. • PM2 treatments which comprise a double, dotted white line with bicycle stencil pavement marking through the entire intersection improved driver behavior with respect to visual attention. • PM3 treatments which comprise a skipped green bicycle lane with white outline through the entire intersection improved driver's performance in crash avoidance. • PM4 treatments which comprise a full green bicycle lanes with dotted white outline through the entire intersection improved driver's performance in crash avoidance and potential crash severity.	Simulation	Driving simulator	Time to Crash	○
Jensen (2007) completed a before-after study with a general comparison group of 65 signalized intersections with 1, 2 or 4 blue bicycle crossing markings in Copenhagen, Denmark. They used traffic volume data and crash data for all modes from 1-5 years before and after treatment implementation. Regarding overall safety of all modes at intersections, the authors found that:	Before-after study	Police records	Injury rate and severity	

Key literature findings	Study method	Safety data source	Safety measure	Safety outcome *
• one blue crossing in an intersection resulted in a reduction of 10% in accidents and 19% in injuries mainly due to a significant reduction in bicycle and pedestrian injuries.				●
• two blue bicycle crossings in an intersection lead to increases of 23% in accidents and 48% in injuries primarily due to an increase in rear-end vehicle crashes and red-light running incidents.				■
• four blue bicycle crossings in an intersection lead to increases of 60% in accidents and 139% in injuries primarily due to an increase in rear-end vehicle crashes and red-light running incidents.				■
Monsere et al. (2015) conducted an observational study of 78 hours of video from 5 different intersection types in which 6,082 bicyclists and 7,574 turning vehicles were observed across the United States. In additional, self-reported comprehension was collected from 1,245 residents and 690 bicyclists. The authors found that using a through bicycle lane for turning zones works well for its intended purpose. The authors conclude that  **Turning Zone with Post Restricted Entry and Through Bike Lane (TBL)** use of semi protected through bicycle lanes (as implemented at L Street and 15th Street in Washington DC) help position bicyclists and reduce confusion compared to sharrows in mixing zones. This design, where vehicles have a limited entry into the turning lane, had a high correct lane use by turning vehicles (87%) and by through bicyclists (91%).	Observational	Observations/ video	Conflict rate	○

* Safety outcome:
○ positive outcome ● statistically significant positive outcome ($p < 0.05$)
□ negative outcome ■ statistically significant negative outcome ($p < 0.05$)
Table acronyms: OR – odds ratio, CI – confidence interval

Key findings regarding the safety perception of intersection crossing markings are presented in Table A-18. Overall, the literature indicates that intersection crossing markings improve bicyclists perception of safety. Research also indicates that in the mixing zones with turning vehicles that approach intersections, bicyclists perception of safety is more influenced by the number of turning vehicles rather than how vehicles and bicycles interact in these zones.

Table A-18: Key safety perception findings for intersection crossing markings

Key literature findings	Study method	Safety data source	Safety measure	Safety outcome *
Wang et al. (2018) conducted an empirical analysis of perceived bicyclist intersection safety based on data collected from a visual online survey on the main campus of Ohio State University, with responses from 1,376 people. The authors found that intersection crossing markings significantly improve bicyclists safety perceptions. Results suggest that bicycle safety perception may increase with the number of marked bicycle crossings at an intersection, but the results are not conclusive.	Survey Analysis	Survey	Perception of safety	○
Monsere et al. (2015) conducted an observational study of 78 hours of video from 5 different intersection types in which 6,082 bicyclists and 7,574 turning vehicles were observed across the United States. In additional, self-reported comprehension was collected from 1,245 residents and 690 bicyclists. The authors found that bicyclist perception of safety appears to be more heavily influenced by the volume of turning motor vehicle traffic than correct turning movements of motorists at the studied locations. It is also possible that turning zones make bicyclists feel less safe because of the requirement that they cross the turn-lane to enter the through bicycle lane, whereas in a mixing zone, the merging is more evenly split between bicyclist and motorist.	Survey Analysis	Survey	Perception of safety	○

* Safety outcome:

○ positive outcome ● statistically significant positive outcome ($p < 0.05$)

□ negative outcome ■ statistically significant negative outcome ($p < 0.05$)

Table acronyms: OR – odds ratio, CI – confidence interval

A.1.2.5 Cross-rides

Cross-rides are crosswalks for bicycles that allow bicyclists to remain on their bicycles and safely cross through intersections. They can be separate from an adjacent crosswalk or combined with a crosswalk.

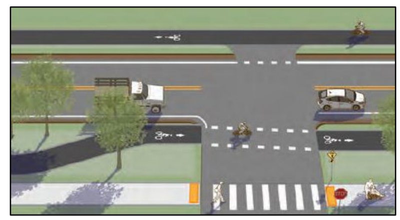
Cross-rides are a relatively new treatment and few studies examine the bicycle safety impacts of cross rides. Cross-rides seem to improve bicyclist safety at roundabouts.

Key literature findings

Sakshaug et al. (2010) completed a cross-section study of two types of roundabout treatments in Lund, Sweden to determine which option is safer for bicyclists. It was determined that the roundabout with cross-rides beside the crosswalks was safer than the roundabout with no bicycle facility.

A.1.2.6 Bend-in & bend-out intersection approaches

Bend-in intersection approaches shift the bicycle lane to be adjacent to the right-turn lane at the intersection to increase bicyclist conspicuity.



Bend-out intersection approaches shift the bicycle lane away from the intersection to create space for turning vehicles to wait for bicyclists without impeding other vehicle traffic.

There are few research studies available for bend-in intersection approaches. In Australia, bicyclists felt safer crossing roadways when they were required to yield to vehicle traffic rather than trusting that motorists would yield to bicyclists approaching from a bend-in and bend-out treatment.

Key literature findings

Ng et al. (2017) surveyed 214 bicyclists in Queensland Australia and suggest that bicyclists safety perception at un-signalized intersections seems to be associated with vehicle yielding behavior. Specifically, bicyclists felt safer using bicycle infrastructure where they are required to yield to motorists (e.g. off-road multi-use pathways) rather than bicycle infrastructure where they have the right of way (e.g. bend-in and bend-out intersection approaches); in other words, bicyclists felt safer when they were required to make the crossing decision rather than trust vehicles will stop for them. The authors recognize that Queensland motorist behavior should be considered when applying results elsewhere.

A.1.2.7 Protected signal phase

A protected signal phase is a phase that does not conflict and is not required to yield to another movement and may be indicated by a green arrow or bicycle signal. Key findings from the literature regarding the safety performance of protected signal phase are presented in Table A-19. Overall, the literature indicates that protected signal phases increase bicyclist safety at signalized intersections. Alternatively, intersections with longer green light bicycles tend to have a lower risk of bicyclist injury.

Table A-19: Key safety findings for protected signal phases

Key literature findings	Study method	Safety data source	Safety measure	Safety outcome *
Strauss (2013) completed a cross-section regression study on 64 intersections in Montreal that used bicyclist crash data for which an ambulance was dispatched (2003 – 2008) and bicycle traffic count data from turning movement counts and automated bicycle counters. Results indicate that protected left turn signals and pedestrian signals with countdowns decreased bicyclist injury occurrence.	Cross-Section	Ambulance services	Injury rate	○
Casello et al. (2016) reviewed video of 322 bicyclists completing left turns at 5 different intersection types in Toronto to quantify bicyclist compliance with the Highway Safety Act and the intended travel path of each intersection treatment. The intersection with the best compliance had one left-turn lane, one through-lane, one painted bicycle lane, a bike box, and an advanced green left-turn signal. Approximately 90% of all bicyclists made the left turn legally and more than 65% did so using the intended design. Based on the theory that increased bicyclist compliance results in increased bicyclist safety, the authors make a primary design recommendation to include bike boxes supplemented with advanced green signals phases whenever possible.	Cross-Section	Video observation	Compliance with traffic signal	○
Burbidge (2015) completed a case-control study in Salt Lake City of high-risk and low-risk intersections based on non-motorized crashes that occurred between 2006 and 2010. The authors found that intersections with significantly longer signal lengths (green light time) have a lower risk of bicyclist injury.	Case-control	Police records	Crash rate	○

* Safety outcome:

○ positive outcome ● statistically significant positive outcome ($p < 0.05$)

□ negative outcome ■ statistically significant negative outcome ($p < 0.05$)

Table acronyms: OR – odds ratio, CI – confidence interval

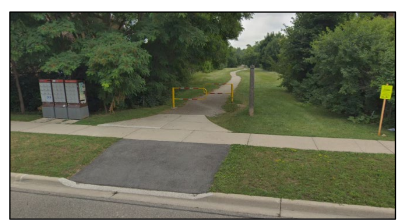
Key findings regarding the safety perception of protected signal phases are presented in Table A-20. Overall, the literature indicates that bicycle signals improve bicyclist perception of safety through intersections with right-turning vehicles and that bicyclists seem to travel further distances to access protected bicycle signals phases.

Table A-20: Key safety perception findings for protected signal phases

Key literature findings	Study method	Safety data source	Safety measure	Safety outcome *
Winters et al. (2013) found from a travel behaviour analyses, and focus groups in the Vancouver metropolitan area, that bicyclists detoured on route to use bicycle facilities such as bicycle-activated crossing signals.	Survey Analysis	Survey	Perception of safety	○
Abdul Rahimi et al. (2013) completed an experiment where 14 participants bicycled through a test site with 5 different intersections configurations to measure bicyclist safety and comfort through an intersection on a one-way roadway with left turning vehicles in Japan. This experiment is analogous to vehicles making a right-turn in Canada as Japan is left-side drive. The authors suggest that a bicycle signal is a safe treatment based on the video observation and found that it was the most comfortable treatment based on bicyclists survey compared to the implementation of a painted bicycle lane, advanced stop line, bike box, and no treatment.	Survey Analysis	Survey	Perception of safety	○

* Safety outcome:
○ positive outcome ● statistically significant positive outcome ($p < 0.05$)
□ negative outcome ■ statistically significant negative outcome ($p < 0.05$)
Table acronyms: OR – odds ratio, CI – confidence interval

A.1.2.8 Gates, fencing and bollards



Gates, fencing and bollards imply the use of vertical obstructions to force bicyclists to slow or dismount when approaching an intersection or rail crossing. In general, slowing bicyclists prior to vehicle conflict zones should improve reaction capabilities of both bicyclists and motorists to avoid collisiosns. There was no research was reveiwed on bicyclist safety outcomes of gates, fencing and bollards.

A.2 Additional considerations of bicycle safety

The literature reviewed as part of this task also revealed many other confounding factors that influence bicyclist safety while travelling on bicycle infrastructure. These confounding factors are important to consider when selecting the most appropriate bicycle infrastructure for specific roadway characteristics. This section provides a brief summary of common considerations of bicycle safety and other findings.

A.2.1 Vehicle speed

Key findings from the literature regarding the impact of vehicle speed on bicyclist safety are presented in Table A-21. Overall, the literature indicates that higher vehicle speeds increase the risk of bicyclist crash frequency and injury severity in the event of a crash along roadways and at intersections. Specifically, vehicle speeds less than 30 km/h significantly reduces bicyclist risk of injury at intersections.

Table A-21: Key safety findings for the impact of increased vehicle speed

Key literature findings	Study method	Safety data source	Safety measure	Safety outcome *
Cripton et al. (2015) used multiple logistic regression to examine associations with personal, trip, route and crash characteristics on bicyclist injury severity. The data is based on interviews with 683 adult bicyclists that were admitted to hospital due to a crash in Toronto and Vancouver. The following four crash outcomes were used to classify injury severity (1) did not continue trip by bicycle; (2) transported to hospital by ambulance; (3) admitted to hospital; and (4) Canadian Triage and Acuity Scale (CTAS). The authors found that for a 9.5 km/h increase in average motor vehicle speed there is a statistically significant risk of a bicyclist requiring ambulance transportation to the hospital (OR = 1.21; 95% CI = 1.01, 1.43; $p < 0.05$).	Case-crossover	Hospital records	Injury severity	■
Harris et al. (2013) studied 683 adult bicyclists who were injured in Toronto and Vancouver in a case-crossover study. It was found that motor vehicle speeds less than 30 km/h reduced risk (adjusted OR 0.52, 95% CI 0.29, 0.92).	Case-crossover	Hospital records	Crash frequency	■
Bíl et al. (2010) evaluated critical factors that influence bicycle-vehicle crashes based on a multivariate regression of crash data from police records in Czech Republic between 1995 and 2007. The authors found that vehicle speeding, particularly on straight sections, was the most serious factor for fatal crashes involving bicyclists. They suggest that vehicle speed limits should be reduced on roadways with bicycle facilities.	Regression cross-section	Police records	Injury rate	□

Key literature findings	Study method	Safety data source	Safety measure	Safety outcome *
Garder et al. (1998) observed bicyclists at 4 reconstructed intersections in Sweden and compared the bicyclists' input to experts' input. It was found that raising a bicycle crossing at an intersection leads to reduced vehicle speeds, and reduced vehicle speeds lead to reduced risk.	Before-after study	Government database	Crash frequency	□
Chen et al. (2016) found, using a generalized ordered logit model and a generalized additive model on data from Seattle, Washington. The authors found that posted speed limit is positively associated with the probability of evident injury and severe injury or fatality.	Case study	Government database	Injury severity	□
* Safety outcome with an increase in vehicle speed: ○ positive outcome ● statistically significant positive outcome ($p < 0.05$) □ negative outcome ■ statistically significant negative outcome ($p < 0.05$) Table acronyms: OR – odds ratio, CI – confidence interval				

Key findings from the literature regarding the safety perception of vehicle speed are presented in Table A-22. Overall, the literature indicates that in general bicyclists prefer to bicycle along routes with lower vehicle speeds. Although one source indicates there is no significant relationship between posted speed limit and bicyclists perception of safety at intersections.

Table A-22: Key safety perception findings for the impact of increased vehicle speed

Key literature findings	Study method	Safety data source	Safety measure	Safety outcome *
Wang et al. (2018) conducted an empirical analysis based on data collected from a visual online survey on the main campus of Ohio State University, with responses from 1376 people. The analysis suggests that the width of the curb lane, stop signs and posted speed limits do not exhibit significant influences on bicyclist safety perceptions at intersections.	Regression cross-section	Survey	Perception of safety	
Winters et al. (2011) surveyed 1402 adult current and potential bicyclists from Metro Vancouver regarding the relative importance of 73 potential motivators and deterrents to bicycling. Results indicate that the top deterrents for choosing a certain route were ice and snow; streets with a lot of traffic; streets with glass/debris; streets with high speed traffic (> 50km/h); and risk from motorists.	Survey Analysis	Survey	Perception of safety	□

Key literature findings	Study method	Safety data source	Safety measure	Safety outcome *
Sener et al. (2009) identified the importance of attributes influencing bicyclists' route choice preferences by surveying 1621 people in Texas. The results corresponding to the speed limit variables show a preference for roadways with lower speed limits, though this preference is tempered for individuals experienced in bicycling and for long distance commuting.	Survey Analysis	Survey	Perception of safety	☐
* Safety outcome with an increase in vehicle speed: ○ positive outcome ● statistically significant positive outcome ($p < 0.05$) ☐ negative outcome ■ statistically significant negative outcome ($p < 0.05$) Table acronyms: OR – odds ratio, CI – confidence interval				

A.2.2 Vehicle traffic volume

Key findings from the literature regarding the impact of vehicle traffic volume on bicyclist safety are presented in Table A-23. Findings reveal that as vehicle traffic volumes increase crash severity decreases and crash frequency decreases for segments and intersections combined. However, at intersections crash frequency increases with an increase in vehicle traffic volumes.

Table A-23: Key safety findings for the impact of increased vehicle traffic volume

Key literature findings	Study method	Safety data source	Safety measure	Safety outcome *
Caviedes et al. (2018) analyzed data from 7,147 bicycle/motorized vehicle crashes (mostly outside major urban areas) recorded in the Oregon Statewide Crash Data System between 2007 to 2014. Results from the single variable models indicate that an increase in vehicle AADT results in a decrease of crash severity.	Case-Control	Police and insurance records	Crash severity	○
Osama et al. (2016) studied 134 traffic analysis zones in Vancouver, The authors found the risk of a bicycle-vehicle crash is reduced as the number of bicycles and vehicles on the road increases.	Case Study	Multiple	Crash frequency	○
Kaplan et al. (2015) developed a multivariate Poisson-log normal model based on a sample of 5,349 bicyclist/motorist crashes that occurred in Copenhagen between 2009 and 2013. The authors found that crash rates decrease as motorized traffic volume increases.	Regression cross-section	Police records	Crashes frequency	○

Key literature findings	Study method	Safety data source	Safety measure	Safety outcome *
Park et al. (2015) conducted both a cross sectional study and a before and after study using empirical Bayes methods to calculate crash modification factors for painted bicycle lanes in Florida. The models considered roadway characteristics, socio-economic characteristics, financial projections and crash data between 2003 and 2012. The authors found that the safety effects were higher for the roadways with (1) low AADT per lane, (2) narrow median width, (3) narrow lane width, and (4) 4–5ft width of bicycle lane.	Regression cross-section	Hospital records	Crash frequency	☐
Nordback et al. (2014) used AADB, AADT and crash data, from Boulder Colorado to develop models which showed that motorist-cyclist crashes at signalized intersections are significantly related to the AADT and AADB. Motorist-cyclist crashes at signalized intersections increase non-linearly with increasing bicyclist and motorist volumes.	Regression cross-section	Police records	Crash frequency	☐
Oh et al. (2008) analyzed 151 signalized intersections in Incheon, Korea and found bicycle crashes at urban intersections increased with a corresponding increase in the total traffic volume (correlation coefficient 6.06 and standard error 1.67).	Case Study	Police records	Crash frequency	☐

* Safety outcome with an increase in vehicle traffic volume:
○ positive outcome ● statistically significant positive outcome ($p < 0.05$)
☐ negative outcome ■ statistically significant negative outcome ($p < 0.05$)
Table acronyms: OR – odds ratio, CI – confidence interval

Key findings regarding the safety perception of vehicle traffic volume on bicyclist safety presented in Table A-24. Overall, the literature indicates that bicyclists perception of safety decreases with an increase in vehicle traffic volume.

Table A-24: Key safety perception findings for the impact of increased vehicle traffic volume

Key literature findings	Study method	Safety data source	Safety measure	Safety outcome *
Abadi et al. (2018) surveyed 181 people in the United States and found ambient traffic had the highest effect on perceived level of safety. Bicycling in high traffic volumes decreased perceived level of safety by 22.8%.	Survey Analysis	Survey	Perception of safety	☐
Wang et al. (2018) conducted a visual survey on the main campus of Ohio State University, with responses from 1376 people. It was found that vehicle traffic volume along the major roadway shows a negative impact on bicyclist safety perceptions.	Regression cross-section	Survey	Perception of safety	☐
Monsere et al. (2015) conducted an observational study of 78 hours of video from 5 different intersection types in which 6,082 bicyclists and 7,574 turning vehicles were observed across the United States. In additional, self-reported comprehension was collected from 1,245 residents and 690 bicyclists. The authors found that bicyclist perception of safety appears to be more heavily influenced by the volume of turning motor vehicle traffic than correct turning movements of motorists at the studied locations.	Survey Analysis	Survey	Perception of safety	☐

* Safety outcome with an increase in vehicle traffic volume:

○ positive outcome ● statistically significant positive outcome ($p < 0.05$)

☐ negative outcome ■ statistically significant negative outcome ($p < 0.05$)

Table acronyms: OR – odds ratio, CI – confidence interval

A.2.3 Bicycle traffic volume

It is well documented that bicyclist safety risk decreases with higher bicyclist traffic volumes (Elvik, 2009; Kaplan & Giacomo Prato, 2015; Nordback, Marshall, & Janson, 2014; Osama & Sayed, 2016; Pucher, Buehler, & Seinen, 2011; Strauss, Miranda-Moreno, & Morency, 2013).

A.2.4 Road classification

Jurisdictions classify their roadways by their function into expressways, major arterials, minor arterials, collectors and local roads to represent various roadway characteristics that include vehicle volume, posted speed limit, number of vehicle lanes, presence of parking, presence of a median, and number of intersections. While each jurisdiction defines their roadways classifications differently, in general the intention of each classification is similar where lower functional classes (e.g. local roads) represent quiet streets with low vehicle volumes and speeds and higher functional classes (e.g. expressways) represent busy roadways with high vehicle volumes and speeds. In the absence of safety research on specific roadway characteristics, research on the safety impacts of roadway functional classifications can provide a general understanding of safety.

Key findings regarding bicyclist safety as a function of roadway functional classification are presented in Table A-25. Overall, the literature indicates that the risk of bicyclist injury increases as roadway functional classification increases.

Table A-25: Key safety findings for roadway functional classification

Key literature findings	Study method	Safety data source	Safety measure	Safety outcome *
Harris et al. (2013) studied 683 adult bicyclists who were injured in Toronto and Vancouver in a case-crossover study. It was found that intersections of two local streets had approximately one fifth of the risk (adjusted OR 0.19, 95% CI 0.015 to 0.66) of intersections of two major streets.	Case-crossover	Hospital records	Crash frequency	■
Teschke et al. (2012) found that local streets (median of 48 vehicles per hour) and no bicycle infrastructure had significantly lower bicycling risk (OR = 0.51; 95% CI = 0.31, 0.84; p < 0.05) when compared to bicycling on major streets (median of 816 vehicles per hour) with parked cars and no bicycle infrastructure and adjusted for 13 other bicycle route types. They conclude that busy streets are associated with higher risks than quiet streets.	Case-crossover	Hospital records	Injury rate	■
Teschke et al. (2012) found that local streets without parked cars and designated as a bicycle route had significantly lower bicycling risk (OR = 0.49; 95% CI = 0.26, 0.90; p < 0.05) when compared to bicycling on major streets with parked cars and no bicycle infrastructure and adjusted for 13 other bicycle route types.	Case-crossover	Hospital records	Injury rate	■
Osama et al. (2017) studied 134 traffic analysis zones in Vancouver and found a higher proportion of arterial roads, as well as a higher proportion of arterial plus collector roads, were found to increase bicycle crash frequency.	Case-control	Insurance records	Crash rate	□
Aguilar et al. (2018) analyzed data from the Howard University Traffic Data Center and DC's open data website, found roads with a high functional classification are associated with an increase in crashes.	Case-Control	Video observation	Crash frequency	□

* Safety outcome with an increase in vehicle traffic volume:
○ positive outcome ● statistically significant positive outcome (p < 0.05)
□ negative outcome ■ statistically significant negative outcome (p < 0.05)
Table acronyms: OR – odds ratio, CI – confidence interval

A.2.5 Presence of vehicle parking

The presence of vehicle parking along a bicycle route has been found to increase the risk of bicyclist crash (Teschke et al., 2012). One reason for the increase in crashes is due to drivers opening their door into the bicyclists travel path (termed "dooring") causing the bicyclist to swerve into the adjacent vehicle lane or collide with the vehicle door. Research suggests that bicycling guidelines do not adequately account for the door zone and as a result bicyclists travelling in painted bicycle lanes have been found to travel to closely to parked vehicles (Schimek, 2017). Furth et al. (2011), indicate that a centre lane sharrow is effective in shifting bicyclist position away from right-side hazards.

Research has found the presence of vehicle parking along bicycle facilities to reduce bicyclists perception of safety (Chataway, Kaplan, Nielsen, & Prato, 2014; Winters & Teschke, 2010).

A.2.6 Other considerations

Roadway width

Hamann et al. (2013) conducted a case-control study of 147 bicycle crash locations that occurred between 2007 and 2010 compared to 147 control sites without crashes in Iowa. Results found that for every 10 ft (3 m) of curb-to-curb width the risk of bicycle-vehicle crash increases (statistically significant adjusted OR = 1.37, 95% CI = 1.05, 1.79).

Number of vehicle travel lanes

Research by Teschke et al. (2012) found that the number of market traffic lanes is not significantly associated with an increase in bicyclist injury risk compared to no market traffic lanes (2 lanes: OR = 1.2; 95% CI = 0.79, 1.8; > 2 lanes: OR = 1.4; 95% CI = 0.97, 1.9). Conversely, an increase in the number of vehicle travel lanes is associated with a decrease in bicyclists perception of safety (Chataway et al., 2014; Wang et al., 2018).

Roadway curb type

Romonow et al. (2012) completed a case-control study based on 274 injury sites (151 in Edmonton and 123 in Calgary) identified through interviews with hospitalized bicyclists that were involved in a crash with a motorized vehicle or with serious injury (cases) and matched to those that were not involved in a crash with a motor vehicle or discharged from the emergency department. The authors found that non-mountable curbs presented statistically significant higher odds of bicyclist severe injury than mountable curbs (matched OR=4.51, 95% CI: 1.08, 18.8).

Bicycle facility surface type

Winters et al. (2010) surveyed 1402 adult current and potential bicyclists from Metro Vancouver regarding their preference to bicycle on 16 different route types. Results indicate that for off-street paths, paved routes were preferred over unpaved routes, especially among regular bicyclists.

Bicycle facility surface condition

Dozza et al. (2014) analyzed data collected from 20 bicyclists that travelled 1549 km around Sweden using instrumented bicycles and found the risk of experiencing a critical event was significantly higher (OR = 10.3; 95% CI = 2.16, 49.4) when the road surface was poorly maintained and in proximity to intersections.

In addition, Gustafsson et al. (2013) found from studying 16 bicyclists in Stockholm, Sweden, the second most frequent safety problem was found to be attributable to the surface of the road or bicycle-lane/path.

Bicycle facility grade

Downhill sloped bicycle facilities (< 0 degrees) have been found to both increase the risk of bicyclist crash (OR = 2.32; 95% CI = 1.72, 3.13; $p < 0.05$) (Teschke et al., 2012) and the chances of the bicyclists requiring ambulance transportation to the hospital (OR = 1.62; 95% CI = 1.14, 2.32; $p < 0.05$) (Cripton et al., 2015); both results are statistically significant.

Presence of transit

The presence of bus stops was found to increase bicyclist crash frequency (Chaney & Kim, 2014; Strauss et al., 2013) and decrease bicyclist safety perception (Gustafsson & Archer, 2013). Teschke et al. (2012), found that the presence of streetcar or train tracks is significantly associated with increased risk of bicyclist injury (OR = 3.04; 95% CI = 1.80, 5.11; $p < 0.05$).

Street lighting

Street lighting has been found to improve bicyclist safety (Chen & Shen, 2016; Reynolds, Harris, Teschke, Cripton, & Winters, 2009). However, a study of roadway light illuminance in Montreal found that an increase in street lighting resulted in more bicycle crashes. They suggest that this unexpected result may be caused by the intentional implementation of street lighting at accident prone locations.

A.3 Works cited

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A.4 Photo credits

A-2	Off-road bicycle pathway	MORR
A-4	Off-road multi-use pathway	MORR
A-8	Protected bicycle lanes	MORR
A-12	Buffered bicycle lane	Google Street View
A-14	Painted bicycle lane	Google Street View
A-19	Bicycle accessible shoulder	MORR
A-20	Major street shared lane	Eric Fischer
A-23	Bicycle boulevards	Google Street View
A-25	Advisory bicycle lanes	Ali Kassim
A-26	Protected intersection	Dylan Passmore
A-26	Experimental levels of protect intersection treatment	Hurwitz et al
A-27	Bike box	NACTO
A-30	Two-stage turn queue box	NACTO
A-30	Intersection crossing markings	NACTO
A-35	Cross-rides	City of Ottawa
A-35	Bend-in intersection approach	FHWA
A-35	Bend-out intersection approach	FHWA
A-36	Protected signal phase	MORR
A-37	Gates, fencing and bollards	Google Street View

Appendix B: End user surveys

This appendix contains results from the *mature* end user survey and the *youth* end user survey.

B.1 Mature end user survey methodology

This section describes the survey design, survey distribution, analysis methodology, and survey limitations. The objective of the survey was to investigate how the bicycling community and different types of bicyclists define safety and the perceived safety performance of different bicycling facilities.

B.1.1 Survey design

The survey questions were first developed in Microsoft Word to facilitate feedback from the project steering committee (PSC) and subsequently transformed into an interactive on-line survey using SurveyGizmo software. In total, the PSC was given the following two opportunities to review the draft survey:

- June 15th, Draft 1 Word document provided to PSC, comments due July 3rd
- July 9th, Final draft online survey provided to PSC, comments due July 11th

Once the survey content was finalized it was published using SurveyGizmo online survey software. The number of questions in the survey varied between 36 and 69 questions depending on respondents' familiarity with the different facility types or intersection treatments included in the survey. A copy of the final survey is provided in Section B.4.

B.1.2 Survey distribution

The general approach to survey distribution was to send the survey and an introductory email to bicycling organizations across the country and then have those organizations distribute the survey to their members using the distribution mechanism at their disposal. The distribution list of bicycling organizations is provided in Table B-1. This distribution approach resulted in 624 people responding to the survey.

Table B-1: Bicycling organization distribution list

Group	Email
British Columbia	
Cycling BC	iride@cyclingbc.net
BC Bicycling Coalition	info@bccycling.ca
Greater Victoria Bicycling Coalition	info@gvcc.bc.ca
Vancouver Bicycle Club	http://vbc.bc.ca/contact-us
Kelowna Bicycling	http://www.kelownacycling.org/contact/
HUB Bicycling	info@bikehub.ca
Active Transportation Policy Council (CoV)	atpcenquiries@vancouver.ca
Alberta	
Alberta Bicycle Association	info@albertabicycle.ab.ca
Bike Calgary	connect@bikecalgary.org

Group	Email
Edmonton Bicycle Commuters	info@edmontonbikes.ca
Saskatchewan	
Sask Bicycling	cycling@accesscomm.ca
Bike Regina	Info@bikeregina.org
Manitoba	
Manitoba Bicycling Association	cycling.ed@sportmanitoba.ca
Bike Winnipeg	contact@bikewinnipeg.ca
Winnipeg Trails	info@winnipegtrails.ca
Green Action Centre	wco@greenactioncentre.ca
Trails Manitoba	http://www.trailsmanitoba.ca/contact/
Ontario	
Ontario Bicycling Association	http://www.ontariocycling.org/contact-ontario-cycling/
Share the Road Cycling Coalition	info@sharetheroad.ca
Bike Ottawa	info@bikeottawa.ca
Cycle Toronto	https://www.cycleto.ca/contact-us
Cycle Hamilton	info@cyclehamont.ca.
Quebec	
Velo Quebec	https://www.velo.qc.ca/fr/mail-service
Montreal Bicycle Coalition	info@coalitionvelomontreal.org
ACDA Quebec	info@acdaquebec.com
Club bicycliste Beaconsfield	info@clubcycliste.com
Club bicycliste Bicycle Pop	club@cyclepop.ca
Académie bicycliste	velovirtuel.acq_gmail.com
New Brunswick	
Velo NB	http://velo.nb.ca/contact/
River Valley Bicycling	http://www.rivervalleycycling.com/contact-us/
Nova Scotia	
Bicycle Nova Scotia	abarnett@bicycle.ns.ca
Halifax Bicycling Coalition	contact@cyclehalifax.ca
Prince Edward Island	
Cycling PEI	mconnolly@sportpei.pe.ca
Newfoundland and Labrador	
Bicycle Newfoundland Labrador	admin@bnl.nf.ca
Bike St. John's	http://www.bikestjohns.ca/more-info/contact-us
Yukon	
U Kon Echelon	trenairving@gmail.com
National	
TransCanada Trail	info@tctrail.ca
Cycling Canada	general@cyclingcanada.ca

B.1.3 Analysis methodology

The end user survey questions were grouped as follows:

1. General questions: Gender, age, location
2. Cycling characteristics: Why, when and where does the respondent ride
3. Cycling safety characteristics: bicyclist type, collision experience and bicycle friendliness of their jurisdiction
4. Safety perceptions of bicycle Facilities: Respondents' perception of safety riding in different roadway and roadside environments with and without bicycling facilities
5. Safety perceptions of bicycle intersection treatments: Respondents' perception of safety riding through different intersection treatments
6. Safety perceptions of bicycling infrastructure: Ranking of five most significant factors influencing the respondents' feeling of safety while bicycling

The grouping of questions allowed for a breakdown of bicyclists perception of safety of different factors and facilities/treatments (Groups 4 to 6) relative to their characteristics as bicyclists (Group 1 to 3). The first step was to identify respondent characteristics (Group 1 to 3) by how they self-identified into the three bicyclist types; strong and fearless, enthused and confident, and interested but concerned so that common features of each bicyclist type could be identified. For example, three-quarters of respondents that identified as strong and fearless riders were male and they rode more frequently and more often during winter than the other two bicyclist types. Next, the Group 4 to 6 responses for each common bicyclist type were assembled and compared with each other to identify areas of consistency in the data as well as anomalies. Areas of consistency and anomalies were then examined in more detail to identify core characteristics that could be linked back to the end users and their perception of safety. This approach identified patterns and anomalies in the responses relative to end user characteristics and enabled comparison of end user perceptions of safety for different facilities with actual safety performance for these different facilities determined through other study tasks.

B.2 Mature end user respondent characteristics

B.2.1 Geographic distribution of respondents

Responses were received from most regions across Canada, except for the north. Figure B-1 illustrates the location and number of respondents by jurisdiction. As illustrated in Figure B-1 and Table B-2, the highest response rates were from British Columbia, Alberta and Nova Scotia and more specifically Victoria, Vancouver, Calgary and Halifax. Relative to population (Table B-2), Ontario and Quebec had lower response rates. No responses were received from Newfoundland or Prince Edward Island and there were three respondents who did not indicate their location.

Figure B-1: Location of survey respondents

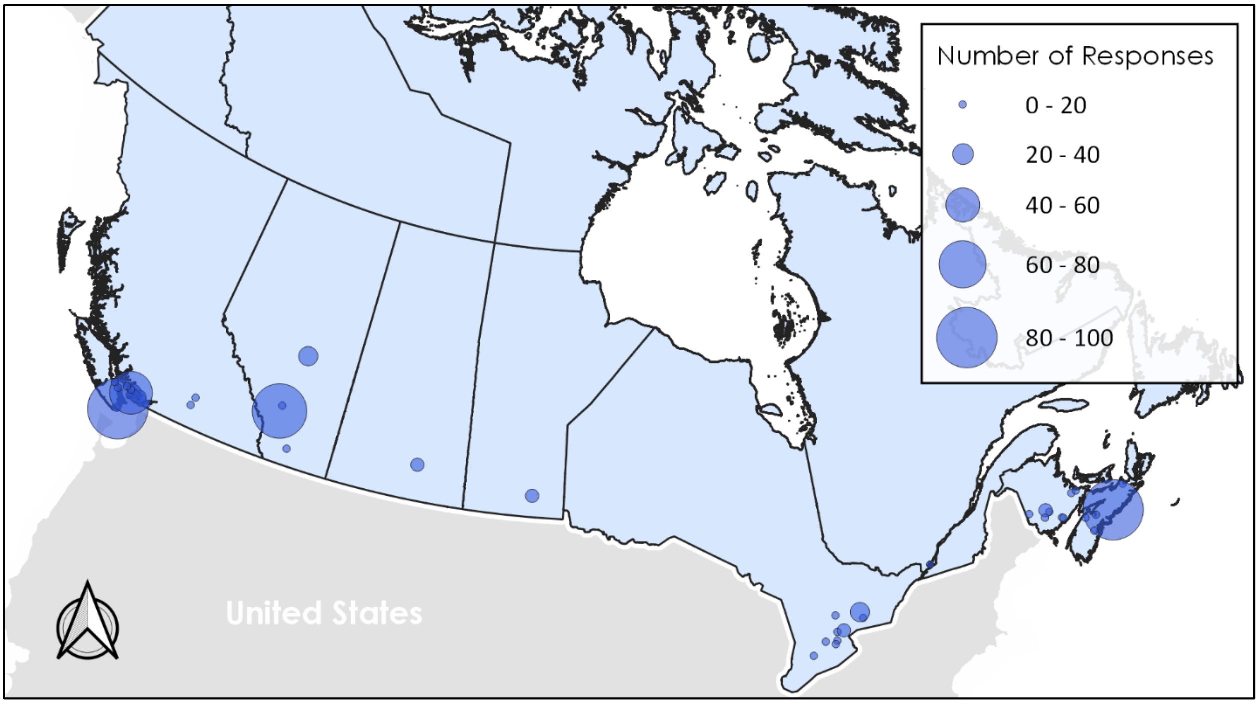


Table B-2: Proportion of survey responses by province compared to population

	Population (2016 Census)	Proportion of Totals	Survey Responses
Total	**35,151,728**		**621**
Ontario	13,448,494		49
Quebec	8,164,361		42
British Columbia	4,648,055		260
Alberta	4,067,175		108
Manitoba	1,278,365		12
Saskatchewan	1,098,352		12
Nova Scotia	923,598		103
New Brunswick	747,101		35
Newfoundland and Labrador	519,716		0
Prince Edward Island	142,907		0
Northwest Territories	41,786		0
Nunavut	35,944		0
Yukon	35,874		0
Total	**35,151,728**		**621**

B.2.2 Bicyclist type

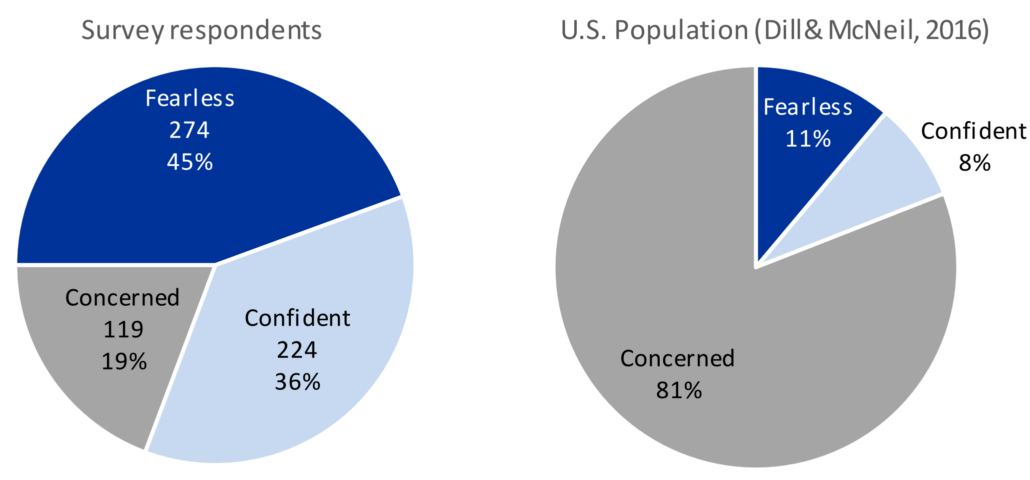
As noted in the methodology, a key reference point for the survey was how respondents self-identified into strong and fearless (fearless), enthused and confident (confident), and interested but concerned (concerned) bicyclist types. These three types are identified in TAC's Geometric Design Guide for Canadian Roads (2017) based on research completed in the U.S. (Dill & McNeil, 2013). A brief description of each follows:

- Strong and fearless – bicyclists that will typically ride anywhere regardless of road conditions or weather.
- Enthused and confident – bicyclists who are fairly comfortable riding on all types of bicycleways, but usually choose low traffic streets or multi-use paths where available.
- Interested but concerned – bicyclists who typically ride a bicycle on low traffic streets or multi-use paths under favourable weather conditions.

A fourth bicyclist type, "No-way, no-how" was excluded, as this bicyclist type in effect represents individual who are not bicyclists.

Figure B-2 illustrates the breakdown of survey respondents into the three bicyclist types (note that seven respondents did not self-identify). As the figure shows, the survey respondents are mainly confident or fearless, which differs from the characteristics of the general population, where fearless bicyclists account for approximately 11% of the bicycling population, confident account for 8%, and concerned account for 81% (Dill & McNeil, 2016). Dill and McNeil (2017) also found that the proportion of the three bicyclist types make up 63% of the total population and 37% of the population fall under the "No-way, no-how" category. The actual categorization of respondents is thought to reflect the survey being distributed to end users through bicycling organizations, whose membership tend to have much greater representation from enthusiastic, experienced and confident bicyclists than the public at-large. More important to the survey was having a reasonable number of respondents in each category to get as complete a reflection as possible of the perception of safety from people who bicycle. Survey responses are summarized by the three bicyclist types discussed above.

