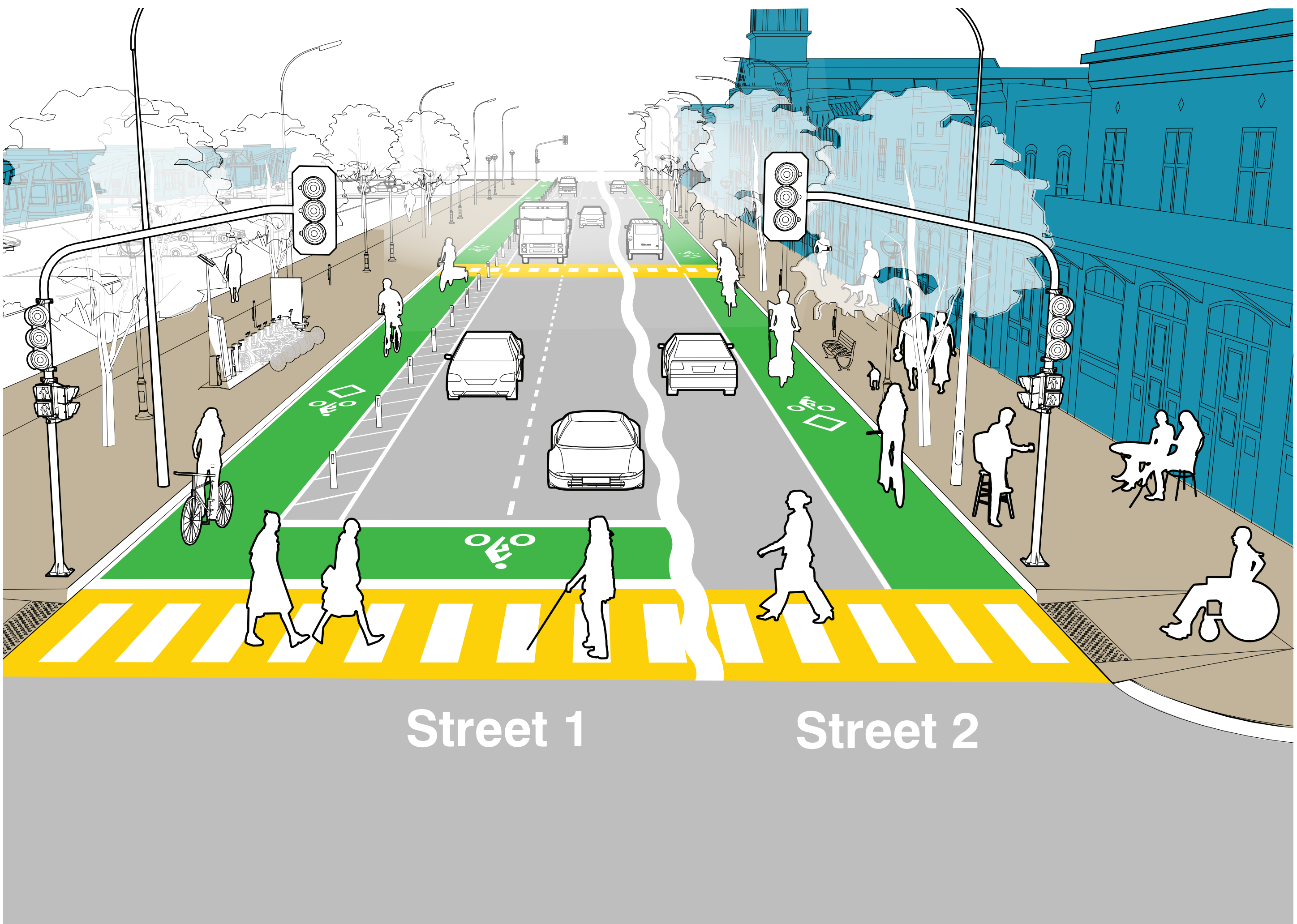
Healthy Streets

Evidence Review

October 2014



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About this Report

In May 2013, Toronto's City Council recommended that city staff develop Complete Streets Guidelines to help reshape Toronto streets. In advance of the development of the Complete Streets Guidelines, Toronto Public Health (TPH) has commissioned a series of reports. Their purpose is to review the available research evidence in order to provide information about how the design elements of Complete Streets are associated with more active lifestyles and better health. The reports are [1] *Healthy Streets: Design Features & Benefits,*[2] *Healthy Streets: Evidence Review,* and [3] *Healthy Streets: Jurisdictional Review*.

This report builds on previous City efforts to promote health through better community design as described in many plans, polices, guidelines, and reports, including the *Official Plan, Sustainable Transportation Initiatives, Bike Plan, Pedestrian Charter, Accessibility Design Guidelines, Vibrant Streets Guidelines, Streetscape Manual, Walking Strategy, Road to Health,* and *the Walkable City*, among others. This report identifies and assesses published evidence about the association of specific street design choices with health outcomes, and draws conclusions about how the information can be used to promote healthier street design in Toronto. It most directly builds on the evidence of the health benefits of walking and biking compiled in the *Road to Health: Improving Walking and Cycling in Toronto*, which describes the health benefits of active transportation[27]. This report provides a summary of the evidence about how specific street design elements help promote more walking, biking, and better health in general.

Introduction

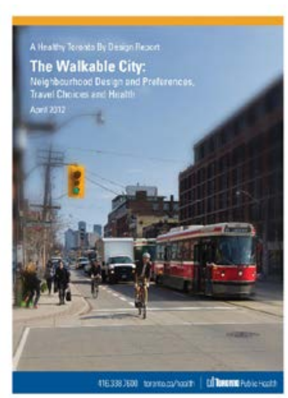
Most people know intuitively that our surroundings impact our health – clean water, safe housing, sanitary waste disposal, and clean air are all essential to any community that hopes to thrive. Urban planning and public health professionals are examining the connection between urban planning and health. While the arrival of the car and suburban development in the mid-20th Century brought many benefits, it has also had a number of unintended consequences, and often health related - pollution exposure, traffic collisions, and a reliance on the car for almost all travel.

There are many health outcomes that have been found to be associated with transportation and land use patterns, including physical activity, obesity, obesity-related chronic disease, respiratory conditions, vehicular collisions, and stress and mental health.[1,2,3,4] Compact neighbourhoods with walkable streets and a variety of destinations within walking distance of housing are associated with more walking, lower rates of obesity and higher rates of physical activity.[5,6,7,8] Because regular physical activity has many mental health benefits – lower stress, depression and anxiety levels[6,9] – walkable neighbourhoods, with their association with more physical activity, can also be linked conceptually to mental health.

In contrast, places that are auto oriented in design, with low-density housing separated from common destinations, are associated with less walking, higher obesity rates, and lower rates of physical activity.[5,6,7,8] Auto oriented places are also associated with more driving, which in turn has been consistently associated with higher obesity.[10,11,12,13] Auto oriented places have been positively associated with obesity related health conditions such as cardiovascular disease,[14] diabetes,[15] and hypertension.[16] These connections probably exist for multiple reasons. Obviously, driving is a sedentary activity. On top of that, spending long stretches of time in the car may mean less time for recreational activities that contribute to better physical and emotional wellness. Decades of research on the relationship between driving and physical manifestations of stress have linked traffic congestion and delays to high blood pressure,[17,18] more sick days out of work,[19] more days in the hospital,[20] and decreased job performance.[21] Although all forms of transportation can be stressful at times, research indicates that driving is more stressful, more consistently, than other forms of travel.[22,23]

Although this research is largely cross-sectional and cannot prove causation, the vast majority of the research has found statistically significant associations between auto-oriented land use and transportation systems and poorer health outcomes. These associations have been consistently found in many different places, at many different scales of measurement. In response to this large and growing body of research, urban planners and public health staff have been working together to find ways to redesign our streets and cities to facilitate physical activity, decrease exposure to harmful pollutants, and improve traffic safety.

At the same time, City of Toronto residents have indicated preferences for communities which facilitate living healthier lifestyles. Most residents taking part in a recent survey summarized in a 2012 TPH Healthy Toronto by Design report, called *The Walkable City: Neighborhood Design and Preferences, Travel Choices and Health*, expressed a strong preference for living in walkable and transit-supportive neighbourhoods.[24] Many residents living in auto-oriented neighbourhoods expressed a desire for more walkable neighbourhood features. Those living in more walkable neighbourhoods were more



likely to engage in physical activity, use transit more, drive less, and have lower body weights.

There is also growing interest in increasing children's physical activity and health by increasing their walking and cycling to school. In the Greater Toronto Area between 1986 and 2006 walking to school trips have declined for 11 to 15 year olds.[25] Children who walk or cycle to school are more active during the day and are more cardiovascularly fit, than those who do not.[26] Two popular programmatic efforts to encourage active transport to school are Walking School Buses and Safe Routes to School. Both programs typically provide promotional, educational and encouragement components. Safe Routes to School efforts often include a component to identify and fix obstructive and dangerous street design elements.

TPH's 2012 *Road to Health* report[27] concluded the benefits of increased physical activity through walking and cycling are numerous and diverse, including:

- *"significantly reducing the risk of all-cause mortality, cardiovascular disease, obesity, type II diabetes, and certain types of cancer.*
- *. . . generat[ing] significant social, environmental, economic and transportation system benefits.*
- *. . . the health benefits experienced by individuals who increase their physical activity through the use of active transportation greatly outweigh the risks [from traffic collisions].*
- *Walking and cycling infrastructure investments are extremely cost-effective, even when considering the health benefits alone.*
- *Better design for active modes, such as walking and cycling, can greatly increase safety for all modes; increasing the proportion of trips made by walking and cycling can also independently lower collision and injury rates (the 'safety in numbers' effect)."*

Like most contemporary cities, many streets in Toronto currently favour automobile movement over active modes or transit. Some governments have put into place policies or directions to try and reverse this hierarchy, including the City of Toronto's Official Plan. For example, York, United Kingdom uses a modal hierarchy when it considers land use and transport related decisions and implementation practices. It prioritizes consideration of pedestrians, followed by people with mobility problems, cyclists, public transport users, and then other motor vehicle users.[28] The City of Vancouver, BC has a similar modal hierarchy.[29]

Many North American cities have also recently adopted ordinances which require the development of "Complete Streets" when new roads are built or existing ones redesigned. A definition of a Complete Street is one that is "designed for all ages, abilities, and modes of travel,"[30] where street design is modified to better accommodate pedestrians, cyclists, transit users, and other vulnerable users, rather than providing for the needs of the automobile to the detriment of other groups. Complete Streets not only are designed for all users, but also expand the function of streets from simply moving people to also including serving social, cultural, environmental and economic functions.

While there is not a singular design prescription, Complete Streets typically include sidewalks, bike facilities, public transit access, and a vehicular right-of-way that encourages safe automobile use at an appropriate speed. Choosing the appropriate mix of Complete Street elements requires an understanding of the characteristics of a given street segment, including the surrounding neighbourhood context, potential volume of activity, composition of current and anticipated future users, and any other locally-specific needs, challenges, or opportunities. Complete Streets also often include safety features for pedestrians and cyclists, trees and other landscaping, pedestrian-oriented buildings directly accessible from the sidewalk, and other amenities aimed at providing a safe and pleasant experience for the most vulnerable users.

Complete Streets policies dovetail with existing policies to provide universal accessibility or barrier-free travel, which focus on removing physical impediments to people with disabilities engaging in their community. In terms of street design, barrier-free access means re-designing crosswalks and intersections, traffic signals, sidewalks, street furniture, and lighting. Because barrier-free design benefits not only those with disabilities, but many others – for example, anyone with a bicycle, cart, or stroller – there is a large amount of synergy between barrier-free design and Complete Street elements. The City of Toronto's own 2004 Accessibility Design Guidelines include best practices to achieve a barrier free community.[31]

Background

Design has been hypothesized to have an influence on health through a number of pathways. The following sections describe each.

Access to Destinations

Access to destinations is of primary importance when making the choice to walk or cycle. At the most fundamental level, having access to employment, shops, and other essential destinations is a basic human need. The ability to access destinations within a convenient walking or cycling distance provides physical activity, which in turn helps maintain a lower body weight and reduce risk for chronic diseases such as type 2 diabetes and cardiovascular disease.

Safety and Security

Providing access to destinations alone is insufficient to get most people to walk or cycle. People need to feel safe and secure on the street, both in terms of safety from automobile traffic and crime. Design characteristics, like lighting and transparency, can help reduce threats from criminal activity. Buildings, transit waiting areas, and public spaces designs should minimize dark corners, dead ends, and isolated areas, and enhance the visibility ("eyes on the street") of these areas. Planning for uses along streets should also be done to attract positive activity in a neighbourhood (such as a corner store or community center). In some cases, additional effort and attention from neighbourhood residents, police, and others may be necessary.

