

DELIVERING SAFE, COMFORTABLE, AND CONNECTED PEDESTRIAN AND BICYCLE NETWORKS: A REVIEW OF INTERNATIONAL PRACTICES



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16. Abstract: The purpose of this study was to identify noteworthy and innovative international designs, treatments, and other practices that have potential to improve bicycle and pedestrian safety and access and increase walking and bicycling in the United States. This report covers treatments and practices from a total of 11 countries, covering six thematic areas: (1) network infrastructure, (2) limited auto traffic areas, (3) signalization, traffic control, and intelligent transport systems, (4) policy change, (5) criteria or methods for prioritizing improvements, and (6) goals and network performance measures. A number of treatments and practices appear to have significant potential to help improve bicycle and pedestrian network safety, comfort, and connectivity in the U.S. Additional study and actions are needed to better understand, test, and refine the most promising designs and practices for use by U.S. jurisdictions.					
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Executive Summary

The purpose of this study was to identify noteworthy and innovative international designs, treatments, and other practices that have potential to improve bicycle and pedestrian safety and access and increase walking and bicycling in the United States. The study was conducted by searching published literature and electronic resources and by reaching out to professionals working for foreign local, regional, and national jurisdictions for up-to-date information on innovative plans, policies, practices, and designs.

This report covers treatments and practices from a total of 11 countries. Based on information gleaned from the study, the team identified six thematic areas, with four covering infrastructure or treatments: (1) network infrastructure (including large-scale intersection design), (2) limited auto traffic areas, (3) signalization, traffic control, and intelligent transport systems, and (4) policy change; and two topic areas focusing on innovations in: (1) methods or measures for prioritizing improvements, and (2) goals and network performance measures. In addition, the team identified and summarized a few recent guidance documents. Finally, information on network outcomes is summarized, including an example of recent findings and actions resulting from national safety monitoring and evaluations of innovative treatments.

A number of treatments and practices appear to have significant potential for use in the United States (U.S.), particularly for completing and expanding bicycle networks to enable longer and safer trips with less delay. Note that not all of the covered treatments are considered particularly innovative. Some of the most interesting things that are happening internationally are improving on prior successes (e.g., going from separated bike lanes—typically called cycle tracks in Europe—to bicycle superhighways), studying the effects of past innovations, and designating clear and ambitious mobility goals, which in turn lead to active strategies to retrofit space and provide other improvements to meet bicyclist and pedestrian needs.

One of the key lessons from international jurisdictions with high levels of walking and bicycling and good safety records, is that bicycling and walking are clearly prioritized in plan goals, which, as expressed through broad performance measures, are seen as having value to help achieve public health, environmental, livability, economic, and transport sustainability goals, as well as providing transportation options in their own right. Therefore, project and decision criteria reflect greater priority to make bicycle and pedestrian travel safer, faster, and more convenient, even if changes sometimes may hinder motor vehicle mobility or access.

The ambitious pedestrian and bicycle mobility goals established by many foreign jurisdictions can only be achieved if the networks provide safe and convenient choices and are perceived as such by potential users. A variety of criteria and formal and informal processes are used to assess whether networks and facilities are meeting network goals and how they can be improved. Processes used include leveraging staff expertise, performing quality assessments, examining complaint data, applying risk indexes to develop priorities, applying a broader goal or policy framework (including safety principles and design guidance criteria), and gathering input from the public (including a from broad array of potential roadway users) and from bike unions. Public input seems to be highly valued and used by most jurisdictions, and some take

proactive measures to gather input directly from the community. For example, in one city, staff cycle to meetings, ride the network (sometimes using a variety of bike types), and attend community meetings to listen to concerns. Other cities regularly perform formal surveys of users. Some jurisdictions have used bicycle unions and tools to help assess their networks. Further study is needed to clarify the processes used, how widely they are used and in what combinations, and which might work best in the U.S. to help create a more representative and equitable decision process.

The types of infrastructure and network completion measures identified as most promising for U.S. practitioners to examine further include the following:

- Various types of bicycle priority streets (superhighways, shared bicycle priority streets, wider separated lanes, and “green waves”) for longer cycle trips and improving connections to employment and urban centers. Some communities have planned extensive networks of connected facilities linking important origins (outlying areas and cities) to important destinations. Overpasses, underpasses, and grade separated junctions are frequently used to bypass major roads and other barriers such as rivers and canals.
- Lower-speed, experimental designs for multi-lane, at-grade roundabouts and their approaches to help bicyclists safely travel through.
- Path or lane lighting (energy-efficient) for nighttime use, using technologies to detect users and raise the lighting and then dim the lighting as the user moves away.
- Bicycle signals and various measures for bicycle priority at intersections, including:
 - “Green waves” signal progression.
 - More green time for bicyclists.
 - More split phasing to separate conflicting motor vehicle and bicycle movements
 - Allowing non-conflicting bicycle through movements (bicycle green) when signal is red for parallel motorized traffic.
 - Leading bicycle interval / head start.
- Path or two-way bicycle facility priority at junctions with low-volume streets.
- Traffic restricted, pedestrian priority zones.

