Bicycle Infrastructure and Safety

Overview

Many Canadian communities are currently pursuing bicycle infrastructure improvements as part of their strategies to encourage bicycle use and improve bicycle safety. However, the safety impacts of common types of bicycle infrastructure—such as shared routes, bicycle lanes, segregated bicycle tracks, on off-street paths—remain poorly understood. There is a limited body of research on the relative safety merits of different types of bicycle infrastructure. This report highlights some of this research, with a focus on types of bicycle infrastructure that are commonly used in Canadian communities or that could otherwise be readily implemented in the Canadian context. The aim is to provide Canadian municipalities with basic understanding of the safety impacts of bicycle infrastructure to help them develop bicycle route networks that encourage bicycle use and help increase bicycle safety.

Selected Resources

Websites

Bicycle Injuries in the Cycling Environment (BICE)
http://www.cher.ubc.ca/cyclingincities/

Books/Technical Manuals

Velo Quebec (2010)
Planning and design for pedestrians and cyclists: A Technical Guide
http://www.velo.qc.ca/english/bikewaysdesign.php?page=handbook

Research

Reynolds, C., Harris M.A., Teschke, K., Cripton, P., & Winters, M. (2009). The impact of transportation infrastructure on bicycling injuries and crashes: a review of the literature. *Environmental Health* 8(47) (http://www.ehjournal.net/content/8/1/47).

See end of document for a full list of resources.

Introduction

While cycling has long been a popular form of recreation, it is increasingly gaining acceptance in Canada as a viable mode of urban transportation. Communities and various public agencies across Canada are increasingly undertaking efforts to encourage bicycle use for utilitarian purposes, recognizing that it entails a number of benefits. These include:

- **environmental benefits:** reduced automobile dependency; lower oil consumption; reduced greenhouse gas and other contaminants emissions;
- **socioeconomic benefits:** reduced household expenditures on transportation; reduced work hours lost in traffic jams; and reduced healthcare costs because of an increase of regular exercise and reduced pollution; and
- **health benefits:** reduced risk of diseases related to physical inactivity and excessive body weight, including cardiovascular diseases, diabetes, and cancer; improved cardiovascular health; and improved mental health.

Though cycling is clearly associated with certain long-term health benefits, it is also associated with some health risks. Specifically, cyclists have a relatively higher risk of death or injury compared to other road users. Research on road safety shows that, both on a per trip or per kilometre travelled basis, cyclists are at least seven times more likely to be injured than motorists (Reynolds et al., 2009).

A Transport Canada (2004) study of vulnerable road users identified the following as the primary risk factors for cyclists:

- **time of day:** 17% of cyclists killed and 23% of those seriously injured were struck during the afternoon rush hour period (4 p.m. to 6 p.m.);
- **visibility:** 30% of cyclist fatalities occurred at night or in artificial lighting conditions;
- **urban areas**: 56% of cyclists killed and 85% of those seriously injured had accidents in urban areas;
- **rural roads and highways** – 44% of cyclist fatalities occurred on roads with posted speed limits of 80 km/h or higher;

- **location:** 39% of cyclists killed and 64% of those seriously injuries were involved in accidents at intersections; in urban areas, 50% of fatal accidents and 72% of accidents resulting in serious injury occurred at intersections;
- **traffic controls:** 30% of cyclists killed and 38% of those seriously injured were involved in accidents at road locations with traffic signals or other traffic control signs; in urban areas, 46% of fatal accidents and 45% of accidents occurred at controlled intersections; and
- **age:** cyclists 24 years old and younger are 39% more likely to be killed and 99% more likely to be seriously injured than the average death and serious injury rates for the entire population respectively.

With the exception of the age of the cyclists, the risk factors listed above are related to the physical environment and are, for the most part, modifiable—i.e., the risks can to some extent be mitigated through infrastructure improvements.

Two key objectives motivating the development of bicycle infrastructure should be pursued: (1) encouraging bicycle use and (2) improving bicycle safety. Infrastructure is generally thought to encourage bicycle use by improving cyclists' comfort—i.e., by making cyclist *feel* safer. There is an erroneous tendency to equate increased comfort with increased actual safety. In reality, guided experience evidence suggests that, while some types of bicycle infrastructure may provide significant improvements in comfort, they do not necessarily provide significant improvements in real safety. Certain types infrastructure may even increase safety risks.