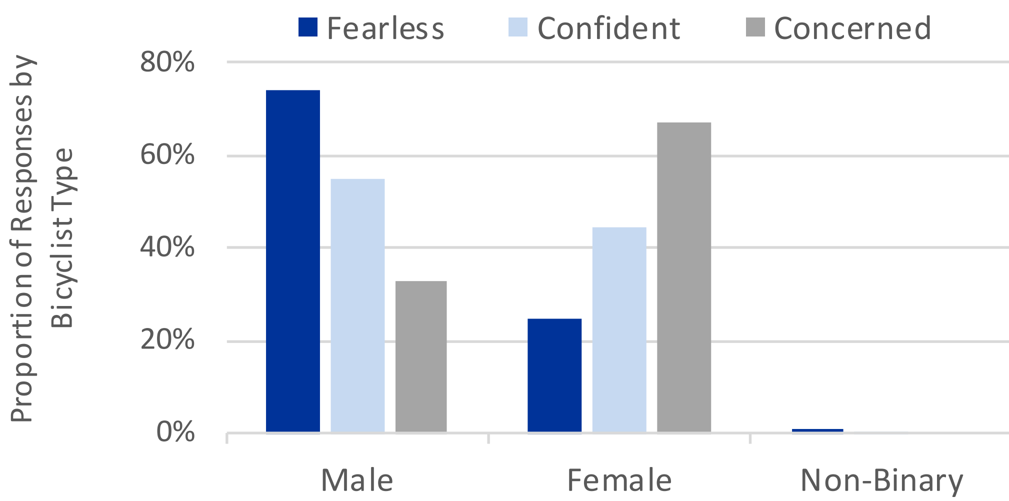
Figure B-2: Number of survey responses by bicyclist type



B.2.2.1 Respondent demographics

The demographics portion of the survey broke down respondent characteristics in terms of age and gender through the lens of bicyclist type. Of the total respondents, 365 were male, 246 were female, and 4 identified as non-binary. As illustrated in Figure B-3, male respondents represent the highest proportion of fearless riders and the lowest proportion of concerned riders, whereas female respondents represent the opposite proportions, with the highest level of concerned riders and the lowest level of fearless riders.

Figure B-3: Proportion of responses by bicyclist type and gender

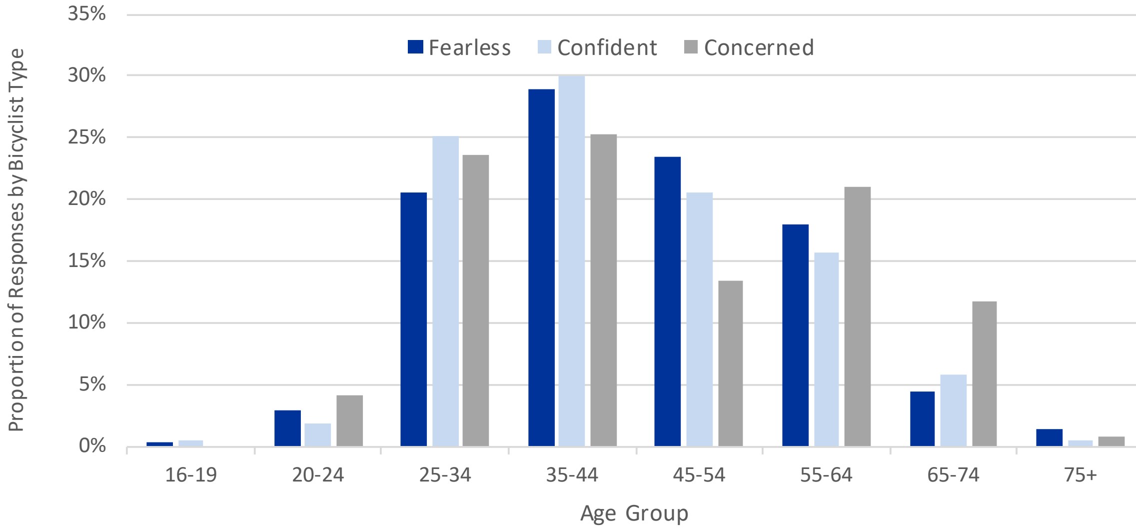


The relationship between gender and bicyclist type suggests that designing facilities that are inclusive of all genders requires explicit consideration of concerned riders.

Figure B-4 provides a summary of responses by bicyclist type as a function of age group. As the figure shows, most of the people who responded fall into the 35 to 44 age group followed by the adjacent older and younger age groups. Few respondents fall in the oldest and youngest age groups of the survey. The figure shows that the highest number of fearless and confident bicyclists are within or adjacent to the 35-44 age group while the concerned bicyclists have a relatively low representation in the 45-54 age group but high representation in the 55-64 and 65-74 age groups.

The proportion of people that bicycle is expected to decrease as age increases (Statistics Canada, 2017), which would indicate that younger bicyclists are under represented in the survey results.

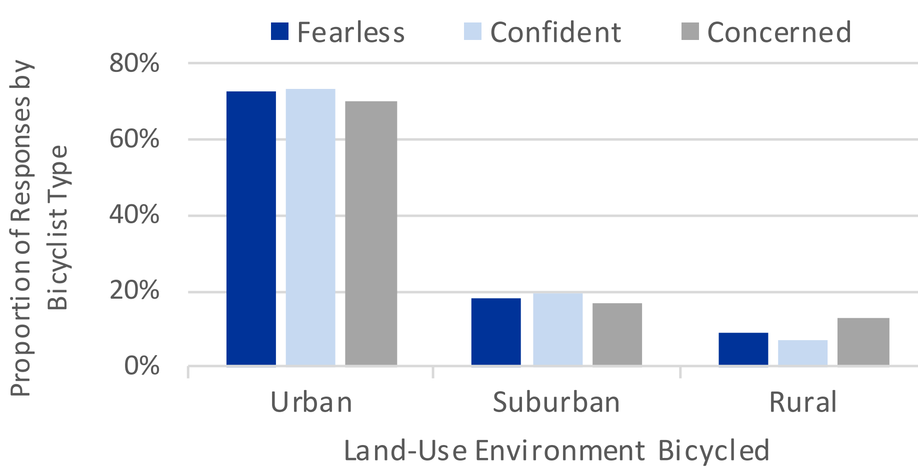
Figure B-4: Proportion of responses by bicyclist type and age group



B.2.2.2 Respondent bicycling trip characteristics

Figure B-5 illustrates the environments (urban, suburban, rural) where respondents most commonly bicycle. For this question, respondents were only able to select one type of environment. As illustrated by the graph, the urban environment is by far the most common environment where people bicycle regardless of user type. This result reflects that survey respondents are mostly located in urban municipalities.

Figure B-5: Proportion of responses by bicyclist type and the land-use environment they commonly bicycle



The bicycling characteristics portion of the survey focused on why, where, when and how often respondents ride. Figure B-6 illustrates respondents' main reason for bicycling. Commuting is the main reason for bicycling for all bicyclist types followed by recreation and utilitarian reasons (e.g. running errands, shopping and socializing). Fearless and confident bicyclists' reasons for bicycling are very similar; concerned bicyclists cited a higher proportion of recreational and utilitarian bicycling trips and lower proportions of commuting relative to the other two types.

Figure B-6: Proportion of responses by bicyclist type and their main reason for bicycling

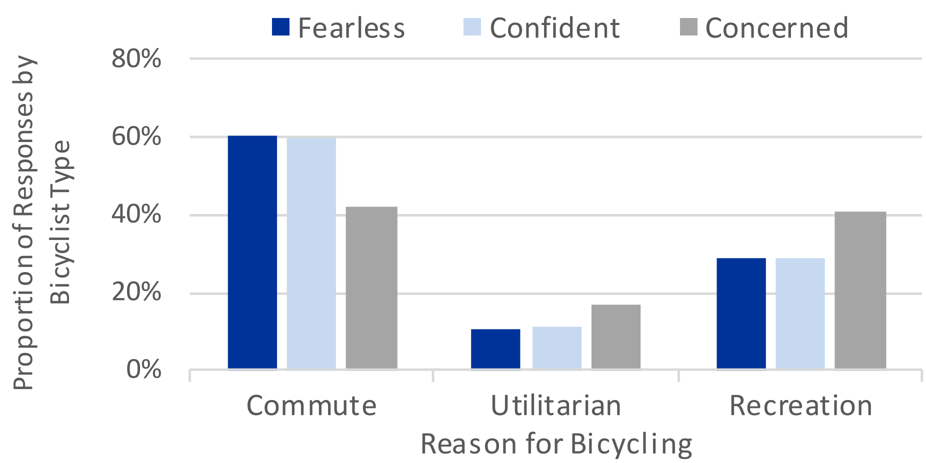


Figure B-7 illustrates the proportion of bicyclists that ride during a specific season. More than 90% of fearless, confident and concerned bicyclist ride in each of the spring, summer and fall seasons. In winter, the proportion of fearless bicyclists riding is approximately 70%, the proportion of confident bicyclists is approximately 50% and the proportion of concerned bicyclists is just above 20%.

These results illustrate the significant extent to which bicycling drops in the winter, particularly when consideration is given to the fact that concerned bicyclists represent approximately 80% of the general population who bicycle (based on a national U.S. survey (Dill & McNeil, 2016)).

Respondents were asked to indicate the frequency they bicycle during times when there is no snow on the ground and times when there is snow on the ground. Figure B-8 illustrates the bicycling frequency of respondents by type when there is snow cover on the ground. The results indicate that fearless and confident riders bicycle more frequently than concerned bicyclists and that the 3-4 days per week level appears to be the tipping point above which fearless and confident bicyclists have greater representation than concerned.

Figure B-7: Proportion of bicyclists who ride during each individual season

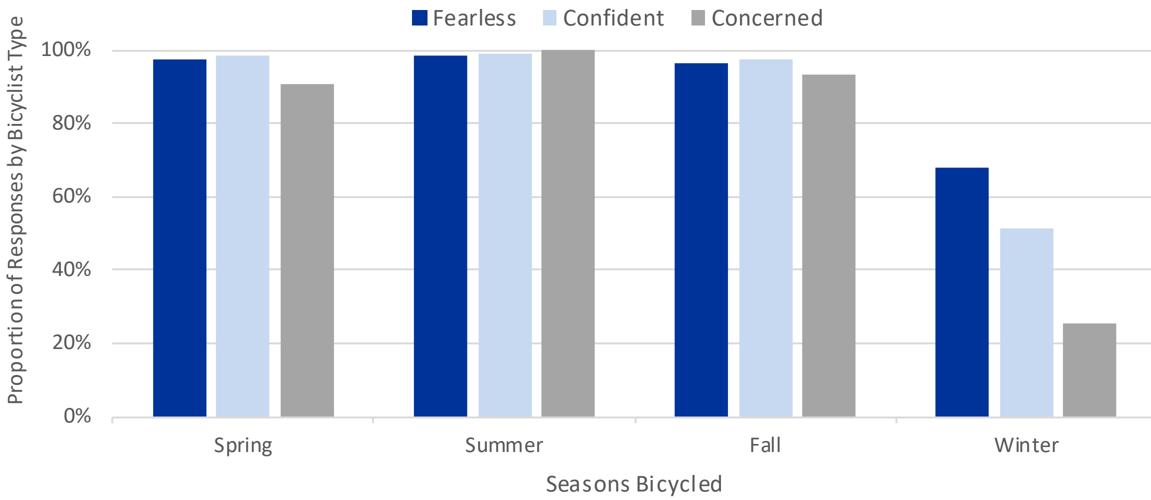


Figure B-8: Bicycling frequency by bicyclist type when there is *no snow on the ground*

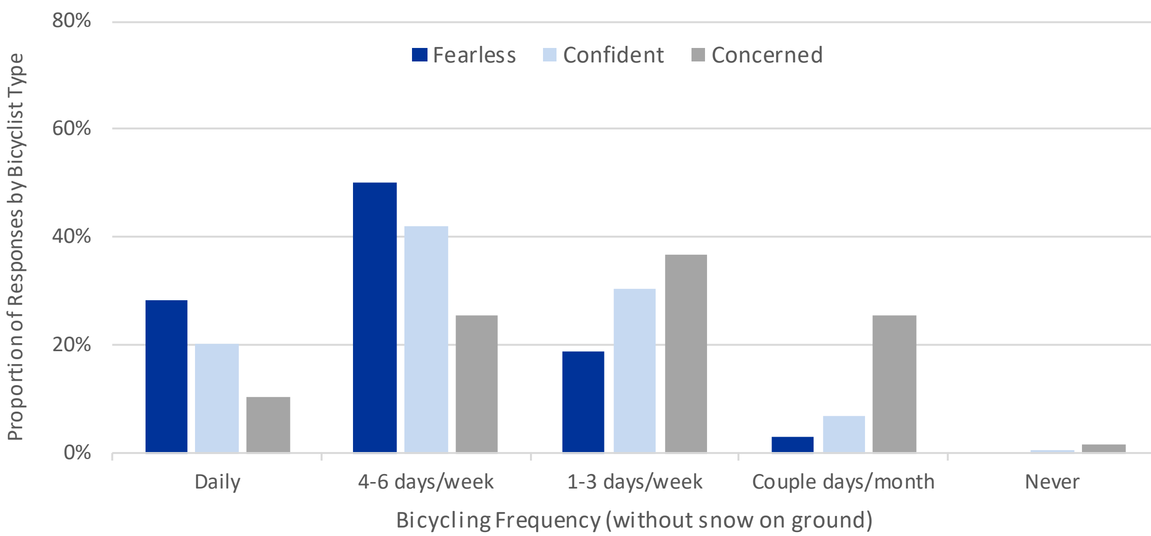
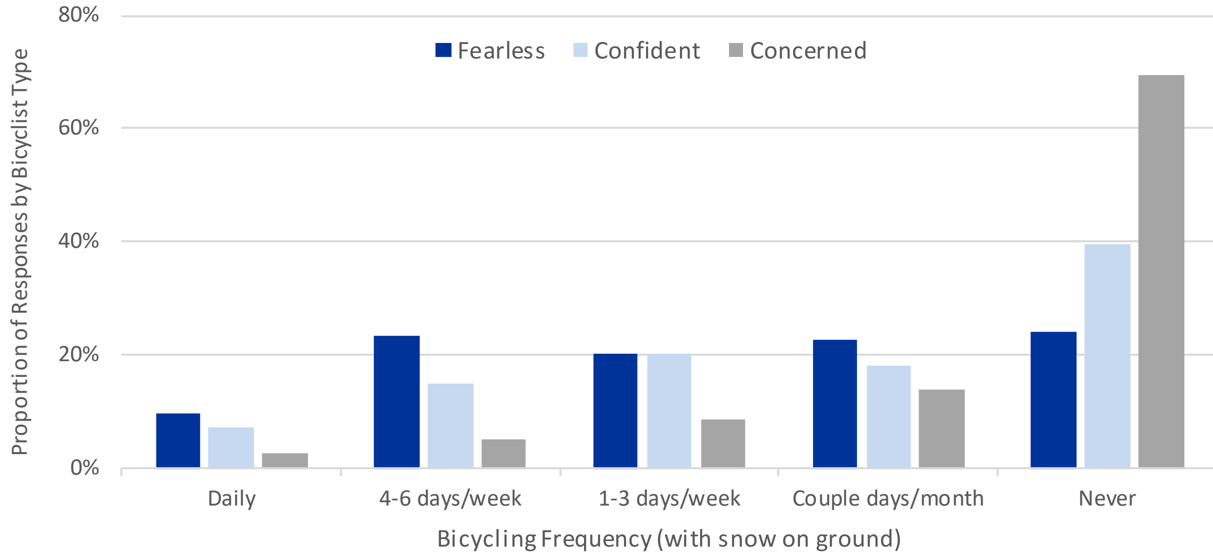


Figure B-9 illustrates the bicycling frequency of respondents by type when there is snow cover on the ground. Results indicate that fearless bicyclists are most likely to ride with snow on the ground; about 50% of fearless and 40% of confident bicyclists indicate they bicycle more than 1 day per week with snow on the ground. A significant number of respondents indicate they never bicycle when there is snow on the ground with 24% of fearless, 40% of confident, and 70% of concerned bicyclists indicating so.

Figure B-9: Bicycling frequency by bicyclist type when there is *snow on the ground*



B.2.2.3 Respondent bicycling safety characteristics

The final section of the survey addressing respondent characteristics looked at respondents' actions and opinions specific to bicycle safety. Figure B-10 shows that approximately 80% of respondents across all user types always wear a helmet while bicycling.

Figure B-10: Proportion of responses by bicyclist type and helmet use

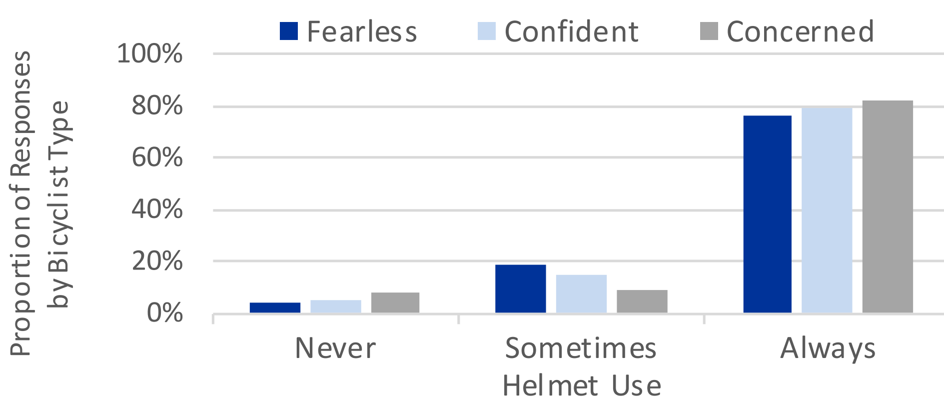
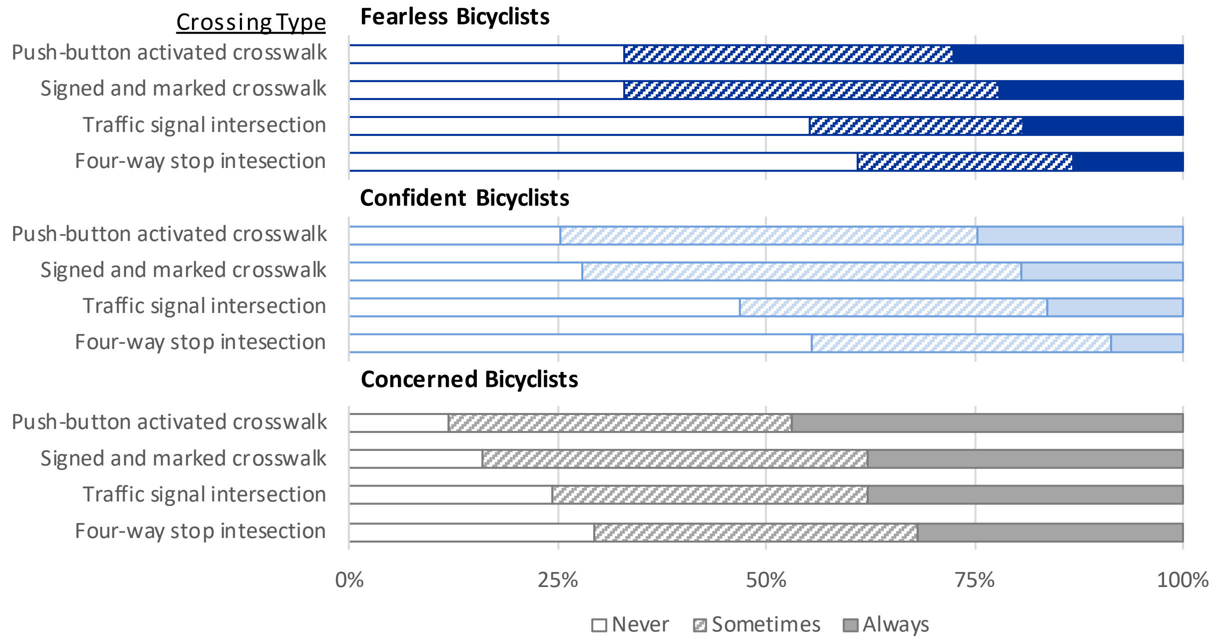


Figure B-11 results describe respondents' willingness to dismount off their bicycles at different types of crossing points when required by signage. Relative to the type of crossing, results are reasonably consistent across all bicyclist types with compliance ranging from lowest to highest in the order of four-way stops, traffic signals, signed and marked crosswalks, and push-button activated crosswalks. In general, the level of compliance shown by all results is relatively low. The breakdown by bicyclist type shows that concerned bicyclists generally show a greater level of compliance when required to dismount than the confident and fearless bicyclists.

Figure B-11: Proportion of responses by bicyclist type and their willingness to dismount when required by signage at various crossing types



With respect to survey respondents' personal safety associated with collisions while riding, 40% of fearless, over 50% of confident, and over 60% of concerned bicyclists indicated that they have not be involved in a collision as a bicyclist within the last 10 years. However, of those who have been involved in a collision, collisions with roadway objects were most common, followed by collisions with vehicles, other bicycles and pedestrians. The high proportion of collisions with roadway elements is noteworthy as collisions of this nature are unlikely to generate collision data outside of medical records related to treatment of injuries, if at all. This also applies to collisions with other bicyclists and pedestrians, though the proportions are smaller.

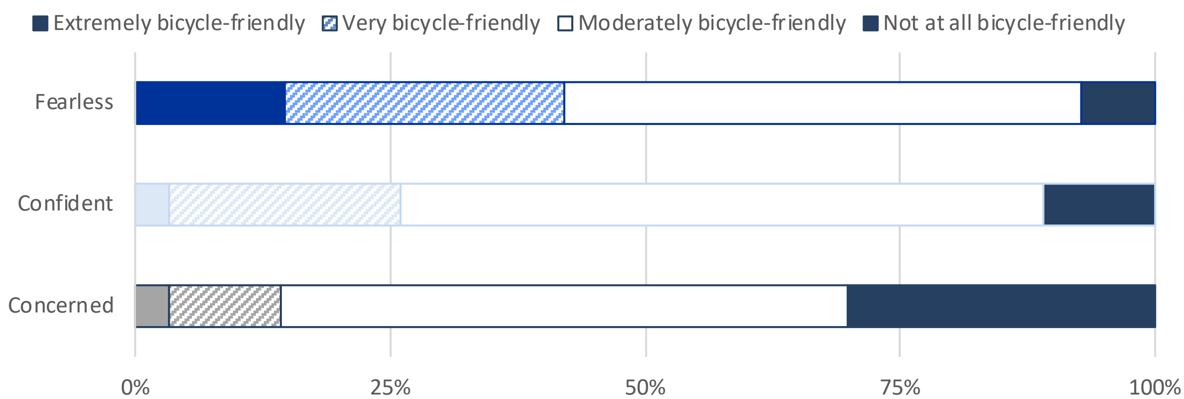
B.3 Mature end user survey analysis and discussion

Survey results regarding respondents' perception of bicycle infrastructure are summarized based on the three bicyclist types previously defined as fearless, confident and concerned. This section discusses respondents' perception of: (1) the bicycle-friendliness of their local bicycle infrastructure; (2) ease-of-use, safety and stress associated with bicycling along bicycle facilities; (3) safety and stress associated with bicycling on protected bicycle facilities through intersections; (4) safety, ease-of-use and stress associated with bicycling through different types of intersection treatments; and (5) factors that influence bicyclists feeling of safety while bicycling.

B.3.1 Perception of local bicycle infrastructure

Figure B-12 illustrates bicyclists' perception of the overall bicycle friendliness of their local bicycle infrastructure. Overall, as the figure shows, most survey participants indicated that their jurisdiction is moderately bicycle-friendly. When summarized by bicyclist type, the results indicate that concerned bicyclists most commonly indicate that their local bicycling infrastructure is 'not at all bicycle friendly', while fearless bicyclists most commonly indicate that their local bicycle infrastructure is either extremely or very bicycle friendly when compared to confident and concerned bicyclists.

Figure B-12: Proportion of responses by bicyclist type and their perception of the bicycle-friendliness or their local bicycle infrastructure



B.3.2 Bicycle facilities

Survey respondents were asked to provide their opinion regarding the ease-of-use, safety and stress level associated with bicycling on various bicycle faculties. Respondents addressed the following statements:

- In your opinion, these bicycle facilities *are easy to use*.
- In your opinion, these bicycle facilities *are safe*.
- In your opinion, these bicycle facilities *are stress-free to ride along*.

Figure B-13 presents the bicycle facilities that were included in the survey.

Figure B-13: Bicycle facilities included in the survey

Residential street (local)

Residential collector

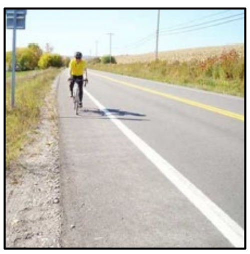
Arterial street

Bicycle boulevard

Advisory bicycle lane

Major street shared lane

Bicycle accessible shoulder

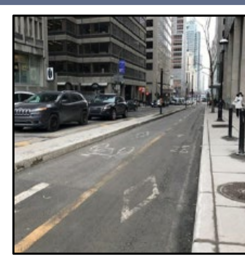


Painted bicycle lane

Buffered bicycle lane

Protected bicycle lane (Uni-directional)

Protected bicycle lane (Bi-directional)



Off-road multi-use pathway

Off-road bicycle pathway

B.3.2.1 Bicyclist perceptions of facility safety

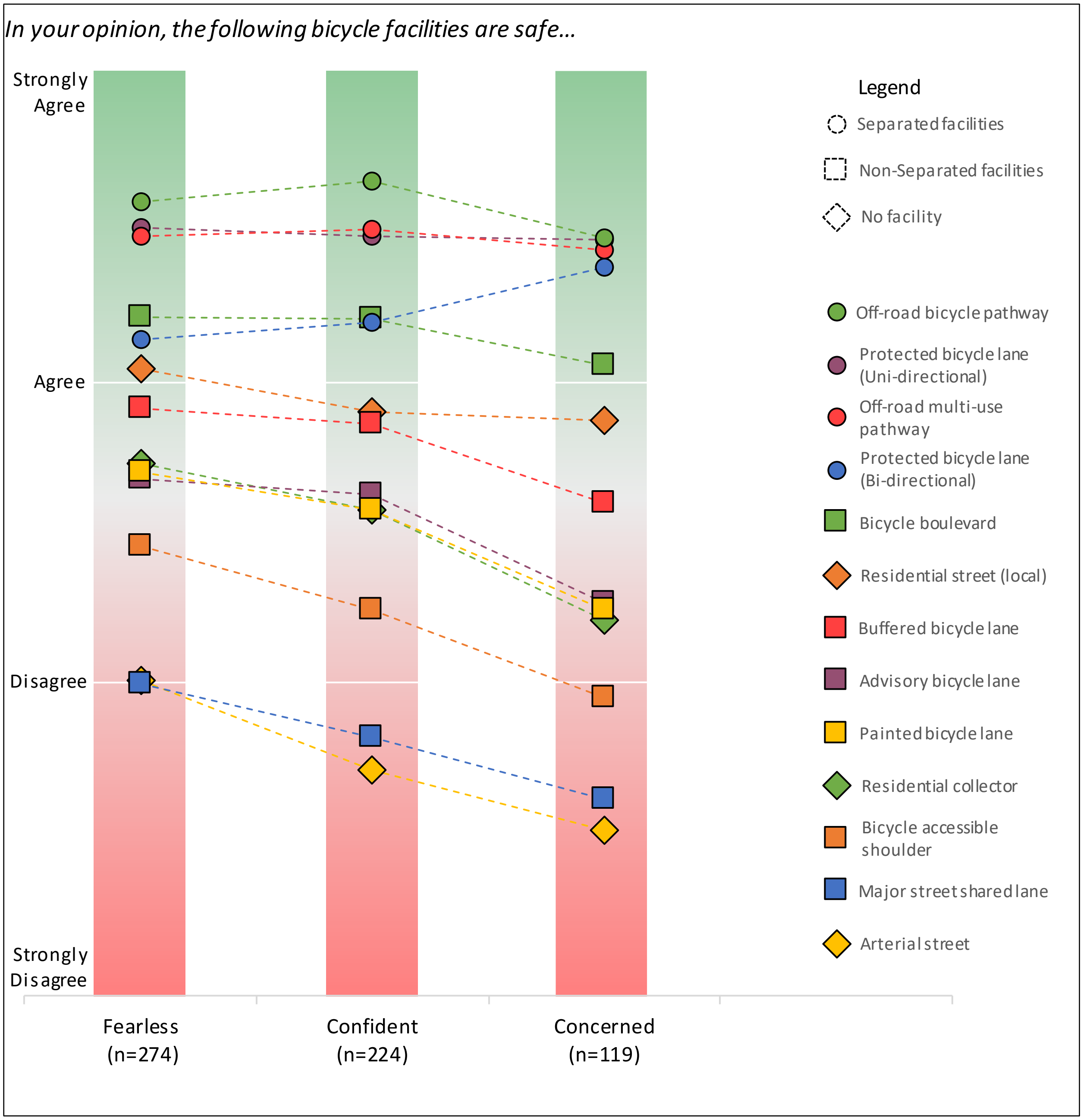
Figure B-14 shows how respondents perceive the safety of bicycle facilities based on their self-identified bicyclist type. Separated facilities (e.g. off-road multi-use path, off-road bicycle pathways and protected bicycle lanes) are perceived to be the safest bicycle facilities with off-road bicycle pathways being perceived as the safest bicycle facility amongst all bicyclist types. Bi-directional protected bicycle lanes, while perceived safer than other non-separated facilities by confident and concerned bicyclists, are not viewed the same way by fearless bicyclists. In fact, they are perceived less safe than bicycle boulevards, buffered bicycle lanes and residential streets by these users. Major street shared lanes and arterial streets were identified by all types of bicyclists as being unsafe. Bicycle accessible shoulders are also perceived to be unsafe, mainly by concerned bicyclists.

In general, separated facilities are perceived as safe, followed by lower classification streets with or without a facility, higher volume streets with continuous facilities (e.g. painted bicycle lanes), and finally, higher classification streets with intermittent (sharrow) or no facility. As such, the perception of safety appears to follow a hierarchy related to the level of exposure to vehicle traffic in terms of both the extent of buffering from vehicles and vehicle volume.

Advisory bicycle lanes are perceived less safe than residential streets, where they may be implemented; although this may be a result of respondents being unfamiliar with advisory bicycle lanes as they have not seen wide-spread adoption.

The increase in perceived safety of bi-directional protected bicycle lanes from more confident bicyclists to concerned bicyclists may be the result of concerned bicyclists preference for protected facilities and simpler routing options versus a more confident bicyclist’s awareness of the potential increase in vehicle turning movement conflicts due to bi-directional bicycle travel at intersections.

Figure B-14: Bicyclist perception of the safety of bicycle facilities

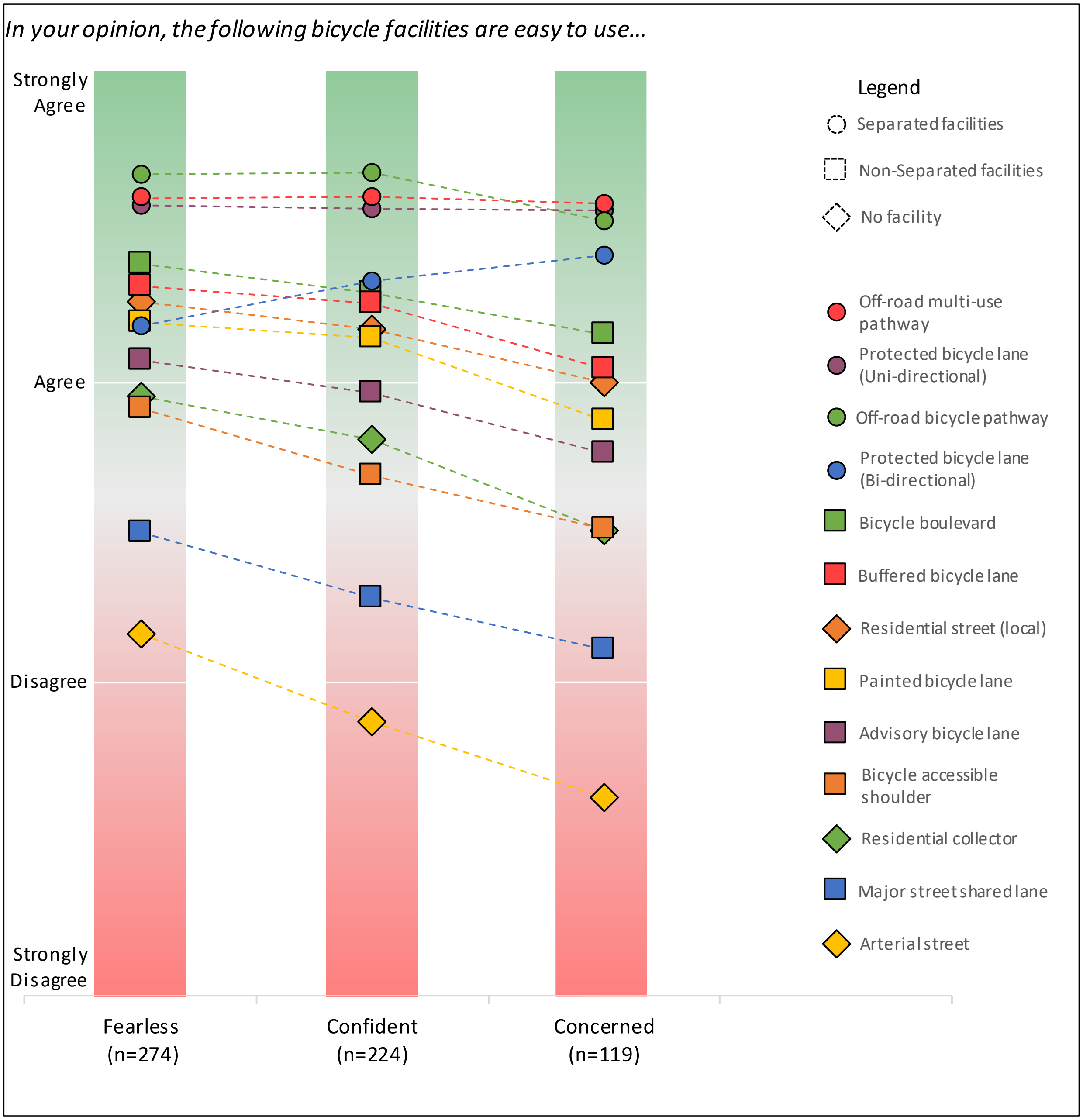


B.3.2.2 Bicyclist perceptions of facility ease-of-use

Figure B-15 shows how respondents perceive the ease-of-use of the various types of bicycle facilities based on their self-identified bicyclist type. Separated facilities (e.g. off-road multi-use path, off-road bicycle pathways and protected bicycle lanes) are perceived to be the easiest facilities to use, except for bi-directional protected bicycle lanes, which are not ranked the same by fearless bicyclists. Bi-directional protected bicycle lanes, while perceived as easier to use than non-separated facilities by confident and concerned bicyclists, are not viewed the same way by fearless bicyclists. In fact, they are perceived to be less user-friendly than bicycle boulevards, buffered bicycle lanes and residential streets by these users. Arterial streets and major street shared lanes are the two facilities identified as the least user-friendly.

In general, similar to the case regarding safety perception, more confident bicyclists find the same facilities easier to use than less confident riders. However, there are two exceptions: (1) bi-directional protected bicycle lanes appear to be easier to use by concerned bicyclists than confident and fearless bicyclists; (2) off-road multi-use pathways and uni-directional protected bicycle lanes are not perceived any differently between all three bicyclist types in terms of ease-of-use.

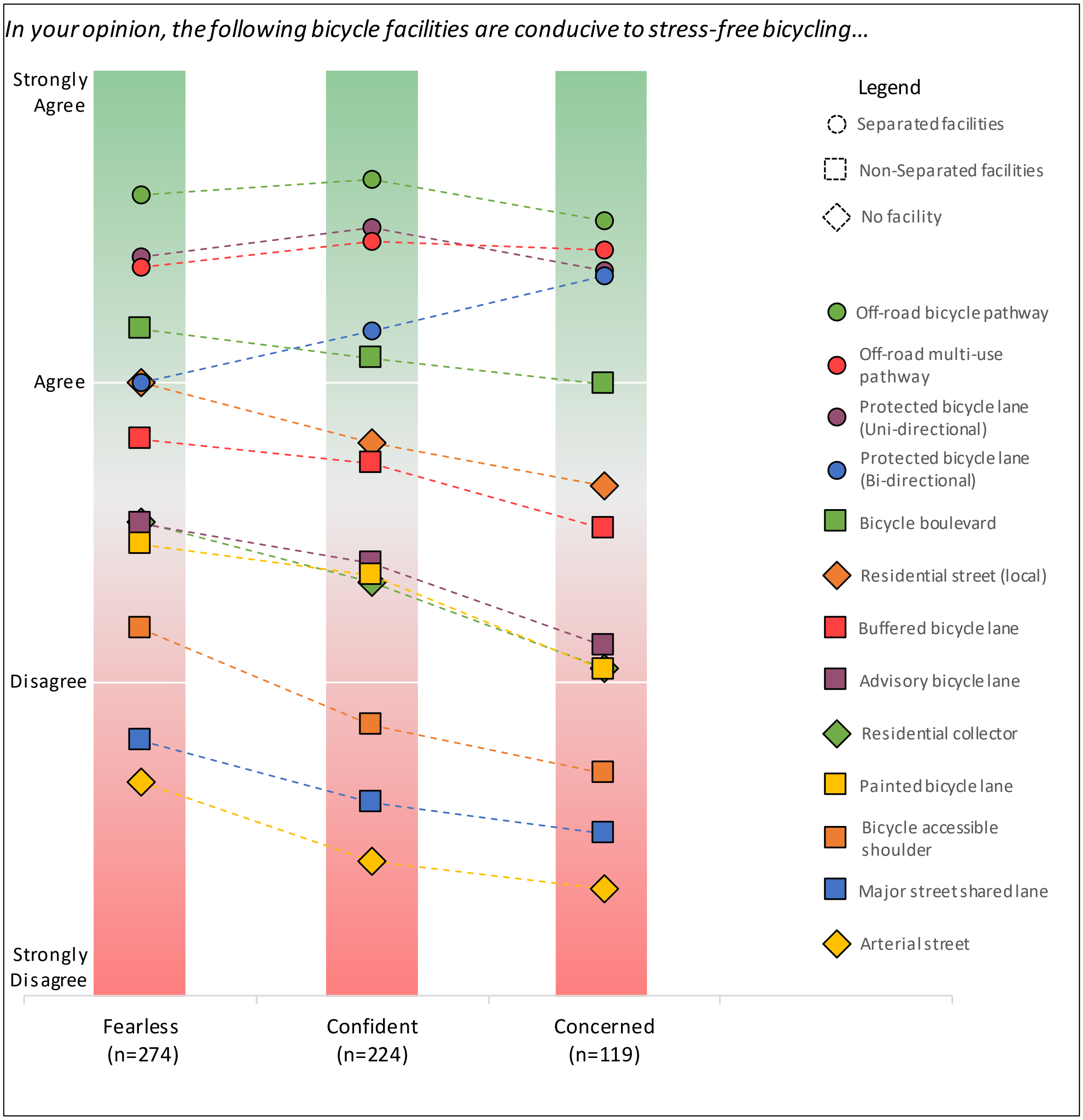
Figure B-15: Bicyclist perception of the ease-of-use of bicycle facilities



B.3.2.3 Bicyclist perceptions of stress associated with riding along facilities

Figure B-16 shows how respondents perceive bicycle facilities regarding the level of stress they feel when riding on them. These results are very similar to the results for perceived safety and ease of use presented in the previous two sections, where general facilities ranks are consistent among each bicycle type and trends between the three types are the same.