In terms of pedestrian and cyclist safety, street design can help minimize potential conflicts between automobiles and these more vulnerable users. Street design can reduce motor vehicle speeds, which help to decrease the likelihood of collisions. Also, slower motor vehicle travel speeds result in less severe injuries and decrease the likelihood of death.[32] Figure 1 shows the results from a study by Anderson et. al. (1997).[33] A pedestrian has a 90 percent chance of surviving a crash that happens at 30 km/h or below.[34,35] If the crash happens at double the speed (60 km/h), the pedestrian is unlikely to survive.[33] The elderly are even more vulnerable.[32] Studies on cyclists show a similar relationship between speed and survival rates – compared to a crash that happens at less than 32 km/h (20 mph); impacts at 32-48 km/h (20-30 mph) have a 92 percent greater probability of fatality. Impacts at 48-64 km/h (30-40 mph) are three times more likely to result in fatality, and with impacts at 64-80 km/h (40-50 mph), a fatality is 10 times more likely.[36]

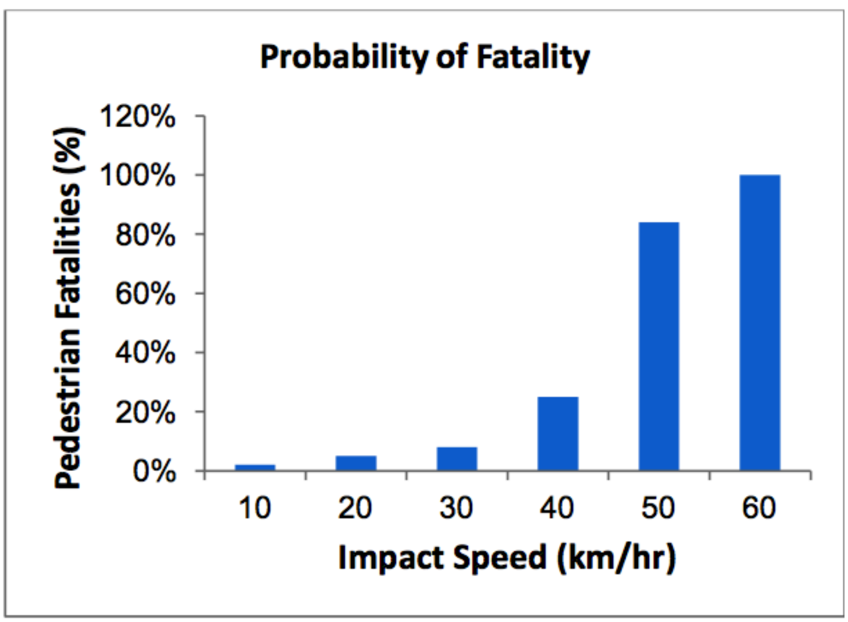


Figure 1: Speed and Probability of Fatality.[27,33]

Although reductions in speed limits and enforcement campaigns can help to reduce vehicle speeds, their impact will remain limited unless they are supported by changes to reduce the “design speed” of the street. Many Complete Street elements can help to reduce a street’s design speed, such as street trees, sidewalks, cycle lanes, narrower and fewer travel lanes, medians, traffic calming (e.g. curb extensions at intersections, chicanes, traffic circles, speed tables/humps) and tighter turning radii. In what is called the “Safety in Numbers” phenomenon, streets with many cyclists and pedestrians may also cause drivers to move more slowly and cautiously. This can cause a positive feedback loop, where the slower traffic speeds encourage yet more walking and cycling.

Aesthetics and Comfort

Attractive street design can also encourage discretionary or recreational walking and cycling, in addition to making utilitarian trips more pleasant. Good street design can also have a positive influence on mental and social health. An attractive street with seating, interesting destinations, and minimal annoyance from vehicular traffic helps to encourage social activity on the street. Trees and vegetation are known to have a calming effect that helps promote better mental health. The absence of stressors such as noise, air and visual pollution are consistent with better mental health and create a more enjoyable walking or cycling experience. Exposure to vehicular exhaust can be somewhat mitigated through traffic control, adjacent building design, and providing vegetation.

Most of these influences are mutually reinforcing. Calmed traffic can encourage increased pedestrian and social activity. More pedestrian and social activity help deter crime. Low crime encourages additional pedestrian and social activity. Additional activity has a further calming influence on traffic. Conversely, if one of these elements discourages activity (e.g. a street with wide sidewalks, cafes, and trees, but disrupted by a 6-lane arterial), it can have a ripple effect limiting the health benefits of all other elements.

Results

The following sections provide an overview of the results of the literature review, including a brief summary of substantive findings and a discussion of considerations to prioritize the implementation of Complete Streets elements. Following that are the detailed evidence-based findings for the main categories of Complete Street elements. Appendix A describes the methods used to conduct the literature review. Appendix B summarizes the methodologies used by the studies that were reviewed. The referenced cited here are provided in the End Notes section.

The vast majority of studies reviewed focused on the impacts of one or more Complete Street elements on physical activity and traffic safety. A few studies focused on other health outcomes such as body weight, physical health, or mental and social health. In terms of the populations studied, most were focused on adults or the general public, with less attention on seniors, children /youth, and those with disabilities. Where evidence was found for these groups, it is presented in the detailed findings below. No studies were found that assessed the health impact of adopted Complete Streets policies or guidelines.[37]

Evidence of the Complete Street element influences on safety, and physical and social activity outcomes are summarized in Table 1 below. Positive associations with health impacts, based on the reviewed studies, hypothesized relationships and professional judgment, are indicated with a "+". Conversely, negative health impacts are indicated with a "-".

Table 1. Complete Street health related element associations with safety, physical and social activity

Category	Design element	Safety	Physical activity	Social Activity
Street & network	Street connectivity	+	+	NK
Pedestrian category	Sidewalk presence & width	+	+	+
	Buffer zone	+	+	NK
	Lighting	+	+	NK
	Furnishings	NK	+	+
	Trees & vegetation	+	+	NK
	Public transit facilities	NK	+	NK
	On-street parking	+/-[1]	+	NK
Cycling category	Bike lanes	+	+	NK
	Cycle tracks	+	+	NK
	Off-street bike paths/trails	-	+	NK
	Bike boulevards	NK	+	NK
	Bicycle parking	NK	+	NK
	On-street parking	-	-	NK
Roadway	Minimize street width / # lanes	+	+	+
	Narrow lane width	+	+	NK
	Median inclusion	+	+	NK
	Traffic calming features	+	+	NK
Intersections & crossings	Intersection control	+	+	NK
	Midblock control	+/-[2]	+	NK
	Small corner radius & other curb treatments	+	+	NK
Adjacent buildings and land uses	Retail uses	+	+	+
	Open space uses	NK	+	NK
	Building enclosure & façade	+	+	NK
	Café/vending space	+	+	+

* NK = not known

* +/- = both positive and negative impacts were found, conflicting evidence

[1] +/-: On-street parking seems to provide safety benefits for adult pedestrians, but can have negative impact on children, bicyclists, and motor vehicles.

[2] +/-: Impacts for pedestrians tend to be positive for low volume streets with few lanes and negative for higher volume, multi-lane streets. However, with proper signalization and stop control impacts can be positive on higher volume streets. The selection of the right treatment is an engineering design issue that is very context-sensitive.

In some cases, both positive and negative impacts were found for a particular element. For example, on-street parking seems to provide safety benefits for adult pedestrians but can have negative impact on children, bicyclists, and motor vehicles. Cases with conflicting evidence are indicated with a “+ / -“. Further details on the findings are provided in subsequent sections organized by Complete Street categories and design elements.

The remainder of this literature review is organized using the following broad Complete Street element categories:

- Street and network considerations
- Pedestrian space
- Cycling facilities
- Roadway
- Intersections & crossings
- Adjacent buildings and land uses
- Additional planning & design considerations

Within each category, sub-categories of related elements are provided, and for each the literature is reviewed.

Street and network considerations

Street connectivity is critical for pedestrians and cyclists because low travel speed and limited human energy constrain non-motorized travel range, effectively limiting the number of opportunities accessible to pedestrians and cyclists. While not every street can accommodate vehicles, cyclists and pedestrians equally, all need access to safe connected networks suitable for safe, efficient travel. Street connectivity consists of several components, including a high density of intersections, short street blocks between intersections, and frequency of 4-way intersections relative to 3-way intersections. Higher street connectivity reduces travel distances thus increasing the number of opportunities within reasonable range of pedestrians and cyclists. Pedestrians and cyclists often cite minimizing travel distance as the most important criterion for route choice. [38,39] Evidence from Toronto suggests that the likelihood of crossing mid-block is higher for those living on streets with long blocks that provide limited crossing opportunities.[38] Street connectivity was identified as an important predictor of walking attractiveness in a study of households in Portland, Oregon, neighbourhoods.[39] For cyclists, an important aspect of connectivity also includes continuity of cycling facilities to minimize the need to traverse through or detour around high-stress sections where threats from motor vehicles are especially high.[40]

A 2011 Toronto Project BEAT study of school travel modes for 5th and 6th grade students found street connectivity and household income to be important.[41] Children living in pre-World War II neighbourhoods with well-connected street systems, and high and low incomes, were more likely to walk to school when compared to those in newer suburban neighborhoods with disconnected street systems and high incomes. Children in the newer, more suburban neighborhoods with lower incomes also had high rates of walking. Children living in the newer neighborhoods with higher incomes were 2.5 to 3 times more likely to be driven to school than those living in older neighbourhoods, regardless of income.

Higher street connectivity is widely recognized as being one of the most important features of an urban environment for promoting physical activity.[8,42,43,44] In a meta-analysis of studies linking built environment characteristics to travel behavior, intersection density was the strongest predictor of more walking and a strong predictor of more transit use and less vehicle miles of travel.[45] In a route choice study in downtown Boston, commuters were more likely to choose a route from the subway to their workplace that had a high density of intersections along the route.[46] While street connectivity has consistently been associated with active modes of transportation, the influence of street connectivity on leisure physical activity is less clear.

Evidence also suggests that street connectivity may have benefits for reducing collision frequency and severity. Higher intersection density has been associated with reduced collision frequency and severity due to overall network speed reductions,[47] though one study noted that connectivity was associated with increased collision frequency but reduced collision severity.[48] Similarly, collision rates are higher in areas with more lane miles of arterials and collectors relative to local streets.[49]

Pedestrian Space

The following sections consider elements typically found between adjacent buildings and the curb, including sidewalks, landscaped or other buffers, lighting, street furniture, street trees, transit stops and similar amenities. Proper design of these features helps to ensure a safe and inviting space for pedestrians with adequate separation from nearby vehicles.

Sidewalk Presence & Width

The positive influence of sidewalks on pedestrian safety is clear. Two reviews noted that the presence of sidewalks helps to reduce vehicle-pedestrian collisions along street segments.[2,50] In addition to a sidewalk's presence, its condition can also affect people's choice to walk. Trip and fall hazards hamper the ability to walk safely, especially for someone with vision impairments or balance/strength problems. An exploratory study in Ottawa found "environmental hazards related to traffic and falls risks can be significant barriers to walking for seniors."[51] A Northern California study of people 45 and older found walking was the most common fall related activity. Most outdoor falls were found to occur on sidewalks, curbs and streets.[52]

Proper attention is needed to assure the initial design of a project provides for universal accessibility, including meeting proper standards for people with disabilities. Once sidewalks are constructed, proper maintenance is needed to assure their safe use. Typical maintenance issues include addressing uneven or broken sidewalk surfaces, narrowed areas due to the addition of sign posts, newspaper boxes, benches, etc., untrimmed trees/bushes which hangover the sidewalk, and in the winter the lack of proper clearing of snow and ice.

In a 2013 survey, when Torontonians were asked to think "about the City services that have the greatest impact on 'walkability'. They cited winter sidewalk snow removal (86%), lighting on pedestrian walkways/paths (78%), and general sidewalk maintenance/repairs (78%) as the most important".[53]

A community walkability checklist, developed by the National Centers for Safe Routes to School and other agencies, considers several factors in developing an overall walkability score. Communities with higher scores have sidewalks which are continuous, and free of tripping hazards and obstacles.[54]

As expected the presence of sidewalks has been shown to have a positive impact on physical activity, though there are some inconsistencies in the literature. In a meta-analysis of self-reported neighbourhood conditions, those reporting sidewalks in their neighbourhood were more likely to engage in physical activity.[55] Other reviews have found sidewalks to be associated with walking but not with the more all-inclusive category of general physical

activity,[56, 69] while others have found no association between sidewalks and physical activity.[44] Findings were also mixed in a review of studies linking sidewalk availability to child and teen physical activity.[57] However, the review found children's physical activity was correlated with traffic speed/ volume, access/proximity to recreation facilities, mixed land use, residential density, and walkability, and for adolescents it was land-use mix and residential density.
In one route choice study in downtown Boston, commuters were more likely to choose a route with wider sidewalks, even after adjusting for route distance (that is, given two routes of the same distance, commuters were more likely to pick one with sidewalks rather than one without).[46] Similarly, a study of mode choice in Chapel Hill, North Carolina, indicated that commuters were more likely to choose to walk relative to other modes with an increase in the length of sidewalk relative to street length along the shortest path from home to work.[58]

One study in Perth, Western Australia, found that the length of sidewalk within a 1.6 km buffer of the home was associated with more neighbourhood-base walking for transportation purposes but was not associated with recreational walking.[59] Studies of neighbourhood sidewalk availability and width found significant positive correlations with transportation walking,[74,72,65] recreational walking,[97] any walking,[98] or overall physical activity,[60] while others have found no association.[61,70]

Finally, in an analysis of urban design features on block segments in urbanized neighbourhoods in the Boston metro area, sidewalk width was identified as an important predictor of social activity.[62]

Buffer

Little research has investigated the impact of a buffer between the sidewalk and the curb, or the size of this buffer, on physical activity and health. The presence of at least five feet of separation between the sidewalk and the curb was identified as an important predictor of walking attractiveness in a study of households in Portland, Oregon.[39] In one correlational study, the presence of a buffer was found to be associated with more transportation walking but not associated with recreational walking or overall moderate/vigorous physical activity.[74]

Lighting

In terms of safety, one review noted that the installation or improvement of lighting along street segments was associated with a reduction in pedestrian-vehicle collisions at crosswalks in multiple studies.[50] Two studies were identified that linked the lack of lighting along a road segment to increased collision frequency for cyclists.[36,63] The presence of lighting is also known to improve perceptions of safety[68] and act to deter criminal activity.[64]

Positive associations were found between lighting and physical activity in some correlational studies. In urban neighbourhoods in Minneapolis and St. Paul, Minnesota, street light density along road segments near the home was associated with more transportation walking but was not associated with leisure walking or objectively-measured moderate/vigorous physical activity.[65] In a longitudinal study of older adults living in Alameda County, California, self-reported "inadequate lighting" was identified as the strongest neighbourhood-level determinant of the loss of the ability to complete physical tasks over time.[66]

In the only known longitudinal study evaluating the impact of new lighting installation on physical activity, pedestrian activity was found to increase after the installation of street lighting at four mixed-use locations in London, England, where criminal activity had been occurring or other safety concerns had been expressed.[67] However, in several reviews of correlational studies in suburban residential neighbourhoods, street lighting has generally not been found to be associated with physical activity.[55,68,69]

Furnishings

In an analysis of urban design features on block segments in urbanized neighbourhoods in the Boston metro area, the presence of public seating was identified as an important predictor of social activity.[62] In a correlational study in urban neighbourhoods in Savannah, Georgia, and St. Louis, Missouri, adults living in neighbourhoods with "trees, benches, or other comfort amenities" on more than 25 percent of street segments engaged in more transportation-related physical activity than those with amenities on fewer than 25 percent of street segments.[70]

In an unpublished study in New York City, the number of pieces of street furniture on a street segment was associated with higher counts of pedestrians.[71] In another unpublished study, the presence of benches or other places to sit was associated with more transportation-related physical activity but not associated with leisure physical activity.[72] In contrast, several published studies have found no association between street furnishings and physical activity.[73,74] In a qualitative study of seniors' preferences, many participants expressed that the presence of benches and other seating opportunities would help facilitate more walking.[75]

Trees & Vegetation

The health benefits of nature have been suggested by a wide variety of theories such as the biophilia hypothesis (that humans have an instinctive need for a connection with the natural world)[76], attention restoration theory (that exposure to nature can improve directed attention and reduce stress)[77], and nature deficit disorder (that a lack of exposure to nature is associated with behavioral, developmental, and physical disorders)[78]. Evidence to-date suggests that better access to nature and green space is associated with more physical activity and better physical, mental, and social health.[79,80,81,82]

Contrary to conventional engineering theory, evidence suggests that in urban street sections, the presence of fixed objects such as trees and planting containers do not contribute to increased vehicular collisions.2 On the contrary, accumulating evidence indicates that tree-lined street sections may actually have lower collision rates than sections without trees.[83] One possible reason for this relationship is that trees along the roadside provide a visual constraint that signals to the driver to slow down, whereas a wide open viewshed may encourage a driver to speed up. A second possibility is that the presence of trees conveys a calming effect to as well as adding interest for the driver, encouraging slower speeds.