This report highlights key findings from the limited existing body of research on the safety impacts of different types of bicycle infrastructure.[1] The focus is on types of bicycle infrastructure that are commonly found in Canadian communities or types that could otherwise be readily implemented in the Canadian context. A better understanding of the safety impacts of different types of infrastructure can help Canadian communities develop bicycle infrastructure that meets the joint objectives of encouraging bicycle use *and* reducing the risk of cycling accidents.

Measuring Bicycle Safety

Cyclists are vulnerable to several types of accidents. These include:

- falls
- collisions with stationary objects
- collisions with vehicles
- collisions with pedestrians
- collision with other cyclists

Aside from falls and collisions, cyclists are also likely to experience conflicts with other users of roads and paths. These include motorized vehicles (cars, trucks, buses, motorcycles), pedestrians, other cyclists, in-line skaters and skateboarders. Conflicts are situations in which a cyclist must take action, such as a change in speed or course, in order to avoid a collision with another road or path user.

In theory, the safety of bicycle infrastructure can be measured in terms of the risk of falls and of all types of collisions, as well as the potential for conflicts between individual cyclists and other road or path users. In practice, when evaluating the relative safety of bicycle infrastructure, transportation researchers and engineers tend to aggregate the above into a single measure of risk of collision, which conflates falls and all of the types of collisions. Public health researchers, on the other hand, tend to address bicycle safety in terms of the outcomes of collisions—i.e., the risk of injury and death. The two approaches are ultimately related—many collisions are likely to result in injuries, and some may result in deaths.

Safety Impacts of Different Types of Bicycle Routes

Bicycle infrastructure can be broken down into four conceptual categories. In order from the least to most segregated from vehicular traffic, these include: (1) shared routes; (2) bicycle lanes; (3) bicycle tracks; and (4) off-street paths. The first three categories may but do not necessarily entail special provisions for bicycles at intersections. The fourth category, while off-street, may include road crossings that are not necessarily at road intersections.

Shared Routes

Shared routes consist of streets on which bicycles are required to share the carriageway with motorized vehicles; there is no portion of the street surface designated only for bicycles. Usually, shared routes are marked with signs or road markings, such as *sharrows*—a pictogram of a bicycle with chevrons above it, indicating the direction of bicycle traffic (Figure 1). Generally, shared routes are designated on local, residential streets with a low volume of vehicular traffic, or streets that are simply too narrow to fit dedicated bicycle lanes or a bicycle track. In many cases, streets on which shared routes are designated may feature traffic calming features, designed to slow down vehicles. Shared routes are

[1] See Reynolds et al. (2009) for an extensive review of the existing research.

sometimes also designated on arterial roads that have wide curb lanes.

Figure 1. Sharrows used to designate roads as shared routes (photo: Todd Boulanger)

There appears to be relatively few studies that have addressed the safety merits of designated shared routes. The few examples include a study by Moritz (1998 a), which assessed the relative safety of different types of infrastructure by developing a *relative danger index*. The index was developed using self-reported data on the use of different types of bicycle infrastructure and collisions collected from a relatively large number of cyclists (*N*=2,978). The index rates risk by calculating the number of crashes divided by the percentage of distance travelled on a given type of bicycle infrastructure. An index of 1.0 indicates that the number of collisions is proportional to the number of kilometers travelled on the given type of infrastructure; an index greater than 1.0 indicates a greater risk of collision per kilometer travelled, while an index less than 1.0 indicates of lower risk of collision per kilometer travelled. The danger index of shared routes (0.51) was found to be better than that of major roads without bicycle facilities (0.66) and minor roads without bicycle facilities (0.94), but worse than that of bike lanes (0.41).

Given that shared routes can have a very wide range of characteristics, it is not exactly clear what makes them safer than undesignated roads. One possible factor is that designation as a bicycle route leads to an increase in bicycle traffic, which in turn produces a "strength in numbers" effect. A number of researchers (e.g., Leden et al., 2000; Jacobsen, 2003) have observed that the number of bicycle accidents decreases when bicycle traffic volumes increase. Other factors might include that streets designated as shared bicycle routes are quiet residential streets with low traffic volumes and speeds.