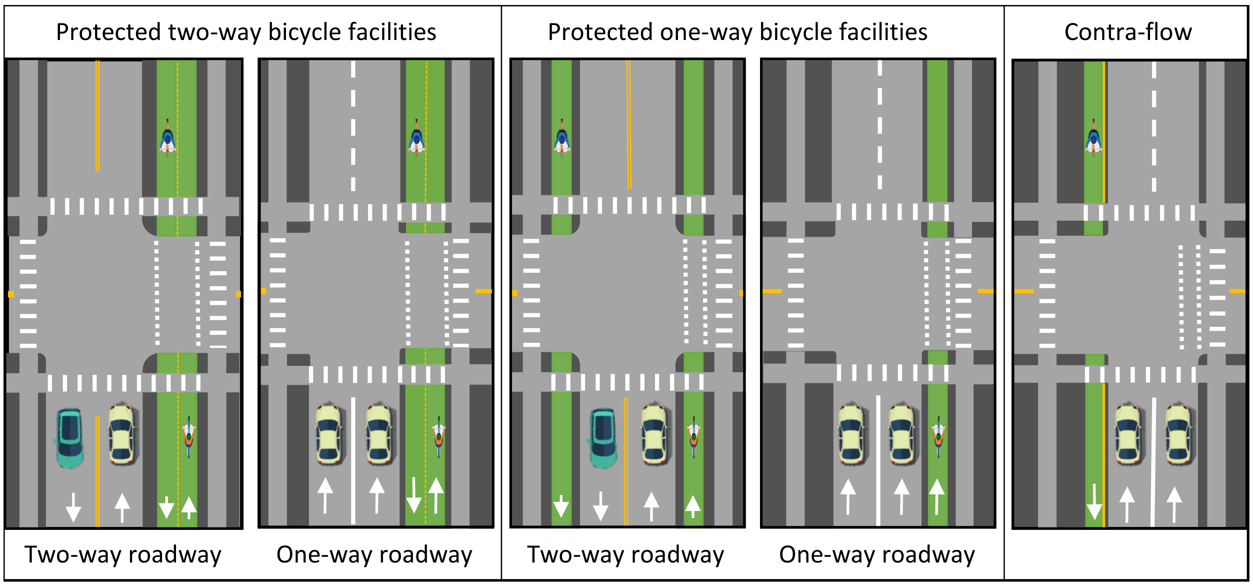
Figure B-16: Bicyclist perception of stress-free riding along bicycle facilities



B.3.3 Protected bicycle facilities at intersections

Protected bicycle facilities may be designed to carry bi-directional bicycle traffic on one side of the street. This presents unique safety concerns at intersections because motorists may not be prepared to check for bicyclists travelling in both directions on one side of the street. Because of this concern, survey respondents where asked to share their views regarding bicycling through intersections when travelling on one-way and two-way protected bicycle lanes along one-way and two-way roadways and on contra-flow bicycle facilities (i.e. in the opposite direction of vehicle travel). The various intersection configurations considered in this question are illustrated in Figure B-17.

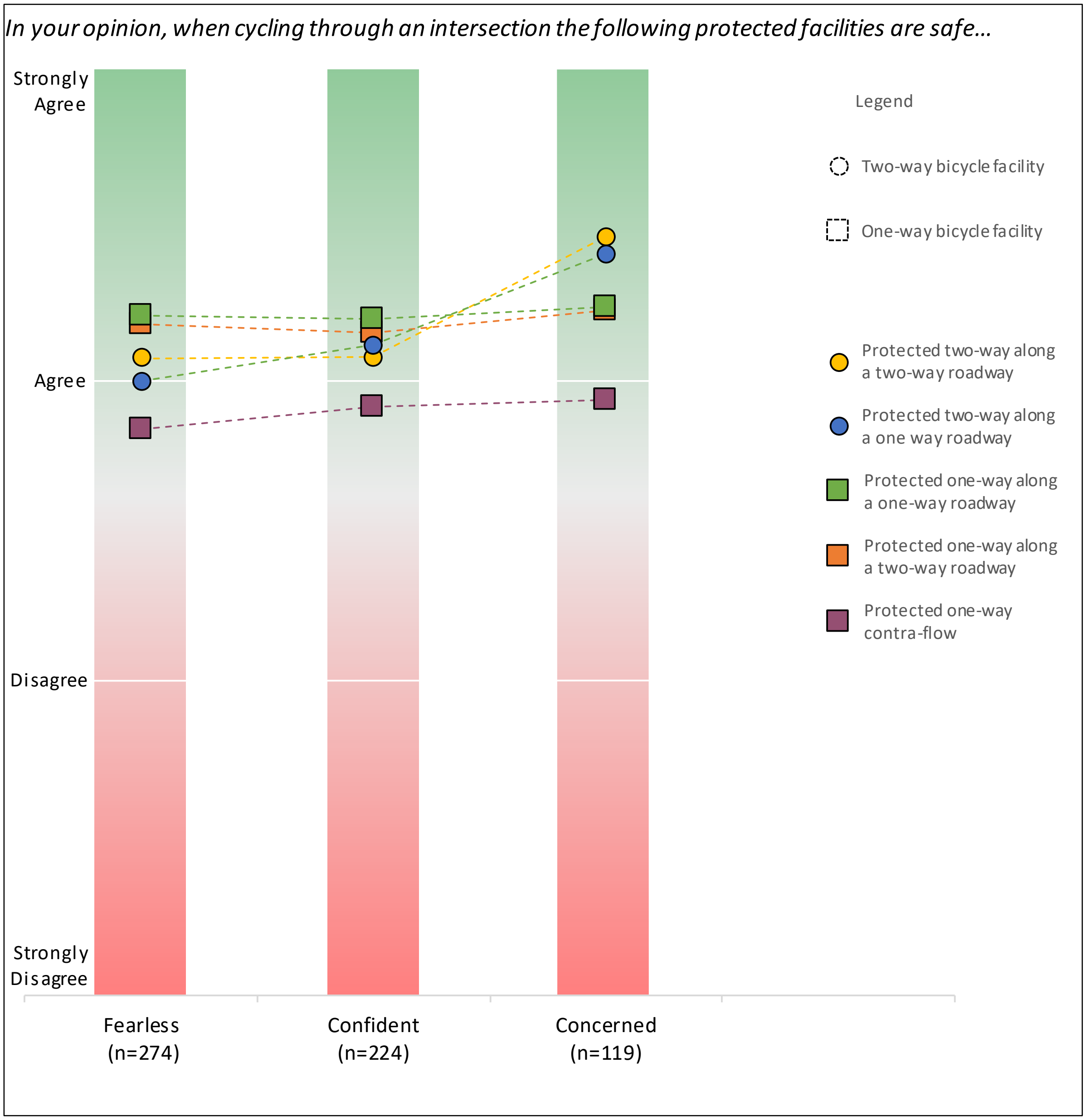
Figure B-17: Configurations of protected bicycle facilities at intersections



B.3.3.1 Bicyclist perception of facility safety

Figure B-18 shows how respondents perceive the safety of bicycling through intersections using the various configurations of protected bicycle facilities and roadways. Results indicate that fearless and confident bicyclists perceive one-way bicycle facilities to be safer than two-way bicycle facilities at intersections regardless of whether they are implemented along one-way or two-way roadways. Concerned bicyclists perceive the opposite, that two-way bicycle facilities are safer than one-way bicycle facilities at intersections. Contra-flow protected bicycle lanes are perceived to be the least safe configuration at intersections by all types of bicyclists.

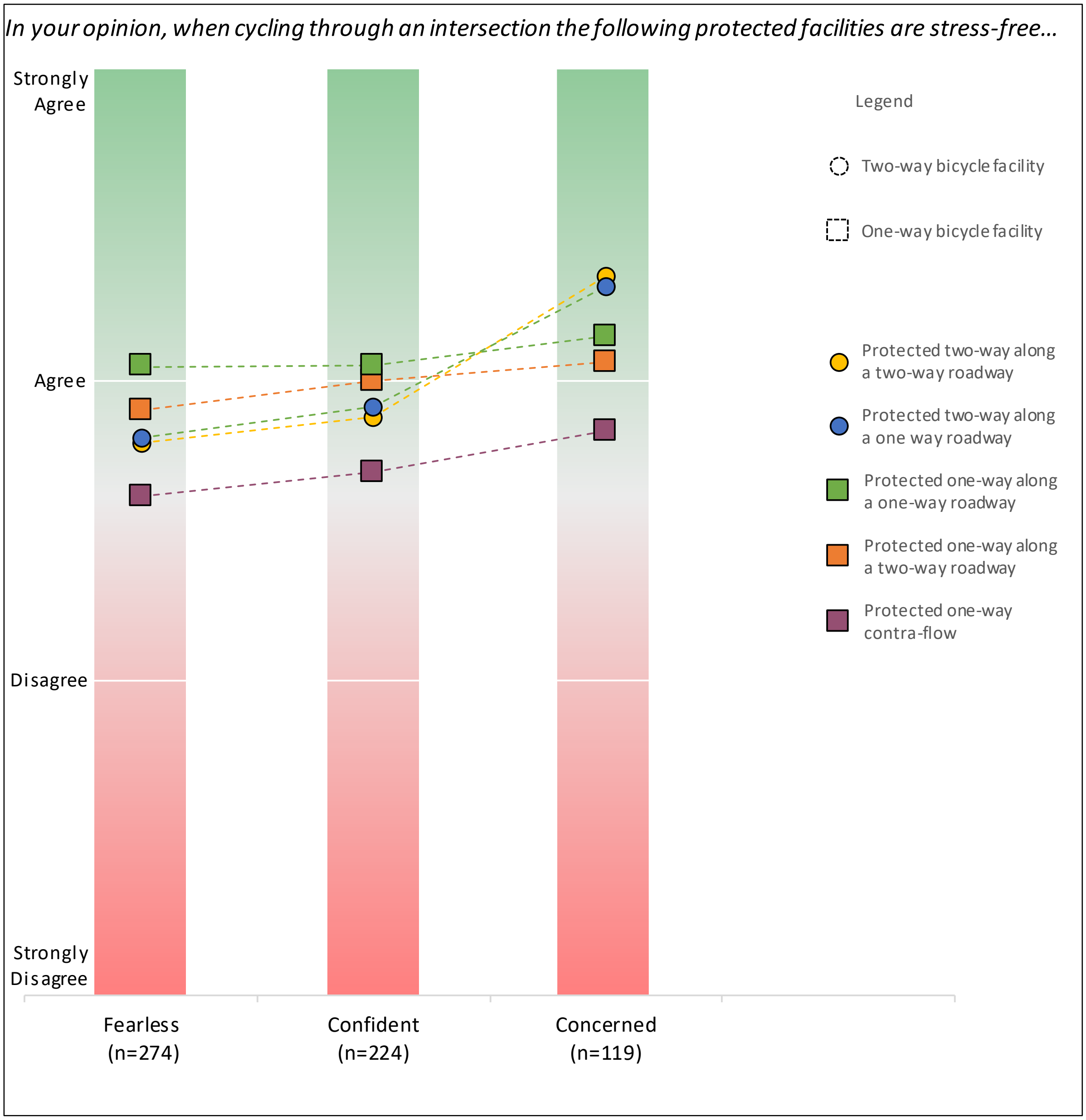
Figure B-18: Bicyclist perception of safety bicycling through intersections from protected bicycle facilities



B.3.3.2 Bicyclist perception of stress associated with riding through intersections

Figure B-19 shows how respondents perceive the stress associated with bicycling on protected bicycle facilities through intersections. Results are similar to those presented in the previous section regarding safety perception. Fearless and confident bicyclists perceive one-way protected bicycle lanes to be less stressful than two-way protected bicycle facilities, and concerned bicyclists perceive the opposite, that two-way protected bicycle lanes are less stressful than one-way protected bicycle facilities. Protected contra-flow lanes were identified by all users as being the most stressful to use when traveling through intersections.

Figure B-19: Bicyclist perception of stress associated with protected bicycle facilities when bicycling through intersections



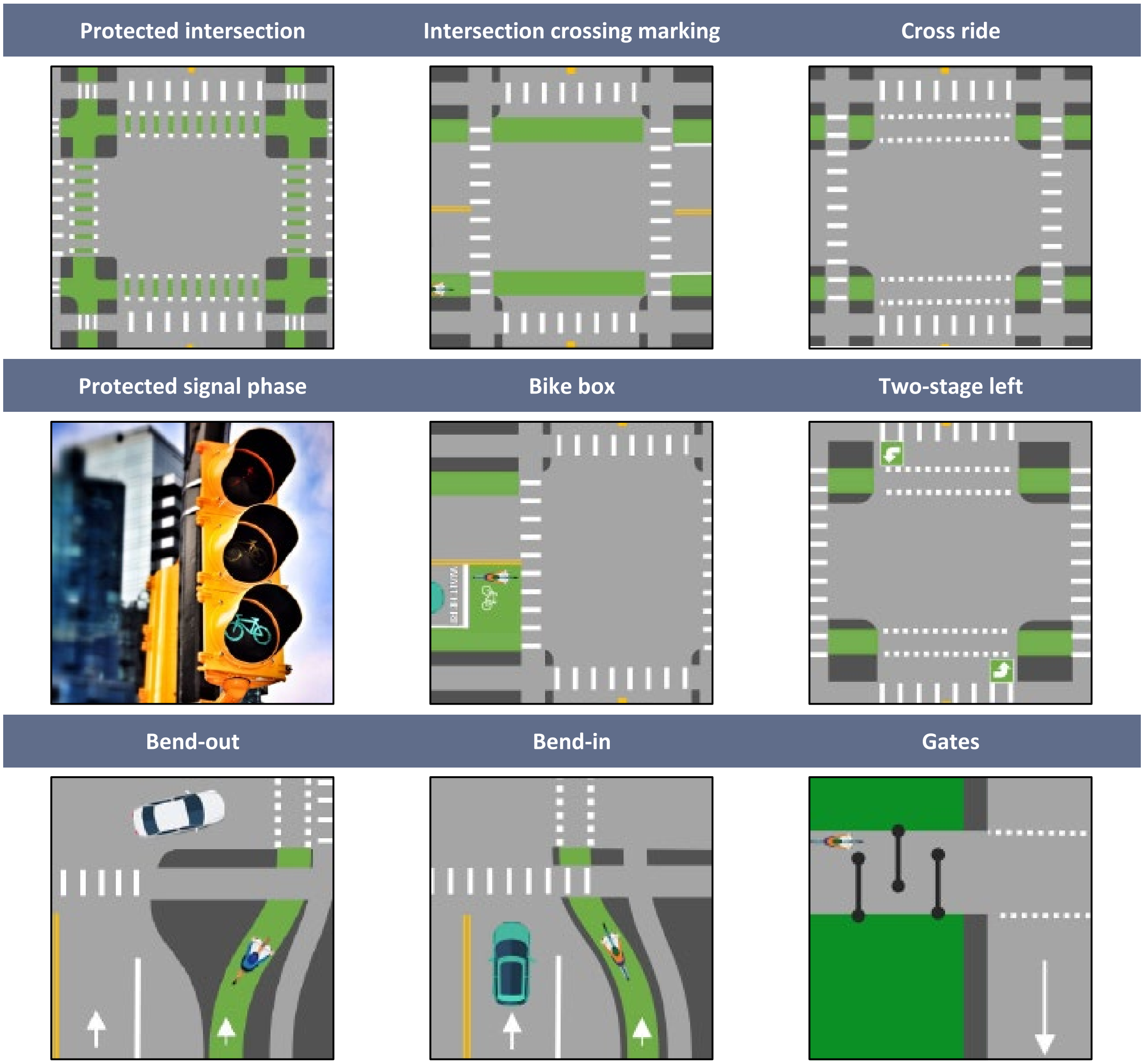
B.3.4 Bicycle intersection treatments

Survey respondents were asked to provide their opinion regarding the safety, ease-of-use and stress level associated with bicycling on various bicycle intersection treatments. Respondents addressed the following statements:

- In your opinion, these bicycle intersection treatments are *safe intersection treatments*.
- In your opinion, these bicycle intersection treatments are *easy to use.*
- In your opinion, these bicycle intersection treatments are *conducive to stress-free bicycling*.

Figure B-20 presents the bicycle intersection treatments that were included in the survey.

Figure B-20: Bicycle intersection treatments included in the survey



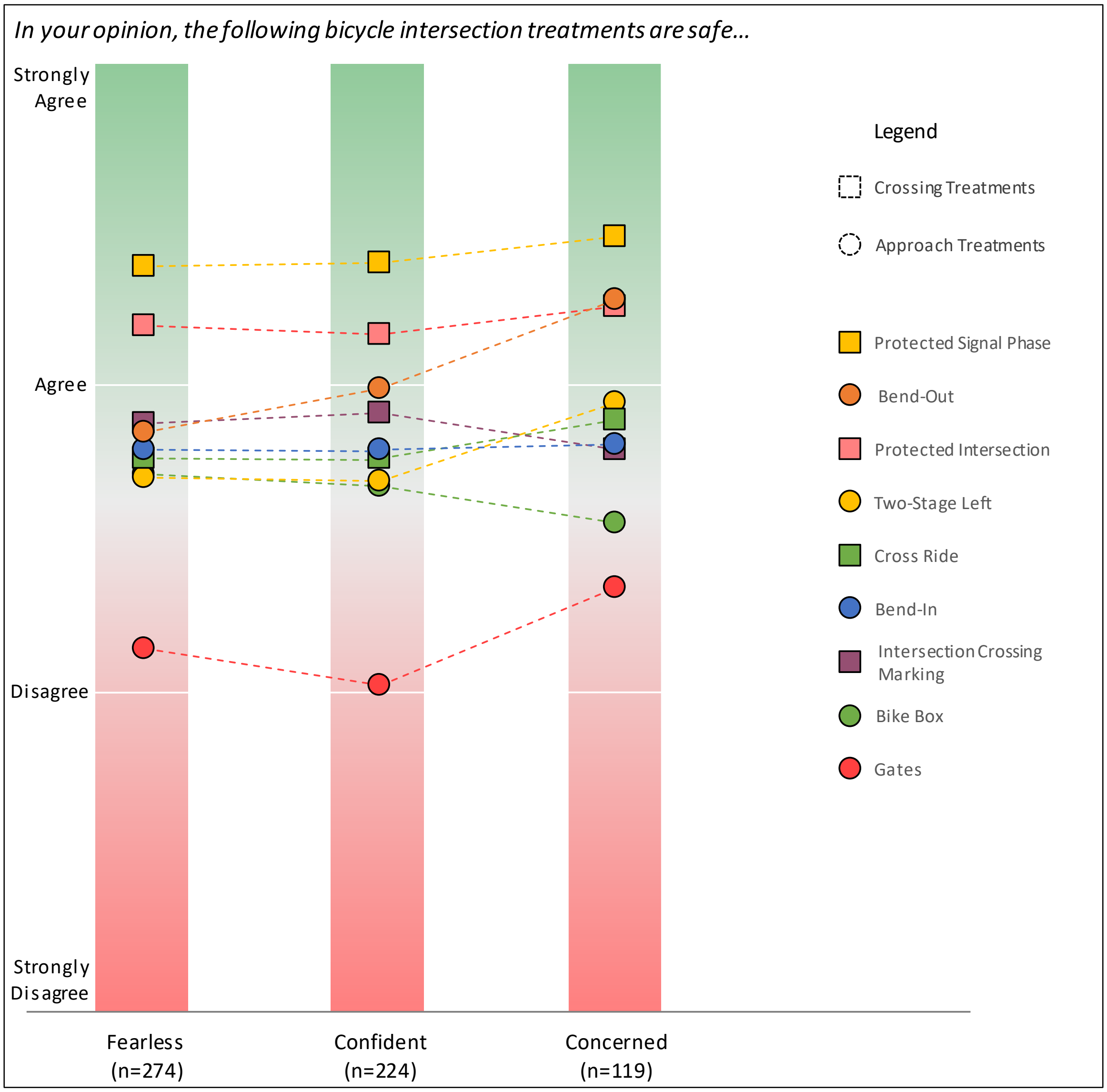
B.3.4.1 Bicyclist perceptions of intersection treatment safety

Figure B-21 shows how respondents perceive the safety of bicycle intersection treatments based on their self-identified bicyclist type. All bicycle intersection treatments, with the exception of gates, are perceived to be safe by respondents. Protected signal phases are perceived to be the safest followed by protected intersections. The perception of safety by fearless bicyclists is relatively consistent with confident bicyclists but not with concerned bicyclists.

In general, bend-out approaches are perceived to be much safer by concerned bicyclists than fearless and confident bicyclists. This may be attributed to the relatively small sample size of all bicyclist types that have used bend-out approach treatments, which may result in a more volatile result.

Bike boxes and two-stage left turn queues are both implemented to position bicyclists in front of vehicles at intersections to ensure that they are visible prior to entering conflict zones in the intersection. It is conceivable that these treatments may not be preferred by concerned bicyclists who prefer not to ride in vehicle lanes. However, while concerned bicyclist perceive bike boxes to be less safe than more confident bicyclists, they perceive two-stage lefts to be safer than more confident bicyclists. Further analysis reveals that two-stage lefts and bike boxes are perceived to be equally as safe when considering only concerned bicyclists who have experience bicycling on both treatments.

Figure B-21: Bicyclist perception of the safety of bicycle intersection treatments

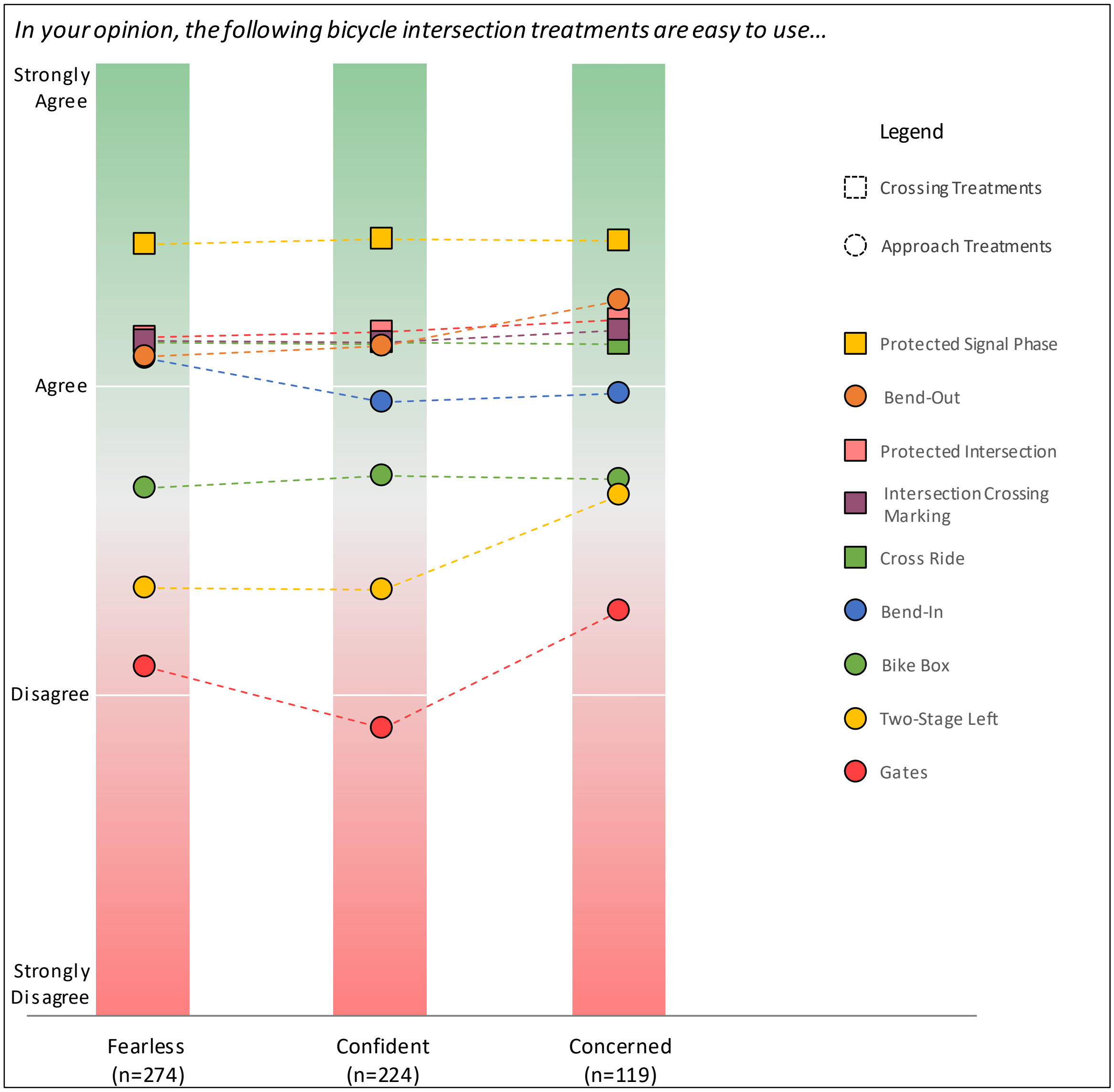


B.3.4.2 Bicyclist perceptions of intersection treatment ease-of-use

Figure B-22 shows how respondents perceive the ease-of-use of bicycle intersection treatments based on their self-identified bicyclist type. Protected signal phases are perceived to be the easiest treatment for all respondents to use. Fearless bicyclists perceive protected intersections, intersection crossing markings, cross-rides, bend-out approaches and bend-in approaches to be equally as easy to use. The same result is found for confident and concerned bicyclists excluding bend-in intersections which are perceived less easy to use. bike boxes, two-stage lefts and gates were the least favoured for ease-of-use by all respondents; two-stage lefts and gates were perceived to be difficult to use.

In general, for all bicyclist types, crossing treatments that provide guidance across the intersection or bicycle specific signal phases are perceived to be easier to use than approach treatments that position bicyclists prior to crossing. There is no consistent trend between the bicyclist types and bicycle infrastructure treatments which was observed for bicycle facilities.

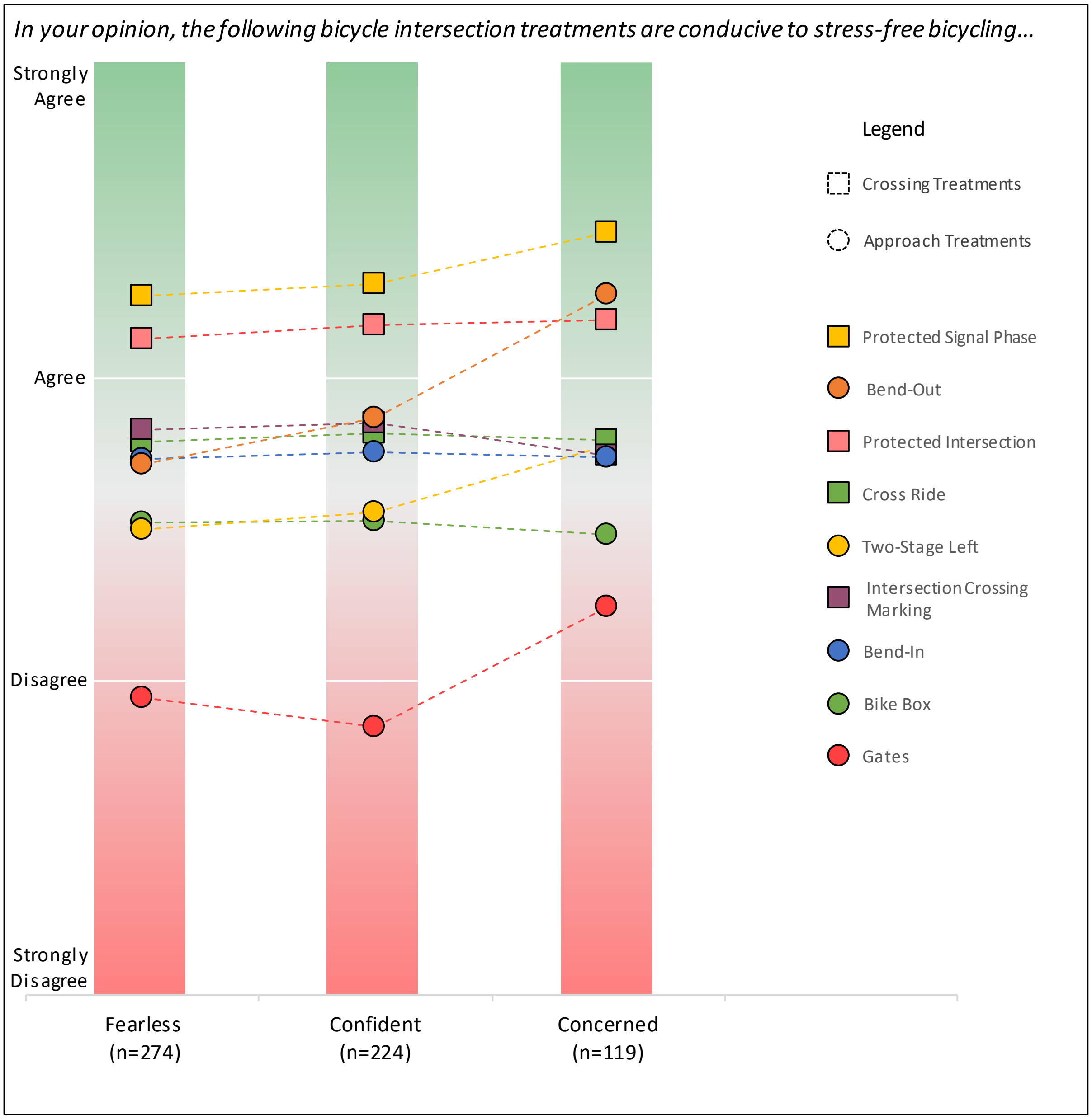
Figure B-22: Bicyclist perception of the ease-of-use of bicycle intersection treatments



B.3.4.3 Bicyclist perceptions of stress associated with different intersection treatments

Figure B-23 shows how respondents perceive bicycle intersection treatments to be conducive to stress-free bicycling based on their self-identified bicyclist type. Results are consistent with those found for the perception of safety presented in the previous section. Protected signal phases and protected intersections are perceived to be the least stressful and gates are perceived to be the most stressful to bicycle on.

Figure B-23: Bicyclist percept of stress-free bicycling through bicycle intersection treatments



B.3.5 Factors influencing bicycling safety perception

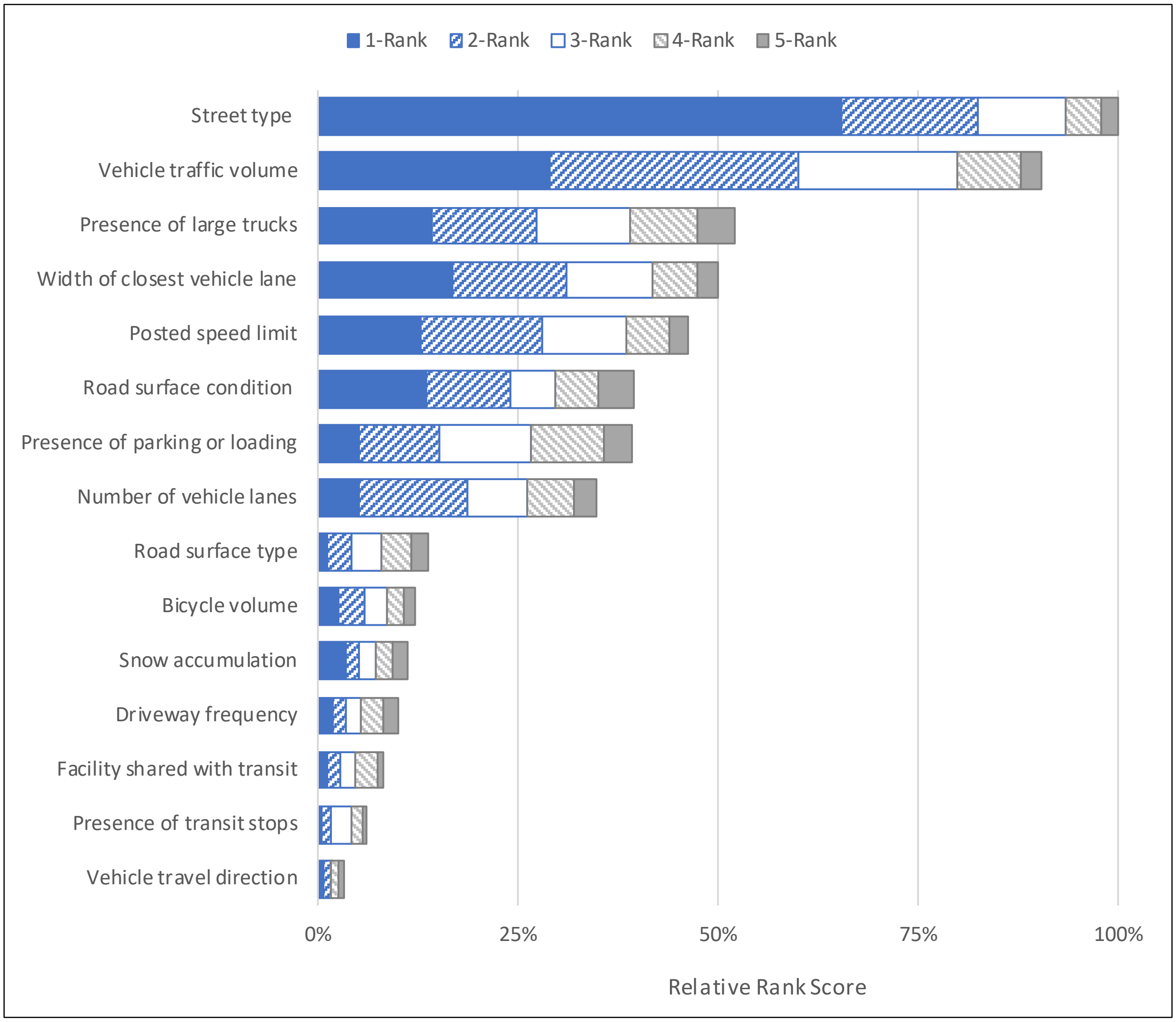
Survey respondents were asked to rank the top five factors that influence their feeling of safety while bicycling from a list of 13 factors provided in Figure B-24. A factor ranked as first by a respondent would receive five points, the second ranked factor would receive four points and so on, ending with the fifth-ranked factor receiving one point and the remaining factors receiving no points (i.e. rank-1 = 5 points; rank-2 = 4 points; rank-3 = 3 points; rank-4 = 2 points; rank-5 = 1 points). The points from each response were totalled for each factor to produce the rank-score and determine the relative rank of each factor. The relative rank of factors influencing respondents' perception of safe bicycling is shown in Figure B-24.

Results show that street type and vehicle traffic volume, which are closely related factors, are most significant in respondents' perception of safety while bicycling. After street type and vehicle traffic flow, a second group of factors with similar significance include the presence of large trucks, width of the closest vehicle travel lane, posted speed limit, road surface condition, presence of vehicle parking or loading along the roadway, and number of vehicle travel lanes. Posted speed limit and number of vehicle travel lane are often used to define street type. The presence of large trucks, width of closest vehicle lane, posted speed limit and presence of parking and loading are all related to the presence of vehicles but differ based on vehicle size (large trucks vs vehicle) and vehicle speed (moving vs stationary).

Vehicular traffic volume, posted speed limit, presence of parking or loading, and number of vehicle travel lanes are common factors that influence bicyclist safety perception and are often used to define street type or roadway classification. This underscores the importance of well-defined street types and the potential impact of diverse street types definitions between jurisdictions when applying a bicycle facility implementation tool nation-wide. The high rank-score of vehicle traffic volumes suggests that, of the factors that define street type, vehicle traffic volume has the largest influence on bicyclists' perception of safety. As a result, the vehicle traffic volume ranges that define street type should be considered with care and may need to be considered in finer detail when deciding what bicycle facilities to implement.

The remaining seven factors all scored less than 15% compared to the highest-ranking factor, street type. These factors include road surface condition, bicycle volume, snow accumulation, driveway frequency, facility shared with transit, presence of transit stops, and vehicle direction of travel. The low score of transit related factors is not supported by the high score of the presence of large trucks, given that transit vehicles can be considered as large vehicles. Snow accumulation was identified as rank-1 the most often amongst the bottom seven factors; there is a potential bias reducing the rank-score of the snow accumulation factor because only about 50% of respondents indicated that they bicycle in winter months and may have only considered factors that influence their perception of safety in other seasons.

Figure B-24: Relative rank-score of factors influencing bicyclist perception of safety



B.3.6 Moving Forward

The objective of the end user survey was to investigate how the bicycling community and different types of bicyclists define safety and the perceived safety performance of different bicycling infrastructure. The survey was administered through on-line survey software and distributed to 38 bicycling organizations across Canada, who were asked to distribute the survey to their membership. A total of 625 responses were received from across the country.

Survey respondents were categorized by their self-assessed bicyclist type as strong and fearless (fearless), enthused and confident (confident), and interested but concerned (concerned). Each bicyclist type was defined by respondent characteristics that include demographics, bicycling trip characteristics, and bicycling safety characteristics to provide a deeper understanding of who comprises each type. The analysis presents findings about the perceived safety, ease-of-use and stress associated with using different bicycle facilities. In addition, the analysis also identifies factors that influence respondents' perception of safety.

The end user survey results can be used as a check against the facility/treatment selection flowchart to identify whether flowchart decision points and selection outcomes align with end user perceptions of safe facilities and treatments. The intent of implementing bicycle infrastructure is to increase the number of bicyclists in a safe manner, thus it is important to consider the safety perception of bicyclists in addition to the actual safety performance of infrastructure to ensure both intentions are met.

B.4 Mature end user survey questionnaire

Thank you for taking time to complete this survey!

A Transportation Association of Canada project is currently underway assessing present and future safety performance of bicycle infrastructure in Canada. As part of this project, we are asking bicycle users to complete this survey to understand how they perceive the safety of the various bicycle facilities being implemented across Canada.

This survey is a very important piece of the overall project and your willingness to dedicate time to this task and represent your community in this discussion is very much appreciated. It will take you about 30 minutes to complete the survey.

We appreciate your contribution.

1. What is your gender?
   - Female
   - Male
   - Non-Binary

2. What is your age?
   - 16-19
   - 20-24
   - 25-34
   - 35-44
   - 45-54
   - 55-64
   - 65-74
   - 75+

3. Where do you live? (e.g., Oakville, Winnipeg, Yorktown)?

4. In what seasons do you bicycle? Check all that apply.
   - Winter
   - Spring
   - Summer
   - Fall

5. In the last year, during months **WITHOUT** snow on the ground, how often have you bicycled on average?
   - Daily
   - 4-6 days per week
   - 1-3 days per week
   - A couple days per month
   - Never

6. In the last year, during months **WITH** snow on the ground, how often have you bicycled on average?
   - Daily
   - 4-6 days per week
   - 1-3 days per week
   - A couple days per month
   - Never

7. What is the main reason that you bicycle?
   - To commute to work or school
   - For exercise and recreation
   - To run errands and other activities (e.g., shopping, socializing)
   - Other, please explain

8. What land-use environment do you most commonly bicycle in?
   - Urban
   - Suburban
   - Rural

9. How important are each one of these factors in your decision to ride a bicycle?

	Very important	Important	Unimportant
Health reasons			
Cycling is economical			
Travel time predictability			
Cycling is fun			
Cycling is encouraged at work/school			
Bicycling infrastructure			
Enter another option			

10. Do you wear a helmet when you ride your bicycle?

- Always
- Sometimes
- Never

11. If required by the presence of a sign, would you dismount your bicycle when crossing a roadway...

	Always	Sometimes	Never
At a 4-way stop intersection?	○	○	○
At a signed and marked crosswalk?	○	○	○
At a push-button activated crosswalk?	○	○	○
At a traffic signal controlled intersection?	○	○	○

12. Have you been involved in any of the following collision types while bicycling in the last 10 years? Select all that apply.

