# Literature Review

Resource Guide for Separating Bicyclists from Traffic

**July 2018**

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| **AASHTO** | American Association of State Highway and Transportation Officials |
| **ADT** | Average Daily Traffic ADA |
| **ASCE** | American Society of Civil Engineers |
| **CMF** | Crash Modification Factor |
| **CSD** | Context Sensitive Design |
| **CROW** | Centre for Research and Contract Standardization in Civil and Traffic Engineering |
| **FARS** | Fatality Analysis Reporting System |
| **FHWA** | Federal Highway Administration |
| **ITE** | Institute of Transportation Engineers |
| **LAW** | League of American Wheelmen |
| **MOE** | Measure of Effectiveness |
| **NACTO** | National Association of City Transportation Officials |
| **NCHRP** | National Cooperative Highway Research Program |
| **MUTCD** | Manual on Uniform Traffic Control Devices |
| **OECD** | Organization for Economic Cooperation and Development |
| **PBCAT** | Pedestrian and Bicycle Crash Analysis Tool |
| **SBL** | Separated Bicycle Lane |
| **SLM** | Shared Lane Markings |
| **SUP** | Shared Use Path |
| **TAC** | Transportation Association of Canada |
| **UVC** | Uniform Vehicle Code |

# Introduction

Research over the last 40 years has shown that providing bikeways which separate bicyclists from high-volume and high-speed traffic improves safety, compared to operating within a shared travel lane. This separation can be achieved by shifting bicyclists away from arterials onto traffic calmed bicycle boulevards, by providing soft separation with pavement markings to designated bicycle lanes or shoulders, or by providing a physical barrier between bicyclists and motorized traffic on separated bike lanes or paths. A key consideration for determining separation type is the desired bicyclist design user profile, in addition to the traffic and land use context. To maximize a community's bicycling potential, it is necessary to provide designs which are attractive to the largest segment of the population which has been identified as the "Interested but Concerned" bicyclists user profile.

This report summarizes the results of the literature review conducted for the development of a *Resource Guide for Separating Bicyclists from Traffic*. The purpose of this literature review is to identify and evaluate existing guidance for separating bicyclists from traffic, identify common bikeways for separating bicyclists from traffic, summarize the relative safety impact on bicyclists for these bikeways, and identify and evaluate decision making strategies for selecting a bikeway considering potential tradeoffs. This literature review also discusses the history of guidance for separating bicyclists from traffic in the United States to provide context for current bicycling activity and safety. The literature identifies example practices and metrics for selecting an appropriate bikeway treatment to accommodate bicyclists on public roadways.

Bicycle facilities considered in the literature review (with generally increasing separation from traffic) include:

- Bicycle Boulevards (shared lanes, but low traffic volume operating at low speeds)
- Advisory Bicycle Lanes
- Shoulders
- Bicycle Lanes
- Separated Bicycle Lanes
- Sidepaths (Shared Use Paths parallel to a roadway designed to mix pedestrians and bicyclists)

This literature review also considered the following treatments which are not considered bikeways because they do not materially improve conditions for bicycling, but are commonly used by bicyclists:

- Shared Lanes (baseline condition, but not considered a bikeway)
- Shared Lane Markings in Shared Lanes (not considered a bikeway)
- Sidewalks (Walkways where bicyclists may operate, where allowed by law or ordinance, without benefit of bicyclist consideration in design)

The goal for this literature review is to identify examples and information for a process to select an appropriate bikeway treatment to accommodate bicyclists on public roadways. Bikeways are bicycle boulevards or any other facility intended for bicycle travel which designates space for bicyclists distinct from motor vehicle traffic. A bikeway does not include shared lanes, sidewalks, signed routes, or shared lanes with shared lane markings because they do not materially improve the operating conditions for bicyclists. The process should allow practitioners to consider tradeoffs to bicyclists comfort and safety as well as for other users of the roadway and have clear criteria for decision making.

# Historical Context of Bicycling as a Transportation Mode in the United States (1880-1980)

Bicycling has been an important part of our transportation culture since its invention in the early 1800s. The following summarizes literature that describes how the history of bicycling has influenced cyclists' preferences and roadway design.

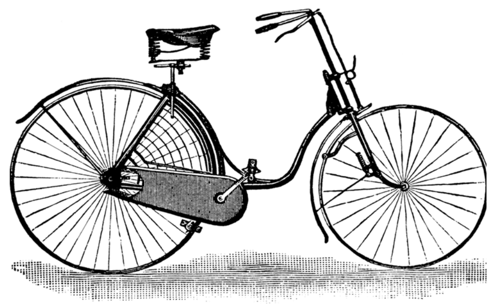

**Figure 1 – 1889 The Safety Bicycle**

Source: www. collection.sciencemuseum.org.uk

In 1885, the "safety bicycle" was invented with two relatively equal sized wheels and a design that allowed a bicyclist to put their foot on the ground while seated (see Figure 1). This style has remained relatively consistent to the present day.[1] The popularity of the bicycle led to the formation of the League of American Wheelmen (LAW) to advocate for improved bicycling conditions throughout the United States in 1880. In 1892, the League began publishing *Good Roads Magazine* to promote the smooth paving of streets and sidepaths alongside railroads to ease bicycle travel. This became known as the Good Roads Movement.[2]

With the invention and increasing popularity of the automobile in the early 1900s, efforts to promote the smooth paving of roads for the public were joined by a new organization, the National Highways Association, which formed in 1911. They promoted a vision of a 50,000-mile network of paved roads to "directly serve 66 percent of the population of the country, while connecting the capitals and all-important cities."[3] The sidepath movement to pave paths for bicyclists alongside railroads was quickly abandoned as federal, state, and local governments initiated programs to develop a paved highway and roadway network.

As motor vehicles became prevalent, it became necessary to create a national vehicle code to promote a uniform approach to the registration and operation of vehicles on highways. In 1926, the first Uniform Vehicle Code (UVC) was developed. As a document that was originally developed to manage motorized traffic, the UVC has struggled to reconcile the fact a bicyclist is neither a motorist or a pedestrian and a bicyclist can operate in both realms. The only mention of bicycles in the 1926 UVC was to differentiate bicycles from motor vehicles:

- For the purposes of registering and regulating vehicles, bicycles were not considered vehicles
- For the purposes of operating bicycles on highways, "a bicycle or a ridden animal shall be deemed a vehicle" to promote a uniform operation of bicycles on the roadway alongside motorists

The UVC also had to define the term "roadway." In 1930 it was defined as "that portion of a street or highway between the regularly established curb lines or that part improved and intended to be used for vehicular travel." In 1975, it was redefined to mean "that portion of a highway improved, designed or ordinarily used for vehicular travel, exclusive of the sidewalk, berm or shoulder even though such sidewalk, berm or shoulder is used by persons riding bicycles or other human powered vehicles."

[1] http://collection.sciencemuseum.org.uk/objects/co25833/rover-safety-bicycle-1885-bicycle
[2] https://www.nytimes.com/1892/01/15/archives/good-roads-desirable-jersey-leads-in-a-movement-for-their.html
[3] https://www.fhwa.dot.gov/infrastructure/davis.cfm

In 1944, the UVC clarified that bicycles are human powered devices, not vehicles. This definitional clarification was complemented by new provisions which restricted bicycle operation within the roadway presumably in the interest of promoting predictable traffic flow. The first provision is the "ride to the right rule" which requires bicyclists to ride "as close as practicable to the right-hand curb or edge of the roadway." A second provision has become known as the mandatory sidepath law as it states: "Wherever a usable path for bicycles has been provided adjacent to a roadway, bicycle riders shall use such path and shall not use the roadway." While not required, these two provisions together have been interpreted by some people to imply there is a "mandatory use law" in the UVC to require a bicyclist to use a sidepath, a marked bike lane, or a roadway shoulder, rather than other adjacent travel lanes provided for motor vehicles. The mandatory use of a bikeway is not implied by these two provisions; however, it can be enacted by statute at the state or local level. By the 1970s, 38 states did in fact incorporate specific language requiring mandatory use of bikeways where provided. This has since been reduced to 17 states, with only 11 having broad laws that apply to most bikeways.[4] In 1975 the definition of bicycle was refined in the UVC again to mean "Every vehicle propelled solely by human power on which any person may ride, having two tandem wheels, except scooters and similar devices."[5]

In 1944, the UVC added a provision which limited the ability of bicyclists to socialize while bicycling stating they "shall not ride more than two abreast, except on paths or parts of roadways set aside for exclusive use of bicycles." This provision remains in the 2000 UVC. As of 2010, 44 states had versions of this statute, with 23 states allowing bicycling two abreast when it does not "impede the normal and reasonable movement of traffic."

The fundamental issue of bicyclists having a "right" to operate on the road has been a longstanding concern for some bicyclists, particularly sport bicyclists. The UVC was developed in part to provide order to traffic, but it also was written to prioritize the movement of motorized traffic in some respects. The ride to the right rule and mandatory sidepath provisions have been used by police to ticket bicyclists operating in travel lanes for "impeding traffic."[6,7] Interestingly, the 1969 UVC includes language which clearly states motorcyclists are not subject to the ride to the right rule stating, "All motorcycles are entitled to full use of a lane and no motor vehicle shall be driven in such a manner as to deprive any motorcycle of the full use of a lane." Since 1969, the ride to right rule for bicyclists has been updated with an exception for where bicyclists are operating in a "substandard lane width," defined as being "too narrow for a bicycle and a vehicle to travel safely side by side within the lane."[8] While substandard is not defined in the UVC, it is defined in the 2012 American Association of State Highway and Transportation Officials (AASHTO) *Guide for the Development of Bicycle Facilities* as being a lane that is less than 14 feet in width.

Between 1926 and the late 1960s, there was very little effort in the United States to accommodate bicycling on public roads or to build paved bicycle paths. In 1966 the US Department of the Interior published the *Trails for America* report to address this lack of action. It promoted a nationwide network of trails for bicycling and walking to increase health and safety in urban and rural areas. This report emphasized the

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[4] http://bikeleague.org/content/bike-law-university-mandatory-use-separated-facilities
[5] Jeremy R. Chapman. *Uniform Vehicle Code and State Statutes Governing Bicycling, 2010. Analysis of Definitions and Statutes.*
[6] Cyclist ticketed for impeding traffic. http://www.abajournal.com/magazine/article/bicyclists_rules_of_the_road/ accessed February 21, 2018
[7] Cyclists ticketed for riding outside of bike lanes. http://gothamist.com/2017/04/28/nypd_bike_lane_tickets.php accessed February 21, 2018
[8] 2000 Uniform Vehicle Code

existing roadway network, funding programs, and the suburban development patterns prioritized motor vehicle travel, sometimes resulting in unsafe and inhospitable conditions for bicycling and walking. The report noted, that while a similar trend of increasing levels of automobile use was occurring in Europe, the Europeans were making "a special effort to provide for those who walk or cycle" and similar efforts should be undertaken within the United States.

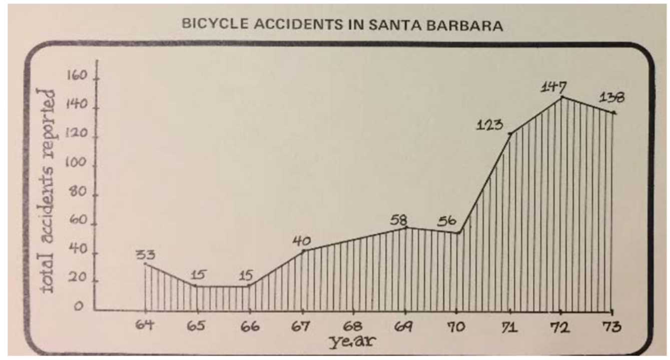



**Figure 2 - Bicycling crashes in Santa Barbara 1964 – 1973.**

Source: 1974 Santa Barbara Bikeway Master Plan

During the late 1960s and early 1970s, efforts to improve conditions for bicycling began to occur at the Federal, State, and local level to respond to citizen concerns regarding environmental pollution and increases in bicycle crashes (see Figure 2) resulting from the bicycle boom of the early 1970s. A 1970 study by the National Safety Council reported 820 bicyclist deaths from motorist crashes, an increase of 78 percent since 1960.[9] During this period, Davis, California become the first city in the US to implement a connected network of bicycle lanes, separated bike lanes, and sidepaths between 1966 and 1972 that was comfortable and appealing for people of all ages and abilities, including women, children, university students, and seniors.

State and Federal funding supported research efforts to evaluate the safety and design of the bikeways produced a series of research reports and bikeway design guidelines throughout the 1970s. These studies generally found the implementation of bicycle lanes, separated bike lanes, and sidepaths resulted in the following:

- improved safety, although additional treatments were necessary to address increased bicycle crashes at some intersections
- separation from motor vehicles and pedestrians increased bicyclist comfort and bicycle ridership
- bicyclists and motorists preferred streets with bike lanes to those without
- some bicyclists improperly turned left from bikeways to cross streets
- maintenance of separated bike lanes and sidepaths was inadequate or non-existent, creating safety challenges or complaints
- intersection sight lines were inadequate at sidepath and separated bike lane crossings of streets and driveways where parking was allowed up to the crossing (see Figure 3)
- pedestrians walked in sidewalk level bike lanes with no separation between bikes and pedestrians
- contra-flow bicycle movements were consistently over-represented in crashes
- some barrier strategies presented hazards to motorists and bicyclists where they were built too narrow or not adequately visible (see Figure 4)

[9] Fisher, G., Hulbert, S., Ramey, M. R., Fass, S., Gonzales, D., Horowitz, A., Kefauver, J., Kobritz, B., Lum, W., Millar, M., Nicodemus, C., Ravindranath, A., Stenson, D., & Weller, E. Bikeway Planning Criteria and Guidelines. University of California, Institute of Transportation and Traffic Engineering, School of Engineering and Applied Science, Los Angeles, CA, 1972.


**Figure 3 - Image of driveway on sycamore lane in Davis, CA where parking was allowed up to driveway restricting sight lines.**

Source: 1974 USDOT Bikeways State of the Art

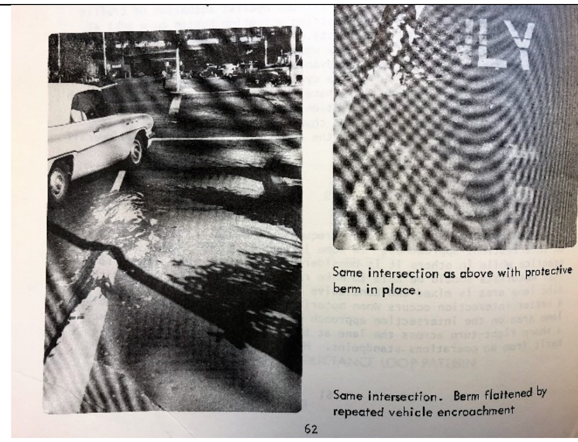



**Figure 4 - Image of asphalt protective berm damaged by motorist encroachment across the bike lane**

Source: 1974 USDOT Bikeways State of the Art

To address safety concerns related to the increase of bicyclists being struck by motor vehicles in shared lanes, early research efforts recommended specific guidance for separating bikes from traffic based on speed and volume of motorized traffic (see Figure 5).

Based on the findings of these research efforts, the first edition of the AASHTO Bicycle Design Guide (1974) called for the creation of networks of bike lanes, separated bike lanes, and sidepaths to serve a wide range of bicyclists. The primary design user was a person bicycling for transportation or recreational purposes operating at slower speeds (7-15 mph), not sport bicyclists who operated at higher speeds (15-30 mph). The 1974 AASHTO Bike Guide (see Figure 6) recommended bicycle lanes be installed where vehicle volume greater than 2,000 ADT or vehicle speeds were greater than 30 mph. It also suggested the following:

- minimum bicycle facility design speed of 10mph with 15mph being desirable
- continuous bike lanes up to intersections (images a, b, c below)
- marked bicycle lane crossing parallel with pedestrian crosswalks
- provision of two-stage left turn boxes (left turn pocket in image, image c below)
- provision of protected intersections (offset crossing, image b below)

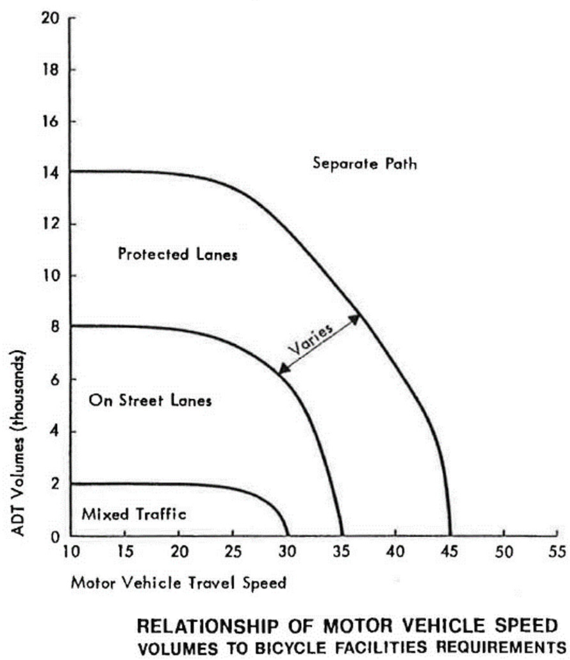



**Figure 5 - Bikeway selection graph for City of Davis, CA**

Source: Bicycle Safety and Circulation study. DeLeuw, Cather and Company (1972)

- bicycle lanes should operate as one-way facilities
- provision of maintenance activity to keep bikeway functional and safe

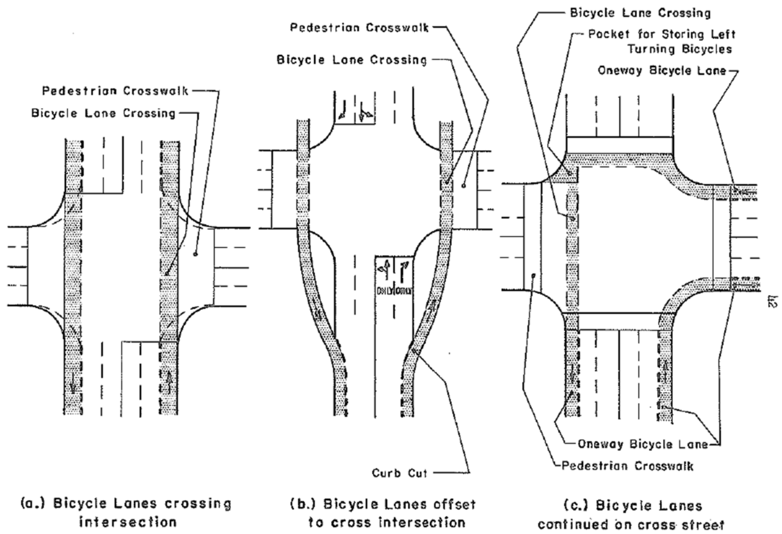



**Figure 6 - Typical design configurations for intersections with bike lanes.**
Source: 1974 AASHTO Bike Guide

Some cities, such as Palo Alto, CA, began to implement a bicycle network by installing bike lanes and signed bicycle routes – including sidewalk bike routes on streets which had high volumes of traffic but were too narrow for bike lanes. Due to laws prohibiting bicycling on sidewalks, cities which signed sidewalk bike routes had to create ordinances allowing bicycling on designated sidewalks. In some cases, they also created ordinances requiring the use of bike lanes (but generally not the sidewalk bike routes).

The development of bike lanes and the designation of sidewalks as bike routes concerned some bicyclists, who were fearful they were losing their right to bicycle on the road. Many club, touring, or sport bicyclists could ride at 20 mph or faster over longer distances. Many frequently rode with larger groups of cyclists recreationally on weekends, or to train for bicycle races or long-distance bicycle tours. They opposed mandatory use ordinances and sidewalk bicycling policies understanding that bicycling at high speeds in large groups could be impractical, and in some cases hazardous, if they were bicycling in bike lanes or on paths or narrow sidewalks shared with pedestrians or sidewalks where curb ramps were missing.[10]

These concerns led to the development of the “Effective Cycling” philosophy (also known as vehicular cycling). It was popularized by Palo Alto resident, John Forester who stated in his 1975 book, *Effective Cycling*, that “bicyclists fare best when they act as, and are treated as, drivers of motor vehicles.” It was believed that bikeways would do nothing to improve safety and would in many cases worsen safety, and that bicyclists needed an education program to learn how to assertively operate in traffic. The vehicular cycling philosophy recommended streets be designed for high-speed recreational bicyclists, traveling at 30mph, to

[10] Bicycling Safely On The Road. Effective Cycling Training Video 1979. https://www.youtube.com/watch?v=IAOHWV6ZaPI

attract serious bicyclists. In the late 1970s, the League of American Wheelman[11] (LAW) developed a Bicycle Education program based on the Effective Cycling philosophy.[12]

Bike lanes, separated bike lanes and paths were advocated by some as a strategy to attract people who were concerned about bicycling in traffic. However, some outspoken bicycle advocates at the time believed people not bicycling had an unreasonable fear of traffic and would likely never bicycle.

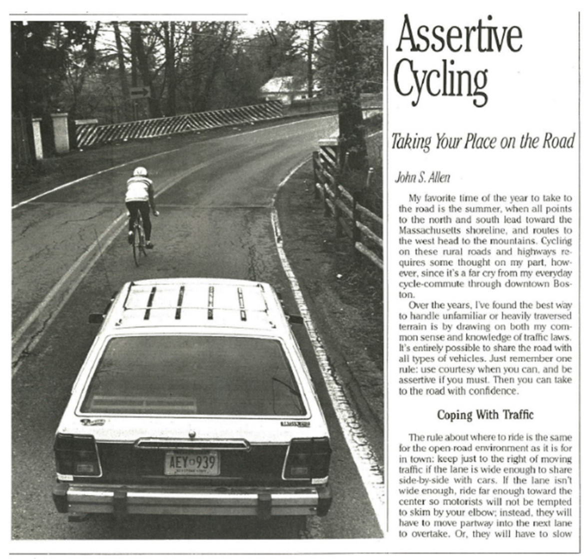
The most vocal vehicular cycling advocates tended to be men who were skeptical bikeways would result in more people bicycling. They largely believed the public preferred driving over bicycling, and efforts to build bikeways for "hypothetical cyclists" would only serve to increase harassment of the existing "proficient bicyclists" by motorists who would demand they use the "inferior" bikeways at slower speeds.[13] Wide outside lanes were seen as preferable to bikeways because they allow "motorists to overtake cyclists without delay, and remove cyclists the feeling of guilt at delaying motorists," wrote Forester.

However, these beliefs were not supported by research at the time which found that separated bike lanes increased bicycling, and drew a wider variety of people to bicycling. A 1976 study of the addition of bike lanes in Davis, California found that they attracted people from other routes, and that certain demographics, such as women over 25 years old and middle, high school, and college students, were much more likely to ride on the street after bike lanes were installed. The research also found that most cyclists who were not training or racing operated at speeds below 15 mph. Other research completed prior to 1977 showed bikeways generally improved safety overall compared to operating in shared travel lanes. Nonetheless, articles and editorials published in *Bicycling Magazine* throughout the 1970s and 1980s helped to promote the vehicular cycling philosophy throughout North America.

Vehicular cycling advocates often found common ground with highway engineers by emphasizing cost savings under the assumption that bicycling would remain a minor activity. In a 1974 ASCE paper, CalTrans engineer Harold Munn argued that efforts to separate bicycles from the normal flow of vehicular traffic were not practical in the 20th century, where the priority was to accommodate motorized vehicular traffic. He concluded that "the bicyclist will have no choice but to mix with motorized traffic," and that it would be necessary to convince adult cyclists "to operate their bicycles as they do vehicles."

Speaking at the Bicycles USA conference in 1973 organized by USDOT, USDOT Assistant Secretary John Hilten summarized the bikeway debate with a simple question: "Should bikeways be designed to accommodate a smaller number of people moving at the maximum rate of speed achievable by the bicyclist over long distances or should they be designed to accommodate the maximum number of people willing to travel for shorter trips?"

The people who were preferred vehicular cycling were often motivated to join bicycle advocacy organizations and other official organizations which influenced roadway design policy.



Assertive Cycling

*Taking Your Place on the Road*

*John S. Allen*

My favorite time of the year to take to the road is the summer, when all points to the north and south lead toward the Massachusetts shoreline, and routes to the west head to the mountains. Cycling on these rural roads and highways requires some thought on my part, however, since it's a far cry from my everyday cycle-commute through downtown Boston.

Over the years, I've found the best way to handle unfamiliar or heavily traversed terrain is by drawing on both my common sense and knowledge of traffic laws. It's entirely possible to share the road with all types of vehicles. Just remember one rule: use courtesy when you can, and be assertive if you must. Then you can take to the road with confidence.

**Coping With Traffic**

The rule about where to ride is the same for the open-road environment as it is for in town: keep just to the right of moving traffic if the lane is wide enough to share side-by-side with cars. If the lane isn't wide enough, ride far enough toward the center so motorists will not be tempted to skim by your elbow; instead, they will have to move partway into the next lane to overtake. Or, they will have to slow

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**Figure 7 - Article explaining effective cycling lane control techniques.**

Source: Bicycling Magazine (July 1982)

[11] Renamed the League of American Bicyclists in 1994.

[12] Also commonly referred to as Vehicular Cycling, Bicycle Driving, or Cycling Savvy

[13] John Finley Scott. Editorial Bicycling Magazine November 1977. *The cycling community. Who leads, who follows. A reply to Bob Somner*

The result was that bikeway design guides began to incorporate vehicular cycling ideas, treating bicyclists as motor vehicles in road design, beginning with the 1978 CalTrans *Bicycle Design Guide*. This guide codified vehicular cycling as the primary method for accommodating bicyclists, stating: “An effective program is one that is conducted in recognition of the fact that billions of dollars have been spent on a road system to allow people to travel almost any place they wish. Most of these roads are sufficient to accommodate shared use by bicyclists and motorists, and hence, most bicycle travel has occurred and will continue to occur on that system.” It also de-emphasized the role bikeways could play to address safety concerns stating: “Many of the common problems are related to improper bicyclist and motorist behavior and can only be corrected through effective education and enforcement programs” and recommended against separated bike lanes and sidepaths.[14] The Guide prohibited physical separation of bike lanes and did not provide guidance for specific motor vehicle volume and speed thresholds which would warrant separation. Munn’s 1974 ASCE paper and Forrester’s *Cycling Traffic Engineering* handbook were listed as primary source materials for the Guide.

As California was considered the leader in bicycling accommodation at the time, the 1981 AASHTO Bicycle Guide closely followed the 1978 CalTrans Bikeway Guide. It discarded most of the content of the 1974 AASHTO Guide including the elimination of protected intersections, bicycle crossings, guidance for continuing bike lanes to intersections, and motor vehicle and speed thresholds which would warrant separation was warranted. Emphasizing design for the “serious cyclist,” the Guide increased the minimum design speed to 20 mph, suggesting a 30 mph design speed as more desirable. This guidance remained relatively unchanged through the 1991 and 1999 versions of the AASHTO Guides. More nuanced guidance was developed for the 2012 AASHTO Guide.[16]

[14] Schultheiss, W. Sanders, R. Toole, J. A Historical Perspective on the AASHTO Guide for the Development of Bicycle Facilities and the Impact of the Vehicular Cycling Movement. 2018 Transportation Research Board.

# Bicyclist Typology (Design User) Research

This section summarizes research on bicyclists' user characteristics and approaches to defining bicyclist design users. This section also discusses facility types preferred by the selected design user and common criteria considered by agencies when selecting bicycle facilities.

As with driving an automobile, using a bicycle for transportation requires using the skills of control, guidance, and navigation at the same time[15]. As a human-powered mode of transportation, the ability to successfully achieve these three simultaneous tasks depends on the cyclist's cognitive and physical abilities. As a vulnerable user of the roadway lacking crash protection in the form of a crash-worthy vehicle, a person's willingness to bicycle is also contingent upon their perception of safety and comfort related to operating with or near motorized traffic. Research on bicyclists characteristics has generally termed this "traffic stress tolerance." The inability to prioritize or define a design user that represents the mainstream population has created a challenge for developing criteria for determining when it is appropriate to separate bicyclists from traffic.

## Cyclist Typologies

Roger Geller, bicycle coordinator for the City of Portland, created four categories that are commonly used to denote how comfortable people are bicycling and how likely they are to do it.[16] The categories are "strong and fearless", "enthused and confident", "interested but concerned", and "no way no how." The proportions of a given city's population fitting into these four categories varies, but Geller hypothesized that generally the "strong and fearless" type composes a very small percentage, while the "interested but concerned" type is largest among the portion of the population that may be candidates for using bicycles for transportation.

This typology's fit with the general population was tested in a survey in Portland, Oregon, and then again more recently in a national survey.[17] [18] The findings from the latter indicate that Geller's typology is more or less reliable: 12 percent of respondents were classified as either "strong and fearless" or "enthused and confident" (compared to Geller's estimated 8 percent), 51 percent were "interested but concerned" (compared to Geller's 60 percent), and 37 percent were classified as "no way no how" (compared to Geller's 33 percent). The data from both surveys also found that women were more likely to be in the "no way no how" and "interested but concerned" categories. Among all respondents in the "interested but concerned" category, those who did occasionally ride a bicycle were more likely to have friends or family who rode a bike, and to have a strong preference for separated facilities and bicycle boulevards. Automobile traffic concerns were a prevalent factor in the "interested but concerned" and the "no way no how" groups' responses to the survey.

Other recent studies have built upon the Geller typology. A study in Davis, California, approached the typology from a behavioral standpoint to test attitudes towards bicycling and predict how small policy

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[15] USDOT, 1990.

[16] Dill, D. and McNeil, N. Four Types of Cyclists? Examination of Typology for Better Understanding of Bicycling Behavior and Potential. In *Transportation Research Record 2387*. TRB, National Research Council, Washington, DC, 2013.

[17] Ibid.

[18] Dill, D. and McNeil, N. (2016). Revisiting the Four Types of Cyclists. In *Transportation Research Record 2587*. TRB, National Research Council, Washington, DC.

changes could bring those in the "no way no how" category into the "interested but concerned" group.[19] While more rigorous than the Geller typology, this study was also more complex and therefore less "catchy." Another study in Montreal devised a typology for cyclists in terms of cyclist motivations and perceptions of convenience, but did not address non-cyclists.[20] Thus, despite these attempts at refining the typology of cyclists and non-cyclists due to some issues with the Geller methodology (mainly that it weighs stated preferences more heavily than behavior), the "Four Types" scheme has become ubiquitous because it is relatively accurate and easy to use and reference.

## Influence of Cyclist Age

Riding a bicycle is an activity that may be undertaken by any demographic or age group. Children and older adults, however, may have cognitive and physical limitations on their abilities to process stimuli and information. Studies focused on childhood development have shown that while children have fully developed spatial and temporal abilities, they have slower response and execution times than adults, particularly prior to age 14.[21,22] Research also shows that children often ignore cognitive stimuli in the interest of maintaining balance on a bicycle.[23] This tendency may increase children's risk when riding a bicycle near automobile traffic. Children are also more likely to take risks, as their maturing pre-frontal cortex has difficulty regulating risky behavior, which could put them in greater danger while riding a bicycle.[24]

According to recent data, the majority of child pedestrian fatal crashes and child bicyclist fatal crashes occurred at non-intersection locations (70% and 52%, respectively).[25] Studies suggest that educating and training children in groups, with both classroom and behavioral training components, may be the most beneficial means to reduce crash likelihood for children riding bicycles.[26]

While younger children are often impulsive and may not make wise decisions regarding oncoming traffic, this ability is considered mature in the early twenties.[27] Cognitive abilities may be greatest between ages 22 and 42, and decline gradually through age 60, after which cognitive decline accelerates.[28] Although all adults, regardless of age, show a slowing of task performance when faced with multiple stimuli, when the duration

[19] Thigpen, C., Driller, B., and Handy, S. (2015). Using a Stages of Change Approach to Explore Opportunities for Increasing Bicycle Commuting. *Transportation Research Part D*: 39, pp. 44-55.
[20] Damant-Sirois, G., Grimsrud, M., and El-Geineidy, A. M. (2014). What's Your Type: A Multidimensional Cyclist Typology. *Transportation*: 41, pp. 1153-1169.
[21] Plumert, J., Kearney, J., and Cremer, J. (2004). Children's Perception of Gap Affordances: Bicycling Across Traffic-Filled Intersections in an Immersive Virtual Environment. *Child Development*: 75 (4), pp. 1243-1253.
[22] Kail, R. (1991). Processing time declines exponentially during childhood and adolescence. Developmental Psychology, 27, 259-266. doi:10.1037/0012-1649.27.2.259.
[23] Wierda, M., & Brookhuis, K. A. (1991). Analysis of cycling skill: A cognitive approach. Applied Cognitive Psychology, 5, 113-122. doi:10.1002/acp.2350050205.
[24] Steinberg, L., Dustin, A., Cauffman, E., Banich, M., Graham, S., & Woolard, J. (2008). Age differences in sensation seeking and impulsivity as indexed by behavior and self-report: Evidence for a dual systems model. Developmental Psychology, 44, 1764-1778. doi:10.1037/a0012955.
[25] Traffic Safety Facts: 2015 Data. (2017). National Highway Traffic Safety Administration: Washington, DC. Report No. DOT-HS-812-383.
[26] Rivara, F. P., & Metrik, J. (1998). Training programs for bicycle safety. Retrieved from http://depts.washington.edu/hiprc/pdf/report.pdf
[27]Casey, B. J., Giedd, J. N., & Thomas, K. M. (2000). Structural and functional brain development and its relation to cognitive development. Biological Psychology, 54, 241-257. Retrieved from http://dept.wofford.edu/neuroscience/NeuroSeminar/pdfSpring2008/GieddJNRev1.pdf
[28] Salthouse, T. (2009). When Does Age-related Cognitive Decline Begin? *Neurobiology of Aging*: 30, pp. 507-514.

or number of stages required to process information is increased, older adults show declines in performance.[29] Older adults also have difficulty paying attention to multiple stimuli and making subconscious decisions about the relative importance of stimuli. This effect can be especially problematic in tasks like driving.[30] Research suggests that the knowledge of skills such as bicycling is stored in procedural memory, and does not significantly deteriorate with age. However, increased age can also lead to difficulty in coordinating motor performance and smoothness of motion, reduced stability and balance, and general slowing of performance. Older adults may compensate for reduced accuracy of movement by performing tasks more slowly.[31] These cognitive difficulties are likely to impact reaction time and motor performance required to bicycle, especially in complex environments. Designing more predictable environments and bicycle facilities that do not require as much cognitive speed and processing would benefit older adults as well as children.

## Facility Preferences by Design User Type

Research attempting to understand "types of cyclists" has also often focused on preferences for bicycle facilities. Multiple studies have found that both current and potential bicycle riders strongly prefer physically separated facilities. The majority of cyclists prefer to ride in a facility that is off-street or separated from automobile traffic by some type of barrier.[32,33,34] Studies considered both stated and revealed preference for various types of bicycle facilities, which included hypothetical designs as well as actual facilities. Research indicates that even protection as minimal as flexible plastic posts yields significant increases in perceived comfort for bicyclists. Drivers have expressed a greater comfort with separated facilities, as well. Separation from on-street parking, while not as important as separation from moving traffic, has also been found to be significantly associated with greater perceived comfort for both cyclists and drivers. In general, greater separation from automobile traffic increases comfort for cyclists and drivers.[35]

## AASHTO Guidance

The 1974 AASHTO Bicycle Guide provided explicit guidance for when to separate bicyclists from traffic based on motorized traffic volume and speed. The guide does not discuss bicyclists tolerance for traffic stress, but stress tolerance is implied by suggesting separation is warranted where traffic volume exceeds 2,000 ADT or motor vehicle speeds exceed 30 mph.

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[29] Verhaeghen, P. and Cerella, J. (2002). Aging, Executive Control, and Attention: A Review of Meta-analyses. *Neuroscience and Biobehavioral Reviews*: 26, pp. 849-857.
[30] Glisky, E. Changes in Cognitive Function in Human Aging. In *Brain Aging: Models, Methods, and Mechanisms (*D. Riddle, ed.). Boca Raton: CRC Press/Taylot & Francis, 2007.
[31] Seider, R., et al. (2010). Motor Control and Aging: Links to Age-Related Brain Structural, Functional, and Biochemical Effects. *Neuroscience Biobehavioral Review*: 34 (5), 721-733.
[32] McNeil, N., Monsere, C., and Dill, J. (2015). The Influence of Bike Lane Buffer Types on Perceived Comfort and Safety of Bicyclists and Potential Bicyclists. *In Transportation Research Record 2520.* TRB, National Research Council, Washington, DC.
[33] Sanders, R. (2014). Roadway Design Preferences Among Drivers and Bicyclists in the Bay Area. Paper presented at the 93rd Annual Meeting of the Transportation Research Board, Washington, DC.
[34] Winters, M., et al. (2014). How Far Out of the Way Will We Travel? Built Environment Influences on Route Selection for Bicycle and Car Travel. In *Transportation Research Record 2520.* TRB, National Research Council, Washington, DC.
[35] Buehler, R., and Dill, J. (2015). Bikeway Networks: A Review of Effects on Cycling. *Transport Reviews*: 36 (1), pp. 9-27.

While the 1981 AASHTO Guide eliminated the specific traffic speed and volume warrant for separation, it does discuss two types of bicyclists based on their tolerance of traffic stress: one group can tolerate higher traffic volumes on arterials to minimize travel distance, and another group that prefers a lower stress experience, who are "willing to go out of their way to ride on residential streets, bicycle lanes, or paths." The 1981 Guide also states "In general, inexperienced bicyclists will not ride on heavily traveled high speed arterials but will prefer quieter streets. Thus, cyclists' preferred routes may change over time as their skill levels change" implying a traffic stress tolerance can be acquired through training (such as an effective cycling course) or experience bicycling. This premise remained in the 1991 Guide.

The 1999 Guide classified three types of bicyclists based on their comfort operating with motor vehicle traffic using a classification system recommended in a 1994 Federal Highway Administration (FHWA) Report.[36] The design user was still primarily defined by their skill or confidence, not comfort or stress tolerance. It described an "A" cyclist as confident and experienced, "riding for convenience and speed," therefore they would be comfortable with a wide outside lane. They were assumed to consist of 5 percent of the population. Recreation, inexperienced, or child bicyclists were described as "B/C" riders who would prefer well-defined separation on arterials consisting of 95 percent of the population. This approach still assumed people could become "A" cyclists through training or experience. Nonetheless, this classification was vehemently opposed by vehicular cycling advocates as noted by Forester, who stated this "policy then assumes that the B/C group will continue to be the large majority for whom the entire system must be designed. In effect, the FHWA advocates dumbing down the cycling traffic system to suit the desires of the least competent possible users." The real purpose of this policy is "to promote the highway establishment's major cycling interest, its desire to prevent cyclists from delaying motorists."

The 2012 Guide eliminated the A/B/C typology in favor of a more nuanced discussion of user skill and comfort which was correlated to a person's tolerance for motor vehicle traffic stress based on the 1997 Bicycle Level of Service research which measured a bicyclists comfort and stress operating with motor vehicle traffic. The findings of the research more clearly link stress of bicycling in traffic with motor vehicle volume and speed, placing less of an emphasis on the skill or confidence of the bicyclist.

The draft 2018 AASHTO Guide for Bicycle Facilities has proposed to follow the "four types" typology identified in research by Dill and McNeil. It includes guidance which also describes bikeway preferences for each user typology consistent with bicyclists typology as discussed below (see Figure 8):

- **Highly Confident Bicyclists**, sometimes known as Experienced and Confident Bicyclists, represent between 4 and 7 percent of the general population and are the smallest group identified by the bicyclists typology studies. While some of these individuals bicycle very little, when they do, they prefer direct routes and do not avoid operating in mixed traffic, even on roadways with higher operating speeds and volumes. Many also enjoy bikeways separated from traffic, although their high tolerance for traffic stress and overall preference for faster routes may result in their riding in mixed traffic to avoid bikeways which they perceive to be less safe or too crowded.
- **Somewhat Confident Bicyclists**, also known as the Enthused and Confident Bicyclists, represent between 5 and 9 percent of the general population. They generally bicycle more than the Highly Confident Bicyclists, and are comfortable on most types of bicycle facilities. They have a lower tolerance for traffic stress than the Highly Confident Bicyclist and generally prefer striped or separated

[36] Wilkinson, W.C., Clarke, A., Epperson, B., Knoblauch, R. *Effects of Bicycle Accommodations on Bicycle/Motor Vehicle Safety and Traffic Operations*. FHWA, U.S. Department of Transportation, Virginia, 1994.

bike lanes on major streets and low-volume residential streets, but they are willing to tolerate higher levels of traffic stress for short distances to complete trips to destinations.

- **Interested but Concerned Bicyclists** represent between 51 -56 percent of the general population and are the largest group identified by the bicyclists typology studies. This group has the lowest tolerance for traffic stress. Bicycling by this group is suppressed in many communities, as those who fit into it the group avoid bicycling except where they have access to networks of separated bikeways or very low volume streets with safe crossings of higher volume streets. Probably for this reason, this group tends to bicycle for recreation but not transportation. To maximize the potential for bicycling activity, it is important to design bicycle facilities to meet the needs of the Interested but Concerned Bicyclist category.
- **Non-Bicyclists** represents between 31-37 percent of the general population and is the group that is unable to or is not interested in bicycling.