Bicycle Lanes

Bicycle lanes (Figure 2) are narrow lanes (1.2 m to 1.5 m wide) on the carriageway reserved exclusively for bicycles. They provide only partial segregation from vehicular traffic – there is nothing physically preventing vehicles from entering a bicycle lane. They are usually adjacent to the curb on streets with no parking, or between the parking lanes and the outer (right-hand) traffic lanes on streets with parking. They are most often marked with continuous lines, separating them from the parking and traffic lanes. Sometimes, the width of the bicycle lane is paved with a different material or painted to have a different colour than the vehicular lanes. Bicycle lanes can be readily combined with advanced stop lines or bicycle boxes, which help cyclists safely execute left turns.

Figure 2. Contra-flow bicycle lane in Montreal allows cyclists to travel in the direction opposite to traffic on a one-way street (photo: Christopher DeWolf)

There is a considerable amount of research showing that bicycle lanes have a positive impact on bicycle safety. Among the earliest research on the subject, Lott and Lott (1976) compared similar roads with and without bicycle lanes found that the presence of bicycle lanes reduced collision frequency by 53%. Smith and Walsh (1988) looked at the same roads before and after bicycle lanes were added. They found that accident rates increased initially after the introduction of the bicycle lanes were added. In the long-term, however, the addition of the bicycle lanes was found to have no significant effect on accident rates. Rodgers (1997) used a regression analysis looking at several risk factors associated with bicycle use to evaluate the relative risk of using different types of bicycle infrastructure. He found that the odds of having a collision were lower for cyclists who primarily used bicycle paths or lanes than for those who used unmodified roadways. Moritz (1998 a & 1998 b) conducted two studies that used data on bicycle accidents collected from cyclists across the U.S. and developed a danger index for different types of cycling environments. In both cases, on-street bicycle lanes were found to have the lowest danger index among the studied environments than roads without modifications for bicycles. Van Houten and Seiderman (2005) found that, after bicycle lanes were added, more cyclists tended to ride 9 to 10 feet (2.7-3.0 m) from the curb, which is considered far enough to avoid crashing into opening car doors. Motorists surveyed after the installation of the bicycle lanes reported that the lane increased their awareness of cyclists.

Bicycle Tracks

Bicycle tracks, unlike bicycle lanes, segregate cyclists from motorists more completely through the use of a physical barrier. Bicycle tracks are usually either grade separated or separated from the traffic lanes with a concrete median or a row of bollards. Bicycle tracks can be provided as two unidirectional tracks heading in opposite directions on either side of the road (Figure 3); or as a single bidirectional track on one side of the road (Figure 4). The configuration with two unidirectional paths straddling the road, which is widely used in Denmark, is functionally more similar to bicycle lanes. Near intersections, the tracks can be made to merge with the automobile traffic lanes. This allows for the use of advanced stop lines or bicycle boxes, which help cyclists safely execute left turns. Bidirectional tracks, on the other hand, are incompatible with bicycle boxes and may therefore require special modifications at intersection to allow cyclists to turn left.

Figure 3. Unidirectional bicycle tracks in Copenhagen, Denmark (photo: streetsblog.org)

Figure 4. Bidirectional bicycle track in Montreal separeated from traffic by bollards and parked cars (source: streetsblog.com)

Studies by the Danish Road Administration (1994 a & 1996) investigated the relative safety of bicycle lanes and bicycle tracks and found that both designs reduce collision risks between intersections. However, at intersections, particularly uncontrolled intersections, it was found that bicycle tracks increase collision risks. The Dutch National Road Safety Research Institute (SWOV, 1994) came to similar conclusions to those in the Danish studies. It was found that, at intersections, separate bicycle tracks are less safe than sharing traffic lanes with automobiles, even if they offer a slight advantage between intersections. Considering safety along road links and at intersections together, it was observed that bicycle tracks offered no significant advantage over mixed traffic situations.

Ekman and Kronborg (1995) conducted an extensive literature review and interviewed bicycle safety and traffic-engineering experts across Scandinavia and in the Netherlands to compare the merits of unidirectional versus bidirectional bicycle tracks. They found that bidirectional tracks on one side of the road are cheaper to build than two unidirectional paths on opposite sides of the road but that the former are less safe. Bidirectional paths are less safe, they argued, because they do not allow cyclists to merge with traffic lanes when near intersections. Merging with traffic lanes reduces the risk of being struck by turning vehicles.

Off-street Paths

Off-street paths come in two basic varieties: mixed-use paths and bicycle-only paths. Mixed-use paths are those intended to be shared by cyclists and pedestrians, with no markings or physical barriers separating the two types of users. Bicycle-only paths are those strictly reserved for cyclists. They can be adjacent to a pedestrian path, provided that the two are clearly demarcated.