- ☐ Collision with a vehicle
- ☐ Collision with a bicycle
- ☐ Collision with a pedestrian
- ☐ Collision with roadway elements (e.g., curb, pothole)
- ☐ I haven't been involved in a collision in the last 10 years

13. How would you describe yourself as a cyclist? Choose one.

- **Strong and Fearless** (extremely confident): You are willing to ride a bicycle on any roadway with limited or no bicycle-specific infrastructure.
- **Enthused and Confident** (very confident): You are confident riding a bicycle if some bicycle-specific infrastructure is in place.
- **Interested but Concerned** (moderately confident): You are more cautious but willing to ride a bicycle on major streets if high-quality bicycle infrastructure is in place. Prefer separated pathways or low traffic neighborhood streets.

14. How bicycle-friendly is your jurisdiction in terms of infrastructure for each type of cyclist listed in Question 13?

	Not at all bicycle-friendly	Moderately bicycle-friendly	Very bicycle-friendly	Extremely bicycle-friendly
Strong and Fearless (extremely confident)	○	○	○	○
Enthused and Confident (very confident)	○	○	○	○
Interested but Concerned (moderately confident)	○	○	○	○

Questions 15-27:
For each applicable facility type shown, please select the description that best fits your perception of the facility when you've bicycled on it.

Residential Streets

15. Have you ridden a bicycle on a residential street?

- Yes
- No

16. **In your opinion, residential streets are...**

	Strongly Disagree	Disagree	Agree	Strongly Agree
Easy to use	○	○	○	○
Safe while riding between intersections	○	○	○	○
Stress-free to ride along	○	○	○	○

Residential Collector Streets

17. Have you ridden a bicycle on a residential collector street?

- Yes
- No

18. **In your opinion, residential collector streets are...**

	Strongly Disagree	Disagree	Agree	Strongly Agree
Easy to use	○	○	○	○
Safe while riding between intersections	○	○	○	○
Stress-free to ride along	○	○	○	○

Arterial Streets

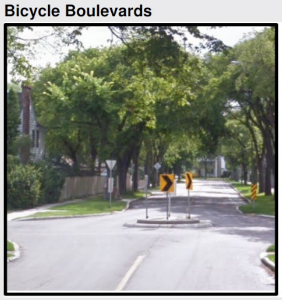
19. Have you ridden a bicycle on an arterial street?

- Yes
- No

20. **In your opinion, arterial streets are...**

	Strongly Disagree	Disagree	Agree	Strongly Agree
Easy to use				
Safe while riding between intersections				
Stress-free to ride along				

Bicycle Boulevards



Bicycle Boulevards: Often located on local roads, bicycle boulevards incorporate traffic calming measures to facilitate through access by bicycles while inhibiting through access by motor vehicles

21. Have you ridden a bicycle on a bicycle boulevard?

- Yes
- No

22. **In your opinion, bicycle boulevards are...**

	Strongly Disagree	Disagree	Agree	Strongly Agree
Easy to use				
Safe while riding between intersections				
Stress-free to ride along				

Advisory Bike Lanes

Advisory Bike Lanes: Advisory bike lanes run on both sides of a single, bi-directional, vehicle travel lane. They are marked by a dashed line which permits opposing motor vehicles to enter the advisory bike lane temporarily when safe to do so to pass a vehicle moving in the opposite direction.

23. Have you ridden a bicycle on an advisory bike lane?

- Yes
- No

24. **In your opinion, advisory bike lanes are...**

	Strongly Disagree	Disagree	Agree	Strongly Agree
Easy to use				
Safe while riding between intersections				
Stress-free to ride along				

Sharrows on Major Streets

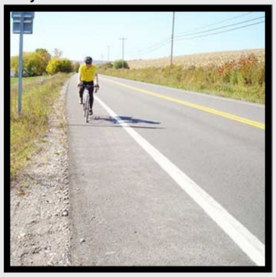
25. Have you ridden a bicycle on a sharrow on a major street?

- Yes
- No

26. **In your opinion, sharrows on major streets are...**

	Strongly Disagree	Disagree	Agree	Strongly Agree
Easy to use				
Safe while riding between intersections				
Stress-free to ride along				

Bicycle Accessible Shoulders



27. Have you ridden a bicycle on a bicycle accessible shoulder?

- ○ Yes
- ○ No

28. **In your opinion, bicycle accessible shoulders are...**

	Strongly Disagree	Disagree	Agree	Strongly Agree
Easy to use	○	○	○	○
Safe while riding between intersections	○	○	○	○
Stress-free to ride along	○	○	○	○

Painted Bicycle Lanes

29. Have you ridden a bicycle on a painted bicycle lane?

- ○ Yes
- ○ No

30. **In your opinion, painted bicycle lanes are...**

	Strongly Disagree	Disagree	Agree	Strongly Agree
Easy to use	○	○	○	○
Safe while riding between intersections	○	○	○	○
Stress-free to ride along	○	○	○	○

Buffered Bicycle Lanes

Buffered Bicycle Lanes: A buffered bicycle lane is marked primarily with white pavement markings running parallel to the roadway, that act as a buffer to increase the separation between bicyclists and adjacent motor vehicles.

31. Have you ridden a bicycle on a buffered bicycle lane?

- ○ Yes
- ○ No

32. **In your opinion, buffered bicycle lanes are...**

	Strongly Disagree	Disagree	Agree	Strongly Agree
Easy to use	○	○	○	○
Safe while riding between intersections	○	○	○	○
Stress-free to ride along	○	○	○	○

Uni-Directional Protected Bicycle Lanes or Cycle Tracks

Protected bicycle lanes or cycle tracks: A protected bicycle lane is an on-road bicycle lane separated from motor vehicle traffic by a physical element, such as a curb.

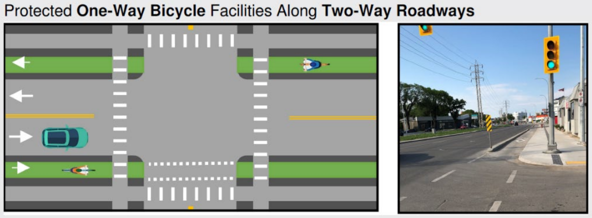
33. Have you ridden a bicycle on a uni-directional protected bicycle lane or cycle track?

- ○ Yes
- ○ No

34. **In your opinion, uni-directional protected bicycle lanes or cycle tracks are...**

	Strongly Disagree	Disagree	Agree	Strongly Agree
Easy to use	○	○	○	○
Safe while riding between intersections	○	○	○	○
Stress-free to ride along	○	○	○	○

Protected **One-Way Bicycle** Facilities Along **Two-Way Roadways**



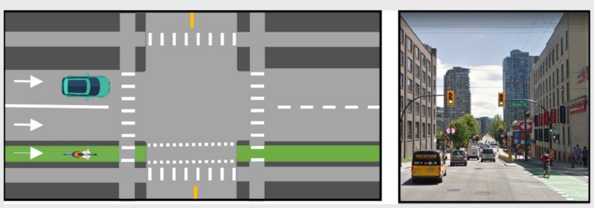
35. Have you ridden a bicycle on a protected one-way bicycle facility along a two-way roadway?

- Yes
- No

36. When bicycling straight through an intersection on protected one-way bicycle facilities along two-way roadways, I feel...

	Strongly Disagree	Disagree	Agree	Strongly Agree
Safe				
Stress-free				

Protected **One-Way Bicycle** Facilities Along **One-Way Roadways**



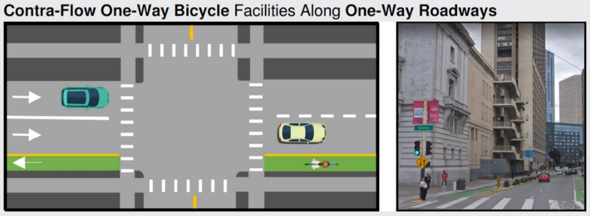
37. Have you ridden a bicycle on a protected one-way bicycle facility along a one-way roadway?

- Yes
- No

38. When bicycling straight through an intersection on protected one-way bicycle facilities along one-way roadways, I feel...

	Strongly Disagree	Disagree	Agree	Strongly Agree
Safe				
Stress-free				

Contra-Flow One-Way Bicycle Facilities Along **One-Way Roadways**



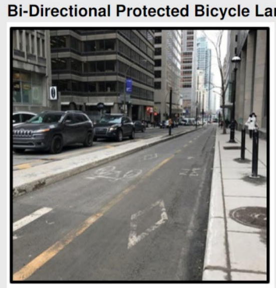
39. Have you ridden a bicycled on a contra-flow one-way bicycle facility along a one-way roadway?

- Yes
- No

40. When bicycling straight through an intersection on contra-flow one-way bicycle facilities along one-way roadways, I feel...

	Strongly Disagree	Disagree	Agree	Strongly Agree
Safe				
Stress-free				

Bi-Directional Protected Bicycle Lanes or Cycle Tracks



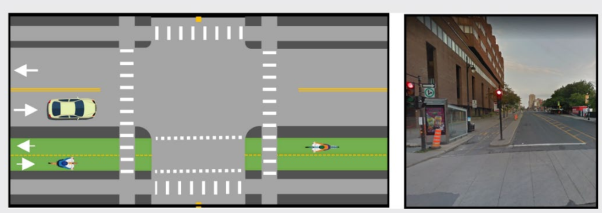
41. Have you ridden a bicycle on a bi-direction protected bicycle lane or cycle track?

- Yes
- No

42. **In your opinion, bi-directional protected bicycle lanes or cycle tracks are...**

	Strongly Disagree	Disagree	Agree	Strongly Agree
Easy to use				
Safe while riding between intersections				
Stress-free to ride along				

Protected **Two-Way Bicycle** Facilities Along **Two-Way Roadways**



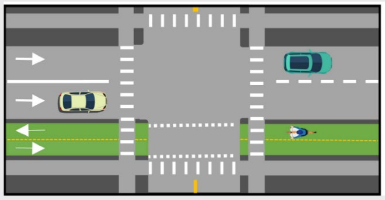
43. Have you ridden a bicycle on a protected two-way bicycle facilities along a two-way roadway?

- Yes
- No

44. When bicycling straight through an intersection on protected two-way bicycle facilities along two-way roadways, I feel...

	Strongly Disagree	Disagree	Agree	Strongly Agree
Safe	○	○	○	○
Stress-free	○	○	○	○

Protected **Two-Way Bicycle** Facilities Along **One-Way Roadways**




45. Have you ridden a bicycle on a protected two-way bicycle facility along a one-way roadway?

○ Yes

○ No

46. When bicycling straight through an intersection on protected two-way bicycle facilities along one-way roadways, I feel...

	Strongly Disagree	Disagree	Agree	Strongly Agree
Safe	○	○	○	○
Stress-free	○	○	○	○

Off-Road Multi-Use Pathways

47. Have you ridden a bicycle on an off-road multi-use (pedestrians and bicycles allowed) pathway?

○ Yes

○ No

48. **Off-road multi-use pathways are...**

	Strongly Disagree	Disagree	Agree	Strongly Agree
Easy to use	○	○	○	○
Safe while riding between intersections	○	○	○	○
Stress-free to ride along	○	○	○	○

Off-Road Bicycle Pathways

49. Have you ridden a bicycle on an off-road bicycle (bicycles only) pathway?

○ Yes

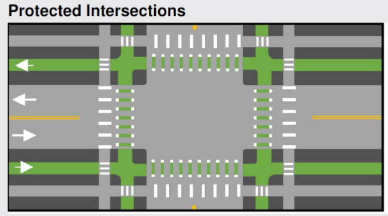
○ No

50. **Off-road bicycle pathways are...**

	Strongly Disagree	Disagree	Agree	Strongly Agree
Easy to use	○	○	○	○
Safe while riding between intersections	○	○	○	○
Stress-free to ride along	○	○	○	○

Questions 28-36:
For each intersection treatment type shown, please select the description that best fits your perception of the treatment when you've used it as a cyclist.
Note: Assume all vehicle and cycling movements are allowed at the intersection.

Protected Intersections




51. Have you ridden a bicycle through a protected intersection?

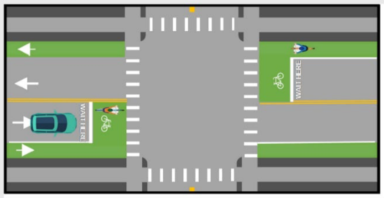
○ Yes

○ No

52. **Protected Intersections are...**

	Strongly Disagree	Disagree	Agree	Strongly Agree
Easy to use	○	○	○	○
Safe intersection treatments	○	○	○	○
Conducive to stress-free cycling	○	○	○	○

Bike Boxes



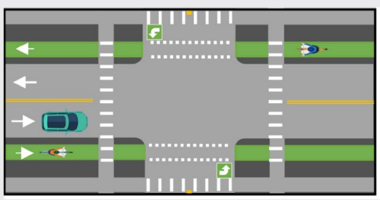

53. Have you ridden a bicycle through an intersection with a bike box?

- Yes
- No

54. **Bike Boxes are...**

	Strongly Disagree	Disagree	Agree	Strongly Agree
Easy to use				
Safe intersection treatments				
Conducive to stress-free cycling				

Two-Stage Turn Queue Boxes



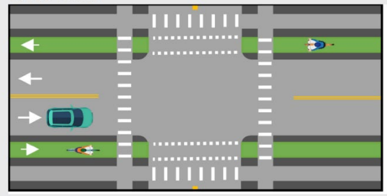

55. Have you ridden a bicycle through an intersection with a two-stage turn queue box?

- Yes
- No

56. **Two Stage Turn Queue Boxes are...**

	Strongly Disagree	Disagree	Agree	Strongly Agree
Easy to use				
Safe intersection treatments				
Conducive to stress-free cycling				

Cross Rides



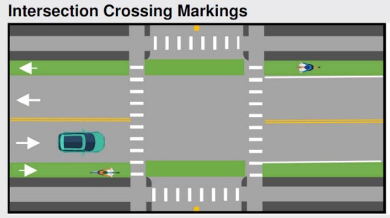

57. Have you ridden a bicycle through an intersection with a cross ride?

- Yes
- No

58. **Cross Rides are...**

	Strongly Disagree	Disagree	Agree	Strongly Agree
Easy to use				
Safe intersection treatments				
Conducive to stress-free cycling				

Intersection Crossing Markings



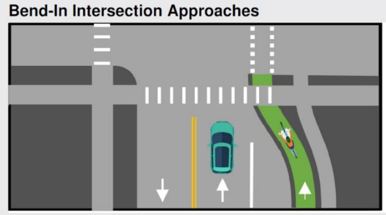
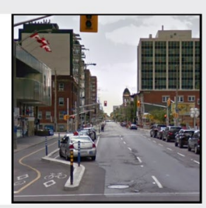

59. Have you ridden a bicycle through an intersection with intersection crossing markings?

- Yes
- No

60. **Intersection Crossing Markings are...**

	Strongly Disagree	Disagree	Agree	Strongly Agree
Easy to use				
Safe intersection treatments				
Conducive to stress-free cycling				

Bend-In Intersection Approaches

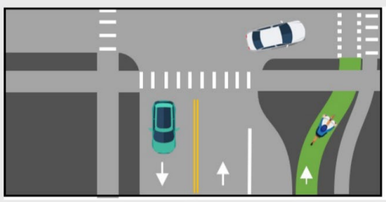
61. Have you ridden a bicycle through an intersection with a bend-in intersection approach?

- Yes
- No

62. **Bend-in Intersection Approaches are...**

	Strongly Disagree	Disagree	Agree	Strongly Agree
Easy to use				
Safe intersection treatments				
Conducive to stress-free cycling				

Bend-Out Intersection Approaches



63. Have you ridden a bicycle through an intersection with a bend-out intersection approach?

- Yes
- No

64. **Bend-out Intersection Approaches are...**

	Strongly Disagree	Disagree	Agree	Strongly Agree
Easy to use				
Safe intersection treatments				
Conducive to stress-free cycling				

Protected Signal Phases (Bicycle Signals)

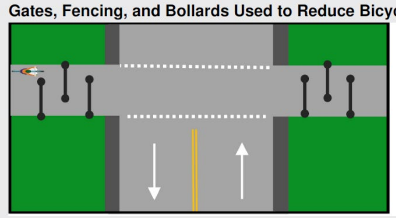
65. Have you ridden a bicycle through an intersection with a protected signal phase (bicycle signal)?

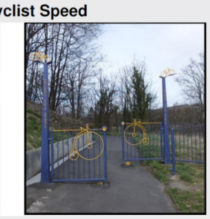
- Yes
- No

66. **Protected Signal Phases (Bike Signals) are...**

	Strongly Disagree	Disagree	Agree	Strongly Agree
Easy to use				
Safe intersection treatments				
Conducive to stress-free cycling				

Gates, Fencing, and Bollards Used to Reduce Bicyclist Speed





67. Have you ridden a bicycle through an intersection with gates, fencing, or bollards used to reduce bicyclist speed?

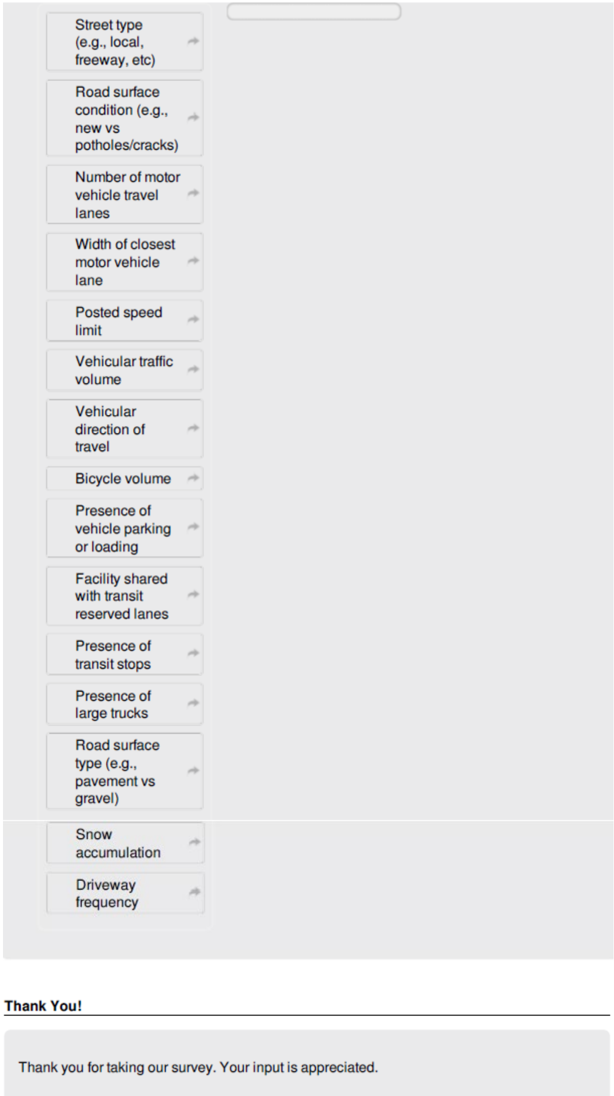
- Yes
- No

68. **Gates, Fencing, and Bollards use to reduce bicyclist speed are...**

	Strongly Disagree	Disagree	Agree	Strongly Agree
Easy to use				
Safe intersection treatments				
Conducive to stress-free cycling				

69. Based on your opinion, select and rank the 5 most significant factors influencing your feeling of safety while bicycling (1 being the most significant).

Drag items from the left-hand list into the right-hand list to order them.



Street type (e.g., local, freeway, etc)

Road surface condition (e.g., new vs potholes/cracks)

Number of motor vehicle travel lanes

Width of closest motor vehicle lane

Posted speed limit

Vehicular traffic volume

Vehicular direction of travel

Bicycle volume

Presence of vehicle parking or loading

Facility shared with transit reserved lanes

Presence of transit stops

Presence of large trucks

Road surface type (e.g., pavement vs gravel)

Snow accumulation

Driveway frequency

Thank You!

Thank you for taking our survey. Your input is appreciated.

B.5 Youth end user survey methodology

The purpose of this survey was to investigate opinions of youth (school children in grades 7, 8 and 9) with respect to perception of safety and comfort when riding their bicycles. The intent of this survey was to augment the information collected from the end user survey and apply it in the development of the flow chart and gap analysis for this project.

The survey questions were developed by the project team and reviewed by the PSC. A copy of the final survey is provided in Section B.7. Once the survey content was finalized it was published using SurveyGizmo online survey software and distributed to 360 schools in Manitoba in January 2019. These schools were identified as housing Grade 7, 8, or 9 students and for which contact information was available.

A request was sent out to all school principals in advance of sending the survey, asking them for their willingness to assist with the survey distribution to parents of children in these grades. Once they had agreed to participate, a link to the survey was sent to these principals for distribution to parents. Survey responses were directly received by MORR from students who participated in the survey.

One limitation of this survey is its geographic coverage, having been sent only to schools in Manitoba. However, given the time and budget limitations of the project, it was agreed by PSC members that although limited in scope, the findings from this survey could still provide some insight into the safety and comfort perception of children in this age group, particularly given the observed lack of youth participants in the end user survey. Another limitation of the survey is that it was not translated into French, therefore, only English-speaking schools participated.

B.6 Youth end user survey analysis and discussion

A total of 86 children responded to the survey from across Manitoba. The following discussion summarizes survey findings based on the following: (1) respondent characteristics; (2) reasons for bicycling and barriers encountered; and (3) perception of safety and comfort by children when riding their bicycles.

B.6.1 Respondent characteristics

Of the 86 children that responded to the survey, 58% were boys and 42% were girls. Figure B-25 shows the distribution of participants based on the school grade they attend. Most of the children who ride a bicycle, do it often – nearly daily during non-winter months, as shown in Figure B-26.

Figure B-25: Distribution of survey participants by school grade

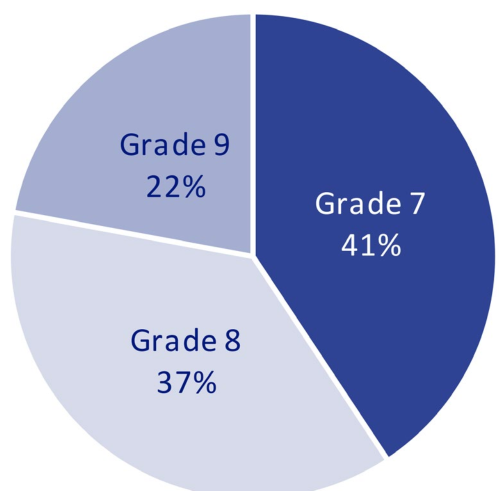
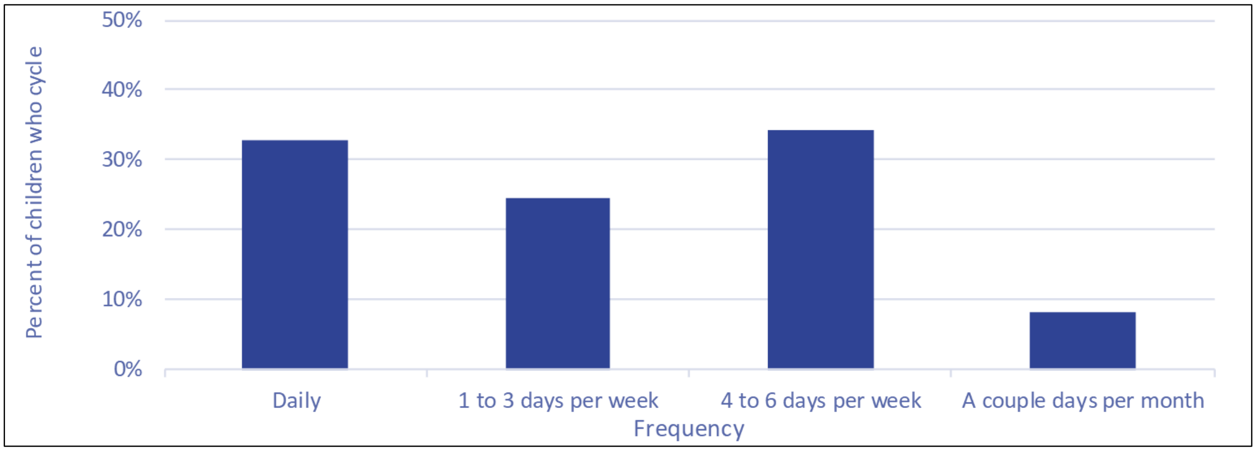


Figure B-26: Bicycling frequency



B.6.2 Reasons for bicycling and barriers encountered

Nearly all survey participants (80%) indicated that they ride unaccompanied by an adult, 15% indicated that they do not ride their bicycles at all, and the remaining 5% stated that they ride their bicycle only when accompanied by an adult. For the children who ride their bicycle, Figure B-27 shows the reasons provided by them. As the figure illustrates, the main reasons children cited for riding their bicycle are for fun or to spend time with friends. Some children also use their bicycle to go to school.

Figure B-28 shows the reasons given by participants who do not ride their bicycles or who only ride accompanied by an adult. As the figure illustrates, the main reasons provided by those who do not ride at all, include too many vehicles on the road, vehicles traveling fast, or simply not interested. The children who only ride accompanied by an adult also cited the first two issues, as well as lack of adequate infrastructure.

Figure B-27: Reasons for riding a bicycle

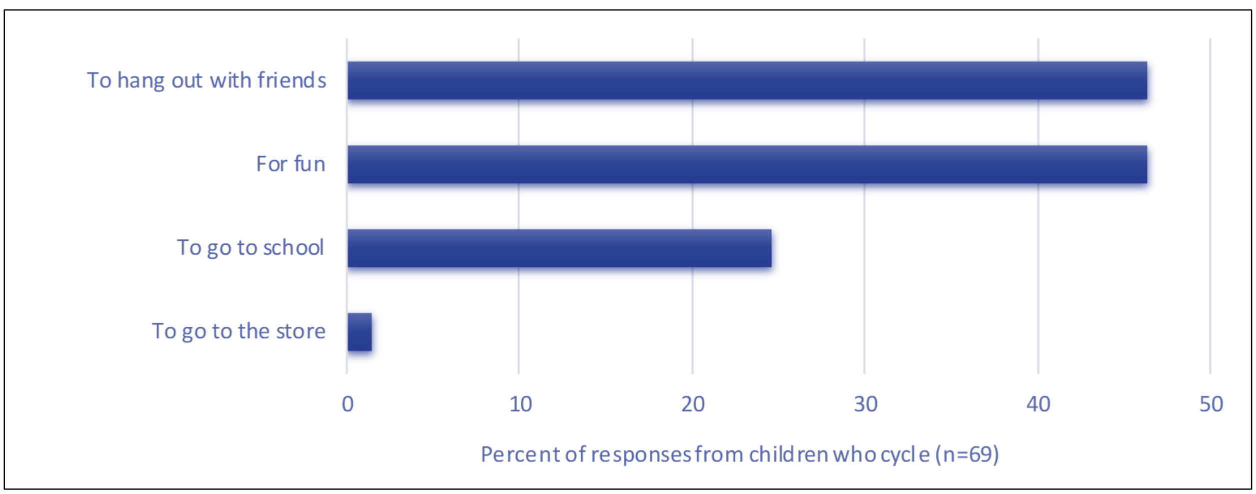
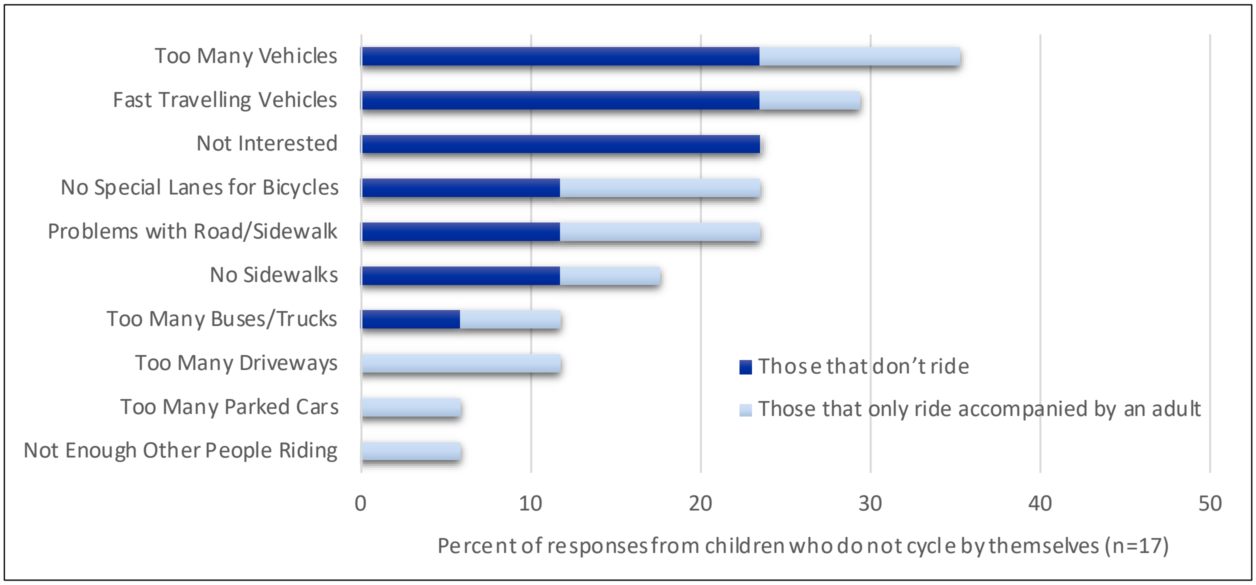


Figure B-28: Barriers to bicycling



B.6.3 Perception of safety and comfort

Children were asked where they like to ride their bicycle and why. Figure B-29 shows that about 35% of children prefer to ride on the sidewalk. The main reasons provided for this are that they feel safe or they feel comfortable riding there. The second most common place where children like to ride their bicycle (nearly as commonly cited as riding on the sidewalk) is on the road, even if there is no special bicycle lane. In this case, however, safety was not identified as one of the main reasons but rather, they expressed that they find it comfortable to ride there, they can go fast, and they can ride with their friends. Approximately 28% of children expressed that they prefer to ride their bicycles on the road but only on quiet streets. In this case, safety and comfort were about equally weighed for making this choice.

There are clear differences, however, between boys and girls with respect to where they like to ride their bicycle. These differences can be seen in Figure B-30 and Figure B-31. Over one-half of girls prefer to ride their bicycle on the sidewalk, compared to less than one-quarter of boys. Girls cited safety and comfort as the main reasons they selected this option. Boys prefer to ride their bicycle on the road, even if there is no special bicycle lane. Key reasons cited were comfort and being able to ride with friends. Nearly one-third of boys also indicated that they like riding their bicycle on quiet streets, compared to about one-quarter of girls.

Children were also asked how they feel when approaching a busy, signalized intersection. As Figure B-32 shows, most children feel somewhat safe (one-third of children) when approaching this type of intersection. Approximately one-half feel somewhat unsafe or very unsafe, and 16% feel very safe.

The approach children take when they arrive at an intersection depends on whether it is a busy, signalized intersection or a quiet, stop-controlled intersection. As Figure B-33 illustrates, most children get off their bicycle and walk across busy signalized intersections, while stop-controlled intersections are treated differently. At these locations, children reported to just slow down and ride through the intersection if it was safe to do so. The figure also shows that over 20% of children responding to the survey indicated that they only slow down and ride through busy, signalized intersections if it is safe to do so. The ‘other’ behaviour cited by children when approaching an intersection was to follow the signals and ride through when it is safe to do so.

The last question in the survey asked about the most important factors that make children feel safe while bicycling. Figure B-34 shows that, regardless of gender, the issues that were most commonly cited by children as inducing a feeling of safety when riding a bicycle are:

- Low traffic volumes
- Riding in their own neighbourhood
- Riding on the sidewalk
- Low bus and truck volumes

In all cases, except for riding in their own neighbourhood, more girls than boys identified those as the key issues that make them feel safe when riding a bicycle. One difference between boys and girls (although in very low numbers) is that boys feel safer when there are parked vehicles on the road, while girls feel safer where there are not too many driveways.

Figure B-29: Preferred infrastructure for bicycle riding (boys and girls combined)

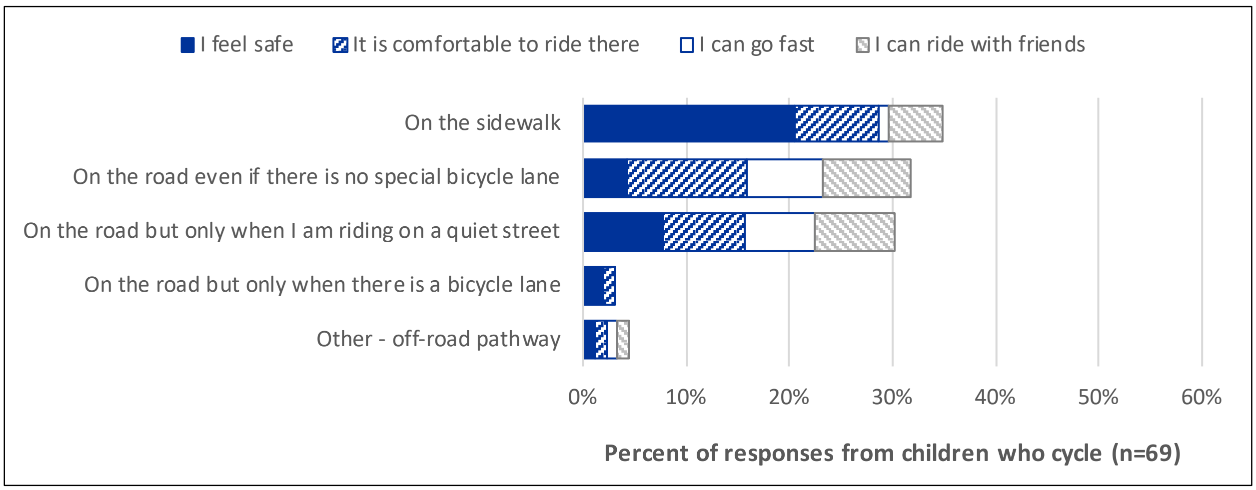


Figure B-30: Preferred infrastructure for bicycle riding by boys

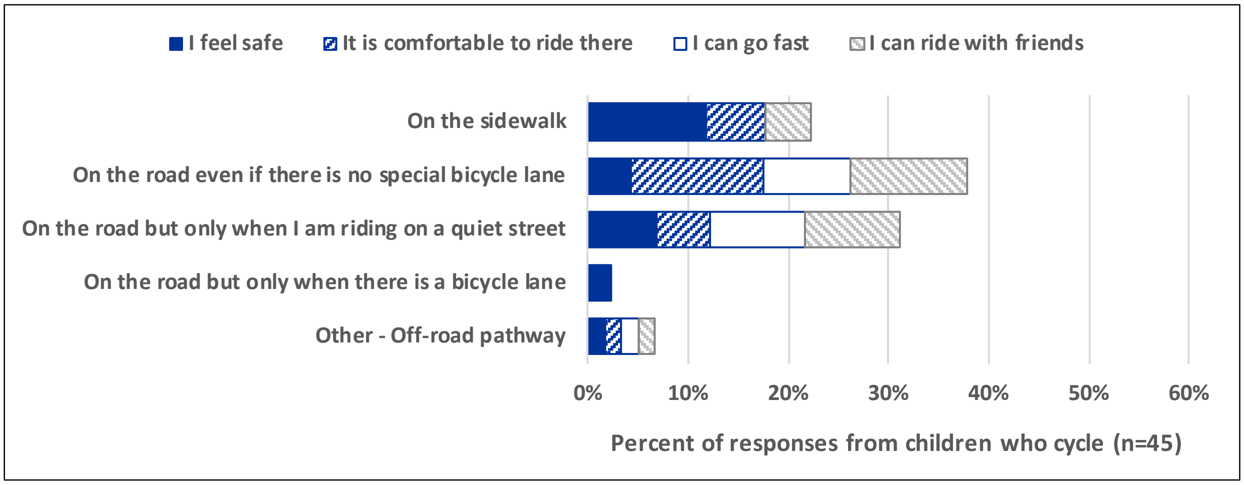


Figure B-31: Preferred infrastructure for bicycle riding by girls

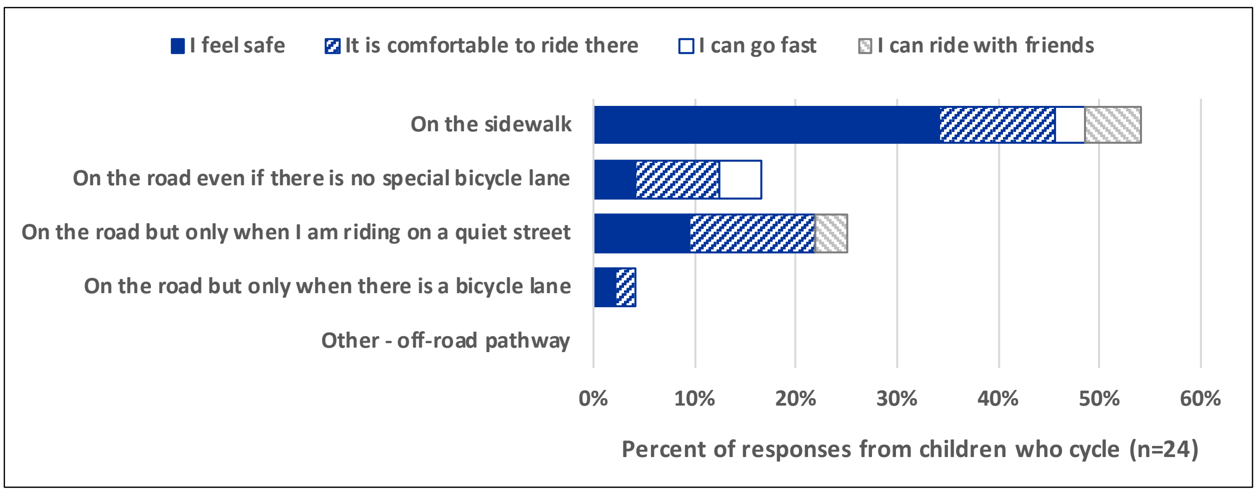


Figure B-32: Perception of safety at large signalized intersections

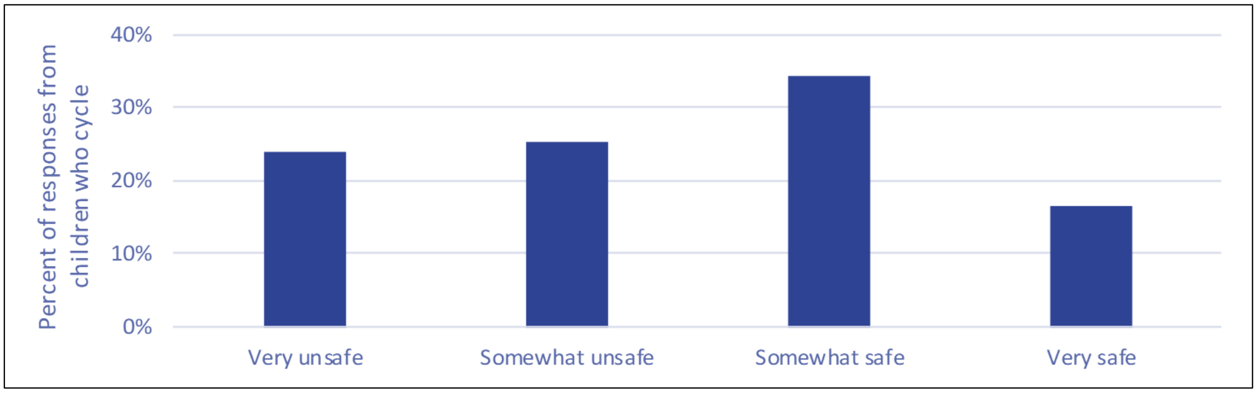


Figure B-33: Children's behaviour by intersection type

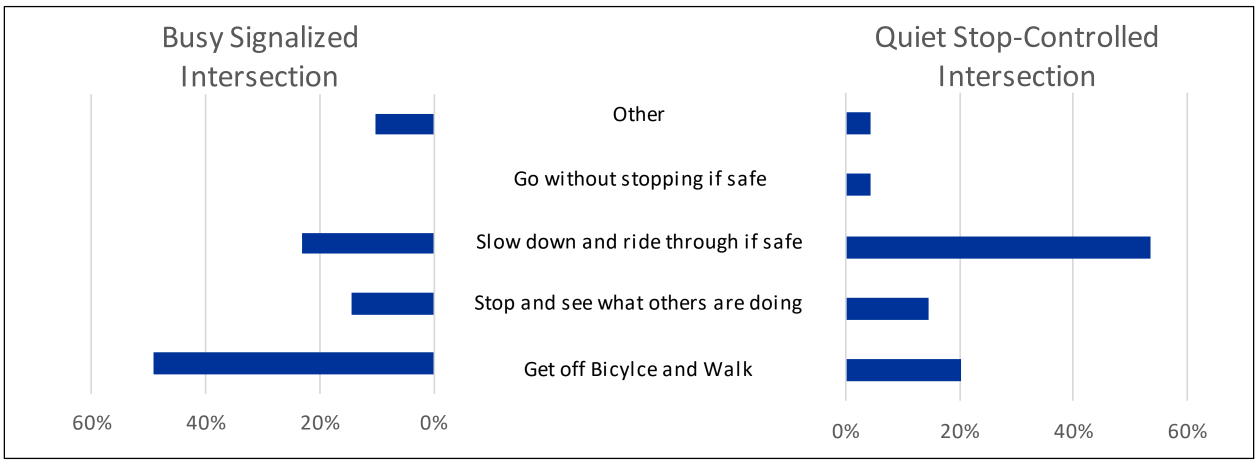
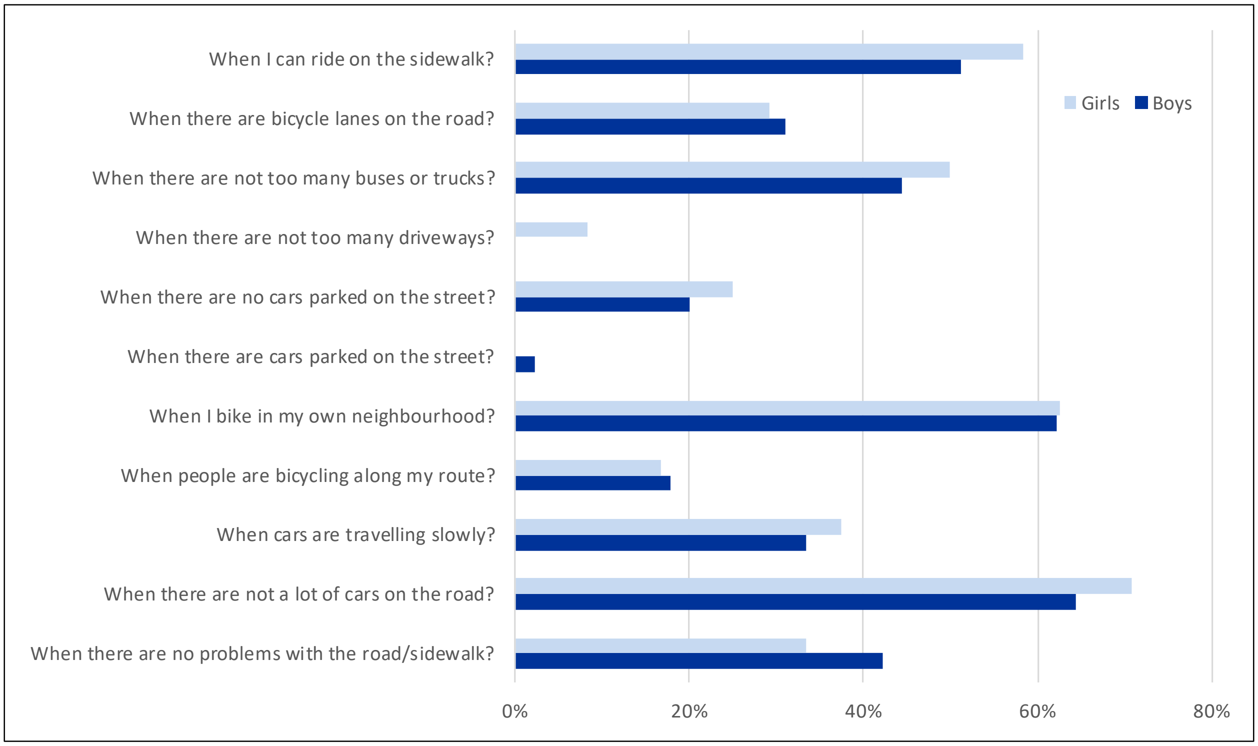


Figure B-34: Factors that make children feel safe when riding a bicycle



B.6.4 Summary of results

The purpose of this survey was to augment the information obtained from the end user survey with respect to safety and comfort experienced by children when they ride their bicycles.