When people are outside, trees affect the amount of sunlight and wind they are exposed to, which affect people's thermal comfort.[84] Thermal comfort level can influence people's decisions to walk or bicycle. Tree types should be selected to maximize shading in the summer and allow sun penetration to sidewalks and open areas during the rest of the year, while reducing wind speeds year round.

The presence of street trees can also have a strong influence on urban "heat islands" and vulnerability to extreme heat events. Research demonstrates that neighbourhoods dominated by commercial and industrial land uses, which tend to have high levels of impervious surface and low levels of vegetative coverage, have relatively high surface temperatures within an urbanized area.[85,86,87] In contrast, areas with large amounts of open space, water, and vegetative cover have relatively low surface temperatures. There is evidence that street trees in particular provide benefits for mitigating heat island impacts, reducing cooling costs for adjacent buildings, and reducing maintenance costs for pavement below the street tree canopy.[88,89,90] In addition to providing shade and heat reduction, some evidence suggests that greater urban tree canopy can reduce harmful ultraviolet radiation exposure that leads to skin cancer.[91,92]

In a study of pedestrian activity in the city center of Lille, France, higher pedestrian counts were observed on street segments with trees.[93] In two correlational studies of adults in New York City, the street tree density within 1 kilometre of home was associated with lower body mass index,[94] but the street tree density in the home zip code was not associated with the likelihood of walking or biking for at least 10 blocks anytime in the past month.[95] In a correlational study in Minneapolis and St. Paul, Minnesota, the density of street trees within an 805 x 805 metre home zone was associated with greater leisure walking but not associated with transportation walking or total moderate/vigorous physical activity.[65] In an unpublished correlational study, a composite tree index (composed of the number of trees, spacing of trees, and the percent of the sidewalk shaded by trees) was associated with transportation-related physical activity for adults (but not for children, teens, and seniors) and was not associated with recreational physical activity or total moderate/vigorous physical activity for any age group.[72] In a longitudinal study in Tokyo, seniors with more parks and tree-lined streets near their residence had a higher 5-year survival rate.[96] Several additional studies found no relationship between street trees and various measures of physical activity.[97,70,98,99]

In a study in neighbourhoods in four Dutch cities, the quantity and quality of greenery visible along the streetscape were both associated with better self-reported health, fewer acute health-related complaints, and better mental health status.[100] The authors identified stress reduction and higher social cohesion as mediators of the greenery-health relationship. In a study of livable street design in San Francisco, residents of tree-lined boulevards with landscaped medians indicated less annoyance and better social conditions despite heavier traffic than streets lacking these amenities.[101]

In a review of child and teen studies of environmental predictors of physical activity, positive associations between streetscape vegetation and physical activity were found in 36 percent of child studies and 12 percent of teen studies.[57]

Evidence linking street trees to respiratory outcomes is mixed and requires additional research to understand the combined impact of pollution reductions and allergen creation. Urban trees are known to help reduce both gaseous and particulate air pollution.[102,103] A correlational study in New York City found that greater street tree density within United Hospital Fund areas was associated with lower prevalence of asthma in children.[104] Later research by the same author using stronger data and methods found the opposite result – the greater the tree canopy within 0.4 kilometre of the prenatal address, the higher the likelihood of asthma and allergic sensitization to tree pollen.[105] Other researchers have found a similar association between proximity to trees and allergen-related respiratory conditions.[106,107,108] New research also suggests that street-trees may disrupt wind flow that would otherwise help disperse vehicular pollutants and trap pollutants below the canopy, thereby increasing pollutant concentrations at street level.[109,110]

Public Transit Facilities

The focus of this section is limited to transit stop design and accessibility, as opposed to vehicle type, transit design and operations in the travel way, such as curb radii and lane design (restricted/mixed traffic) and placement (center, curbside). Curb radii and lane width considerations for transit vehicles are addressed in the "Additional planning & design considerations" section.

Recent research provides evidence that transit users engage in more physical activity than non-transit users.[111,112] Several correlational studies have found that a higher density of transit stops/stations or shorter distance from home to the nearest stop/station is associated with more physical activity and lower body weight.[113,65] One correlational study found that physical activity was higher in neighbourhoods with more transit stops.[70] A second unpublished correlational study found that the presence of transit stops was associated with more transportation-related physical activity for adults, teens, and children, less recreational physical activity for children, and found no association for overall physical activity.[72]

One review noted that in several studies, pedestrian-motor vehicle collisions were found to decrease after relocating a bus from before an intersection to after an intersection, as pedestrians will frequently cross in front of a near side bus and cannot be seen by motor vehicles.[114]

Cycling Facilities

While dedicated cycling facilities are not the only factor which facilitate higher rates of cycling, most cyclists express a preference for bike lanes or other designated bicycle facilities.[115,116] A recent global positioning system (GPS) analysis of cycling activity in Portland, Oregon, indicated that even though designated bike facilities (e.g. bike lanes, paths, and boulevards) accounted for only 8% of the road network, nearly 50% of all cycling activity occurred on them.[39] Nearly all (95%) of the City of Boulder's (Colorado, US) arterial network accommodates bicycles. Boulder residents cycle 21 times more often than the U.S. national average.[117]

One review reported large increases in cycling activity and reduction in bicycle collisions following widespread bicycle network improvements (including the construction of bike lanes and cycle tracks, on the road, but separate from traffic and the sidewalk).[37] Differences have also been noted between types of cyclists, with less frequent and inexperienced cyclists more willing to divert from the shortest path to make use of bike facilities, especially to access bicycle boulevards (lower speed roads improved for cyclists).[116] Among the least experienced cyclists, separated paths or trails are often most preferred as they are perceived to be the safest.[118]

A bikeability checklist developed by the Pedestrian and Bicyclist Information Center shows several features which positively impact a community's bikeability, including route/trail continuity, good surface conditions (e.g. no potholes, broken/rough/uneven pavement, debris/litter) and intersections with traffic signals providing sufficient time, and good visibility for oncoming traffic.[119]

Bike Lanes

A review of cycling infrastructure concluded that on-road cycle facilities (e.g. lanes or routes) were associated with lower collision frequency than on similar roads without bicycle facilities.[120] A recent analysis in New York City found that despite more cyclists using newly installed bike lanes the number of collisions in that area did not increase.[121] The authors attributed the lack of an increase in collisions to the reduction in vehicular travel speeds and reduction of vehicle-bicycle conflicts. In a related study, an increase in collisions was found at intersections with new bike lanes, though the authors were unable to adjust for increases in bike volume.[139] One review noted that the increased visibility provided by painted bike lanes was associated with improved safety.[50]

One review suggests that collisions with bicyclists are higher on street sections with on-street parking directly adjacent to where cyclists ride.[2] Evidence from Toronto indicates that on-street parking is specifically a problem in downtown, and involves collisions of cyclists with doors being opened by motorists ("dooring").[122] A proposed design for Harbord Street and Hoskin Avenue in Toronto responds to dooring collisions by providing a 0.5 to 1m buffer (using painted stripes) between the park cars and the cycle lanes.[123] In addition to the benefit to the cyclist, the buffered area also provides an additional location for snow storage.

Cycle Tracks and Bike Paths

The literature is mixed as definitions of on-road cycle tracks and off-road multi-use paths vary and are unclear or lumped together in some studies as "bike paths". It is also sometimes unclear whether these studies refer to one-way facilities on both sides of a road or two-way facilities on only one side of the road. The mixed findings are indicative of this inconsistency in "bike path" definition.

One review identified two studies demonstrating that bike paths separated from vehicular traffic were safer and five studies demonstrating that separated bike paths were more dangerous, though definition of "bike paths," the distance and method of separation, and the types of collisions varied widely between studies.[120] A recent case-control study of two-way cycle tracks along one side of the street in Montreal found that streets with cycle tracks were safer for bicyclists than similar parallel streets without cycle tracks.[124] A case-crossover study in Toronto and Vancouver found cycle tracks alongside streets to be safer for bicyclists than major streets with parked cars and no bike infrastructure.[125] Researchers in this study also found cycle tracks to be safer for cyclists at non-intersection locations as compared to riding on streets with no cycling facilities, but found no safety difference at intersection locations.[126]

In a study of nine cycle tracks (protected cycle lanes) in five United States' cities it was found that cycle ridership, within a year of installation, increased +21% to +171%.[127] The researchers found that these increases were greater than overall cycle commuting increases, but acknowledge that some of it may be attributable to existing cyclists diverting to the new facility. Participants in this study also consistently indicated their perception of safety while cycling had improved due to the protected cycle lanes; however drivers' and walkers' perception of safety improvements were more varied.

Safety of separated bike facilities also seems to differ at intersections as compared to between intersections. A review article reports that most cycling collisions with motor vehicles occur at intersections rather than mid-block, and most studies have found cycle paths separated from vehicular traffic to be less safe than on-road facilities where they intersect with cross-streets.[128] A second review found one-way cycle tracks to be safer than two-way facilities, and that intersection treatments such as pavement markings, warning signs/signals, raised bicycle crossings, or merging cyclists onto an on-street bike lane in advance of the intersection were shown to improve safety.[129] In a correlational study of unsignalized intersection safety in the Netherlands, when cyclists are moving in the direction of the legal right-of-way, higher collision risk was found for two-way as compared to one-way cycle tracks.[130] The authors found no safety difference for cycle tracks within 2m or further than 5m from the road, but that cycle tracks between 2-5m of the road were safer than roads with bike lanes or no bike facilities. The presence of raised bicycle crossings at intersections also provided a major safety benefit. It is also important to recognize the large number of lot design/engineering factors which also contribute to the safety of the facility. These factors include sight lines, horizontal curve, topography and design speed of the intersecting roads, and design of traffic controls at intersections.

Bicycle Parking

One review found evidence that bicycle parking at a destination increased the perceived convenience, and in turn the likelihood of cycling, especially for sheltered and secured bicycle parking. [131]

Emissions Exposure

Although some concern has been expressed about the potential exposure for cyclists to harmful vehicular exhaust shifting travel from polluting modes to cycling can help reduce aggregate pollution levels. A recent review indicated that cyclists had the least exposure to fine particulate matter as compared to other common travel modes.[132] The authors also noted that there was substantial variation in exposure depending on differences in such things as traffic parameters, meteorology and ventilation. A study of cyclist route choice in Berkeley, California, found that particulate matter, carbon monoxide, and black carbon exposure were all higher along a high-traffic route as compared to a low-traffic route.[133] One recent review suggested that cyclists can minimize their exposure by choosing low-traffic routes whenever possible.[134] This review also found that several studies reported that physical activity benefits outweigh the health risks related to pollutant exposure and collisions.

Roadway

Design considerations for vehicular travel are often related to roadway type and include the functional classification, overall travel way width, number of vehicular lanes, and vehicular lane width, and often also incorporate medians, traffic calming features, and mid-block crossings. These features have an influence on traffic volume and speed, which in turn influence the likelihood of walking and cycling, pedestrian/cyclist collision risk with vehicles, air and noise pollution, and the potential for social interaction. Specific design elements and their relationship with healthy behaviors and health outcomes are described in further detail below. According to the 2012 TPH Healthy Toronto by Design report, called *The Walkable City: Neighborhood Design and Preferences, Travel Choices and Health,* "more than half of the Toronto residents surveyed expressed a strong preference for street designs that allow them to walk, cycle or take transit even if means that there will be greater foot and car traffic on their streets." [135]

Street Width / Total Number of Lanes

Collision rates tend to be higher for wider roads, even after adjusting for traffic volume, particularly when comparing two or three-lane sections to four-lane and wider sections.[2,47,136] Road diets provide especially strong evidence of the association between road width and collision rates. A typical road diet consists of removing one lane in each direction of a four-lane street section, adding a center turn lane and/or landscaped median, and repurposing the additional road space for such things as bike lanes, or wider sidewalks. In many cases, road diets occur where there is currently excess road capacity. Road diets benefits to bicyclists, pedestrians, and motorists can include reduced vehicle speeds, improved mobility and access, reduced collisions and injuries, and improved livability and quality of life.[137]

Before/after studies of road diets, including evidence from the St. George Street road diet in Toronto, have consistently indicated that collisions are reduced after reducing the number of travel lanes.[2,138,139] The added center turn lane helps to maintain smoother traffic flow than before the road diet. Some studies have also revealed an increase in cycling activity after a road diet implementation that also added bicycle lanes.[138] Several reports suggest that minimizing road widths (crossing distances) is especially important for seniors and pedestrians with disabilities.[140,141] A community walkability checklist considers roads which are too wide to have a negative impact on walkability.[54]

Narrower road widths and fewer travel lanes also seem to provide benefits for physical activity, though the evidence is inconsistent. In an analysis of Bay Area Rapid Transit (BART) users in San Francisco, CA, the likelihood of walking to transit relative to choosing other transit access modes was higher for those with narrower right-of-way width along the shortest route from home to the BART station.[142] A 2014 Toronto study found that providing a separated right-of-way for streetcars on St. Clair Avenue was associated with a reduced rate of pedestrian/motor vehicle collisions.[143]

In a study of livable street design in San Francisco, those living on streets carrying less traffic volume reported less annoyance, lower noise, and better social conditions than residents living on streets carrying higher traffic volume.[101]

Narrow Lane Width

Evidence also suggests that narrower lanes reduce vehicular travel speed, as the constraints of the lane force drivers to operate more cautiously.[2,144,145] While wide lanes may provide safety benefits in rural areas, the opposite is found in urban areas.[146] Evidence suggests a maximum threshold of an 11’ lane width for speeds of up to 45 mph (72 km/h) above which higher collision rates may be found.[2,147] Higher collision rates may be found for lane widths of 3 metres (10 feet) and narrower on undivided, multi-lane arterial roadways, or for lane widths of 2.7 metres (9 feet) and narrower on divided, multi-lane arterial roadways.[147] Narrower lane widths also provide the benefit of reduced crossing distance for pedestrians.