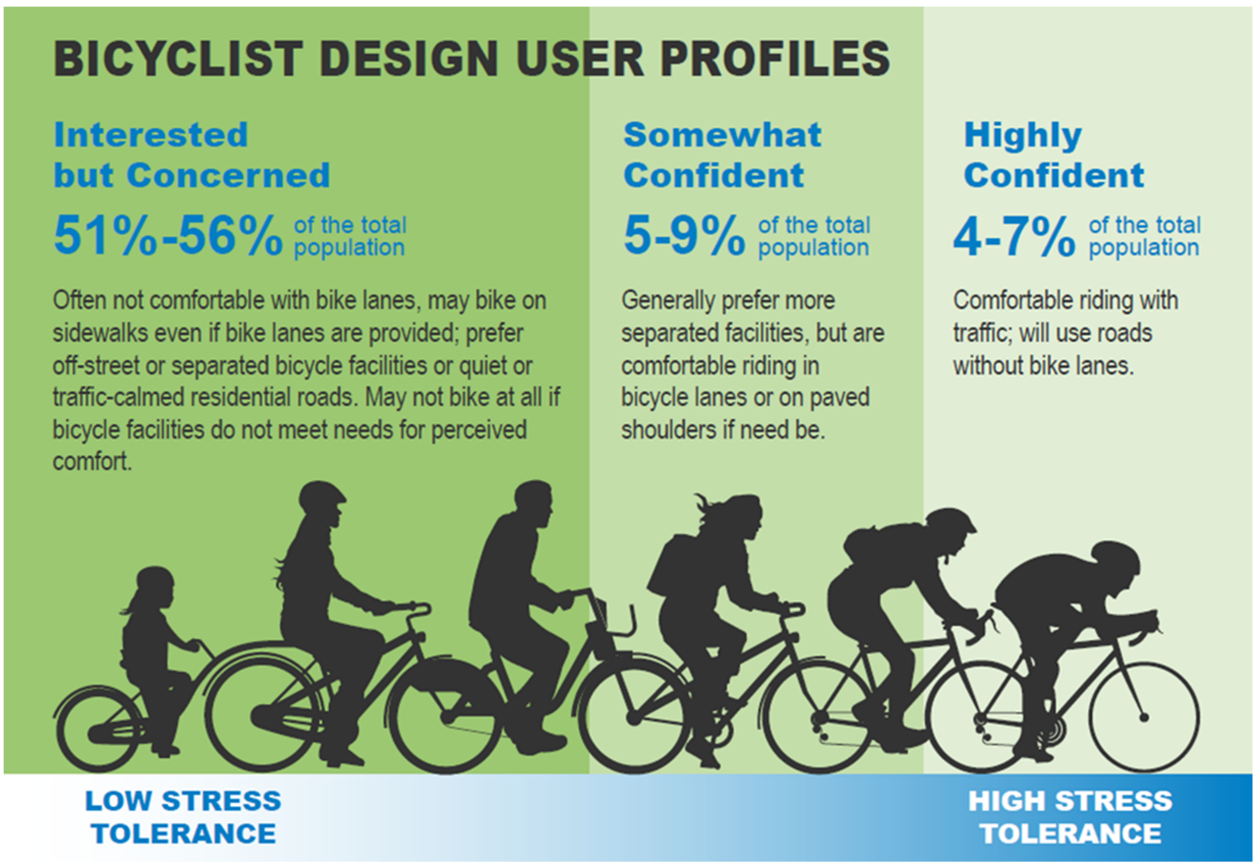


**Figure 8 - Summary of Cyclist Typologies Profile, proposed for 2018 AASHTO Bike Guide Review of Bikeway Selection Guidance**

Source: Toole Design Group

## Design User

Research over the last decade in the United States confirms there is a relatively small percentage of people who can be classified as being comfortable bicycling in mixed traffic, and a large majority of people prefer some level of separation from higher volume, higher speed motorized traffic.[37,38] Previous assumptions that confident bicyclists were comfortable sharing operating space with high volumes of motorized traffic are proving to be inaccurate, as a majority of all bicyclists prefer facilities that are separated from general traffic.[39,40,41] If jurisdictions seek to increase and encourage bicycling, it is critical for bikeway design guidance to match the needs and preferences of "Interested but Concerned" users who prefer some separation from motorized traffic[42,43]. Evidence suggests that new guidance is moving in this direction and beginning to prioritize this group's needs, as well as recommending bicycling facilities designed for users of all ages and abilities.

Nearly all existing guidance reviewed for this summary provides at least a brief discussion of the different types of bicyclists, and many specify or default to a specific design user. The National Association of City Transportation Officials (NACTO), AASHTO, New Zealand, Transportation Association of Canada (TAC), Vancouver, FHWA *Separated Bike Lane Planning and Design Guide*, Institute of Transportation Engineers, and Massachusetts Department of Transportation (MassDOT) guidance generally make an explicit recommendation for the "the Interested but Concerned" bicyclist to be the default design user. The Montgomery County, Maryland Department of Transportation (MCDOT), Washington State Department of Transportation (WSDOT), and Washington County, Oregon guidance emphasize the importance to accommodate the "Interested but Concerned" bicyclist, but also provide guidance geared towards situations when one might be planning for more experienced and confident bicyclists. For example, both the WSDOT and MCDOT guidance provide a different bikeway selection chart for the "Interested but Concerned" and "Confident Cyclists" design users.

The CROW *Design Manual for Bicycle Traffic*, which guides bikeway design in the Netherlands, is unique as it does not specify a "design user." The manual specifies that bikeways will serve the entire public and should therefore have "infrastructure that enables, direct, comfortable journeys by bicycle in a safe and attractive (traffic) environment." Similar to the AASHTO Green Book. which assumes slower reaction times for inexperienced motorists and reduced physical abilities for drivers who may be younger or older, the CROW manual emphasizes designs to accommodate children who are small and inexperienced and older people who may have limited physical fitness. The manual focuses on the creation of an environment that is comfortable for bicycling by reducing stress created by operating with motorized traffic.

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[37] Dill, J. and N. McNeil. Revisiting the Four Types of Cyclists: Findings from a National Survey. *Transportation Research Record: Journal of the Transportation Research Board*, *No. 2587*, Washington, D.C., 2016, p. 90-99.

[38] Geller, R. Four Types of Cyclists. Portland Bureau of Transportation, Portland, Oregon 2006. http://www.portlandoregon.gov/transportation/article/264746. Accessed February 8, 2018.

[39] Sanders, R. (2014). Roadway Design Preferences Among Drivers and Bicyclists in the Bay Area. Paper presented at the 93rd Annual Meeting of the Transportation Research Board, Washington, DC.

[40] McNeil, N., Monsere, C., and Dill, J. (2015). The Influence of Bike Lane Buffer Types on Perceived Comfort and Safety of Bicyclists and Potential Bicyclists. *In Transportation Research Record 2520.* TRB, National Research Council, Washington, DC.

[41] Winters, M. and Teschke, K. (2010). Route Preferences Among Adults in the Near Market for Bicycling: Findings of the Cycling in Cities Study. *American Journal of Health Promotion*: 25 (1), pp. 40-47.

[42] Schultheiss, W., Sanders, R. L., and Toole, J. A Historical Perspective on the *AASHTO Guide for the Development of Bicycle Facilities* and the Impact of the Vehicular Cycling Movement.

[43] Dill, J. and N. McNeil. Revisiting the Four Types of Cyclists: Findings from a National Survey. *Transportation Research Record: Journal of the Transportation Research Board*, *No. 2587*, Washington, D.C., 2016, p. 90-99.

## Bikeway Selection Criteria

### Motor Vehicle Speed and Volume

Many factors influence the decision of which type of bikeway to install. However, existing bikeway guidance focuses on two criteria: motor vehicle volume and operating speed.

Almost all bikeway selection guidance reviewed includes motor vehicle speed (e.g., target speed, 85th percentile speed, or average traveled speed) and motor vehicle volume (e.g., ADT) as primary selection criteria. One exception to this is the TAC Manual, which focuses primarily on speed, but has a strong emphasis on additional roadway considerations. In general, the manual advises physical separation if a roadway has a motor vehicle volume of at least 6,000 ADT and a motor vehicle speeds of at least 30 mph. The Ottawa chart also includes vehicle congestion (see Figure 9). There is variation in this guidance, especially at lower volumes and speeds depending on the source. For example, the WSDOT facility selection guidance doesn't advise separated bike lanes until vehicle speeds are at least 35 mph or 8,000 ADT. The AASHTO and NACTO (see Figure 10) guides[44] recommend buffered bike lanes at lower volumes between 3,000 to 6,000 ADT and lower speeds of 25 to 30 mph .[45]

In addition to the two primary selection criteria, most guidance incorporates additional roadway characteristics, and in some cases, user characteristics into bikeway selection decisions. The CROW and NACTO guidance make explicit recommendations related to the number of through travel lanes, suggesting physical separation on streets which have more than two through travel lanes. Other frequently mentioned contextual guidance considerations include the presence of on-street parking, bicycle demand, design user, peak hour traffic volume, driveway/intersection density, vehicle mix, vehicle congestion, land use, roadway type, and curbside activity, such as transit stops.[46] The guidance from NACTO, CROW, TAC, New Zealand, and AASHTO recommend pedestrian volume be incorporated into bikeway selection decisions when deciding between a sidepath or a separated bike lane.

[44] Draft 2018 AASHTO Guide
[45] Draft 2018 AASHTO Guide
[46] Refers to both the roadway's function in terms of the vehicle network and/or bicycle network.

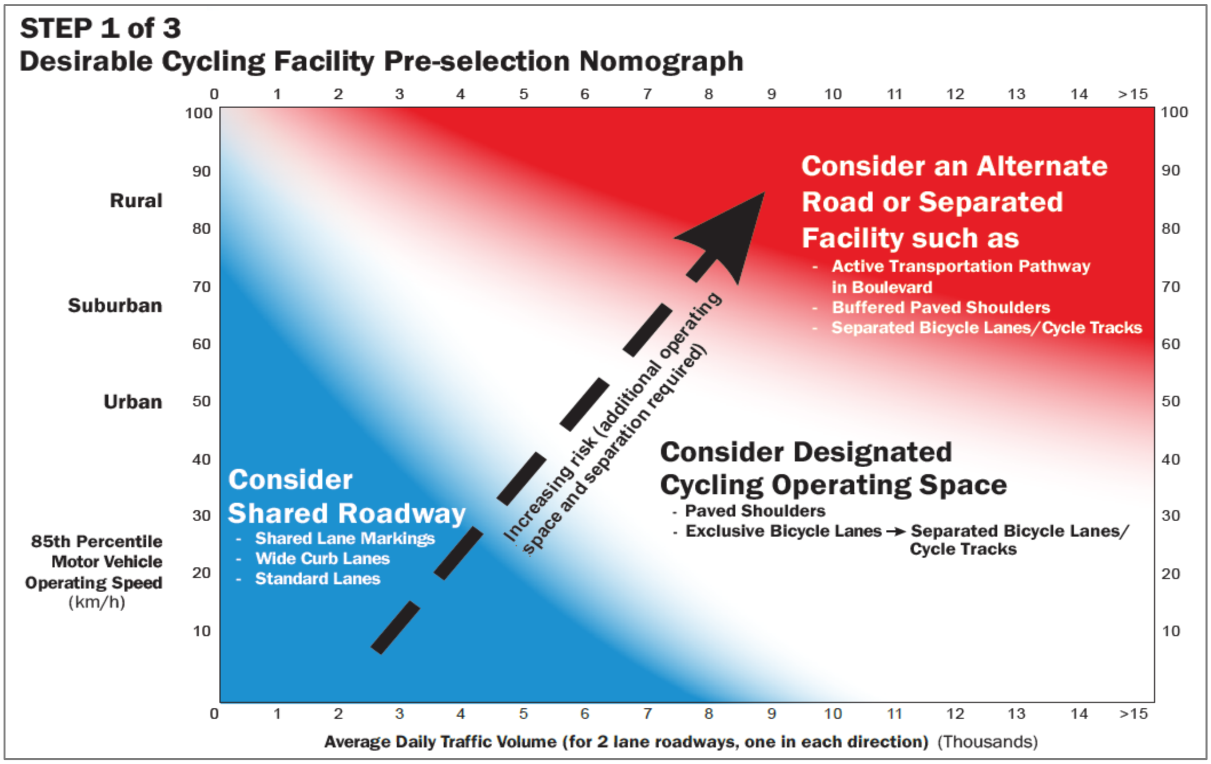


**Figure 9 - Cycling Facility Selection Graph**

Source: *Ontario Traffic Manual*. Book 18: Cycling Facilities (2013)

| Contextual Guidance for Selecting All Ages & Abilities Bikeways | | | | |
|---|---|---|---|---|
| Roadway Context | | | | All Ages & Abilities Bicycle Facility |
| Target Motor Vehicle Speed* | Target Max. Motor Vehicle Volume (ADT) | Motor Vehicle Lanes | Key Operational Considerations | |
| *Any* | | *Any* | *Any of the following:* high curbside activity, frequent buses, motor vehicle congestion, or turning conflicts‡ | **Protected Bicycle Lane** |
| < 10 mph | Less relevant | No centerline, or single lane one-way | Pedestrians share the roadway | **Shared Street** |
| ≤ 20 mph | ≤ 1,000 – 2,000 | | < 50 motor vehicles per hour in the peak direction at peak hour | **Bicycle Boulevard** |
| ≤ 25 mph | ≤ 500 – 1,500 | | | |
| | ≤ 1,500 – 3,000 | Single lane each direction, or single lane one-way | Low curbside activity, or low congestion pressure | **Conventional or Buffered Bicycle Lane, or Protected Bicycle Lane** |
| | ≤ 3,000 – 6,000 | | | **Buffered or Protected Bicycle Lane** |
| | Greater than 6,000 | | | **Protected Bicycle Lane** |
| | Any | Multiple lanes per direction | | |
| Greater than 26 mph† | ≤ 6,000 | Single lane each direction | Low curbside activity, or low congestion pressure | **Protected Bicycle Lane, or Reduce Speed** |
| | | Multiple lanes per direction | | **Protected Bicycle Lane, or Reduce to Single Lane & Reduce Speed** |
| | Greater than 6,000 | *Any* | *Any* | **Protected Bicycle Lane, or Bicycle Path** |
| High-speed limited access roadways, natural corridors, or geographic edge conditions with limited conflicts | | *Any* | High pedestrian volume | **Bike Path with Separate Walkway or Protected Bicycle Lane** |
| | | | Low pedestrian volume | **Shared-Use Path or Protected Bicycle Lane** |

**Figure 10 - NACTO contextual bikeway selection guidance**

Source: NACTO *Designing for All Ages and Abilities* (2017)

## Network Approach

Most sources of guidance take a corridor, or isolated segment approach to bikeway selection, whereas the Montgomery County, New Zealand, TAC, CROW, and AASHTO Guides emphasize a network-oriented approach. The difference between the network-oriented and corridor approaches are minor, but important. The guides that take a network approach generally consider the network role of the bikeway on the roadway segment where there the bikeway will be installed (e.g., primary route or filling a gap). This information can help practitioners anticipate the potential volume of cyclists or types of cyclists that might be using the route and incorporate that information into their selection decision. It is also used to inform tradeoff decisions when evaluating the impacts of providing an alternative or parallel route for less confident bicyclists. The MCDOT guide states, "The "Interested but Concerned" population is unlikely to be served if their trip length increases by more than 30 percent." The draft 2018 AASHTO Guide provides additional guidance for detours, advising the designer that requiring users to leave the primary route for more than 30 percent of its length will deter many bicyclists or result in bicyclists using the primary route in an unsafe manner, such as bicycling on sidewalks the wrong way.

## Land Use

Roadway environments vary significantly when planning in an urban, suburban, or rural context. Most current sources of guidance do not account for these nuances, and may therefore not be as applicable as they could be to all practitioners in the United States. For example, the NACTO guidance does not discuss guidance for situations when bicyclists ride on shoulders, which can be common in suburban and rural environments. The CROW, AASHTO, and FHWA guidance provide detailed guidance for rural and urban environments, while AASHTO and the FHWA *Small Town and Rural Multimodal Networks* guide provide the greatest amount of guidance for rural bikeway selection decisions.

## Curbside and Access Management

Many conflicts between bicyclists and motorists occur along the curbside – with short and long-term parking, loading, car-share parking, street vendors, electric vehicle charging, valet parking, taxi access, and transit access. On many projects, the provision of space for bicyclists will require the repurposing of space dedicated to motor vehicles; space that is repurposed is often a travel lane, while in other cases it could be parking. This is an important consideration where the repurposing of one or more travel lanes is not viable. Some agencies have begun to develop guidance for evaluating curbside management policies to consider actively managing curbside uses to serve more purposes than long term parking. Examples include San Francisco, Chicago, and Washington, DC. Washington, DC has recognized that restricting parking may be necessary to implement bus and protected bike lanes, as part of MoveDC, their multimodal transportation master plan.[47] The plan includes a table which identifies trade-offs for different approaches to managing the curbside space (see Figure 11).

[47] https://comp.ddot.dc.gov/Documents/District%20Department%20of%20Transportation%20Curbside%20Management%20Study.pdf

| Approach | Goal / Intent | Priority Users/Uses | Trade-offs |
|---|---|---|---|
| District Existing Program | Provide access to commercial areas to support businesses.<br><br>Protect residential neighbor-hoods from outside intrusions and pressures. | ▪ Users prioritized based on land use context<br>- Commercial patrons and loading in commercial areas<br>- Residents in residential areas<br>- Open availability near public institutions such as schools and parks | Some commercial areas lack adequate access for patrons<br>Some residential areas have more residential demand than supply<br>Spill over parking effects be-tween the two |
| Local Amenity Support | Support and enable strong amenities within walking distance of residents of all neighborhoods throughout the District. | ▪ Commercial loading and delivery<br>▪ High capacity access (transit, bikes, and shared vehicles)<br>▪ Commercial patrons<br>▪ Residents and visitors | Little preserved parking for resi-dences near commercial<br>Assumes all neighborhoods have market to support local amenities |
| Equitable Access | Provide all District residents equal access to the goods, services and opportunities of the city, without the barrier of exces-sive cost. | ▪ District residents citywide/ commercial patrons<br>▪ Regional residents/commer-cial patrons<br>▪ Commercial loading and deliveries<br>▪ Workers and visitors | Demand likely to exceed supply resulting in no curbside avail-ability<br>Circling may lead to congestion<br>Unreliable access to curb may degrade retail and quality of life |
| Resident Priority | Protect and preserve residential neighborhoods primarily for lo-cal, long term residents. | ▪ Existing residents/residences<br>▪ Visitors of existing residents/ residences<br>▪ Commercial loading and delivery<br>▪ Commercial patrons | Little support for local businesses<br>Unequal treatment of "new" versus "existing" residents and properties |
| Managed Availability | Roughly balance demand to supply across all user groups to ensure a space is available when needed. | ▪ High-capacity access (transit, bikes and shared vehicles)<br>▪ All other users | Higher parking rates and permit fees |

**Figure 11 - DC Parking management strategy options**

Source: District of Columbia Department of Transportaton. *moveDC* (2015)

## Flexibility

Most of the guides allow for different amounts of flexibility in design and decision-making processes. TAC, Montgomery County, Ontario, and AASHTO's guidance are more flexible than others, like NACTO, which is very prescriptive. The flexibility in these approaches is evident in the way the tools are designed. The charts presented in Ontario's and TAC's guidance imply a more flexible approach by highlighting the fact that there is some 'grey area', and there may not always be one ideal treatment. By comparison, matrices like NACTO's are rigid - either the situation fits the matrix or it doesn't, and if it doesn't, there may not be specific guidance to guide the practitioner to the best bikeway. The 2016 FHWA *Achieving Multimodal Networks* guide[48] emphasized the use of existing AASHTO design flexibility to solve safety problems for bicyclists in constrained corridors where tradeoffs for design criteria are necessary. The FHWA guide provides contextual

[48] https://www.fhwa.dot.gov/environment/bicycle_pedestrian/publications/multimodal_networks/

considerations and a planning and design process when designing separated bike lanes. Further, the FHWA guide provides case study examples of successful application of design flexibility to address safety issues.

More prescriptive tools make the selection decision easier for practitioners. They can be useful for identifying a preferred bikeway, however a challenge with this approach is that not all situations are accounted for in the decision tool. For example, the NACTO guide does not provide guidance for selecting a conventional bike lane versus a buffered or protected lane when traffic volume is less than 6,000 ADT. Additional guidance is necessary to account for anomalies or other considerations.

### Safety and Comfort

Bikeway safety and comfort are important considerations in bikeway planning that can sometimes be left out of bicycle route and facility planning and design efforts. Existing facility selection guides do not directly provide guidance for how to weigh safety tradeoffs between bikeway choices against other considerations. Many guides including NACTO's discuss safety, but do not explain how it relates to bikeway selection or incorporate a measure of safety or comfort directly into the bikeway selection process. The TAC manual directly states perceived safety and actual safety are related and important factors which will "motivate or deter potential and existing cyclists." The NACTO, CROW, Montgomery County, and TAC manuals each emphasize the importance of providing bikeways that appeal to the design user. Safety research (see Section 5) supports a wide range of treatments to accomplish this. What these guides do not address is how to evaluate tradeoffs between safety and comfort with bicycle ridership goals and when considering tradeoffs with other modes.

The ITE *Protected Bikeways Practitioners Guide* does not directly incorporate a measure of safety; however, it does present a general discussion of safety, and provides research on the safety and comfort of different types of bikeways. Evaluation of safety is more directly addressed in guidance on processes for non-bicycle transportation (see Section 4).

### Tool Format

Many of the facility selection tools are in the form of either a chart, matrix, or decision tree. Excluding NACTO, CROW, TAC, and Ottawa, all bikeway facility selection tools reviewed show the two primary selection criteria, motor vehicle volume and speed. CROW's matrix also includes road category, number of through lanes, and bicycle volume. NACTO's matrix includes number of vehicle lanes, pedestrian volume, curbside activity, congestion pressure, and motor vehicle volume during the peak hour. Most bikeway selection tools present all bikeways in one graphic. However, FHWA's Small Town and Rural Multimodal Networks Guide and most pedestrian facility selection treatments present a different graphic or tool for each individual treatment. While this approach may allow for more detail and nuance, it can make selecting the best facility more difficult. It may be better suited for situations when one is seeking general facility application guidance, or has a facility in mind to implement, rather than a roadway segment that needs a facility. A few sources, such as Maryland State Highway Administration, MassDOT, and Vancouver, do not provide a bikeway selection charts or discuss a specific selection process, and instead provide general guidance for situations when separated bike lanes may be appropriate.

Some existing guides, such as the two FHWA guides, and Montgomery County's guide, include case studies and design challenges to help practitioners understand how to implement the tools and guidance.

# Review of Evaluation Tools and Decision-Making Processes

## Bikeway Evaluation Tools and Processes

Roadway and user characteristics are critical components of a bikeway selection process, but decisions about which bikeway to install are rarely made without the influence of planning-related factors such as political support, budget, or maintenance. The most user-friendly selection guides include more than general design considerations and a bikeway selection tool, they also include a discussion (and often a diagram) of the bikeway selection process. The level of detail included in the documents with a discussion of the process varies considerably. To date, there isn't one comprehensive and user-friendly process description or diagram. Montgomery County's (see Figure 12), Ontario's, and Washington County's guidance describe relatively straight forward processes in three to five steps. The tradeoff with this simple approach is that it doesn't provide sufficient detail to guide the reader through the incorporation of all planning considerations in the planning process – the user must refer to other resources to find this type of guidance.

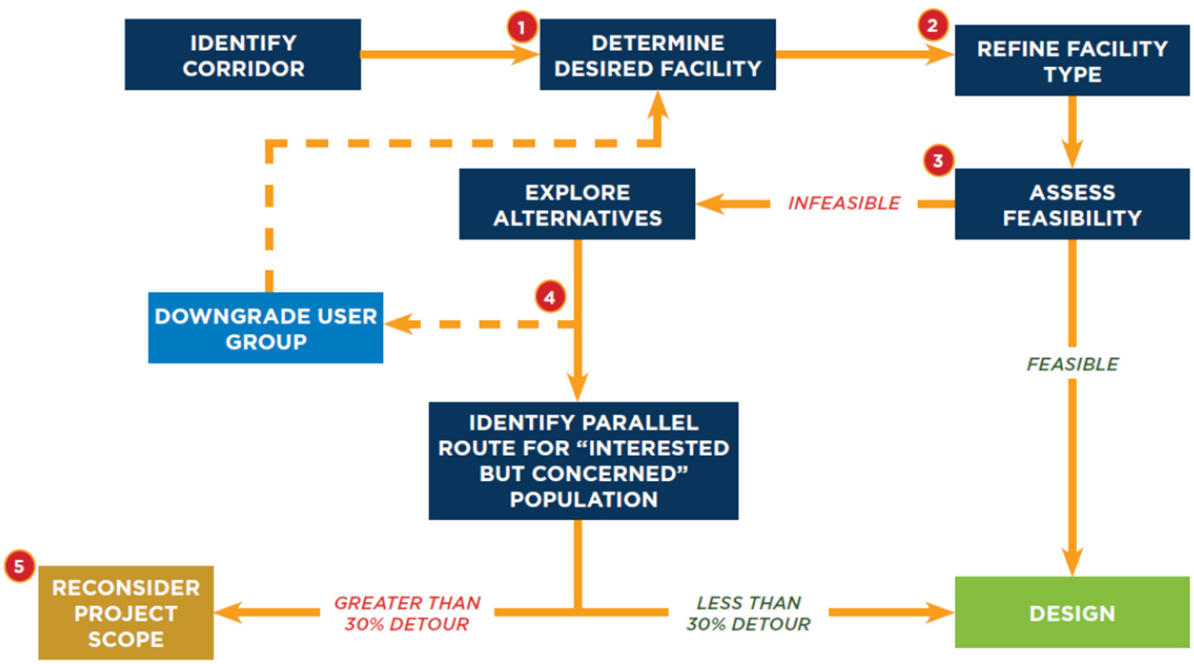


**Figure 12 - Montgomery County bikeway selection tool for interested but concerned bicyclist profile**

Source: Montgomery County. *Bicycle Planning Guidance* (2014)

General cost estimates of treatments are one of the least common planning-related considerations provided in current guidance. Washington County's tool provides a user-friendly chart that practitioners can use to compare relative maintenance and construction costs of different types of bikeways. Ontario, ITE, New Zealand, and TAC guides provide general maintenance guidance for different bikeways, however, these guides do not thoroughly discuss how a practitioner might weigh maintenance costs against other considerations like safety. Very few guides provide a way to measure and compare the tradeoffs that can impact the feasibility of choosing one type of bikeway over another. The ActiveTrans Priority Tool provides a way for practitioners to weight tradeoffs and compare the impacts these tradeoffs can have on selection decisions. New Zealand's guide includes clear sections on the advantages and disadvantages of different types of roadways for use as bicycle routes which can assist practitioners during the selection process. New

Zealand provides a flow chart to help practitioners choose between separated bike lanes and shared use paths (see Figure 14), while the AASHTO Guidance recommends use of the Shared Use Path LOS calculator.

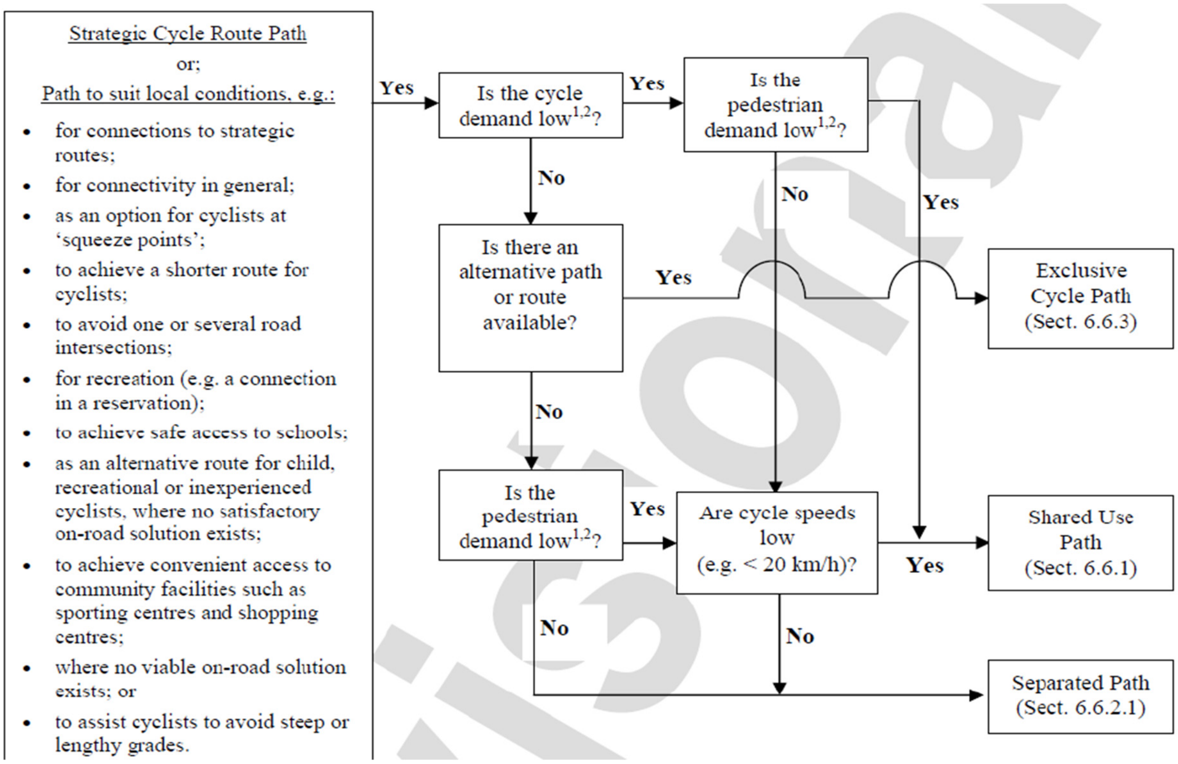


**Figure 13 - New Zealand shared use path versus separated bike lane decision tree**

Source: Land Transport Safety Authority. *Cycle Network and Route Planning Guide*. New Zealand (2004)

Guidance on how to integrate planning-related considerations or weight tradeoffs is a notable gap in existing guidance. FHWA's *Separated Bike Lane Planning and Design Guide* provides a relatively thorough discussion of the planning process, including bikeway design, funding, stakeholder outreach, and data collection for project evaluation. The guide provides a comprehensive list and description of planning and design elements to consider during the process, the list is more comprehensive than many other guides and includes funding opportunities, equity, evaluation, and local support. A few other guides, including the ActiveTrans Priority Tool and New Zealand's *Cycle Network and Route Planning Guide* also emphasize the inclusion of stakeholder input into the selection process. The ActiveTrans Priority Tool is also the only guide that includes a discussion and direct mechanism for integrating equity into bikeway selection decisions.

Only a few facility selection guides directly integrate safety into a facility selection tool or process. For example, Ottawa integrated safety (measured as crash history) into the facility selection tools. The ActiveTrans Priority Tool includes safety in its prioritization guidance and worksheet. A significant part of Montgomery County's bikeway planning guidance incorporates bicyclist comfort via a level-of-traffic stress methodology. Similarly, Washington County's and AASHTO's guidance do not directly incorporate a measure of safety but do advise that practitioners should specifically consider whether the bikeway will be located near a school or park, which can serve as a reminder to the designer to consider whether safety considerations may be of particular concern due to a high likelihood that vulnerable users, like children, are likely to use the bikeway.

## Non-Bikeway Evaluation Tools and Processes

Over the past 30 years, a variety of guides, tools and processes have been developed to help practitioners evaluate alternative roadway design outcomes, tradeoffs between competing strategies or goals, and safety outcomes. Very few of these tools provide a way to measure and compare the tradeoffs that can impact the feasibility of choosing one type of bikeway over another or the safety impact of that decision.

*NCHRP Synthesis 422: Trade-Off Considerations in Highway Geometric Design* describes the evolution of design strategies transportation agencies use to evaluate geometric design trade-offs between competing interests. The assessment of highway safety is evolving. From the 1930s through the 1990s, roadway safety has predominantly been based on a standards-based approach (conventional approach), where it was assumed that the provision of conservative design values in conformance with design standards such as the AASHTO Green Book would produce a safe transportation system. However, many of the design values were largely derived for use on the interstate system and are not applicable to urban streets where bicycle activity is likely. Existing AASHTO guidance does not specifically address or quantify safety tradeoffs for different design treatments for bicyclists in the Green Book or the Bike Guide.

With the passage of Intermodal Surface Transportation Efficiency Act of 1991, there was a shift to a flexible design approach which became known as the context-sensitive solutions/context-sensitive design (CSS/CSD) initiative. The CSS/CSD interdisciplinary project development process includes geometric design and attempts to address safety and efficiency while being sensitive to the roadway's natural environment and human environment. This process identifies design problems in functional or performance terms and then tries to solve those problems directly, especially rationalizing the need for adjustments of design criteria. The process typically involves a wide range of stakeholders which can be an effective tool for building consensus. However, the process does not provide a direct way to evaluate safety tradeoffs and is heavily driven by the goals of the active stakeholders and project participants, thus bicycle safety issues could be ignored if there is no proponent for solving them.

A variation of this approach is a practical based design which focuses on ensuring projects are addressing system wide performance measures to achieve a "maximum rate of return" on investments. This can be help address bicyclists safety issues where there is a clear plan for providing a bicycle network with specific recommendations for bicyclists performance stated in a plan. However, if the plans do not clearly articulate the performance measure to be met for bicycling, assessments of trade-offs can be biased towards motorists and transit operations which are frequently viewed as having a larger, regional purpose. Monetizing the value of project outcomes could be difficult based on bicycle related Measures of Effectiveness (MOE) in communities where bicycling networks are emerging, and overall bicycle user is or appears low compared to other transportation modes. It can likewise be difficult to justify safety improvements where the MOE is focused on crash reduction due to the dispersed nature of bicycle crashes or if the existing road conditions suppress bicycling. This is a similar challenge with Value Engineering approaches.

With many agencies joining the Towards Vision Zero initiative, there is starting to a be an exploration of systematic safety approaches to analyzing safety needs and programming improvements. Systemic Safety is a process to proactively identify safety needs based on an evaluation of an entire system to identify contributing factors to crashes. This is a useful strategy for crashes which are less frequent and dispersed across a region which is common challenge when assessing motorist crashes on rural roads as well as bicyclist and pedestrian crashes in all land use contexts. The approach is flexible and allows aggregated data to be analyzed to identify the most common types of roadway or operational features associated with crashes including combinations of features. A systemic bicycle safety analysis in Seattle identified significant factors which were likely to contribute to a crash including intersections with 5 or more legs, steep grades, opposite direction crashes, and arterial classification to allow the team to identify locations for targeted improvement.[49] The prioritization of countermeasures can be developed to address the roadway or operational features identified. The FHWA *Guide for Improving Pedestrian Safety at Uncontrolled Crossing Locations* provides an example chart of countermeasures tied to roadway configuration and traffic operating conditions that is based on a systemic safety analysis of uncontrolled pedestrian crossings (see Figure 14). A challenge with this approach is it requires a system wide assessment and doesn't scale down to a corridor level.

| Roadway Configuration | Posted Speed Limit and AADT | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Vehicle AADT <9,000 | | | Vehicle AADT 9,000–15,000 | | | Vehicle AADT >15,000 | | |
| | ≤30 mph | 35 mph | ≥40 mph | ≤30 mph | 35 mph | ≥40 mph | ≤30 mph | 35 mph | ≥40 mph |
| **2 lanes** (1 lane in each direction) | ❶ 2 3 4 5 6 | ❶ ❸ 5 6 7 | ① ❸ 5 6 ❼ | ❶ 3 4 5 6 | ❶ ❸ 5 6 7 | ① ❸ 5 6 ❼ | ❶ 3 4 5 6 7 | ① ❸ 5 6 7 | ① ❸ 5 6 ❾ |
| **3 lanes with raised median** (1 lane in each direction) | ❶ 2 3 4 5 | ❶ ❸ 5 7 | ① ❸ 5 ❼ | ① 3 4 5 7 | ① ❸ 5 ❼ | ① ❸ 5 ❼ | ① ❸ 4 5 7 | ① ❸ 5 ❼ | ① ❸ 5 ❾ |
| **3 lanes w/o raised median** (1 lane in each direction with two-way left-turn lane) | ❶ 2 3 4 5 6 7 | ❶ ❸ 5 6 7 | ① ❸ 5 6 ❾ | ① 3 4 5 6 7 | ① ❸ 5 6 ❼ | ① ❸ 5 6 ❾ | ① ❸ 4 5 6 7 | ① ❸ 5 6 ❾ | ① ❸ 5 6 ❾ |
| **4+ lanes with raised median** (2 or more lanes in each direction) | ❶ ❸ 5 7 | ❶ ❸ 5 7 | ① ❸ 5 ❾ | ① ❸ 5 7 | ① ❸ 5 ❼ | ① ❸ 5 ❾ | ① ❸ 5 ❼ | ① ❸ 5 ❾ | ① ❸ 5 ❾ |
| **4+ lanes w/o raised median** (2 or more lanes in each direction) | ❶ ❸ 5 6 7 8 | ① ❸ 5 ❻ 7 8 | ① ❸ 5 ❻ 8 ❾ | ① ❸ 5 ❻ 7 | ① ❸ 5 ❻ ❼ | ① ❸ 5 ❻ 8 ❾ | ① ❸ 5 ❻ ❼ 8 | ① ❸ 5 ❻ ❾ | ① ❸ 5 ❻ 8 ❾ |

Given the set of conditions in a cell,

- # Signifies that the countermeasure is a candidate treatment at a marked uncontrolled crossing location.
- ● Signifies that the countermeasure should always be considered, but not mandated or required, based upon engineering judgment at a marked uncontrolled crossing location.
- ○ Signifies that crosswalk visibility enhancements should occur in conjunction with other identified countermeasures.*

The absence of a number signifies that the countermeasure is generally not an appropriate treatment, but exceptions may be considered following engineering judgment.

1 High-visibility crosswalk markings, parking restriction on crosswalk approach, adequate nighttime lighting levels
2 Raised crosswalk
3 Advance Yield Here To (Stop Here For) Pedestrians sign and yield (stop) line
4 In-Street Pedestrian Crossing sign
5 Curb extension
6 Pedestrian refuge island
7 Pedestrian Hybrid Beacon (PHB) or Rectangular Rapid-Flashing Beacon (RRFB)
8 Road Diet
9 PHB/High-Intensity Activated crossWalK beacon (HAWK)

*Refer to the Guide for Improving Pedestrian Safety at Uncontrolled Crossing Locations (FHWA-SA-17-072), Chapter 4, for more information about using multiple countermeasures.*

**Figure 14 - Pedestrian crossing countermeasures tied to roadway configuration and traffic operating conditions**

Source: FHWA *Guide for Improving Pedestrian Safety at Uncontrolled Crossing Locations* (2018)

[49] Sanders, R. Pursuing Vision Zero in Seattle – Results of a Systemic Safety Analysis. 2016

# Bicyclist Safety Overview

Even though most studies of bicycle facility safety have been unable to account for the impact of exposure on crash risk, as described in the prior section, studies have still generally found that bicycle facilities improve safety in communities. Research has also been clear that people generally feel safer and are more likely to bicycle if bicycle facilities are present. This section further explores these connections.

## Bicyclist Exposure and Crash Data Limitations

Historically, bicyclists have not been counted systematically by transportation agencies, or when they are, the counts are not stored in a central database. Additionally, agencies have not systematically tracked the bikeway installation data including the date of installation, type of bicycle facility, width of the facility. This lack of data on exposure and bicycle facility type impedes bicycle safety analysis and the creation of bicycle specific crash modification factors (CMFs) which is increasingly becoming a standard strategy for evaluating motorists' safety countermeasures following guidance in the Highway Safety Manual.

Without exposure data, one might conclude that facilities with high use are unsafe because they have many crashes, but if exposure is included, one might find that the facilities are safer than expected given the volume of bicycle trips. Without knowing when facilities were installed, one cannot evaluate changes in safety before and after the facility was installed. Fortunately, some municipalities do collect bicyclist exposure and facility type data, but this collection is not standardized and often is piecemeal, hampering efficient bicycle facility safety analysis. Note that the lack of CMFs does not indicate that these pieces of infrastructure do not reduce risk, but rather shows the need for additional investment in exposure data collection to better determine impacts on risk.

Another data limitation, is most information on bicyclist injury crashes comes from crashes with motor vehicles occurring in the public right-of-way, because reporting these crashes—at least when injury or a certain amount of property damage occurs—is mandatory in most states. Bicyclist-motor vehicle crashes that occur in non-roadway locations (paths, parking lots, and driveways), as well as injury crashes that do not involve a moving motor vehicle, are usually not included in state department of transportation (DOT) crash databases, although these data may be collected at the local level through police departments, emergency medical services (EMS), or emergency room (ER) data. While bicycle/motor vehicle crashes are often serious enough to be reported (although research suggests that they are underreported[50]), studies have found that these crashes are only a fraction of total bicycle crashes. Research suggests that somewhere between just under half and about two-thirds of treated bicyclist injuries are bicyclist-only, with specific findings depending on the location.[51,52]

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[50] Heesch, K. C., Garrard, J., et al. (2011). Incidence, severity and correlates of bicycling injuries in a sample of cyclists in Queensland, Australia. *Accident Analysis and Prevention*. Vol. 43, 2018-2092.
[51] Lopez, D. S., Sunjaya, D. B., Chan, S., Dobbins, S., & Dicker, R. A. (2012). Using Trauma Center Data to Identify Missed Bicycle Injuries and Their Associated Costs. *Journal of Trauma and Acute Care Surgery,* Vol. 73, No. 6, 1602-1906.
[52] Schepers, P. et al. (2014). An International Review of the Frequency of Single-Bicycle Crashes and Their Relation to Bicycle Modal Share. *Injury Prevention*: 21(1), pp. 138-143.

Other problems with bicycle crash data include:

- Under reporting due to bicycle damage being less than the property damage reporting threshold for non-injury crashes. A bicycle's total cost may be less than the $1000 reporting threshold used by some states.[53]
- Motor-vehicle-specific collision forms makes it hard for officers to report bicycle-specific crash types such as "dooring."
- A bicyclist's location relative to the roadway is a key variable missing from many collision report forms.[54]
- Bicycle "crash type" (i.e., the sequence of events and precipitating actions leading to crashes) is not included in most crash databases, which simply record bicycle-involved crashes as "bicycle" crashes without any specifics (e.g., pre-crash maneuvers, the bicyclist's direction of travel, etc.).

## Crash Types

Numerous cities and regional government entities have conducted investigations of prevalent bicycle crash types. In many cases, crashes involving bicycle riders coincide with exposure factors. For instance, males tend to ride more than females, and crashes are three to six times more likely to involve male riders than female riders.[55,56,57,58] Similar findings show that in the months when bicycling is more common (spring/summer/autumn), crash rates are also higher. Crash rates are also higher during the workweek and during the evening peak period.[59,60,61] Between 25 and 36 percent of crashes involving bicyclists are hit-and-run, in which the driver leaves the scene before law enforcement or emergency response arrive.[62,63]

Research from across the U.S. has determined that the following situations are the most commonly associated with bicyclist crashes on roadways:[64,65]

- Cyclists riding against traffic on roadways
- Failure to yield by the motorist (more common) or by the cyclist (less common)
- Running stop signs or traffic signals by the motorist or by the cyclist, and
- Right- and left-hook crashes.

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[53] Gibson, G., Nordback, K., Kothuri, S., Ferenchak, N. & Marshall, W. (2017). *Motorist-Cyclist Crash Data Needs in U.S. Communities*. 96th Annual Meeting of the Transportation Research Board, Washington, DC.
[54] Berkow, M., van Hengel, D. & Blanc, B. (2017). Improvement to Statewide Collision Reporting to Understand Sidewalk-related Bicycle Collisions. 96th Annual Meeting of the Transportation Research Board, Washington, DC.
[55] Arizona Department of Transportation. (2012). *ADOT Bicycle Safety Action Plan*.
[56] City of Boston. (2013). *Boston Cyclist Safety Report*.
[57] City of Chicago. (2012). *City of Chicago 2012 Bicycle Crash Analysis*.
[58] URS. (2012). *Pinellas County Bicycle and Pedestrian Master Plan Update: Crash Data Report Technical Memorandum.*
[59] City of Boulder. (2012). *Safe Streets Boulder: A Study of Motor Vehicle Collisions Involving Bicyclists and Pedestrians*.
[60] See note 64.
[61] Bike Louisville, Public Works Department, and Louisville Metro. (2014). *Understanding Bicyclist-Motorist Crashes in Louisville, Kentucky.*
[62] See note 64.
[63] McLeod, K., and Murphy, L. (2014). *Every Bicycle Counts*. League of American Bicyclists.
[64] Portland Office of Transportation. (2007). *Improving Bicycle Safety in Portland*.
[65] Thomas, L., Levitt, D., and Farley, E. (2014). *North Carolina Bicycle Crash Types: 2008-2012.* North Carolina Department of Transportation Division of Bicycle Transportation.