In summary, there are a number of planning and decision processes and innovative infrastructure treatments that have potential for use in the U.S. These include setting ambitious mobility goals and identifying formal or informal methods to assess public and user satisfaction and desires. These procedures might potentially be as simple as getting staff and decision-makers to bike or walk more often in more areas, but may also include more formalized processes to gather a better cross-section of public concerns and input into the planning and prioritization process. Most of the infrastructure innovations are expanding on ideas that have been working well and improving on designs and traffic controls to further enhance safety and mobility. Some of the ideas may have significant potential for improving bicycle and pedestrian safety and mobility in the U.S. *if well implemented*. Additional study is needed to better understand and facilitate the best ideas and test and refine them for use by U.S. jurisdictions.

Introduction and Study Objectives

Spurring more walking and bicycling continues to be a challenge in the United States. Safety issues—perceived and real—are primary concerns for seniors, parents, and many others who could choose to walk or cycle more if safety and other mobility barriers were reduced. The numbers and percentages of bicyclists and pedestrians killed and injured in U.S. traffic crashes have not sustained the safety improvements observed for most motorized modes in recent years. In a single year (2012), more than 4,700 pedestrians and 720 bicyclists were killed, and 125,000 pedestrians and cyclists were injured as a result of collisions with motor vehicles on U.S. streets and highways (NHTSA, 2014).¹ Many others are injured in other types of crashes and falls that often result from inadequate or poorly-maintained infrastructure. Some travelers deem the built environment to be excessively dangerous or uncomfortable and choose not to walk or cycle regularly. When it comes to providing infrastructure that best accommodates pedestrian and bicycle travel, most communities in the U.S. lag behind many jurisdictions in other developed countries. Differences in policies and practices, culture and values, funding, and decision-making structures may all be factors in some of the differences in developing, testing, implementing, and widely disseminating the designs and other features of safe and connected pedestrian and bicycle networks. Thus, it is not only important to identify measures that enhance connectivity and safety for pedestrians and bicyclists, but to also identify and implement policies, practices, stakeholder involvement, coordination, funding, and implementation activities needed for successful outcomes.

The purpose of this desk-based review was to identify noteworthy and innovative international designs, treatments, and other practices that might be transitioned for use to improve bicycle and pedestrian safety and access in the United States, helping to complete networks that will enable people to walk and bicycle to virtually any destination. In 1994 and 2009, FHWA sponsored study tours related to pedestrian and bicyclist safety and mobility.^(2,3) Reports from each of these tours document lessons learned based on study teams traveling to several European countries; speaking with agency representatives; gathering relevant guidelines, reports, and research; and observing traffic and roadway facilities first-hand. Key information and lessons from each of these tours is summarized in the respective documents. A number of innovations identified in those earlier tours—such as bike boxes, raised pedestrian crossings, pedestrian crossing islands, and others—have been implemented and evaluated in U.S. cities. Some U.S. design guides and policy documents now, for example, routinely recommend pedestrian crossing islands for multi-lane crossings. Other innovations identified in the earlier tours do not seem to have received as much attention in the U.S. These include nearside traffic signals (to reduce encroachment on crosswalks), bicycle signals to reduce conflicts with motor vehicles at signalized intersections, widespread child traffic safety education, and use of automated enforcement for speeding and red light running. These practices also form part of the environment and context of pedestrian and bicycle networks in the countries examined in the present study.

This report provides up-to-date information on practices, designs, and treatments that are currently being used by many of the leading and up-and-coming cities and countries to

continue building on success. Although this study and report avoided, as much as possible, duplicating what was learned from these previous international scans, some of that information is still relevant and provides background and the basis for continuing improvements.

To perform this review, the project team drew from existing information in policy documents, guidelines, design documents, plans, internet-based resources, academic literature, and other sources, as well as professional expertise. For this study, the project team tapped this expertise solely through electronic means rather than through site visits. In particular, this study focused on published resources and the knowledge base and experiences of practitioners from foreign jurisdictions that are leading the way and from those that have more recently increased their focus on enhancing opportunities for safe bicycling and walking. Professional staff from these jurisdictions helped identify innovative practices, designs, guidance, evaluations, and policies used to meet pedestrian and bicycle network goals and to characterize the goals that are providing the framework for decisions. The project team derived the treatments and practices collected as part of this review from many European cities and countries as well as municipalities and other jurisdictions from Japan, Canada, Australia, and New Zealand.