On-street Parking

A case-crossover study in Vancouver and Toronto found major streets with no bike infrastructure and no on-street parking to be significantly safer than major streets with no bike infrastructure but did have on-street parking.[125] A correlational study in Edmonton found that the severity of mid-block cycling collisions was greater where on-street parking was present.[148] In a stated preference survey, bicyclists expressed a preference for routes without on-street parking.[116] This may be related to concerns about 'dooring' or conflicts when cars have to merge into the street.

On the other hand, on-street parking is often cited as a buffer between moving vehicles and pedestrians that helps to increase comfort and security for pedestrians. The presence of on-street parking was identified as an important predictor of walking attractiveness in a study of households in Portland, Oregon, neighbourhoods.[39] In a correlational analysis of the built environment within 805 x 805 meter “home zones,” the presence of on-street parking was associated with more transportation-related physical activity but unassociated with other forms of physical activity.[74]

In contrast, a second correlational analysis reported that the presence of on-street parking was associated with more leisure physical activity for some age groups but that on-street parking was unrelated to transportation activity.[72] A third study found that the prevalence of on-street parking at the census tract level was associated with higher likelihood of making a non-work trip by a mode other than a personal motor vehicle.[149] Finally, in a correlational study of children in neighbourhoods in six Dutch cities, the frequency of parallel parking spaces in the neighbourhood was associated with more physical activity.[150]

Conflicting evidence is found for the impact of on-street parking on collisions. One review demonstrates higher frequency of vehicular collisions along roads with on-street parking, especially angled parking, compared to roads with no on-street parking.[151] In contrast, a correlational study found reduced total collision frequency and especially reduced collision severity in sections with on-street parking, versus those without on-street parking, but were comparable in terms of speed, volume, and the number of lanes.[152] Another review notes that on-street parking is directly attributable for a large percentage of urban collisions, with children being especially vulnerable in sections with on-street parking.[2] This same review also suggests that collisions with bicyclists are higher in sections with on-street parking. Evidence from Toronto indicates that on-street parking is specifically a problem in downtown, and involves both dooring collisions with cyclists and collisions with vehicles exiting parking spaces.[122] A proposed design for Harbord Street and Hoskin Avenue in Toronto responds to cyclists collisions with doors being opened by parked motorists by providing a 0.5 to 1 metre buffer (using painted stripes) between the park cars and the cycle lanes.[123]

Median Inclusion

Raised medians are not only known to reduce vehicular collisions due to their enhanced separation between vehicles and ability to limit turning access, evidence also suggests that medians help to reduce vehicular collisions with crossing pedestrians.[153] Although narrow raised medians may provide some benefit for vehicular collisions, evidence suggests that wider medians (e.g. 10’) were much safer for pedestrians than narrow medians (e.g. 4’).[2] Medians intended to be used for pedestrian refuge are recommended to be at least 6’ wide but preferably at least 8’ wide.[154] A study of the impact of the installation of a raised 7.5’ median in New Jersey noted that vehicle travel speeds were lower after median installation and that the time pedestrians spent exposed to traffic was reduced by 28%.[155] One review found that the presence of raised medians substantially reduced pedestrian-vehicle collision frequency as compared to roads without raised medians, particularly on wider roads (more than 2 lanes) with higher volumes (more than 15,000 vehicles per day).[50] In addition to raised medians, most access management features such as limiting driveways, limiting left turns, and providing turn lanes tend to have positive benefits for safety.[2]

Traffic Calming Features

Traffic calming features such as speed humps, speed tables, and traffic circles, are designed to reduce traffic speeds and in some cases traffic volumes. As such, traffic calming features have consistently been associated with reductions in collision frequency, even after adjusting for differences in traffic volume.[2,156,157,158] However, several studies do exist that have found no influence of traffic calming on collisions, such as the recent longitudinal analysis in New York City.[139]

Wide variations exist in the appropriate selection, design, and impact of traffic calming features dependent on traffic conditions and surrounding land use context. Treatments appropriate for commercial streets may include but are not limited to speed limit reductions, warning signs and lighting, narrowed lanes, speed tables, rumble strips, pavement markings, and various forms of curb extensions that either narrow the lane (e.g. pinch point) or force a horizontal shift (e.g. chicane).[159] Treatments appropriate for residential streets are the same, except rumble strips are not typical, and features can include 2-lane to 1-way narrowings, speed humps, partial or full closures to vehicles, and variations of shared-use, traffic-restricted streets based on the Dutch Woonerf (or home zone) concept.[3]

The evidence linking traffic calming to increased physical activity in mixed use, urbanized areas is unclear, as most studies have occurred in predominantly suburban, residential locations. One correlational study found that traffic calming features were associated with more transportation walking but not associated with recreational walking,[65] while another found that traffic calming features were associated with more leisure walking but not transportation walking or overall physical activity.[74] One review article reported that traffic calming features have been associated with more physical activity for adolescent boys and more observed adult and child pedestrian activity.[160] In a study of local residents before and after the installation of traffic calming, participants reported engaging in more outdoor activity and physical health was found to improve after installation but no change was found for mental health.[161] Some researchers have noted that certain traffic calming features can generate excessive noise and

[3] Woonerf - http://streetswiki.wikispaces.com/Woonerf

exhaust due to the tendency of some drivers to accelerate rapidly after navigating a traffic calming feature, though those problems are typically mitigated through proper design.[162,163]

Intersections & Crossings

This section reviews traffic control, warning, and other safety features typically found at intersections and mid-block crossings, which have been studied to determine their connection with user safety and convenience.

Intersection Control

Two reviews reported significantly improved pedestrian safety at intersections with scrambles (all-stop phases), where all vehicle movement is stopped and pedestrians can cross the intersection in any direction.[2,50] These are commonly applied with high levels of pedestrian traffic. A more recent longitudinal study in New York City reported a 35% reduction in pedestrian collisions after adding an all-stop phase.[139] The same study also reported pedestrian collision reductions after increasing the crossing time for pedestrians, which validates findings from an earlier review.[50] The review article also found safety benefits for a leading pedestrian interval (where pedestrians are prompted to begin crossing before the vehicular signal turns green) and the installation of a device that prompts pedestrians to check for vehicular threats before crossing. In a case-control study of intersection crosswalks in six Washington and California cities, a 3.6 times higher risk of pedestrian collisions was found at crosswalks at intersections where traffic was not required to stop (i.e. neither a signal nor stop sign were present) as compared to similar intersections without crosswalks.[164] Collision rates were not significantly different at intersections where traffic was controlled (by signal or stop sign) when comparing those with crosswalks to those without.

One review found that most cyclists prefer the use of bike boxes, allowing bicyclists to stop (at intersections) in a more visible location in front of motor vehicles, though most studies have not shown evidence that bike boxes provide a measurable safety benefit.[2] A more recent case-control study found that bike boxes reduced encroachment of bikes and motor vehicles into the pedestrian crosswalk and reduced the number of bicycle-motor vehicle conflicts at the intersections with bike boxes.[165] A new and unstudied concept design called “Protected Intersections” proposes a way to use cycle lanes through traffic signal controlled intersections to separate cyclists from motor vehicle travel lanes, even when making left turns.[166] Another review article found that a separate bike phase of the traffic signal helps to reduce bicycle collisions within an intersection.[131]

One review article found evidence that collisions are more frequent at intersections with four or more legs as compared to those with three legs.[2] The same article suggests that all-way stops provide safety benefits as compared to traffic signals up to traffic volumes of about 10,000 vehicles per hour. A recent law in Idaho allows cyclists to treat stop signs as a yield only, allowing cyclists to keep their momentum at controlled intersections when absent of other users with a legal right-of-way.[167]

Roundabouts have been found to reduce collision frequency and severity as compared to signalized intersections by reducing speed and the number of conflict points, particularly in the case of single-lane roundabouts.[2,168] Crash reduction is most significant for vehicles, less significant for pedestrians, and the impact on cyclists is mixed. At a minimum, the slower vehicular speeds enforced by roundabouts reduces the speed differential between motor vehicles and cyclists, which should reduce injury severity. At low volumes, it is safer for cyclists to mix with traffic in the roundabout, as bike lanes through a roundabout have been found to contribute to collisions.[168] At high traffic volumes, the continuous traffic flow can make pedestrian crossing challenging and increase conflicts with cyclists. In the high-volume case in Europe, it is common to separate the bicycle facilities from the roundabout and have cyclists cross adjacent to the pedestrian crossing. Additional pavement marking, warning signs/signals, or traffic control can also help ensure safe pedestrian and cyclist crossing at high volume roundabouts. Another review focused on pedestrians only found significant safety benefits at single-lane roundabouts but no benefit at multi-lane roundabouts.[50]

Midblock Control

Findings are somewhat mixed for the safety benefits of midblock crosswalks. One review found that on low-volume/low-speed roads, there's some evidence of vehicular speed reduction at midblock crosswalks and increased pedestrian activity, but no change in driver yielding behavior or collision rates. [2]On multilane roads with higher volumes (>12,000 vehicles per hour), collisions were higher at crosswalks. To improve visibility and driver compliance, effective strategies include advance stop lines that help keep drivers from encroaching on the crosswalk, flashing warning lights to help reduce vehicular speed and reduce conflicts with pedestrians, and the use of high-visibility crosswalk treatments.[2,139] One review found mid-block crossing signals that stop traffic to allow pedestrians to cross to be highly effective at increasing driver yielding and reducing collision frequency.[2]

Small Corner Radius and Other Curb Treatments

A study of intersections in Texas and Georgia found that higher right turn speeds were associated with large corner radii and shorter turn lane length, while collision rates were highest at intersections with median islands separating thru-traffic from turning traffic (and which typically implies a large corner radius).[169] This finding is consistent with recent Complete Streets guidelines indicating that large corner radii allow for faster vehicular movement through the turn while also extending the crossing distance that must be traversed by pedestrians. [141]

Curb extensions may decrease conflicts between pedestrians and vehicles. One unpublished report found that installing curb extensions helped to increase driver yielding at uncontrolled crossings. It also found that pedestrian delay before crossing was reduced, and the distance between the crosswalk and the point where cars yielded to pedestrians was increased.[170] A second unpublished report found similar improvements in driver yielding behavior.[171] At an intersection, a curb extension typically decreases the corner radius, thus slowing turning speeds. At an intersection or midblock, a curb extension effectively narrows the crossing distance for a pedestrian, reducing the time spent exposed to oncoming traffic.[172]

Adjacent Buildings and Land Uses

The following sections describe land uses and buildings adjacent to the public right-of-way on health, which in turn have an influence on the amount and visibility of activity along a street.

Retail Uses

A fairly consistent base of evidence suggests that the presence of retail uses (e.g. shops, restaurants, etc.) encourages transportation-related physical activity. In route choice studies in downtown Boston, New York, and Hong Kong, pedestrian commuters were more likely to choose a route with a high proportion of pedestrian-oriented retail frontage, even after adjusting for route distance.[173,46] In mode choice studies, transit users were more likely to walk or bike to transit when the route contained more retail uses.[73,142] In an unpublished study in New York City, the presence of adjacent retail uses along a street segment was associated with higher counts of pedestrians.[71] In a correlational analysis, commercial street frontage was associated with more walking and biking for transportation purposes but not with recreational or total physical activity.[72]

In an analysis of urban design features on block segments in urbanized neighbourhoods in the Boston metro area, the presence of community-oriented retail such as coffee shops, book stores, and restaurants, was identified as an important predictor of social activity, including conversing, eating, sitting, or walking with at least one other person.[62]

Open Space

Open space (e.g. parks, plazas) adjacent to the street has a similarly positive influence on physical activity, though the evidence is somewhat less consistent than as for adjacent retail uses. The presence of an adjacent park was identified as an important predictor of walking attractiveness in a study of households in Portland, Oregon, neighbourhoods.[39] In a route choice study New York and Hong Kong, commuters were more likely to choose a route with a high proportion of adjacent open space, even after adjusting for route distance.[173] The presence of public squares adjacent to a street segment was associated with higher counts of pedestrian activity in Lille, France.[93] The presence of adjacent open space did not have an influence on the choice to walk or bike to transit in two mode choice studies.[73,142] Findings in general correlational studies are mixed, with open space along street segments associated with transportation walking and objectively-measured physical activity in one,[74] associated with recreational physical activity for children but not for other age groups or other types of physical activity in another,[72] and finding no associations with physical activity in a third.[98]

Building Scale & Façade Design

Although characteristics of adjacent buildings (e.g. scale, massing, height/right-of-way ratio, façade design) are commonly theorized to help promote pedestrian activity, there is little evidence connecting building design to transportation or physical activity. In an unpublished study of pedestrian activity in New York City, counts of pedestrians were higher on segments with "continuous building facades forming a street wall" and "windows overlooking the street" than those without these characteristics.[71] In an unpublished correlational study, higher building enclosure (the ratio of building height to the width between buildings on opposite sides of the street) was associated with more walking and biking for transportation purposes for all age groups, with recreational physical activity for seniors, and for overall moderate/vigorous physical activity for teens and seniors.[72] In the same study, attractive building façade design was associated with recreational physical activity for seniors and not associated with walking/biking for transportation or with overall moderate/vigorous physical activity. Other general correlational studies have found no association between building design and physical activity, though in most cases, the evaluation of building design has been very general and often lumped in with aesthetics in general.[70,98,74]

While building heights are not typically part of Complete Street design consideration, they are important to be considered due to potential negative impacts on the pedestrian environment. As one way to improve pedestrian comfort through increased exposure to sun and protection from wind, a Toronto study recommended that the allowable height of buildings be limited, and along the sidewalks of the Central area limited to "guarantee three or more hours of sunlight during a period encompassing midday."[174] In addition to height, building massing (shape and size) can also contribute to blocking the sun. It also recommended establishment of pedestrian protecting standards regarding building induced wind forces. Related to building height and orientation, Moonen et al. note that "High-rise buildings can introduce high wind speed at pedestrian level, which can lead to uncomfortable or even dangerous conditions."[175]

One study of sidewalk-level fine particulate air pollution found that concentrations were higher along street segments lined with buildings over 5 stories tall, after adjusting for traffic, metrological, and other factors.[176]

Café/Vending Space

Few studies have investigated the influence of sidewalk café, dining, and vending space on pedestrian activity and physical activity. In two correlational studies of adults in New York City, the presence of a sidewalk café in the home zip code was associated with higher likelihood of walking or biking for at least 10 blocks anytime in the past month[95] while the presence of a sidewalk café within 1 kilometer of home was associated with lower body mass index.[94] In an analysis of urban design features on block segments in urbanized neighbourhoods in the Boston metro area, the presence of commercial seating was identified as the most important predictor of social activity.[62]

Additional Planning & Design Considerations

The goal when designing a healthy Complete Street is to choose and customize elements that best promote physical activity, safety, social engagement, and related health benefits for a wide variety of users. Not every Complete Street element is appropriate and should be designed identically in all contexts. The appropriate selection and design of a Complete Street requires an understanding of a number of key considerations and characteristics of a given street segment. When looking at different alternatives, a set of consistent criteria should be considered and applied in order to ensure a balanced approach to selection.