While off-street paths may offer the highest level of comfort for cyclists, they are not necessarily the safest type of bicycle infrastructure. The research on bicycle paths offers conflicting evidence regarding their safety. Tinsworth et al. (1994) used a multiple regression analysis to assess the odds of being injured using a bicycle primarily (more than 50% of the time) on different types of infrastructure, including: major thoroughfares, neighbourhood streets, sidewalks, and off-street bicycle paths. Controlling for frequency of bicycle use, age, sex, community size, and time of day, they found that off-street bicycle-only paths had lowest odds ratio for injury of the investigated infrastructure types. Rodgers (1997), on the other hand, found that cyclists using off-road trails (mixed-use and bicycle-only confounded) faced much higher odds of colliding or falling than those using regular roads or bicycle lanes or tracks (conflated).

Evidence in the literature suggests that mixed-use off-street paths are more dangerous for cyclists than bicycle-only paths. Moritz conducted one study (Moritz, 1998 a) in which he evaluated the safety of off-road mixed-use relative to other types of infrastructure, and another (Moritz, 1998 b) in which he did the same with bicycle-only paths. Using a *relative danger index* (explained in the section of shared routes above), he found mixed-use paths (index 1.39) are more dangerous than major and minor roads without bicycle facilities (0.66 and 0.94 respectively), on-road shared routes (0.51), and bicycle lanes (0.41). They were however found to be less dangerous than unpaved, off-road/unpaved trails (index 4.49) and other infrastructure (16.3), which primarily includes sidewalks. In the second study (Moritz, 1998 b), off-street, bicycle-only paths (index 0.67) were found to be safer than major and minor roads with no bicycle facilities (1.26 and 1.04), but less safe than shared routes and bicycle lanes (0.50). Taken together, the results of Moritz's two studies suggest that off-street, mixed-used paths are more dangerous whereas off-street bicycle-only paths are safer than major and minor roads with no bicycle facilities. This is likely to be due to conflicts with other users on mixed-use paths, especially pedestrians, a problem identified by other researchers (Federal Highway Administration, 2006).

Safety at Intersections and Crossings

As noted in the Transport Canada (2004) study on vulnerable road users, the majority (64%) of bicycle injuries in Canada occur at intersections; looking at urban areas only, the share is even higher (72%). A similar pattern has been observed in the U.S., where 63% of cyclist injuries in 2004 occurred at intersections (National Highway Traffic Safety Administration, 2004). As noted in some of the research reviewed earlier, providing bicycle facilities between intersections does not necessarily reduce the overall number of bicycle accidents, and in some cases can even increase the risk of accidents at intersections (Danish Road Administration, 1994 a & 1996; SWOV, 1994). Together, these findings suggest that special attention needs to be paid to intersections.

A common intervention used at controlled intersections in Europe and in some North American cities, such as Portland, OR (Figure 5) and New York City (Figure 6), are *bike boxes*, also referred to as *advanced stop lines* (ASLs). They consist of moving the stop line for vehicles back three to five meters from their original location and allowing only bicycles to stop there. Allowing bicycles to stop ahead of cars is thought to prevent bicycles and vehicles making right turns from colliding. It also allows cyclists to position themselves closer to the centre of the street to facilitate turning left. Bike boxes are usually installed at intersections on streets with bicycle lanes or unidirectional bicycle tracks. In the latter case, to make use of the bike box, the bicycle tracks must merge with the roadway some 20 to 30 meters before the intersection, in effect becoming bicycle lanes.

Figure 5. Bike box in Portland, OR
(photo: streetsblog.org)

Figure 6. Bike box in New York City
(photo: streetsblog.org)

A Swedish study (Linderholm, 1992) investigated intersections along streets with unidirectional bicycle tracks at which bike boxes were installed. A marked safety improvement was observed, the accident risk dropping an average of 35% after the installation of bike boxes. A Danish study (Danish Road Administration, 1994 b) studied a similar configuration, focusing on the right turn behaviour of motorists. It was found that before the intersections under study were modified, between 12 and 24% of drivers turning right did so just ahead of cyclists on the bicycle track, creating a potentially dangerous conflict. After the modification, only 3 to 6% of motorists turning right would do so just ahead of a cyclist. It was concluded that this intervention was likely to improve the safety of cyclists using the bicycle track.