A total of 86 responses were received from schools across Manitoba from children attending Grade 7, 8 or 9. Most of the children who responded ride their bicycle often, however, 17 of the 86 either do not ride at all or only ride when accompanied by an adult. The main reasons cited for this were that there are too many vehicles on the road, vehicles are traveling fast, or there is a lack of adequate infrastructure.

For the children who ride their bicycle (69 of 86), the survey found that there are clear differences between boys and girls with respect to where they prefer to ride their bicycle. Most girls prefer to ride on the sidewalk, compared to less than one-quarter of boys. Girls cited safety and comfort as the main reasons for wanting to ride on the sidewalk. Boys prefer to ride their bicycle on the road, even if there is no special bicycle lane. Key reasons cited were comfort and being able to ride with friends. Nearly one-third of boys also indicated that they like riding their bicycle on quiet streets, compared to about one-quarter of girls.

Regarding children perception of safety at busy, signalized intersections, most feel somewhat safe. However, nearly one-half of children reported feeling somewhat unsafe or very unsafe.

The most important factors that make children feel safe while riding a bicycle are: low traffic volumes, riding in their own neighbourhood, riding on the sidewalk, low bus and truck volumes. In addition, girls feel safer when there are no driveways present while boys feel safer when there are parked vehicles on the street.

B.7 Youth end user survey questionnaire

The Transportation Association of Canada and MORR Transportation Consulting are conducting a country-wide study regarding bicycle safety. Part of this project involves gathering information from young bicycle users to understand how safe and comfortable they feel when riding their bicycle.

Every family's input is important to the success of this project. Therefore, we ask that you take a few minutes with your child (enrolled in Grade 7, 8, or 9) to complete this brief survey. If you have more than one child enrolled in Grade 7, 8, or 9, please complete a survey for each child.

1. What **grade** does your child attend?

- Grade 7
- Grade 8
- Grade 9

2. What is the **gender** of the child you are answering this survey for?

- Female
- Male
- Other

LOGIC Show/hide trigger exists.

3. Does your child ride a bike? *

- Yes
- No

LOGIC Hidden unless: #3 Question "Does your child ride a bike?" is one of the following answers ("No")

4. Why does your child not ride a bike (select all that apply)?

- ☐ There are no sidewalks
- ☐ There are potholes, cracks or other problems with the road or sidewalk
- ☐ There are a lot of cars on the road
- ☐ Vehicles travel to fast
- ☐ There are too many parked cars
- ☐ There are not enough other people riding their bikes
- ☐ There are too many driveways
- ☐ There are too many buses or trucks
- ☐ There are no special lanes for bicycling on the road
- ☐ My child is not interested in bicycling
- ☐ Other - Write In (Required) *

LOGIC Hidden unless: #3 Question "Does your child ride a bike?" is one of the following answers ("Yes")

5. How often does your child ride their bike in summer months (select one)?

- ○ Daily
- ○ 4 to 6 days per week
- ○ 1 to 3 days per week
- ○ A couple days per month

LOGIC Show/hide trigger exists. Hidden unless: #3 Question "Does your child ride a bike?" is one of the following answers ("Yes")

6. Does your child ever ride a bicycle unaccompanied by an adult? *

- ○ Yes
- ○ No

LOGIC Hidden unless: #6 Question "Does your child ever ride a bicycle unaccompanied by an adult?" is one of the following answers ("No")

7. Why does your child not ride a bike unaccompanied by and adult?

- ☐ There are no sidewalks
- ☐ There are potholes, cracks or other problems with the road or sidewalk
- ☐ There are a lot of cars on the road
- ☐ Vehicles travel to fast
- ☐ There are too many parked cars
- ☐ There are not enough other people riding their bikes
- ☐ There are too many driveways
- ☐ There are too many buses or trucks
- ☐ There are no special lanes for bicycling on the road
- ☐ Other - Write In

Page description:
The following questions apply to your child's experience when riding unaccompanied. Please ask him/her to answer the following questions.

8. What is the main reason you like to ride your bicycle (select one)?

- ○ For fun
- ○ To go to school
- ○ To hang out with friends
- ○ To go to the store
- ○ Other - Write In

9. Where do you prefer to ride your bicycle (select one)?

- ○ On the road even if there is no special bicycle lane
- ○ On the road but only when there is a bicycle lane
- ○ On the road but only when I am riding on a quiet street
- ○ On the sidewalk
- ○ Other - Write In

10. Why do you prefer to ride your bike where you stated in the previous question (choose all that apply)?

- ☐ I feel safe
- ☐ It is comfortable to ride there
- ☐ I can go fast
- ☐ I can ride with friends
- ☐ Other - Write In

11. How safe do you feel when you need to ride your bicycle through a busy, signalized intersection with many vehicles (select one)?

- ○ Very safe
- ○ Somewhat safe
- ○ Somewhat unsafe
- ○ Very unsafe

12. What do you typically do when you get to a busy, signalized intersection (select one)?

- ○ I keep going without stopping or slowing down if it is safe to do so
- ○ I slow down and ride through if it is safe to do so
- ○ I get off the bicycle and walk across
- ○ I stop and wait to see what others are doing
- ○ Other - Write In

13. What do you typically do when you get to a quiet, stop-controlled intersection (select one)?

- ○ I keep going without stopping or slowing down if it is safe to do so
- ○ I slow down and ride through if it is safe to do so
- ○ I get off the bicycle and walk across
- ○ I stop and wait to see what others are doing
- ○ Other - Write In

14. What are the most important factors that make you feel safe while bicycling (select up to 5)?

- ☐ When there are no potholes, cracks, or other problems with the road or sidewalk
- ☐ When there are not a lot of cars on the road
- ☐ When cars are travelling slowly
- ☐ When there are other people bicycling along my route.
- ☐ When I bike in my own neighbourhood
- ☐ When there are cars parked on the street
- ☐ When there are no cars parked on the street
- ☐ When there are not too many driveways
- ☐ When there are not too many buses or trucks
- ☐ When there are special lanes for riding your bicycle on the road
- ☐ When I can ride on the sidewalk

Thank You!

Thank you for your time, your response is very important to us. This is the end of the survey.

Click here to fill out an additional survey for another child.

B.8 Photo credits

B-4	Location of survey respondents	MORR
B-12	Bicycle facilities included in the survey	MORR
B-17	Configurations of protected bicycle facilities at intersections	MORR
B-20	Protect intersection	MORR
B-20	Intersection crossing markings	MORR
B-20	Cross ride	MORR
B-20	Protected signal phase	MORR
B-20	Bike box	MORR
B-20	Two-stage left	MORR
B-20	Bend-out	MORR
B-20	Bend-in	MORR
B-20	Gates	MORR

Appendix C: Jurisdiction survey

C.1 Jurisdiction survey questionnaire

GENERAL INFORMATION ABOUT YOUR JURISDICTION

Please provide us with your contact information *

Name:

Title:

Jurisdiction:

Email:

Phone:

1. **Does your jurisdiction currently implement a facility type that does not fit into any of the above definitions?**
   - Yes
   - No

2. **Please upload a clearly labelled image (<2 MB) for each alternative bicycle facility.**

   Browse...

3. **Please describe how you define each alternative bicycle facility.**

4. **Does your jurisdiction currently implement an intersection design treatment that does not fit into any of the above definitions?**
   - Yes
   - No

5. **Please upload a clearly labelled image (<2 MB) for each alternative intersection treatment.**

   Browse...

6. **Please describe how you define each alternative intersection treatment.**

7. **Please indicate the approximate overall length of your jurisdiction's bicycle network in route-kilometres (i.e., measured as the length of the facility along the street regardless of whether bicyclists are accommodated in both directions of travel).**

   Please enter a number (insert 0 if you don't have a bike network)

   km

8. **Please indicate how frequently your jurisdiction installs the following bicycle facility types.**

Along All Types of Roadways

	Never	Occasionally	Frequently	Don't know
Off- Road Multi-Use Pathway	○	○	○	○
Painted Bicycle Lane	○	○	○	○
Bicycle Accessible Shoulder	○	○	○	○
Major Street Sharrow	○	○	○	○
Bicycle Boulevard	○	○	○	○
Advisory Bicycle Lane	○	○	○	○

Along a One-Way Roadway

	Never	Occasionally	Frequently	Don't know
Protected One-Way Bicycle Facility	○	○	○	○
Protected Two-Way Bicycle Facility	○	○	○	○
Buffered One-Way Bicycle Facility	○	○	○	○
Buffered Two-Way Bicycle Facility	○	○	○	○
Contra-Flow One-Way Bicycle Facility	○	○	○	○

Along a Two-Way Roadway

	Never	Occasionally	Frequently	Don't know
Protected One-Way Bicycle Facility	○	○	○	○
Protected Two-Way Bicycle Facility	○	○	○	○
Buffered One-Way Bicycle Facility	○	○	○	○
Buffered Two-Way Bicycle Facility	○	○	○	○

Indicate any other bicycle facilities used in your jurisdiction below.

	Occasionally	Frequently
Enter another option	○	○
Enter another option	○	○

9. **Please identify preferred guides that your jurisdiction uses for bicycle facility design.**
(select all that apply)

- ☐ TAC Geometric Design Guide for Canadian Roads
- ☐ TAC Bicycleway Traffic Control Guidelines for Canada
- ☐ CROW Design Manual for Bicycle Traffic (the Dutch Guide)
- ☐ NACTO Urban Bikeway Design Guide
- ☐ FHWA Separated Bike Lane Planning and Design Guide
- ☐ AASHTO Guide for the Development of Bicycle Facilities
- ☐ MASSDOT Separated Bike Lane Planning & Design Guide Documents
- ☐ ITE Traffic Calming State of the Practice
- ☐ In-house bicycle design guide
- ☐ Other

Please upload (< 2MB) any other bicycle guides you use regularly, including "in house" bicycle guides.

Browse...

10. **How are bicycle volumes determined in your jurisdiction?**
(select all that apply)

- ☐ Surveys and counts conducted as needed
- ☐ Volumes are determined from a bicycling demand model or other forms of latent bicycling demand projections
- ☐ Volumes are available from a scheduled bicycling or active transport monitoring program
- ☐ Bicyclists counted as part of intersection turning movement counts
- ☐ Other, please describe

11. **What types of technologies does your jurisdiction use to measure bicycling exposure (i.e., bike volumes)?**
(select all that apply)

- ☐ Infrared sensors
- ☐ Inductive loops
- ☐ Manual counters
- ☐ Video detection
- ☐ Mobile app (crowd sources like Strava)
- ☐ Other, please describe

12. **What sources of bicycle safety data related to all collision and conflict types relative to bicycling does your jurisdiction typically use when evaluating the safety performance of a facility?**
(select all that apply)

- ☐ Bicycle collision data from police records
- ☐ Bicycle collision data from insurance records
- ☐ Bicycle collision data from hospital records
- ☐ Bicycle collision data from other (Specify)
- ☐ Video conflict data
- ☐ Public feedback
- ☐ Manual observations
- ☐ Lack of data is a barrier to evaluating the safety performance of bike facilities
- ☐ Other data sources, please describe

13. **Please identify the severity type of collision information collected.**
(select all that apply)

- ☐ Fatal
- ☐ Injury major (admitted to hospital)
- ☐ Injury minor (not admitted to hospital)
- ☐ Injury all types (not classified by severity)
- ☐ Property damage
- ☐ Other, please describe

14. **Does your jurisdiction have any formal warrants in place to determine the type of bicycle facility required at a given location?**

- ○ Yes
- ○ No

If yes, please upload (< 2MB) document here.

Browse...

15. **Various input variables can be used for deciding which type of bicycle facility to implement under different situations. Please indicate if your jurisdiction considers each of the following input variables through a formal warrant system or through informal policy or practice.**

Roadway Characteristics

	Considered through warrants or standards	Considered through policy or practice	Beneficial and feasible to consider in future	Not considered	Don't know
Street classification	○	○	○	○	○
Vehicular traffic volume	○	○	○	○	○
Right-of-way width	○	○	○	○	○
Street width	○	○	○	○	○
Number of motor vehicle travel lanes	○	○	○	○	○
Density of access points	○	○	○	○	○
Posted speed limit	○	○	○	○	○
Longitudinal grade or slope	○	○	○	○	○
Type of traffic control (when selecting an intersection treatment)	○	○	○	○	○
Presence of traffic control	○	○	○	○	○
Presence of parking or loading	○	○	○	○	○
Presence of school zone	○	○	○	○	○
Presence of transit service	○	○	○	○	○
Transit stop density	○	○	○	○	○
Presence of large trucks	○	○	○	○	○
Adjacent land use	○	○	○	○	○
Enter another option	○	○	○	○	○

Safety Considerations

	Considered through warrants or standards	Considered through policy or practice	Beneficial and feasible to consider in future	Not considered	Don't know
Network-level collision history	○	○	○	○	○
Expected motorist compliance	○	○	○	○	○
Bike / motor-vehicle collisions or conflicts	○	○	○	○	○
Bike / pedestrian collisions or conflicts	○	○	○	○	○
Enter another option	○	○	○	○	○

Bicycling Characteristics

	Considered through warrants or standards	Considered through policy or practice	Beneficial and feasible to consider in future	Not considered	Don't know
Bicycle volume counts	○	○	○	○	○
Bicycle volume projections	○	○	○	○	○
Pedestrian volume	○	○	○	○	○
Target cycling ability-level	○	○	○	○	○
Bicyclist delay	○	○	○	○	○
Closing gaps in bike infrastructure	○	○	○	○	○
Route connectivity	○	○	○	○	○
Climate	○	○	○	○	○
Enter another option	○	○	○	○	○

16. **Which of the following intersection treatments have been implemented in your jurisdiction, and what type of bicycling facility are they associated with?**

Along All Types of Roadways

	Off-Road Pathway	Protected Bicycle Lane	Buffered Bicycle Lane	Painted Bicycle Lane	Bike Boulevard
Intersection Crossing Marking	☐	☐	☐	☐	☐
Bike Box	☐	☐	☐	☐	☐
Two Stage Turn Queue Box	☐	☐	☐	☐	☐
Cross Rides	☐	☐	☐	☐	☐
Protected Signal Phase (Bike Signal)	☐	☐	☐	☐	☐
Gates, Fencing, and Bollards	☐	☐	☐	☐	☐

Along a Two-Way Roadway

	Off-Road Pathway	Protected Bicycle Lane	Buffered Bicycle Lane	Painted Bicycle Lane	Bike Boulevard
Bend-In Intersection Approach	☐	☐	☐	☐	☐
Bend-Out Intersection Approach	☐	☐	☐	☐	☐

17. **Have any evaluations or studies been conducted in your local jurisdiction regarding the following?**
(select all that apply)

- ☐ Before and after studies of bicycle infrastructure safety
- ☐ Safety evaluations of bicycle infrastructure (i.e., bicycle road safety audit)
- ☐ Warrants for deciding whether or not to provide bicycle facilities
- ☐ Warrants for selecting the type of bicycle facilities to implement
- ☐ Appropriate application of different types of bicycle facilities
- ☐ Motorist compliance with different types of facilities
- ☐ Cyclist compliance with different types of facilities
- ☐ Demographic and health studies
- ☐ I am unaware of any evaluations or studies conducted in my local jurisdiction regarding the safety performance of bicycle facilities
- ☐ Other, please describe

Please upload (< 2MB) any available study documents from above or briefly describe the study here.

Browse...

Comments

18. **Has your jurisdiction completed any studies comparing the actual safety (i.e., number of collisions or number of conflicts) vs perceived safety (including level of comfort) of bicycle facilities implemented in the last 10 years?**

- ○ Yes
- ○ No

If yes, please explain in the box below.

19. **The consulting team will be conducting 10 case studies of bicycle facilities between June and November 2018 as part of this project. Is your jurisdiction interested in being included as one of the case studies?**

- ○ Yes
- ○ No

Please indicate types of data and other information available for the candidate bicycle facility.

- ☐ Bicycle volume data before and after implementation
- ☐ Safety (collision or conflict) data before and after implementation
- ☐ Other, please describe *
- ☐ Other, please describe *
- ☐ Other, please describe *

Appendix D: Canadian and international case studies

This appendix presents the results of 13 case studies conducted to assess and quantify the safety performance of selected bicycle facilities across Canada and internationally. Case studies are typically used as an exploratory mechanism to bring forward new knowledge, or to confirm existing knowledge, about situations or issues that would otherwise be difficult to explain or understand if a larger population would have to be analyzed. In addition, for the purpose of this project, case studies can also be used to highlight successes or other experiences resulting from the implementation of different types of bicycle facilities in various settings.

A combination of primary and secondary research was used to conduct the case studies. Four of these were based on primary research and the remaining nine were based on secondary research. Table D-1 shows the facilities for which case studies were completed, the jurisdictions that participated, the type of research applied to each case study, and the main sources of information used for each study.

A standard template was developed and applied for each case study to ensure proper and meaningful conclusions could be drawn about the various facility types in a consistent manner. Each study starts with an overview about the facility being evaluated and its land use context. This is then followed by the methodology used for the case study itself, which depends on whether the case study is based on primary or secondary research. For example, if it is based on secondary research, a description of the methodology used by the authors of the reference report is included in this section. Following the methodology, each case study contains information on performance along segments and at intersections for before and after facility implementation. For example, road cross section, presence and type of pavement markings, vehicular and bicycle volumes, collisions or conflicts, public perception information, and other observations. Each case study concludes with a discussion about the findings and opportunities for future work.

Table D-1: Canadian and international case-study participants

Facility type	Jurisdiction	Research type	Main information sources
Off-road bicycle pathway	Waterloo	Secondary	• Report "Upgrades to Central Promenade" • Report "Functional Design of the Central Promenade in Waterloo Park, 2016"
Off-road multi-use pathway	Winnipeg	Primary	• Collision data, bicycle counts, turning movement counts, desktop research
Protected one-way facility	Ottawa	Secondary	• Report "Laurier Avenue Segregated Bicycle Lanes Pilot Project"
Protected two-way facility	Vancouver	Secondary	• Report "Downtown Separated Bicycle Lanes Status Report" (Summer 2011) • Report "Downtown Separated Bicycle Lanes Status Report" (Spring 2012)
Buffered bicycle facility	Toronto	Secondary	• Report "Bloor Street West bicycle Lane Pilot Project Evaluation"
Painted bicycle lane	London	Primary	• Collision diagrams • Vehicle and truck turning movement counts • Inductive loop bicycle counts • Results from a network screening of stop-controlled intersections
Major street shared lane	Calgary	Primary	• Turning movement counts before and after. • Bicycle collision data. • Bicycle count data.
Bicycle boulevard	Vancouver	Secondary	• Report "Phase 1 of Point Grey-Cornwall Active Transportation Corridor" (2013) • Report "Phase 2 - Public Realm & Sidewalks Point Grey Road, Alma Street to Tatlow Park" (2016)
Advisory bicycle lane	Ottawa	Secondary	• Journal Paper "Operational Evaluation of Advisory bicycle Lane Treatment on Road User Behavior in Ottawa Canada"
Contra-flow bicycle facility	Quebec City	Primary	• Automated bicycle count data • Turning movement counts for before and after facility implementation
Bicycle-accessible shoulder	Florida	Secondary	• Report "An Evaluation of Red Shoulders as a Bicycle and Pedestrian Facility"
Two-way buffered bicycle facility	Chicago	Secondary	• Report "Lessons from the Green Lanes: Evaluating Protected bicycle Lanes in the U.S."
Painted bicycle lane	Copenhagen	Secondary	• Journal paper "Bicycle Tracks and Lanes: a Before-After Study" • Report "Effekter af cykelstier og cykelbaner"

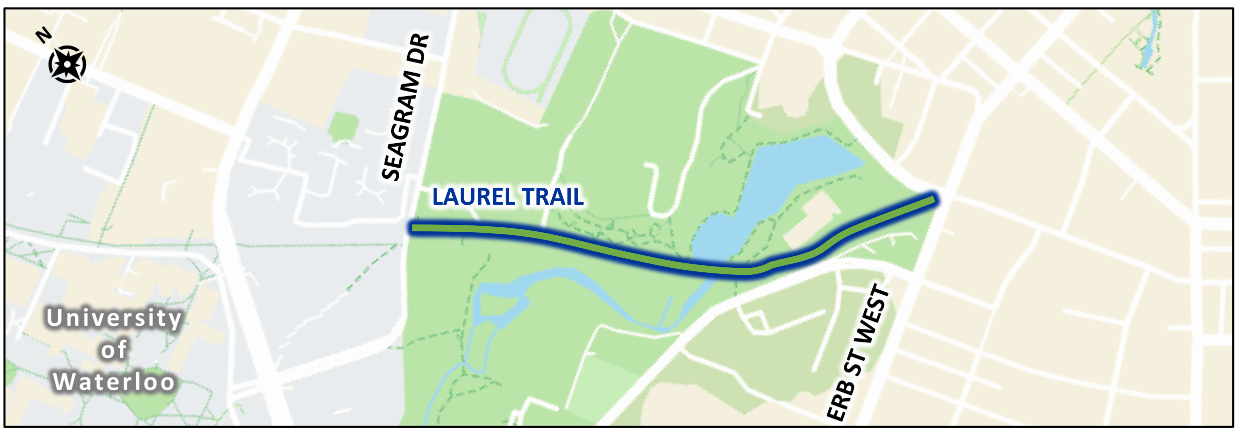
D.1 Canadian case studies

D.1.1 Off-road bicycle pathway (Waterloo, ON)

Laurel Trail from Seagram Drive to Erb Street West

Case study overview: The Central Promenade represents the main spine for pedestrian and bicycling traffic through Waterloo Park and Laurel Trail is a major active transportation route in the promenade. Laurel Trail (shown in the figure below) is the roughly 1-km stretch between Erb Street West to Seagram Drive that is designated as part of the Trans Canada Trail. The Promenade has received several improvements over the years, including installation of uniform hard surfaces, greater trail width, dedicated trails for bicyclists and a multi-use trail for pedestrians with appropriate signage and trail markings. The bridge over Silver Lake was twinned in 2018 to provide a separate route for bicyclists and pedestrians. In addition to this major spine, the area also includes connections between the Promenade and existing and future elements of Waterloo Park. The Promenade was completed late summer of 2018 with a grand opening on September 6, 2018.

Land use context: Laurel Trail is an off-road bicycle pathway located inside Waterloo Park that provides a bicycle only connection between the University of Waterloo to the north and London's commercial district to the south. The trail runs along side the Region of Waterloo's Ion rapid transit system railway.



CASE STUDY METHODOLOGY

This case study is based on secondary research that relies on the City of Waterloo website information titled *"Upgrades to Central Promenade"* and a report titled *"Functional Design of the Central Promenade in Waterloo Park, 2016."*

DESIGN FEATURES OF BICYCLE FACILITY

The trail contains uniform hard surfaces and an enhanced width ranging from 4.8 m for the multi-use trail component, to 4.0 m exclusively for bicyclists. The implemented improvement also includes adding an exclusive bicycle path for a second bridge across the Laurel Creek, near Silver Lake.

DESIGN FEATURES OF BICYCLE FACILITY - MIDBLOCK

	Trail conditions prior to upgrade	Upgraded trail conditions
Cross section	• Off-road multi-use pathway (4.8 m). • Multiple surface materials, including gravel.	• Off-road bicycle pathway (4 m) for bicyclists and an off-road multi-use trail for pedestrians. • Asphalt surface.
Bicycle pavement markings	• Unknown	• Pavement markings to alert bicyclists of upcoming yield to pedestrians as well as upcoming connections. • Bike graphics on pavement marks the bicycle path. • White lane lines down the middle delineate directionality.
Cycling volumes	• On average, 340 bicycle trips per day (based on data collected between Aug 26, 2014 and Sep 05, 2018)	• On average, 520 bicycle trips per day (based on data collected between Sep 06, 2018 and Nov 25, 2018)
Motor vehicle volumes	• Not applicable.	• Not applicable.
Motor vehicle travel time	• Not applicable.	• Not applicable.

DISCUSSION AND OPPORTUNITIES FOR FUTURE CASE STUDIES

This case study provides an example of replacing an off-road multi-use pathway with an off-road bicycle pathway that separates pedestrian and bicycle traffic. There are few examples of this type of facility enhancement in Canada, possibly because it is usually preferred to direct available resources toward a location that does not yet have a bicycle facility, instead of upgrading a facility that may be considered of good quality.

One of the challenges associated with this case study is the lack of available data to properly assess the safety performance of the facility. No collision information is available for this facility, or any information regarding perceived safety or comfort. While an increase in perceived safety and comfort may be expected due to the separation of pedestrians and bicyclists, no real evidence exists to make this assertion. Available bicycle volume data shows that bicycle traffic has increased from before to after upgrading of the facility (from 340 bicycle trips/day to 520 bicycle trips per day), which may suggest that people find the upgraded facility to be more appealing than the previous one, therefore, pointing to increased comfort and/or perceived safety.

Based on the findings from this case study, there is an opportunity for a comprehensive evaluation of the safety performance of off-road bicycle pathways. Important issues that may be worth exploring are:

- The role that these facilities play in the safety of the overall road network.
- Performance during winter conditions, both from the operational and safety perspectives, particularly due to snow accumulation. Do these facilities observe similar bicyclist volumes in winter as in non-winter months?
- How are these facilities being used by bicyclists? Are they for recreational purposes, utilitarian purposes or combinations?
- Safety performance at intersections.
- Perceived safety by various segments of the population.

D.1.2 Off-road multi-use pathway (Winnipeg, MB)

Northeast Pioneer's Greenway from Talbot Avenue to Springfield Road

Case study overview: The Northeast Pioneers (NEP) Greenway off-road multi-use pathway was constructed along a decommissioned railbed between the 4.25-km stretch from Talbot Avenue to Springfield Road in the fall of 2009 in Winnipeg. Prior to implementation of this facility, there was no bicycle facility provided on either of the two roadways that run adjacent to the off-road multi-use path. In the spring of 2012, Chief Peguis Trail was opened to traffic and Springfield Road to the east of the NEP Greenway was transitioned to a local road. By 2015, the NEP Greenway had been extended north to the City limits for a total length of 7 km.

Land use context: The NEP Greenway is an asphalt paved pathway that provides a north-south connection for active transportation users living in a residential neighbourhood in the northeast quadrant of Winnipeg. The greenway is constructed on an old railbed located between two roadways. To the west of NEP Greenway is Raleigh Street, a two-lane, two-way collector street with about 2,500 vehicles per day. To the east of NEP Greenway is Gateway Road, a two-lane, two-way arterial street with between 11,900 and 20,600 vehicles per day. Both roads have posted speed limits of 60 km/hr.

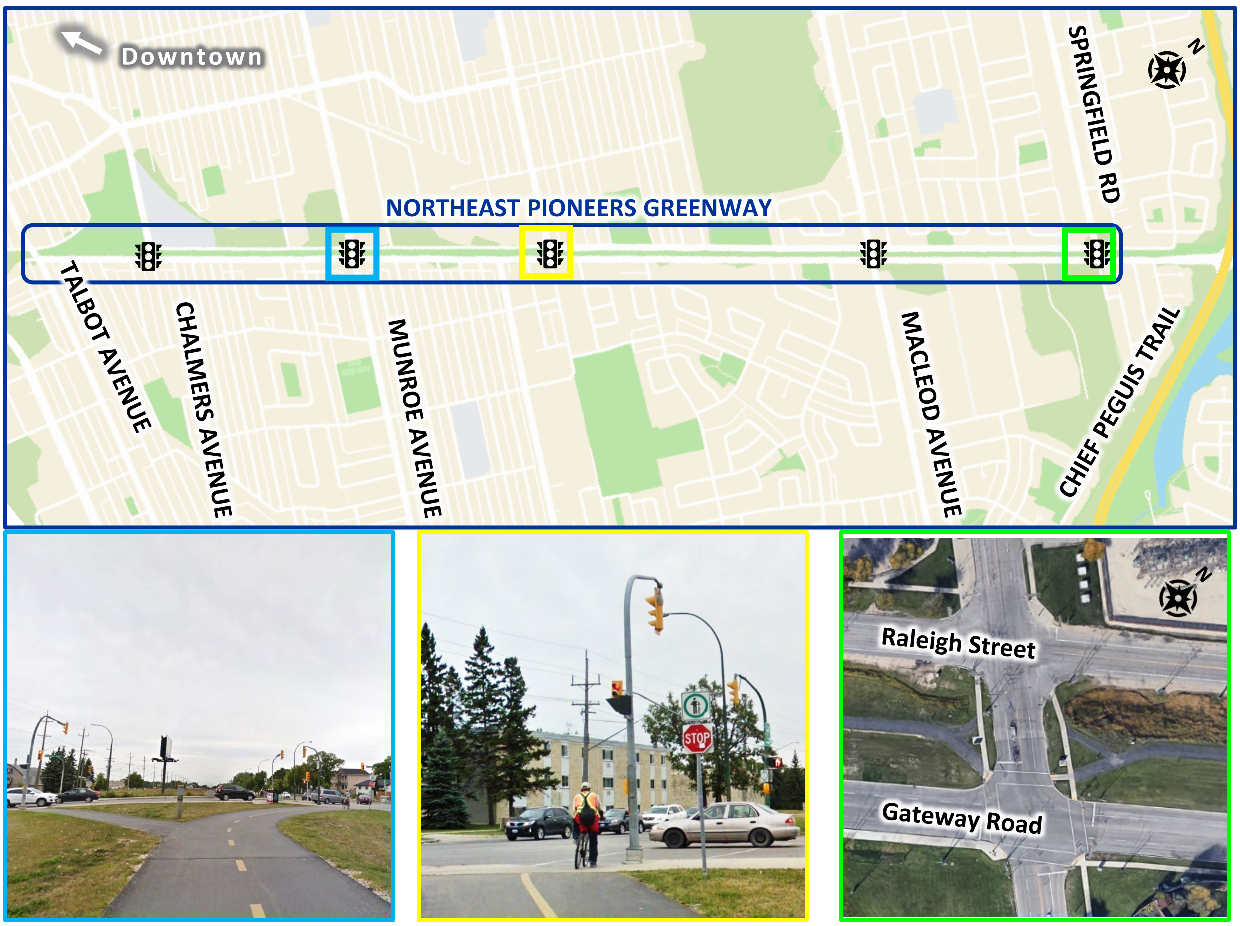


Image credit: Google Maps and Streetview

CASE STUDY METHODOLOGY

This case study is based on primary research relying on available data provided by the City Winnipeg, including the following:

- Collision history on Gateway Road between 2003 and 2016.
- Turning Movement count data collected at the following intersections:
    - Gateway Road and Springfield Road (2008-04-21 and 2012-02-02)
    - Gateway Road and McLeod Avenue (2006-10-10 and 2016-06-10)
    - Gateway Road and Munroe Avenue (2006-11-21 and 2014-05-07)
    - Gateway Road and Chalmers Avenue (2015-05-14)
- Continuous bicycle count data collected on the NEP Greenway between October 2013 and November 2018 at three sites:
    - South of Munroe Avenue.
    - South of McLeod Avenue (just north of Roberta Avenue).
    - North of Springfield Road.

The study period is based on the availability of historical count data starting in 2003, construction of the NEP Greenway in 2007, and construction of the Chief Peguis Trail Expressway in 2012 which significantly impacted transportation along the corridor. As a result, the collision analysis before period is 4 years from 2003 to 2007 and the after period is 4 years from 2008 to 2012.

DESIGN FEATURES OF BICYCLE FACILITY

Mid-block segments	Intersections
• 4.25 km continuous asphalt surface, off-road multi-use pathway. • 16m grass boulevards on both sides of the pathway.	• Six roadways cross the NEP Greenway corridor. The pathway splits at each roadway to provide a crossing opportunity across Raleigh Street to the west and across Gateway Road to the east. However, to continue north-south along the pathway, crossing is only provided at the Gateway Road intersections. • Five of six intersections with Gateway Road are signalized. On each pathway approach there is a stop sign and a dismount bicycle sign.

PERFORMANCE EVALUATION – MID BLOCK SEGMENT

	Conditions without bicycle facility	Conditions with bicycle facility
Cross Section	• No pathway.	• 4m off-road multi-use pathway. • 16m grass boulevard on both sides.
Bicycle Pavement Markings	• Not applicable.	• Yellow dashed directional dividing lane line.
Cycling Volumes	• Unknown along Gateway Road and Raleigh Street (streets adjacent to the facility).	Summer (includes July and August) average daily bicycling volume: • 600/day in 2014. • 540/day in 2015. • 570/day in 2016. • 540/day in 2017. • 500/day in 2018.
Motor Vehicle Volumes	Crossing the NEP Greenway: • No data at Chalmers Ave. • 15,000/day at McLeod Ave (2006-10). • 11,800/day at Munroe Ave (2006-11). • 19,200/day at Springfield Rd (2008-04).	Crossing the NEP Greenway: • 9,400/day at Chalmers Ave (2015-05). • 16,400/day at McLeod Ave (2016-06). • 14,200/day at Munroe Ave (2014-05). • 6,600/day at Springfield Rd (2012-02).
Motor Vehicle Travel Time	• No information available.	• No information available.

PERFORMANCE EVALUATION – INTERSECTIONS

	Conditions without bicycle facility	Conditions with bicycle facility
Cross Sections at Intersection	• No facility.	• Pathway splits and bends toward adjacent roadways on either side.
Bicycle Markings Through Intersection	• Not applicable.	• Dismount signs require bicyclists to use pedestrian crossing.
Bicycle Markings Approaching Intersection	• Not applicable.	• Solid yellow dividing lane line.
Motor Vehicle Right-Turn Volumes	• No data at Chalmers Ave. • 900/day at McLeod Ave (2006-10). • 1,500/day at Munroe Ave (2006-11). • 1,300/day at Springfield Rd (2008-4).	• 2,600/day at Chalmers Ave (2015-05). • 1,100/day at McLeod Ave (2016-06). • 1,800/day at Munroe Ave (2014-05). • 2,700/day at Springfield Rd (2012-02).
Right Turn Lane Length	• None.	• None.
Transit Accommodation at Intersections	• None.	• None.
Intersecting bicycling Facilities	• None.	• None.
Adjacent Markings	• None.	• None.
Signal Timing	• None.	• None.

PERFORMANCE EVALUATION – COLLISIONS AND OBSERVATIONS

	Conditions without bicycle facility	Conditions with bicycle facility

Collisions	Along Gateway Road:
	• 262 total collisions (2003-2007).
	• 4 bicycle collisions (2003-2007).
	  ○ 1 Intersection 90 degree at Burnett Ave.
	  ○ 1 Right-turn opposite direction at Burnett Ave.
	  ○ 1 Left-turn opposite direction at Concordia Ave.
	  ○ 1 Sideswipe same direction At Concordia Ave.
		Along Gateway Road:
		• 278 total collisions (2008-2011).
		• 3 bicycle collisions (2008-2011).
		  ○ 3 Intersection 90 degree (1 at Talbot Ave and 2 at Kimberly Ave).

Conflicts with bicyclists	• No information available.	• No information available.
Overall Public Perception	• No information available.	• No information available.
Other Observations	• No information available.	• No information available.