In a companion report to this one, called *Healthy Streets: Jurisdictional Review*, North American jurisdictions which adopted a Complete Streets policy or approaches were interviewed. Interviews with Key Informants explored their perceptions, knowledge and experiences about the relationships between street designs and health. Results from the *Healthy Streets: Jurisdictional Review* included some priority areas to influence health outcomes and that should be considered when making street design decisions (Table 2). These issues will be explored further in this section.

Table 2: Elements Influencing Health Outcomes

City	Cycle Tracks	Buffered bike lanes	Curb extensions; yield lines in front of crosswalks	Reduce design speed with smaller design vehicle for tighter turning radii	Pedestrian Islands
Boston	X			X	
Calgary	X				
Chicago	X	X		X	
Edmonton	X			X	
Hennepin	X				
New York City	X			X	
Ottawa	X			X	
Philadelphia	X	X			
San Francisco			X	X	
Waterloo					X

Criteria which may be considered when confirming a potential corridor application include accessibility, cost, visibility, sustainability, place making objectives and connectivity, among others. Following the application of the criteria and proceeding with the development of design concepts, secondary considerations should be reviewed including surrounding neighbourhood context, future anticipated usage of the space / volume of users, the different user groups as well as context sensitive needs, threats or opportunities.

The design of public infrastructure, should also strive to provide sufficient capacity and consideration of future changes in travel demand which can be caused by a change in surrounding population levels, land uses, employment opportunities and urban form. Travel demand and habits are also strongly influenced by population demographics. A prime example is the growing aging population. This group of individuals requires significant consideration as their mobility, visibility and varying comfort levels can have a strong influence on their sense of safety and overall interaction with the public space.

Common needs that emerged in a study of older adults with mobility disabilities in King County, Washington, were the application of curb ramps, appropriately designed and to not be textured; amenities such as seating, lighting, and street trees; wide and level sidewalks in good condition; crosswalks and appropriate crossing devices such as signals and flags; and a buffer between sidewalks and nearby vehicular traffic.[177] Other researchers have found positive results for textured curb ramps for visually-impaired pedestrians, but the evidence is limited.[178] A recent report provides additional guidance for the design of Complete Streets elements with older adults in mind, including recommendations for extending pedestrian signal phases and providing audible pedestrian cues at crosswalks.[141] A correlational study found that people with disabilities engaged in more physical activity in neighbourhoods where more of these street design characteristics were present.[179]

Though the aging population is a critical component of our society, they are not the only demographic group that should be considered when designing public spaces. Each socio-cultural-demographic group - youth, new residents, mobility challenged, young adult, etc. have individual expectations for the design of public spaces which should be taken into consideration when identifying potential design alternatives. It is not realistic to accommodate all of these individual wants and needs but ongoing communication and consultation with key groups and stakeholders during a project's scoping and design phases will help to facilitate a deeper understanding of those design features and applications which promote a sense of safety and comfort for a wide variety of users.

It is important to call attention to certain Complete Streets elements that may conflict with non-health goals of Complete Streets. In some cases, these elements may also provide a mix of positive and negative benefits for users. These elements are discussed in further detail below.

Complete Streets Elements That May Conflict with Other User Needs

Complete Streets design elements can provide health benefits as well as other benefits such as environmental, economic, social, and improved traffic flow; however there are cases where elements could result in negative impacts for specific users or purposes.

The inclusion and design of various elements depends on the local context and requires an understanding of who the current and/or expected users may be. In some instances, it may be possible to design features or provide other mitigation strategies to negate or minimize the negative impacts. In general addressing and mitigating the potential conflicts can be accomplished through the development of a standard set of design guidelines and concepts consistent with current standards and practices as well as emerging design concepts and trends.

Participants in the *Healthy Streets: Jurisdictional Review* were asked a series of questions about how they integrate health information into their street design decision-making process. When asked the interviewees highlighted some specific situations, where from a health and safety perspective, conflicts between road users could arise from the implementation of some Complete Streets elements. These situations pertain largely to intersection design for cyclists, pedestrians and emergency/large vehicles, such as cycle tracks, buffered bike lanes, curb extensions, and tighter curve turning radii.

Making trade-offs is a common transportation practice, especially in urban centres with restricted right-of-ways. However the health implications of these trade-offs are not typically considered.

For example street design or traffic calming features that narrow lanes and/or reduce curb radii improve conditions for pedestrians, can also make travel and especially turning movements more challenging for emergency vehicles, buses, and other large vehicles. On narrow streets there may be no option but to provide a curb radius large enough to accommodate large vehicles. But even then, the available turning space can be increased by placing the stop bars far enough from the intersection to allow large vehicles to swing into the oncoming lane while turning.

Another design option is to include on-street parking or on-street bike facilities that push the travel lanes away from the curb, increasing the effective turning area. Similarly, the receiving lanes could be widened at the intersection to increase the effective turning area, and then taper beyond the turning area. It is important to note that some of these options have the negative impact of increasing crossing distance for pedestrians, allowing vehicles to turn at faster speeds, and limiting opportunities to use features such as curb extensions. A management alternative is to provide large corner radii only on designated truck/bus routes and/or to prohibit large vehicles from making turning movements at intersections with small corner radii. Similarly, wide lanes (11') can be reserved for designated truck/bus routes while narrower lanes are used elsewhere. For multi-lane roads, a wide lane can be provided on the curb side while narrow lanes are maintained in the middle of the road.

Certain traffic calming features such as speed tables or speed humps may present a safety hazard and are typically not appropriate for roads carrying high traffic volumes, though there are a few exceptions.[190] For example, speed tables are often used in conjunction with crosswalks to create raised crosswalks, which force drivers to slow down and be more aware of crossing pedestrians. These features are generally appropriate on roads no wider than 50 feet and posted speeds of approximately 48 km/h (30 mph) or less. On bus or emergency vehicle routes, speed cushions that provide wheel cutouts for large vehicles could be used in lieu of speed humps or tables. A speed cushion consists of two (or more) adjacent, but physically separate, speed humps. The smaller, separated humps are sized to allow the tires of vehicles with higher ground clearance to travel through the cushion without deviating from the road surface.

Concerns about the impacts of street design on First Responders was explicitly explored in the Key Informant interviews. The table below provides a summary of the design and process responses of the interviewed jurisdictions to First Responder/Emergency concerns about Complete Streets elements that could impact response times.

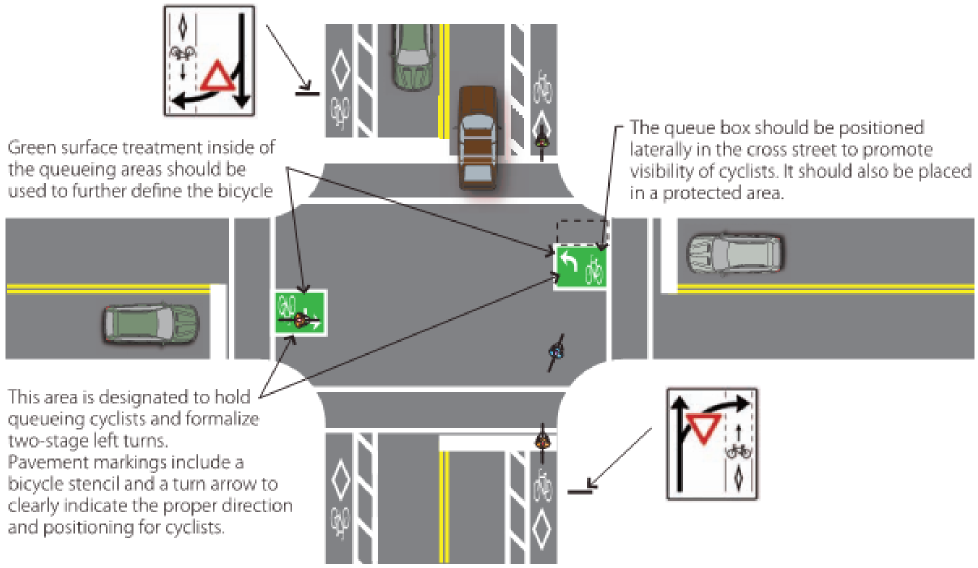
Table 3: Jurisdictional interview responses to providing for emergency vehicles. (Source --*Healthy Streets: Jurisdictional Review*)

City	First Responders/Emergency
Boston	Flexibility regarding vehicle use of the entire right-of-way (ROW) (15 metres)
Calgary	Flexibility regarding vehicle use of the entire ROW; detailed out intersections in guidelines
Chicago	Flexibility regarding vehicle use of the entire ROW; change size of design vehicle; mountable curbs
Edmonton	Flexibility regarding vehicle use of the entire ROW
Hennepin	Advocacy required, otherwise doesn't happen
New York City	Standard corner radii, Fire Department changed policy five years ago in response to letter from Commissioner arguing the number of fatalities saved through traffic changes was substantially more compared to number of deaths saved by reducing travel time to a fire

City	First Responders/Emergency
Ottawa	Ongoing and handled on a case-by-case basis; but there are examples where they have showed the overall benefit of tighter radius.
Philadelphia	Flexibility regarding vehicle use of the entire ROW
San Francisco	Better Street Design Guidelines includes section on design vehicles
Waterloo	Worked through the issues with the Fire Department on individual projects. Reached an agreement that narrow streets don't affect their operations. Agree to minimize the use of vertical alignment features (raised crosswalks, speed humps) which affect them more.

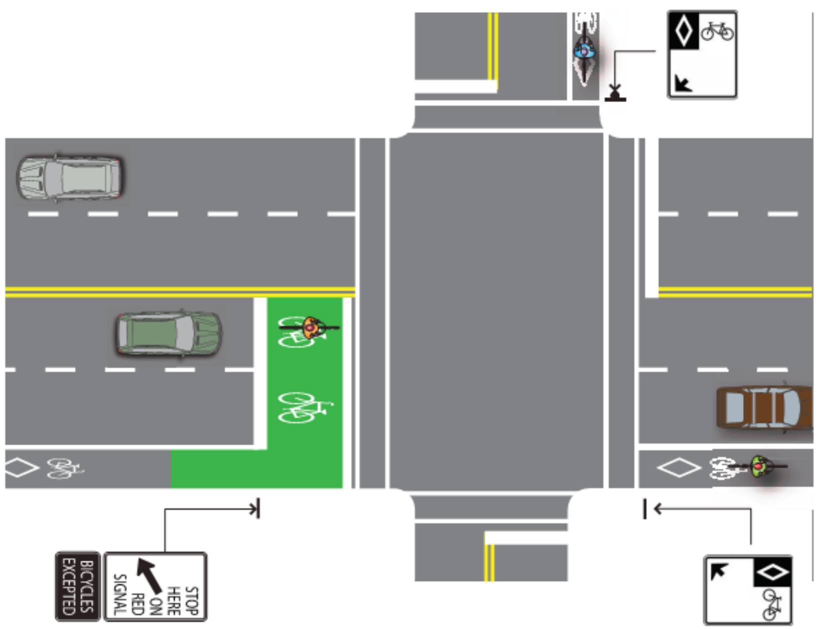
During this project several additional potential conflict situations were identified. In response to these situations possible options for design solutions were identified. The solutions have not been endorsed or approved by Toronto's Transportation Services or any other City Division. In the interest of supporting conversations that make healthy streets more likely the conflict situations and the potential design responses are presented here for the interest of the reader as supplementary information, as summarized below:

- Cyclists prefer routes providing non-stop travel, but intersections and traffic control help to slow traffic and provide for better street connectivity.
    - Potential Design Response: Cycling facilities which help prioritize cyclists at intersections include such treatments as bike boxes or two-stage left turn queue boxes and pavement marking in conflict areas at intersections and crossing driveways / entrances. These provide a space for cyclists to safely stop at these locations before continuing their trip. Please see the figure below for additional details. In addition, design concepts such as a cross-ride where cyclists and pedestrians have separated / designated space to use to cross at the intersection may facilitate connectivity. When applied, cyclists are not required to dismount but can continue to cycle through the intersection when safe to do so. For additional details regarding the design of cross-ride facilities please refer to section 5.8.1 in the Ontario Traffic Manual Book 18 – Cycling Facilities (OTM 18). [180]