In urban settings, crashes are far more likely to occur at intersections, but fatalities are more common in rural non-intersection locations. In cyclist fatalities, motorist inattention accounts for between 26 and 42 percent of cases.[66]

While bicyclists have consistently accounted for 2 percent of all roadway fatalities, the absolute number of bicyclists killed steadily declined between 1975 and 2010 (see Figure 15). According to OECD (Organization for Economic Cooperation and Development) data, the United States' per capita pedestrian and bicyclist fatality rate fell by 35 percent and 30 percent, respectively, between 1990-1994 and 2010-2014. Further, research indicated that children and seniors were more vulnerable to pedestrian and bicyclist fatalities and serious injuries than other age groups.[67] Despite the recent decline in pedestrian and bicyclist fatalities, these numbers have recently begun climbing again, and 2015 saw the highest number of bicyclist fatalities since 1995. The 818 fatalities reported in 2015 represent a 12.2 percent increase over the previous year, the largest percentage increase of all roadway user groups that year. For the 10-year period between 2006 and 2015, the estimated average number of bicyclists injured per year was 48,200. There is evidence that bicycle use in the United States may have also increased during this time (based on an increase from 0.4 to 0.6 percent bicycle commute mode share from American Community Survey journey-to-work data), but bicyclist fatalities as a percentage of total crashes indicate that bicycle crashes may be overrepresented.[68] Further, bicyclist fatalities increased by 1.3% from 2015 to 2016 (to 840 fatalities), while pedestrian fatalities increased by 8.9% (to 5,987 fatalities).

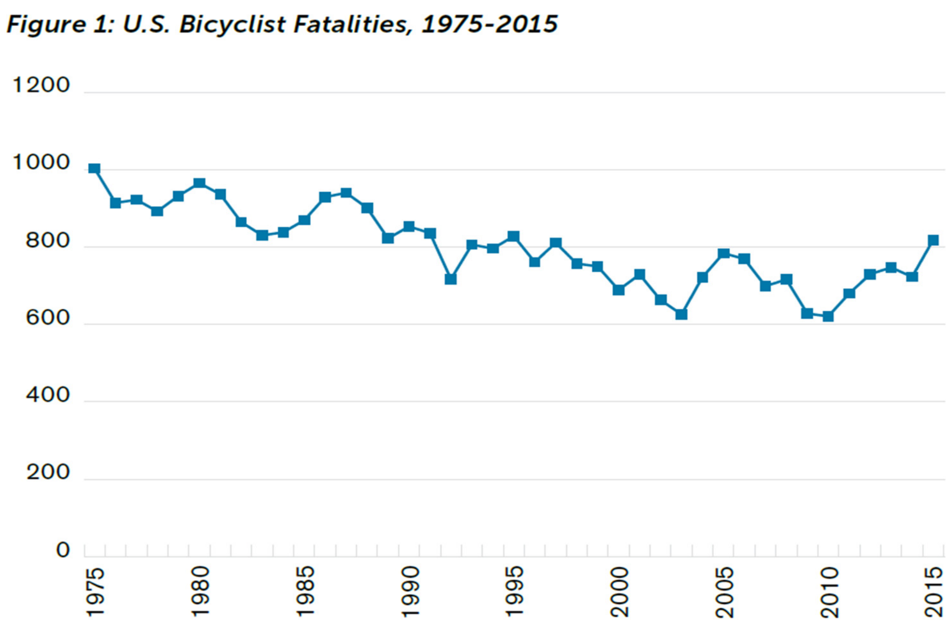


**Figure 15 - Bicycle fatalities over time generally trended down from the peak of the early 1970s, but have steadily increased since 2010.**

Source: Governors Highway Safety Association (2017)

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[66] See notes 68 and 70.

[67] Buehler, R., and Pucher, J. (2017). Trends in Walking and Cycling Safety: Recent Evidence From High-Income Countries, With a Focus on the United States and Germany. *American Journal of Public Health*: 107(2). https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5227927/

[68] https://www.ghsa.org/resources/bicyclist-safety2017

Using FARS to examine crashes nationally, the National Highway Traffic Safety Administration reports that the majority of bicyclist fatalities occur in urban areas (70 percent in 2015), which corresponds with where more bicyclists are riding. FARS data also indicate that most fatalities occur at non-intersection locations (61 percent in 2015). However, state-level analyses illustrate how the distribution of fatalities differs by area type. For example, in North Carolina, 72 percent of fatalities in rural areas occur at non-intersection locations, as compared to only 51 percent of fatalities in urban areas, which include suburban areas. For cities, the proportion of intersection bicycle crashes to total can be even higher. Higher motor vehicle speeds partially explain why fatalities vary greatly by area type.

While multiple city- and state-level bicycle crash studies show that common crash types include left and right hook crashes (driver turns across bicyclist path), running stop signs/traffic signals by the motorist or by the bicyclist, and bicyclists riding against traffic on roadways, national bicyclist fatality data from FARS coded in PBCAT for 2014 and 2015 reveal that the top crash type killing bicyclists in both urban areas is, by far, motorists overtaking bicyclists (see Figure 16). [69,70,71,72,73] Motorists overtaking bicyclists represents over a quarter (28 percent) of all fatalities in the United States. for 2014 and 2015.[74] This crash type occurs when a motor vehicle hits a bicyclist from behind when both are traveling in the same direction. It is caused by the motorist not seeing the bicyclist or misjudging the space needed to pass, by unexpected bicyclist swerving, or by some other reason. These crashes commonly occur on two-lane, two-way undivided roads in both rural and urban areas, indicating the need for separated bicycle facilities.

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[69] Arizona Department of Transportation. (2012), ibid.

[70] Thomas, L., Levitt, D., & Farley, E. (2014), ibid.

[71] McLeod, K. & Murphy, L. (2014). *Every bicyclist counts*. League of American Bicyclists. Available: http://bikeleague.org/sites/default/files/EBC_report_final.pdf

[72] Bike Louisville, Louisville Public Works Department, & Metro Louisville. (2014). *Understanding bicyclist-motorist crashes in Louisville, Kentucky*.

[73] Chicago Department of Transportation. (2012). *City of Chicago 2012 bicycle crash analysis: 2005-2010 crash data summary report and recommendations*. Available: https://www.cityofchicago.org/content/dam/city/depts/cdot/bike/general/BikeCrashReport2012.pdf

[74] National Highway Traffic Safety Administration, Fatality Analysis Reporting System, 2014 and 2015 data. Accessed 2017.

| Top 12 Urban Bicyclist Fatality Types (2014-2015) | | | |
|---|---|---|---|
| Crash Type | U.S. Urban Bicyclist Fatalities 2014 and 2015 | Percentage of Total Urban Bicyclist Fatalities | Percentage at Intersections |
| Motorist Overtaking Bicyclist | 240 | 23% | 10% |
| Bicyclist Failed to Yield - Signalized Intersection | 92 | 9% | 100% |
| Parallel Paths - Other Circumstances | 88 | 9% | 26% |
| Crossing Paths - Other Circumstances | 86 | 8% | 86% |
| Bicyclist Left Turn / Merge | 81 | 8% | 23% |
| Bicyclist Failed to Yield - Midblock | 79 | 8% | 0% |
| Bicyclist Failed to Yield - Sign-Controlled Intersection | 63 | 6% | 100% |
| Other / Unknown - Insufficient Details | 54 | 5% | 35% |
| Wrong-Way / Wrong-Side | 49 | 5% | 14% |
| Loss of Control / Turning Error | 47 | 5% | 47% |
| Motorist Left Turn / Merge | 39 | 4% | 87% |
| Motorist Right Turn / Merge | 36 | 3% | 89% |
| **Total of all urban bicyclist fatalities** | 1035 | **100%** | 44% |

**Figure 16 - FARS bike fatality data summary, per PBCAT coding, for urban areas**

Source: NHTSA FARS 2014-2015 Data (Retrieved in 2017)

## Influence of Cyclists' Near Miss and Crash Experiences

Several studies in the last few years have sought to understand how cyclists' experiences, as well as those of their friends and family, influence their perceptions of cycling safety. Through in-depth interviews with residents of Davis, CA, researchers found that crash and near-crash experiences did influence perceptions of safety and comfort while bicycling.[75] Incidents involving cars were much scarier than crashes resulting from the cyclist's own mistake or a fall, and incidents involving friends and family were quite influential—particularly for interviewees who did not regularly bicycle. These findings were corroborated by a survey of potential and current bicyclists in the San Francisco Bay Area about their near miss and crash experiences.[76] This study found that concerns about bicycling were significantly related to experiences, particularly for near misses. Further, near misses were much more prevalent than crashes, and that there was no detectable pattern from crashes to near misses, suggesting that crash statistics give an incomplete picture of the danger cyclists face while riding.

Additionally, a survey of UK cyclists found similar results, calculating a mean incident rate of 0.293 incidents (defined as causing annoyance or fear) per mile and 2.41 incidents per hour.[77] Incidents spiked in the a.m. and p.m. peak periods, along with all traffic. These high rates of annoying/scary incidents provide some clarity as to why cycling is often perceived to be dangerous, even when crashes are relatively rare. The findings also suggest that separated facilities could be critically important to addressing the discomfort and danger cyclists face on so many roadways. A more detailed analysis of these survey results found that over half of incidents could have been prevented by infrastructure change, and the top change recommended by participants was "dedicated space for cycling" (i.e., separated bike lanes), followed by intersection redesign. These figures were higher for incidents involving heavy vehicles or transit vehicles.[78]

## Relationship between Perceived Comfort and Objective Safety

The perceived safety of bicycling, while less routinely analyzed than objective safety as reported in crash reports, is important for designers to consider due to its role as a formidable barrier to bicycling. Research has found a significant relationship between how safe and comfortable people feel bicycling, whether and how often they bicycle, their preferences for facility types, and the provision of those facilities.[79,80,81,82] If planners and designers do not know how safe people feel along various routes, they will not be best equipped to plan for bicycling.

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[75] Lee, A., Underwood, S., and Handy, S. (2015). Crashes and Other Safety-Related Incidents in the Formation of Attitudes Toward Bicycling. *Transportation Research Part F: Traffic Psychology and Behavior*: 28, pp. 14-24.

[76] Sanders, R. (2015). Perceived Traffic Risk for Cyclists: The Impacts of Near Miss and Collision Experiences. *Accident Analysis and Prevention:* 75, pp. 26-34.

[77] Aldred, R., and Crosweller, S. (2015). Investigating the Rates and Impacts of Near Misses and Related Incidents Among UK Cyclists. *Journal of Transport and Health:* 2(3), pp. 379-393.

[78] Aldred, R. (2016). Cycling Near Misses: Their Frequency, Impact, and Prevention. *Transportation Research Part A: Policy and Practice*: 90, pp. 69-83.

[79] Sanders, R. L. (2016). We can all get along: The alignment of driver and bicyclist roadway design preferences in the San Francisco Bay Area. *Transportation Research Part A*, 91, 120-133.

[80] Dill, J., & McNeil, N. (2016), ibid.

[81] Handy, S.L., Y. Xing, and T.J. Buehler. (2010) Factors Associated with Bicycle Ownership and Use: A Study of Six Small U.S. Cities. *Transportation* 37(6): 967-985.

[82] Winters, M., Davidson, G., et al., 2010. Motivators and deterrents of bicycling: comparing influences on decisions to ride. Transportation 1–16.

Additionally, data on perceived safety can provide important insights into street conditions and actual dangers that may not be reflected in crash data. For example, a safety study in the City of Cambridge found a high degree of correlation between reported crashes and reported perceptions of safety for much of the City, and also revealed areas of the City where people felt unsafe despite a lack of reported crashes.[83] In many cases, a lack of crashes does not indicate that there are no incidents, as studies have shown that near misses happen to a much greater degree than crashes.[84,85] Also, various studies have found that bicycle and pedestrian crashes, even those involving cars, tend to be underreported.[86,87] It is also possible that some streets are deemed so unpleasant or unsafe that few but the bravest or those without choice will bicycle there. A resulting lack of incidents therefore does not necessarily indicate that the street is safe, but rather that there are fewer opportunities for incidents to occur and thus crashes appear to move around an area somewhat randomly and crashes are not sufficient at one location to draw statistically valid conclusions. However, when bicycle safety is reviewed through a systemic safety lens, key traffic and roadway features (such as number of lanes, volume of traffic etc.) can be identified to allow an evaluation of bicyclist risk across a system. This risk will often align with perceived perceptions of danger expressed by the public.

## Bicyclists Safety In Numbers

Over the last few decades, several studies have documented the phenomenon of "safety in numbers," wherein bicyclist risk decreases as the number of bicyclists increases, and particularly when bicycling numbers are very high.[88,89,90] Greater safety attracts more bicyclists and higher numbers of bicyclists result in safer cycling conditions overall, further increasing safety. To achieve "safety in numbers" it is necessary to provide safe, comfortable bicycle networks that not only make current bicycling safer, but also attract additional bicyclists. Multiple studies have established a positive correlation between the provision of bicycle facilities—particularly low-stress bicycle facilities that separate bicyclists from motor vehicle traffic, such as separated bike lanes and bicycle boulevards—and increasing numbers of bicyclists.[91,92] A recent study of a network of separated bike lanes found that the provision of the network improved safety at the municipal level, leading to and then benefiting from increased numbers of bicyclists, further strengthening the concept of safety in numbers.[93]

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[83] City of Cambridge. 2015. Toward a Bikeable Future 2015.
[84] Sanders, R. L. (2015). Perceived traffic risk for cyclists: The impact of near miss and collision experiences. *Accident Analysis and Prevention*, 75, 26-34.
[85] Joshi, M.S., Senior, V., et al., 2001. A diary study of the risk perceptions of road users. Health Risk Soc. 3 (3), 261–279.
[86] Lopez, D. S., Sunjaya, D. B., Chan, S., Dobbins, S., & Dicker, R. A. (2012), ibid.
[87] Stutts, J. C., & Hunter, W. W. (1997), ibid.
[88] Jacobsen, P. L. (2003). Safety in numbers: more walkers and bicyclists, safer walking and bicycling. *Injury Prevention*, 9(3):205–209.
[89] Elvik, R. (2009). The non-linearity of risk and the promotion of environmentally sustainable transport. *Accident Analysis and Prevention*, 41(4):849–855.
[90] Marques, R. and Hernandez-Herrador, V. (2017) On the effect of networks of cycle-tracks on the risk of cycling. The case of Seville. *Accident Analysis and Prevention* 102: 181-190.
[91] Monsere, C., Dill, J., McNeil, N., Clifton, K., Foster, N., Goddard, T., Berkow, M., Gilpin, J., Voros, K., van Hengel, D., & Parks, J. (2014). Lessons from the Green Lanes: Evaluating Protected Bike Lanes in the U.S. National Institute for Transportation and Communities, Portland, OR.
[92] Dill, J. and Carr, T. (2003). Bicycle Commuting and Facilities in Major U.S. Cities – If you Build Them, Commuters Will Use Them. *Transportation Research Record*, 1828, 116-123.
[93] Marques, R. and Hernandez-Herrador, V. (2017), ibid.

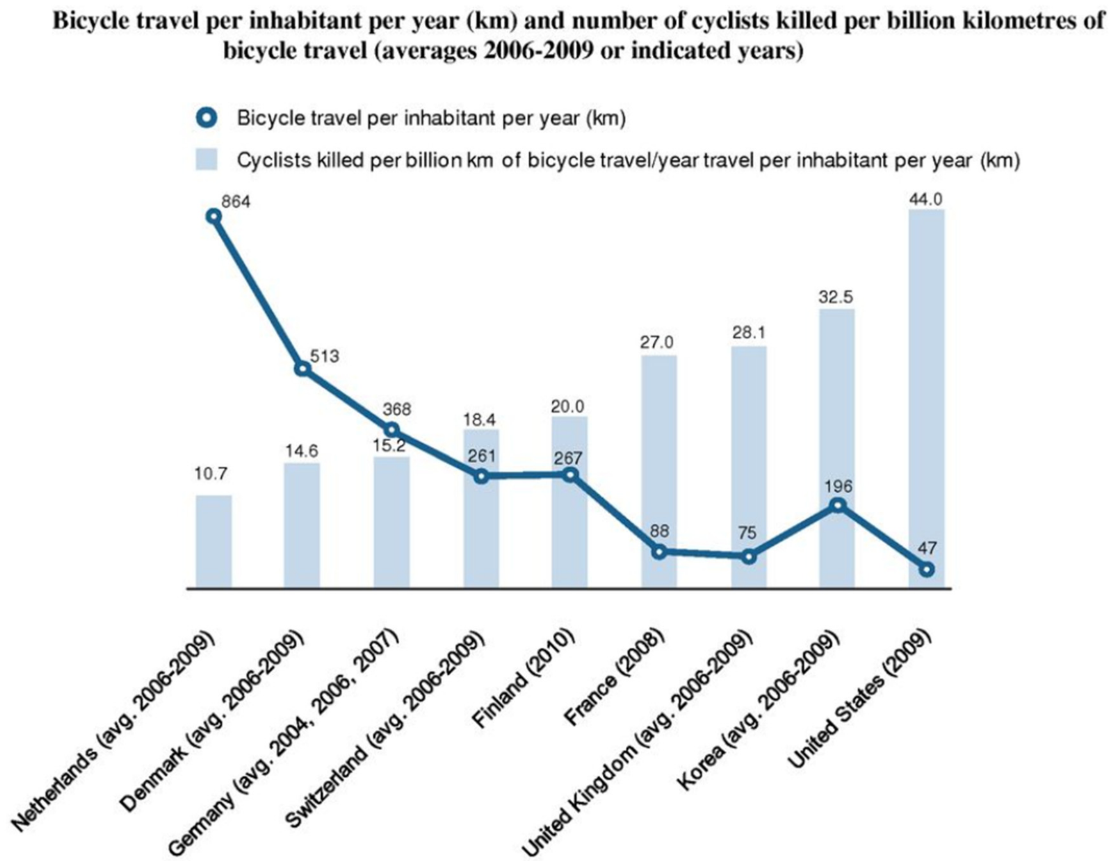


**Figure 17 - Comparison of bicycle safety between developed countries illustrates safety in numbers impact**

Source: Cycling, Health and Safety Report by International Transport Forum's Cycling Safety Working Group (2013)

## Bicyclist Safety Overview for Common Bikeway Treatments

Below is a brief summary of research related to the safety of design treatments that would likely be recommended as strategies to improve bicycle safety in a potential *Resource Guide for Separating Bikes from Traffic*. In general, the overall body of research demonstrates the provision of bikeways which separate bicyclists from traffic, or roadway designs which minimize vehicle operating speed and volume, improve safety outcomes for bicyclists compared to operating in shared lanes (as a "before" condition").[94]

With evidence growing stronger of a "safety in numbers" effect, the development of connected networks of comfortable bikeways attractive to the widest range of bicyclists (e.g. the "Interested but Concerned" bicyclist profile) would have the greatest potential to increase bicycle use, and thereby increase individual bicyclist safety. The efficacy of each treatment below requires consideration of many contextual factors such as traffic volume, traffic speed, intersection design, and land use, among other factors. For example, bicycle

[94] Mead, J., McGrane, A., Zegeer, C., Thomas, L. (2014) Evaluation of Bicycle-Related Roadway Measures: A Summary of Available Research. Federal Highway Administration.

safety research consistently finds bicyclists traveling contra-flow to motor vehicle traffic are at an elevated risk of a crash due to reduced awareness of motorists across all types of facilities.[95,96,97,98]

Research in Vancouver and Toronto illustrate the overall trend showing the provision of bikeways improves safety outcomes for bicyclists over shared lanes (see Figure 18).[99]

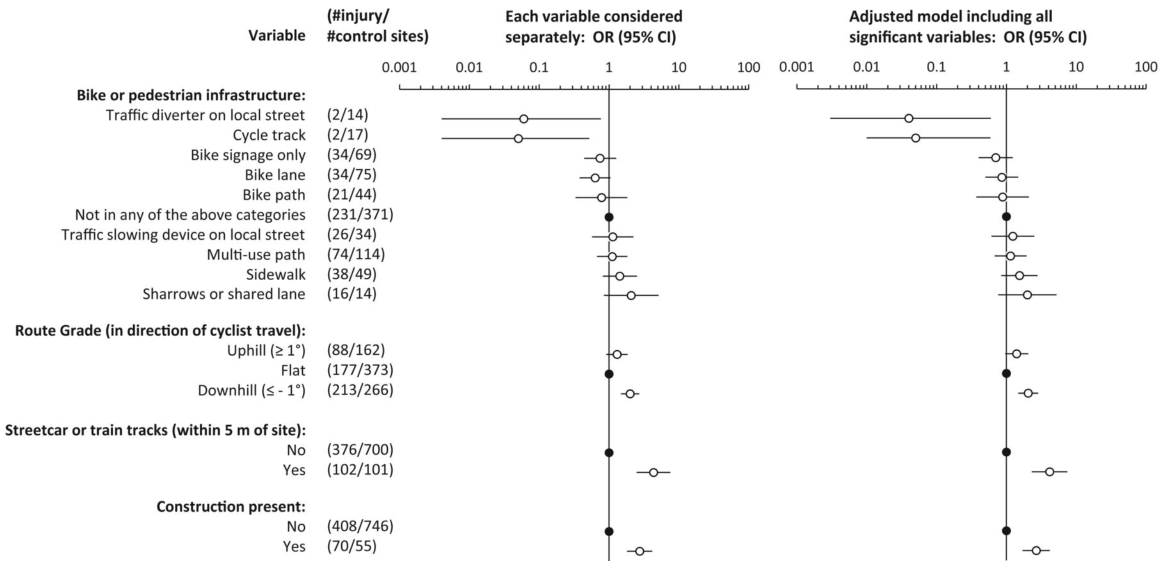


**Figure 18 - Relative crash risk between different bikeway treatments in Vancouver and Toronto compared to baseline of shared lanes without pavement markings (1.0 risk)**

Source: American Journal of Public Health (2012)

## Shared Lanes

The vast majority of crashes in the US occur in shared lanes. Analysis of crash data in the 1990s found over 75 percent of bicyclists crashes occurred in shared lanes. The same study found motorist over-taking crashes were 24.2 percent of all parallel movement crashes.[100] While operating conditions vary widely and have a direct impact on safety, more recent research in Vancouver and Toronto showed the presence of parking can have a significant impact on bicyclists safety operating in shared lanes.[101] Arterial streets without parking had

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[95] Wachtel, A., and Lewiston, D. (1994). Risk Factors for Bicycle-Motor Vehicle Collisions at Intersections. *ITE Journal*, pp. 30-35.
[96] Kim, K. and Li, L. (1996). Modeling Fault Among Bicyclists and Drivers Involved in Collisions in Hawaii, 1986-1991. *Transportation Research Record 1538*, pp. 75-80.
[97] Wessels, R. (1996). Bicycle Collisions in Washington State: A Six-Year Perspective, 1988-1993. *Transportation Research Record 1538*, pp. 81-90.
[98] Petrisch, T., Landis, B., Huang, H., and Challa, S. (2014). Sidepath Safety Model: Bicycle Sidepath Design Factors Affecting Crash Rates. *Transportation Research Record 1982*, pp. 194-201.
[99] Teschke et al. Route Infrastructure and the Risk of Injuries to Bicyclists: A Case-Crossover Study. American Journal of Public Health, Vol. 102, No. 12, 2012, pp. 2336-2343.
[100] Hunter, W. et al. Pedestrian and Bicycle Crash Types of the Early 1990s. FHWA-DD-95-163. McClean: 1994.
[101] Teschke et al. Route Infrastructure and the Risk of Injuries to Bicyclists: A Case-Crossover Study. American Journal of Public Health, Vol. 102, No. 12, 2012, pp. 2336-2343.

lower crash risk compared to arterial streets with parking (see Figure 19). Research of shared lanes as a baseline condition prior to the application of shared lane markings or bike lanes show bicyclists operate closer to parked vehicles increasing their risk of being struck by opening doors.

Another type of shared lane, is the wide outside lane, or wide curb lane. As stated in the history portion of this literature review, this was a preferred treatment by the vehicular cycling proponents. Research on wide outside lanes has generally found safety performance for bicyclists to be diminished as bicyclists tended to ride closer to the edge of the pavement, curb, or parking. Research generally found motorist passed bicyclists with greater distance on roadways where bicyclists were not operating in shoulders or bike lanes. However, the same research also found motorist passing distance of bicyclists is impacted by traffic volume in the adjacent or opposing lane.[102] Where traffic volume was higher, passing distance to bicyclists was closer. Wide outside lanes are also associated with higher rates of wrong-way bicycling than streets with bikeways or shared lane markings.

Another type of shared lane is the bus/bike lane is a marked transit-only lane where bicyclists are permitted. This treatment has been implemented in multiple jurisdictions where there is constrained curbside space, although there is limited research on the safety effectiveness of shared bus/bike lanes.

| Variable | Number of Injury Sites | Number of Control Sites | Unadjusted OR (95% C.I.) | Adjusted OR (95% C.I.) |
|---|---|---|---|---|
| Major street route with parked cars and no bike infrastructure | 155 | 114 | 1.00 (Reference category) | 1.00 (Reference category) |
| Major street route, no parked cars and no bike infrastructure | 112 | 118 | **0.65* (0.44, 0.97)** | **0.63* (0.41, 0.96)** |
| Major street route, no parked cars and shared lane | 13 | 12 | 0.66 (0.24, 1.82) | 0.60 (0.21, 1.72) |
| Major street route, no parked cars and bike lanes | 35 | 46 | **0.47* (0.26, 0.83)** | 0.54 (0.29, 1.01) |

* Indicates a p-value of <.05.

**Figure 19 - Comparison of route types and crash risk**

Source: American Journal of Public Health (2012)

Shared lane markings (SLM) have been implemented in cities all over North America. While a solid body of research about SLM is still lacking, recent studies have shown that when used appropriately, these markings can be moderately successful in highlighting proper cyclist positioning in a travel lane, and can decrease the prevalence of sidewalk riding.[103, 104] However, research on roadway design preferences suggests that the majority of bicyclists (current or potential) and drivers do not feel comfortable on multi-lane or higher-speed

[102] Mead, J., McGrane, A., Zegeer, C., Thomas, L. (2014) Evaluation of Bicycle-Related Roadway Measures: A Summary of Available Research. Federal Highway Administration.
[103] Brady, J., Loskorn, J., & Mills, A. (2011). Effects of shared lane markings on bicyclist and motorist behavior. Institute of Transportation Engineers. ITE Journal, 81(8), p.33.
[104] Hunter, W. W., Srinivasan, R., Martell, C., & University of North Carolina (System). Highway Safety Research Center. (2012). Evaluation of Shared Lane Markings in Miami Beach, Florida. University of North Carolina, Highway Safety Research Center.

roadways with SLM, suggesting that SLM should be used with caution in those situations.[105] Recent research indicates that traffic impacts may not significantly differ on streets with "sharrows" than streets with no bicycle markings.[106] When SLM are used, the accompanying signage, "Bicycles May Use Full Lane" (MUTCD R4-11) was found to be the most consistently comprehended signage, compared to "Share the Road" (MUTCD W16-1P) in communicating to all road users that cyclists may occupy a travel lane (shared lane markings were comprehended more frequently than "Share the Road" but less than "Bicycles May Use Full Lane").[107]

### Bicycle Boulevards

Bicycle boulevards are low-stress bicycle facilities primarily located on low-volume, low-speed local streets where treatments such as shared lane markings, wayfinding signage, and traffic calming features are implemented to prioritize bicycle travel, including at crossings with higher volume arterials. Research thus far shows that bicycle boulevards have a lower incidence of bicycle-involved crashes than parallel arterial routes.[108] Additionally, current and potential bicyclists have been found to prefer bicycle boulevards over riding on arterial roadways without protected bike lanes.[109] Residents on bicycle boulevards tend to view the corridors positively and claim the bike boulevard makes them more likely to ride a bicycle, although the benefit to pedestrians and other road users is not uniformly perceived.[110] A key feature of successful bicycle boulevards is to provide safe crossings of arterial roadways. One possibility to evaluate the safety of bicycle boulevard crossings is to follow the procedures outlines in the FHWA *Guide for Improving Pedestrian Safety at Uncontrolled Crossing Locations*.[111]

### Advisory Bicycle Lanes

Advisory bicycle lanes are continuously dashed bicycle lanes that allow motorists to temporarily enter the bicycle lane to provide oncoming traffic sufficient space to safely pass on narrow, low-volume streets without center lines. As of February 2018, there are 20 known treatments installed in North America.[112] Two studies have been performed on related treatments: one in Edina, Minnesota, and one in Boulder, Colorado. This treatment has been relatively common in Europe for a few decades having been installed extensively in the Netherlands and France with additional installations in England, Scotland, Ireland, Germany, Denmark, Sweden and Norway. Research conducted to date in Europe has found motorists and bicyclists are generally understanding and operating as required on the treatment. Crash reductions or safety improvements have not been documented. Dutch research has found this treatment has been effective at reducing motor vehicle

[105] Sanders, R. (2014). Roadway Design Preferences Among Drivers and Bicyclists in the Bay Area. Paper presented at the 93rd Annual Meeting of the Transportation Research Board, Washington, DC.
[106] Lindsey, G., Hourdos, J., Lehrke, D., Duhn, M., Ermagun, A., & Singer-Berk, L. (2017). *Traffic impacts of bicycle facilities*(No. MN/RC 2017-23). Minnesota. Dept. of Transportation. Research Services & Library.
[107] Hess G, Peterson MN (2015) "Bicycles May Use Full Lane" Signage Communicates U.S. Roadway Rules and Increases Perception of Safety. PLoS ONE 10(8): e0136973. doi:10.1371/journal. pone.0136973.
[108] Minikel, E. (2012). Cyclist Safety on Bicycle Boulevards and Parallel Arterial Routes in Berkeley, California. *Accident Analysis & Prevention*: 45, pp. 241-247.
[109] Winters, M., & Teschke, K. (2010). Route Preferences Among Adults in the Near Market for Bicycling: Findings of the Cycling in Cities Study. *American Journal of Health Promotion*: *25*(1), pp. 40-47.
[110] VanZerr, M. (2010). Resident Perceptions of Bicycle Boulevards: A Portland, Oregon Case Study. Transportation Research Board 89th Annual Meeting, January 2010.
[111] Blackburn, L., Zegeer, C., and Brookshire, K. (2017). *Guide for Improving Pedestrian Safety at Uncontrolled Crossing Locations* (No. FHWA-SA-17-072).
[112] https://www.advisorybikelanes.com/uploads/1/0/5/7/105743465/list_of_abls.docx

operating speeds which has contribute to 25 percent reductions in midblock causality crashes, and 44 percent reductions in intersection causality crashes for all modes.[113]

## Shoulders

Research on the safety of shoulders has primarily been focused on motorist safety. In general, the provision of shoulders has improved safety performance for motorists, while the removal or narrowing of shoulders has decreased safety performance of roadway segments. Research found that paved shoulders and bicycle lanes act essentially the same in terms of operations.[114] A major factor in the safety of shoulders for bicyclists is the presence and design of rumble strips which can present a crash hazard or render a shoulder un-rideable for bicyclists.

[113] Jaarsma, R, R Louwerse, A Dijkstra, J de Vries and JP Spaas (2011) Making minor rural road networks safer: the effects of 60km/h-zones. Accident Analysis & Prevention 43, no.4: 1508–1515.
[114] Harkey, D., and Stewart, J. (2014). Evaluation of Shared-Use Facilities for Bicycles and Motor Vehicles. *Transportation Research Record 1578,* pp. 111-118.

## Bicycle Lanes

Several studies have found that bicycle lanes improve safety outcomes for bicyclists, reducing total crashes on corridors where installed.[115,116,117] A research review of the safety impacts of bicycle infrastructure design found mixed results on the safety performance of (marked) bicycle lanes. several studies have shown that bicycle lanes result in a greater number of collisions, however many studies do not account for factors such as exposure, maintenance or differences in implementation (i.e., implementation of bike lanes that are narrower than recommended, sudden lane drops at intersections, presence of parked cars).[118] One three-star study found that the installation of cycle tracks or bicycle lanes slightly increased the number of bicyclist crashes. Further, different intersection designs impacted the safety effects of cycle tracks, as the number of crashes were found to increase at intersections (and decreased slightly on roadway segments).[119] A second three-star study found that injury rates for streets with bike lanes or cycle tracks decreased compared to control streets, although design elements impacted the safety effects.[120]

## Separated Bicycle Lanes

Bicycle facilities that are physically separated from adjacent travel lanes have the greatest support among cyclists, and in many cases, motorists.[121,122] The type of separation varies, from a painted buffer to a physical curb, but these types of bike lanes produce the most comfortable experience for bicycle riders. The implementation of separated bike lanes has grown substantially over the last few years and numerous studies have assessed their operation. Separated bike lanes, and especially separated bike lanes with a

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[115] Highway Safety Manual: Knowledge Base.

[116] Jensen, S. U. (2008). Biseparated bike lanes and Lanes: A Before-after Study. In *87th Annual Meeting of the Transportation Research Board. Transportation Research Board, Washington, DC*.

[117] Nosal, T. and L.F. Miranda-Moreno. "Cycle-tracks, bicycle lanes & on-street cycling in Montreal: a preliminary comparison of the cyclist injury risk." Presented at the 91st Annual Meeting of the Transportation Research Board, January 22-26, Washington, DC, 2012.

[118] Stuart, R., & Adams, S. (2010). Infrastructure and cyclist safety. Final Project Report PPR580. Transport Research Laboratory. http://www.cycling-embassy.org.uk/document/infrastructure-and-cyclist-safety-trl-report-ppr-580.

[119] Jensen, S.U. "Bicycle Tracks and Lanes: a Before-After Study." TRB 87th Annual Meeting Compendium of Papers CD-ROM. Washington, D.C., (2008).

[120] Nosal, T., & Miranda-Moreno, L. F. (2012). *Cycle-Tracks, Bicycle Lanes, and On-street Cycling in Montreal, Canada: A Preliminary Comparison of the Cyclist Injury Risk* TRB Report No. 12-2987.

[121] Monsere, C., McNeil, N., & Dill, J. (2012). Multiuser Perspectives on Separated, On-street Bicycle Infrastructure. *Transportation Research Record 2314*, pp. 22-30.

[122] Sanders, R. (2014). Roadway Design Preferences Among Drivers and Bicyclists in the Bay Area. Paper presented at the 93rd Annual Meeting of the Transportation Research Board, Washington, DC.

physical curb separation, have been shown to reduce injury risk and increase bicycle ridership due to their greater perceived safety and comfort.[123,124,125,126]

Along routes with separated bike lanes, intersection design and operation need special attention. Signalization and detection are important components of bicycle friendly intersection design.[127] Bicyclists prefer to have a dedicated through lane approaching intersections rather than mixing zones with vehicles, and bike boxes and bike signals are viewed favorably.[128,129] However, recent research suggests that situational awareness among drivers is significantly lower when cyclists are approaching from behind, in contrast to riding in front of the driver, as motorists tend to focus their attention on things more likely to be perceived as hazards, such as oncoming traffic.[130] Thus, designs that promote visibility of bicyclists and raise awareness of the potential conflict are likely important.

Separated bike lanes can be designed as one-way or two-way facilities. Most studies have found that one-way separated bike lanes are safer than two-way tracks,[131,132,133] although some studies have not found any issue with two-way separated bike lane.[134] Where two-way separated bike lanes are implemented, siting these facilities to the right of automobile lanes has resulted in safer intersections for bicyclists by reducing conflicts as compared to siting facilities on the left side of automobile lanes.[135] Moreover, research suggests that the application of treatments that slow turning drivers (in particular, raised crossings), improve sight

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[123] Lusk, A. C., Morency, P., Miranda-Moreno, L. F., Willett, W. C., and Dennerlein, J. T. (2013). Bicycle Guidelines and Crash Rates on Separated bike lanes in the United States. *American Journal of Public Health*, *103*(7), 1240-1248.

[124] McNeil, N., Monsere, C. M., & Dill, J. (2015). Influence of Bike Lane Buffer Types on Perceived Comfort and Safety of Bicyclists and Potential Bicyclists. *Transportation Research Record 2520*, pp. 132-142.

[125] Goodno, M., McNeil, N., Parks, J., & Dock, S. (2013). Evaluation of Innovative Bicycle Facilities in Washington, DC: Pennsylvania Avenue Median Lanes and 15th Street Separated bike lane. *Transportation Research Record 2387*, pp. 139-148.

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

[127] Fitts, T. (2014). Improving Access for Cyclists at Signalized Intersections. Australian Institute of Traffic Planning and Management National Conference.

[128] McNeil, N., Monsere, C., and Dill, J. (2015). The Influence of Bike Lane Buffer Types on Perceived Comfort and Safety of Bicyclists and Potential Bicyclists. *In Transportation Research Record 2520.* TRB, National Research Council, Washington, DC.

[129] Rahimi, A., Kojima, A., and Kubota, H. (2013). Experimental Research on Bicycle Safety Measures at Signalized Intersections. *Journal of the Eastern Asia Society for Transportation Studies*: 10, pp. 1426-1445.

[130] Hurwitz, D., Jannat, M., Warner, J., Monsere,C., and Razmpa A. (2015). Towards Effective Design Treatment for Right Turns at Intersections with Bicycle Traffic. FHWA-OR-RD-16-06.

[131] Schepers, J. P., Kroeze, P. A., Sweers, W., and Wüst, J. C. (2011). Road Factors and Bicycle–motor Vehicle Crashes at Unsignalized Priority Intersections. *Accident Analysis and Prevention*, *43*(3), pp. 853-861.

[132] Zangenehpour, S., Strauss, J., Miranda-Moreno, L. F., & Saunier, N. (2016). Are Signalized Intersections With Separated bike lanes Safer? A Case–control Study Based on Automated Surrogate Safety Analysis Using Video Data. *Accident Analysis and Prevention*: 86, pp. 161-172.

[133] Thomas, B. and DeRobertis, M. (2013). The Safety of Urban Separated bike lanes: A Review of the literature. *Accident Analysis and Prevention:* 52, pp. 219–227.

[134] Harris, M. A., Reynolds, C. C., Winters, M., Cripton, P. A., Shen, H., Chipman, M. L., ... and Hunte, G. (2013). Comparing the Effects of Infrastructure on Bicycling Injury at Intersections and Non-intersections Using a Case–crossover Design. *Injury Prevention*: 19(5), 303-310.

[135] Ibid., see note 119.

lines, raise awareness, or separate phases at signals can mitigate the elevated risk of two-way facilities. For example, crash reductions up to 50 percent were documented at locations where the separated bike lane is deflected away from the parallel traffic lanes by six to twenty feet to improve motorist visibility, or by raising the crossing at the conflict point to slow the speed of turning drivers.[136]

## Sidewalk Bicycling

One frequently cited study recommended against sidewalk riding.[137] The study authors concluded bicyclists were 1.8 times more at risk of injury riding on the sidewalk versus riding within the road, thus bicycling on the sidewalk should be discouraged. The researchers only examined bicycle-motor vehicle crashes occurring at intersections, including intersections with driveways. Crashes occurring between intersections and driveways were not considered in the evaluation, including sideswipes, hit-from-behind, and doorings. When this data was re-analyzed to include midblock crashes, the relative risk of sidewalk riding was virtually the same as that of riding in the road (1.07).[138] The researcher had also found that much of the sidewalk-riding risk arose from a relatively small number of cyclists riding the "wrong way" (riding along the left side of the road). Upon reanalysis of the data, the researchers found the relative risk of sidewalk riding dropped to half of the risk (0.5) of riding in the street if wrong-way cyclists are excluded. These findings may help explain the unexpected finding that children cyclists (who overwhelmingly rode on the sidewalk) had a lower crash risk than adults (who tended to prefer riding in the street).

## Sidepath Bicycling

Guidance for sidepaths has consistently recommended care should be taken at intersections due to the two-way operation of bicycles on sidepaths. Crash patterns consistently show contra-flow movement of bicyclists are disproportionately a factor in in crashes due to motorists failing to yield or look for approaching bicyclists.[139] An analysis of bicycle crashes in Wisconsin identified sidepaths as the location for 27 percent of all bike crashes (305 crashes) in the state in 2003. Of these crashes, the most common crash type was Motorist Drive-Out– Stop or Yield Control which represented 23 percent of sidepath crashes (sidepath crashes were 45 percent of Motorist Drive-Out—Signal Control crashes). As expected, all 23 percent of these crashes are sidepath-crosswalk crashes. The next most common was Motorist Drive-Out – Right Turn on Red which accounted for 13 percent of sidepath crashes.[140]

Another safety challenge with sidepaths is the shared use operation with pedestrians and other users of the path. Conflicts between path users and falls due to surface defects or obstructions on the path are a primary source of injuries and may comprise a high percentage of sidepath crashes. Additionally, conflicts between path users can result in a degraded experience between all users, undermining support for paths and increasing animosity between pedestrians and bicyclists.[141]

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[136] Ibid., see note 118.
[137] Wachtel, A., & Lewiston, D. (1994). Risk factors for bicycle-motor vehicle collisions at intersections. *ITE Journal*, 64(9), 30-35.
[138] Lusk A., Furth P., Morency P*.*, et. al. (2011). Risk of Injury For Bicycling On Separated bike lanes versus in the street
*Injury Prevention*: 17, pp. 131-135.
[139] Hunter, W. et al. Pedestrian and Bicycle Crash Types of the Early 1990s. FHWA-DD-95-163. McClean: 1994.
[140] Amsden, M., Huber, T. Bicycle Crash Analysis for Wisconsin Using a Crash Typing Tool (PBCAT) and GIS. Final Report No. 0092-05-18. 2006
[141] Moore, Roger L. Federal Highway Administration and National Recreational Trails Advisory Committee. Conflicts on Multiple-Use Trails: Synthesis of Literature and State of Practice. FHWA-PD-94-031. McClean: 1994.

# Considerations for FHWA *Resource Guide for Separating Bikes from Traffic*

Due to the bias of early design guidance towards vehicular cyclists, bike networks which separated bicyclists from traffic were implemented slowly throughout much of the United States. The bicycle mode share in cities remained below 1 percent from the late 1970s until the mid-2000s, even though approximately 40 percent of trips consistently were 4 miles or less[142] for over 40 years. Exceptions were generally smaller college towns such as Davis, California, Cambridge, Massachusetts, Fort Collins and Boulder, Colorado, which developed networks of trails and bike lanes during the 1970s and 1980s to serve college students.

Research over the last 40 years has shown that providing bikeways which separate bicyclists from high-volume and high-speed traffic improves safety, compared to operating within a shared travel lane. This separation can be achieved by shifting bicyclists away from arterials onto traffic calmed bicycle boulevards, by providing soft separation with pavement markings to designated bicycle lanes or shoulders, or by providing a physical barrier between bicyclists and motorized traffic on separated bike lanes or paths. A key consideration for determining separation type is the desired bicyclist design user profile, in addition to the traffic and land use context. To maximize a community's bicycling potential, it is necessary to provide designs which are attractive to the largest segment of the population. Previous research efforts identified this group as the "Interested but Concerned" population.

A review of the research shows a general convergence of design criteria (see Figure 20) suggesting physical separation from traffic as traffic volumes exceed 3,000 to 6,000 ADT and traffic speeds exceed 25 to 30mph. Bicycle lanes are recommended up to about 7,000 to 10,000 ADT if vehicle speeds do not exceed 25mph. Physical separation is recommended above these values, with a sensitivity to speed of traffic exceeding 25 to 30mph.