DISCUSSION AND OPPORTUNITIES FOR FUTURE CASE STUDIES

This case study was based on data provided by the City of Winnipeg. The challenge associated with this evaluation was the absence of a clear 'before' situation and some confounding factors in the 'after' situation. For example, while the installed off-road multi-use pathway can carry significant bicyclist volumes (about 550 per day), it is not possible to determine whether these bicyclists 'came when it was built', or they were already users of the system. If they were users of the system, where were they operating? Along the streets immediately adjacent to this facility (Gateway Road and Raleigh Street) or on residential or collector roads? There is no 'before' bicycle traffic data available along either of the streets adjacent to the facility, which makes it challenging to understand the impact of this new facility. Further, some confounding factors that add complexity to this situation is the fact that a major east-west connector (Chief Peguis Trail) was built near this facility, significantly impacting transportation along it prior to opening of Chief Peguis Trail.

The collision data provided by the City shows that prior to the installation of the facility, there was an average of one collision per year on Gateway Road involving bicyclists. After the installation of the facility, the collision frequency remained unchanged on Gateway Road. The challenge with this information is that it is not obvious that this off-road facility was introduced with the purpose of removing bicycle traffic from Gateway Road of Raleigh Street. Those two streets continue to operate the way they have always operated and none of them have a dedicated bicycle facility along them. This makes it difficult to understand the real safety performance of the off-road facility.

From a perception perspective, there are no surveys or analysis regarding what users or the general public think about having access to off-road multi-use bicycle pathways. However, from anecdotal information, off-road pathways in Winnipeg, are perceived as safe and comfortable, except at night, due to lack of artificial lighting. Northeast Pioneers, however, is one of the few off-road pathways in

Winnipeg with artificial lighting, which would lead one to think that it is perceived as safe, from an anecdotal perspective only.

Overall, this case study presents a real opportunity for a comprehensive evaluation of the safety performance of off-road multi-use pathways. Important issues that may be worth exploring are:

- The role that these facilities play in the safety of the overall road network.
- Performance during winter conditions, both from the operational and safety perspectives, particularly due to snow accumulation. Do these facilities observe similar bicyclist volumes as in non-winter months?
- Safety performance at intersections. In this case bicyclists must dismount and cross at the pedestrian crossing locations.
- Perceived safety by various segments of the population
- How to measure the real impact of these facilities on adjacent streets, in terms of collision reduction, comfort, vehicular delay?

D.1.3 Protected bicycle lane, one-way (Ottawa, ON)

Laurier Avenue West from Bronson Avenue and Elgin Street

Case study overview: Temporary protected bicycle lanes were installed along Laurier Avenue West in July 2011 as part of a two-year pilot project to assess the performance of protected bicycle lanes in Ottawa. The main objective of the pilot project was to significantly increase bicycle traffic and bicycling mode share within the downtown area. A performance monitoring program was established to understand the impact of the protected bicycle lane on road safety, bicycle mode share, vehicle traffic operations, parking and loading, emergency response, and public/business perceptions. As a result of this pilot study, Ottawa City Council approved the permanent installation of protected bicycle lanes on Laurier Avenue West and has approved the facility to be upgraded to a raised protected bicycle lane when the roadway is maintained sometime after 2018.

Land use context: Laurier Avenue West is a two-way, two-lane urban arterial roadway with one parking lane located in downtown Ottawa. The roadway provides connection over the Rideau Canal to the University of Ottawa in the east and terminates in a residential area to the west.

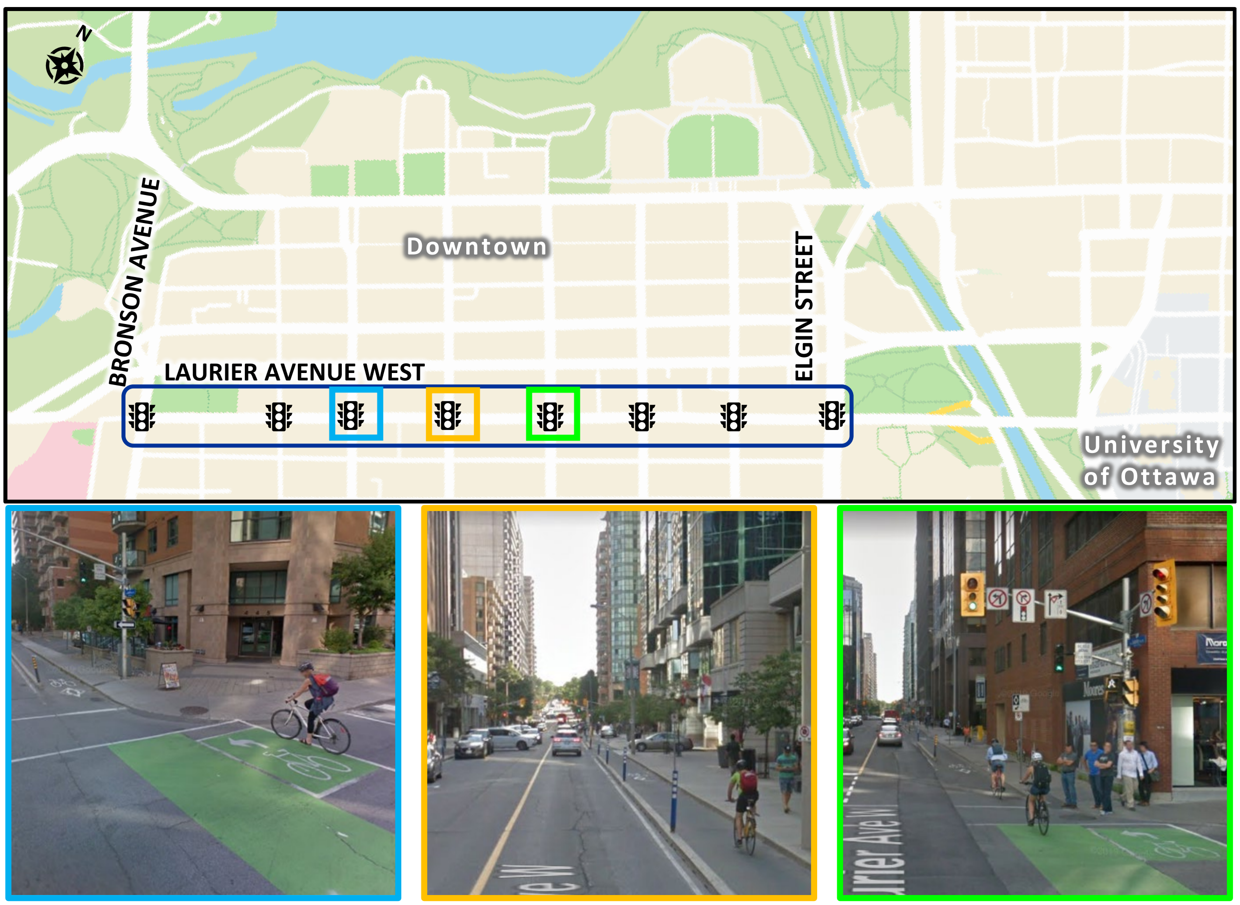


Image credit: Google Maps and Streetview

CASE STUDY METHODOLOGY

This case study is based on secondary research presented in the administrative report *"Laurier Avenue Segregated Bicycle Lanes Pilot Project"* that was delivered to the Transportation Committee and Council on June 28, 2013. The report presents findings regarding 12 indicators that were monitored during the two-year pilot project. In addition, the *Laurier Ave. W. Safety Review* completed by Mobycon in 2017, provided detailed collision analysis.

DESIGN FEATURES OF BICYCLE FACILITY

Mid-block segments	Intersections
• Continuous one-way protected bicycle lanes. • Separation from traffic provided by a curb buffer (0.8 m) supplemented with parking. • Separation from pedestrian clearway provided by a full barrier curb. • Two-lane, two-way roadway. • Parking maintained only on one side of the traffic lane. • Few loading zones interspaced within parking areas.	• Corridor includes eight 4-leg signalized intersections and one 3-leg unsignalized intersection. • Intersections are marked with continuous green area. • Driveways and laneways marked with white dashed lane lines and some have green paint. • There are two left-turn lanes (at Bank Street and Elgin Street) and two right-turn lanes (at Metcalfe Street and O'Connor Street).

PERFORMANCE EVALUATION – MID BLOCK SEGMENT

	Conditions without bicycle facility	Conditions with bicycle facility
Cross Section	• Curb-to-curb width 14 m. • Two travel lanes (3.5 m). • Two off-peak parking/loading lanes (3.5 m) on curbsides.	• Curb-to-curb width unchanged. • Two travel lanes (3.2 m). • One parking/loading lane (2.5 m) curbside. • Two, one-way protected bicycle lanes on each side of the road (2.0 m) with curb buffer (0.25 m).
Bicycle Pavement Markings	• No bicycle markings.	• Diamond/bicycle reserved-lane markings.
Cycling Volumes	• No information available.	• Cycling volumes tripled. • 2,500/day in peak season. • 70% increase in downtown bicycling traffic between 2005 and 2011.
Motor Vehicle Volumes	• 400/peak-hour at Bay Street • 800/peak-hour at Lyon Street • 1300/peak-hour at Metcalfe Street	• 400/peak-hour at Bay Street • 600/peak-hour at Lyon Street • 900/peak-hour at Metcalfe Street • No increase in vehicle traffic on adjacent downtown roadways.
Motor Vehicle Travel Time	• AM Peak: WB 0:04:18, EB 0:05:15 • PM Peak: WB 0:06:20, EB 0:04:20	• AM Peak: WB 0:04:54, EB 0:05:02 • PM Peak: WB 0:05:50, EB 0:05:24
Parking	• No information available.	• Loss of parking was a common complaint. • $60,000 annual loss of parking revenue.

PERFORMANCE EVALUATION – INTERSECTIONS

	Conditions without bicycle facility	Conditions with bicycle facility
Cross Sections at Intersection	• Curb-to-curb width 14 m. • Four travel lanes (3.5 m).	• Curb-to-curb width unchanged. • Two travel lanes (3.2 m). • Two left-turn and two right-turn lanes (2.5 m) provided. Parking lane maintained elsewhere. • Two, one-way protected bicycle lanes (2.0 m) with curb buffer (0.25 m).
Bicycle Markings Through Intersection	• No bicycle markings.	• Continuous green area.
Bicycle Markings Approaching Intersection	• No bicycle markings.	• Diamond/bicycle reserved-lane markings. • Flexible bollard on end of curb.
Motor Vehicle Right-Turn Volumes	• No information available.	• No information available.
Right Turn Lane Length	• None.	• Two right-turn lanes; 40 m at Metcalfe Street and 50 m at Bank Street
Transit Accommodation at Intersections	• No transit.	• No transit.
Intersecting bicycling Facilities	• None.	• Two-way protected bicycle lane at O'Connor Street has continuous green area with white bicycle symbol and white directional arrow.
Adjacent Markings	• None.	• Two-stage left queue boxes.
Signal Timing	• No information available.	• 5-second advanced green straight arrow provided to allow bicyclists and pedestrians to clear before turning vehicles enter the intersection. • Intersection LOS generally decreased for motor-vehicle traffic but still acceptable.

PERFORMANCE EVALUATION – COLLISIONS AND OBSERVATIONS

	Conditions without bicycle facility	Conditions with bicycle facility
Collisions	• 13.69 collisions / 1 million bicycle kilometers. • 5 bicycle collisions annually (2007-2010). Intersections or driveways were related to 70% of bicycle collisions. • 10% of collisions occurred at or near private driveways. • 60 total collisions annually (2007-2010).	• 9.31 collisions / 1 million bicycle kilometers. • 8.5 bicycle collisions annually (2012-2015). Intersections or driveways were related to 80% of bicycle collisions. • More than 50% of bicyclist collisions are related to right-turning vehicles. • 30% of collisions occurred at or near private driveways. • Reduction of 25% in dooring related collisions. • 55 total collisions annually (2012-2015).
Conflicts with bicyclists	• No information available.	• Initial results from conflict analysis study indicate that there are less bicyclist conflicts at intersections along Laurier compared to two other intersections that were used as control intersections.
Overall Public Perception	• No information available.	• 86% of bicyclists indicated they were somewhat or much more comfortable bicycling on Laurier Avenue compared to a street without protected bicycle lanes. • 60% of pedestrians indicated they felt Laurier now offered a safer environment for pedestrians. • 35% of residents and 40% of auto drivers/passengers agreed with the statement that the protected bicycle lanes have improved road safety.
Other Observations	• No information available.	• The most common concerns raised by bicyclists include vehicle parking in the protected bicycle lanes, lack of connections to the east and west, pedestrians crossing the bicycle lanes without looking, and the requirement for improved clarity and enforcement for both bicyclists and drivers navigating the corridor.

DISCUSSION AND OPPORTUNITIES FOR FUTURE CASE STUDIES

This case study shows that one-way protected bicycle lanes can be successfully implemented in a situation where the right of way is available, and intersections allow for the special accommodation of bicyclists. The collision information illustrates a potentially significant decrease in total collision rate as well as a significant decrease in bicycle collision rate. This safety improvement, which is a combination of a large decrease in the average number of total collisions (from 60 per year to 55 per year) and a tripling of bicycle volumes post facility installation, may be the result of reduced driver workload as a result of the new facility. While there is no data to support this statement, it may be beneficial to test this hypothesis at other locations.

From a safety perception perspective, the introduction of this facility appears to have increased comfort and perceived safety for both bicyclists and pedestrians. However, there is still a challenge regarding how to deal with vehicle parking in the protected bicycle lanes, pedestrians crossing the bicycle lanes without looking, and the requirement for improved clarity and enforcement for both bicyclists and drivers navigating the corridor.

Important issues that may be worth exploring are:

- Performance during winter conditions, both from the operational and safety perspectives, particularly due to snow accumulation.
- Different treatments to improve pedestrian safety.
- Public perception regarding safety and comfort.

D.1.4 Protected bicycle lane, two-way (Vancouver, BC)

Hornby Street from Pacific Street to Dunsmuir Street

Case study overview: Two-way protected bicycle lanes were constructed on Hornby Street between Pacific Street and Dunsmuir Street in December 2010. This bicycle facility provides connection between the Burrard bridge one-way protected bicycle lanes in the south and in the north to the Dunsmuir Street two-way protected bicycle lanes and the waterfront.

Land use context: Hornby Street is a two-lane, one-way minor arterial roadway located in downtown Vancouver and has an average of 14,000 vehicles per day and 1,300 bicycles per weekday. The corridor supports commercial, residential and institutional functions.

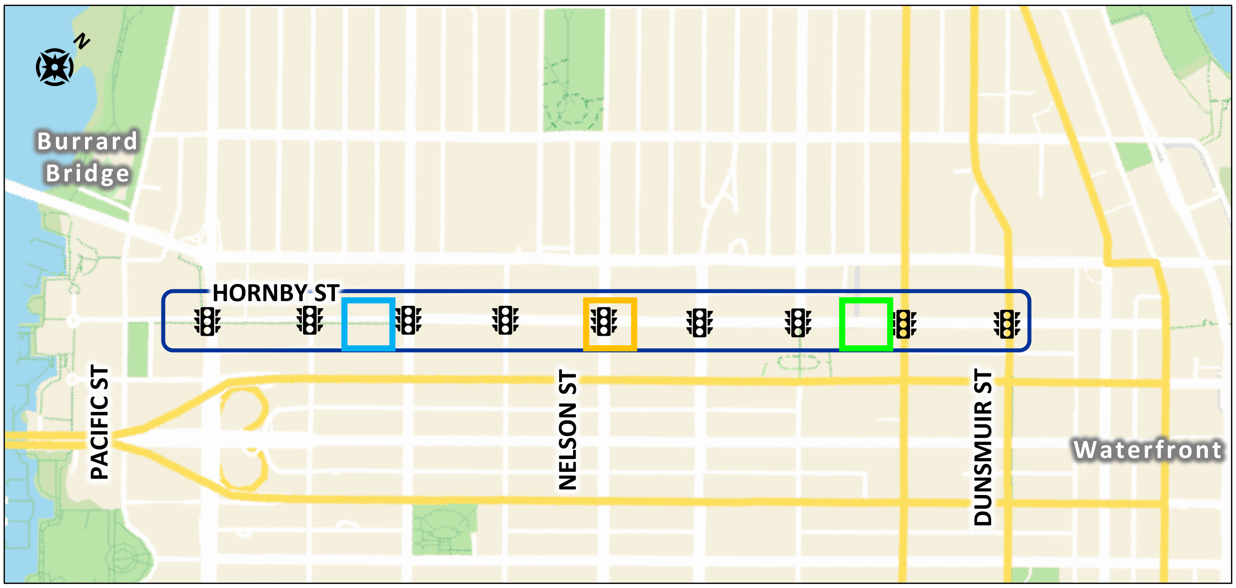


Image credit: Google Maps and Streetview

CASE STUDY METHODOLOGY

This case study is based on secondary research. It relies on the administrative reports "*Downtown Separated Bicycle Lanes Status Report, Summer 2011*" and "*Downtown Separated Bicycle Lanes Status Report, Spring 2012*" prepared for the Standing Committee on Planning and Environment. The reports are based on bicycling growth from before to after implementation, safety, pedestrian volumes, the effect on transit operations, vehicle volumes and travel times, financial impacts and public opinion. The reports also included information about Dunsmuir Street.

DESIGN FEATURES OF BICYCLE FACILITY

Mid-block segments	Intersections
• Continuous two-way protected bicycle lanes to the right of vehicles. The facility is located on the east side of the road. • Separation from traffic provided by a curb buffer (0.8 m) supplemented with planters and/or parking. • Separation from pedestrian clearway provided by a full barrier curb. • Parking maintained only on one side of the traffic lane. Parking is located on the driver's left side south of Nelson Street and to the right side in the north. • Few loading zones interspaced within parking areas.	• Corridor includes nine signalized intersections at four-legged intersections. Five are with other one-way roadways and three with two-way roadways. • Intersections are marked with intersection crossing markings comprised of elephants' feet markings, green paint and white bicycle symbols. • Driveways and laneways marked with elephants' feet markings and some have green paint. • Right-turn lanes are provided at three intersections. The other 5 intersections do not have any special accommodation for turning.

PERFORMANCE EVALUATION – MID BLOCK SEGMENT

	Conditions without bicycle facility	Conditions with bicycle facility
Cross Section	• Curb-to-curb width 12.1-12.8 m. • Two, one-way travel lanes (3.0-3.2 m). • One-way painted bicycle lane (1.5 m) between the rightmost travel lane and curbside parking. • Two parking/loading lanes (2.5 m) on curbsides.	• Curb-to-curb width unchanged. • Two, one-way travel lanes (3.0-3.2 m). Only one, one-way travel lane on the two blocks south of Davie Street. • One parking/loading lane (2.5 m) curbside. Two parking/loading lanes south of Davie Street. • Protected two-way bicycle lane (2.9-3.0 m) with curb/planter buffer(0.8 m; includes 0.15 m curb plus 0.65 m planter).
Bicycle Pavement Markings	• Diamond/bicycle reserved-lane markings.	• Diamond/bicycle reserved-lane markings. • Yellow directional dividing line on the facility. • White triangle warning symbols on the pavement used to indicate bicycle direction of travel.
Cycling Volumes	• 10,000/month (2009). • 24,000/month from July 2010 and March 2011 on the Burrard Bridge.	• 29,400/month (Average of Jan 2011-Mar 2012). • 30,000 from July 2011 and March 2012 on the Burrard Bridge.
Motor Vehicle Volumes	• 14,000/day	• 14,000/day
Motor Vehicle Travel Time	• Not included in the report used for this case study	• For most of the roadway travel times were unchanged. Between Pender Street and Hastings Street there was an average travel time increase of 30 seconds.

PERFORMANCE EVALUATION – INTERSECTIONS

	Conditions without bicycle facility	Conditions with bicycle facility
Cross Sections at Intersection	• Curb-to-curb width 12.1-12.8 m. • Two, one-way travel lanes (3.0-3.2 m). • One-way painted bicycle lane (1.5 m) between the rightmost travel lane and curbside parking. • Left and right-turn lanes (2.5 m) in place of parking lanes.	• Curb-to-curb width unchanged. • Two, one-way travel lanes (3.0-3.2 m). • Protected two-way bicycle lane (3.0 m wide lane with 0.8m curb buffer). • One turning lane (2.5 m) in place of parking lane.
Bicycle Markings Through Intersection	• No bicycle markings.	• Elephants' feet markings, green paint and white bicycle symbols.
Bicycle Markings Approaching Intersection	• Dashed white lane lines. • Diamond/bicycle reserved-lane markings.	• Curb barrier. • Diamond/bicycle reserved-lane markings. • Bicycle stop bar.
Motor Vehicle Right-Turn Volumes	• No information available.	• Ranges from 10 to 150 right-turning vehicles during the peak hours.
Right Turn Lane Length	• No information available.	• 25 m.
Transit Accommodation at Intersections	• No transit routes.	• No transit routes.
Intersecting bicycling Facilities	• No information available.	• One-way protected bicycle lane at Pacific Street. • Two-way protected bicycle lanes at Drake Street, Helmcken Street and Dunsmuir Street. • Painted bicycle lane at Smithe Street.
Signal Timing	• No bicycle signal timing.	• Bicycle signals provided in southbound direction at every intersection and northbound direction for some intersections.

PERFORMANCE EVALUATION – COLLISIONS AND OBSERVATIONS

	Conditions without bicycle facility	Conditions with bicycle facility
Collisions	• Not included in the report used for this case study.	• Reduced total collisions on Hornby Street by 18% from 2008 and 2009 compared to 2011. • Only one collision involving a bicyclist reported in 2011.
Conflicts	• Not included in the report used for this case study.	• Reduction in 80% of bicyclists using the sidewalk.
Overall Public Perception	• 56% support a protected bicycle lane on Hornby while 30% do not and 14% are undecided.	• 64% support the protected bicycle lane on Hornby while 28% do not and 8% are undecided.
Other Observations		• Some right turns were prohibited with the implementation of separated bicycle lanes, meaning some driving trips were rerouted, adding 90 seconds to their trip.

DISCUSSION AND OPPORTUNITIES FOR FUTURE CASE STUDIES

The introduction of protected bicycle lanes on Hornby Street has led to an increase in bicycle traffic volumes, reduction in bicyclists using the sidewalk, and minimal impact to vehicle traffic. In addition, it appears that there have been safety improvements in terms of a reduction in total collisions on Hornby Street, as well as, improved public perception regarding the implementation of these facilities. Important issues that may be worth exploring in a future similar undertaking are:

- Conflict analysis at the various intersection configurations to identify potential safety concerns and to evaluate existing bicycle intersection treatments.
- Safety performance over a more significant time period after a facility is implemented.
- Any specific issues associated with the interaction of the bicycle facility with trucks and buses.
- Accessibility issues for people on wheel chairs (e.g. loading zones and other access points).

D.1.5 Buffered bicycle facility, one-way (Toronto, ON)

Bloor Street from Shaw Street to Avenue Road

Case study overview: This facility was piloted by the City of Toronto along 2.5 km of Bloor Street between Shaw Street and Avenue Road. The purpose of the pilot was to improve safety and reduce risk for all road users, as well as to reduce impacts to curbside users (e.g. parking, loading, deliveries, and waste collection).

Bloor Street provides an east-west connection for motorists, bicyclists and pedestrians. Before the implementation of the bicycle facility, Bloor Street was a 4-lane undivided road with a speed limit of 50 km/h and parking on both sides. It carried approximately 24,000 motor vehicles and 3,300 bicyclists per day. Following the implementation of the bicycle facility, the road was reduced to one lane per direction and bicycling volumes increased to approximately 5,000 bicyclists per day. The roadway is scheduled for reconstruction within 5 years. At this time, the paint and bollard “retrofit” bicycling facility may be reconstructed as permanent bicycle tracks.

Land use context: Bloor Street is a major arterial roadway, located in the downtown core of an urban centre. The corridor supports commercial, residential and institutional functions.

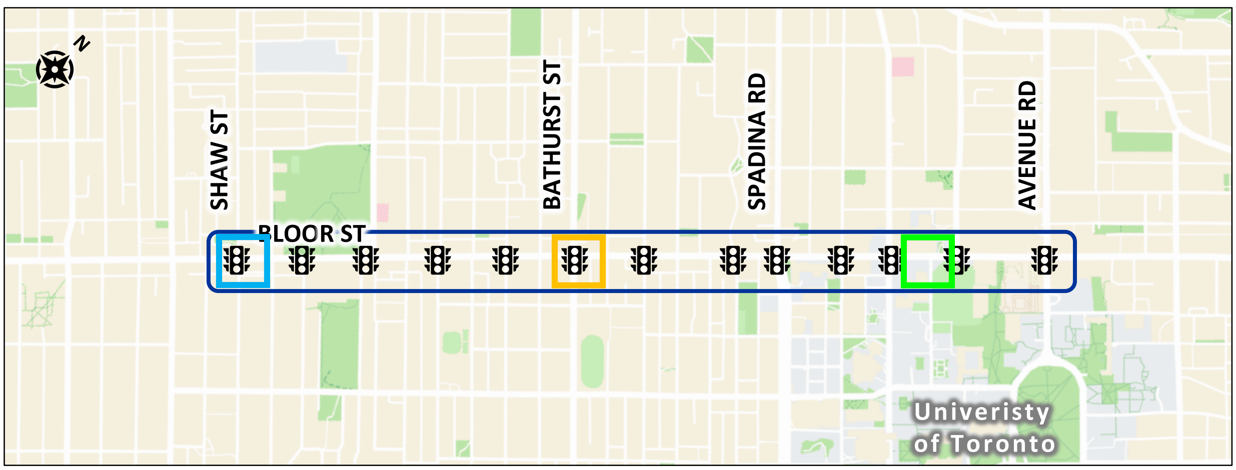


Image credit: Google Maps and Streetview

CASE STUDY METHODOLOGY

This case study is based on secondary research. It relies on the publicly-available report "*Bloor Street West bicycle Lane Pilot Project Evaluation*" prepared for the City of Toronto Public Works and Infrastructure Committee in October 2017. The report is based on before and after data collected for the purposes of the evaluation (i.e. motor vehicle traffic, bicycle traffic, collision/conflicts, motor vehicle travel time and public opinions). In addition to evaluating Bloor Street, the methodology for the pilot project also included evaluation of the parallel corridors of Dupont Street and Harbord Street, as well as economic impact on local businesses along Bloor Street.

DESIGN FEATURES OF BICYCLE FACILITY

Mid-block segments	Intersections
• Continuous unidirectional buffered bicycle lanes adjacent to curb on both sides of the street. • Parking maintained only on one side between the buffered bicycle lanes and the traffic lane. Parking switches sides along the length of the corridor. • Loading zones interspaced within parking areas. • Separation from traffic provided by painted buffer (0.3 to 3.0 m wide) and flexi-post bollards and/or parked cars. • Separation from pedestrian clearway provided by a full barrier curb. • Painted buffer area may be used for snow storage.	• Corridor includes 13 signalized intersections. • All intersections are marked with intersection crossing markings comprised of white lane lines and double chevron directional markings. • Driveways and laneways marked with elephant's feet markings. • Two right-turn lanes (at Bathurst St) and 10 left-turn lanes provided for motor vehicles at key intersections.

PERFORMANCE EVALUATION – MID BLOCK SEGMENT

	Conditions without bicycle facility	Conditions with bicycle facility
Cross Section	• Curb-to-curb width 12.2-12.8 m. • Four travel lanes (3.0 m wide). • Parking/loading allowed from both curb lanes during off-peak periods.	• Curb-to-curb width unchanged. • Two travel lanes (3.3 m wide). • Permanent 24-hour parking/loading allowed on one side of the road (2 m wide). • Buffered bicycle lane on both sides of road (1.5 m wide lane with 0.3 m to 1.0 m buffer).
Bicycle Pavement Markings	• None.	• Bicycle markings with diamond reserved lane markings.
Cycling Volumes	• 3,300 bicycles/day.	• 4,900 bicycles/day.
Motor Vehicle Volumes	• 24,300 vehicles/day.	• 20,400 vehicles/day – reduction mainly in the peak period because of motor vehicle re-routing due to the bicycle lanes.
Motor Vehicle Travel Time	• A.M. peak - 10 min (EB); 7 min (WB). • P.M. peak – 12 min (EB); 11 min (WB).	• A.M. peak - 12 min (EB); 8 min (WB). • P.M. peak – 12 min (EB); 15 min (WB). • All after signal timing improvements.

PERFORMANCE EVALUATION – INTERSECTIONS

	Conditions without bicycle facility	Conditions with bicycle facility
Cross Sections at Intersection	• Curb-to-curb width 12.2-12.8 m. • Four travel lanes (3.0 m wide). • Left-turn lanes provided at most intersections with arterial roads.	• Curb-to-curb width unchanged. • Two travel lanes (3.3 m). • Left-turn lanes (2.8 m) provided at most intersections with arterial roads. • Buffered bicycle lane on both sides of road (1.5 m wide lane with 0.3 m buffer).
Bicycle Markings Through Intersection	• No bicycle markings.	• White lane lines and double chevrons used through intersections.
Bicycle Markings Approaching Intersection	• No markings between the end of curbside parking and the intersection.	• Painted buffer (0.3 m wide) with bollards used to gradually taper the through motor vehicle lane toward the bicycle lane to make room for the left turn lane. • White lane lines and double chevrons used to indicate that right turning motor vehicles merge across the bicycle lane. • Right-turn lanes marked with turn arrow and sharrows on left side of the turn lane.
Motor Vehicle Right-Turn Volumes	• RT volumes pre-installation for two locations where RTLs installed.	• RT counts post installation, for two locations where RTLs installed.
Right Turn Lane Length	• During off-peak; parking prohibited 15 m from intersections. • During peak; parking/stopping restricted in curb lane.	• Right-turn lanes provided allow for storage of two to three motor vehicles, with bicycle lane on left side.
Transit at Intersections	• Bus stops located nearside, on approach to intersections.	• Bus stops generally located nearside, on approach to intersections.
Intersecting bicycling Facilities	• Four intersections have intersecting bicycle lanes.	• White lane line and chevron markings provided along Bloor St. only.
Adjacent Markings	• Zebra stripe pedestrian crossing markings provided at most signalized crossings.	• Separation between pedestrian crossing markings and buffered bicycle lane is typically 1.0 m.
Signal Timing	• No protected bicycling phases.	• Corridor re-timed for operational efficiency of motor vehicle traffic.

PERFORMANCE EVALUATION – COLLISIONS AND OBSERVATIONS

	Conditions without bicycle facility	Conditions with bicycle facility
Collisions	Average of 22 collisions per year between 2008 and 2012 in pilot corridor with most common types being dooring (32%), motorists overtaking a bicyclist (17%), and motorists accessing on-street parking (8%).	No data available yet but preliminary indications, based on anecdotal evidence, show that despite an increase in bicycling volume, collisions involving bicyclists have remained the same as before.
Conflicts with bicyclists	• Not included in the report used for this case study.	Before and After conflict analysis was conducted by the University of Toronto Transportation Research Institute at three locations. Results are: • Conflicts between motor vehicles and bicyclists decreased by 61%. • Conflicts between pedestrians and bicyclists increased by 61% (primarily due to 'jaywalking'). • Conflicts between all road users decreased by 44%. • Conflicts between motor vehicles decreased by 71%. • Conflicts between motor vehicles and pedestrians decreased by 55%.
Overall Public Perception	• 14% of drivers reported feeling comfortable driving next to bicyclist. • 3% of bicyclists reported feeling comfortable riding next to motor vehicles.	• 66% of drivers reported feeling comfortable driving next to bicyclist. • 85% of bicyclists reported feeling comfortable riding next to motor vehicles. • Increased desire to bicycle. • Increased perception of safety by new bicyclists and women. • The configuration of parking separated bicycle lanes next to curb raised concerns by motorists and bicyclists due to limited visibility at intersections.
Other Observations		• Observed re-routing of bicyclists from adjacent, parallel facilities to Bloor. • People with disabilities expressed concerns about accessible loading.

DISCUSSION AND OPPORTUNITIES FOR FUTURE CASE STUDIES

The findings from this study show that a buffered bicycle facility like the one piloted on Bloor Street can have increased demand in terms of bicycling volumes as well as potential bicycling safety benefits. Prior to the installation of the buffered facility, about 3,300 bicycles per day travelled on this 2.5-km segment of Bloor street. This activity increased by nearly 50% to 4,900 bicycles per day following the installation of the facility. Because collision information also existed for the 'before' condition, it was possible to calculate a bicycle collision rate for this road segment. Given that there was an average of 22 collisions per year between 2008 and 2012 prior to the installation of the buffered bicycle facility, the corresponding collision rate is 7.3 bicycle collisions per million bicycle-kilometres of travel (MBKT).

While no collision data was available for the 'after' condition at the time of the evaluation of the facility, anecdotal evidence shows that despite an increase in bicycling volume, collisions involving bicyclists have remained the same as before at about 22 collisions per year. When considering the increased bicycle volume, and if collisions in fact remained constant, this represents a bicycle collision rate of approximately 4.9 bicycle collisions per MBKT, or a 33% improvement in safety performance.

Further to the increase in bicycle volume, the implementation of this facility also resulted in a decrease in vehicular volume of about 15% (from 24,300 vehicles per day prior to implementation to 20,400 vehicles per day post implementation) and an observed increase in travel time for vehicular traffic.

The study also shows extensive evidence of decreased conflicts between the following combinations of users based on before-after studies: motor vehicles and bicyclists (61%), motor vehicles and pedestrians (55%), and motor vehicles with motor vehicles (71%). However, there was an observed increase in conflicts between pedestrians and bicyclists (61%), which has been mainly attributed to jaywalking.

From a public perception perspective, the introduction of a buffered bicycle facility has resulted in a significant increased sense of security and comfort for both drivers and bicyclists. This has resulted in increased desire to bicycle, particularly for new bicyclists and women. However, there are concerns regarding accessibility for people with disabilities who need access to the curb for loading.

Overall, this case study presents positive observed and perceived safety outcomes resulting from the implementation of a buffered bicycle facility. Important issues that may be worth exploring in future similar undertakings are:

- The impact on pedestrians in terms of conflicts and/or collisions
- Performance during winter conditions, both from the operational and safety perspectives, particularly due to snow accumulation.
- Any specific issues associated with the interaction of the bicycle facility with trucks and buses.
- Perceived safety by other segments of the population such as youth.
- Accessibility for people on wheel chairs.
- Further exploration regarding the performance of these facilities at intersections.

D.1.6 Painted bicycle lane (London, ON)

Ridout Street South from Craig Street to Commissioners Road East

Case study overview: This facility was installed by the City of London, ON, in 2008 along 2.0 km of Ridout Street South between Craig Street and Commissioners Road East. The bicycle lanes are marked with solid white lane lines and diamond/bicycle reserved-lane symbols. The bicycle lanes are signed as a designated bicycle lane and a bicycle route. The City believes that painted bicycle lanes make it easier for bicycles and vehicles to share the road.

Land use context: Ridout Street South is a north-south primary collector roadway in a residential area. The roadway has two lanes (i.e. one lane per each direction) and heavy vehicles are prohibited. Average daily traffic is estimated to be 10,800 vehicles per day based on a turning movement count collected by the City on March 25, 2015 at the intersection of Rideout St N and Horton St E.

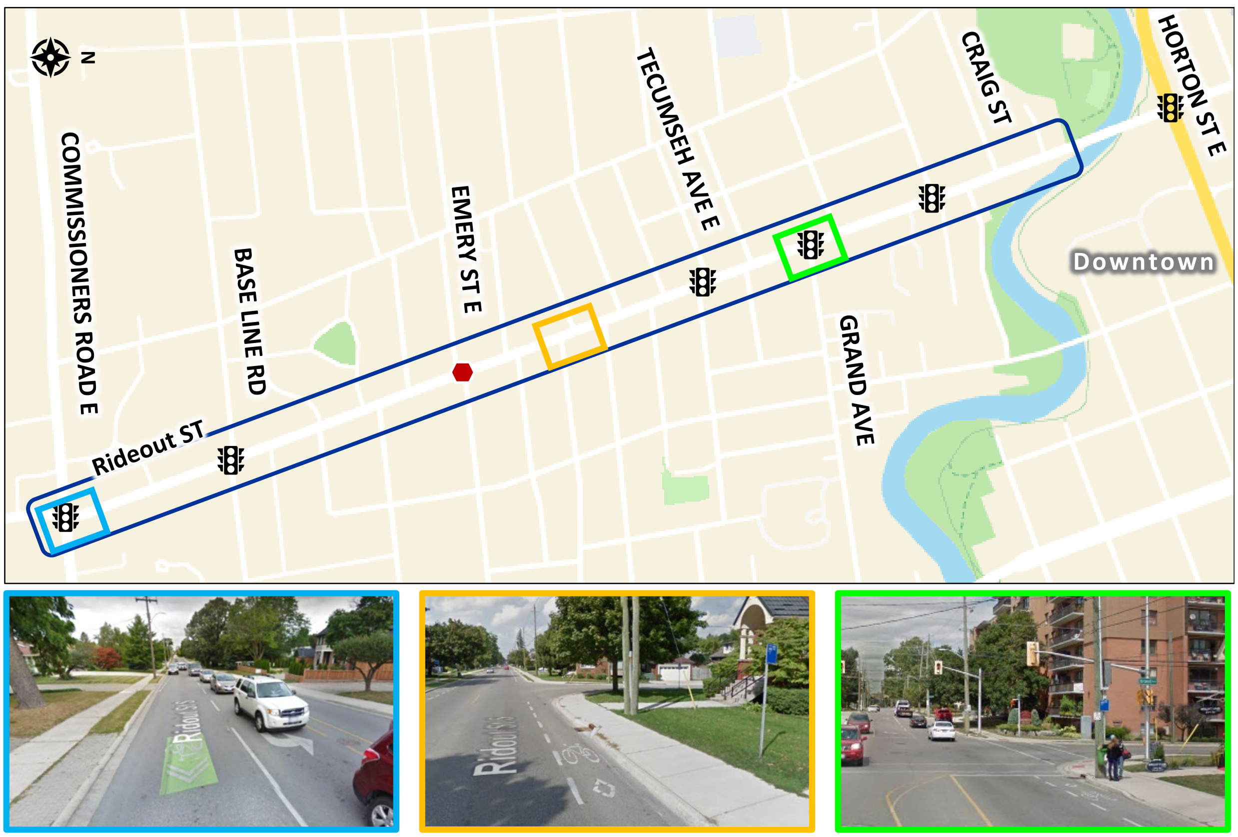


Image credit: Google Maps and Streetview.

CASE STUDY METHODOLOGY

This case study is based on primary research relying on available data provided by the City of London. In addition to correspondence with City staff, the data used in this case study includes:

- Collision diagrams for collisions involving bicyclists along the corridor between 2008 and 2017.
- A vehicle and truck turning movement count collected by the City at Ridout Street South and Horton Street East on March 25, 2015.
- An inductive loop bicycle count collected by the City on Ridout Street South, south of Craig Street from March 01, 2018 to August 13, 2018.
- Results from a network safety screening of stop-controlled intersections completed by the City in 2017.

DESIGN FEATURES OF BICYCLE FACILITY

Mid-block segments	Intersections
• Continuous unidirectional painted bicycle lanes adjacent to curb on both sides of the street. • Curb side parking is prohibited on both sides of the street. • Access to driveways and parking lots for low and medium density dwellings. • The painted bicycle lane transitions to a major street shared lane at the bridge to the north and at Commissioners Rd E. • Separation from sidewalk provided by a full barrier curb.	• Corridor includes five signalized intersections and one all-way stop-controlled intersections. • Painted bicycle lane lines are not provided through the intersection. • Three of the five signalized intersections provide exclusive left-turn lanes for motor vehicles.

PERFORMANCE EVALUATION – MID BLOCK SEGMENT

	Conditions without bicycle facility	Conditions with bicycle facility
Cross Section	• Curb-to-curb width (10 m) • One travel lane (3.5 m) per direction. • One parking lane (3.0 m) on the east side.	• Curb-to-curb width unchanged. • One travel lane per direction (3.3 m). • Permanent prohibition of parking along both sides of the road. • Painted bicycle lane (1.5 m) on both sides of the road.
Bicycle Pavement Markings	• No bicycle markings.	• White lane lines. • Diamond/bicycle reserved-lane markings.
Cycling Volumes	• No data available.	• 145 bicycles per day (Weekday: 164, Weekend: 97) based on data collected between March 01, 2018 and August 13, 2018.
Motor Vehicle Volumes	• No data available.	• 10,800 vehicles per day based on a turning movement count collected at Rideout Street North and Horton Street East on March 25, 2015, seven years after bicycle lane installation.