Source: MMM/ALTA, 2013

Two-Stage Left Turn Queue Box in Curb Area

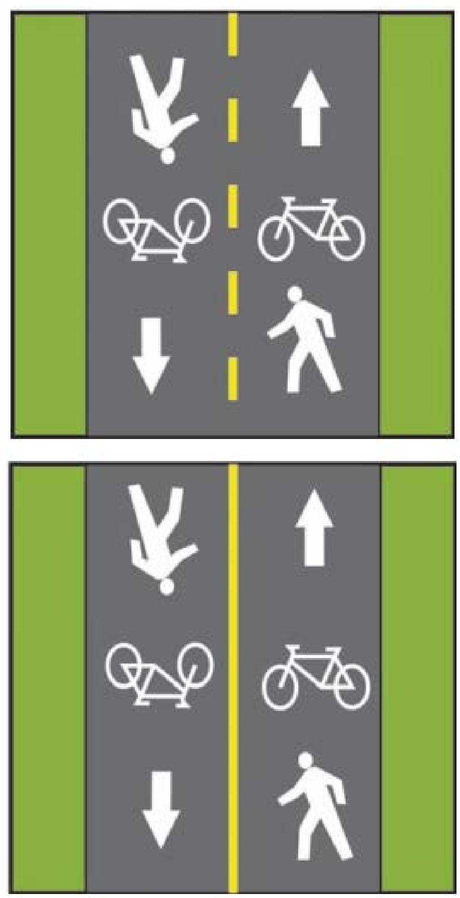


Source: MMM/ALTA, 2013

Bike Box Design Treatment

Figure 2: Intersection Design Examples.[180]

- Multi-use trails within the road right-of-way provide cyclists and pedestrians with a common space to use which is separated from motorized vehicles but if not used properly / safely may cause potential conflicts between users.
    - <u>Potential Design Response</u>**:** Applying clear signage such as the Shared Pathway sign as well as pathway organization signage and in some cases a dashed or solid centre-line on multi-use trails can help to guide the use of the space by different groups. In all cases the multi-use trail should include the application of a white bicycle symbol and a pedestrian symbol to promote awareness of shared space. If the space is available, the application of a one-way active transportation pathway with adjacent sidewalk may mitigate potential conflicts. Additional details and considerations regarding the design and marking of these facilities are shown below and can be found in section 4.4 of OTM 18.[180]



Source: MMM, 2013

Figure 3: Shared Pathway Signage and Typical Pavement Markings for Shared Use pathway.[180]

- Separated cycling facilities adjacent to a street are perceived as being more desirable by less experienced cyclists, but evidence indicates that at cross-streets and when provided for two-way cycling they can be less safe than on-street facilities.
    - Potential Design Response: The design of cycling facilities should take into consideration the perceived level of comfort and safety of users. The unnecessary application of a separated facility may be a result of a lack of understanding on behalf of designers and practitioners regarding the use of space. Providing adjacent alternatives e.g. a combination of a multi-use trail in place of a sidewalk / active transportation pathway and bike lane as well as clear signage and effective education programs may help to facilitate or support an individual's level of comfort when using the space. However, when designing a multi-use trail within the boulevard of the roadway, designers must be aware of the number of potential conflict points between cyclists, pedestrians and motorists. By applying a multi-use trail design treatment on roadways with in-frequent driveways to adjacent land uses, potential conflicts may be mitigated. Where a crossing cannot be avoided the application of crossing enhancements such as additions signage or pavement markings should be considered.

      Potential conflicts also may arise as a separated cycling facility approaches and crosses at an intersection. At or within an intersection, a fully separated cycling facility such as a multi-use trail may be guided through an intersection using a number of different design applications including a cross-ride, sharrows or coloured pavement markings. Additional details regarding these potential design applications can be found in OTM Book 18, and in the images below. However, in general, when selecting and designing cycling facilities, the roadway characteristics and surrounding conditions play a key role in the identification and design of a preferred cycling facility, and should be guided by the OTM 18 facility selection tool where applicable, or internal design guidelines.[180]

Figure 4: Sample Active Transportation Pathway / Multi-use Trail in Place of a Sidewalk on Roadway with Infrequent Crossings / Driveways.[177]

Figure 6: Active Transportation Pathway Crossing at an Intersection using Cross Ride Application.[177]

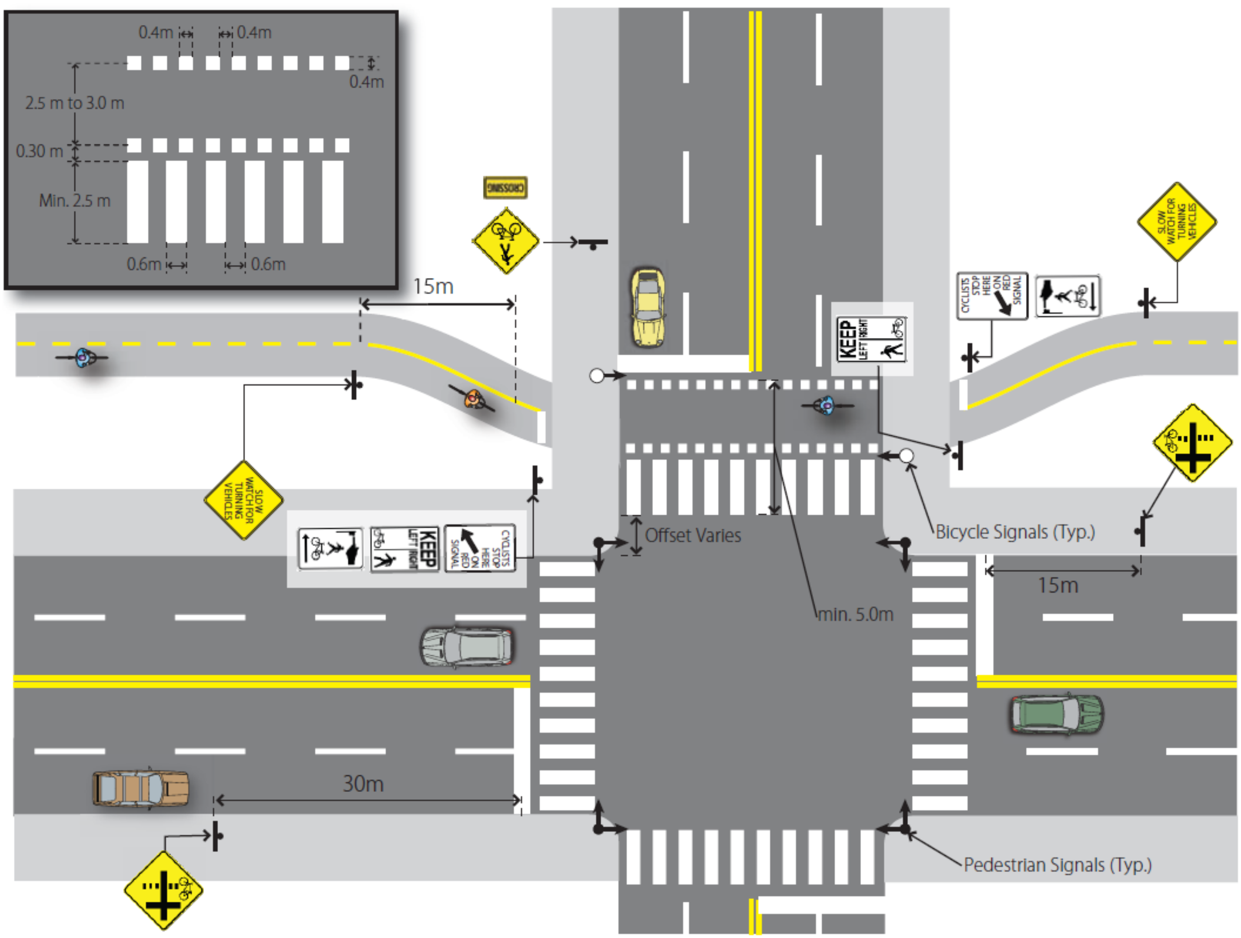
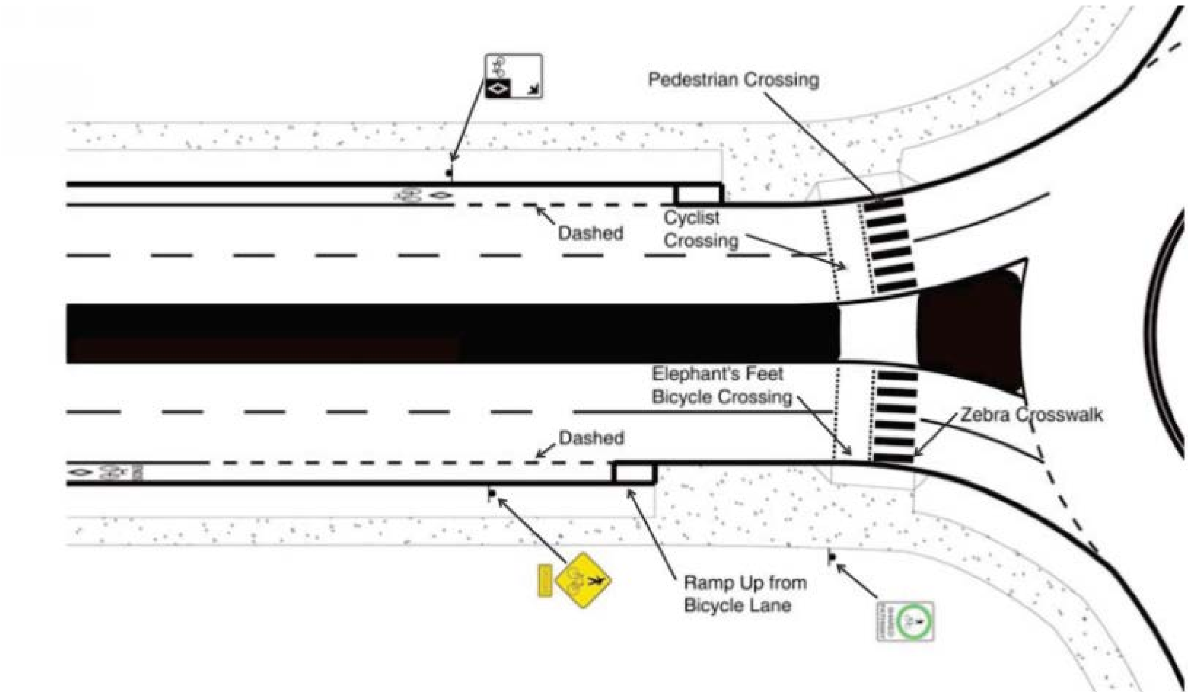


Figure 5: Sample Design Application - Cross-Ride to Facilitate Crossing a Multi-use Trail / Active Transportation Pathway.[180]

- Roundabouts help improve traffic flow and can be safer for vehicles, pedestrians, and bicycles, but safety varies based on the size of the roundabout and local context.
    - Potential Design Response: At single-lane roundabouts, cyclists are expected to share the roadway with motorists. A bicycle lane should transition to a shared roadway in advance of the roundabout and should be supplemented with clear signage and sharrows where applicable to indicate shared use of the space. For a multi-lane roundabout, cyclists should be provided with the choice between sharing the road with motorists or transitioning to an in-boulevard bypass facility.

      An in-boulevard bypass is a pathway that is intended to be used by cyclists as well as pedestrians. It is typically surfaced with asphalt with a yellow directional dividing line. This design application provides the greatest potential flexibility of use to prevent conflicts by allowing cyclists to yield to pedestrians or to overtake as necessary. For additional design considerations regarding the proposed design treatments please refer to section 5.3 of OTM 18, and to the image below.[180]



Source: TAC Bikeway Traffic Control Guidelines for Canada, 2012 (Figure 35, p. 89)

Figure 7: Bicycle Lane at Multi-Lane Roundabout with Bicycle Bypass.[180]

- On-street parking helps buffer pedestrians from nearby traffic but can be a safety concern for vehicles, bicyclists, and children.
    - Potential Design Response: Where on-street parking is available on roads with a cycling facility the design treatment, at a minimum, should include clear signage indicating the shared use of the space by cyclists and motorists. It is the responsibility of motorists in this case, as per the Highway Traffic Act Section 165 (a) and (b),[181] to be aware of an on-coming traffic, including cyclists, and act accordingly. Where appropriate, consideration of providing sharrow, share the road, and children at play signage for additional visibility and awareness may be considered. Reduced speed limits in areas of particular concern also reduce collision risk.

      If space is available on the roadway a striped buffer can be considered between the bicycle lane and the parking lanes (Figure 8), to minimize the danger of cyclists colliding with opening car doors.[123] Another design treatment places the cycle lane adjacent to the curb between the curb and the parking lane thus using the on-street parking as a buffer.