Given that the topic of “safe and connected” networks is relatively broad, the project team sought information that fell generally into the following topical categories:

- How jurisdictions determine what is a complete and safe network;
- What performance measures are used to assess how well the networks are meeting the community’s goals and priorities overall;
- What methods are used to identify safety problems or gaps in the networks;
- What measures or criteria are used to prioritize improvements; and
- What innovative treatments have been used to address safety problems or other network connectivity issues.

This report summarizes the best examples found in the published and internet sources and from information gathered directly from jurisdictions. The report covers noteworthy design and traffic control practices, Intelligent Transport Systems (ITS), and other types of measures. The report also describes recent evidence of effectiveness relating to designs and treatments that may merit follow-up, and characterizes some of the notable practices related to performance goals and measurement and project prioritization.

Study Approach

The development of this desk review summary report involved searching the literature and original internet sources; obtaining information electronically from international jurisdictions; and by screening, compiling, and synthesizing the information to identify and describe noteworthy practices. The basic steps included an initial search for relevant literature, gathering input from select foreign jurisdictions through an internet questionnaire and direct communications, and acquiring additional documents and resources identified by the contacted jurisdictions.

The study team used resources from the Pedestrian and Bicycle Information Center (PBIC) International Information Library (<http://www.pedbikeinfo.org/data/international.cfm>) and performed an updated search of databases and select websites for relevant published (peer reviewed and other) material,ⁱ specific conference proceedings,ⁱⁱ government publications and white papers,ⁱⁱⁱ and other primary sources, including agency and jurisdiction websites.

The project team worked with FHWA to identify candidate countries, cities, and foreign experts to contact to obtain information directly. Of particular interest were countries and local jurisdictions widely considered to be leaders in providing safe and connected pedestrian and bicycle networks. The project team was also interested in jurisdictions that have more recently begun focusing greater priority on improving networks for pedestrian and bicycle mobility and safety and that may offer lessons for the U.S. The project team identified an initial list of countries and jurisdictions and also followed up on referrals from experts in other countries.

The project team contacted staff at the identified jurisdictions and invited them to share their jurisdictions' practices and innovations through an on-line questionnaire or by telephone. The questions related to the topics described in the introduction.^{iv} The research team ultimately reached out to more than 100 individuals in 50 cities across 14 countries. Thirty-seven jurisdictions provided at least partial information, with 25 completing questionnaires about bicycle networks and 14 providing information about pedestrian networks.

The research team prepared this summary based on the information provided directly by the foreign agencies, or follow-up discussions, as well as from policy and planning documents, guidelines, evaluations, and other information from the literature. Not all good examples could be included in this report. The examples selected represent variations of strategies and solutions that are often used in multiple jurisdictions.

ⁱ These included searching: TRID (Transportation Research Information Database); PubMed/ISI Web of Science; PAIS (Public Affairs Information Service)) for planning and public policy research; Transport Research Portal, a federated search of international transport databases; and Google Scholar.

ⁱⁱ Conference proceedings, with a particular focus on international applications included: TRB (Transportation Research Board) Annual Meeting, International Transport Forum, Road Safety on Four Continents, Transportation Research Arena.

ⁱⁱⁱ PBIC International Information Library, and For Europe: European Road Safety Organization (ERSO) Knowledgebase, CORDIS: the R&D database for the EU, Transport and Innovation Portal (TRIP).

Government transportation sites including SWOV (Netherlands); INRETS (France); Department for Transport (UK); and VTI (Sweden); Traffic Injury Research Center (Canada), Transport Canada, and Transportation Association of Canada; and for Japan: Government Ministry of Land, Infrastructure, Transport and Tourism, Transport Safety Board, and Japan Bicycle Promotion Institute.

^{iv} Copies of the pedestrian and bicycle questionnaires can be provided upon request.

Results of Review

Based on information gleaned from the above process, the team identified six thematic areas. Four covered treatments: (1) network infrastructure (including large-scale intersection design), (2) limited auto traffic areas, (3) signalization, traffic control, and intelligent transport systems, and (4) policy change. Two topic areas focus on innovations in: (1) methods or measures for prioritizing improvements and (2) strategies to measure performance of the system. Below, this report first discusses the primary nature, aim, and purpose of each thematic area; outlines some considerations for application in the U.S.; and then describes some examples of each innovation and treatment within the context of which community the treatment is from.