In providing for the "Interested but Concerned" user profile, it is also important to consider the needs of the highly confident cyclists and sport cyclists. Other user profiles need to be able to operate their bicycles at higher speeds, in many cases over longer distances. Both New Zealand and the Dutch CROW manuals provide some guidance within the document to help guide recommendations. Within cities and urban areas, this generally can be accomplished within shared lanes where motor vehicle speeds are at or below 30 mph. This design option would require supportive laws allowing a bicyclist to operate on bicycle lanes or separated facilities. As motor vehicle speeds reach or exceed 35mph, which is more common in suburban areas and typical in rural areas, it becomes more difficult to share lanes with motorized traffic, and bicyclists' safety operating in shared lanes decreases. In these cases, it may be beneficial to provide bicycle lanes or shoulders. In suburban areas where shared use paths or separated bike lanes are provided, designs should consider treatments which safely allow bicycle operating speeds of 20 to 25mph by larger groups of cyclists without creating safety challenges for slower bicyclists or pedestrians.

An emerging strategy for determining when to separate bicyclists from traffic is the use of a chart comparing facility types with traffic volume and speed. The use of a chart allows a practitioner to quickly identify a preferred bikeway type for the context. However, a chart does not allow for a tradeoff assessment. In addition, guidance that helps practitioners determine what to do when the preferred bikeway is not feasible will add value to existing bikeway selection processes and allow for further tradeoff evaluation.

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[142] Dougherty, N., and Lawrence, W. *Bicycle Transportation*. US EPA Office of Planning and Evaluation. 2012 National Household Travel Survey data finds 43 percent of trips are 3 miles or less.

Of the contextual decision-making processes reviewed, the context sensitive design (CSD) and systemic safety approaches have the most value. The systemic safety approach helps to overcome the challenge of inadequate data for bicycle volume and the infrequent, and somewhat random locational nature of bicycle crashes. The CSD process allows for a more thorough assessment of existing corridors needs and local context. Both strategies require the designer to clearly identify an appropriate design user and to understand the facility type that best suits their desires and needs. The preferred facility can conflict with agency delivery goals where maintenance concerns, right-of-way ownership, or project delivery mechanisms limit the available bikeway options. For example, agencies that operate and maintain only the vehicle portion of the roadway, but not sidewalks, paths or separated bike lanes located outside the motor vehicle portion of the road, will require local partnerships to build physically separated bikeways.

The process needs to clearly articulate this challenge and help agencies understand that choosing bikeways which are not suitable for a wide range of the population will result in reduced use of the bikeways provided. Therefore, the decision-making tool or guidance should account for the costs or benefits to choosing a preferred facility type for accommodating cyclists along roadways.

| Source | Design User | Facility Selection Process | Facility Selection Tool | Shared Lane Criteria | | Advisory Bicycle Lane Criteria | | Bicycle Lane Criteria | | Buffered Bicycle Lane Criteria | | Separated Bicycle Lane Criteria | | Shared Use Path Criteria | | Contextual Guidance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Traffic Volume | Traffic Speed | Traffic Volume | Traffic Speed | Traffic Volume | Traffic Speed | Traffic Volume | Traffic Speed | Traffic Volume | Traffic Speed | Traffic Volume | Traffic Speed | |
| NACTO's Designing for All Ages and Abilities (2017) | Interested but Concerned | | X | <1,500 ADT | <20mph | | | | | 3,000 - 6,000 ADT | <25mph | >6,000 ADT | >26mph | | | pedestrian volume, transit, congestion, # travel lanes |
| AASHTO (2018) | Interested but Concerned | | X | < 3,000 ADT | < 25 mph | | | | | < 6,000 ADT | < 30 mph | > 6,000 ADT | > 30 mph | > 6,000 ADT | > 30 mph | unique conditions warrant further separation: congestion, trucks, senstive population, commercial area |
| New Zealand | Interested but Concerned | | X | < 5,000 ADT +<br>< 2,000 ADT + | ≤ 25 MPH ≤ 30 MPH | | | ≤ 10,000 ADT +<br>≤ 2,000 ADT + | ≤ 25 MPH<br>< 45 MPH | | | > 10,000 ADT +<br>any ADT + | > 25 MPH<br>> 45 MPH | | | Separate in congested conditions |
| TAC | Interested but Concerned | | X | | ≤ 25 mph | | ≤ 25 mph | | ≤ 30 mph | | ≤ 30 mph | | ≤ 50 mph | | any speed | |
| WSDOT | Interested but Concerned | | X | ≤ 3,500 ADT | ≤ 30 mph | | | ≤ 7,500 ADT | ≤ 30 mph | < 8,000 ADT | < 35 mph | > 9,000 ADT +<br>> 3,000 ADT + | ≥ 30 MPH<br>≥ 40 MPH | > 9,000 ADT +<br>> 3,000 ADT + | ≥ 30 MPH<br>≥ 40 MPH | SUP vs SBL depends on ped volume |
| CROW | entire population | | X | ≤ 5,000 ADT | ≤ 20 mph | | | < 3 lanes | ≤ 20 mph | | | > 3 lanes OR | > 20 MPH | | | where bicycle volume > 2,000 bikes/hr and vehicle speed < 20mph, separate bikes or create bicycle street. Advisory bike lanes may be used on higher speed, rural roads if low volume |
| FHWA Rural and Small Towns | Interested but Concerned | | X | ≤ 2,000 ADT | ≤ 20 mph | < 2,500 ADT | ≤ 25 mph | ≤ 9,000 ADT | ≤ 35 mph | | | > 3,000 ADT | > 35 mph | > 4,000 ADT | > 40 mph | |
| Montgomery County Bicycle Planning Guidance (2014) | Interested but Concerned | X | X | < 3,000 ADT | < 25mph | | | ≤ 7,500 ADT | ≤ 25mph | < 7,500 ADT | < 35mph | > 9,000 ADT +<br>any ADT + | <35mph<br>>35mph | | | |
| Ontario | Interested but Concerned | | X | < 3,000 ADT +<br>< 2,000 ADT + | < 25 MPH < 35 MPH | | | ≤ 15,000 ADT +<br>≤ 3,000 ADT + | ≤ 25 MPH<br>≤ 50 MPH | | | > 15,000 ADT +<br>> 3,000 ADT + | > 25 MPH<br>> 50 MPH | | | |
| Ottawa | Interested but Concerned | | X | < 5,000 ADT +<br>< 2,000 ADT + | ≤ 25 MPH ≤ 30 MPH | | | ≤ 10,000 ADT +<br>≤ 2,000 ADT + | ≤ 25 MPH<br>< 45 MPH | | | ≥ 10,000 ADT +<br>any ADT + | ≥ 25 MPH<br>≥ 45 MPH | | | Separate in congested conditions |
| Washington County | Interested but Concerned | | X | < 3,000 ADT | < 25 mph | | | < 10,000 ADT | < 40 mph | < 10,000 ADT | < 40 mph | > 10,000 ADT | > 40 mph | | | |
| AASHTO (2018) | Confident | X | X | < 1,500 ADT | < 65 mph | | | > 6,000 ADT + > 1,500 ADT + | ≤ 30 MPH<br>> 30 MPH | | | | | | | recommendations restricted to shoulders |
| Montgomery County Bicycle Planning Guidance (2014) | Confident | X | X | < 30,000 ADT | < 30 mph | | | < 40,000 ADT | < 40 mph | < 50,000 ADT | < 45 mph | < 50,000 ADT | < 45 mph | > 45 mph | | |
| WSDOT | Confident | | X | < 10,000 ADT | < 30 mph | | | < 20,000 ADT | < 35 mph | < 30,000 ADT | < 45 mph | < 40,000 ADT | < 50 mph | > 40,000 ADT | > 50 mph | |

**Figure 20 _ Summary of bikeway facility selection criteria from literature review**

# Appendix A: Bikeway Selection Tools Review

# New Hampshire DOT Bureau of Highway Design Multimodal Design Criteria. 2017.

## Structure and Content of Guidance

### Purpose:

Provide a framework for NHDOT staff to follow to provide access and safety for all modes, borrowing concepts from MassDOT's Cross Section and Roadside Elements, FHWA's Achieving Multimodal Networks, and FHWA's *Small Town and Multimodal Networks Guide*.

### Design User:

The report does not specify a design user.

### Guidance provided:

Want to approach roadway design from a "right-of-way edge to right-of-way edge" perspective.

There are 4 main roadway cross section design forms, while providing some other supplementary forms.

- Form 1 - Shared Accommodation for Pedestrians, Bicyclists and Motor Vehicles
- Form 2 - Separate Accommodation for Motor Vehicles and Shared Bicycle/Pedestrian Accommodation
- Form 3 - Separate Pedestrian Accommodation and Shared Bicycle/Motor Vehicle Accommodation
- Form 4 - Separate Accommodation for Pedestrians, Bicyclists and Motor Vehicles

Other Models:

- Yield Roadway (Advisory Bike Lanes)
- Pedestrian Lane (A striped pedestrian lane adjacent the vehicle lanes)
- Constrained Bridges Solutions
- Interstate Highway Ramps Solution

## Process

The multimodal design criteria takes a "right-of-way edge to right-of-way edge" approach to designing.

## Facility Selection Tool

The facility selection tool references several charts from FHWA's *Small Town and Rural Multimodal Networks Guide*. There is no formal selection process, but depending on the traffic volume, speed, and available resources, "one of the forms" may best optimize access and safety for all modes of traffic.

## Evaluation

### Pros:

- The six-page document is simple and to the point.
- It provides a smaller town, rural perspective.
- There are a limited number of cross section choices a designer can make, so a decision can be reached quickly.

### Cons:

- There is no formalized or explicit process to choose a form.
- There are limited to no options to provide complete separation from vehicular traffic.
- Solutions limited to bicycle lanes, regardless of traffic volume and speed which conflicts with other resources.

# Maryland State Highway Administration. *Bicycle Policy and Design Guidelines*. 2015.

## Structure and Content of Guidance

### Purpose:

The standalone Maryland State Highway Administration guide provides guidance for accommodations to improve bicycling statewide. The purpose of the guide is to help improve the regional bike network and mitigates safety concerns about mixing bicycles with motor vehicle traffic.

### Design User:

There is no design user mentioned in this guide.

### Guidance Provided:

- Discussion of design of bikes bike lanes, shared lanes, shared use paths, cycle tracks, buffered bike lanes, bike boxes, transition areas, bikeway signs, and bicycle access at interchanges and through work zones.
- Bike lane width guidance based on posted speed limit and vehicle mix.
- Discussion of different types of bike routes, including regional, local, and recreational.
- Strategies for bikeway design at intersection approaches, and areas with pocket lanes, roundabouts, and high parking turnover.

## Process

This guide does not include a discussion of the process to select a preferred bikeway.

## Facility Selection Tool

This guide does not include a facility selection tool; however, it does provide general guidelines for situations when cycle tracks may be appropriate. These guidelines include situations when:

- On-street parking is present, high bicycle volumes, high motor-vehicle volumes and/or speed, infrequent cross streets, driveways, and/or longer block spacing
- Where there is continuous minimum shoulder width as stated in Table 2.1 for at least 2,500 ft. inclusive of any intersection length, the shoulder shall be marked and signed as a designated bike lane, and in no case, shall a bicycle lane be marked as such when less than 4 feet.
- "Every effort shall be made to narrow the travel lanes to provide marked bicycle lanes or to widen the shoulder to improve bicycle compatibility."

**All projects that involve widening or new construction shall meet the mandatory conditions in Table 1 - Minimum Shoulder and Bike Lane Widths**

- regardless of the presence of or the requirement to provide a marked bike lane as part of the project.
- Along urban and suburban roadways where it is not possible to stripe a separate bicycle lane due to width constraints, consideration should be given to providing Shared Lane pavement markings
- Separated Bike Lanes are allowed on State roadways, but are not required and their use should be based on engineering judgment.

| Minimum Shoulder Widths for Marked Bike Lanes | | |
|---|---|---|
| **Posted Speed Limit** | **Truck Volumes (%ADT)** | **Shoulder/Lane Width** |
| ≤ 35 MPH | | 4 Feet |
| > 35 MPH and ≤ 45 MPH | ≤ 8% trucks | 5 Feet |
| | > 8% trucks | 6 Feet |
| > 45 MPH | | 6 Feet |

**Table 1 - Minimum Shoulder and Bike Lane Widths**

Source: Maryland State Highway Administration. *Bicycle Policy and Design Guidelines* (2015)

## Evaluation

### Pros:

- detailed and provides design considerations for different roadway environments.
- recommends bicycle lanes be provided as a default condition, requiring design waiver to not

### Cons:

- This guide does not provide an intended design user.
- This guide does not provide sufficient background information about the role of separated bike lanes.
- No guidance for choosing cycle track over a buffered bike lane or a buffered bike lane or bike lane.

# Draft Update to the AASHTO *Guide for the Development of Bicycle Facilities*. Chapter 4: Contextual Guidance for Selecting Bikeways and Implementation. 2018.

## Structure and Content of Guidance

### Purpose:

This resource is one chapter in the *draft* AASHTO Bike Guide. This chapter provides a framework for selecting a preferred bikeway based on traffic characteristics in different land use contexts.

### Design User:

This guidance is applicable to all design users, including highly confident, somewhat confident, and interested but concerned.

### Guidance Provided:

- Discussion of importance of defining project purpose, project limits, land use context, anticipated users, and performance criteria, including safety, implementation strategies, design flexibility.
- Implementation strategies for situations with constrained rights-of-way or project type (e.g., new construction or reconstruction).
- Discussion of tradeoffs, such as:
    - Construction costs,
    - Maintenance costs,
    - Estimated bicycle ridership, and
    - Impacts on motor vehicle capacity and travel time.

## Process

This guide does not include a facility selection process but does discuss factors to be considered when selecting a bikeway and determining the level of separation, such as:

- Land use context (urban, rural),
- Unusual motor vehicle peak hour volumes,
- Traffic vehicle mix,
- Parking turnover and curbside activity,
- Driveway/intersection frequency,
- Vulnerable populations,
- Network connectivity gaps, and
- Separated bikeways vs shared use paths.

## Facility Selection Tool

AASHTO's facility selection tool is in the form of two charts. A range of bikeways for specific traffic volume and speed combinations is provided for the Urban Core, Urban, Suburban, and Rural Town Contexts assuming the Interested But Concerned Bicyclist is the design user. For Rural Contexts it is assumed the Design User is the Highly Confident or Somewhat Confident Bicyclist who operating on lower volume rural roadways, therefore shoulders are generally sufficient. For roads with operating speeds above 45mph, shared use paths are recommended in addition to a shoulder accommodation.

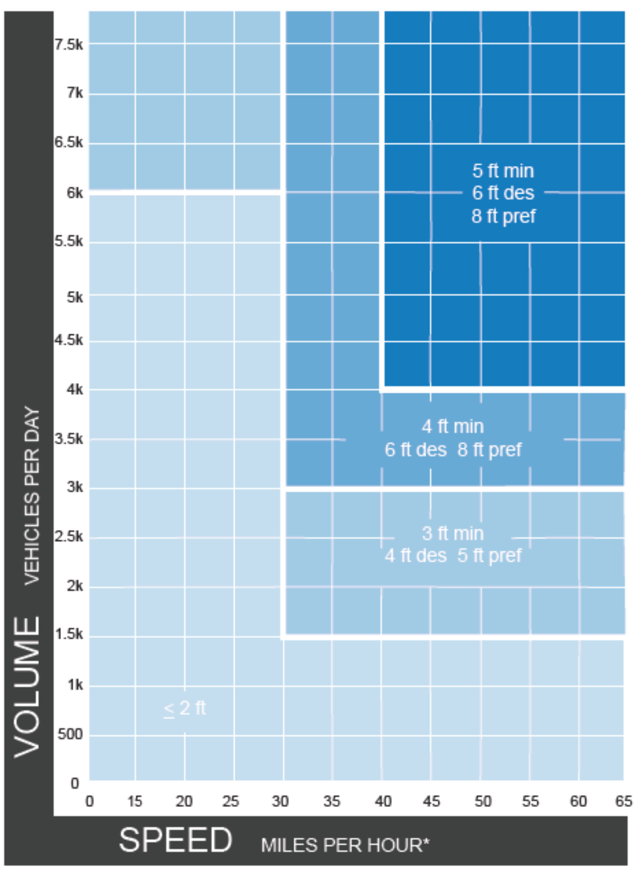
## Evaluation

### Pros:

- This guide provides a brief discussion of tradeoffs and, in some cases, refers to other resources for more information.
- This guide assumes the Interested but Concerned bicyclist is the default user.
- This guide provides a broad overview and important context for bikeway selection processes.
- This guide provides summary of design principles that relate to bicyclist safety and comfortable bikeway design.
- This guide includes information to help apply the facility selection chart including how different elements of a roadway environment or design users can influence bikeway selection.

### Cons:

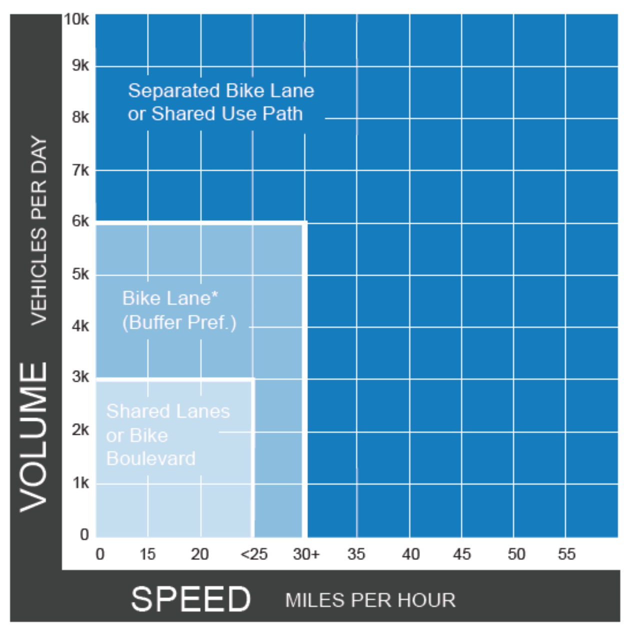
- This guide does not include a clear process for evaluating tradeoffs where the preferred bikeway is not provided.




* For the purposes of facility selection, it is assumed that posted speeds are approximately the same as operating speeds. If operating speeds differ from posted speeds, then operating speed should be used instead of posted speed.
** advisory bike lanes may be an option where traffic volume < 6k ADT

**Figure 22 - Shoulder Widths for Rural Context**
**Design User: Highly Confident or Somewhat Confident Bicyclist**

Source: Toole Design Group




*advisory bike lanes may be an option where traffic volume < 6k ADT

**Figure 21 - Bicycle Facility Selection Chart**
**(Urban Core, Urban, Suburban, and Rural Town)**
**Design User: Interested but Concerned Bicyclist**

Source: Toole Design Group

# FHWA *Delivering Safe, Comfortable, and Connected Pedestrian and Bicycle Networks: A Review of International Practices*. 2015.

## Structure and Content of Guidance

### Purpose:

This standalone FHWA report identifies noteworthy and innovative international designs, treatments, and other practices that can improve bicycle and pedestrian safety and increase walking and bicycling in the U.S.

### Design User:

This report does not specify a design user.

### Guidance Provided:

- Discussion of international examples of network infrastructure (e.g., priority bike streets, roundabouts, signalization).
- Discussion of project prioritization criteria in different countries. Generally, there is an emphasis on including bicycle demand, crash history, discomforting factors (e.g., heavy motor vehicle traffic and poor lighting), connections to other projects and bikeways, and prioritizing projects near schools and businesses.

## Process

This report has very little discussion of a bikeway selection process, however, there seems to be a greater emphasis on public opinion of comfort and safety of facilities in European countries than in the U.S. Jurisdictions also used qualitative assessment processes such as road safety assessments/audits, (around 40%) to identify bicycle gaps or issues. The purpose of bicycle networks in some countries is to achieve mode shift, environmental, sustainability, or public health goals. Some countries have established performance goals to provide linear continuity of specific types of facilities including separated bike lanes, segregated paths, and cycle priority streets.

Copenhagen has a relatively dense bicycle network. Efforts focus on closing gaps in the protected bike lane network and addressing safety needs at spot locations. They beginning to build a bicycle superhighway network to provide low-delay, longer-distance routes into the suburbs to attract bicycle commuter trips. Copenhagen also uses a priority network (PLUSnet) that follows the highest demand routes. The routes are designed to a higher standard and have winter maintenance priority.

## Facility Selection Tool

Only one example of a facility selection tool was provided. An intersection tool for the City of 's-Hertogenbosch in the Netherlands where hierarchy of the bike and car networks is used to develop a target intersection treatment.

## Evaluation

### Pros:

- The report refers to existing guidance documents for more information.
- The report presents a useful summary of international practices

### Cons:

- The report is long and text heavy.

| Bicycle Network Level | Auto Network Level | | |
|---|---|---|---|
| | Arterial | Collector | Other |
| Primary | Always grade-separated | Preferably grade-separated, otherwise roundabout or traffic signal | Bicycle network always has priority (right-of-way) |
| Other main route | Preferably grade-separated, otherwise roundabout or traffic signal | Roundabout or traffic signal | In principal, priority to the bicycle network |
| Other route | Roundabout or traffic signal | Priority to collector street or roundabout or traffic signal | Either can have priority |

**Table 2 - Intersection Treatment Based on Bike and Motorist Network Hierarchy**

Source: FHWA Delivering Safe, Comfortable, and Connected Pedestrian and Bicycle Networks: A Review of International Practices. (2015)

# Massachusetts Department of Transportation. *Separated Bike Lane Planning and Design Guide*. 2015.

## Structure and Content of Guidance

### Purpose:

The standalone MassDOT guide is a supplement to MassDOT's existing bikeway design guidance and provides direction on where to implement and how to design separated bike lanes as part of a safe and comfortable network of bikeways.

### Design User:

This guide has two design users, 'Casual and Somewhat Confident' and 'Experienced and Confident'.

### Guidance Provided:

- Discussion of three principles of low stress networks, including safety, comfort, and connectivity.
- Discussion of research supporting separated bike lanes.
- Discussion of planning process, including network connectivity, low stress networks, planning process, and assessing feasibility.
- Discussion of public outreach as part of planning process. – not mentioned in many facility selection tools
- Discussion of design considerations on various topics, including bike lane elevation, stormwater management, lighting, intersection design, curbside activity, signals, and maintenance.

## Process

MassDOT's guide provides a framework for selecting separated bike lanes. The framework includes a brief discussion of the following elements.

1. **Determining when to provide physical separation.**
   The guide explains that generally, on streets with operating speeds less than 25mph and motor vehicle traffic volumes below 6,000 ADT separated bike lanes are not needed. The guide also provides a few scenarios that may warrant separated bike lanes, including multilane roadways, curbside conflicts, large vehicles, vulnerable populations, low-stress network connectivity gaps, and unusual peak hour volumes.
2. **Choosing separated bike lanes or shared use paths.**
   The guide refers users to the Shared-Use Path Level of Service Calculator.[143]
3. **Determining separated bike lane configuration.**
   The guide provides design guidance and graphics to help practitioners think through various configurations of separated bike lanes.
4. **Feasibility.**
   Space, funding, construction, and maintenance considerations are discussed.
5. **Public process.**
   The guide advocates for the inclusion of public engagement in the separated bike lane planning process.

143 Hummer, J., et. al. (2006). Evaluation of Safety, Design, and Operation of Shared-Use Paths. Federal Highway Administration. FHWA-HRT-05-137

It also lists the following factors which warrant physical separation from traffic:  multi-lane roadways, curbside conflicts, heavy trucks, higher volumes of children or seniors bicycling, to fill low-stress network gaps, locations with unusually high peak hour traffic volume.

## Facility Selection Tool

MassDOT's guide does not include a bikeway selection tool, however it provides a graphic which illustrates the concept of minimizing exposure to motorists when considering intersection design which recommends protected intersections as a preferred design outcome at intersections.

## Evaluation

### Pros:

- The guide discusses planning considerations at the site, network, and corridor level.
- The guide provides powerful graphics to depict the impact separated bike lanes can have on a motorist's field of vision.
- The guide provides useful maintenance considerations.

### Cons:

- The guide does not include a bikeway selection process graphic.
- The guide touches on a variety of important implementation and planning considerations but does not provide sufficient information on planning-related topics to help practitioners weigh tradeoffs.

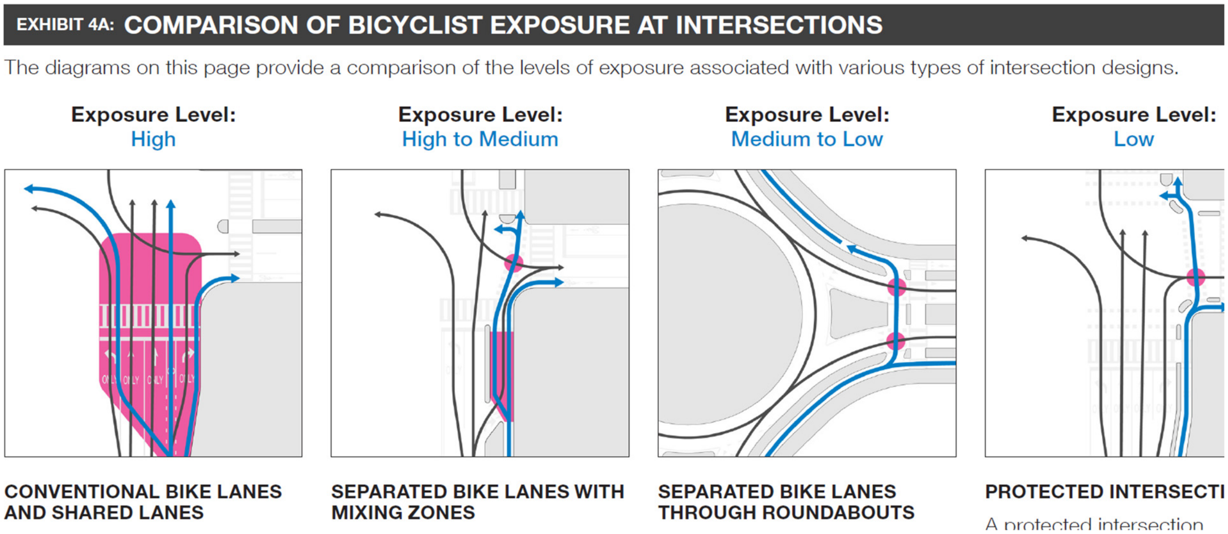



**Figure 23 - Comparison of the levels of bicyclist exposure to motorized traffic associated with various types of intersection designs**

Source: Massachusetts DOT *Separated Bike Lane Planning and Design Guide*. (2015)

# NACTO *Designing for All Ages and Abilities*. 2017.

## Structure and Content of Guidance

### Purpose:

The standalone NACTO guide provides design guidance for the purpose of helping communities recommend bicycle facilities that are comfortable for *all* user types.

### Design User:

This guide defaults to the Interested but Concerned design user: populations who feel the least confident riding a bike with motorized traffic, with an emphasis on accommodating children, seniors, people of color, bike share riders, and women.

### Guidance Provided:

- Defines an all ages and abilities network
- Descriptions of the different types of bikeways that are suitable for all ages and abilities.
- A discussion of the relationship between motor vehicle volume and speed to bicyclist stress.
- Discussion of design, operation, and network changes that can be implemented to manage motor vehicle volume and speed to keep the bikeway comfortable for all ages and abilities.
- Strategies to improve bicyclists' comfort on multi-lane roads and at intersections, or locations with motor vehicle queuing, trucks and large vehicles, frequent curbside or transit activity.

## Process

This guide does not include a discussion of the process to select a preferred bikeway.

## Facility Selection Tool

NACTO's bikeway selection tool is in the form of a matrix which prescribes a range of bikeways for specific vehicle lane combinations in addition to traffic volume and speed combinations with consideration of other operational issues.

## Evaluation

### Pros:

- The guidance is simple to understand, provides users with a clear description of the two main barriers to comfort on a roadway (motor vehicle speed and volume), and discusses multiple strategies to mitigate those barriers in different contexts.
- The guide prioritizes comfort and has a single "design user" – all ages and abilities. It describes how the unique needs of different types of users fit within the all ages and abilities context.
- The guidance simplifies to a preference for separating bikes from traffic where traffic volumes >1,500 vehicles/day, operating speeds > 25mph and/or, there are more than 2 through lanes of traffic with solid barrier traffic volumes >6,000 vehicles/day.
- The guidance is written to be applicable to all land use contexts.
- The guide remains concise by not trying to "do it all" and provides references to other existing resources for specific bikeway design guidance, and focuses more on how roadway characteristics affect bikeway selection.

## Cons:

- The guide mentions the importance of safety, but provides little evidence of the connection between bikeways and safety.
- The guide doesn't provide a decision-making process or offer guidance for what a designer should do if the preferred bikeway is not feasible. For example, the guide does not discuss what to do when operating within budget constraints nor does it discuss maintenance tradeoffs associated with the different facilities.
- The guide is generally prescriptive and does not allow for flexibility when choosing a bikeway.
- The guide does not provide guidance for selecting a conventional bike lane vs. a buffered or protected lane when traffic volume < 6,000 veh/day.
- The guide does not discuss land use context or potential differences of approach in urban, suburban and rural contexts.
- The guide does not offer guidance for how to consider key operational considerations.
- The guide does not define all terms used in the matrix (e.g. low curbside activity, low pedestrian volume, or high motor vehicle congestion).

## Contextual Guidance for Selecting All Ages & Abilities Bikeways

| Roadway Context | | | | All Ages & Abilities Bicycle Facility |
|---|---|---|---|---|
| **Target Motor Vehicle Speed*** | **Target Max. Motor Vehicle Volume (ADT)** | **Motor Vehicle Lanes** | **Key Operational Considerations** | |
| *Any* | | *Any* | *Any of the following:* high curbside activity, frequent buses, motor vehicle congestion, or turning conflicts‡ | **Protected Bicycle Lane** |
| < 10 mph | Less relevant | No centerline, or single lane one-way | Pedestrians share the roadway | **Shared Street** |
| ≤ 20 mph | ≤ 1,000 – 2,000 | | < 50 motor vehicles per hour in the peak direction at peak hour | **Bicycle Boulevard** |
| ≤ 25 mph | ≤ 500 – 1,500 | | | |
| | ≤ 1,500 – 3,000 | Single lane each direction, or single lane one-way | Low curbside activity, or low congestion pressure | **Conventional or Buffered Bicycle Lane, or Protected Bicycle Lane** |
| | ≤ 3,000 – 6,000 | | | **Buffered or Protected Bicycle Lane** |
| | Greater than 6,000 | | | **Protected Bicycle Lane** |
| | Any | Multiple lanes per direction | | |
| Greater than 26 mph† | ≤ 6,000 | Single lane each direction | Low curbside activity, or low congestion pressure | **Protected Bicycle Lane, or Reduce Speed** |
| | | Multiple lanes per direction | | **Protected Bicycle Lane, or Reduce to Single Lane & Reduce Speed** |
| | Greater than 6,000 | *Any* | *Any* | **Protected Bicycle Lane, or Bicycle Path** |
| High-speed limited access roadways, natural corridors, or geographic edge conditions with limited conflicts | | *Any* | High pedestrian volume | **Bike Path with Separate Walkway or Protected Bicycle Lane** |
| | | | Low pedestrian volume | **Shared-Use Path or Protected Bicycle Lane** |

* While posted or 85th percentile motor vehicle speed are commonly used design speed targets, 95th percentile speed captures high-end speeding, which causes greater stress to bicyclists and more frequent passing events. Setting target speed based on this threshold results in a higher level of bicycling comfort for the full range of riders.

† Setting 25 mph as a motor vehicle speed threshold for providing protected bikeways is consistent with many cities' traffic safety and Vision Zero policies. However, some cities use a 30 mph posted speed as a threshold for protected bikeways, consistent with providing Level of Traffic Stress level 2 (LTS 2) that can effectively reduce stress and accommodate more types of riders.[18]

‡ Operational factors that lead to bikeway conflicts are reasons to provide protected bike lanes regardless of motor vehicle speed and volume.

**Figure 24 - Facility Selection Matrix**

Source: NACTO *Designing for All Ages and Abilities*. (2017)

# *NCHRP 15-42: Recommended Bicycle Lane Widths for Various Roadway Characteristics.* 2013.

## Structure and Content of Guidance

### Purpose:

This standalone NCHRP report provides design guidance on bicycle lane widths for various roadway characteristics in urban and suburban environments.

### Design User:

This report does not specify a design user.

### Guidance Provided:

- Discussion of relevant literature, including domestic and international guidance and *Safety and Design Research Related to Bicycle Lanes and Shared Use Lanes*.
- Discussion of field studies.
- Research-based design guidance based on width of bike lanes, travel lanes, parking lanes, traffic volume, vehicle mix, grade, and allocation of total roadway width.

## Process

This NCHRP report does not provide a discussion or graphic outlining a process for designing or planning bikeways.

## Facility Selection Tool

This NCHRP report does not provide a bikeway selection tool to help with selecting which type of bikeway to install, however, it does provide a table with a matrix that suggests a bike lane and buffer lane width based on parking lane width, motor vehicle volume and vehicle mix, curb to curb width, and curb to center line width.

## Evaluation

### Pros:

- The report provides a chart which recommends buffer and bike lane widths for different contexts (Figure 1)
- The report offers a research-based justification for inclusion of buffers near bike lanes explained in terms of different roadway characteristics and how these characteristics impact bicyclist behavior, comfort, and safety.

### Cons:

- The report only discusses buffered bike lanes.
- The report is long and text heavy.
- The report does not discuss a decision-making process nor does it discuss design considerations beyond the roadway, such as budget or curbside activity.

| Widths (ft)—One Direction of Travel | | | | | | Curb to Curb (ft) | Travel Conditions[1] |
|---|---|---|---|---|---|---|---|
| Parking Lane | Buffer | Bike Lane | Buffer | Travel Lane | Curb to CL | | |
| 8 | 3* | 4 | 2 | 10 | 27 | 54 | All conditions |
| 7 | 3* | 4 | 2 | 10 | 26 | 52 | All conditions |
| 7 | 2* | 4 | 2 | 10 | 25 | 50 | High volume or high truck percentage |
| 7 | 3 | 5 | 0 | 10 | 25 | 50 | Low volume and low truck percentage |
| 7 | 1.5 | 4 | 1.5 | 10 | 24 | 48 | High volume or high truck percentage |
| 7 | 3 | 4 | 0 | 10 | 24 | 48 | Low volume and low truck percentage |
| 7 | 2 | 5 | 0 | 10 | 24 | 48 | Low volume and low truck percentage |
| 7 | 2 | 4 | 0 | 10 | 23 | 46 | All conditions |
| 7 | 0 | 5 | 0 | 10 | 22 | 44 | All conditions |
| 7 | 1** | 4 | 0 | 10 | 22 | 44 | All conditions |

**Table 3 - Suggested Lane Widths for Urban and Suburban Two-Lane Undivided Roadways with On-Street Parking and Constrained Roadway Width**

Source: *NCHRP 15-42: Recommended Bicycle Lane Widths for Various Roadway Characteristics* (2013)

# Land Transport Safety Authority. *Cycle Network and Route Planning Guide*. New Zealand. 2004.

## Structure and Content of Guidance

### Purpose:

This standalone guide provides best practices for bicycle network and route planning for the purpose of helping practitioners make bikeway selection decisions.

### Design User:

The guide has three design users, including ‘child/novice’, ‘basic competence’, and experienced cyclists.

### Guidance Provided:

- Discussion of cyclists needs and preferences based on designer user type of trip (e.g. sport cyclist, commuter cyclist, route locations, route components and requirements, and five approaches to developing a bikeway network.
- Discussion of planning and policy contexts.
- A description of design recommendations and a summary of advantages and disadvantages of installing bikeways for each type of roadway and bikeway listed in the guide.
- Discussion of design considerations for intersections, structures, and traffic calming.
- Discussion of a five-point hierarchy (safety, comfort, directness, coherence, attractiveness) to improve the comfort of cyclists on a roadway.
- Discussion of factors to consider when selecting a bikeway not included in the tool (see Figure 5).

## Process

The guide provides a detailed discussion on how to complete each stage of the network planning process, these steps include assessing demand, identifying and evaluating route options, prioritization, implementation, and evaluation. It also discussed the following network approaches:

- every street – No special improvements. Let cyclists determine their route based on their comfort, traffic volume and speed.
- roads or paths – separated path networks, complemented by separated bike lanes and striped bike lanes on roads.
- dual networks – provide on street bike lanes with off-street paths or shared lanes with separated bike lanes on same road section.
- hierarchy approach -develop routes based on trip length and user type to serve their unique needs. Longer distance routes may be designed to higher quality or standard for faster travel (e.g. a bicycle superhighway).
- needs approach - achieve the best results for cyclists and other stakeholders within the context
- of all the prevailing opportunities and constraints.

When it comes to prioritizing routes, the guide recommends the review of seven criteria: LOS/cycle review, existing demand, crash history, blockage removal, demonstrable achievement, area consolidation, and quality demonstration projects.

## Facility Selection Tool

Land Transport Safety Authority's bikeway selection tool is in the form of a chart which prescribes a range of bikeways for traffic volume and speed combinations. In addition to the chart, the guide refers to a decision tree that provides additional guidance for selecting the type of separated bikeway to install; this decision tree is included in a separate guidebook.[144]

## Evaluation

### Pros:

- This guide presents detailed design and process guidance.
- The guide presents a planning and implementation guidance based on a network approach, rather than piecemeal projects.
- The guide provides detailed background and emphasis on the needs of different types of users.
- Discussion of safety
- This guide refers to other guidance documents for assessing financial feasibility.

### Cons:

- The guide does not discuss trade-offs of different elements of the planning process nor the tradeoffs of emphasizing different traffic/roadway elements aside from what is presented in facility selection chart.
- There is no simple-process diagram.
- The guide does not present information related to the facility selection process in one place, it is spread out throughout the entire document and even a second document.
- The facility selection tool is not applicable to rural environments.

[144] Transit New Zealand. *New Zealand Supplement to the AustRoads Guide to Traffic Engineering Practice.* Part 14: Bicycles. 2008.

| | CYCLIST TYPE | NEIGHBOURHOOD | COMMUTING | SPORTS | RECREATION | TOURING |
|---|---|---|---|---|---|---|
| | Cyclists' possible cycling objectives | To shops, school, or riding near home | To get to their destination efficiently | To be physically challenged | To enjoy themselves and get some exercise | To see and enjoy new places and experiences |
| NETWORK/ROUTE REQUIREMENTS | CRITERIA | | | | | |
| Safety | Personal security (good lighting etc) | 🚲🚲🚲🚲🚲 | 🚲🚲🚲🚲 | 🚲🚲🚲🚲 | 🚲🚲🚲🚲🚲 | 🚲🚲🚲🚲 |
| | High degree of safety | 🚲🚲🚲🚲🚲 | 🚲🚲🚲 | 🚲 | 🚲🚲🚲🚲🚲 | 🚲🚲🚲 |
| | Separated from busier/faster urban traffic | 🚲🚲🚲🚲🚲 | 🚲🚲🚲 | 🚲 | 🚲🚲🚲🚲🚲 | 🚲🚲🚲🚲🚲 |
| | Rural road shoulders or paths | 🚲🚲🚲🚲🚲 | 🚲🚲🚲 | 🚲🚲🚲🚲 | 🚲🚲🚲🚲🚲 | 🚲🚲🚲🚲🚲 |
| Comfort | Screening from weather and wind | 🚲🚲🚲 | 🚲🚲🚲🚲 | | 🚲🚲🚲 | 🚲 |
| | High-quality riding surfaces | 🚲🚲 | 🚲🚲🚲🚲🚲 | 🚲🚲🚲🚲🚲 | 🚲🚲🚲 | 🚲🚲🚲 |
| Directness | Direct routes | 🚲🚲🚲🚲 | 🚲🚲🚲🚲🚲 | 🚲🚲 | | 🚲🚲🚲 |
| | Minimal delays | 🚲🚲🚲 | 🚲🚲🚲🚲🚲 | 🚲🚲🚲🚲🚲 | 🚲 | 🚲🚲 |
| Coherence | Continuity | 🚲🚲🚲🚲🚲 | 🚲🚲🚲🚲🚲 | 🚲🚲🚲🚲🚲 | 🚲🚲🚲 | 🚲🚲🚲🚲🚲 |
| | Sign-posted; recognisable | 🚲 | 🚲🚲🚲 | 🚲🚲🚲🚲 | 🚲🚲🚲🚲🚲 | 🚲🚲🚲🚲🚲 |
| Attractiveness | Pleasant and interesting routes or destinations | 🚲🚲🚲 | 🚲🚲 | 🚲🚲🚲🚲 | 🚲🚲🚲🚲🚲 | 🚲🚲🚲🚲🚲 |
| | Physically challenging routes or grades | | | 🚲🚲🚲🚲🚲 | 🚲🚲 | |
| Complementary facilities | Parking facilities located near destinations | 🚲🚲🚲🚲🚲 | 🚲🚲🚲🚲🚲 | 🚲 | 🚲🚲🚲🚲 | 🚲🚲 |
| | Security of bicycle parking | 🚲🚲🚲🚲 | 🚲🚲🚲🚲🚲 | 🚲🚲 | 🚲🚲 | 🚲🚲🚲🚲🚲 |
| | Showers, baggage lockers | | 🚲🚲🚲🚲 | | | 🚲🚲 |
| | Water, toilets, shelter, shops, phones | 🚲 | 🚲 | 🚲 | 🚲🚲🚲🚲🚲 | 🚲🚲🚲🚲 |

Legend: 🚲 minimal benefit, 🚲🚲🚲 moderate benefit, 🚲🚲🚲🚲🚲 most benefit

*Table 3.1: The relative importance of network or route criteria to different cyclist groups*

**Figure 25 - The relative importance of network or route criteria to different cyclist groups**

Source: Land Transport Safety Authority. *Cycle Network and Route Planning Guide.* New Zealand. (2004)

| CYCLE FACILITY OPTION | CHILD/NOVICE | BASIC COMPETENCE | EXPERIENCED |
|---|---|---|---|
| Kerbside cycle lane | 🚲🚲 | 🚲🚲🚲🚲🚲 | 🚲🚲🚲🚲🚲 |
| Cycle lane next to parking | 🚲 | 🚲🚲🚲🚲 | 🚲🚲🚲🚲 |
| Contra-flow cycle lane | 🚲 | 🚲🚲🚲🚲 | 🚲🚲🚲🚲🚲 |
| Wide kerb side lane | 🚲🚲 | 🚲🚲🚲 | 🚲🚲🚲🚲 |
| Sealed shoulder | 🚲🚲 | 🚲🚲🚲🚲🚲 | 🚲🚲🚲🚲🚲🚲 |
| Bus lane | 🚲 | 🚲🚲 | 🚲🚲🚲🚲 |
| Transit lane | 🚲 | 🚲🚲 | 🚲🚲🚲🚲 |
| Slow mixed traffic | 🚲🚲🚲 | 🚲🚲🚲🚲 | 🚲🚲🚲🚲🚲 |
| Paths | 🚲🚲🚲🚲🚲 | 🚲🚲🚲🚲 | 🚲🚲🚲 |

Legend: Benefit: 🚲 minimal benefit, 🚲🚲🚲 moderate benefit, 🚲🚲🚲🚲🚲 most benefit

**Figure 26 - Suitability of Bikeway for Different Types of Bicyclists**

Source: Land Transport Safety Authority. *Cycle Network and Route Planning Guide*. New Zealand. (2004)

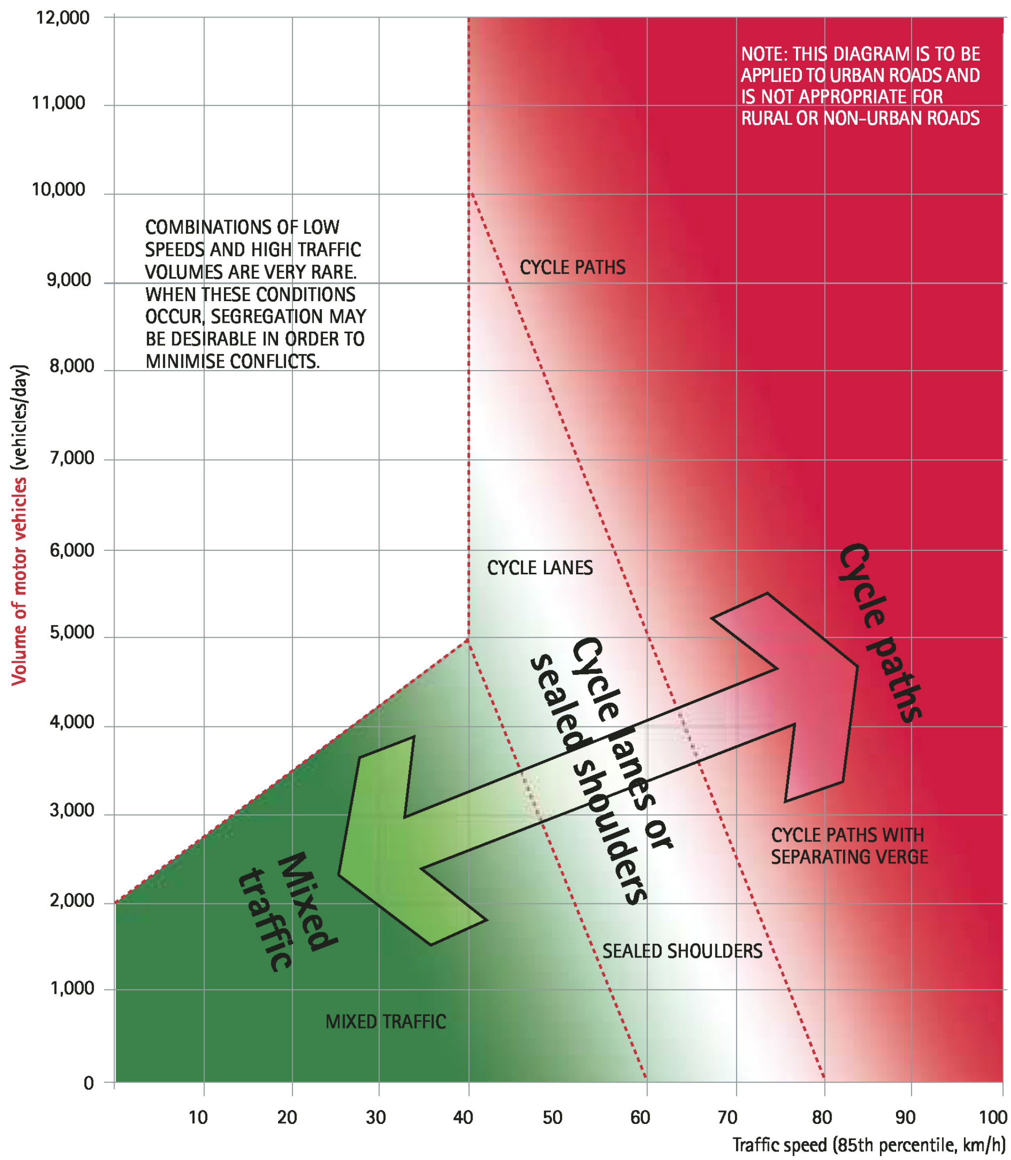



*Figure 6.1: Preferred separation of bicycles and motor vehicles according to traffic speed and volume.*

This diagram is based on RTA NSW (2003) and Jensen et al (2000), also DELG (1999), Ove Arup and Partners (1997) and CROW 10 (1993).