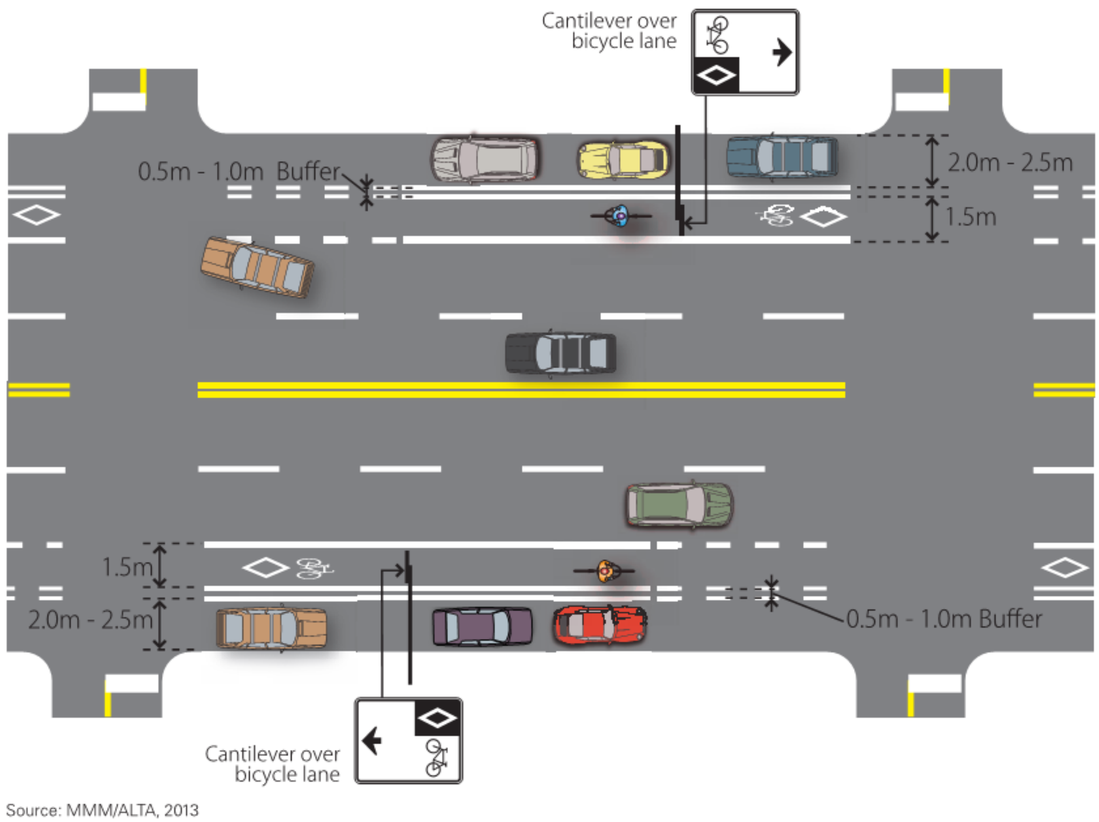


Figure 8: Bicycle Lane on Two-Lane Two-Way Road with On-Street Parking.[180]

- Curb extensions can increase pedestrian safety by reducing the road-width to be crossed, but it can also reduce cycle lane widths and the safe space available for cyclists.
    - Potential Design Response: The cycle lane can be tapered to accommodate the curb extension, as suggested in the Transportation Association of Canada Bikeway Control Guidelines in section [8.9,182] and shown in the figures below. An additional design treatment involves incorporating the cycle lane into the curb extension. The proper design requires appropriate pavement markings and textual variations to accommodate / meet the Accessibility for Ontarians with Disabilities Act (AODA) requirements.[183]

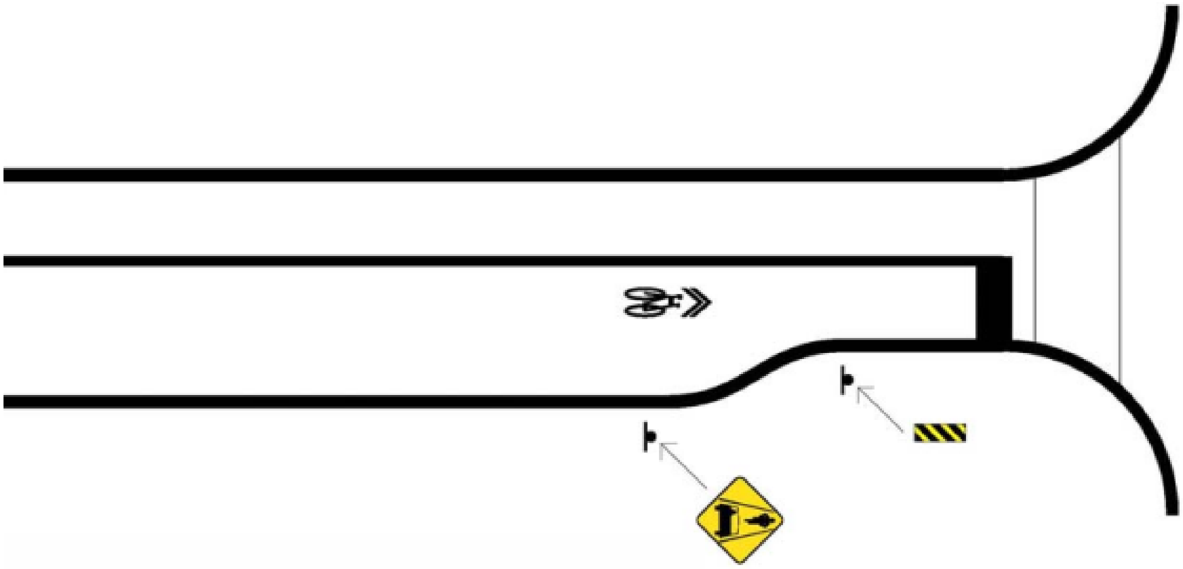


Figure 9: Sharrow Application at Intersection with Curb Extension.[182]

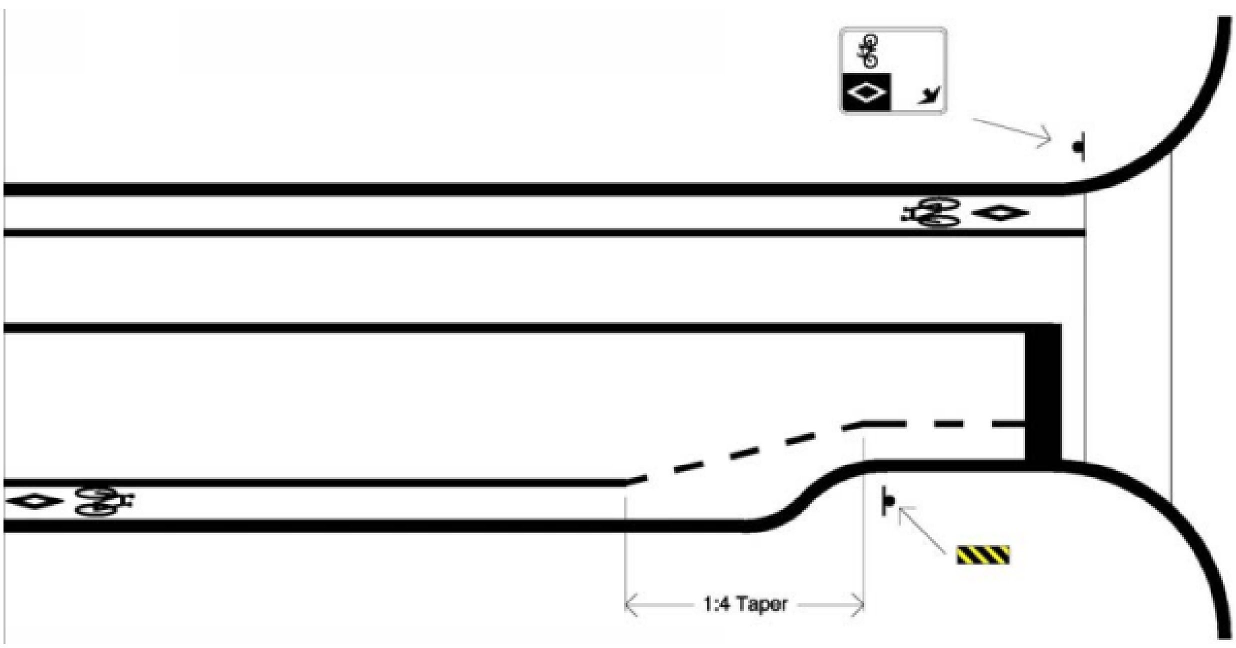


Figure 10: Bike Lane Tapered at Intersection with Curb Extension.[182]

- Midblock crossings help improve connectivity for pedestrians but may not be appropriate on all streets, and generally require additional warning signs/signals or other traffic control to ensure their safe use.
    - Potential Design Response: Mid-block crossings are typically applied when the distance between signalized intersections may be too far for cyclists or pedestrians to travel to them to cross. Mid-block crossings can be either signalized or un-signalized. The decision to signalize a crossing requires review and consideration of key roadway characteristics including the width of the roadway, volume of traffic, speed of traffic and potential user groups. For additional considerations regarding the application of a mid-block crossing including the mid-block crossing on a multi-use trail, please refer to the image below and to OTM Book 18.[180]

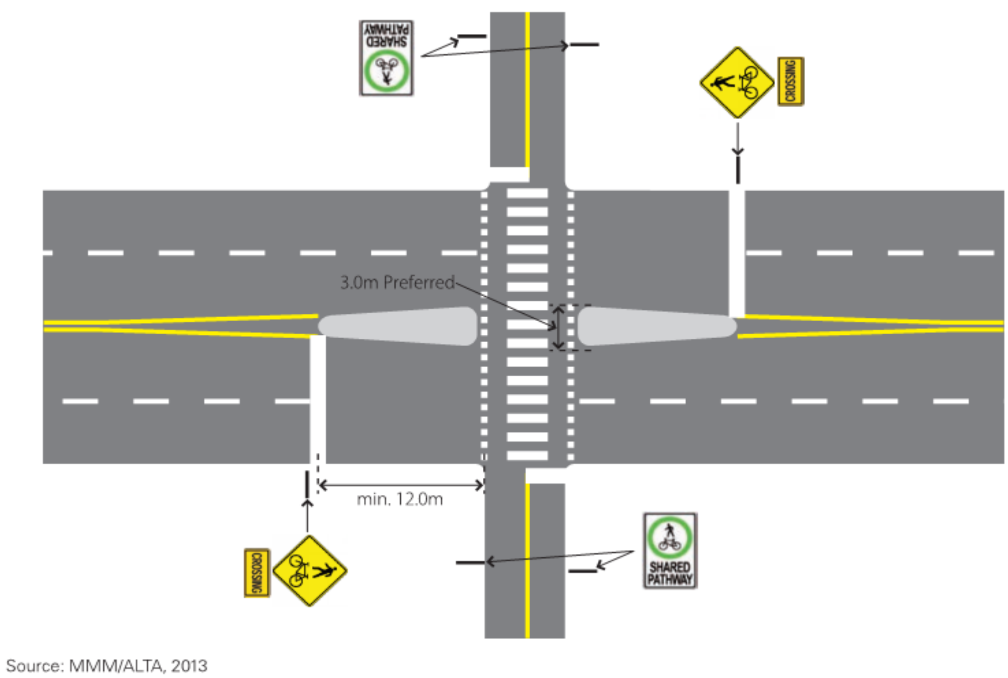


Figure 11: Midblock Crossride.[180]

- Complete street design concepts may also include the design of cycling facilities on roads with transit stops or routes. Where a bus stop is present there may be additional potential for conflicts between cyclists, the transit vehicle when stopping for curbside passenger loading/unloading, and passengers loading and unloading from the bus.
    - Potential Design Response: In situations where bus bays (which allow the bus to leave the main travel lane to access a bus stop) and a cycle lane are present the bus will need to cross the curbside bike lane (Figure 12). The use of a dashed line directs

and alerts to this movement. Where there is no bus bay, buses must minimize the gap between the curb and the passenger loading by directly abutting the curb. In this case the design of the cycling facility may be incorporated into the transit platform and may include a ramp up to the platform and contrasting paving materials and tactile paving for those who are visually impaired. For in-boulevard transit stop facilities cycle facilities can be designed to pass behind transit stops. For additional design concepts and details please refer to section 5.4.2 of OTM Book 18.[180]

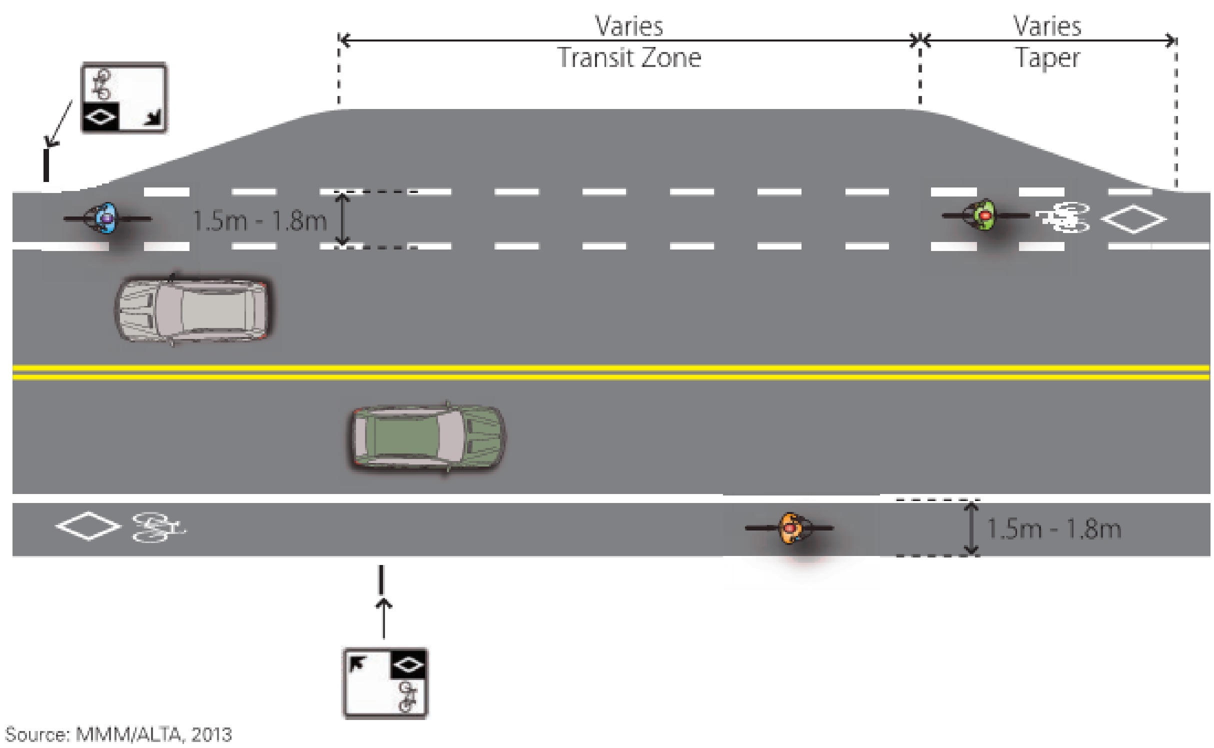


Figure 12: Bicycle Lane Passing a Transit Stop.[180]

- At an intersection, cyclists, motorists and pedestrians all interact within a similar space. In most cases these areas create the greatest potential for conflict as motorists perceive their travel to be the priority.