Looking at a different approach to modifying intersections, Jensen (2008) investigated the safety merits of painting bicycle track crossings bright blue. Crash and injury rates were measured before and after coloured crossings were implemented at 65 different intersections in Copenhagen. Interestingly, the risk of collision and injury declined (19% and 10% respectively) at intersections where only one coloured crossing was added, but increased at intersection where two, three, or four coloured crossings were installed. The author speculated that sites with multiple coloured crossings could be confusing to motorists.

Gårder et al. (1998) studied raised bicycle crossings that were installed at several locations in the Swedish city of Gothenburg. The bicycle crossings were raised between 4 and 12 cm above the road surface, making them more visible and forcing automobiles to slow down before passing over them, like a speed bump. They found that while there was an 8% increase in the absolute number of crashes at the sites where the raised crossings were installed, bicycle traffic volumes grew by more than 50% compared to other, unmodified crossings. The authors concluded that, given the modest increase in accidents with respect to the very large increase in bicycle traffic volume, raised crossing appear likely to constitute a safety improvement. Raised crossings are interventions worth considering along bidirectional bicycle on-street bicycle tracks as well as along off-street bicycle paths.

Comfort versus Safety

Cyclist comfort—i.e., the perception of safety—and actual safety—i.e., the risk of having an accident—can both be influenced by bicycle infrastructure. However, the two do not necessarily overlap.

Cyclist comfort is influenced by a number of factors (Landis, 1998), including:

- proximity to traffic
- traffic volume
- traffic speed
- share of heavy vehicles
- parked cars

Unsurprisingly, recent Canadian research conducted by a team of researchers at the School of Population and Public Health at the University of British Columbia, led by Megan Winters and Kay Teschke (Cycling in Cities, 2010), shows that cyclists prefer environments in which they are physically separated from traffic. The researchers surveyed current and potential cyclists in Metro Vancouver, asking them to rate 16 types of different environments—including roads with and without bicycle facilities as well as a few different types of off-road facilities—according to the likelihood that they would cycle on them. The top five choices were:

1. paved off-street paths for bicycles only
2. paved off-street mixed-use paths
3. unpaved off-street mixed-used paths
4. cycle tracks along major city streets separated by a barrier
5. designated bicycle routes on traffic calmed residential streets

Cycling away from traffic noise and pollution was cited as the main motivator for respondents' stated route preferences.

The safety research reviewed in this report suggests that some of the top choices above are not necessarily the safest choices. For instance, regarding the top choice—off-street bicycle-only paths—Moritz's (1998 b) findings suggest that these are safer than roads without bicycle facilities, but not necessarily safer than bicycle lanes, which do not provide physical separation from traffic. The second and third choices—off-street mixed-use paths—appear to be considerably more dangerous than on-street bicycle facilities (Rodgers, 1997), especially if they are unpaved (Moritz, 1998 a). Cycle tracks along major roads, the third choice and the top choice among on-street facilities, are also not necessarily the safest type of on-street bicycle infrastructure given that they tend to produce conflicts at intersections (Danish Road Administration, 1994 a & 1996; Ekman and Kronborg, 1995). Only in the case of designated bicycle routes on traffic calmed streets, the fifth choice, do comfort and safety considerations overlap—people like to cycle on them and the empirical research suggest they are indeed relatively safe.

Winters's and Teschke's team is currently working on a study evaluating bicycle safety in the same set of environments included in the survey, called the Bicyclists'

Injuries and the Cycling Environment (BICE) study. The results are expected in mid-2011. It will be interesting to see how cyclists' preference for certain types of environments compares to the actual level of safety provided by the same environments.

When weighing options for bicycle infrastructure, decision makers should consider both the comfort and safety dimensions of the different infrastructure types. Infrastructure that offers a higher level of comfort is likely to induce more bicycle use. Noland (2005) found that a 10% increase in perceived safety (i.e., comfort) results in a 10% or greater increase in the number of people commuting by bicycle. The City of Vancouver, for example, cited the perception of safety and attracting new cyclists as reasons when it recently announced that it would develop segregated bicycle tracks along major downtown streets (City of Vancouver, 2009).

Safety in Numbers

The provision of attractive cycling facilities is likely to induce additional bicycle traffic, which in itself is likely to have a significant impact on safety. A number of researchers in different parts of world have observed the so-called "strength in numbers" effect—e.g., Leden et al. (2000) in Europe; Jacobsen (2003) and Purcher and Bueler (2006) in North America; and Wang and Nihan (2004) in Asia.