**Figure 6.1: Notes**

1. In general, roads with higher traffic speed and traffic volumes are more difficult for cyclists to negotiate than roads with lower speeds and volumes. The threshold for comfort and safety for cyclists is a function of both traffic speed and volume, and varies by cyclist experience and trip purpose. Facilities based on this chart will have the broadest appeal.

2. When school cyclists are numerous or the route is primarily used for recreation then path treatments may be preferable to road treatments.

3. Provision of a cycle path does not necessarily imply that an on-road solution would not also be useful, and vice-versa. Different kinds of cyclists have different needs. Family groups may prefer off-road cycle paths while racing or training cyclists, or commuters, tend to prefer cycle lanes or wide sealed shoulders.

**Figure 27 - Facility Selection Tool (Land Transport Safety Authority.**

Source: *Cycle Network and Route Planning Guide*. New Zealand. (2004)

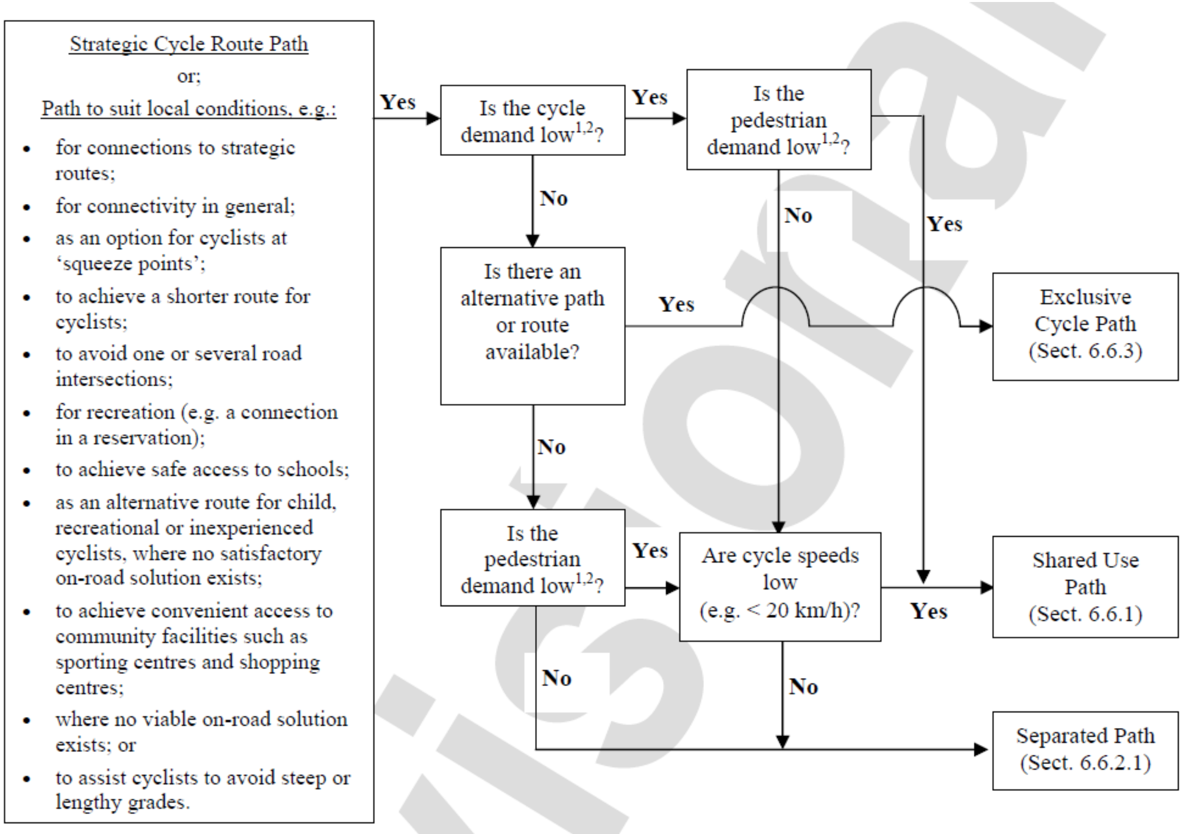



**Figure 28 - Decision Tree for Separated Bikeway Selection**

Source: Land Transport Safety Authority. *Cycle Network and Route Planning Guide*. New Zealand. (2004)

| TRAFFIC | ENVIRONMENT | INFRASTRUCTURE | CONTROLS/OTHER |
|---|---|---|---|
| • Traffic speeds and volumes<br>• Traffic composition, especially % of heavy vehicles<br>• Other road/path users' demands and requirements<br>• Collision history | • Route/road cross-section measurements<br>• Topographic and land use information<br>• Parking controls<br>• Access and parking demand characteristics<br>• Intersection layout details<br>• Key infrastructure details<br>• Local traffic calming measures | • Drainage and utility services<br>• Public lighting<br>• Property driveway positions<br>• Traffic management controls and operational details, for example traffic signals | • Planning regulations<br>• Local initiatives and developments<br>• Local technical requirements<br>• Applicable route design guidelines<br>• Land ownership<br>• Land owner requirements |

**Figure 29 - Factors to Consider When Selecting a Route**

Source: Land Transport Safety Authority. *Cycle Network and Route Planning Guide*. New Zealand. (2004)

# Bicycle Safety Guide and Countermeasure Selection System (BIKESAFE). 2014 Update.

## Structure and Content of Guidance

### Purpose:

This standalone FHWA resource summarizes existing literature and research for 46 engineering, education, and enforcement countermeasure that are in common use and have been shown to improve bicycle safety and increase bicycling in the U.S. The tool provides a list of potential countermeasures to address performance goals (increase bicycling) or to address specific crash types (e.g. – motorist right turn conflict).

### Design User:

This report does not specify a design user but it does discuss the importance of considering bicyclists with "all ages and abilities" as it references complete streets policies and public health goals to encourage bicycling.

#### Guidance Provided:

- The resources are compiled from other sources and do not provide original guidance
- 46 countermeasures are reviewed in a consistent format to provide an overview of the treatment, purpose of the treatment, considerations for applying the treatment, estimated cost of the treatment, a list of research related to the safety impact of the treatment, and case studies of its application.

### Process

The resource provides two matrices to guide decision making. The Performance Objective Matrix describes common treatments to meet some broad objectives for bicycling such as improving safety, improving compliance, or encouraging bicycling. It also provides a Crash Type Matrix to guide the identification of potential countermeasures to address specific crash types. The process is designed to help users identify potential treatments or countermeasures which are relevant to the performance objective or crash type.

### Facility Selection Tool

The tool sources one figure from the FHWA Bicycle Road Safety Audit Guideline which suggests that more separation is desirable when motor vehicle speeds and volumes increase. However, the graphic does not provide any specific thresholds. The countermeasure selection tool allows users to enter project goals, road characteristics (including motor vehicle volume and speed) and specific crash types to resolve. It outputs a list of potential countermeasures to be evaluated, however it does not provide guidance to practitioners to help them choose a bicycle treatment.

### Evaluation

#### Pros:

- The resource concisely allows a person to review countermeasures and quickly become familiar with what it is and a baseline of research.
- The tools allow users to quickly search countermeasures.

#### Cons:

- The countermeasure selection tool does not provide guidance to practitioners for choosing a bicycle treatment.

**BIKESAFE**

Bicycle Safety Guide and Countermeasure Selection System

**Guide:** Background | Statistics | Analysis | Implementation | **Countermeasures:** List | Tool | Matrices | **Case Studies** | **Resources**

## Performance Objective Matrix

View the Crash Type Matrix here.

| Objective Type | Shared Roadway | On-Road Bike Facilities | Intersection Treatments | Maint-enance | Traffic Calming | Trails/ Shared Paths | Markings, Signs & Signals | Other Measures |
|---|---|---|---|---|---|---|---|---|
| Provide safe on-street facilities/space for bicyclists | X | X | | X | X | | X | X |
| Provide off-road paths or trails for bicyclists | | | | X | | X | X | X |
| Provide and maintain quality surfaces for bicyclists | X | | | X | | | X | |
| Provide safe intersections for bicyclists | X | | X | | X | X | X | |
| Improve motorist behavior/ compliance with traffic laws | X | | X | X | X | | X | X |
| Improve bicyclist behavior/ compliance with traffic laws | X | X | X | X | X | X | X | X |
| Encourage and promote bicycling | X | X | | X | | X | X | X |

**Figure 30 - Performance Objective Matrix**

Source: BIKESAFE (2014 Update)

## Crash Type Matrix

View the Performance Objective Matrix here.

| Crash Type | Shared Roadway | On-Road Bike Facilities | Intersection Treatments | Maintenance | Traffic Calming | Trails/ Shared-Use Paths | Markings, Signs & Signals | Other Measures |
|---|---|---|---|---|---|---|---|---|
| Motorist failed to yield - signalized intersection | X | | X | | X | X | X | X |
| Motorist failed to yield - non-signalized intersection | X | | X | | X | X | X | X |
| Bicyclist failed to yield - signalized intersection | X | | X | | X | X | X | X |
| Bicyclist failed to yield - non-signalized intersection | X | | X | | X | X | X | X |
| Motorist drove out - midblock | X | | | | | X | X | X |
| Bicyclist rode out - midblock | X | X | | | X | X | X | X |

**Figure 31 - Crash Type Matrix**

Source: BIKESAFE (2014 Update)

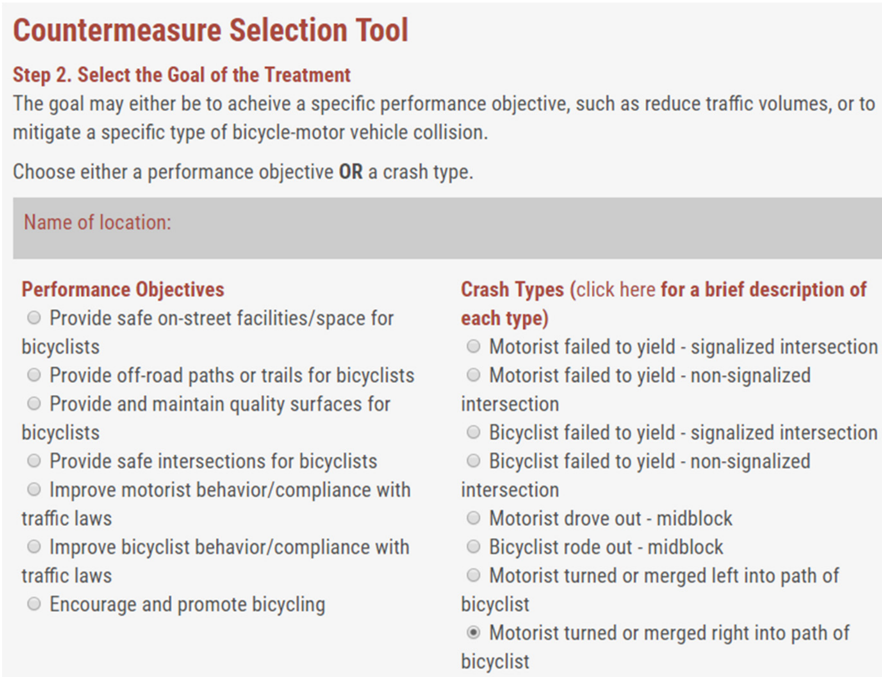



**Figure 32 - Countermeasure Selection Tool Step 2 Example**

Source: BIKESAFE (2014)

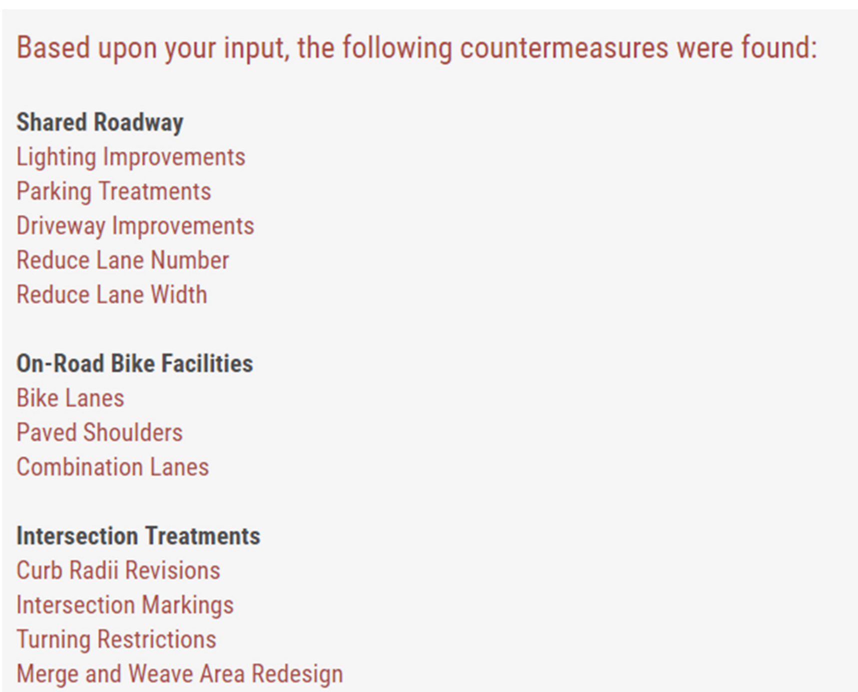



**Figure 33 - Countermeasure Tool Step 4 Results Example**

Source: BIKESAFE (2014)

# Transportation Association of Canada. *Geometric Design Guide for Canadian Roads.* Chapter 5: Bicycle Integrated Design. 2017.

## Structure and Content of Guidance

### Purpose:

The standalone TAC guide provides design guidance to help communities design bikeways in a consistent format.

### Design User:

This guide defaults to the Interested but Concerned design user: populations who feel the least confident riding a bike with motorized traffic.

### Guidance Provided:

- The Guide starts with clarifying statement: "This edition of the Guide shifts the focus of bicycle integrated design from a viewpoint of "bicycles as vehicles" to "people riding bicycles". This shift considers broader human and community design needs, enabling bicycle facilities to encourage bicycle riding more often and more safely."
- Discussion of design user characteristics and geometric design implications are very clear and emphasize the need to consider the inherent vulnerability of bicyclists.
- Discussion of bicycle design needs, such as operating space, safety and security, speed, connectivity, and bikeway surface.
- Discussion of the safety performance of protected bike lanes, bike lanes, and local streets with strategies to improve actual and perceived safety.

## Process

This guide does not include a discussion of the process to select a preferred bikeway.

## Facility Selection Tool

TAC's bikeway selection tool is in the form of a chart which prescribes a range of bikeways for specific posted speeds. While the facility selection tool does not present speed and volume (like most other tools), it provides guidance in the text to describe how different volumes might affect the suitability of a given bikeway. For example, on streets where speeds are 30 -50 km/hr with motor vehicle volumes of 4,000 veh/day or more, it states protected bike lanes or bike paths /multi-use paths are more suitable. It also recommends physical protection on streets with 10 or more heavy vehicles in the peak hour

## Evaluation

### Pros:

- The facility tool presents some clear selection criteria but also allows for flexibility with its delineations of "facility is suitable" and "depends on context" – no other tool reviewed does this.
- The guide includes a good description for how the framework can be used in different contexts, (e.g., road reconstruction, bikeway retrofit, or setting vehicle speed).
- The guidance provided is very detailed.
- The guide provides easily applicable safety performance information for each bikeway.

Cons:

- The guide does not include a discussion of a bikeway selection process.
- The guide provides minimal discussion of what to do when preferred bikeways are not feasible.

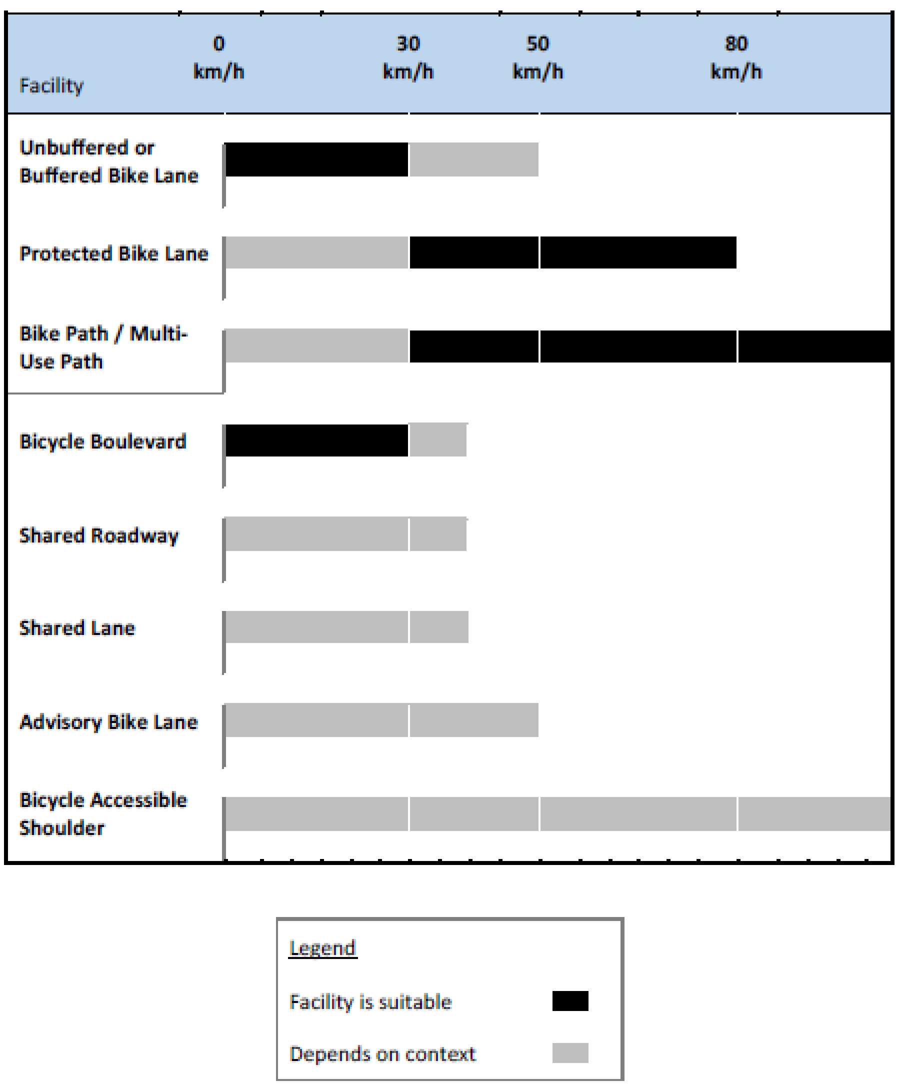



**Figure 34 - Facility Selection Tool**

Source: Transportation Association of Canada. *Geometric Design for Canadian Roads*. (2017)

# CalTrans. *Toward an Active California State Bicycle + Pedestrian Plan.* 2017.

## Structure and Content of Guidance

### Purpose:

This standalone plan summarizes California's most recent efforts to improve active transportation statewide.

### Design User:

This plan has a design user of 'Interested but Concerned' and is geared towards designs for all ages and abilities.

### Guidance Provided:

- Discussion of California's current walking and bicycling policy framework.
- Discussion of the plan's public outreach efforts.
- Discussion of the State's goals, strategies, and performance measures related to safety, mobility, transportation system, and equity.
- Defines bikeways, including separated bike lanes.
- References to more detailed design guides.

## Process

This plan does not discuss a design or planning process for selecting bikeways.

*Facility Selection Tool*

This plan does not present a facility selection tool but it does recommend using a bicycle LTS over bicycle LOS to measure comfort, and generally emphasis connected and comfortable bike networks in its design guidance.

## Evaluation

### Pros:

- The plan is easy to read and well organized.
- The plan provides many pictures of preferred roadway designs.

### Cons:

- The plan does not provide a process or tool to help local practitioners choose bikeways that will help them achieve the statewide goals.
- The plan discusses the importance of safety but doesn't relate it to bikeway selection decisions in a way that is applicable to practitioners who are tasked with applying the guidance and meeting the safety goals.

# Washington State Department of Transportation. *Highway Design Manual.* Chapter 1520 Bicycle Facilities. 2015.

## Structure and Content of Guidance

### Purpose:

This chapter is a guide for designing bicycle facilities within state highway right of way or between the curb lines on city streets designated as state highways.

### Design User:

This guide uses the 'interested but concerned' design user but also provides considerations for confident cyclists.

### Guidance Provided:

- Discussion of different bikeway types with relevant design guidance for each.
- Design considerations for certain scenarios, such as, on-street parking, speed, different user types, and high volumes of cyclists, intersections, traffic signals, rail crossings…etc.
- Discussion of relationship between speed and safety

## Process

This guide does not discuss a process for selecting a bikeway.

## Facility Selection Tool

Washington's bikeway selection tool is in the form of a chart which prescribes a range of bike lanes for specific motor vehicle volume and speed combinations.

## Evaluation

### Pros:

- This guide provides a bikeway selection graphic.
- This guide provides a brief discussion of cyclist safety and the relationship of bicyclist safety and motor vehicle speed.

### Cons:

- This guide contains some graphics, but is not as user-friendly or eye-catching as other design guidance.
- This guide does not provide sufficient bikeway selection guidance.
- This guide does not make it clear whether any variables aside from ADT and speed should be included in the major decisions making processes.
- This guide does not mention which factors, aside from speed should be included in a bikeway selection process, such as budget, maintenance, land use context, number of lanes…etc.
- The facility selection chart uses speeds to indicate when to separate bicycles that to not correspond to typical speed limits or round numbers which may make it difficult to interpret the guidance.

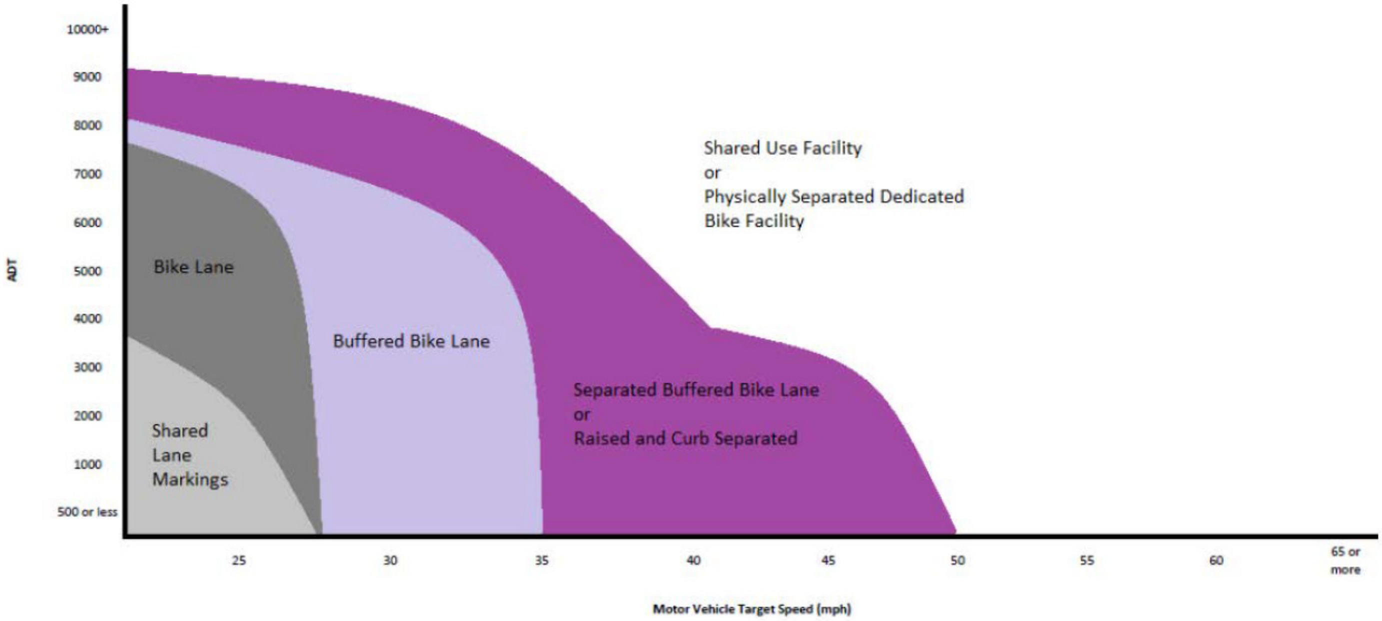



**Figure 35 - Facility Selection Chart for Interested but Concerned Cyclists**

Source: Washington State DOT Highway Design Manual. (2015)

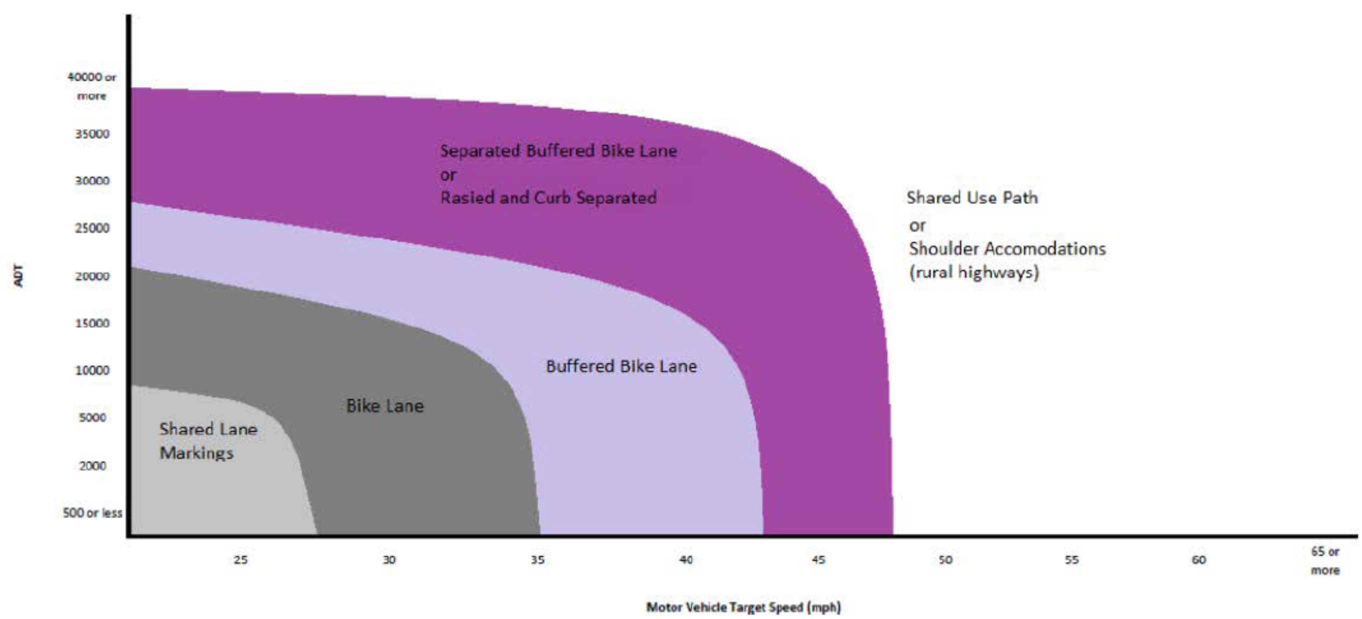



**Figure 36 - Facility Selection Chart for Confident Cyclists**

Source: Washington State DOT *Highway Design Manual*. (2015)

# CROW *Design Manual for Bicycle Traffic*. Chapter 5: Road Sections. 2017.

## Structure and Content of Guidance

### Purpose:

CROW's facility selection tool is included in a chapter of the design manual. The purpose of the chapter is to provide design guidance to explain suitable road environments for bikeways.

### Design User:

The Design Manual does not specify a design user. However, there is an implicit design user that is comparable to what is known as the "Interested But Concerned" bicyclist.

### Guidance Provided:

- Discussion of road requirements for a bikeway, including directness, safety (e.g., crash trends, importance of infrastructure improvements, biggest threats to bicyclists), comfort, and attractiveness.
- Discussion of general bikeway selection guidance which includes pedestrian-bicycle interactions, reducing opportunities for motor vehicles to interact with bicyclists, importance of speed, bidirectional traffic, bike lane buffer standards.

## Process

This guide does not include a bikeway selection process; however, the guide does advise that decisions should consider safety, exposure to pollution, and available space. The guide also explains that bikeway selection decisions should consider three principles:

- Most desirable situation for cyclists,
- Cycle infrastructure and entire traffic situation are important, and
- There is often more than one solution.

## Facility Selection Tool

CROW's bikeway selection tool is in the form of a series of matrices which prescribes a range of bikeways for specific motor vehicle volume, motor vehicle speed, bicycle volume, and road category combinations. The text accompanying the chart indicates that the tool should be applied to built-up areas and should focus on expected speeds (not posted).

## Evaluation

### Pros:

- The guidance is comprehensive and covers many design situations, including pedestrian volumes.
- The guidance provides good background information for the purpose of bicycle infrastructure and how it can be designed and implemented to promote safety and comfort.

### Cons:

- The guide is very text heavy.

- The facility selection tool's integration of bicycle volumes may not be useful in the US where bicycling rates are generally low.
- The guide recognizes that there are situations where two bikeways might be warranted, but it does not explain a process for choosing which one to implement.
- The guide does not provide a clear process for selecting a bikeway to install.

| Road category | Speed limit motorized traffic (km/h) | Volume of motorized traffic (PCU/ 24-hour period) | Cycle network category | |
|---|---|---|---|---|
| | | | Basic structure | Main cycle network or bicycle highway ($I_{bicycle}$ > 500/ 24-hour period) |
| *Residential road* | 60 (or 30) | < 2,500 | mixed traffic | bicycle street if $I_{car} < I_{bicycle}$ 1); cycle path or mixed if $I_{car} > I_{bicycle}$ |
| | | 2,000-3,000 | cycle path, possibly cycle lanes | |
| | | > 3,000 | cycle path | |
| *Distributor road* | 80 | not relevant | cycle/moped path | |

1) plus any additional requirements in terms of speed

**Figure 37 - Selection Plan for Cycle Facilities in the Case of Road Sections Outside of Built-Up Areas**

Source: CROW *Design Manual for Bicycle Traffic*. (2017)

# FHWA *Bicycle Road Safety Audit Guidelines and Prompt List*. 2012.

## Structure and Content of Guidance

### Purpose:
FHWA's guidance is a standalone document developed to provide practitioners with guidelines and prompts to conduct road safety audits to evaluate bicyclists safety.

### Design User:
This guide has one default design user, all cyclists.

### Guidance Provided:
- Discussion of bicyclists' needs, principles of safety, and characteristics of a bicycle network.
- Discussion of integration of bicyclists into road safety audits.
- List of data that practitioners should review when assessing bicyclist safety.
- Prompts to guide practitioners through a comprehensive road safety audit for intersections, crossings, transitions, transit, streets, paths, and structures.

## Process
There is no facility selection process associated with this guide. The Guide provides prompt lists which can inform a risk assessment to identify existing safety challenges which in many cases could be the installation of a bikeway.

## Facility Selection Tool
The Guide provides a graphic which suggest separating bikes from traffic as traffic volume and speed increases, however the graphic provides no criteria. There is a risk assessment table presented which may be used to as a tool to rank existing safety challenges to prioritize countermeasure selection which in many cases could be the installation of a bikeway.

## Evaluation

### Pros:
- This report provides a good primer on bicyclist safety and bicycle network connectivity.
- This report could be a useful reference in a facility selection tool to show how practitioners can assess a roadway or bicycle facility for accessibility, comfort, and safety.

### Cons:
- This report does not provide a facility selection process to evaluate.
- This report does not provide a facility selection tool to evaluate.
- The report doesn't adequately consider bicyclists risks with same direction traffic, dismissing concerns of safety by cyclists as perceived safety concerns, not real or legitimate safety concerns. Stating, "For example, cyclists may choose routes with more conflict points, such as at driveways or intersections, to reduce perceived conflicts with same-direction traffic." Research since 2008 has shown dangers of same direction traffic are much higher than previously understood and outweigh danger with driveways.
- The report does not discuss the relationship between perceived risk and actual risk.

| | RSA Zones | | | | |
|---|---|---|---|---|---|
| | A. Street or Path | B. Structures | C. Intersections, Crossings, and Interchanges | D. Transitions | E. Transit |
| **1. Presence & Availability** | | | | | |
| | Are cyclists accommodated? | | | | |
| **2. Design & Placement** | | | | | |
| | Are design features present that adversely impact the use of the facility by cyclists? | Are bridges/ tunnels designed with adequate bicycle accommodations on both sides?<br><br>Does the gradient of the cycling accommodations impact the use of the facility? | Are intersection/ interchange accommodations designed to reduce conflicting movements and communicate proper bicycle positioning through the crossing? | Are transition areas designed with logical termini or do they end abruptly, potentially contributing to sudden and difficult merges, midblock crossings, or behaviors such as wrong-way riding? | Are transit facilities designed and placed to minimize conflicts with other modes? |
| **3. Operations** | | | | | |
| | Are there suitable provisions for cyclists given the characteristics of the roadway or path (speed, volume, traffic, and functional classification)?<br><br>Do access management practices detract from cycling safety? | | Do traffic operations (especially during peak periods) create a safety concern for cyclists? | Do shared roadway geometrics change substantially or frequently? | Are transit facilities designed and placed to minimize conflicts with other modes? |
| **4. Quality & Conditions** | | | | | |
| | Is the riding surface smooth, stable, and free of debris and is drainage adequate?<br><br>Are drainage | Is the grating/ bridge surface designed for cyclists?<br><br>Is drainage adequate to | Are there any obstacles at crossings?<br><br>Are the manhole covers properly designed? | Is there an abrupt change in riding surface? | Are transit stops maintained during periods of inclement weather? |

**Figure 38 - Example Prompt List for RSA**

Source: FHWA *Bicycle Road Safety Audit Guidelines and Prompt List.* (2012)

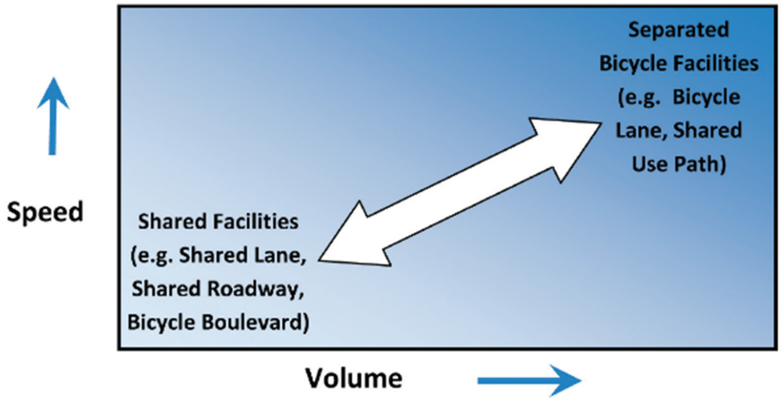



**Figure 39 - General Bicycle Facility Utilization Given the Context of Vehicular Traffic Volume and Speed**

Source: FHWA *Bicycle Road Safety Audit Guidelines and Prompt List*. (2012)

| Frequency of Crashes | Severity of Crashes | | | |
|---|---|---|---|---|
| | Possible/Minor Injury | Moderate Injury | Serious Injury | Fatal |
| Frequent | Moderately High | High | Highest | Highest |
| Occasional | Middle | Moderately High | High | Highest |
| Infrequent | Low | Middle | Moderately High | High |
| Rare | Lowest | Low | Middle | High |

**Figure 40 - Risk Assessment Prioritization Matrix**

Source: FHWA *Bicycle Road Safety Audit Guidelines and Prompt List*. (2012)

# FHWA *Small Town and Rural Multimodal Networks*. 2016.

## Structure and Content of Guidance

### Purpose:

The standalone FHWA guide provides design guidance for the purpose of helping communities in rural areas and small towns to install bicycle and pedestrian facilities that are comfortable, accessible, and safe.

### Design User:

This guide uses an 'all ages and abilities' design user and emphasizes populations who are young, elderly, or have mobility disabilities.

### Guidance Provided:

- Defines an all ages and abilities network.
- Discusses common safety, planning, and design challenges in small towns and rural areas.
- Discussions of the benefits and basic design guidance for each treatment.
- Examples of treatments in use.

## Process

This guide does not include a discussion of the process to select a preferred bikeway or pedestrian treatment.

## Facility Selection Tool

FHWA's guide does not have one facility selection tool, however, for each treatment or bikeway type, the guide provides application guidance based on speed, motor vehicle volume, roadway purpose, and land use.

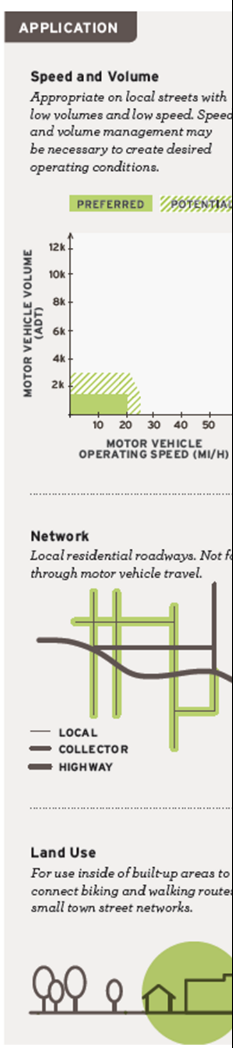
## Evaluation

### Pros:

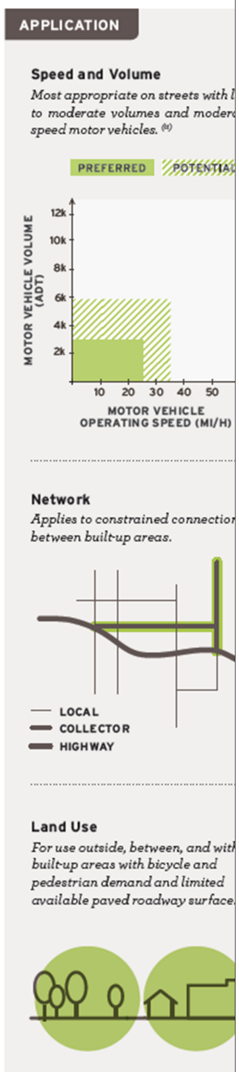
- The guide has concise text, many useful graphics, is well organized and easy to ready.
- The guide takes a network approach to planning and design.
- The guide provides design guidance for school connections.

### Cons:

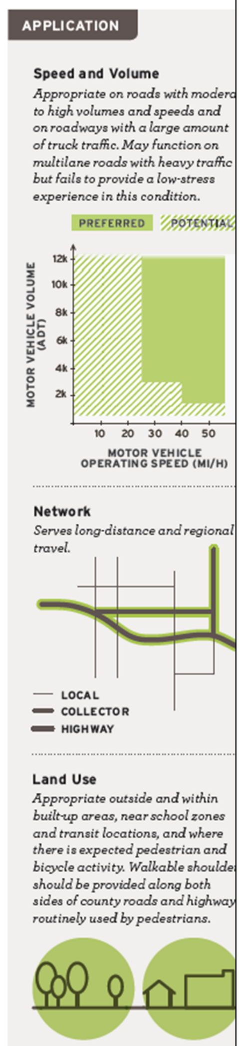
- The guide mentions the importance of safety, but provides little discussion of the connection between bikeways and safety.
- The guide is organized by treatment, making it more applicable for providing background information on a treatment for situations when one has a treatment that they wish to install, rather than having a roadway that needs safety improvements.
- The guide provides a discussion of speed management but doesn't discuss how to apply the strategies presented in combinations with the treatments presented in the guide.