Potential Design Response: There are a large number of intersection treatments and associated signage which could be considered for these spaces. There are varying levels of visibility for these design treatments, including guide lines and the use of green surface treatments and pavement markings to delineate the space. Additional design treatments may include the use of bike stencils, chevrons, sharrows or dashed guide lines with optional use of the stencils and chevrons. Additional details regarding the application of these design treatments can be found in section 4.0 of OTM Book 18.[180]

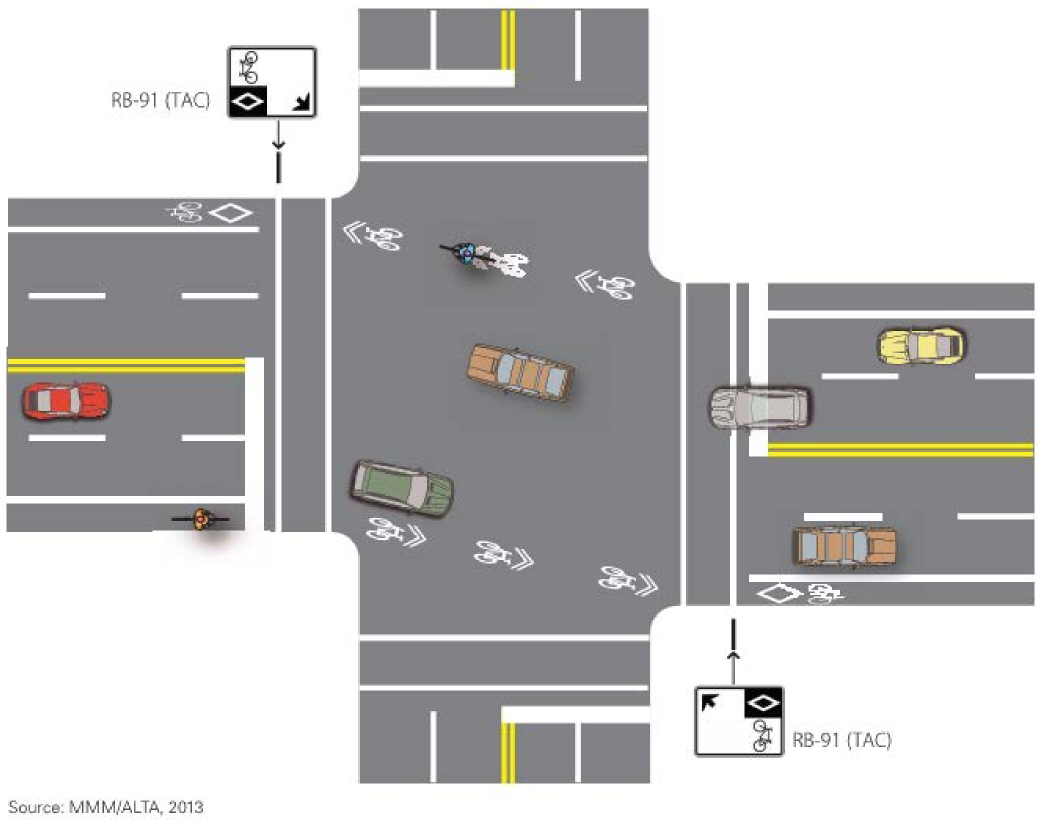


Figure 13: Sharrow Application in an Intersection.[180]

Expanding the Evidence Base

As a result of reviewing the existing literature, several areas where additional research would be useful were identified. These areas include:

- Assessment of the health impacts for specific user groups such as seniors, children, or those with disabilities including visual and hearing impairment.
- Assessments of Complete Street influences on multiple simultaneous health impacts (e.g. physical activity, safety, and respiratory health).
- Studies which seek to further assess and detail the prioritization of Complete Street elements in terms of health benefits.
- Increased focus on recreational physical activity, respiratory health, as well as body weight, obesity-related chronic diseases.
- Increased focus on social activity and mental health.
- Assessment of the health influences of providing café/vending space or about the provision and size of a buffer between the curb and sidewalk.
- Evaluation of the health influence of specific (well detailed/described) bicycle facilities
- Additional study of the impact of trees on health, especially related to benefits/costs of their ability to cleanse pollutants, provide shade, generate allergens and disrupt wind flow.

Conclusion

People's decision to be physically activity through walking and cycling can be influenced by providing streets and other facilities which allow for convenient access to destinations in a safe and enjoyable way. This literature review summarized the available research evidence of how Complete Streets design elements are associated with more active lifestyles and better health. Many health associations have been found, including physical activity, traffic safety, body weight, physical health, and mental and social health.

In response to this large and growing body of research and public interest, urban planners and public health staff have been working together to find ways redesign our streets and cities to facilitate increased physical activity and improve traffic safety. Complete Streets typically include sidewalks, bike facilities, public transit access, and a vehicular right-of-way that encourages safe automobile use at an appropriate speed. Creating policies, plans and design guidelines that are supportive of Complete Streets provides streets designed for people of all ages, abilities, and modes of travel.

The choice of specific Complete Street elements and their design characteristics to best promote health is largely dependent on the context of each specific street segment. It also involves answering questions such as who are the current and expected future users, what are their needs, what health challenges exists, and what existing opportunities can be leveraged for encouraging healthy living? Based on the findings of this literature review, the following approach is recommended for prioritizing the implementation of Complete Street elements:

1. **Provide accessibility**. Providing street connectivity via short blocks and 4-way intersections or permeability through existing long blocks is essential for minimizing travel distances. Continuity of pedestrian and cycling facilities throughout the network is critical. Filling gaps where facilities are missing or inadequate is a key priority. Accessibility also requires there to be places to walk to and from along pedestrian and cycling networks, including residences, jobs, retail destinations, transit facilities, and recreational amenities.
2. **Ensure safety**. At a minimum, users need to have continuous sidewalk and bicycle facilities, adequate lighting, and safe intersection crossings. Depending on traffic and other locally-specific conditions, other features should be considered to improve pedestrian/cyclist safety such as providing medians with pedestrian refuges, enhanced crosswalk and signalization treatments, curb extensions, and other traffic calming features.
3. **Enhance the experience**. Areas with good accessibility and safety can be further enhanced through the provision of wide sidewalks, commercial seating and vending on the sidewalk, public seating, trees and landscaping, human-scaled buildings, and attractive, transparent façade design.

The literature review and findings of this report provides a firm foundation to further inform the City of Toronto's efforts to develop Complete Streets Guidelines in response to the City Council May 2013 recommendation.

Appendix A -- Methods used to conduct the literature review

To conduct this literature review, four general sources were used for identifying evidence of a relationship between Complete Streets elements and health:

1. UD4H resource database of articles and books both in electronic and hard copy format.
2. Academic databases including PubMed, Academic Search Complete (EBSCO), Web of Science, and Google Scholar.
3. Google search engine.
4. References cited within sources identified from one of the above three categories.

Searches were conducted using keywords related to each Complete Street element (e.g. "sidewalks) either alone or paired with keywords related to general (e.g. "physical activity") or specific (e.g. "asthma") health/behavioral outcomes. The resulting abstracts were scanned to identify relevant articles linking Complete Street elements to health/behavioral outcomes. Articles with an urban context were preferred to those with a suburban or rural context, except for rare cases where no relevant evidence was found in an urban context.

Due to the number of matching studies (n=168), the detailed review of articles was prioritized based on the following hierarchy:

1. *Meta-analyses and literature reviews* (n=29). These sources summarize a large number of primary research articles in a single source.
2. *Quasi-experimental primary research* (n=11). These studies investigate the health/behavioral impact of a change in specific Complete Street elements over time. These studies provide the strongest evidence of a causal relationship between Complete Street elements and health. Note that it is extremely rare to find truly experimental research in the field of built environment and health, which would require (among other characteristics) for participants to be randomly sampled and randomly assigned to different built environment treatments.
3. *Context-specific, correlational primary research* (n=35). These studies are cross-sectional and thus cannot provide evidence of a causal relationship between Complete Street elements and health. However, these study designs provide a relatively strong connection between the Complete Street elements and the health/behavioral outcome. Examples of studies falling within this category include those focused on route choice, mode choice, collision frequency at specific locations, counts of pedestrians along street segments, and studies of neighbourhood-level Complete Street elements and behavior

within the same neighbourhood. Most cross-sectional case-control, case-crossover, and discrete choice studies are considered to fall within this category.

4. *General correlational primary research* (n=38). These studies are cross-sectional and thus cannot provide evidence of a causal relationship between Complete Street elements and health. These study designs also provide only a weak connection between the Complete Street elements and the health/behavioral outcome. Examples of studies falling within this category include studies of neighbourhood-level Complete Street elements and behavior that did not necessarily occur within the neighbourhood.
5. *Grey literature* (n=46). These sources have not been published in a formally peer-reviewed journal. Examples include technical reports, white papers, theses/dissertations, conference proceedings, and unpublished manuscripts. Complete Streets policies and guidelines prepared by local governments, non-governmental organizations, or private businesses fall within this category.
6. *Peer-reviewed sources used for discussion purposes only* (n=9). These sources do not provide direct evidence of a connection between Complete Street elements and health but add valuable insights to the discussion of Complete Street elements and/or health/behavioral outcomes.

It was attempted to review all relevant evidence in the first three categories (reviews, experimental/quasi-experimental research, and context-specific, correlational primary research) related to each Complete Street element. The next two categories (general correlational primary research and grey literature) were reviewed and used in cases where there was inadequate evidence available from the first three categories. Exceptions to this rule included articles with particularly strong measurement of Complete Street elements. Sources used for discussion purposes only were incorporated as needed to further explain Complete Street elements and/or health/behavioral outcomes.

The final list of resources reviewed is provided in Appendix C, which is organized by categorization of sources according to the hierarchy described above.

Appendix B -- Methodological findings for the reviewed studies

Many challenges exist in conducting research on the health impact of Complete Street elements.[184] Foremost is that the typical research design of most of the reviewed studies does not provide evidence that Complete Street elements *cause* better health or healthy behaviors, only that certain Complete Street elements are associated with better health or healthy behaviors. Truly experimental research is usually not feasible with built environment research, where individuals are randomly assigned to specific built environment "treatments" to evaluate the impact of the treatment on health. Limited cases were found where researchers were able to conduct "natural experiments" where they were able to measure physical activity behaviors, collisions, or other outcomes before and after the installation of a Complete Street element such as a mid-block crosswalk. There were also some examples of case-control studies where researchers compared behavior or health between two locations that were similar in most ways but differ in terms of a key Complete Street element (e.g. comparing pedestrian activity on four-lane street segments carrying similar traffic volume, but some are tree-lined whereas others have no trees).

In most of the reviewed studies, the research was cross-sectional in nature, meaning that the presence of a Complete Street element and the behavior or health outcome were evaluated simultaneously. In these cases, it was not possible to rule out "reverse-causation," such as the case where street furniture is installed in a location where there is already significant pedestrian activity, or "self-selection," whereby people that are already physically-active choose to live, travel, or recreate in places with Complete Street elements that are more supportive of being physically active.

Another issue with many of the reviewed studies is that there was some disconnect between the location of the measured Complete Street elements and the location of the behavior or health outcome evaluated.[185] For example, there are many studies that measure Complete Street elements within an individual's home neighbourhood and test for an association with physical activity levels. However, several studies suggest that only a small fraction of physical activity occurs within the home neighbourhood.[186] Higher confidence can be had in studies that make a direct connection between the Complete Street element and the outcome of interest, whether within a neighbourhood (e.g. measuring only physical activity occurring within the neighbourhood) or at a more specific location (e.g. collisions at a crosswalk, pedestrian frequency along a street segment, route choice from home to work).

Next, there is often high spatial correlation between many of the Complete Street elements. For example, street furniture, street trees, and sidewalks are all elements commonly found along pedestrian-oriented streets. In cases such as these, it can be challenging to disentangle the independent influence of street furniture from the influence of the other elements. In many of the reviewed articles, researchers combine highly correlated elements into groupings of similar elements. As such, conclusions can often be drawn about groupings of elements but not always conclusions about specific elements.

Similarly, Complete Street elements are often highly correlated with "macroscale" built environment features such as density, land use mix, and street connectivity as noted above. For example, street furniture may be more commonly found in areas with high amounts of street-level activity such as an area with a high density of shops, restaurants, and cafes mixed with multi-story residential buildings. In this case, it is challenging to disentangle the independent influence of street furniture from the influence of the high density of residences and non-residential destinations. Some but not all of the reviewed studies adjusted for macroscale built environment features.

A strength and weakness with many of the reviewed correlational studies is their inclusion of a wide range of Complete Street elements. While this broad inclusion allows us to draw insights on many Complete Street elements from a single source, this lack of focus also decreases the confidence of the findings. These studies suffer from the problem of "multiple comparisons," where the likelihood of a significant finding being due to chance alone increases with the number of different Complete Street elements tested.[187] These types of studies are generally considered to be exploratory only and require additional research using more rigorous methods before drawing strong conclusions about their findings.

Another challenge was identifying the precise nature of the mechanism linking a Complete Street element to better health or behavioral outcomes. Although a study may reveal that elements such as trees- along a street are linked to more physical activity, it is often not possible to determine whether the sight of trees themselves encourage more activity, or whether activity is increased because the trees provide a buffer that increases perceived safety from adjacent motor vehicles, or even that activity is increased because the trees have a psychological influence on by providing a more attractive and pleasant environment. In reality, the increased activity was likely due to a combination of these factors, and often this synergy may have been further increased by the notion that people feel safer in locations where others are present[188] and may be more prone to be physically active in locations where others are also being physically active. Caution must be taken in the interpretation of findings of a relationship between a Complete Street element and any specific health/behavioral outcome, as there are often complicated interactions between perceptions, social influences, behaviors, and health outcomes. Alternatively, a lack of a positive association between a Complete Street element and health may have been due to other influences such as crime or a local cultural norm that discourages healthy behavior.

Finally, while the current research provides valuable general evidence about the inclusion or exclusion of specific elements into a Complete Street design, the nature of the research makes it challenging to draw conclusions about the health related impacts of specific design characteristics of those elements. For example, studies on the influence of street trees on health rarely use a common definition of trees. Some rely on self-reports or trained audits of how "green" a street is on a 1-5 scale or even more simply a 0-1 scale, while others quantify street trees by count, density, or classification via remote imagery. And in most cases, studies do not specifically test for a threshold above which street trees begin to provide health benefits. Lacking such evidence, for most Complete Street elements, conclusions can only be drawn in terms of "more" versus "less" or "yes" versus "no" but cannot go as far as drawing conclusions about "how much" or "what dimensions." While not designed specifically with health in mind (although safety is typically a primary consideration), a number of resources provide measurements and specifications regarding the detailed design of Complete Street elements.[189,190,191,192]

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