The research by Jacobsen (2003), for example, shows that the probabilities of collisions between automobiles and cyclists as well as automobiles and pedestrians decrease as bicycle and pedestrian traffic volumes increase. Given that cyclists and pedestrian are not likely to be more careful if they are more numerous, Jacobsen concluded that their presence in larger number most likely affected motorists' behaviour. He speculated that, in the presence of more cyclists and pedestrians, motorists became more aware of their presence and more cautious. Furthermore, where there are more cyclists, there are likely to be more motorists who are cyclists themselves and thus more attuned to cyclists using the road.

Lessons Learned

The research on the relative safety merits of common types of bicycle infrastructure suggest the following:

- **shared routes:** designated shared routes tend to improve bicycle safety, in part possibly due to a "strength in numbers effect"; traffic calming features are likely to enhance safety gains
- **bicycle lanes:** appear to create some of the safest cycling environments, though may not offer the highest level of comfort
- **bicycle tracks:** do not necessarily reduce collision risks and may actually increase them if attention is not paid to intersection design; offer a higher level of comfort than other types of on-street facilities
- **off-street paths:** if for bicycles only, may offer improved levels of safety; if for mixed cyclist and pedestrian use, may be relatively hazardous; offer a high level of comfort

The research suggests that particular attention needs to be paid to intersections along on-street bicycle routes (shared routes, bicycle lanes, and bicycle tracks) and road crossings along off-street paths, as these are where the overwhelming majority of accidents occur. Interventions such bike boxes for bicycle lanes and unidirectional bicycle tracks and raised or coloured crossing for bidirectional bicycle tracks and off-street paths have the potential to mitigate collision risks at intersections and crossings.

Conclusion

The research presented in this paper shows that the development of appropriate bicycle infrastructure can have a positive effect on levels of bicycle use and bicycle safety. Nonetheless, Canadian communities' efforts to increase bicycle and improve bicycle safety should not exclusively focus on infrastructure. Rather, the development of infrastructure should be pursued as a part of a broader cycling strategy that includes strong public awareness and education components. European nations that have achieved high levels of bicycle use, such as the Netherlands, Denmark, and Germany, have aggressively pursued education of cyclists and motorists as a means of increasing bicycle safety, in addition to developing extensive networks of bicycle infrastructure.

Sources

City of Vancouver (2009). *Separated Bicycle Lanes – FAQ*. Webpage (http://vancouver.ca/engsvcs/transport/cycling/separated/faq.htm).

Cycling in Cities (2010). *Opinion Survey*. Webpage (http://www.cher.ubc.ca/cyclingincities/survey.html).

Danish Road Administration (1994 a). *Cycle lanes on sections in urban conditions*. Notat 12. Copenhagen: Danish Road Administration.

Danish Road Administration (1994 b). Vurdering av nye krydsutformninger for cyklister (Design of urban signalised intersections). Notat 2. Copenhagen: Danish Road Administration.

Danish Road Administration (1996). *Trafiksikkerheds-effekten af cykelbaner i byområder (The traffic safety effect of cycle* *lanes in urban areas).* Rapport 50. Copenhagen: Danish Road Administration.

Ekman, L. & Kronborg, P. (1995). *Traffic safety for pedestrians and cyclists at signal-controlled intersections*. Report 1995: 4E. TFK. Lund.

Federal Highway Administration (FHWA) (2006). *Evaluation of Safety, Design, and Operation of Shared-use Paths: Final Report.* Report No. FHWA-HRT-05-137. Wahsington: Federal Highway Administration.

Gårder, P., Leden, L., & Pulkkinen, U. (1998). Measuring the safety effect of raised bicycle crossings using a new research methodology. *Transportation Research Record* 1636, 64-70.

Jacobsen, P.L. (2003). Safety in numbers: more walkers and bicyclists, safer walking and bicycling. *Injury Prevention* 9, 205-209.

Jensen, S.U. (2008) Safety effects of blue cycle crossings: a before-after study. *Accident Analysis and Prevention* 40, 742-750.

Landis, B. et al. (1998) Real-Time Human Perceptions: Toward a Bicycle Level of Service. *Transportation Research Record* 1578, 119-126.

Leden, L. Gårder, P., and Pulkkinen, U. (2000). An expert judgment model applied to estimating the safety effect of a bicycle facility. *Accident Analysis and Prevention* 32, 589-599.