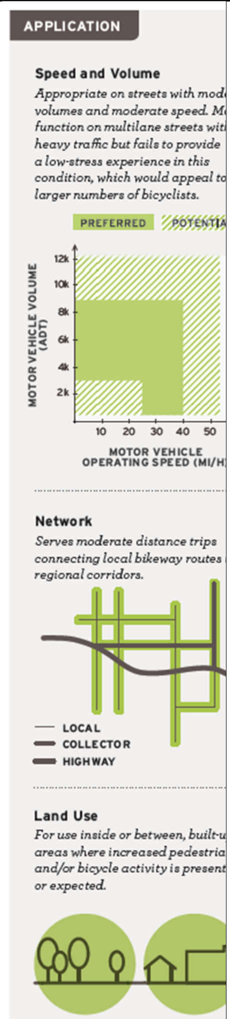

Bicycle Boulevard



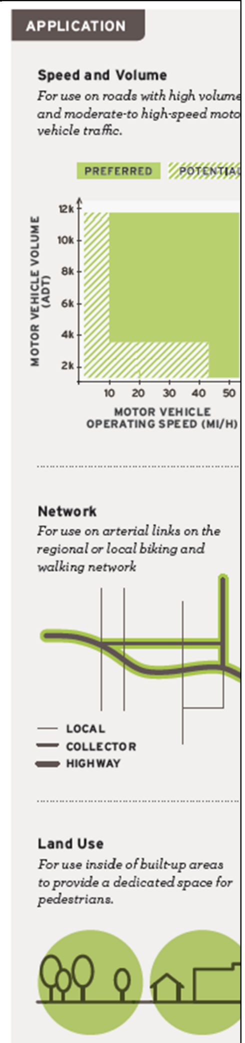

Advisory Bike Lane




Paved Shoulder




Bike Lane




Sidepath

**Figure 41 - Facility Application Guidance**

Source: FHWA *Small Town and Rural Multimodal Networks.* (2016)

# FHWA *Separated Bike Lane Planning and Design Guide*. 2015.

## Structure and Content of Guidance

### Purpose:

The standalone FHWA guide provides design guidance and planning considerations for separated bike lanes.

### Design User:

This guide defaults to the 'Interested but Concerned' design user, with an emphasis on children and the elderly.

### Guidance Provided:

- Definitions, benefits, and context of separated bike lanes.
- Discussion of taking a flexible approach to implementation
- Discussion of low-stress connected networks and four types of cyclists.
- Discussion of safety and separated bike lanes.
- Discussion of many planning and design considerations, including transit stops, accessible parking, driveways, signal phasing, safety benefits, local support, equity, and transitions to other types of bikeways.

## Process

FHWA's guide provides a planning and design process that is accompanied by in-text guidance and examples. The guide provides contextual considerations for designers to evaluate and address when planning and designing separated bike lanes. The guide also recommends the following process to follow to design separated bike lanes:

1. Establish Directional and Width Criteria
2. Select Forms of Separation
3. Identify Midblock Design Challenges and Solutions
4. Develop Intersection Design

## Facility Selection Tool

FHWA's guide does not provide a bikeway selection graphic.

## Evaluation

### Pros:

- The guide provides helpful sample design challenges which highlight ways to think through design situations.
- The guide provides many case studies from around the country.
- The guide provides a comprehensive list and description of planning and design considerations (e.g., funding opportunities, equity, evaluation, and local support).
- The guide emphasizes the use of design flexibility including the use of the FHWA experimentation process to incorporate new traffic control devices.
- The guide provides a comprehensive list of design and context considerations.
- The guide included case studies of safety and ridership data from projects around the U.S.

Cons:

- The guide does not provide a way to evaluate tradeoffs.
- The guide does not provide enough guidance about when to choose separated bike lanes over other bikeways.

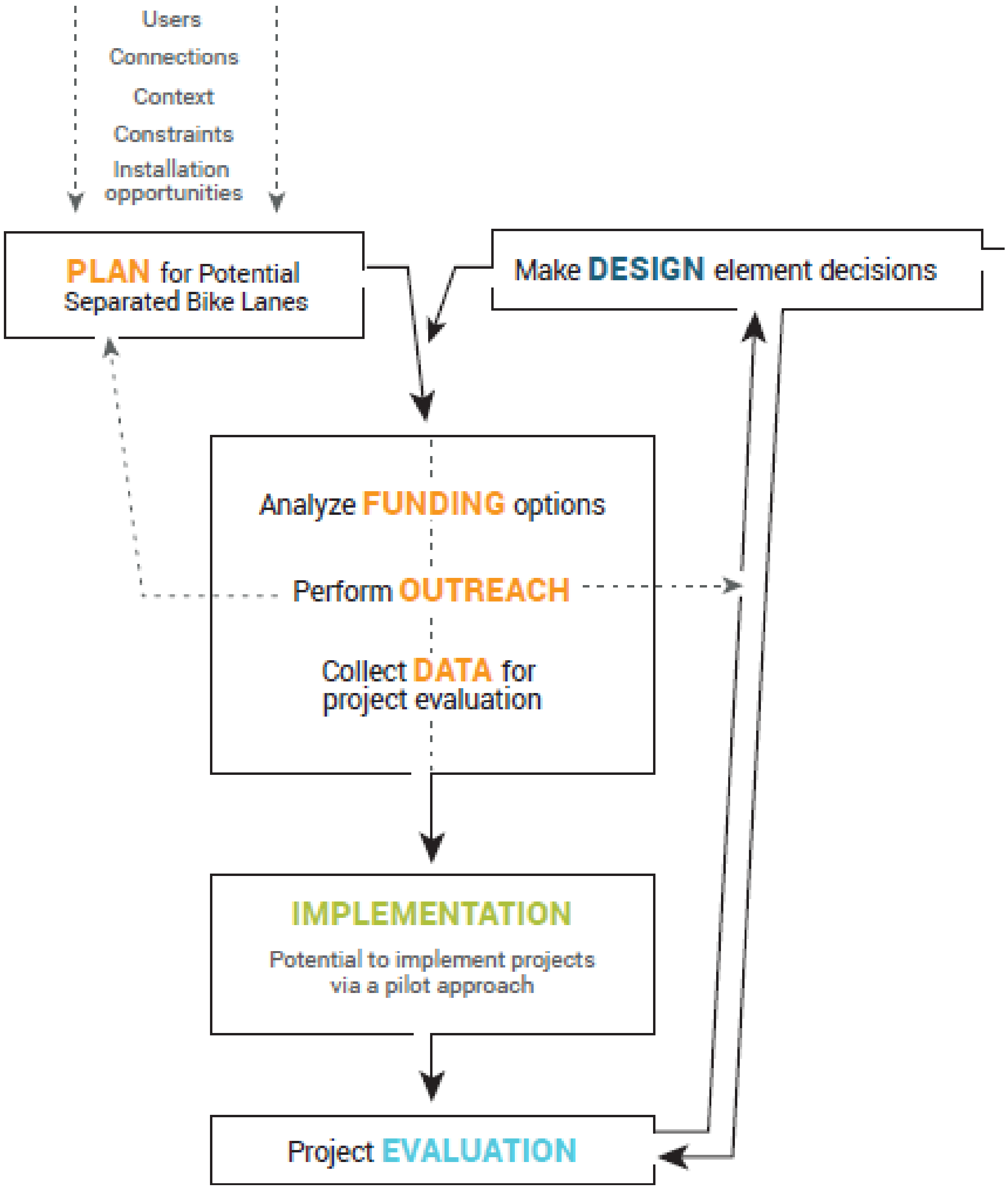



**Figure 42 - Separated Bike Lane Planning and Design Process**

Source: FHWA *Separated Bike Lane Planning and Design Guide*. (2015)

# Institute of Transportation Engineers. *Protected Bikeways Practitioners Guide*. 2017.

## Structure and Content of Guidance

### Purpose:

The standalone ITE guide provides best practices and resources for planning, designing, and implementing protected bikeways for the purpose of improving public health and roadway safety.

### Design User:

This guide's designer user is people of all ages and abilities.

### Guidance Provided:

- Discussion of safety performance, midblock design and operation, intersection design and operation, maintenance, implementation, and resources for national guidelines and standards.
- Discussion of importance of installing protected bikeways.
- Discussion of research where relevant.
- Detailed discussion of maintenance considerations for design and operation including budgeting and staff training.
- Discussion of implementation strategies and performance measures, including data collection, community engagement, and education.

### Process

This guide does not include a discussion of the process to select a preferred bikeway.

### Facility Selection Tool

This guide does not include a discussion of a bikeway selection tool.

## Evaluation

### Pros:

- This guide includes considerations in addition to design changes for improving the effectiveness of bikeway installation.
- This guide has a strong emphasis on safety and comfort. It builds a strong case for prioritizing safety and explains how bikeway design and selection relate to safety.
- This guide is a digestible length and has a good balance of text and graphics.
- This guide provides a short summary of motivators and deterrents which help support the guidance.

### Cons:

- This guide does not explain how to effectively incorporate safety into the bikeway selection process.
- This guide does not discuss the bikeway selection process.
- This guide does not have a bikeway selection graphic.

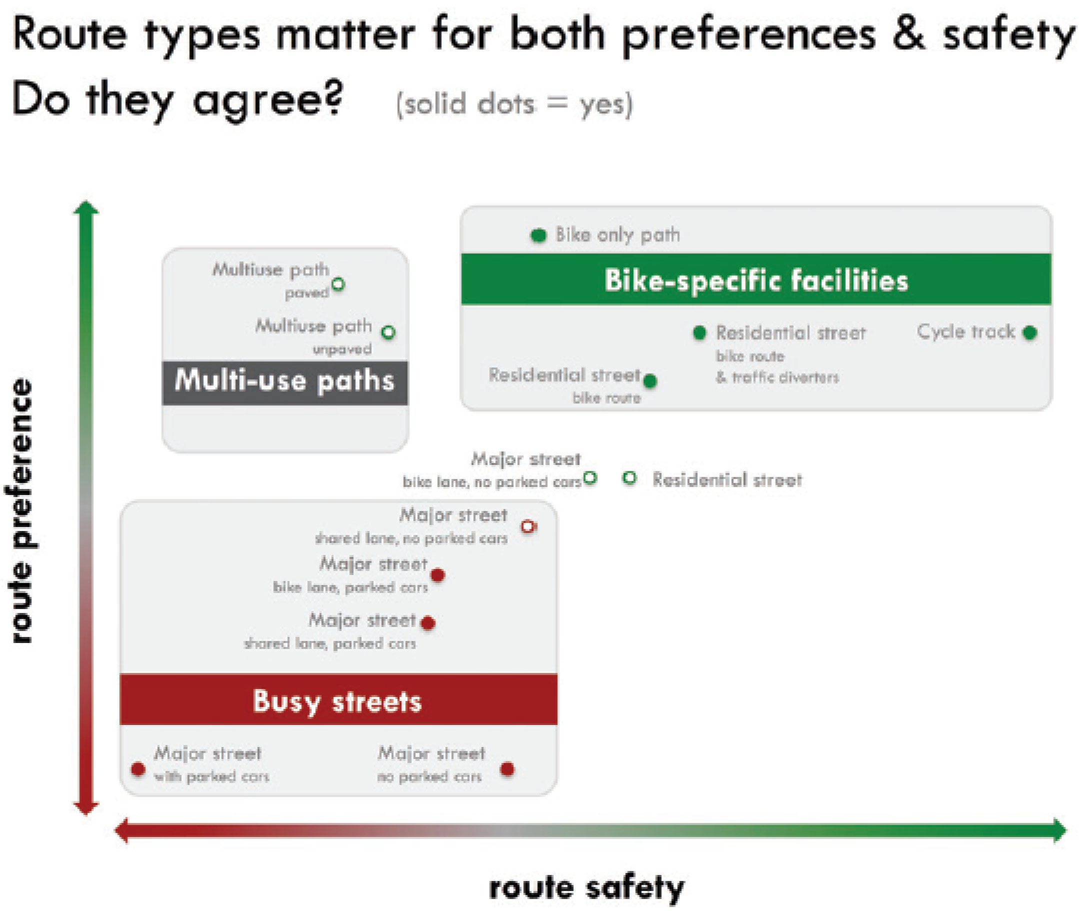



**Figure 43 - Bicycle Safety Comparison between User Preferences and Observed Safety**

Source: Institute of Transportation Engineers. *Protected Bikeways Practitioners Guide*. (2017)

# Montgomery County. *Bicycle Planning Guidance.* 2014.

## Structure and Content of Guidance

### Purpose:

Montgomery County's guidance is a standalone document developed to assist with the process of identifying an appropriate bicycle facility. The guide is designed to help predict the success of a facility in terms of attracting new riders, and to help practitioners make strategic bikeway selection decisions.

### Design User:

This guide has two design users, the "interested but concerned" which is the default design user as well as guidance for the and "enthused and confident".

### Guidance Provided:

- Discussion of cyclist typology; different types of bicycle facilities; and the importance of bicycle network connectivity.
- Design considerations and mitigation strategies for on-street parking, driveways, major signalized intersections, connections between new and existing facilities, and vehicle mix.
- A case study to demonstrate how to implement the recommended facility selection process.

## Process

The bikeway selection tool is accompanied by additional resources that are included as part of a five-step process for bikeway selection, including a level of traffic stress methodology. The tool includes a flow chart which guides practitioners through the facility selection process.

Step 1. Use the "Designing for Interested but Concerned" chart to pre-select bikeway facility type.
Step 2. Use the "Level of Traffic Stress" methodology to refine the facility type.
Step 3. Determine engineering and cost feasibility.
Step 4. Assess facility feasibility and user group.
Step 5. Reconsider project scope if necessary.

## Facility Selection Tool

Montgomery County's facility selection tool is in the form of two speed-volume charts that reflect design considerations for both the "interested but concerned" and "enthused and confident" user groups.

## Evaluation

### Pros:

- The guide provides easy-to-follow process guidance.
- The guide explains how to integrate costs into the bikeway selection process.
- The guide prescribes a network-oriented approach that can also be easily applied by practitioners not following a network approach.
- The guide emphasizes bicyclist comfort.
- The guide provides mitigation strategies to improve the use of certain bikeways in different roadway environments.
- The guide provides a process that can accommodate designing for multiple user groups simultaneously.

Cons:

- The guide does not clearly explain how to weight or incorporate the “additional design considerations” into the facility selection process.
- The guide does not discuss tradeoffs.

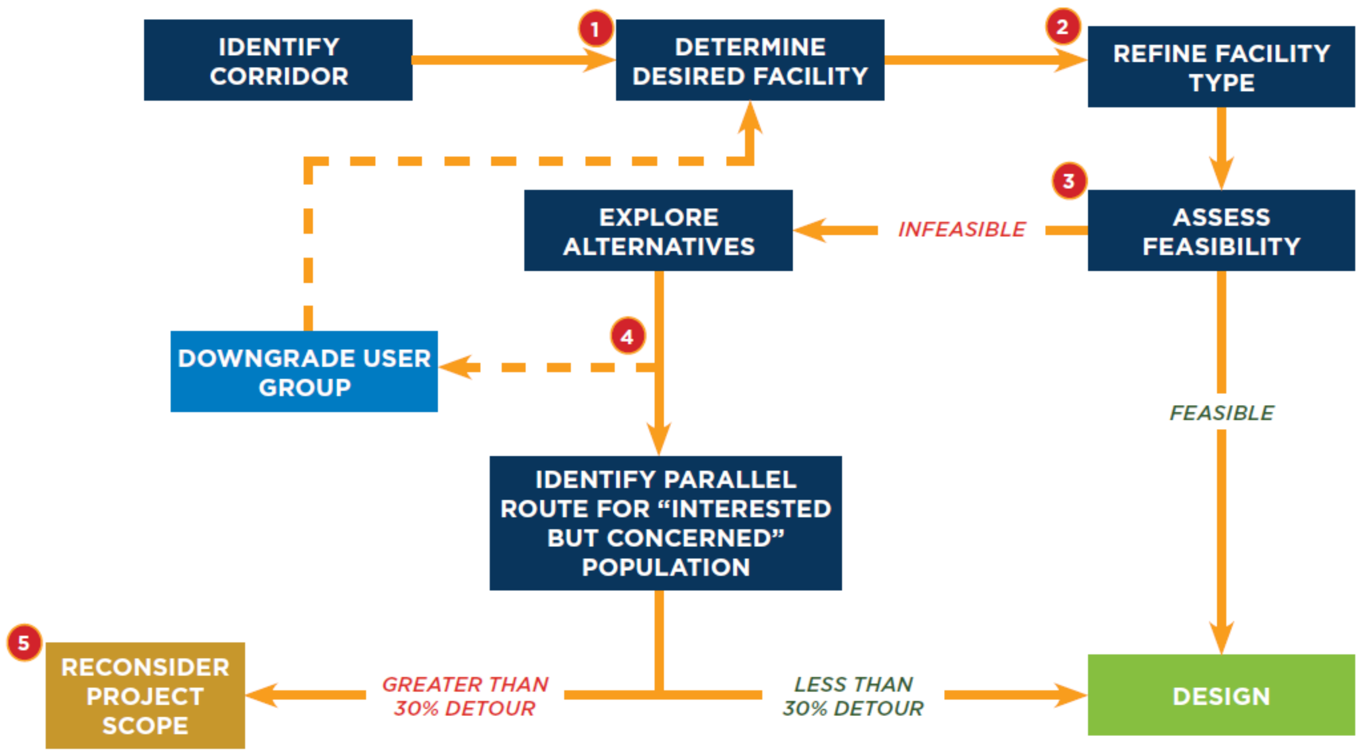



**Figure 44 - Facility Selection Process**

Source: Montgomery County. *Bicycle Planning Guidance*. (2014)

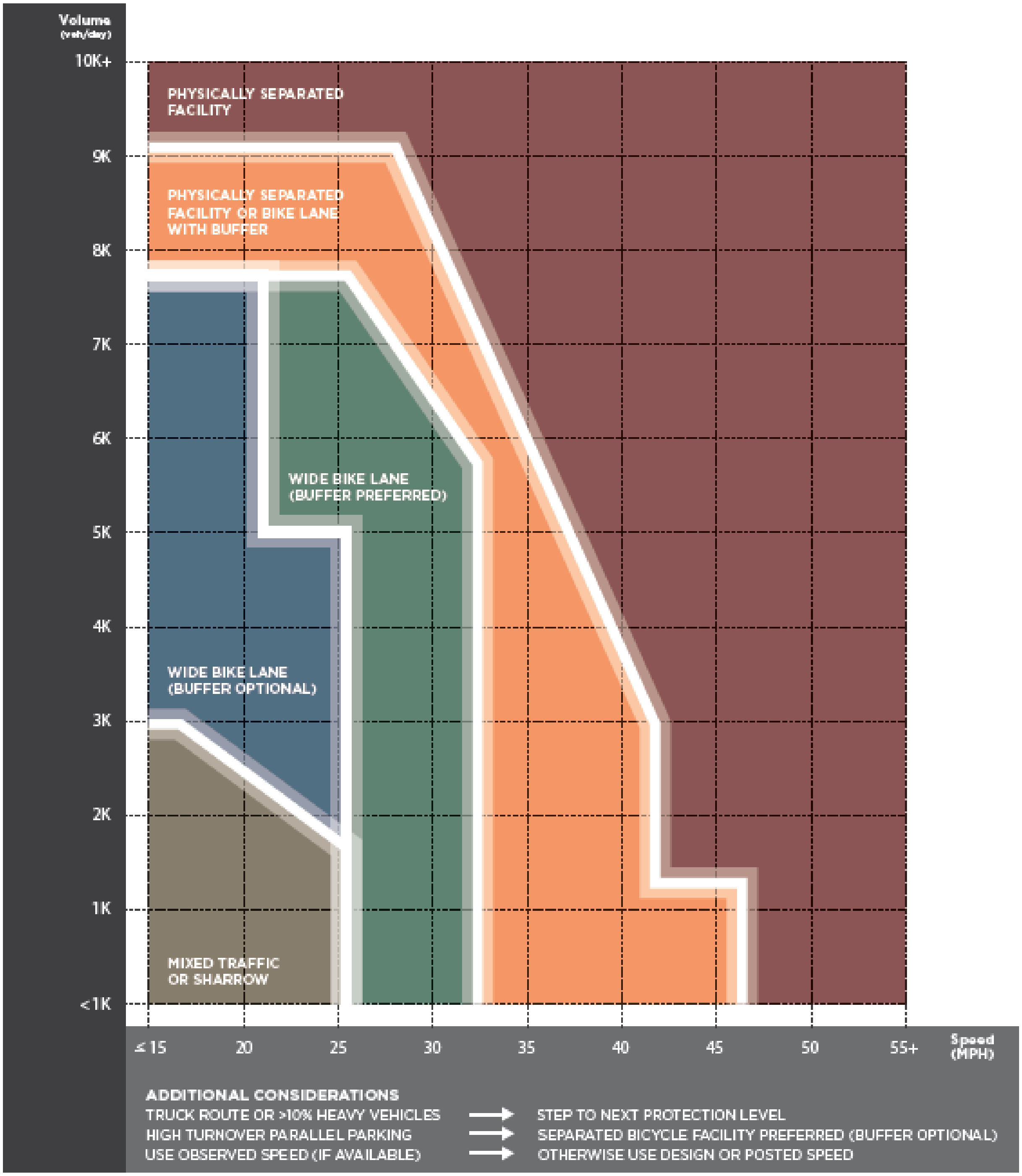



**Figure 45 - Facility Selection Tool for "Interested but Concerned" Users**

Source: Montgomery County. *Bicycle Planning Guidance*. (2014)

# Ontario. *Traffic Manual*. Book 18: Cycling Facilities. 2013.

## Structure and Content of Guidance

### Purpose:

Ontario's facility selection guidance is included as a chapter in Ontario's Traffic Manual. The facility selection chapter provides a consistent framework for bikeway design with a goal of improving roadway safety.

### Design User:

This guide has three design users: experienced cyclists, novice cyclists, and child cyclists.

### Guidance Provided:

- A discussion of the decision to separate bicyclist and motorists.
- A discussion of the importance of context and concerns that may be more or less important in urban and rural environments.
- Design considerations for various scenarios within 13 different selection criteria divided into two tiers.[145]

## Process

The guidance includes a detailed three-step facility selection process. Figure 1 shows the recommended facility selection process. Figure 2 shows a sample worksheet that could be used to complete the facility selection process.

## Facility Selection Tool

Ontario's facility selection tool is in the form of a chart which prescribes a range of bikeways for specific motor vehicle volume and operating speed combinations.

## Evaluation

### Pros:

- The guide explicitly incorporates safety of cyclists (crash risk) into the decision-making process.
- The guide incorporates selection criteria beyond roadway or user characteristics, such as cost, available space, and to a lesser extent – maintenance.
  The guide recognizes nuances and importance of context in selecting bicycle facilities.
- The guide includes description of process for implementing facility selection tool and critically thinking about facility selection.
- The guide defines all terms used in the tool and implementation process.
- The guide includes urban, suburban, and rural design considerations, such as speed, presence of on-street parking, and frequency of intersections.
- The guide provides guidance on a large variety of selection criteria in a way that leaves room for flexibility in the application of the facility selection process.

### Cons:

- The guide does not consider pedestrian volumes or vehicle congestion in the facility selection process.

[145] The primary selection criteria include 85$^{th}$ percentile motor vehicle operating speed, motor vehicle volume, road function, vehicle mix, crash history, and available space. The secondary selection criteria include costs, anticipated users, bicycle volume, function of route within bike network, type of roadway improvement project, on-street parking, and intersection frequency.

- The guide does not provide clear guidance for evaluating alternatives if multiple bikeways could be appropriate, or how to weight selection criteria.
- The bikeway selection guidance is buried in a lengthy design guide.

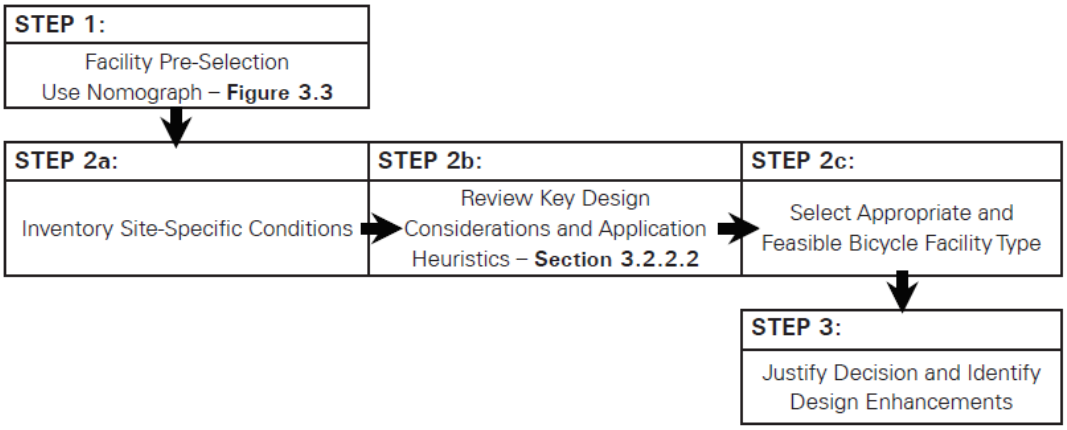



**Figure 46 - Bicycle Facility Selection Three-Step Process**

Source: *Ontario Traffic Manual* Book 18: Cycling Facilities (2013)

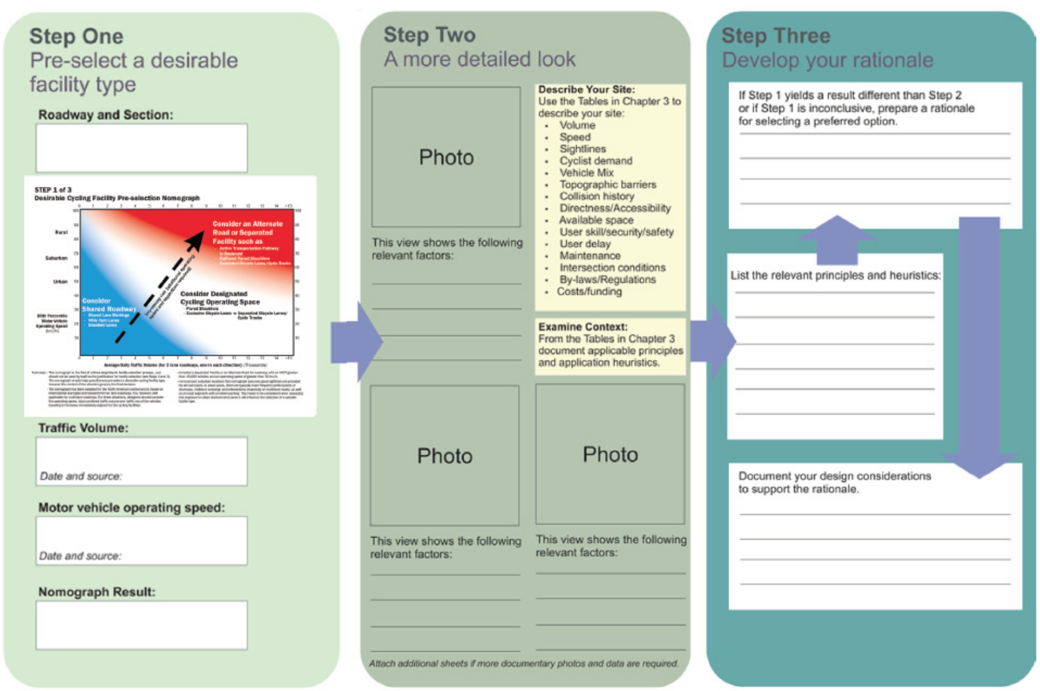



**Figure 47 - Sample Worksheet for Facility Selection Tool**

Source: *Ontario Traffic Manual* Book 18: Cycling Facilities (2013)

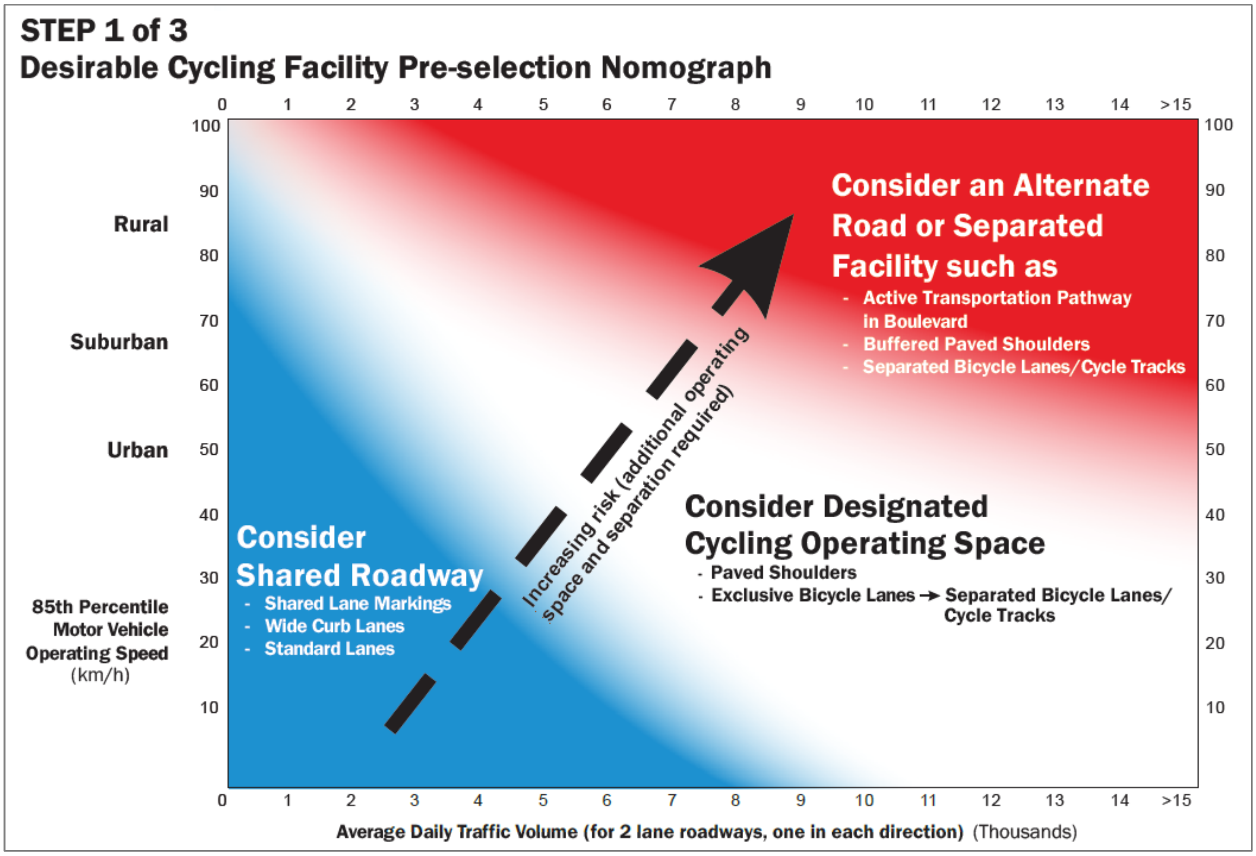



**Figure 48 - Facility Selection Tool**

Source: *Ontario Traffic Manual* Book 18: Cycling Facilities (2013)

# City of Ottawa. *Cycling Facility Selection Decision Support Tool and User Guide.* 2011.

## Structure and Content of Guidance

### Purpose:

The tool and user guide from Ottawa are part of an extensive report on facility selection methodologies. The purpose of this report is to provide a review of existing tools to inform the creation of Ottawa's own facility selection tool.

### Design User:

This report does not specify a specific design user.

### Guidance Provided:

- Discussion of the role of separated facilities.
- Discussion of different types of cyclists.
- Review of facility selection tools from the U.S. and abroad.
- Description of the process for developing the facility selection tool.
- Examples of a completed facility selection worksheet.

## Process

There are three stages involved in Ottawa's bikeway selection process:

1. An initial pre-selection step using a chart to guide the practitioner in selecting an initial facility type (see Figure 2);
2. A decision tree process and roadway characteristics table that guide the practitioner through the decision-making process at a more detailed level (see Figure 1); and
3. A process for summarizing the decision and rationale behind a final facility type (see Figure 3).

## Facility Selection Tool

Ottawa's facility selection tool takes the form of a chart (see Figure 2) which prescribes a range of bikeways for specific motor vehicle traffic volume, congestion, and speed combinations.

## Evaluation

### Pros:

- The tool presented in this guide was created based on an extensive literature review.[146]
- This guide integrates vehicle congestion conditions into the bikeway selection chart and is an improvement upon the nearly identical facility selection tool described in Ontario's Traffic Manual.
- The necessary inputs for the tool are based on easily accessible information.

[146] NCHRP Report 552 (Guidelines for Analysis of Investment in Bicycle Facilities), AASHTO Guide for the Development of Bicycle Facilities, and studies conducted on segregated cycling facilities in the Netherlands, United States, Australia, New Zealand, Denmark, United Kingdom, and Germany.

Cons:

- This tool is presented as part of a report which is long and geared towards an academic audience.
- The bikeway selection tool is not designed to address rural or suburban roads.
- The report does not define the bikeways listed in bikeway selection chart.

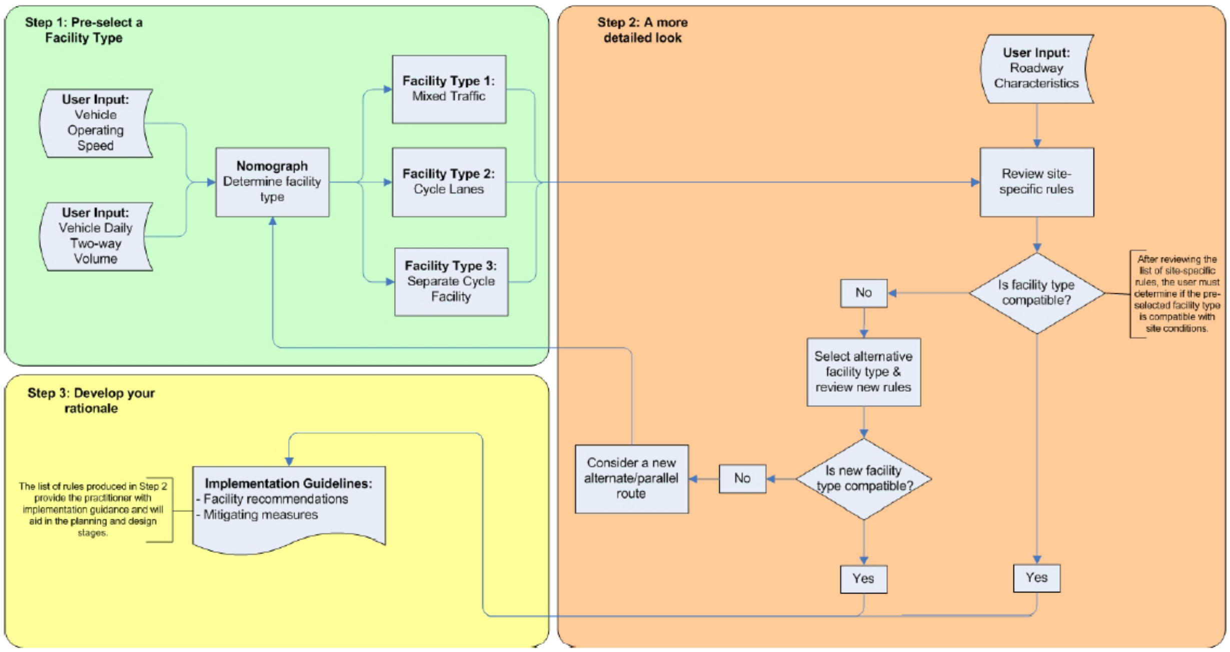



**Figure 49 - Facility Selection Process Diagram**

Source: City of Ottawa. *Cycling Facility Selection Decision Support Tool and User Guide*. (2011)

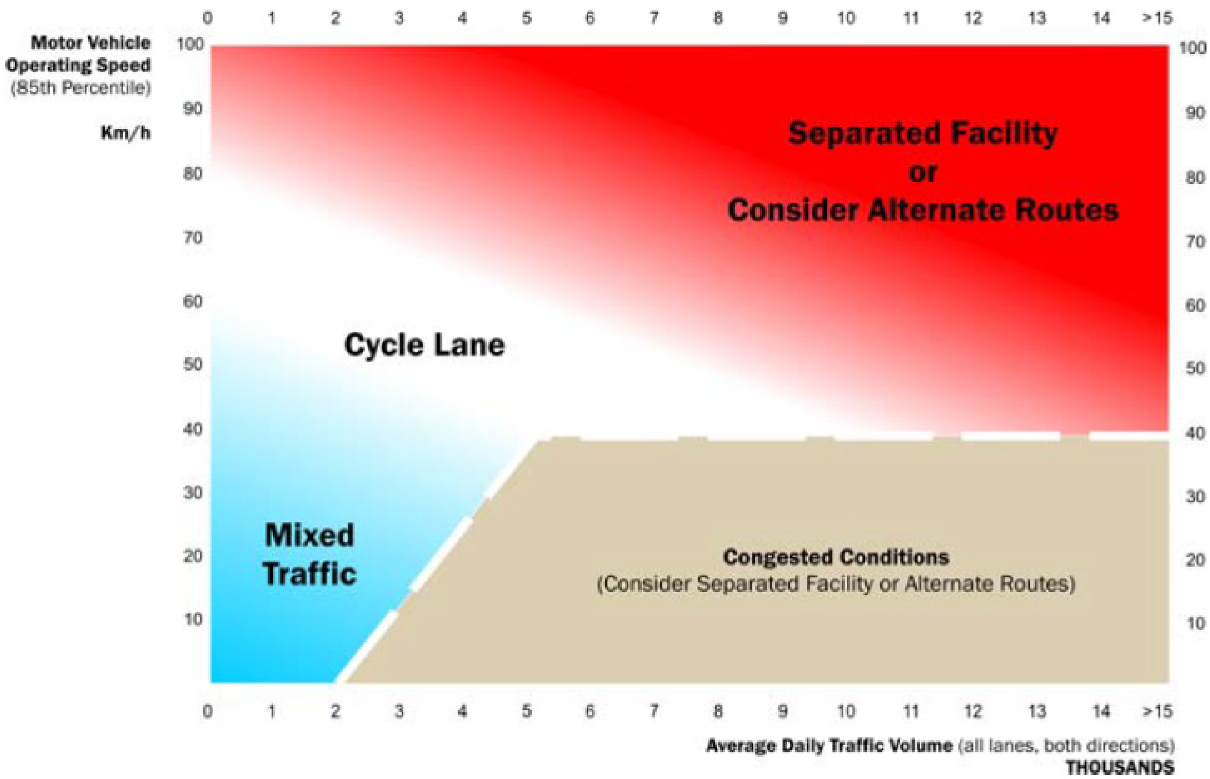



**Figure 50 - Facility Selection Tool**

Source: City of Ottawa. *Cycling Facility Selection Decision Support Tool and User Guide*. (2011)

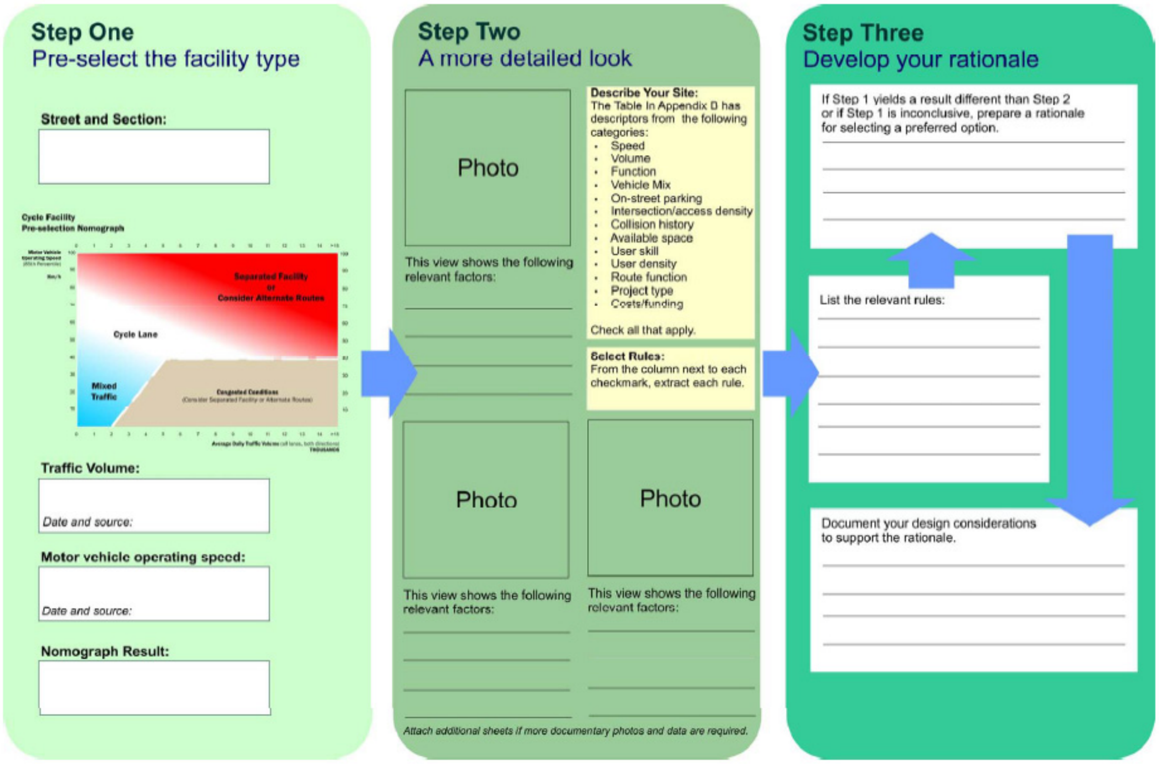



**Figure 51 - Facility Selection Worksheet**

Source: City of Ottawa. *Cycling Facility Selection Decision Support Tool and User Guide*. (2011)

# City of Vancouver. *Transportation Design Guidelines: All Ages and Abilities Cycling Routes.* 2017.

## Structure and Content of Guidance

### Purpose:

The standalone guide from Vancouver provides practitioners with design rules to consider when designing and designating bikeways for bicyclists of all ages and abilities.

### Design User:

This guide has a single design user: populations who feel the least confident riding a bike with motorized traffic, with an emphasis on accommodating families with children, seniors, and new bicyclists.

### Guidance Provided:

- Description and discussion of considerations and applications for 10 design rules (see Figure 1):
    1. Designing for Comfort, including a graphic of the only three facilities that are acceptable for the design user
    2. Provides target for low vehicle volume and considerations for different roadway scenarios
    3. Target vehicle speed below 30km/hour, and considerations
    4. Consider parking/roadway interactions, considerations
    5. Design bike lane width for comfortable passing (uni-direction and bi-direction guidance)
    6. Provide Adequate lighting
    7. Create separate spaces for walking and biking
    8. Provide smooth and paved travel surfaces
    9. Keep grades low
    10. Intersection design
- Discussion of the importance of bicyclist safety in relation to motor vehicle speed and incorporation of this information into design decisions.

## Process

This guide does not include a discussion of the process to select a preferred bikeway.