PERFORMANCE EVALUATION – INTERSECTIONS

	Conditions without bicycle facility	Conditions with bicycle facility
Cross Section at Intersection	• One travel lane per direction (3.5 m) with extra space (3 m) on east side curb from parking restriction near intersections. • Left-turn lanes provided at three of five signalized intersections.	• Curb-to-curb width unchanged. • One travel lane per direction (3.3 m). • Left-turn lanes provided at three of five signalized intersections. • Painted bicycle lane on both sides of road (1.5 m wide).
Bicycle Markings Through Intersection	• No bicycle markings.	• No bicycle markings.
Bicycle Markings Approaching Intersection	• No bicycle markings.	• Solid white lane lines are changed to dashed white lane lines near intersections accompanied with a bicycle diamond lane marking.
Right Turn Lane Length	• Unknown.	• No right turn lanes provided.
Transit Accommodation at Intersections	• There are 15 bus stops along the study roadway that are located on the near side of intersections.	• There are 15 bus stops along the study roadway that are located on the near side of intersections. Buses stop in the bicycle lanes to pick up customers.

PERFORMANCE EVALUATION – COLLISIONS AND OBSERVATIONS

	Conditions without bicycle facility	Conditions with bicycle facility
Collisions	• No data available.	Two collisions involving bicycles occurred during the last 10 years from 2008 to 2017: • One right-turning vehicle collision. • One occurred mid-block along the corridor.
Overall Public Perception	• No information available.	No official safety concern has been received so far from the bicyclists who use this bicycle lane regularly.
Other Observations	• No information available.	Intersections are difficult to navigate and require special attention to ensure bicyclists safety. It is also challenging to connect to side streets.

DISCUSSION AND OPPORTUNITIES FOR FUTURE CASE STUDIES

While the data provided by the City was helpful in establishing the current conditions associated with the bicycle facility, it was difficult to properly evaluate performance without information prior to the installation of the facility. From a safety perspective, the data shows that there have been two collisions involving bicycles in a 10-year period (one collision every five years). The bicycle volume on the facility has been measured to be about 145 bicycles per day. Assuming that these bicyclists travel the entire 2-km length of the facility, this results in an annual exposure rate of about 105,850 bicycle-kilometres travelled (BKT), which translates into a collision rate of approximately 1.9 bicycle collisions per million BKT. Unfortunately, with the data provided, it is not possible to compare this rate to that of vehicular traffic traveling the same road segment. It is also difficult to draw many other conclusions regarding the overall safety performance of this facility given the limited amount of information available. From a public perception perspective, it can be assumed that the facility has performed well given the absence of safety concerns from the public.

As new painted bicycle lanes are planned, it would be beneficial to collect data prior to implementation and post implementation to enhance the understanding about the safety performance of these facilities. Important issues that may be worth exploring are:

- Safety performance at intersections.
- Safety performance along segments.
- Performance during winter conditions, both from the operational and safety perspectives, particularly due to snow accumulation.
- Perceived safety by various segments of the population.
- Any specific issues associated with the interaction of the bicycle facility with trucks and buses.
- Accessibility issues for people on wheel chairs (e.g. loading zones and other access points).

D.1.7 Contra-flow bicycle lane (Quebec, QC)

Rue du Pont from Rue du Prince- Édouard to Rue Saint-Joseph Est

Case study overview: This facility was installed by Quebec City in July 2016 along 280 metres of Rue du Pont from Rue du Prince- Édouard to Rue Saint-Joseph Est.

Contra-flow bicycle lanes are bicycle lanes designed to allow bicyclists to ride in the opposite direction of motor vehicle traffic. They effectively convert a one-way traffic street into a two-way street: one direction for motor vehicles and bicycles, and the other for bicycles only.

Land use context: Rue du Pont is a secondary collector roadway passing through a commercial and residential area.

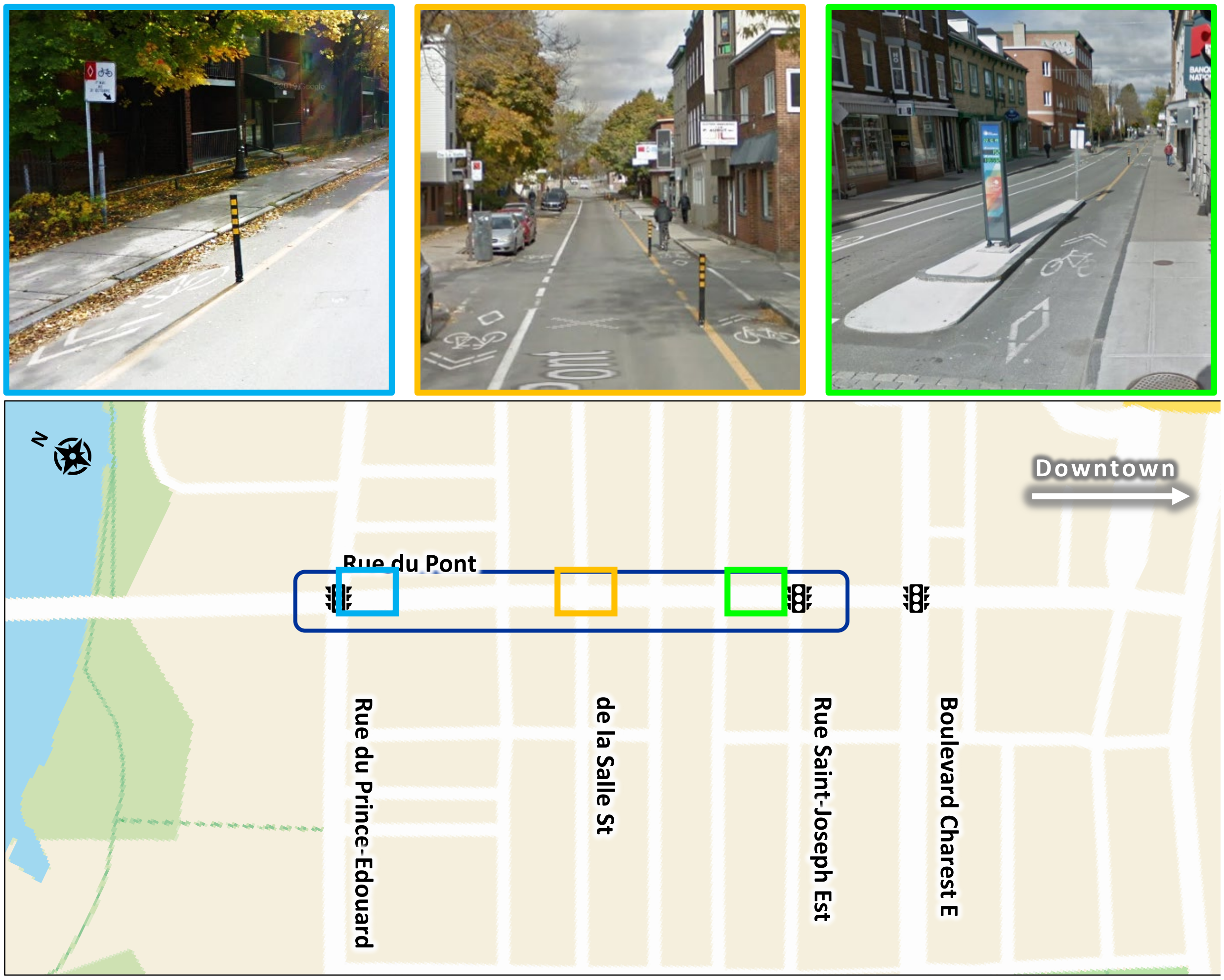


Image credit: Google Maps and Streetview.

CASE STUDY DATA METHODOLOGY

This case study is based on primary research relying on the following data provided by Quebec City:

- Automated bicycle count data on Rue du Pont south of Rue du Prince-Edouard from September 13 to October 3, 2016.
- Two turning movement counts collected at Rue du Pont and Rue du Prince-Edouard before (September 11th, 2014) and after (December 7th, 2018) the contra-flow bicycle lane was implemented.
- Two turning movement counts collected at Rue du Pont and Rue Saint-Joseph Est before (September 10th, 2014) and after (December 18th, 2018) the contra-flow bicycle lane was implemented.

DESIGN FEATURES OF BICYCLE FACILITY

Mid-block segments	Intersections
• One-way street for southbound traffic. • Continuous contra-flow buffered bicycle lane with flexible posts provided along the east side of the street for northbound bicycle traffic. • Continuous painted bicycle lane provided on the west side of the street for southbound bicycle traffic. • Curbside parking is only permitted on the west side of the street. • Separation from the pedestrian sidewalk is provided with a full barrier curb.	• Corridor includes six intersections, of which, two are signalized. • All intersections are marked with intersection crossing markings comprised of dashed white lane lines and dashed yellow lane lines on the contra-flow lane. • Curb bulb-outs are used at intersections and mid-block to discourage vehicle travel in the parking lane. • A median island is implemented on the north approach at Rue Saint-Joseph Est to prevent vehicles from travelling northbound on Rue du Pont. • Crossing streets are also one-way streets.

PERFORMANCE EVALUATION – MID BLOCK SEGMENT

	Conditions without bicycle facility	Conditions with bicycle facility
Cross Section	• Curb-to-curb width 8.0 m. • Two travel lanes (3.0 m each). • One parking lane (2.0 m).	• Curb-to-curb width unchanged. • One, one-way travel lane (3.0 m). • One parking lane (2.0 m). • Bicycle lane on both sides of the road (1.5 m each).
Bicycle Pavement Markings	• No bicycle markings.	• Sharrows with diamond reserved lane markings. • Solid yellow dividing lane line (contraflow northbound) with flexible bollards. • Solid white lane line (south bound).
Cycling Volumes	• Approximately 350 bicycles per day.	• 902 bicycles per day (Weekday: 986, Weekend: 692) based on data collected between September 13, 2018 and October 3, 2018.
Motor Vehicle Volumes	6-hour traffic volume from turning movement counts (7 a.m. to 10 a.m. and 3 p.m. to 6 p.m.): • 1,700 southbound from Rue du Prince-Edouard (Sep. 11, 2014). • 1,600 southbound to Rue Saint-Joseph Est (Sep. 10, 2014).	6-hour traffic volume from turning movement counts (7 a.m. to 10 a.m. and 3 p.m. to 6 p.m.): • 900 southbound from Rue du Prince-Edouard (Dec. 7, 2018). • 700 southbound to Rue Saint-Joseph Est (Dec. 18, 2018).

PERFORMANCE EVALUATION – INTERSECTIONS

	Conditions without bicycle facility	Conditions with bicycle facility
Cross Sections at Intersection	• Curb-to-curb width 6.0 m. • Two travel lanes (3.0 m each). • Curb bulb-outs at intersection in parking lane to prevent right-turning vehicles from using parking lane to turn.	• Curb-to-curb width unchanged. • One, one-way travel lane (3.0 m). • Bicycle lanes on both sides of the road (1.5 m each). • Curb bulb-outs at intersection in parking lane to prevent right-turning vehicles from using parking lane to turn.
Bicycle Markings Through Intersection	• None.	• Dashed yellow lane lines used through intersections on contra-flow lane. • Dashed white lane lines used through intersections for southbound painted bicycle lane.
Bicycle Markings Approaching Intersection	• None.	• Solid yellow dividing lane lines with white sharrow and flexible bollards (northbound). • Dashed white lane lines with white sharrows (southbound). • Diamond reserved-lane markings are added to sharrows after intersections.
Motor Vehicle Right-Turn Volumes	• No information available.	• No information available.
Transit Accommodation at Intersections	• No bus stops along the street.	• No bus stops along the street.

PERFORMANCE EVALUATION – COLLISIONS AND OBSERVATIONS

	Conditions without bicycle facility	Conditions with bicycle facility
Collisions	• No information available.	• No information available.
Conflicts with bicyclists	• No information available.	• No information available.
Overall Public Perception	• No information available.	• No information available.
Other Observations	• No information available.	• No information available.

DISCUSSION AND OPPORTUNITIES FOR FUTURE CASE STUDIES

Given the limited data available for this facility and the absence of any studies evaluating its performance, it is not possible to draw any conclusions regarding the safety performance of this contra-flow lane. Important issues that may be worth exploring in a future evaluation are:

- The impact of a contra-flow lane on pedestrians in terms of conflicts and/or collisions.
- Performance during winter conditions, both from the operational and safety perspectives.
- Any specific issues associated with the interaction of the bicycle facility with trucks and buses.
- Perceived safety by different types of bicyclists.

D.1.8 Major street shared lanes (Calgary, AB)

8th Avenue SW between 3rd Street SW and 11th Street SW (from 2011 to 2015)

Case study overview: This facility was installed by the City of Calgary in 2011 along 900 metres of 8th Avenue SW between 3rd Street SW and 11th Street SW. The facility was replaced in 2015 by a protected bicycle lane in the westbound direction and a buffered bicycle lane in the eastbound direction.

Land use context: 8th Avenue SW is a two-way, two-lane major arterial passing through downtown Calgary. The roadway ends at 11th Street SW in the west and 3rd Street SW in the east at the CORE shopping centre where only bicyclists and pedestrians are allowed to travel.

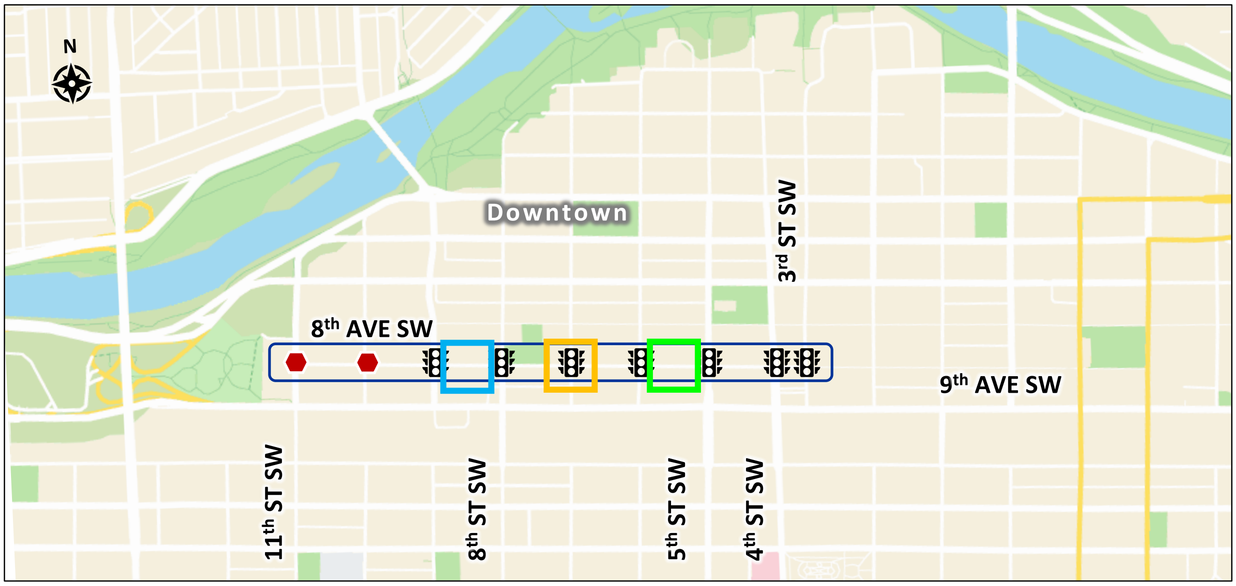


Image credit: Google Maps and Streetview

CASE STUDY METHODOLOGY

This case study is based on primary research conducted using traffic volume and collision data provided by the City of Calgary. The City provided a total of 21 years of bicycle collision data from 1996 to 2017. Ten years of collision data (2001 to 2010) were used for the period before the installation of the sharrows and three years of collision data (2012 to 2014) were used for the period after the installation. The sharrows were introduced in 2011, therefore, this year of data was not included in this analysis. In addition, data from 2015 onward was excluded because the sharrows were replaced in 2015.

Traffic exposure was defined by vehicle volumes and calculated from turning movement counts collected at each of the study corridor intersections before and after the facility was implemented.

DESIGN FEATURES OF BICYCLE FACILITY

Mid-block segments	Intersections
• Corridor includes seven signalized intersections and two stop-controlled intersections. (intersections at 10th and 11th) • Parking bay along eastbound 8th Avenue SW from 3rd Street SW to 4th Street SW. • Curb parking along westbound 8th Avenue SW from 4th Street SW to 5th Street SW. • Curb parking on both sides of 8th Avenue SW from 5th Street SW to 11th Street SW. • Separation from pedestrian clearway provided by a full barrier curb.	• Corridor includes seven signalized intersections and two stop-controlled intersections. • In general, parking is prohibited in the parking lane within 15 m of the intersection which provides storage for two right-turning vehicles.

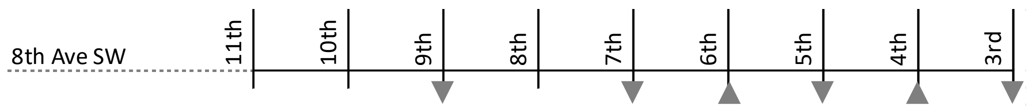
PERFORMANCE EVALUATION – MID BLOCK SEGMENT

	Conditions without bicycle facility	Conditions with bicycle facility
Cross Section	• Curb-to-curb width (13 m) • One travel lane (3.5 m) per direction. • One parking lane (3.0 m) on each side.	• Curb-to-curb width unchanged. • One travel lane (3.5 m) per direction. • One parking lane (3.0 m) on each side.
Bicycle Pavement Markings	• None.	• Sharrows.

Cycling Volumes

Million entering bicycles (MEB) at intersections

	11th	10th	9th	8th	7th	6th	5th	4th	3rd
Before	0.15	0.06	0.15	0.29	0.16	0.33	0.21	0.30	0.24
After	0.25	0.07	0.19	0.25	0.56	0.25	0.27	0.55	0.38
Change/Year*	**10%**	**0%**	**7%**	-3%	**61%**	-2%	**7%**	**21%**	**11%**



Motor Vehicle Volumes

Million entering vehicles (MEV) at intersections

	11th	10th	9th	8th	7th	6th	5th	4th	3rd
Before	5.19	3.17	2.52	5.34	3.16	4.13	4.07	3.46	1.93
After	3.58	2.67	2.66	5.49	3.37	4.00	5.56	4.32	2.18
Change/Year*	-4%	-1%	**1%**	**1%**	**2%**	0%	**9%**	**6%**	**3%**

** The number of years between before and after counts varies by intersection ranging from a difference of 4 to 16 years.*

	Conditions without bicycle facility	Conditions with bicycle facility
Motor Vehicle Travel Time	No data available.	No data available.

PERFORMANCE EVALUATION – INTERSECTIONS

<table>
<tr><th></th><th>Conditions without bicycle facility</th><th>Conditions with bicycle facility</th></tr>
<tr><td>Cross Sections at Intersection</td><td>• Curb-to-curb width (13 m)
• One travel lane (3.5 m) per direction.
• Right-turn storage in parking lane 15 m from intersection (3.0 m wide).</td><td>• Curb-to-curb width unchanged.
• One travel lane (3.5 m) per direction.
• Right-turn storage in parking lane 15 m from intersection (3.0 m wide).</td></tr>
<tr><td>Bicycle Markings Through Intersection</td><td>• No bicycle markings.</td><td>• No bicycle markings.</td></tr>
<tr><td>Bicycle Markings Approaching Intersection</td><td>• No bicycle markings.</td><td>• No bicycle markings.</td></tr>
<tr><td>Right Turn Lane Length</td><td>• Right-turns can be made from parking lane which is generally prohibited 15 m before the intersection.</td><td>• Right-turns can be made from parking lane which is generally prohibited 15 m before the intersection.</td></tr>
<tr><td>Motor Vehicle Right-Turn Volumes</td><td colspan="2">
Average daily westbound right-turn volume at intersections
<table>
<tr><th>8th Ave SW</th><th>11th</th><th>10th</th><th>9th</th><th>8th</th><th>7th</th><th>6th</th><th>5th</th><th>4th</th><th>3rd</th></tr>
<tr><td>Before</td><td>1210</td><td>990</td><td></td><td>670</td><td></td><td>970</td><td></td><td>10</td><td></td></tr>
<tr><td>After</td><td>990</td><td>940</td><td></td><td>760</td><td></td><td>780</td><td></td><td>280</td><td></td></tr>
<tr><td>Change/Year*</td><td>-3%</td><td>0%</td><td></td><td>3%</td><td></td><td>-2%</td><td></td><td>675%</td><td></td></tr>
</table>
Average daily eastbound right-turn volume at intersections
<table>
<tr><th></th><th>11th</th><th>10th</th><th>9th</th><th>8th</th><th>7th</th><th>6th</th><th>5th</th><th>4th</th><th>3rd</th></tr>
<tr><td>Before</td><td></td><td>70</td><td>210</td><td>550</td><td>860</td><td></td><td>780</td><td></td><td>920</td></tr>
<tr><td>After</td><td></td><td>170</td><td>180</td><td>580</td><td>860</td><td></td><td>850</td><td></td><td>880</td></tr>
<tr><td>Change/Year*</td><td></td><td>9%</td><td>-4%</td><td>1%</td><td>0%</td><td></td><td>2%</td><td></td><td>-1%</td></tr>
</table>
* The number of years between before and after counts varies by intersection ranging from a difference of 4 to 16 years.
</td></tr>
<tr><td>Transit Accommodation at Intersections</td><td>• No data available.</td><td>• One transit stop on the far-side of the intersection at 8th St SW. LRT corridor is one block north on 7th Ave SW.</td></tr>
<tr><td>Intersecting bicycling Facilities</td><td>• None.</td><td>• None.</td></tr>
<tr><td>Signal Timing</td><td>• None.</td><td>• None.</td></tr>
</table>

PERFORMANCE EVALUATION – COLLISIONS AND OBSERVATIONS

	Conditions without bicycle facility	Conditions with bicycle facility
Collisions	• The annual average bicycle collisions per million entering bicycles (MEB) across all 8th Avenue SW study intersections was 1.6 collisions/MEB (2001-2010). • 60% of reported bicycle collisions resulted in injury and 40% resulted in property damage only. There were no bicyclist fatalities reported. • Additional details from the collision analysis are discussed below.	• The annual average bicycle collisions per MEB across all 8th Avenue SW study intersections was 1.3 collisions/MEB (2012-2014). • 63% of reported bicycle collisions resulted in injury and 37% resulted in property damage only. There were no bicyclist fatalities reported. • Additional details from collision analysis are discussed below.
Conflicts with bicyclists	Not data available.	Not data available.
Overall Public Perception	Not data available.	Not data available.
Other Observations	Not data available.	Not data available.

There was a total of 42 bicycle-related collisions over the study period with 31 occurring in the 10-year 'before' period (2001-2010) and 11 occurring in the 3-year 'after' period (2012-2014). Table D-2 shows the annual average number of collisions by type of collision for the before and after periods. The most common type of bicycle collisions in the before period was *struck an object* with an average of 2.3 bicycle collisions per year and in the after period it was *sideswipe* in the same travel direction with an average of 1.3 bicycle collisions per year.

Table D-2: Annual average number of bicycle collisions by collision type

Collision Type	Sideswipe, Same Direction	Passing, Right Turn	Passing, Left Turn	Left Turn Across Path	Right Angle	Rear End	Struck Object	Other
Before	0.3	0.0	0.0	0.8	0.3	0.3	2.3	0.2
After	1.3	0.3	1.0	0.7	0.3	0.3	0.3	0.0

Annual average bicycle collisions at intersections on the 8th Avenue SW study corridor from before (2001-2010) and after (2012-2014) the major street shared lanes were implemented are shown in Figure D-1. In addition, the figure shows the bicycle collision rate as annual average bicycle collisions per million entering bicycles at intersections. Results indicate bicycle collision rate increases at two intersections, decreases at five intersections, and no collisions were recorded before and after implementation at two intersections. Considering all study corridor intersections, the collision rate before is 1.6 annual bicycle collisions per MEB and after is 1.3 annual bicycle collisions per MEB which represents a 20% reduction in collision rate.

Figure D-1: Annual average bicycle collisions and collision rates at intersections

8th Ave SW	11th	10th	9th	8th	7th	6th	5th	4th	3rd
Annual average bicycle collisions									
Before	0.10	0	0.10	0.60	0.20	0.90	0.40	0.80	0
After	0		0	0.67	0.67	0.33	1.00	1.00	0
Annual average bicycle collisions per MEB at intersections									
Before	0.67	0	0.68	2.10	1.23	2.76	1.95	2.67	0
After	0	0	0	2.62	1.18	1.32	3.76	1.82	0
Change	-100%		-100%	24%	-3%	-52%	93%	-32%	

DISCUSSION AND OPPORTUNITIES FOR FUTURE CASE STUDIES

This case-study is a result of primary research that compared bicycle collision risk before and after major street shared lanes were implemented on 8th Avenue in Calgary. Bicycle collision risk was calculated based on collisions involving bicyclists and estimates of bicycle exposure.

While there were several bicycle collisions reported during the study period, these only include police-reported collisions involving a bicyclist and resulting in a fatality, injury, or a minimum of $2,000 worth of property damage. Since collisions involving bicyclists may not often result in significant property damage, many bicycle collisions may not be represented in this dataset. In addition, the 3-year duration of the period after the sharrow installation is small and, since collisions are rare occurrences, may introduce regression-to-the-mean bias.

Bicycle exposure was represented by million entering bicycles (MEB), which is the number of bicycles that enter an intersection from all approaches over the span of a year (365 days). MEB was estimated based on 6-hour intersection turning movement counts that were collected at each intersection before and after the facility was implemented. Average daily bicycle volume was estimated for each of the 6-hour counts by adjustment factors provided from 2017 data collected at a permanent count station located on 8th Avenue SW just west of 3rd Street SW. This assumes that the hourly annual distribution of bicycle volumes from the before and after period were the same as in 2017 which is now a protected bicycle lane, not a major street shared lane. In addition, little is known about the error associated with adjusting 6-hour bicycle count data. Despite these limitations, the availability of bicycle volume data at each study intersection before and after implementation is relatively uncommon and very useful.

Overall, results from this case study are inconclusive. While they indicate a general increase in safety across the corridor, they also reveal a significant decrease in safety at some intersections. This variable result is common with bicycle safety evaluations due in part to the rare and random nature of bicycle collisions. Automated video conflict studies that provide information on collision potential without the need for collisions to occur would help to address this gap.

D.1.9 Bicycle boulevard (Vancouver, BC)

Point Grey Road from Dunbar Street to Macdonald Street

Case study overview: Point Grey Road was converted from a collector roadway into a local road in January 2014 by physically cutting off vehicle access to Point Gray Road at McDonald Street and various other access restrictions. In the summer of 2017, the section of Point Grey Road between Dunbar Street and MacDonald Street was converted to a bicycle boulevard.

Land use context: The Point Grey bicycle boulevard is part of the Seaside Greenway and connects two-way protected bicycle lanes to the east and west in addition to the York Avenue bicycle boulevard in the east. The facility is located in a residential neighbourhood on the north shore between Jericho Beach Park to the west and downtown Vancouver.

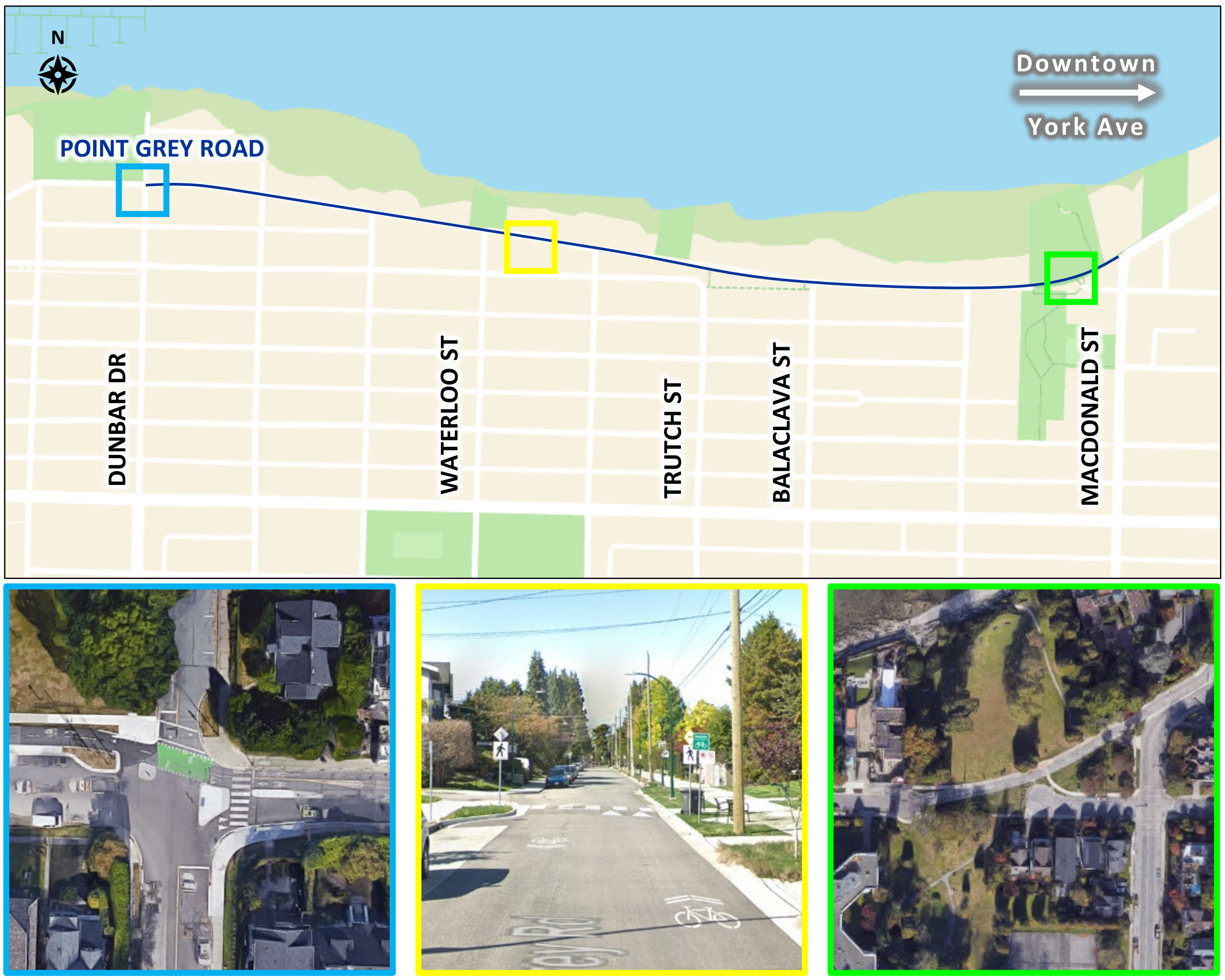


Image credit: Google Maps and Streetview.

CASE STUDY METHODOLOGY

This case study is based on secondary research. It relies on the administrative reports "*Phase 1 of Point Grey-Cornwall Active Transportation Corridor*" presented to Vancouver City Council on July 23rd, 2013 and "*Phase 2 - Public Realm & Sidewalks Point Grey Road, Alma Street to Tatlow Park*" presented to the Standing Committee on Policy and Strategic Priorities on May 4th, 2016. The reports contain infrastructure recommendations for the completion of the seaside greenway that are based on a technical transportation review and input from public consultation. Conditions of the bicycle facility before implementation are based on Point Grey Rd between Dunbar Dr. and Waterloo St.

DESIGN FEATURES OF BICYCLE FACILITY

Mid-block segments	Intersections
• Roadway is 8.5 m wide, including two travel lanes that are shared with bicycles and there is parking on the south side. • Separation from pedestrian sidewalk by treed boulevard (1.5-2.7 m). • Parking maintained only on one side of the traffic lane with 130 parking stalls available on the south side.	• Bicycle access only is provided at Macdonald St and at Trutch St. • Sharrow markings are placed at regular intervals across the intersection. • Corridor comprises six, three-leg uncontrolled intersections. • Intersections with Waterloo Street and Balaclava Street have raised pedestrian crossings to reduce vehicular speeds.

PERFORMANCE EVALUATION – MID BLOCK SEGMENT

	Conditions without bicycle facility	Conditions with bicycle facility
Cross Section	• Curb-to-curb width 8.5m. • Two travel lanes of equal width which also allow parking on the south side and north side. • Yellow directional dividing line.	• Curb-to-curb width remained unchanged. • Two travel lanes of equal width with parking allowed on south side.
Bicycle Pavement Markings	• No bicycle markings.	• Sharrows.
Cycling Volumes	• 450/day in August 2012.	• 2,700 average per weekday in August 2017.
Motor Vehicle Volumes	• 10,000/day in 2012.	• Local traffic only.

PERFORMANCE EVALUATION – INTERSECTIONS

	Conditions without bicycle facility	Conditions with bicycle facility
Cross Sections at Intersection	• Curb-to-curb width 8.5 m.	• Curb-to-curb width remains the same except for three intersection where 3 m curb bulb-outs were implemented on the south side.
Bicycle Markings Through Intersection	• No bicycle markings.	• No bicycle markings.
Bicycle Markings Approaching Intersection	• No bicycle markings.	• Sharrows through the intersection.
Motor Vehicle Right-Turn Volumes	• No information available.	• No information available.
Right Turn Lane Length	• None.	• None.
Transit Accommodation at Intersections	• No transit routes.	• No transit routes.
Intersecting bicycling Facilities	• None.	• None.

PERFORMANCE EVALUATION – COLLISIONS AND OBSERVATIONS

	Conditions without bicycle facility	Conditions with bicycle facility
Collisions	• 5 from 2008 to 2012.	• No information available.
Conflicts with bicyclists	• No information available.	• No information available.
Overall Public Perception	• No information available.	• No information available.
Other Observations	• No information available.	Anecdotally the road feels much safer and there has been an increase in bicycling numbers as well as women and children bicycling.

DISCUSSION AND OPPORTUNITIES FOR FUTURE CASE STUDIES

The findings from this study show that bicycle boulevards can be beneficial to encourage bicycling along a facility like that created along Point Grey Road. The conversion of Point Grey Road to a local street and bicycle boulevard has led to a significant increase in bicycle traffic volumes for people of all ages and abilities. When the street was functioning as a collector, there were about 450 bicyclists per day using the road. Once the change was implemented to convert this street into a local street and bicycle boulevard, bicyclist volume increased to about 2,700 per day – a major increase in use. This, coupled with the large decrease in vehicular traffic volume (from about 10,000 vehicles/day to having only local traffic), has the potential to significantly improve observed and perceived safety and comfort for all vulnerable road users. The anecdotal information presented in the study suggests that the new road feels much safer and there has been a significant increase in women and children bicycling.

The published information used to develop this case study did not provide much insight into the safety performance of the facility. However, this facility is good candidate for a detailed safety study because of the strong bicycle exposure data from the continuous bicycle count site. Therefore, a safety performance study should be considered over a more significant time period after the facility was implemented and based on strong bicycle exposure data. There already exists information about the 'before' situation regarding collisions, where there were 5 collisions involved between 2008 and 2012.

Overall, while this case study presents some positive outcomes resulting from conversion of a collector to a local/bicycle boulevard, future work should be conducted on similar projects to understand the following:

- The before-after safety performance.
- What is the perception of bicyclists with respect to comfort and perceived safety when riding on bicycle boulevards? It would be beneficial to extract these perceptions by gender, age and bicycling ability.
- What is the performance of these facilities at intersections?
- What are the implications regarding connectivity to other elements of the network? This is particularly important for 'interested but concerned' commuter bicyclists.

D.1.10 Advisory bicycle lane (Ottawa, ON)

Somerset Street East between Chapel Street and Range Road

Case study overview: Advisory bicycle lanes were implemented on Somerset Street East between Chapel Street and Range Road on October 16, 2016 in Ottawa. Advisory bicycle lanes are relatively new facilities and the first of their kind implemented in Ottawa. As such, the City completed a before/after evaluation to compare vehicle operating speed and the lateral distance between bicyclists and vehicles before and after the advisory bicycle lanes were implemented.

Land use context: Somerset Street East is a residential collector with two-way vehicle traffic and time-restricted parking on the north side of the street. The roadway has a posted speed limit of 40km/h and less than 1,000 vehicles per day. The roadway connects the University of Ottawa and Downtown in the west to the Adawe active transportation bridge over the Rideau Canal in the east.

Image credit: Google Maps and Streetview

CASE STUDY METHODOLOGY

This case study is based on secondary research using information from an evaluation completed by the City of Ottawa and published in the Journal of the Transportation Research Board (*Transportation Research Record*[1]). The study processed video recordings collected before (May and June 2016) and after (July and September 2017) implementation of advisory bicycle lanes to assess the safety performance of the facility based on the following three surrogate safety performance parameters:

1. the lateral distance between motor vehicles and bicyclists,
2. the lateral distance between bicyclists and curbside edge/cyclist and buffer edge line, and
3. the speed of bicyclists and motor vehicles.

DESIGN FEATURES OF BICYCLE FACILITY

Mid-block segments	Intersections
• Advisory bicycle lanes (1.4 m) on each side of a two-way central travel lane (4.0 m). • Parking lane (2.2 m) on the north side of the roadway with a painted buffer zone (0.5 m).	• Five total intersections; 2 are all-way stop controlled and 3 are two-way stop controlled on the intersecting roadway. • Intersection crossing markings for the advisory bicycle lanes continue through the intersection. • Advisory bicycle lane transitions into a painted bicycle lane approaching Chapel Street.

[1] Kassim, A., Culley, A., McGuire, S. (2019). Operational Evaluation of Advisory bicycle Lane Treatment on Road User Behavior in Ottawa Canada. Transportation Research Record, Washington DC.

PERFORMANCE EVALUATION – MID BLOCK SEGMENT

	Conditions without bicycle facility	Conditions with bicycle facility
Cross Section	• Curb-to-curb width 9.5 m. • Two travel lanes of equal width no lane markings. • Parking permitted on north side of the street.	• Curb-to-curb width remained unchanged. • One, two-way central travel lane (4.0 m). • Two advisory bicycle lanes (1.4 m). • Parking lane (2.2 m) with a painted buffer zone (0.5 m).
Bicycle Pavement Markings	• None.	• White bicycle symbol marking with a directional arrow. • Dashed white lane lines. • Two solid white lane lines with white hatching for buffer zone.
Cycling Volumes	• 568 bicyclists during 8-hour video review period.	• 909 bicyclists during 8-hour video review period.
Motor Vehicle Volumes	• 500 vehicles during 8-hour video review period.	• 352 vehicles during 8-hour video review period.
Motor Vehicle Travel Time	• 32.8 km/h average vehicle speed.	• 30.8 km/h average vehicle speed.

PERFORMANCE EVALUATION – INTERSECTIONS

	Conditions without bicycle facility	Conditions with bicycle facility
Cross Sections at Intersection	• Curb-to-curb width 9.5 m. • Two travel lanes of equal width. • Parking permitted on north side of the street.	• Curb-to-curb width remained unchanged. • One, two-way central travel lane (4.0 m). • Two advisory bicycle lanes (1.4 m). • Parking lane (2.2 m) with a painted buffer zone (0.5 m).
Bicycle Markings Through Intersection	• None.	• Intersection crossing markings.
Bicycle Markings Approaching Intersection	• None.	• White bicycle symbol marking with a directional arrow.
Motor Vehicle Right-Turn Volumes	• No information available.	• No information available.
Right Turn Lane Length	• None.	• None.
Transit Accommodation at Intersections	• One curbside stop at Chapel Street.	• One curbside stop at Chapel Street over top advisory bicycle lane.
Intersecting bicycling Facilities	• None.	• None.
Adjacent Markings	• Not applicable.	• Not applicable.
Signal Timing	• Not applicable.	• Not applicable.