Linderholm, L. (1992). *Traffic safety evaluation of engineering measures -- Development of a method and its application to how physical layouts influence bicyclists at signalised intersections*. Lund: Department of Traffic Planning and Engineering. LTH.

Lott, D.F. & Lott, D.Y. (1976). Effect of Bike Lanes on Ten Classes of Bicycle-Automobile Accidents in Davis, California. *Journal of Safety Research* 8, 171-179.

Moritz, W.E. (1998 a). Adult bicyclists in the United States: characteristics and riding experience in 1996. *Transportation Research Record* 1636, 1-7.

Moritz, W.E. (1998 b). Survey of North American bicycle commuters: design and aggregate results. *Transportation Research Record* 1578, 91-101.

National Highway Traffic Safety Administration (NHTSA) (2004). *Traffic Safety Facts 2004: A Compilation of Motor Vehicle Crash Data from the Fatality Analysis Reporting System and the General Estimates System*. Washington, DC: National Highway Traffic Safety Administration (http://www-nrd.nhtsa.dot.gov/Pubs/TSF2004.PDF).

Noland, R. (1995) Perceived risk and modal choice: risk compensation in transportation systems. *Accident Analysis and Prevention* 27, 503-521.

Organization for Economic Co-operation and Development (OECD) (1998). *Safety of Vulnerable Road Users*. Paris: OECD (http://www.oecd.org/dataoecd/24/4/2103492.pdf).

Pucher, J., & Buehler, R. (2006). Why Canadians cycle more than Americans: a comparative analysis of bicycling trends and policies. *Transport Policy* 13, 265-279.

Pucher, J. & Dijkstra L. (2003). Promoting safe walking and cycling to improve public health: lessons from the Netherlands and Germany. *American Journal of Public Health* 93, 1509-1516 (http://www.policy.rutgers.edu/faculty/pucher/AJPHfromJacobsen.pdf).

Reynolds, C., Harris M.A., Teschke, K., Cripton, P., & Winters, M. (2009). The impact of transportation infrastructure on bicycling injuries and crashes: a review of the literature. *Environmental Health* 8(47) (http://www.ehjournal.net/content/8/1/47).

Rodgers, G.B. (1997). Factors associated with the crash risk of adult bicyclists. *Journal of Safety Research* 28(4), 233-241.

Smith, R. Jr & Walsh, T. (1988). Safety impacts of bicycle lanes. *Transportation Research Record* 1168, 49-56.

SWOV (1994). *Towards a sustainable safe traffic system in the Netherlands*. Research Activities No.1. Leidschendam: SWOV.

Tinsworth, D., Cassidy, S., & Polen, C. (1994). Bicycle-related injuries: Injury, hazard, and risk patterns. *International Journal of Injury Control and Safety Promotion* 1(4), 207-220.

Transport Canada (2004). *Vulnerable Road User Safety: A Global Concern*. Road Safety Fact Sheet RS-2004-03E (http://www.tc.gc.ca/eng/roadsafety/tp-tp2436-rs200403-menu-166.htm#cyclists).

Van Houten, R. & Seiderman, C. (2005). How Pavement Markings Influence Bicycle and Motor Vehicle Positioning: A Case Study in Cambridge, MA. Transportation Research Record, 1939, 3-14 (http://www.cambridgema.gov/~cdd/et/bike/bike_hamp_study.pdf).

Vélo Québec (2006). *État du vélo au Québec 2005*. Montreal: Vélo Québec (http://www.velo.qc.ca/documents/etatduvelo2005-complet.pdf).

Wang, Y. & Nihan, N.L. (2004) Estimating the risk of collisions between bicycles and motor vehicles at signalized intersections. *Accident Analysis and Prevention* 36, 313-321.

Resources

Contacts

Kay Teschke
Professor
School of Population and Public Health
University of British Columbia
604 822 2041
kteschke@mac.com

Websites

Bicycle Injuries in the Cycling Environment (BICE)
http://www.cher.ubc.ca/cyclingincities/

Pedestrian and Bicycle Information Center – Engineer Bicycle Facilities
http://www.bicyclinginfo.org/engineering/

Books/Technical Manuals

Velo Quebec (2010)
Planning and design for pedestrians and cyclists: A Technical Guide
http://www.velo.qc.ca/english/bikewaysdesign.php?page=handbook