## Facility Selection Tool

This guide does not include a facility selection tool.

## Evaluation

### Pros:

- The guide presents a very simple approach to designing for a specific design user.
- The guide prioritizes comfort and safety.
- The guide discusses some design considerations that some bikeway guides do not discuss, such as lighting, surface material, grade, and pedestrian and bicyclist interactions. This guidance may be useful to practitioners seeking to improve bicyclist comfort levels when upgrading to a separated bikeway is not an option.

### Cons:

- The guide does not provide one, go-to graphic to help practitioners select a bikeway.

- The guide does not directly discuss tradeoffs between bikeways or specific scenarios in which each bikeway should be applied.
- The guide does not discuss a process to guide bikeway selection.
- The guide does not provide detailed design considerations.
- There is no guidance to help practitioners determine when to use non-physically separated bike lanes (e.g., painted buffered bike lane or bike lane), which may be the only option in many U.S. contexts.

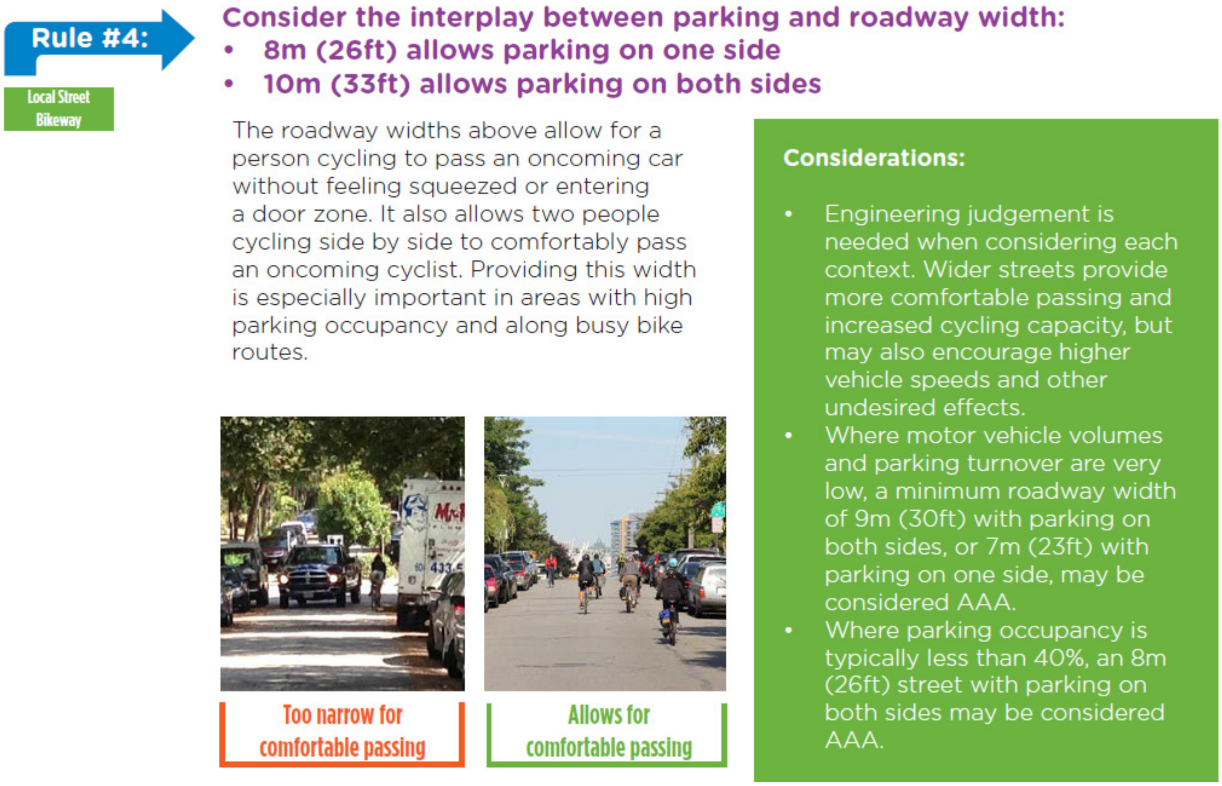



**Figure 52 - Rule 4 of 10**

Source: City of Vancouver. *Transportation Design Guidelines: All Ages and Abilities Cycling Routes.* (2017)

# Washington County, Oregon. *Bicycle Facility Design Toolkit*. 2012.

## Structure and Content of Guidance

### Purpose:

Washington Counties facility selection tool is part of a facility design toolkit that was developed to supplement the County's road design standards.

### Design User:

This guide has three design users, including advanced, basic, and concerned.

### Guidance Provided:

- Discussion of the four types of cyclists; minimum bicycle operating dimensions; freight, transit and emergency services; conflict points (e.g., intersections and driveways); transitions; roadway geometry; maintenance; cost; and roadway modification services.
- Suggested traffic volume, posted speed, and land use context for which the given facility type is appropriate, as well as a summary of the costs associated with each facility.
- Discussion of treatments other than standard bicycle facilities such as colored pavement in conflict zones, contraflow bike lanes, bike signals, bike boxes, and lighting.
- A matrix for facilities and additional treatments (colored bike lanes, bike signals) and their relative maintenance requirements and construction costs.

## Process

The guide provides a three-step process for bikeway selection.

Step 1. Identify preferred bike facility type using daily traffic volume and travel speed.
Step 2. Examine potential roadway modifications needed to accommodate the preferred facility.
Step 3. Use a decision tree and checklist to confirm compatibility between preferred facility and existing roadway environment.

Figure 2 shows a sample project summary sheet used in conjunction with the tool which can be used to document the selection process.

## Facility Selection Tool

Washington County's bikeway selection tool is in the form of a chart which prescribes a range of bikeways for specific motor vehicle volume and speed combinations.

## Evaluation

### Pros:

- The guide provides easy-to-follow process guidance to accompany the bikeway selection graphic.
- The guide provides more maintenance and cost information related to bikeway selection than most tools (see Figure 4).

### Cons:

- The guide does not directly explain how to incorporate maintenance, cost, or other non-roadway information into the bikeway selection process.
- The guide does not directly integrate safety into the bikeway selection process.

- The guide does not provide meaningful land use context guidance.
- The guide does not integrate pedestrian volume into the bikeway selection process.

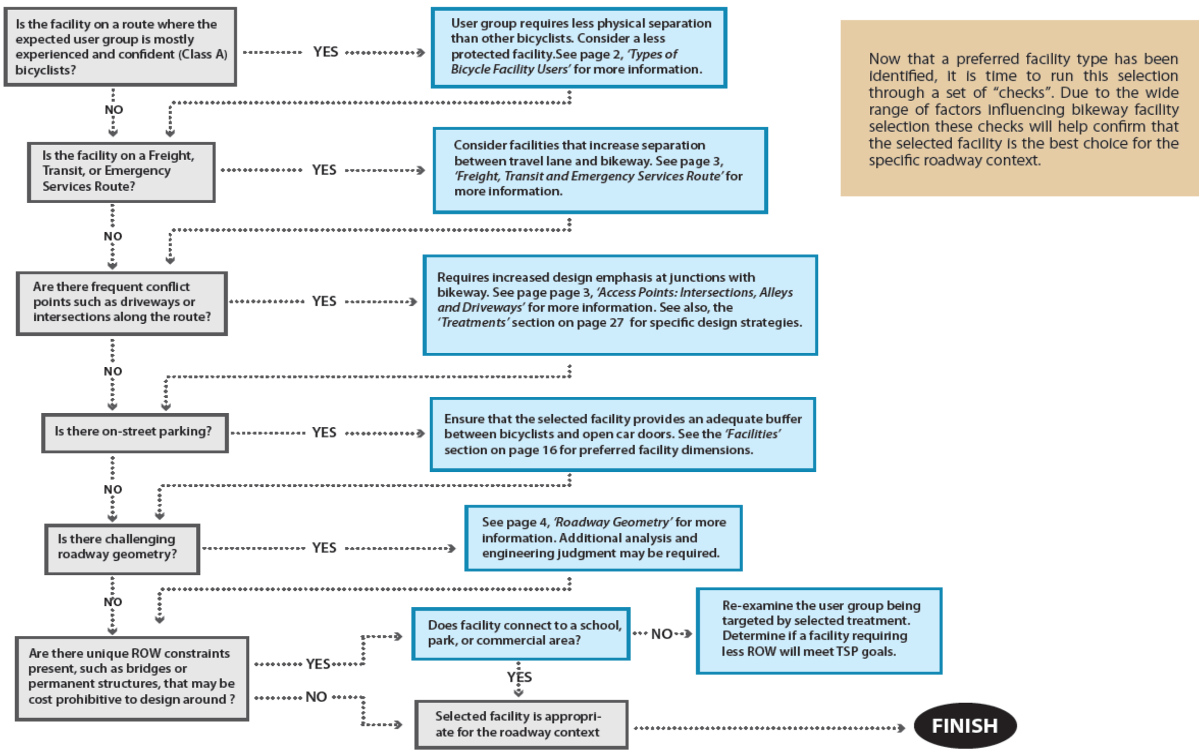



**Figure 53 - Bicycle Facility Selection Decision Tree**

Source: Washington County, Oregon. *Bicycle Facility Design Toolkit* (2012)

# PROJECT WORKSHEET

**Washington County Bicycle Facility Design Toolkit**

PROJECT NUMBER ________ PROJECT NAME ________________ EXTENTS (FROM/TO) ________________

IRIS ROAD OR ASSET NUMBER ________ FUNCTIONAL CLASSIFICATION ________________ LAND USE DISTRICT ________________

DAILY TRAFFIC ________ 85TH-PERCENTILE SPEED ________ PERCENT HEAVY TRAFFIC ________ EXISTING ROW ________ PAVEMENT WIDTH ________

**FACILITY CHECKS**

| | |
|---|---|
| Bicycle system of county-wide significance on TSP: | ☐ YES ☐ NO |
| Expected Bicycle User Group (check all that apply): | ☐ Advanced ☐ Basic ☐ Concerned |
| Designated Freight or Transit Route: | ☐ YES ☐ NO |
| Emergency Services Route: | ☐ YES ☐ NO |
| Density of Conflict Points (Driveways/Intersections): | ☐ HIGH (<200') ☐ MED (200'-600') ☐ LOW (>600') |
| On-Street Parking Prescence: | ☐ YES ☐ NO |
| Challenging Road Geometry: | ☐ YES ☐ NO |

Adjacent School(s): ________________

Adjacent Park(s): ________________

Transit Route(s): ________________

Adjacent Commercial Area(s): ________________

Adjacent Neighborhood(s): ________________

Nearby Point(s) of Interest: ________________

Please describe any special ROW constraints that may be present (e.g., bridges, buildings, wetlands, etc):

Department(s) that populated this worksheet:

CROSS-SECTIONS

Please sketch the existing cross-section

Please sketch the proposed cross-section

Recommended Facility Type:

Recommended Cross-Section Modification(s):

**Figure 54 - Facility Selection Process Summary Worksheet**

Source: Washington County, Oregon. *Bicycle Facility Design Toolkit* (2012)

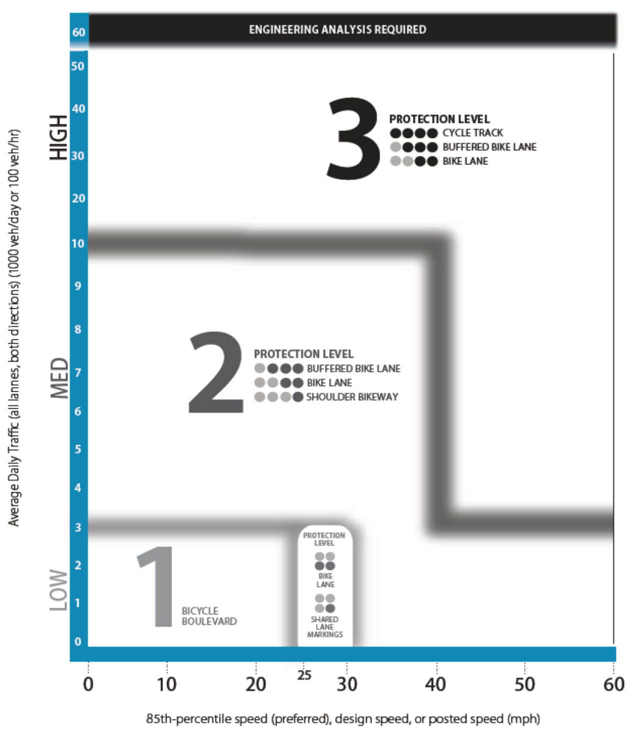



**Figure 55 - Facility Selection Chart**

Source: Washington County, Oregon. *Bicycle Facility Design Toolkit* (2012)

| MAINTENANCE AND CONSTRUCTION MATRIX | MAINTENANCE REQUIREMENTS | CONSTRUCTION COST (Relative to other Facilities and Treatments) | NOTES |
|---|---|---|---|
| **FACILITIES** | | | |
| Shared Lane Markings | ◕ | ● | Depends on placement. Pavment markings that are centered in the travel lane suffer less wear because vehicle wheels will drive over the marking less. |
| Shoulder Bikeway | ● | ● | |
| Bike Lane | ◕ | ● | |
| Buffered Bike Lane | ◔ | ◕ | |
| Protected Cycle Track | ◔ | ◑ | Access by streetsweeping or snow clearing equipment is dependent on the specific protection strategy used. |
| Raised Cycle Track | ◔ | ◔ | Access by streetsweeping or snow clearing equipment is dependent on the specific protection strategy used. |
| Two-way Cycle Track | ◔ | ◑ | Access by streetsweeping or snow clearing equipment is dependent on the specific protection strategy used. |
| Multi-Use Off-Street Path | ◔ | ◔ | |
| Bicycle Boulevard | ● | ● | Depends on the level of treatment. Construction cost increases with the level of traffic calming required |
| **TREATMENTS** | | | |
| Colored Bike Lane | ◔ | ◑ | Durability of colored pavement depends on many factors |
| Contra-Flow Bike Lane | ● | ● | |
| Uphill Bike Lane; Downhill SLM | ● | ● | |
| Bicycle Signal | ◕ | ◑ | |
| Intersection Crossing Markings | ◑ | ◕ | Durability of pavement markings depends on many factors |
| Bike Box | ◑ | ◑ | |
| Two-Stage Left Turn Queue Boxes | ◑ | ◑ | |
| Wayfinding | ● | ◕ | Depends on level of detail and number of signs |

This table provides a general review of the intensity of maintenance needs and overall construction cost of individual facilities.

● Lowest Cost/Easiest to Maintain
◕
◑
◔ Highest Cost/Most Difficult to Maintain

**Figure 56 - Bicycle Facility and Treatment Maintenance and Construction Matrix**

Source: Washington County, Oregon. *Bicycle Facility Design Toolkit* (2012)

# Appendix B: Non-Bikeway Selection and Safety Evaluation Tools Review

# FHWA *Systemic Safety Project Selection Tool.* 2013.

## Structure and Guidance

### Purpose:

The *Systemic Safety Project Selection Tool* is a standalone report that provides a process for incorporating systemic safety planning into traditional safety management processes to allow proactive design of countermeasures to prevent crashes on the roadway based on an evaluation of an entire system using a defined set of criteria that will vary depending on the available data. This can be a useful strategy for bicycle safety assessments where crashes are less frequent and dispersed across a region.

### Design User:

This report does not have a specific design user.

### Guidance Provided:

- Discussion of the system safety planning process (See Figure 1):
  - Identify focus crash types and risk factors
  - Screen and prioritize candidate locations
  - Countermeasure selection
  - Prioritize projects
- A case study to explain how to implement the process.
- A framework for balancing systemic and traditional safety improvements.
- Discussion of a program evaluation process
- Discussion of considerations outside of roadway environment such as time, funding, and coordination with other planned projects.

## Process

The guide provides a step-by-step process for conducting a systemic safety analysis. The guide includes a comprehensive review of existing conditions and risk factors to consider. Risk factors include roadway traffic volumes, speeds, and land use context.

## Facility Selection Tool

FHWA's facility selection tool is in the form of a decision-tree which only includes roadway environment factors.

## Evaluation

### Pros:

- The guide provides case studies to illustrate how process works.
- The guide sets a clear process.
- The guide shows examples of many types of decision-trees which may provide inspiration for how to approach bicycle safety issues.
- The process is generic enough to allow application for bicycle safety projects.

Cons:

- The guide does not provide enough information to guide users from evaluating risk factors to selecting countermeasures to implement.
- The guide does not provide enough information to help communities prioritize treatments.
- The guide case studies do not provide any guidance for assessing bicyclist safety.

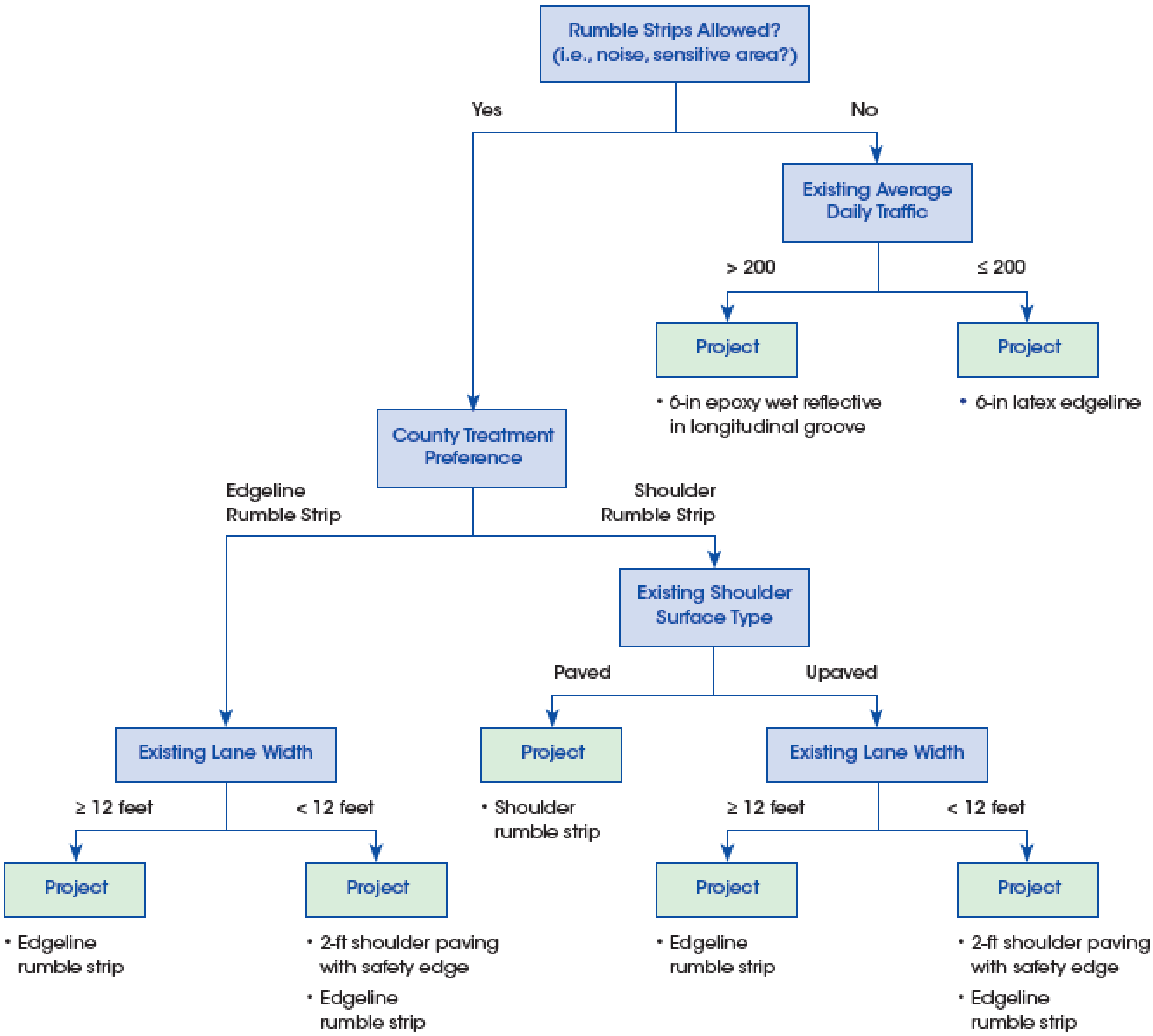



**Figure 57 - Decision-Tree Approach to Project Selection**

Source: FHWA *Systemic Safety Project Selection Tool* (2013)

# City of Boulder. *Pedestrian Crossing Treatment Installation Guidelines.* 2011.

## Structure and Content of Guidance

### Purpose:

This standalone guide provides design guidance to replace previous crossing treatment warrant guidance.

### Design User:

This guide does not have a specified design user and defaults to all pedestrians.

### Guidance Provided:

- Discussion of proposed pedestrian crossing criteria and procedures for evaluating the need for crossing treatments.
- Discussion of pedestrian crossing treatments that may be applicable for a particular set of pedestrian volumes, pedestrian types, vehicular volumes, vehicular speeds, and roadway geometry.
- Discussion of implementation considerations.
- Discussion of safety.

## Process

This guide outlines a four-step process for selecting a pedestrian treatment for a given road environment. The guide presents a worksheet to assist and help organize the process. The process is accompanied by a decision tree.

Step 1: Identification and description of crossing location.

Step 2: Physical data collection.

Step 3: Traffic data collection and operational observations.

Step 4: Apply data to accompanying figures and tools to determine appropriate treatments.

## Facility Selection Tool

Boulder’s crossing treatment selection tool is in the form of a chart which prescribes a selection of pedestrian crossing treatments for specific motor vehicle volume, pedestrian volume, and crossing distance combinations. Boulder divided the facility selection tool into two charts based on speed (i.e., speeds greater than 35 mph and speeds lower than 35 mph).

## Evaluation

### Pros:

- The guide provides a basic process for selecting an appropriate pedestrian treatment and has accompanying tools to assist with the process.
- The guide does discuss some variations to the prescribed guidance. For example, the guide advises that school zones be treated differently.
- The selection process includes a place for practitioner or community input, albeit in limited capacity.
- The guide provides different types of guidance

Cons:

- The guide does not incorporate non-roadway environment considerations (e.g., budget or maintenance).
- The guide, the prescribed process, and the tool all have very little emphasis on safety.
- The guide is very text heavy.

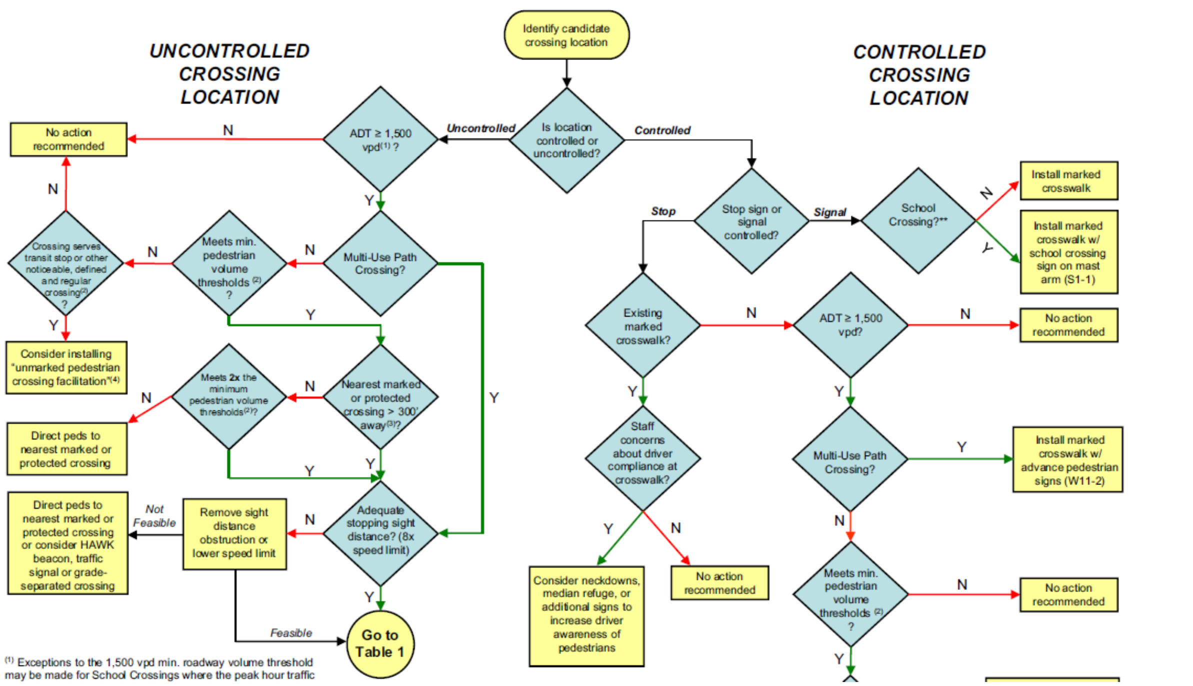



**Figure 58 - Pedestrian Crossing Treatment Selection Decision Tree**

Source: City of Boulder. *Pedestrian Crossing Treatment Installation Guidelines* (2011)

# AustRoad. *Australasian Pedestrian Facility Selection Tool User Guide.* Research Report AP-R472A-17. 2017.

## Structure and Content of Guidance

### Purpose:

This resource is a user guide with an accompanying tool. The purpose of the guide is to explain the operation and outputs of the tool; the tool provides a way to easily compare the impacts and associated costs of a selection of pedestrian treatments.

### Design User:

The guide does not specify a design user and defaults to all pedestrians.

### Guidance Provided:

There is no design or planning guidance that accompanies the tool except for a list of data inputs.

## Process

This guide does not include a discussion of the process for selecting a preferred pedestrian treatment but some elements of a process (e.g., data collection and cost benefit analysis) are inherent within the design of the tool.

## Facility Selection Tool

AustRoad's tool is in the form of a web-based, interactive tool which incorporates roadway information, pedestrian volumes, degree of pedestrian-vehicle turning conflicts, crash history, and construction costs. The full tool can be viewed here: http://austpedtool.com/25teow9.html.

## Evaluation

### Pros:

- This guide explains all elements of the tool in an easy-to-read user guide.
- The tool presents an easy way to compare different aspects of different treatments, such as cost, vehicle/pedestrian delay, predicted crash rate, and monetary savings based on safety improvements.
- This tool incorporates safety concerns in the form of crash data.
- This guide is unique in that it allows the user to easily test the impact of weighting different factors differently or viewing the impact of making slight changes to site conditions.
- The guide provides the calculations embedded in the tool so that it is possible to conduct a similar analysis on treatments not embedded in the tool.

### Cons:

- The only way to incorporate safety information into the tool is with a crash history.
- This guide does not include information about considerations not captured in the tool, or a discussion of strategies that a user might implement in order to incorporate additional considerations into the tool results.
- One cannot easily use the tool for treatments not already embedded in the tool.

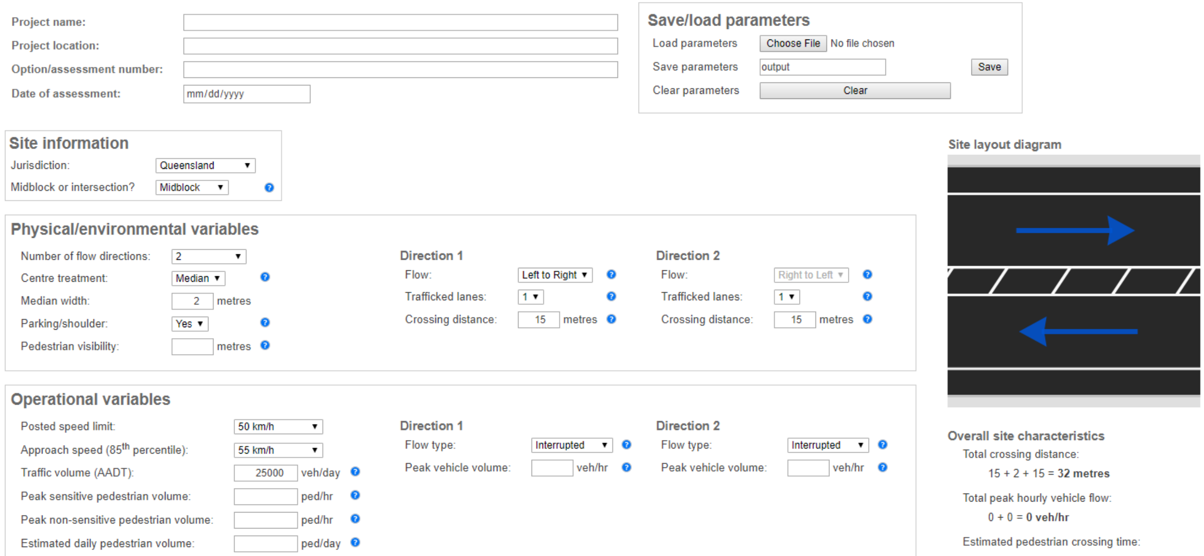
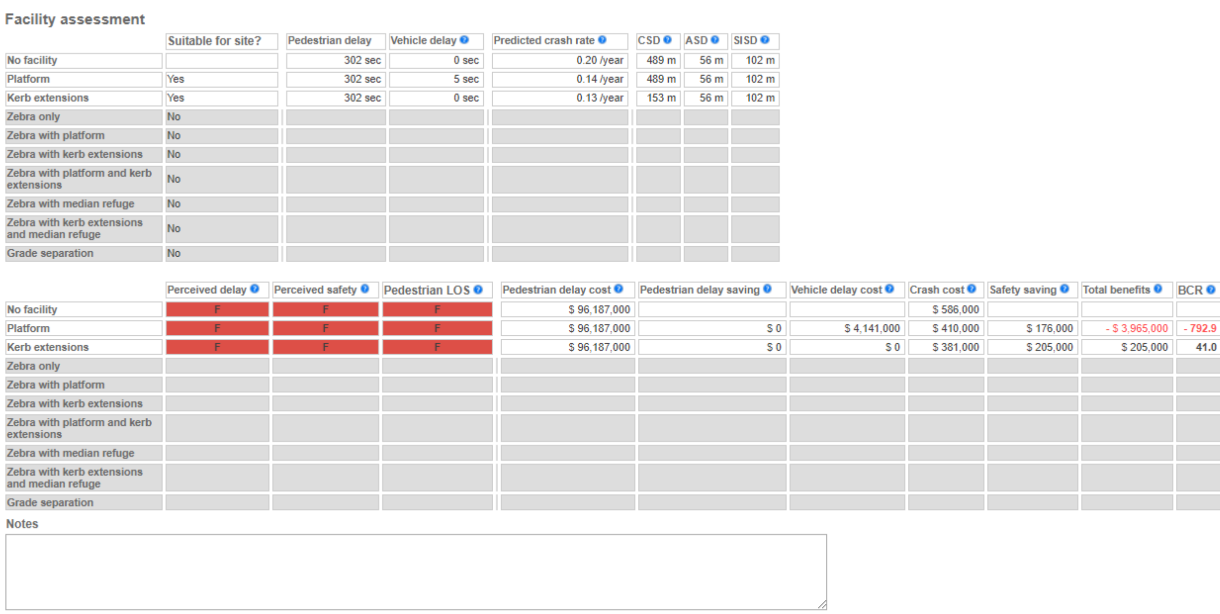



**Figure 59 - Beginning of Pedestrian Treatment Selection Tool**

Source: AustRoad. *Australasian Pedestrian Facility Selection Tool User Guide.* 2017



Facility assessment

| | Suitable for site? | Pedestrian delay | Vehicle delay | Predicted crash rate | CSD | ASD | SISD |
|---|---|---|---|---|---|---|---|
| No facility | | 302 sec | 0 sec | 0.20 /year | 489 m | 56 m | 102 m |
| Platform | Yes | 302 sec | 5 sec | 0.14 /year | 489 m | 56 m | 102 m |
| Kerb extensions | Yes | 302 sec | 0 sec | 0.13 /year | 153 m | 56 m | 102 m |
| Zebra only | No | | | | | | |
| Zebra with platform | No | | | | | | |
| Zebra with kerb extensions | No | | | | | | |
| Zebra with platform and kerb extensions | No | | | | | | |
| Zebra with median refuge | No | | | | | | |
| Zebra with kerb extensions and median refuge | No | | | | | | |
| Grade separation | No | | | | | | |

| | Perceived delay | Perceived safety | Pedestrian LOS | Pedestrian delay cost | Pedestrian delay saving | Vehicle delay cost | Crash cost | Safety saving | Total benefits | BCR |
|---|---|---|---|---|---|---|---|---|---|---|
| No facility | F | F | F | $ 96,187,000 | | | $ 586,000 | | | |
| Platform | F | F | F | $ 96,187,000 | $ 0 | $ 4,141,000 | $ 410,000 | $ 176,000 | - $ 3,965,000 | - 792.9 |
| Kerb extensions | F | F | F | $ 96,187,000 | $ 0 | $ 0 | $ 381,000 | $ 205,000 | $ 205,000 | 41.0 |
| Zebra only | | | | | | | | | | |
| Zebra with platform | | | | | | | | | | |
| Zebra with kerb extensions | | | | | | | | | | |
| Zebra with platform and kerb extensions | | | | | | | | | | |
| Zebra with median refuge | | | | | | | | | | |
| Zebra with kerb extensions and median refuge | | | | | | | | | | |
| Grade separation | | | | | | | | | | |

Notes

**Figure 60 - Final Page of the Pedestrian Treatment Selection Tool**

Source: AustRoad. *Australasian Pedestrian Facility Selection Tool User Guide.* 2017

# *NCHRP Report 562: Improving Pedestrian Safety at Unsignalized Crossings.* 2006.

## Structure and Content of Guidance

Purpose:

The standalone NCHRP report serves to recommend engineering treatments to improve safety for pedestrians crossing high-volume and high-speed roadways at unsignalized locations.

### Design User:

The report's design user is all pedestrians, with an emphasis on older pedestrians and pedestrians with disabilities.

### Guidance Provided:

- Discussion of pedestrian characteristics, pedestrian crossing treatments, and the pedestrian signal warrant.
- Discussion of findings from surveys and field studies.

## Process

The NCHRP report does not include a discussion of a process for designing or implementing pedestrian crossing treatments.

## Facility Selection Tool

The NCHRP report has a treatment selection tool in the form of a decision tree which directs the user to an appropriate treatment based on posted speed, population, presence of transit, signal warrant guidelines, pedestrian delay, and driver compliance. The tool is split into two decision trees, one for roadways with a posted speed of 35 mph or less, and the other for roadways with a posted speed greater than 35 mph. The report also includes an excel worksheet to accompany the decision tree.

## Evaluation

### Pros:

- The report provides a very thorough description of the design user that serves as useful background information.
- The report's pedestrian crossing treatment safety rating from a community survey is an innovative approach.
- The report's detailed examples of the tool and treatment enhancements discussed in the appendix are helpful.

### Cons:

- The report does not discuss planning and design considerations like funding or maintenance.
- The tool's prescriptive approach may not provide enough sensitivity to different context, for example, it may not be useful near schools or senior centers.
- The decision tree assumes street design doesn't inhibit pedestrian demand which can limit use of the tool at crossings with dangerous conditions where the tool could be most helpful.

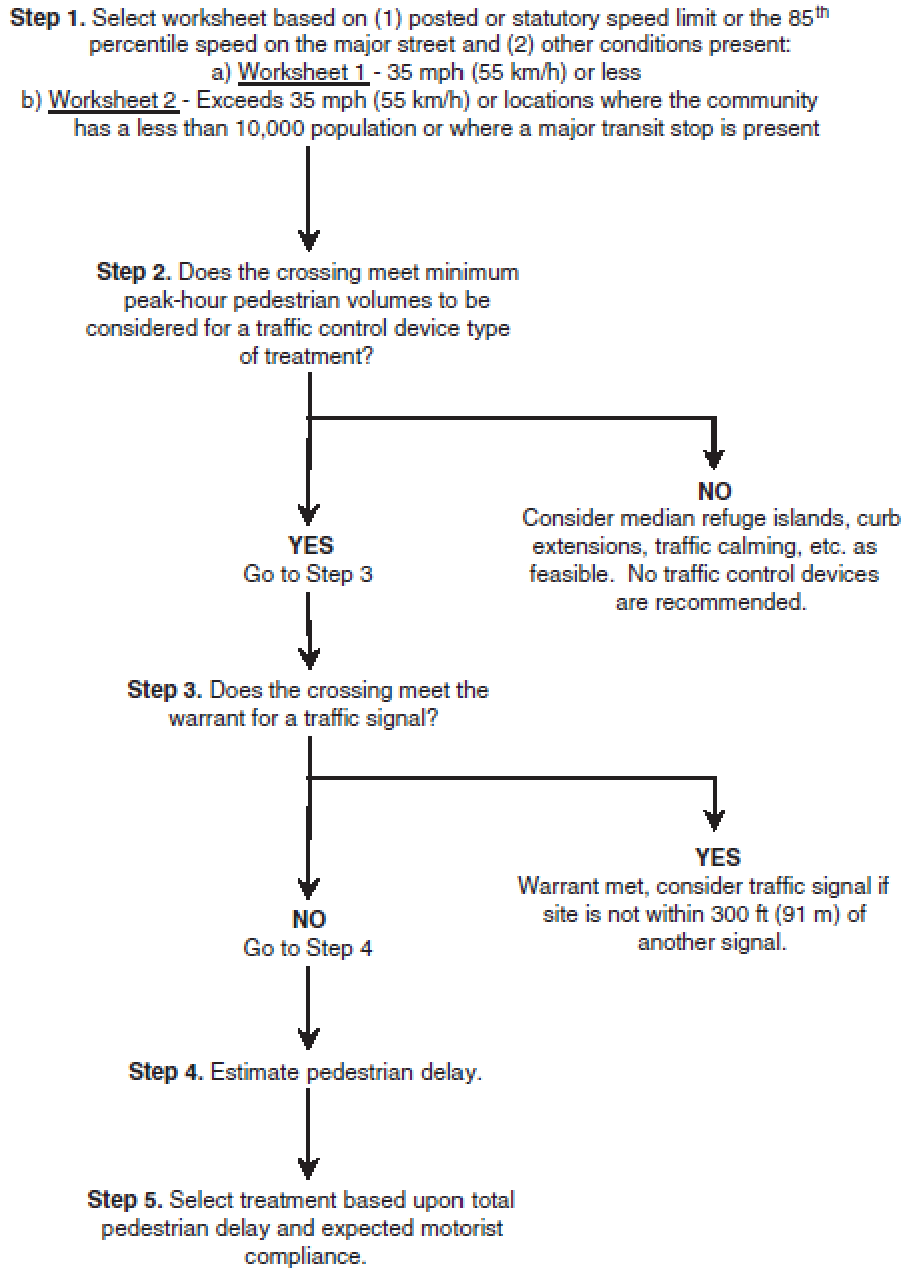



**Figure 61 - Pedestrian Crossing Treatment Decision Tree**

Source: *NCHRP Report 562: Improving Pedestrian Safety at Unsignalized Crossings*. (2006)

# *NCHRP Synthesis 498: Application of Pedestrian Crossing Treatments for Streets and Highways*. 2016.

## Structure and Content of Guidance

### Purpose:

The standalone NCHRP Synthesis identifies pedestrian crossing treatments and discusses policies and processes to help communities prioritize treatments and locations needing treatments. In addition, this Synthesis identifies existing information, knowledge gaps, and highlights effective uses of current treatments.

### Design User:

The Synthesis does not specify a design user.

### Guidance Provided:

- Discussion of policies that can guide pedestrian crossing treatment selection processes.
- Discussion of recommended applications, effectiveness, and use of pedestrian crossing treatments.
- Examples of existing guidance tools and case studies.
- Summary of findings from research about what states use as selection criteria for countermeasure treatments. A few of the most common responses were cost benefit analyses, ADA compliance, public input, internal design resources, CMF Clearinghouse.

The results indicate that respondents are willing to travel up to 20 min more to switch from an unmarked on-road facility with side parking to an off-road bicycle trail, with smaller changes for less dramatic improvements.

## Process

This guide does not include a discussion of the process to select a preferred bikeway.

## Facility Selection Tool:

There is no explicit facility selection tool selection to design pedestrian crossing treatments.

## Evaluation

### Pros:

- The Synthesis provides detailed summaries of existing knowledge about the effectiveness of pedestrian crossing treatments.
- The Synthesis presents some treatment selection tools that integrate crash types that a given treatment is well-suited to prevent – a somewhat similar approach could be incorporated into bikeway selection guidance.
- The Synthesis does not provide a “best practice” in treatment selection processes or treatment selection tools.

### Cons:

- The Synthesis presents prioritization tools for pedestrian treatments that use Crash Modification Factors, however, this approach is not very applicable to bikeways at this point in time.

# *NCHRP Report 803: Pedestrian and Bicycle Transportation Along Existing Roads – ActiveTrans Priority Tool Guidebook*. 2015.

## Structure and Content of Guidance

### Purpose:

The standalone NCRHP report provides a step-by-step methodology to carry out the ActiveTrans Priority Tool (ATP) which will help communities prioritize pedestrian and bicycle improvements along existing roads.

### Design User:

The report does not specify a design user.

### Guidance Provided:

- Overview of the ATP tool with a more detailed discussion of the scoping and prioritization phases.

## Process

The report discusses a two-phase process for prioritizing and selecting treatments.

## Facility Selection Tool

NCHRP's selection tool is in the form of a programmed spreadsheet which includes nine criteria for consideration:

- Stakeholder Input,
- Constraints,
- Opportunities,
- Safety,
- Existing Conditions,
- Demand,
- Connectivity,
- Equity, and
- Compliance.

## Evaluation

### Pros:

- The report provides a useful way to consider the importance of different factors and allows the user to weight these factors in the tool.
- The report provides a thorough and clear process for prioritizing projects which may be segment or intersection based with all steps explained in detail.
- The report includes a methodology for evaluating cost/benefits analyses and safety.
- The report provides a recommended source for each piece of data needed to complete the tool.
- The tool spreadsheet is clear and easy to follow.
- The report and tool are accompanied by many supporting marketing documents (e.g., webinar, and poster) which are helpful in a variety of situations, to help practitioners use and explain the tool to stakeholders to help explain their decisions.

Cons:

- The report is very long and text heavy.