PERFORMANCE EVALUATION – COLLISIONS AND OBSERVATIONS

The before/after study (Kassim et al., 2019) used for this case-study used surrogate safety measures to evaluate the safety performance of the advisory bicycle lanes. Results are as follows:

Surrogate safety measures	Conditions without bicycle facility	Conditions with bicycle facility
Average lateral distance between bicyclist and motor vehicle when adjacent and visible to each other.	2.23 m	2.76 m
…when moving in the same direction.	*1.89 m*	*2.35 m*
…when moving in the opposite direction.	*2.40 m*	*2.93 m*
Vehicle 85th percentile speed.	39.3 km/h	37.3 km/h
Cyclist average speed.	19.0 km/h	20.5 km/h
Distance between bicyclists and buffer edge line.	1.09 m	0.68 m
Distance between bicyclists and curbside edge.	1.13 m	1.10 m

DISCUSSION AND OPPORTUNITIES FOR FUTURE CASE STUDIES

The findings from this study show the potential for advisory bicycle lanes to improve bicyclist safety on roadways with similar characteristics to those of Somerset Street East in Ottawa. Key findings indicate that advisory bicycle lanes encourage bicyclists to travel in the middle of the bicycle lane, increase the distance between passing bicyclists and vehicles regardless of travel direction, and reduce vehicle travel speeds.

With respect to lateral separation between bicyclists and motor vehicles, the study found that there are statistically significant differences in the space between motor vehicles and bicyclists with and without advisory bicycle lanes. When traveling in the same direction and there is no facility present, the space between the two modes was measured at 1.89 m vs 2.35 m when there is a facility in place.

Regarding vehicular speed, while the measured differences in 85th percentile speed were found to be statistically significant, they are not practically different to reduce, in any way, the severity of a potential collision. Prior to the installation of the facility, the measured 85th percentile vehicular speed was measured to be 39km/h and after installation it was measured at 37 km/h.

Overall, while this case study presented some positive outcomes resulting from the installation of advisory bicycle lanes, other important issues that may be worth exploring are:

- Safety performance over time (i.e. behaviour as the novelty of this new infrastructure subsides).
- Performance during winter conditions, both from the operational and safety perspectives.
- Any specific issues associated with the interaction of the bicycle facility with trucks and buses.
- Perceived safety by different types of bicyclists.
- Safety performance at intersections.

D.2 International case studies

D.2.1 Buffered bicycle lane, two-way (Chicago, Illinois)

Dearborn Street from West Kinzie Street to West Polk Street

Case study overview: The Dearborn Street two-way buffered bicycle lanes were completed in 2013 as part of the *Chicago Streets for bicycling Plan 2020* which plans to complete a 645-mile network of bicycle lanes by 2020. One of three vehicle travel lanes had to be removed to make room for the two-way buffered bicycle lane.

Land use context: The two-way buffered bicycle lanes are located in downtown Chicago and run alongside Dearborn Street, a northbound one-way, two-lane roadway with between 8,000 and 18,000 vehicles per day and a 50 km/h posted speed limit.

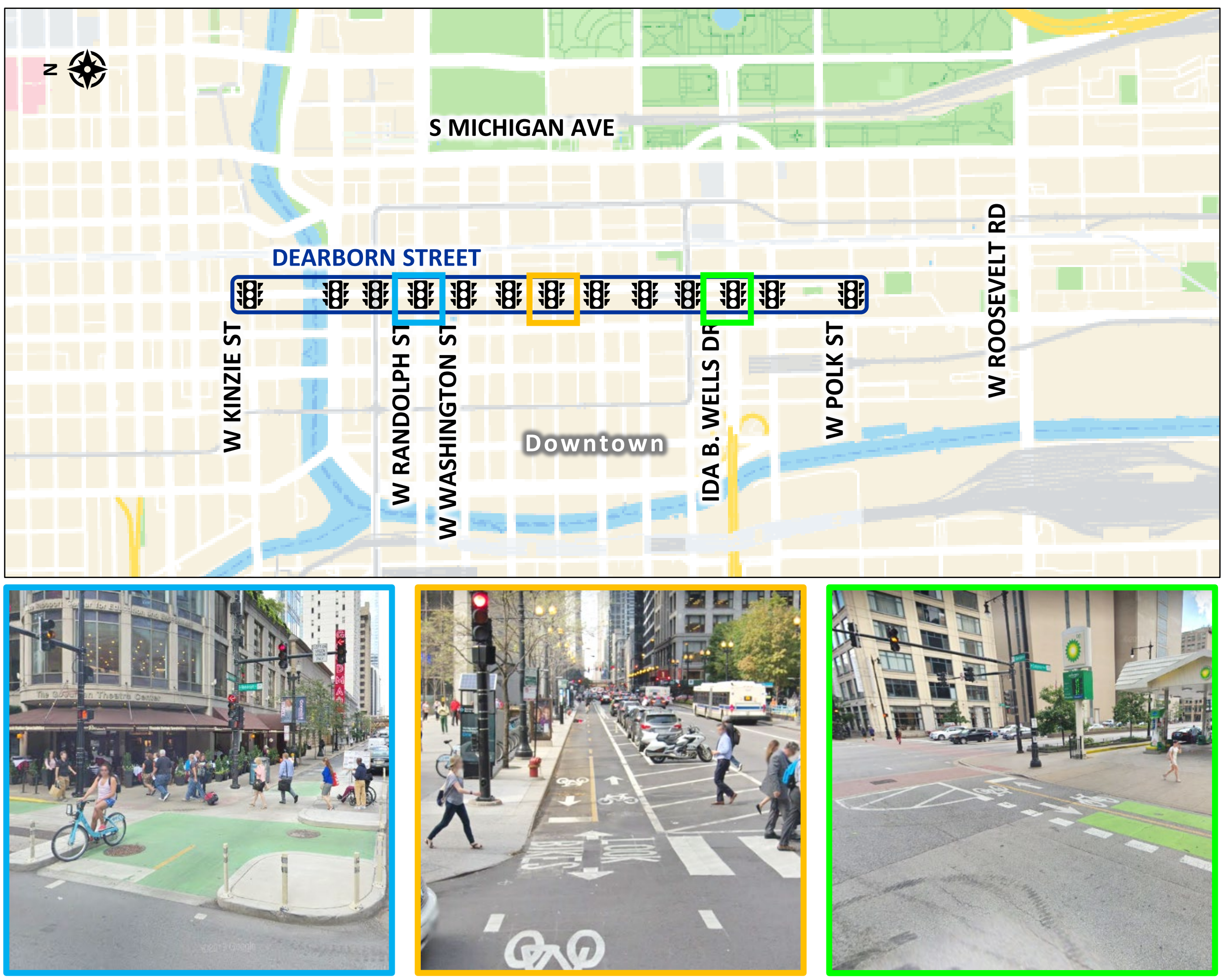


Image credit: Google Maps and Streetview

CASE STUDY METHODOLOGY

This case study is based on secondary research. It relies on the publicly-available report "*Lessons from the Green Lanes: Evaluating Protected Bicycle Lanes in the U.S.*"[2] prepared for the *National Institute for Transportation and Communities* in 2014. The report evaluates buffered bicycle lanes in five cities across the U.S. based on bicyclist intercept surveys, area resident surveys, and video analysis of bicycle vehicle conflicts at signalized intersections. This case-study presents results from the Dearborn two-way buffered bicycle lanes in Chicago, Illinois.

DESIGN FEATURES OF BICYCLE FACILITY

Mid-block segments

- Continuous bi-directional buffered bicycle lanes adjacent to west curb to driver's left.
- Two, northbound one-way vehicle travel lanes.
- Parking maintained only on one side between the buffered bicycle lanes and the traffic lane.
- Loading zones interspaced within parking areas.
- Separation from traffic provided by painted buffer (1.0 m wide) and flexi-post bollards and/or parked cars.
- Separation from pedestrian sidewalk provided by a full barrier curb.

Intersections

- Corridor includes 12 signalized intersections.
- All intersections are marked with intersection crossing markings comprised of white lane lines and sharrows for each direction.
- Two-stage left-turn boxes provided at some intersections.
- Driveways and laneways marked with elephant's feet markings and green paint.
- Pedestrian crossing markings that cross the buffered bicycle lane are supplemented with 'LOOK FOR BICYCLES' text.
- Vehicle left-turn lanes provided at intersections with protected signal phase.

[2] Monsere, C., Dill, J., McNeil, N., Clifton, K., Foster, N., Goddard, T., Berkow, M., Gilpin, J., Voros, K., van Hengel, D., Parks, J. (2014) *Lessons from the Green Lanes: Evaluating Protected Bicycle Lanes in the U.S.*
National Institute for Transportation and Communities. Portland.

PERFORMANCE EVALUATION – MID BLOCK SEGMENT

	Conditions without bicycle facility	Conditions with bicycle facility
Cross Section	• Curb-to-curb width 14.6 m. • Three, one-way travel lanes (3.0 m wide). • Two parking lanes (2.6 m on the west and 3.0 m on the east).	• Curb-to-curb width unchanged. • Two, one-way travel lanes (2.8-3.0 m wide). • Two-way buffered bicycle lane (1.5 m each direction) with painted buffer (1.0 m). • Two parking lanes (2.3 m on the west and 3.0m on the east).
Bicycle Pavement Markings	• None.	• Painted buffer area and flexible posts without parking (1.0 m) and with parking (2.5 m)
Cycling Volumes	• No information available.	• 171% increase in bicycle volumes. • 2,200 average 6-hour count across three locations.
Motor Vehicle Volumes	• No information available.	• No information available.
Motor Vehicle Travel Time	• No information available.	• No information available.

PERFORMANCE EVALUATION – INTERSECTIONS

	Conditions without bicycle facility	Conditions with bicycle facility
Cross Sections at Intersection	• Curb-to-curb width 12.6 m. • Three travel lanes (3.0 m wide). • Left-turn lanes provided at most intersections with arterial roads.	• Curb-to-curb width unchanged. • Two travel lanes (2.8-3.0 m wide). • Two-way buffered bicycle lane (1.5 m each direction) with painted buffer (1.0 m). Painted buffer area in place parking near intersections. • Left-turn and right-turn lanes (2.8 m) provided at most intersections with arterial roads.
Bicycle Markings Through Intersection	• No bicycle markings.	• Dashed white lane lines and double chevrons used through intersections. • ‘LOOK bicycleS’ text used through crosswalk. • Green paint used through driver access areas. • Speed hump used at theatre exit to allow pedestrian access to loading zone.

	Conditions without bicycle facility	Conditions with bicycle facility
Bicycle Markings Approaching Intersection	• No bicycle markings.	• Painted buffer (0.3 m wide) used to gradually taper the through motor vehicle lane toward the bicycle lane to make room for the left turn lane. • White lane lines and bicycle symbol with directional arrow. • Solid yellow dividing lane line to divide two-way bicycle traffic. • 'SLOW' text and transverse white lines used to slow bicycles approaching some driveways.
Motor Vehicle Turning Volumes	• No information available.	• 3,000 average 6-hour left-turning vehicle volume across three sites.
Vehicle Turn Lane Length	• Left-turn and right-turn lanes provided allow for storage of four motor vehicles.	• Left-turn and right-turn lanes provided allow for storage of four motor vehicles.
Transit Accommodation at Intersections	• Transit stops are located on the east side of the roadway.	• Transit stops are located on the east side of the roadway and do not intersect with the bicycle facility.
Intersecting bicycling Facilities	• None.	• One-way buffered bicycle at W Randolph Street. • One-way buffered bicycle lane at W Washington Street.
Adjacent Markings	• None	• Two-stage left-turn box provided.
Signal Timing	• No advanced pedestrian signalization or protected bicycling phases.	• Signalized intersections have protected bicycle signal phases and bicycle signals. The vehicle turn phase is separate and follows the bicycle phase. Thirty-eight (38) bicycle traffic signals and 18 left-turn arrow signals for vehicles were installed. • Bicycle detection sensors installed at the W Polk Street intersection.

PERFORMANCE EVALUATION – COLLISIONS AND OBSERVATIONS

	Conditions without bicycle facility	Conditions with bicycle facility
Collisions	No information available.	No information available.
Conflicts with bicyclists	No information available.	Results from the manual video review of conflicts indicate: • 90 to 95% of bicycle-vehicle intersection interactions resulted in no conflict across three intersections.
Overall Public Perception	No information available.	Results from the bicyclist intercept survey indicate: • 92% of bicyclists felt safe bicycling through study intersections. 82% of bicyclists indicate their feeling of safety increased a lot and an additional 18% increased somewhat. • 21% of bicyclists would have previously made the same trip by a different mode before facility implementation. • 86% of bicyclists travel on the new route more frequently than before. • 59% of bicyclists self-reported a near-collision with a pedestrian in the bicycle lane. Results from the area resident survey indicate: • 76% of area residents felt that safety for bicycling increased, 45% that driving safety decreased, and 43% that waking safety decreased.
Other Observations		• 77 to 93% of bicyclist comply with the bicycle signal phase and 84 to 92% of motorists comply with the lagging protected vehicle turn phase.

DISCUSSION AND OPPORTUNITIES FOR FUTURE CASE STUDIES

The findings from this study show that a two-way buffered bicycle facility like the one implemented on Dearborn Street in Chicago can significantly increase bicycle volumes and make bicyclists feel safer while bicycling. After installation of the two-way buffered bicycle lane, bicycle volumes increased by over 170% on average across the three studied intersections. To evaluate the actual and perceived safety performance of the newly implemented facility, this study conducted a comprehensive bicyclist intercept survey, an area resident survey, and a manual video review of bicycle vehicle conflicts.

Cyclist intercept survey results indicate that not only do 92% of bicyclists surveyed feel safe on the two-way buffered bicycle lanes but 21% of them previously travelled by a different mode prior to the facility being implemented. This indicates that the facility may have encouraged *interested but concerned* bicyclists to travel by bicycle. The most commonly cited near-miss collision type identified by bicyclists was a collision with a pedestrian (59%). According to the area resident survey, 76% of residents felt that the facility was safer for bicyclists. However, 45% felt that safety for drivers decreased and 43% felt that safety for pedestrians decreased. This underscores the importance of public information on the use of new facilities and the potential safety benefit they can achieve.

The manual video review conflict analysis was conducted to measure the safety performance of the facility at three signalized intersections along the corridor. Use of conflicts rather than collisions to measure safety enabled this work to be proactively completed without having to wait for collisions to occur. All three intersections had bicycle signals and vehicle left-turn signals that occurred during separate signal phases. The bicycle phase begins with the northbound vehicle traffic green phase (Dearborn Street is a one-way, northbound roadway with the bicycle facility on the Driver’s right) followed by the protected vehicle left-turn phase to separate these to movements through the intersection. Results from the conflict analysis indicate that there was no conflict for 94% of the 5,499 observations. Of the 326 precautionary avoidance maneuvers 22% were committed by vehicles, 49% by pedestrians, and 21% by bicyclists. This confirms that perceived safety issue between pedestrians and bicyclists identified in the bicyclist intercept survey. There were only 2 minor conflicts observed.

Overall, this case study presents positive observed and perceived safety outcomes resulting from the implementation of a two-way buffered bicycle facility. In particular, the safety performance of two-way facilities at signalized intersections was a novel contribution to research. Important issues that may be worth exploring in future similar undertakings are:

- Any specific issues associated with the interaction of the bicycle facility with trucks and buses.
- The relationship between collisions and conflicts to understand how this method of classifying conflicts relates to actual collisions.
- The ability of automated video conflict analysis technologies to collect conflict data that supports this conflict analysis methodology. This type of study could be used to further refine the technology and make conflict analysis more access to jurisdictions.

D.2.2 Painted bicycle lanes (Copenhagen, Denmark)

Network-wide Evaluation

Case study overview: This before-after case study presents the results of a comprehensive evaluation of the safety performance of one-way painted bicycle lanes along 10 road segments in Copenhagen, Denmark, totalling 5.6 km of road. This evaluation is part of a comprehensive reconstruction and infrastructure upgrade project by the City of Copenhagen.

The bicycle lanes being evaluated were marked between 1988 and 2002. The traffic volumes on those road segments ranged between 7,500 and 15,200 vehicles per day prior to the painting of the lanes. In addition, there was existing bicycle traffic sharing the road with vehicular traffic, ranging from 635 to 4,800 bicycles per day prior to the implementation of bicycle lanes.

Land use context: Six of the roads in the study area are in central Copenhagen and the other four are just outside of the downtown area. In all cases, these roads are surrounded by mixed land uses (e.g. commercial, residential, institutional functions and recreational). The images below illustrate Google Street View images for three of the 10 road segments evaluated in this study. In all cases, the picture shows images captured between 2007 and 2010.

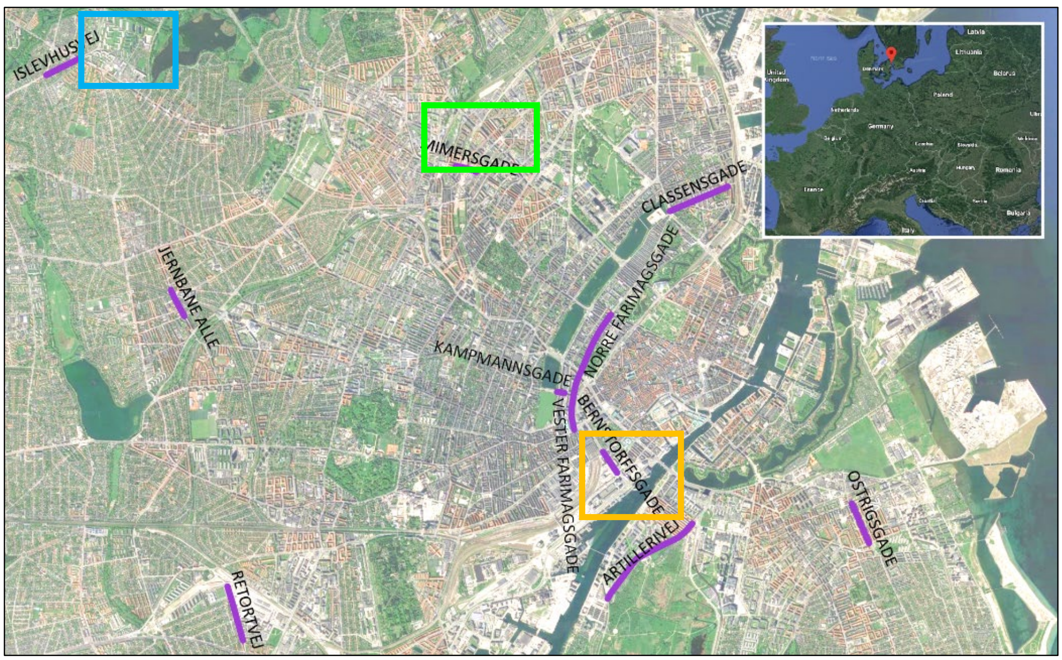


Image credit: Google Maps and Streetview

CASE STUDY METHODOLOGY

This case study is based on secondary research that relies on the publicly-available paper "*Bicycle Tracks and Lanes: a Before-After Study*" prepared by Soren Underlien Jensen, a member of the Transportation Research Board (TRB) Committee on Bicycles. This paper is based on the comprehensive report "Effekter af cykelstier og cykelbaner" by the same author for the City of Copenhagen.

The study relies on collision, injury and traffic volume data for bicycle lanes (and bicycle tracks, which are not considered in this case study) before and after construction. However, because this infrastructure has been in place for many years and there are several differences between sites in terms of cross-sectional features, vehicular volumes, bicycle volumes, intersection treatments and others, the methodology used by the author is not that of a simple observational before-after analysis. Instead, this case study relies on a stepwise methodology comprising the following: (1) use of a general comparison group to account for collision trends; (2) changes in traffic volumes over the years along segments and intersections; and (3) an analysis of long-term collision trends to investigate any abnormalities regarding collision frequency. There was extensive statistical analysis done to correct for variations in traffic volumes (both bicycles and motor vehicles), as well as, regression-to-the-mean effects in the before period.

The evaluation conducted in this study relied only on road segments and intersections that have not undergone any infrastructure changes in the before and after study period.

DESIGN FEATURES OF BICYCLE FACILITIES

Mid-block segments	Intersections
• Continuous unidirectional bicycle lanes adjacent to curb on both sides of the street. • In some cases, parking is maintained on one side of the street between the bicycle lane and the traffic lane. • Loading zones interspaced within parking areas. • Separation from traffic provided by painted lane about 1.5 to 2.0 m in width. • Pedestrians operate on sidewalks.	• A combination of signalized intersections and unsignalized intersections along each facility. • Most intersections are marked with intersection crossing markings comprised of dashed white lane lines. In some cases, colored pavement is used across intersections but this is not common. • Driveways and laneways marked with dashed lines. • Right-turn or left-turn lanes are available at some locations.

PERFORMANCE EVALUATION – MID BLOCK SEGMENTS

	Conditions without bicycle facility	Conditions with bicycle facility
Cross Section	• Varying curb-to-curb widths. • Two to four travel lanes, depending on the site. • Parking/loading allowed with varying characteristics.	• Curb-to-curb width unchanged. • Two to four travel lanes, depending on the site. • Some sites allow parking/loading on one side of the road. • Bicycle lane on both sides of the road (1.5 m to 2.0 m wide lane).
Bicycle Pavement Markings	• None.	• Bicycle markings with diamond reserved lane markings.
Motor Vehicle Travel Time	• No information available	• No information available.

Cycling Volumes

Street	Daily bicycles BEFORE	Daily bicycles AFTER	Difference %
Jernbane Allé	3455	3355	-3
Nørre Farimagsgade	4116	4200	+2
Kampmannsgade	4798	6484	+26
Bernstorffsgade	635	870	+27
Østrigsgade	Unknown	Unknown	-
Mimersgade	Unknown	Unknown	-
Islevhusvej	1331	1548	+14
Retortvej	Unknown	Unknown	-
Classensgade	Unknown	Unknown	-
Artillerivej	2075	2184	+5

Motor Vehicle Volumes

Street	Daily traffic BEFORE	Daily traffic AFTER	Difference %
Jernbane Allé	8000	7850	-2
Nørre Farimagsgade	14785	13200	-12
Kampmannsgade	8270	8440	+2
Bernstorffsgade	15252	18600	+18
Østrigsgade	Unknown	Unknown	-
Mimersgade	Unknown	Unknown	-
Islevhusvej	8590	9140	+6
Retortvej	Unknown	Unknown	-
Classensgade	Unknown	Unknown	-
Artillerivej	7594	8630	+12

PERFORMANCE EVALUATION – INTERSECTIONS

	Conditions without bicycle facility	Conditions with bicycle facility
Cross Sections at Intersection	• Varying curb-to-curb widths. • Two to four travel lanes, depending on the site.	• Curb-to-curb width unchanged. • Two to four travel lanes, depending on the site. • Left-turn or right-turn lanes provided at some intersections. • Bicycle lane on both sides of road (1.5 – 2.0 m wide lane).
Bicycle Markings Through Intersection	• No bicycle markings.	• White lane lines or coloured pavement used through intersections.
Bicycle Markings Approaching Intersection	• No markings between the end of curbside parking and the intersection.	• Solid white lane lines are changed to dashed white lane lines near intersections. • Some cases where right-turn lanes are marked with right turn arrows.
Motor Vehicle Right-Turn Volumes	• No information available.	• No information available.
Right Turn Lane Length	• Unknown.	• Varying lengths, depending on site.
Transit Accommodation at Intersections	• Bus stops along all roads.	• Bus stops along all roads.
Intersecting bicycling Facilities	• Most intersections include corridors with intersecting bicycle lanes or bicycle tracks.	• Same as without bicycle facility.
Adjacent Markings	• Zebra stripe pedestrian crossing markings provided throughout.	• Same as without bicycle facility.
Signal Timing	• No information available.	• No information available.

PERFORMANCE EVALUATION – COLLISIONS AND OBSERVATIONS

<table>
<tr><th></th><th>Conditions without bicycle facility</th><th>Conditions with bicycle facility</th></tr>
<tr><td>Collisions</td><td colspan="2">It is not possible to determine, from the comprehensive report or the paper, whether these collision totals are per year or whether they refer to the full study period. Regardless of the temporal scheme, the difference in safety performance would remain unchanged.

<table>
<tr><th></th><th>Observed BEFORE</th><th>Expected AFTER</th><th>Observed AFTER</th><th>Difference %</th></tr>
<tr><td>Total collisions</td><td>389</td><td>295</td><td>311</td><td>+5</td></tr>
<tr><td>Total injuries</td><td>106</td><td>98</td><td>113</td><td>+15</td></tr>
<tr><td>Collisions at intersections</td><td>327</td><td>249</td><td>247</td><td>0</td></tr>
<tr><td>Collisions on segments</td><td>62</td><td>47</td><td>64</td><td>+36</td></tr>
</table></td></tr>
<tr><td>Conflicts with bicyclists</td><td>• No information available.</td><td>• No information available.</td></tr>
<tr><td>Overall Public Perception</td><td>• No information available.</td><td>The study references information from another study which found that bicycle lanes are perceived to be safer and more satisfying by bicyclists in Copenhagen, compared to a mixed traffic situation.</td></tr>
<tr><td>Other Observations</td><td></td><td>• A larger increase in injuries (22%) was observed among women than men (7%).
• Number of collisions involving right-turning motor vehicles increased by 73% after bicycle lanes were introduced.
• There was an increased number of rear end collisions collision between two bicycles after bicycle lanes were introduced. However, the study does not report what this increase was.</td></tr>
</table>

DISCUSSION AND OPPORTUNITIES FOR FUTURE CASE STUDIES

This case study illustrates that, in Copenhagen, painted bicycle lanes have resulted in negative safety benefits over time from a collision frequency and injury perspective. While the implementation of these facilities has resulted in a 5% increase in bicycle traffic and a corresponding 1% decrease in motor vehicle traffic along the same roads, it has also resulted in a 5% increase in collision frequency and a 15% increase in injuries. This negative outcome holds true for both segments and intersections, however, the study did not investigate any possible traffic or design conditions that may be contributing to this problem.

While the study did not address collision rates, it used a robust methodology to account for regression-to-the-mean effects in the before period. As a result, the observed negative safety impacts due to bicycle lanes can be considered reliable although they are not statistically significant.

Given the discrepancies between this study and current North American knowledge regarding the safety performance of bicycle lanes, it is important to continue to investigate this issue further using extensive before and after data for a variety of locations. Copenhagen is one of the leaders in the world when it comes to road safety and the accommodation of bicyclists in urban infrastructure. The findings from this evaluation raise an important issue that warrants further investigation in Canada.

D.2.3 Bicycle accessible shoulder (Lake County, Florida)

Red Shoulder between Mount Dora and Tavares

Case study overview: This facility was piloted by the Florida Department of Transportation along a nearly two-kilometre stretch of road between Tavares and Mount Dora, Florida. The purpose of the pilot was to determine the impact that a coloured shoulder would have on bicyclist safety. The need for the study resulted from pushback by residents on the installation of shoulders along Lakeshore Dr. between Tavares and Mount Dora. Residents were concerned that adding shoulders to this two-lane undivided scenic road would increase vehicle speeds. However, because this road was extensively used by bicyclists riding for physical exercise or preparing for races, the DOT decided to implement red shoulders along the pilot segment to provide bicyclists with additional space while making the road still appear to be the same width to respect residents' concerns.

Land use context: Lakeshore Drive is approximately eight kilometers long and connects Tavares and Mount Dora, a pair of communities located about 60 kilometres northwest of Orlando. The road is under both city and county jurisdiction, but maintenance is performed by the county. This is a rural facility for most of its length, except the portions that traverse each town.

The speed limit on this road is 60 km/hr and the traffic volume is approximately 1,700 vehicles per day. There are two main intersections along the section where the shoulders were painted red. At one intersection a railroad divides the road into two one-lane sections. At the end of this section there is a roundabout with the railroad extending through the roundabout and the colored shoulders ending at the entry to the roundabout. Several other stop-controlled intersections cross Lakeshore Drive along the red shoulder section.

Photo credit: William W. Hunter

CASE STUDY METHODOLOGY

This case study is based on secondary research. It relies on the publicly-available report "*An Evaluation of Red Shoulders as a Bicycle and Pedestrian Facility*" prepared for the Florida Department of Transportation in July 1998. While this evaluation is 20 years old, its findings are important to the analysis of bicycle accessible shoulders in rural areas. Further, it is the only publication on bicycle accessible shoulders that uses information other than collision data to evaluate the performance of the facility and is also the only publication regarding paved shoulders referenced in the 2014 report for the U.S. Federal Highway Administration, "*Evaluation of Bicycle-Related Roadway Measures: A Summary of Available Research*".

The pilot study is based on video footage of bicyclists traveling along the roadway at three locations with the red shoulders and one location without shoulders (the existing condition on this road). In addition, an intercept survey of bicyclists was conducted to evaluate their perception of safety when riding along the red shoulders versus no shoulders. Other aspects of the methodology included the following:

- Speed data was collected before and after the addition of the red shoulders to determine if motor vehicle speeds had changed as a result of the red shoulders.
- The lateral positioning of bicyclists being passed by motor vehicles, including the magnitude of vehicular encroachment into the opposing lane of travel.
- Conflicts between the passing and oncoming motor vehicles, as well as conflicts between motor vehicles and bicyclists.

DESIGN FEATURES OF BICYCLE FACILITY

Mid-block segments	Intersections
• One-metre red shoulders. • Non-slippery surface with paint used on tennis courts.	• No special treatment at intersections.

PERFORMANCE EVALUATION – SEGMENTS

	Conditions without bicycle facility	Conditions with bicycle facility
Cross Section	• Two-lane undivided road. • No shoulders. • Overall road width 6.0 m. • Two travel lanes (3.0 m wide). • Rural cross-section.	• Two travel lanes (3.0 m wide each). • Red shoulder in both travel directions (1.0 m wide each)
Bicycle Pavement Markings	• None.	• Red surface.
Cycling Volumes	• Not specified.	• Not specified. However, 757 bicyclists were videotaped for this study over eight months. Of these, 80% used the entire length of the red shoulder, 14% did not use the shoulder, and 6% used the shoulder partially (i.e. rode part of the distance on the shoulder an part in the travel lane).
Motor Vehicle Volumes	• 1,700 vehicles/day.	• No observed change.
Motor Vehicle Travel Time	• Estimated at approximately one hour at free flow speed.	• Because no speed changes were observed in the before and after speed data collection, the travel time is estimated to be the same with and without red shoulders.

PERFORMANCE EVALUATION – INTERSECTIONS

	Conditions without bicycle facility	Conditions with bicycle facility
Cross sections at intersection	• Overall road width 6.0 m. • Two travel lanes (3.0 m wide each). • All are typical stop-controlled and one roundabout.	• No special treatments other than red shoulder.
Bicycle markings through intersection	• No bicycle markings or shoulder.	• Red shoulder.
Bicycle markings approaching intersection	• No markings or shoulder.	• Red shoulder (1.0 m wide).
Motor vehicle right-turn volumes	• No information available.	• No information available.
Right turn lane length	• No separate right turn lanes.	• Nothing provided outside of the red shoulder.
Transit accommodation at intersections	• Not applicable.	• Not applicable.
Intersecting bicycling Facilities	• None.	• None.
Adjacent markings	• No information provided.	• No information provided.
Signal timing	• Not applicable.	• Not applicable.

PERFORMANCE EVALUATION – COLLISIONS AND OBSERVATIONS

	Conditions without bicycle facility	Conditions with bicycle facility
Collisions	• No information available.	• Not part of the analysis.
Conflicts with bicyclists	• Not included in the report used for this case study.	The following observations resulted from the analysis of motorists passing bicyclists: • There were 374 encroachments when passing bicyclists. Of these 40% occurred when there was a red shoulder and 60% when there was no shoulder. • At locations without shoulders, motor vehicles passed bicyclists 20 cm farther away than at locations with shoulders. • More conflicts between motor vehicles occurred at the site without red shoulders because the severity of encroachment was greater than at sites with red shoulders.
Overall public perception	• Residents were happy to not have any shoulders on this road between the two communities.	• Excellent public opinion following the installation of red shoulders.
Other observations		• The sites at intersections experienced lower use of the red shoulder. Only 70% of the 757 bicyclists were observed to use the shoulder at these intersections. • 79% of bicyclists felt that the painted red shoulders increased safety and that the shoulders led to more space between bicyclists and passing vehicles. However, this is not what was observed from the video footage.

DISCUSSION AND OPPORTUNITIES FOR FUTURE CASE STUDIES

The pilot project for this case study identifies successes regarding the performance of this bicycle facility from the safety and perceived safety perspective. However, in researching information for this case study it became evident that there is a significant knowledge gap in this area. No recent studies were found, from the U.S. or Europe, on the evaluation of bicycle accessible shoulders.

The closest information about an evaluation of bicycle accessible shoulders is a study conducted for the State of Arizona in 2002: *Bicycle - Motor Vehicle Collisions on Controlled Access Highways in Arizona*. The study concluded that “The rate of bicycle-motor vehicle crashes on controlled access highways is less than one per year across the entire state of Arizona for over a decade, clearly implying that there is not a large-scale safety problem associated with the use of these highways by bicyclists. Further changes on the use of controlled access highways by bicyclists must be evaluated in light of the very small percentage of motor vehicle-bicycle crashes occurring on these roadways.”

Because of the importance of evidence-based decision-making, coupled with research identified in this project on the truck-related air turbulence effect on bicyclists riding on highway shoulders, it is essential that research be done on the safety performance of highway shoulders as a bicycling facility in Canada.

Appendix E: Canadian academic survey

E.1 Introduction

A survey of the Canadian academic community was conducted during the month of June 2018 to identify any on-going and upcoming relevant research in bicycle safety as it relates to different infrastructure facilities. The knowledge obtained from this survey was used as follows: (1) to augment the literature review; (2) to enhance the end user survey questionnaire; and (3) to inform the case studies.

A total of 51 academics were included in the survey, which was comprised of the following two questions:

1. Are you currently (or will soon be) undertaking any research to evaluate the safety performance (either perceived or observed) of bicycle infrastructure? (e.g. painted lanes, separated lanes, two-way facilities, intersection treatments, etc.) If the answer is yes, could you please provide a brief description of what the research entails? (e.g. purpose, objectives, scope, location, project duration, expected outcomes)
2. Are you aware of any current research being undertaken in Canada on the above issue? If yes, could you please provide some information about it? (e.g. describe it as much as possible or let us know who to contact or how to get more information about it)

The overall survey process involved the following steps over a three-week period:

1. General initial email to all.
2. Reminder email to all who had not replied to the initial email.
3. Individual and personal emails to those who had not responded to the first two messages.
4. Telephone discussions with those who were not able to reply by email.

Table E-1 shows the number of academics who were surveyed, the response rate, and the universities represented by these academics. In addition to the 51 academics surveyed, there are eight other academics who were not contacted because it is widely-known that the research of these professors deals with pavement design, asset management from a materials perspective, or permafrost and transportation infrastructure. The universities associated with these academics are: Laval University, University of Manitoba, University of Waterloo and Carleton University.

To our knowledge, this list of 59 academics comprises all academics working in transportation engineering and planning across the country.

Table E-1: Survey response rate by university

University	Academics surveyed	Academics who responded
Carleton University	3	2
Concordia University	3	2
Ecole Polytechnique	4	2
Lakehead University	1	1
McGill University	3	3
McMaster University	1	1
Ryerson University	6	5
University of Alberta	4	2
University of British Columbia	2	2
University of British Columbia Okanagan	2	2
University of Calgary	2	1
University of Manitoba	1	1
University of New Brunswick	2	2
University of Saskatchewan	1	1
University of Toronto	6	2
University of Waterloo	5	5
University of Windsor	3	2
York University	2	2
TOTAL	**51**	**37**

E.2 Survey findings

Of the 37 academics who responded to the survey, eight are either actively engaged or will soon be engaged in some form of research involving bicycle safety, and three have recently completed research involving this topic. The following projects are currently underway:

- At McGill University, two professors are actively engaged in bicycle safety research.
  - The first professor is currently conducting a bilingual survey in Montreal on bicyclist behaviour and perceptions of risk. The findings from the survey are expected to inform changes to local bicycling policy and recommend the direction of future bicycle infrastructure investment. The survey, which has been shared through an extensive mailing list, organizational newsletters, social media and handing out local flyers, received about 1500 responses. The research team is currently in the process of analyzing survey responses.
  - The second professor is conducting research for the City of Montreal on bicycle signals. The purpose of the study is to evaluate the impact of different strategies of bicycle traffic signal phases when they are integrated at intersections with bicycle facilities. Performance indicators being used include level-of-service (LOS) for vehicles, delays for bicycles and vehicles, and safety for bicyclists measured with post-encroachment time through a traffic simulation process. The team is using microsimulation models and video observations for calibration. When this project is completed in 2 years, it is expected to support the design guidelines for the City of Montreal.
- At Ryerson University, one professor is currently conducting research regarding the perceived safety of bicycle infrastructure. The purpose of the research is to understand and measure changes after new bicycle infrastructure is built. The research is being done using the following: (1) a household survey, (2) intercept survey of bicyclists, and (3) before-after investigation of case study sites. Part of the work involves understanding whether the perception of safety changes as a result of the construction of new bicycling facilities.
- At the University of Alberta, one professor is working with the City of Edmonton to evaluate the safety performance of the new bicycle grid network. The project, which started last year, is expected to last until summer 2019.
- At the University of British Columbia, one professor is working on two separate projects involving bicycle safety:
  - The first project evaluates the relationship between bicycle *Score* and collision frequency involving bicyclists. bicycle Score is a measure calculated for each location in a city based on the following factors: bicycling infrastructure (separated bicycle lanes and bicycle paths, local street bicycleways, painted bicycle lanes, etc.), topography, desirable amenities (grocery stores, restaurants, schools, etc.), and bicycle network connectivity.
  - The second project investigates the impact of road network patterns on bicyclist safety.
- At the University of Waterloo, one professor is researching the relationship between road geometry (e.g. 2-lane and 4-lane arterials with and without on street bicycle lanes) and the lateral passing distances between autos that overtake bicyclists. Of interest to this work is the lateral clearances between motorized vehicles and bicyclists during overtaking maneuvers on urban arterial roadways and the quantification of the influence that geometric and traffic-

flow parameters have on these lateral clearances. A Master's thesis has been published on this topic, where more than 5,000 overtaking maneuvers within the Kitchener-Waterloo area were considered in the analysis. The results of the thesis have been included in the literature review for this project.

The following projects are in the planning process:

- At the University of Alberta, one of the professors is in the process of designing a study comprised of the following: (1) a survey to evaluate perceived safety of bicycle infrastructure in Edmonton; and (2) analysis of vehicular speeds adjacent to various types of bicycle facilities. The purpose of the project is to evaluate the perceived safety of various types of bicycle facilities and compare these perceptions to motor vehicle speeds traveling adjacent to each facility type.
- At Lakehead University, the only professor working in the transportation engineering field is planning to conduct an evaluation of the safety performance of the various types of bicycle infrastructure in Thunder Bay. No details are yet available about the approach, project duration, or characteristics of the project.

The following projects have recently been completed:

- At the University of Toronto, one of the professors led the comprehensive evaluation of the Bloor Street West bicycle Lane Pilot Project. This evaluation, which is being used in this report as one of the case studies, involved an extensive before and after analysis of the impact of the new bicycle facility on the following: (1) bicycling environment; (2) traffic monitoring environment; (3) curbside demands and parking; (4) local business; and (5) public perception and level of support from residents and businesses.
- At the University of British Columbia Okanagan, the only professor working in the transportation engineering field has recently completed research using instrumented probe bicycles to develop bicycle safety and comfort prediction models. The findings from this work have been included in the literature review for this project.
- At the University of Waterloo, one professor has recently completed research with a graduate student on the safety performance of various types of left turning bicycle facilities in Philadelphia. The findings from this work have been included in the literature review for this project.

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