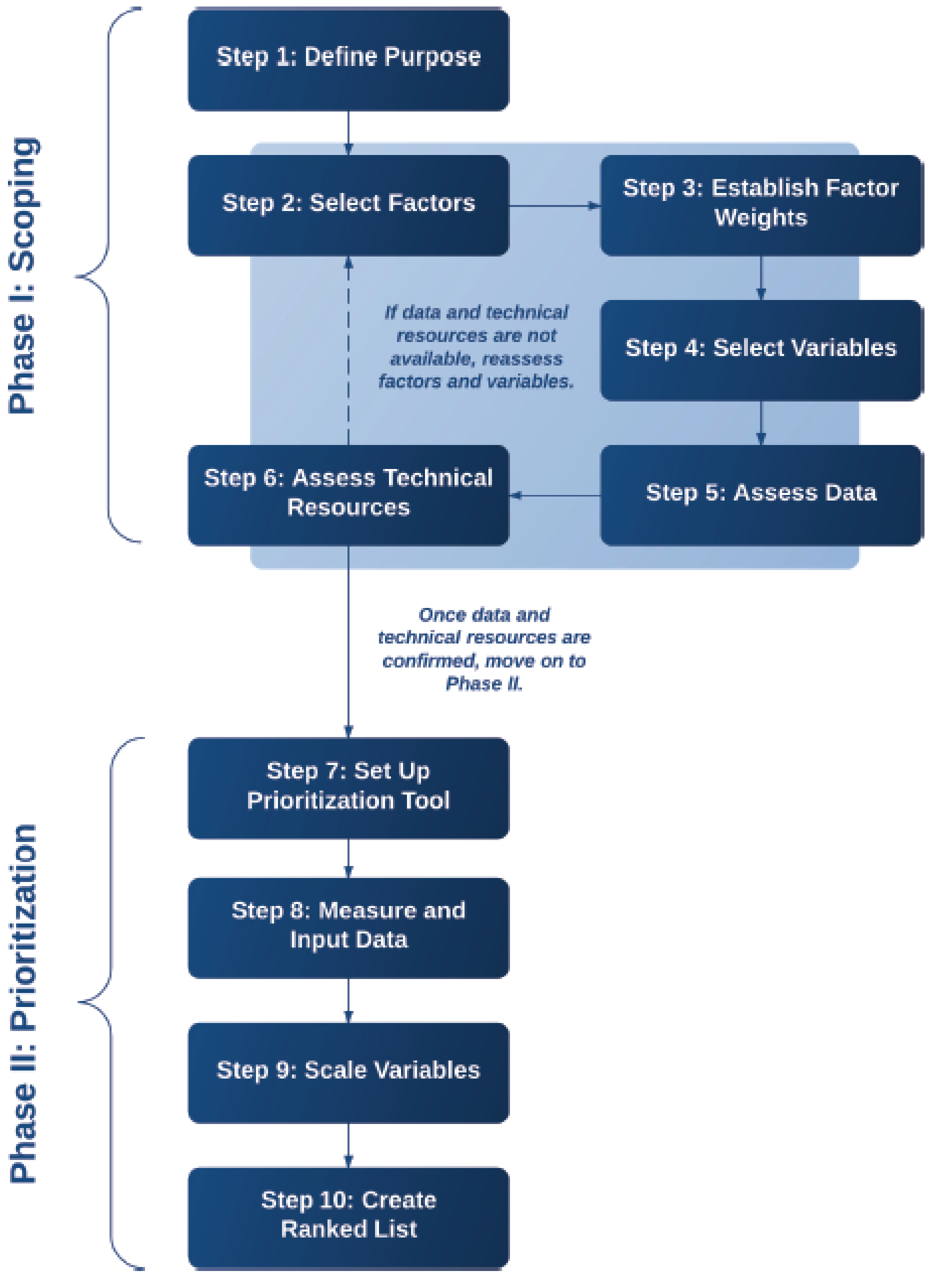



**Figure 62 - ActiveTrans Priority Process Diagram**

Source: *NCHRP Report 803: ActiveTrans Priority Tool Guidebook* (2015)

## *NCHRP Report 500: Vol. 18, Guidance for Implementation of the AASHTO Strategic Highway Safety Plan: A Guide for Reducing Collisions Involving Bicycles.* 2008.

### Structure and Content of Guidance

#### Purpose:

This chapter is part of a longer NCHRP report that presents strategies and guidance for implementing the AASHTO Strategic Highway Safety Plan. This chapter presents a series of strategies that practitioners can implement to improve bicyclist safety.

#### Design User:

This report does not specify a design user.

#### Guidance Provided:

- Discussion of problem types (e.g., intersection crashes, and motor vehicle speeds), factors affecting number and severity of crashes, and where and when crashes occur.
- Discussion of implementation strategies with appropriate timeframe and relative cost.
- Discussion of strategies for installing striped bike lanes and contraflow striped bike lanes.
- Discussion of budget, time, personnel, and capacity constraints.

### Process

This NCHRP report does not specify a design or implementation process for selecting bikeways.

### Facility Selection Tool

This NCHRP report does not provide a bikeway selection tool.

### Evaluation

#### Pros:

- This report provides comprehensive guidance on effective treatments to improve bicyclist safety.
- This report includes a discussion of non-roadway factors that affect planning and design decisions.

#### Cons:

- This report is very long and text heavy.
- This report presents design guidance for bikeways, but it doesn’t provide enough information to indicate in which situations the treatments should be applied. For example, the report mentions that shared lane markings can help reduce dooring, but there are many roadway situations with on-street parking that are inappropriate for shared lane markings.

# *NCHRP Synthesis 422: Trade-Off Considerations in Highway Geometric Design* 2011 – Choosing by Advantages

## Structure and Content of Guidance

### Purpose:

Describing the potential trade-offs in roadway design when applying a Choosing by Advantages (CBA) process.

### Design User:

Does not explicitly or implicitly examine a design user.

### Guidance:

CBA was originally developed by the US Forest Service to make informed decisions on program allocations. This decision-making process focuses on the advantages of each alternative. In particular, deciding the relative importance and increment costs of each alternative needs to be explicitly defined. Also, only the advantages are considered, which simplifies the decision-making process.

## Process:

The CBA process has five basic steps:

1. Summarize the attributes of each alternative – The attributes of each alternative are identified.
2. Decide the advantages of each alternative – The decision-making group needs to share understanding on which attribute provides an advantage.
3. Decide the importance of each advantage – There are four important considerations when deciding the importance of each advantage:
    a. The decision's purpose and circumstances
    b. The needs and preferences of users and stakeholders
    c. The magnitudes of the advantages
    d. The magnitudes of the associated attributes
4. Weigh costs with total importance of the advantages – Graphing the importance-to-cost data is a visual method to assist with decision-making. Here is an example:
5. Summarize the decision

CBA EXAMPLE SPREADSHEET

| Factor | Alternatives | | | | | |
|---|---|---|---|---|---|---|
| | Site 8 | | Site 19 | | Site 23 | |
| Factor 1 — Water | | | | | | |
| *Attributes* | 60 feet away | | 260 feet away | | 150 feet away | |
| *Advantages* | 200 feet closer | 40 | | 0 | 110 feet closer | 30 |
| Factor 2 — Tent Spot | | | | | | |
| *Attributes* | Moderately level | | Almost level | | Quite sloping | |
| *Advantages* | Moderately more level | 30 | Much more level | 70 | | 0 |
| Factor 3 — Table | | | | | | |
| *Attributes* | No table | | No table | | With | |
| *Advantages* | | 0 | | 0 | Table versus no table | 65 |
| Factor 4- — Privacy | | | | | | |
| *Attributes* | Close sites, Near road | | Screened, Distant sites | | Screened, Close sites | |
| *Advantages* | | 0 | Much more privacy due to screening and remoteness | 100 | Moderately more privacy due to screening | 45 |
| **Total Importance of Advantages** | | 70 | | 170 | | 140 |
| **Total Cost per Night** | | $3 | | $20 | | $4 |

*Source: General Management Plan Dynamic Sourcebook (59).*

**Figure 63 - Example of Tabular CBA Process**

Source: *NCHRP Synthesis 422: Trade-Off Considerations in Highway Geometric Design* 2011

Deciding which advantage is paramount can be a challenge. Using a "defender/challenger" method can help understand which advantage is more important. Two advantages are selected, evaluated, and then the next two advantages are selected and evaluated until all advantages are compared and one advantage can be identified as paramount.

## Facility Selection Tool:

There is no explicit facility selection tool selection to design a roadway based on the CBA process.

## Evaluation

### Pros:

- Can effectively quantify attributes and advantages which may seem undiscernible from each other.
- Allows the evaluator(s) to weigh each advantage.

### Cons:

- Participants who have a hidden agenda can "game" the outcome of the decision-making process. Therefore, a strong facilitator is recommended to foster a trust-based environment.
- This process does not appear to have been applied to transportation planning themed projects.

# *NCHRP Synthesis 422: Trade-Off Considerations in Highway Geometric Design* 2011 – Context Sensitive Solutions/Context Sensitive Design

## Structure and Content of Guidance

### Purpose:

Describing the potential trade-offs in roadway design when applying a Context Sensitive Solutions/Context Sensitive Design (CSS/CSD) at a corridor level.

### Design User:

An analytical approach should be used to define the “Design vehicle,” but, there is no explicit mention of a “Design User,” except that the CSS/CSD process should integrate a multidisciplinary team to develop design concepts.

Project Development and Design Guide (MassDOT publication) identified a broader range of design controls including roadway users.

The WSDOT manual (Understanding Flexibility in Transportation Design – Washington) is a companion to the WSDOT’s Design Manual to provide rationale for decision making and trade-offs in transportation projects. One overarching topic is: **Consideration of Facility Users,** which relies on recognizing trade-offs to provide a safe and functional facility for all users.

CSS/CSD often uses “Measures of Effectiveness” to quantify or qualify to reach desired outcomes. This could be the areas where integrating a design user would be appropriate.

### Guidance Provided:

The CSS/CSD interdisciplinary project development process includes geometric design and attempts to address safety and efficiency while being sensitive to the roadway’s natural environment and human environment. This process explicitly states that design trade-offs are needed and should be viewed along a continuum.

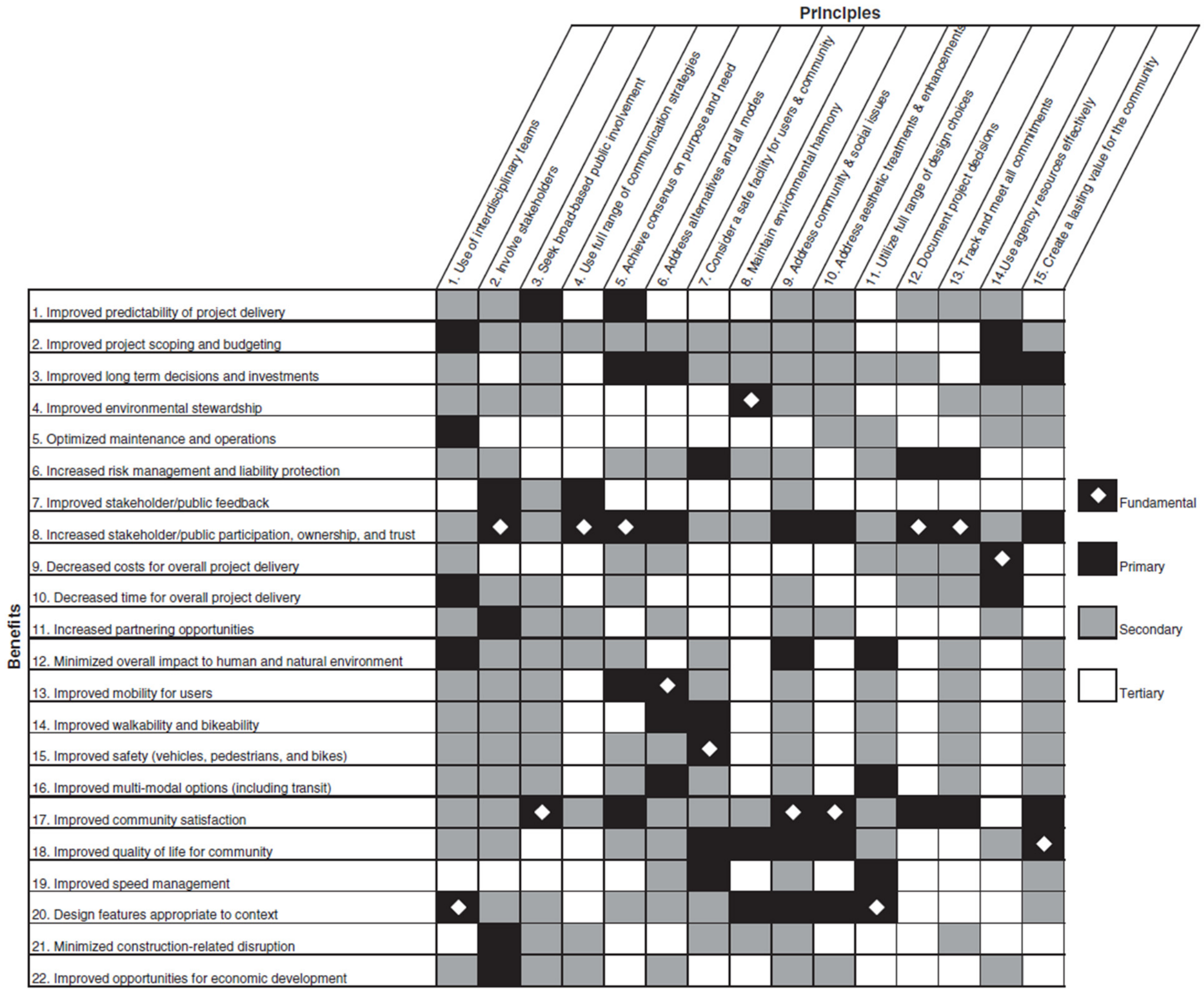



**Figure 64 - Matrix of principles and associated benefits of applying the CSS concepts**

Source: *NCHRP Report 642: Quantifying the benefits of CSS*

## Process:

The basic process in the CSS/CSD transportation decision making should include the following steps:

1) **Define the context** – Refers to social, physical, fiscal, ecological, and political backgrounds of the project.
2) **Characterize the function of the design –** The roadway's function to serve various transportation users should be defined. Should make sure that decision making processes ensure final solutions that address up-front problems. This could include pedestrian/bicycle functions.
3) **Select the road typology** – Select the physical components, arrange these components, define the roadway network adjacent the roadway, and then define a design speed.
4) **Determine the design details** – Include engineering and aesthetic factors. Also, determine the relationship of the roadway to the surrounding buildings, land use, or natural environment.

CSS/CSD identifies design problems in functional or performance terms and then tries to solve those problems directly, especially rationalizing the need for adjustments of design criteria. This approach creates tension around the design consistency associated with the Green Book, as a proposed design may deviate from a nominal dimension value.

As WSDOT has found through early CSS/CSD experience, when a design decision is vetted by the court system, the courts expect that the design decisions made were reasonable under the circumstances. This means it is especially critical to provide sufficient decision-making documentation. Also, when the WSDOT design engineers gained more experience with implementing CSS/CSD projects involving community partnerships, they exercised more professional judgment and critical thinking to develop balanced roadways meeting more community goals.

### Alternatives Analysis

As part of the CSS/CSD process, performing an alternatives analysis allows designers and decision makers to explicitly evaluate the trade-offs of one roadway design to another. Furthermore, this analysis is more robust when there are a careful selection of Measures of Effectiveness (MOEs). The Pennsylvania and New Jersey DOTs outline a process to weigh alternatives as provided in the *Smart Transportation Guidebook: Planning and Designing Highways and Streets that Support Sustainable and Livable Communities*. The steps to weigh alternatives with its respective MOEs include:

- Summarizing the assessment
- Understanding important trade-offs
- Avoiding weighting and scoring schemes
- Collaborating, not voting, on a recommended solution

Often, jurisdictions such as Massachusetts DOT and Arizona DOT will create matrices to compare MOEs with respect to the alternative. Again, with a carefully selected and robust set of MOEs, the alternatives can be effectively compared. In addition, a benefit-cost ratio could be one way to evaluate the outcome of different design solutions; however, these ratios are typically not effective at incorporating factors such as safety, equity, and economic development.

## Facility Selection Tool:

There is no explicit facility selection tool selection to design a roadway based on the CSS/CSD process. However, if a sufficient set MOEs are established, then emphasis on a facility selection tool could be made.

## Evaluation

### Pros:

- Allows the designer to select a comprehensive set of MOEs to evaluate a roadway design.
- Could integrate more precise qualitative bicycle needs into the decision-making process.
- Several STAs have experience with implementing this process and also making thoughtful deviations from the Green Book, when needed.
- Clearly communicates goals and potential solutions, which can be integrated into the design.
- Stakeholders, and users of the transportation project, are typically engaged in the process to help reach a decision. Their involvement would also aid in project acceptance.

### Cons:

- The MOEs do not necessarily illustrate the trade-offs in safety.
- The relationship between the MOEs is not necessarily clarified.
- The CSS/CSD process has many components, which may slow expedient project delivery.
- There is no “right” way to establish a CSS/CSD process.

# *NCHRP Synthesis 422: Trade-Off Considerations in Highway Geometric Design* 2011 – Conventional

## Structure and Content of Guidance

### Purpose:

Describing the potential trade-offs in roadway design when applying a conventional approach, which is typically referred to as the applying the Green Book.

### Design User:

The design user is typically the most common design vehicle navigating the roadway. There is mention of pedestrians/bicyclists in the Green Book process, but they are treated as objects for design. There is no qualification on how risk-averse these users are, or how their experience is related to their comfort navigating the roadway environment.

### Guidance Provided:

The Green Book design criteria values have been created through years of practice and research, but not all criteria are based on robust scientific safety analysis. The standards do promote design consistency, which can impact safety. The Green Book was intended to give a designer a range of values so she/he could apply engineering judgment to a particular project. It is widely held belief that a linear relationship exists between the range of values to the project's quality of benefits and safety performance, which is not necessarily true. The intent was that the designer should interpret this range to recognize dimensional trade-offs. The cause-effect guidance behind design decisions and background material was removed from the Green Book, so understanding design-related trade-off fundamentals is challenging. For example:

- Sight Distance: Designing sufficient driver sight distance is important so vehicle control can be maintained and striking an unexpected object can be avoided. Minimum sight distances are provided for the below-average driver to stop, but **trade-offs to provide this minimum design criteria are not discussed.**
- Superelevation: Designing superelevation should consider speed, curvature, and side friction. However, no guidance on how to evaluate this relationship between characteristics is made.
- Horizontal Alignment: The guidance to design a horizontal alignment focuses on controls such as sight distance, type of potential obstructions, etc. However, no guidance is provided on the importance of each design element or control.
- Vertical Alignment: The major control for a safe vertical curve is the provision of sight distance based on speed. However, guidance specifically indicates vertical curves with sight distance issues do not necessarily experience safety issues; yet, guidance specifies that vertical curves should be designed to provide sight distance minimums. Design controls are listed, but the importance of each is not provided.

Better understanding trade-off criteria for the Green Book has not taken form in the manual itself, but rather with a large body of supplemental information contained in other guides:

- *Older Driver Highway Design Handbook* (FHWA1995)
- *Highway Capacity Manual* (TRB 2010)
- *Guide for the Development of Bicycle Facilities* (AASHTO 2012)
- *Traffic Safety Toolbox: A Primer on Traffic Safety* (ITE 1999)

- *Access Management Manual* (TRB 2003)
- *Access Management Guidelines for Activity Centers* (TRB 1992)
- *Impacts of Access Management Techniques* (TRB 1999)
- *Driveway and Street Intersection Spacing* (TRB 1996)
- *HOV Systems Manual* (TRB 1998)
- *Design and Safety of Pedestrian Facilities* (ITE 1998)
- *Building a True Community* (U.S. Access Board 2001)
- *Interactive Highway Safety Design Model* (FHWA 2010)
- *Highway Safety Manual* (AASHTO 2010)
- *Guide for Achieving Flexibility in Highway Design* (AASHTO 2004)
- *Flexibility in Highway Design* (FHWA 1997)
- *Designing Walkable Urban Thoroughfares* (ITE 2010)

### Nominal and substantive safety:

Design guidance is generally presented as an absolute in the Green Book, not a continuum as it practically exists in the field. Nominal safety refers to a design or alternative's adherence to design control or criteria. A design that meets a design criterion is said to be nominally safe, whereas one that does not is nominally unsafe. Notably, these design criteria are based on meeting the needs of most drivers. There is no apparent consideration to other modes, except for the supplementary literature which provides linkage to design flexibility.

Substantive safety refers to the crash performance of the roadway. Therefore, it is possible that roadway designs are nominally safe but not substantively safe, and vice versa. Also, because of the belief that designs which are not nominally safe (not designed to the standard) are not substantively safe, there is a perspective that no compromises to the design should be made.

Educational materials on the difference between nominal and substantive safety have been developed by FHWA to better describe this problem and more flexible solutions through the document: *Geometric Design: Applying Flexibility and Risk Management, National Highway Institute,* FHWA-NHI-380095).

## Process:

There is no formal design process described in the summary of the Green Book for a normal roadway design.

However, there is a formal process (design exception process) when a roadway design does not adhere to the nominally accepted values of the following 13 controlling design criteria (only items with "*" apply to all roadways):

- Design speed*
- Lane width
- Shoulder width
- Bridge width
- Design Loading*
- Horizontal alignment
- Vertical alignment
- Grade
- Stopping sight distance
- Cross slope
- Superelevation
- Vertical clearance
- Horizontal clearance

This design exception process acknowledges that one or more nominal criteria could not be met and that there was a sufficient evaluation of engineering and social/cultural trade-offs to identify the next most appropriate design value characteristic. The design exception report typically involves:

- Description of the proposed project.
- Description of the substandard feature

- Crash analysis for the last three years of data
- Costs and adverse impacts resulting from meeting current design standards
- Safety enhancements to mitigate the effects of the nonstandard feature
- Evaluation of the compatibility of the proposed improvement with adjacent roadway

However, there is no formal priority when examining the importance of the 13 controlling criteria, nor a quantifiable means of determining how varying from the criteria impact substantive safety.

## Facility Selection Tool:

There is no explicit facility selection tool to design a roadway exception for meeting the minimum design criteria specified in the Green Book.

## Evaluation

### Pros:

- Allows a designer to choose nominal dimensional values to design a roadway based on a century of research with safety in mind.
- Choosing roadway dimensions outside of the nominal values may create a situation with safety consequences.
- Deviating from the nominal values triggers a design exception process to evaluate design trade-offs

### Cons:

- The design trade-offs within or exceeding the range of acceptable Green Book values are not discussed.
- It is possible that roadway designs are nominally safe but not substantively safe, and vice versa.
- When the design exception process is triggered, there is no formal priority when examining the importance of the 13 controlling criteria, nor a quantifiable means of determining how varying from the criteria impact substantive safety.

# *NCHRP Synthesis 422: Trade-Off Considerations in Highway Geometric Design* 2011 – Practical Solutions/Design

## Structure and Content of Guidance

### Purpose:
Describing a design process that attempts to maximize the rate of return for the individual project while maximizing the rate of return for the complete system.

### Design User:
A system wide performance focus, requires definition of the system. It naturally biases motorists and transit operations over pedestrians and bicyclists unless controlled for through clear transportation agency goals such as sustainability or vulnerable user safety.

### General principles are provided to control the overdesign of a project:
- Targeted Goals in a Purpose and Needs (P&N) Statement – necessitates specific targets such as "shorten intersection delay to less than 50 seconds per vehicle during the typical peak hour" to define a rate of return
- Meeting Anticipated Capacity Needs – Quality of service targets should also be identified.
- Safety Evaluation Against Existing Conditions – The incremental gains of safety from each alternative is to be compared to the existing condition.
- While similar to CSS/CSD, the process focuses on systemwide optimization of the entire transportation system with concern for mobility and safety across a region, with less focus on the corridor to optimize the expenditure of finite resources.
- Maximize Rate of Return – Using a performance measure to understand the value of each alternative.

Related to Practical Solutions/Design, Performance-Based Planning is also used at an organization level to assess the overall transportation plan and goals. Using a P&N statement and effective performance measures, alternatives can be effectively evaluated. The document called *A Guidebook for Performance-Based Transportation Planning* has a *Performance Measures Library,* which can be used as an effective resource for well-known performance measures.

## Process:
The four major sections of Practical Solutions/Design and Performance-Based Planning are summarized with the following graphic:

Performance-based planning can also be used to evaluate the CSS/CSD process and outcomes at the agency level.

## Facility Selection Tool:
There is no explicit facility selection tool selection to design a roadway based on the Practical Solutions/Design process.

## Evaluation

### Pros:

- Can focus on how a project could impact system-wide optimization
- Can evaluate a project at an organizational level.
- Can develop specific performance measures based on desired outcomes.

Cons:

- The process appears to be a complement to the CSS/CSD process, so there is interdependence.
- Monetizing the value of project outcomes could be difficult based on pedestrian/bicycle related Measures of Effectiveness.

# *NCHRP Synthesis 422: Trade-Off Considerations in Highway Geometric Design* 2011 – Risk Analysis and Management

## Structure and Content of Guidance

### Purpose:

Describing the potential trade-offs in roadway design when applying a Risk Analysis and Management process. Risk is perceived as the effect of uncertainty on a project or organizational objectives and represents exposure to mischance, hazards, and the possibility of adverse consequences. Risk tolerance is dependent upon the organization and their mission.

### Design User:

While does not explicitly mention a design user, a user could be integrated into risk breakdown structure, such as a *Cause and Effect Diagram*. Also, *risk communication* could be a method to convey the trade-offs of certain designs to the design user.

### Guidance:

The goals of risk analysis and management are to:

- Increase project understanding
- Identify alternatives
- Ensure that risks are considered in a systematic way
- Establish risk implications
- By doing so, the consequences of risk can be shared by multiple parties.

Psychology of Risk Perception

In a different, but similar thread of thought, the psychology of risk perception was examined as pertaining to a roadway user. In short:

1) People do not demand zero risk.
2) People do not judge degree of risk in concert with risk statistics.
3) Emotions control risk perceptions.
4) Once established, risk perceptions are difficult to change.
5) Risk perceptions reside at an emotional level.

Risk perception by an agency and staff can also influence project outcomes. Fear of doing something new, can limit an agency's ability to solve safety problems. Assessing and balancing risk between users can also be challenging if it is based on different assumptions or facts.  Example cited is narrowing travel lanes to provide wider buffer to shared use path. Some may view narrow travel lanes as high risk of vehicle sideswipes, while others view a buffer as more protection of serious injury or death of path user if they fell from path. The assessment of risk requires consideration of likelihood of a crash and the consequences of a crash.

## Process:

Project risk analysis is typically a five-step project:

1. Determine the Objective – The Purpose & Needs (P&N) Project Objective.
2. Identify the Risks – Using a diagrammatic approach can help identify risks, such as a
3. Cause and Effect Diagram.
4. System or Process Flow Chart.
5. Influence Diagram.

## Facility Selection Tool:

There is no explicit facility selection tool selection to design a roadway based on the Risk Analysis and Management process.

## Evaluation

### Pros:

- Can more directly focus and compare the risk-safety relationships associated with a project design.
- Risk mitigation is at the heart of this decision-making process, which inherently tries to maximize safety.
- Risk analysis and management components can integrate other CSS/CSD standard procedures.

### Cons:

- The perception of risk (particularly with respect to bicycle use) may vary widely from user to user and be subject to bias.
- There does not seem to be a standard method to convey varying degrees of risk to all parties.
- There does not appear to be a standard method to design a roadway based on Risk Analysis and Management methods.

# *NCHRP Synthesis 422: Trade-Off Considerations in Highway Geometric Design* 2011 – Safety

## Structure and Content of Guidance

### Purpose:

Describing the potential trade-offs in roadway design which are made through a safety lens.

### Design User:

The primary factor influencing the design user is the human itself, then technological (Infrastructure), then organizational (State Transportation Agency).

Using James Reason's Swiss Cheese Accident Causation Model, the fourth factor (the person) is specified as a road user type. The context is a road user type involved in a crash, but could be applied holistically in to the entire population of roadway users.

### Guidance Provided:

#### There are three important factors related to a crash's cause:

- The crash occurred in a complex environment where elaborate safety devices were employed.
- The crash was not caused by a single failure, but a combination of several each necessary but not sufficient to cause the event by itself.
- Human failures, not technical failures were typically the root cause.

Next, Reason identified **active** and **latent failures** as definitions where humans caused breakdowns in complex systems. Active failures involve immediate violations to safety principles, where latent failures are tied to decisions or actions that later result in failures.

The following graphic illustrates the many different layers of possible locations where a combination of failures could amount to a crash.

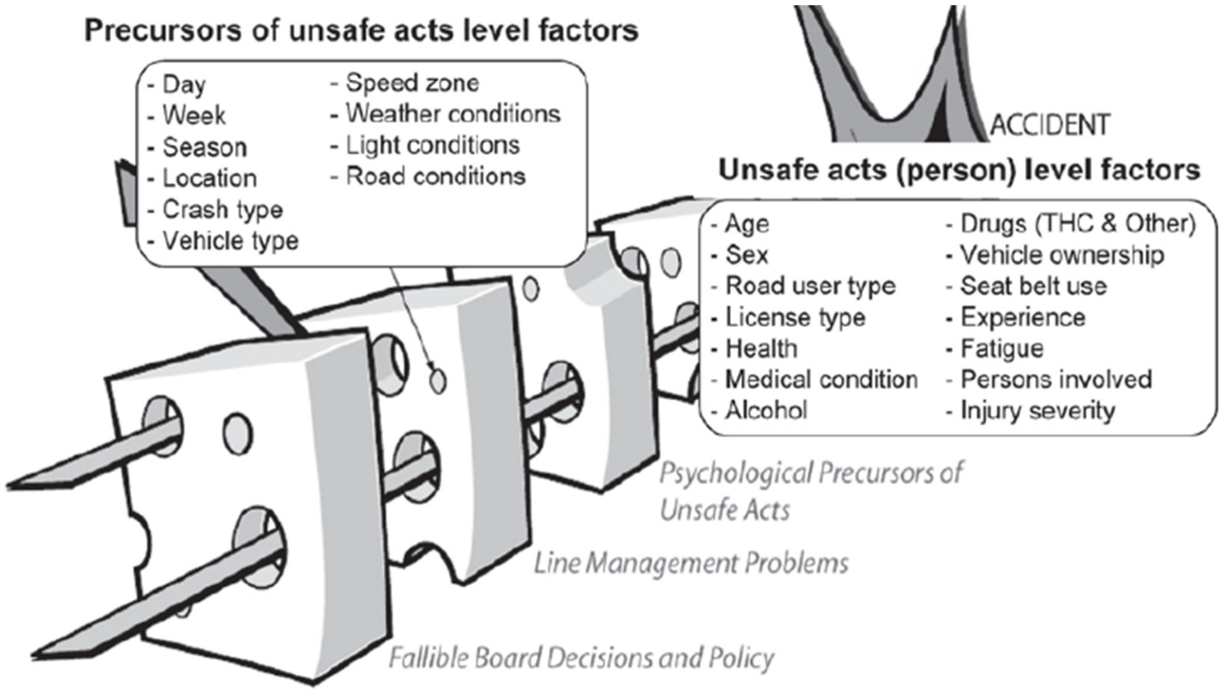



**Figure 65 - Fatal road traffic accident data mapped onto Reason's Swiss Cheese Accident Causation Model**

Source: *NCHRP Synthesis 422: Trade-Off Considerations in Highway Geometric Design* 2011

Reason identifies three types of organizations to how they could approach safety reform:

- Pathological organizations – Use inadequate safety measures
- Calculative organizations – Take a "by-the-book" safety approach (most Transportation Agencies)
- Generative organization – Establish safety targets beyond ordinary expectations and are willing to use unconventional means to achieve them (The Swedish Vision Zero program)

When designing roadways, a holistic (3-Dimensional) decision making approach is necessary when evaluating trade-offs to promote safety. It is necessary to step back and assess the look at all trade-offs holistically as projects are underway, as individual trade-offs that may be perfectly safe in isolation can create unsafe conditions when combined.

## Process:

The concept of safety-conscious planning integrates safety into all decision points of transportation planning including setting policy for project development. Other decision points to integrate includes enforcement, education, as well as emergency response to incidents.

### Road Safety Audit vs. Traditional Safety Review

A Road Safety Audit (RSA) is generally defined as a comprehensive and inclusive approach to review the safety of a roadway, whereas, a traditional approach may be biased toward a design within the realm of 'by-the-book' safety approach or a commonly used set of roadway design practices which may not address the safety issue. Also, a traditional review typically does not develop a formal response.

The RSA process typically involves the following eight steps:

1) Identify project to be audited
2) Select RSA Team
3) Conduct pre-audit to review project information
4) Perform field reviews under various conditions
5) Conduct audit analysis
6) Present audit findings to project owner
7) Prepare formal response
8) Incorporate findings into project

FHWA has developed a process to perform a RSA, including the following prompt lists for the planning stage of the audit including data on intersections, environmental constraints, and other design issues.

### Substantive Safety

The safety performance function (as described by previous editions of the Highway Safety Manual (HSM)) is a means to predict the expected crash frequency of a roadway or intersection based on several roadway inputs. Using substantive safety methods moves closer toward a performance-based design type approach. The HSM can be used to evaluate the trade-offs of various design alternatives. The biggest limitation of the HSM is the lack of pedestrian/bicycle-related characteristics incorporated into the international database of countermeasures.

## Facility Selection Tool:

There is no explicit facility selection tool to create a safety oriented roadway. There are “countermeasures,” which have crash modification factors (CMF) to lower the substantive safety of a roadway, but there is no direct application.

## Evaluation

A safety focus on trade-offs in roadway design.

### Pros:

- Can illuminate the issues the organization’s perspective on safety. (A Vision Zero approach)
- Can better educate internal staff on alternative views to how to approach designing a safe roadway.
- If a generative organizational approach is taken, then the challenge to achieve a lofty safety goal could be started, rather than appearing impossible to achieve.

Cons:

- Don’t directly establish a process to design a “safe” roadway
- Does not explicitly understand the needs to accommodate safe passage of non-motorized traffic, requiring expert review team members to inform the process
- Isolating one or several “unsafe” infrastructure elements is not explicit. An engineer must go through the entire process to understand the nature of their design decisions.
- Relying on Highway Safety Manual approaches will limit potential solutions to bicyclist safety issues until the CMF database improves

# *NCHRP Synthesis 422: Trade-Off Considerations in Highway Geometric Design* 2011 – Value Engineering

## Structure and Content of Guidance

### Purpose:

Describing the potential trade-offs in roadway design when applying a Value Engineering (VE) process.

### Design User:

Used to engage stakeholders to “Better balance the needs of road users and those of the community or the environment.” However, the challenge with VE is monetizing key factors, such as quality of life factors.

### Guidance Provided:

VE is a method to allow the interdisciplinary team to use a common language and more quickly understand project objectives, which will enable a faster decision. CSS/CSD and VE are relatively similar processes.

COMPARISON OF VE AND CSS/CSD PROCESSES

| Value Engineering Steps | Similar Steps in CSS/CSD Project |
|---|---|
| (pre-study): Selection of the projects, processes, or elements for evaluation | DOT may decide to apply CSS approach to all projects. Major projects often get more extensive process. |
| Investigation: Background information (context is one factor), function analysis, team focus (WSDOT includes stakeholders) | Convene team, including stakeholders<br>Investigate, learn about context, understand and discuss purpose and need, functions |
| Speculation: Creative, brainstorming, alternative proposals | Listening, brainstorming, alternative proposals |
| Evaluation: Analysis of alternatives, what are life-cycle cost impacts, which delivers highest value overall? | Understand tradeoffs. Reach consensus, if possible, on alternative delivering the most value to the public |
| Development: Develop technical and economic supporting data | Document decisions and why they were chosen |
| Present recommendations/findings. Fair evaluation. | Present arguments |
| Implementation of VE recommendations | Implementation of CSS recommendations—sometimes a commitment tracking system provides support |
| Audit: Review of completed results, accomplishments, and awards. | Audit: Review of completed results, accomplishments, and awards. |

**Figure 66 - Comparison of Value Engineering and Context Sensitive Design process**

Source: *NCHRP Synthesis 422: Trade-Off Considerations in Highway Geometric Design* 2011

## Process:

The systematic process used in VE is organized into three major components, and then the value study further broken into six different workshop phases.

## Facility Selection Tool:

There is no explicit facility selection tool selection to design a roadway based on the VE process.

## Evaluation

### Pros:

- Allows multiple disciplines to more quickly understand design choices and their impact on outcomes.
- Allows for more rapid decision making.

## Cons:

- The process does not monetize key factors well, (e.g., quality of life factors).
- The process relies upon expert knowledge of factors that impact bicycle safety and comfort.
- The determination of MOEs requires expert knowledge of bicycle safety and comfort.
- Could skip over certain MOEs if not comprehensively stated.

# North Carolina Department of Transportation - *Pedestrian Crossing Guidance and Flow Chart*. 2015.

## Structure and Content of Guidance

### Purpose:

This standalone report provides guidance to North Carolina Department of Transportation (NCDOT) to help jurisdictions determine when to provide pedestrian crossing treatments at uncontrolled and controlled intersections.

### Design User:

This guide does not specify a design user.

### Guidance Provided:

- Discussion of pedestrian crossing treatments.
- Discussion of state of practice.
- Pedestrian delay.

## Process

This guide presents does not include a discussion of a facility selection planning process.

## Facility Selection Tool

NCDOT's facility selection tool is in the form of a decision tree (see Figures 1 through 4) where each step guides the user through a process to select a crossing treatment, or move on to another step to select a different treatment.

## Evaluation

### Pros:

- The guide is well-organized and easy to follow.
- The guide includes useful graphics.
- The guide includes examples of how to use the tool.

### Cons:

- The guide does not include additional process guidance such as weighting criteria or inclusion of non-roadway context factors such as maintenance or budget.
- This guide does not discuss guidance for factors that provide important context for the crossing and would likely influence selection decisions, such as proximity to schools, hospitals, and senior centers.
- The guide's process and guidance may not allow for sufficient flexibility in application.
- The guide does not provide guidance for supplementary treatments to improve the effectiveness of the treatment.

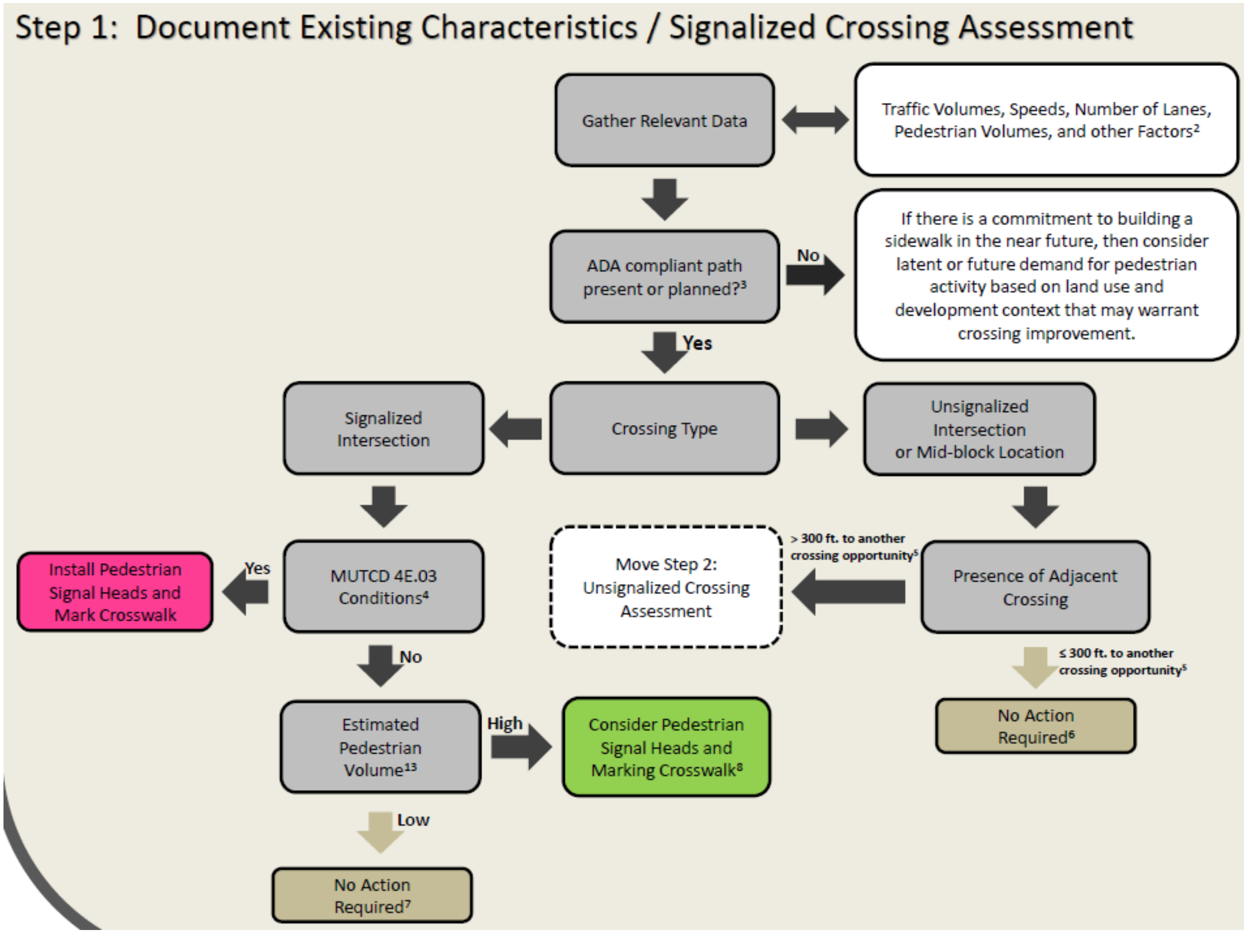



**Figure 67 - Step One of Facility Selection Process**

Source: NCDOT *Pedestrian Crossing Guidelines* (2015)

# Advancing Sustainable Safety. *National Road Safety Outlook for 2005 – 2020.*[147]

## Structure and Content of Guidance

### Purpose:

This research paper provides a summary of road safety planning in The Netherlands so that other places can learn from the success achieved in The Netherlands.

### Design User:

This research paper does not specify a design user.

### Guidance Provided:

- Discussion of a sustainable safety vision which is based on five principles:
    - Functionality of roads,
    - Homogeneity of masses and/or speed and direction,
    - Predictability of road and road user behavior by a recognizable road design,
    - Forgivingness of the environment and of road users, and
    - State of awareness by the road user.
- Discussion of fundamental roadway safety risk factors in traffic (i.e., speed, mass, and protection based on risk and vulnerability).
- Provides discussion of approaches to top crash risk issues including speed, vulnerable users, drunk driving, young drivers, and trucks.
- Discusses the importance of road authorities and society at large taking a larger role for the responsibility for safety then relying upon individual citizens to behave properly.
- Sustainably safe road traffic is best served in conditions where rules reasonably cannot be or can hardly be violated due to design requiring good behavior.
- Discussion of a quality assurance approach to safety that includes a legal framework for road authorities which could include:
    - Restricting unclear commitments by supervision of road authorities at arm's length; a basis is constituted for requirements concerning dissemination of information and knowledge, safety assurance systems, training, audits and reviews, terms of reference for contracting, etc.
    - The assurance that safety is taken on board and weighted in spatial planning and accessibility plans, e.g. by means of impact assessment reports.
    - Conformity and uniformity in infrastructure construction, operation and maintenance.
    - Compulsory analysis and remedial action in case of crashes and latent errors.
    - Compulsory safety monitoring, both in terms of crash statistics and process indicators.
- Discussion of ways that policy implementation can fail:
    - Rigid objectives and policy programs leave executive organizations and target groups with insufficient room to adapt policy to specific circumstances and conditions for implementation;
    - Insufficient resources are made available; and

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[147] Wegman, F., Aarts, L., and Bax, C. Advancing Sustainable Safety. National Road Safety Outlook for 2005 – 2020. Safety Science, Vol. 46, 2008.

- Policy does not line up with the objectives, opportunities and knowledge of executive organizations, policy makers in other sectors, target groups and stakeholders.

## Evaluation

### Pros:

- The document provides a high-level overview for how to apply a systemic safety approach to safety projects and organizational thinking
- Provides strong discussion of importance of changing agency and societal approach to safety

### Cons:

- The document does not provide a process or discussion for how to assess tradeoffs