Network Infrastructure (Including Large-Scale Intersection Design)

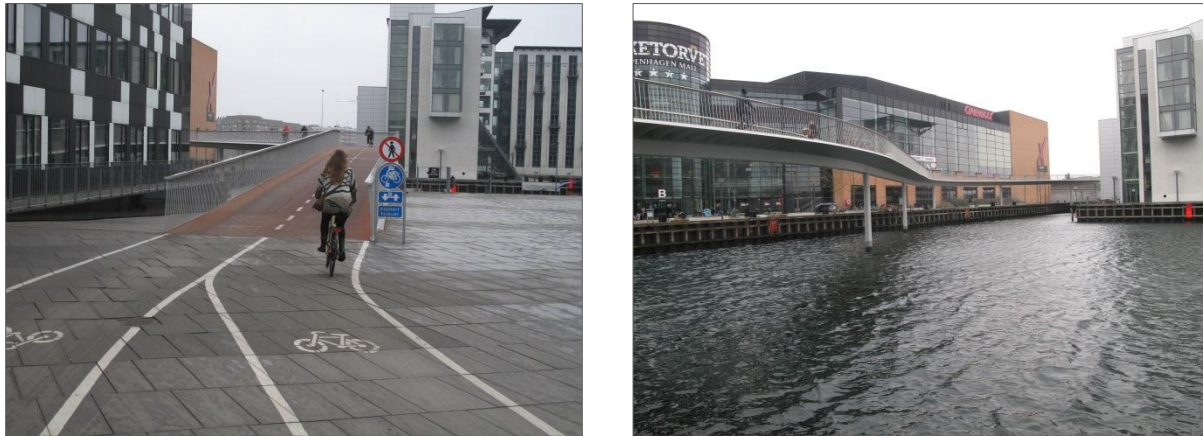
The first category of treatments centers on novel strategies for new or expanded kinds of bicycle routes or facilities. Innovative cycling treatments include superhighways (typically separated facilities are preferred); shared use, priority bicycle streets on local/residential type streets; large scale intersection treatments; and lane lighting schemes that can improve options for nighttime cycling such as on off-road paths. Most of these treatments have been utilized to help improve the safety and mobility of bicyclists, particularly to promote the use of bicycles for longer trips, and for completing extensive networks. There do not seem to be major policy barriers or other restrictions to the use of these types of treatments, which are typically implemented with existing design and traffic management tools. However, it would be useful to see the designs and supporting treatments first hand to make these determinations. The cost of some of the treatments, such as large, grade-separated intersections or tunnels and bridges may at present be a barrier, but as more connected and longer bicycle facilities are created in the U.S., such facilities might be implemented to help further reduce barriers. Some U.S. cities, such as Boulder, CO, have already made extensive use of grade-separated facilities.

Bicycle Superhighways

Particularly popular in Denmark and the Netherlands, bicycle superhighways (*cykelsuperstier*) are a recent innovation over the past decade and are designed to support longer trips at higher travel speeds, avoiding most stops and conflicts. Specifically, the purpose is to increase the number of persons bicycling for trips farther than 5 km (3 mi). Although routes may link several types of bicycle facilities together, including separate paths or separate bike lanes, most major barriers (major highways or water barriers) are crossed by bridges, underpasses, or tunnels. The major hurdle for implementing such bicycle superhighways in the U.S. is identifying the best routes and retrofitting such facilities into developed areas and road networks.

Copenhagen, Denmark: The larger Copenhagen region has received substantial attention because of its efforts to provide direct routes between larger employment and education centers, residential areas, and major public transit transfer points. At times, there is supporting infrastructure such as footrests at traffic signals and air pumps. The bicycle superhighways are intended to be a space to themselves within the roadway right-of-way, rather than an appendage to the road.⁽⁴⁾ Results of an evaluation of the first bicycle superhighway are

summarized in the Outcomes section. Responding to a key missing link in one of its bicycle superhighways (when users were forced through a busy pedestrian area connecting the harbor bridge to the railroad bridge), Copenhagen rolled out the *Cykelslangen* (“Bicycle Snake”) in 2014: a 230-meter (750-foot) bicycle bridge connecting two other bridges (Figure 1).



Source: Paul Ryus

Figure 1. “Cykelslangen” Bicycle Bridge, Copenhagen, Denmark

Esbjerg, Denmark: Esbjerg is constructing a bicycle superhighway along one of the main corridors into the central city. The project combines a variety of bicycle facility types, including off-street pathways, a bicycle boulevard, on-street bicycle facilities, and a bicycle street in the city center. ⁽⁵⁾ New infrastructure will include 600 meters (2,000 feet) of new separated bike lanes, a bicycle underpass at a busy intersection, a raised intersection along the bicycle boulevard, a right-turn bypass route at a traffic signal, and new bicycle parking in the city center. The project is planned to be constructed in 2014-2015 and is expected to save bicyclists 5 minutes of travel time along the length of the 6.5-km (4-mile) corridor, compared to present.. **Aalborg** has also implemented a 5 km long bicycle superhighway to connect a university with the city center. ⁽⁶⁾

The Hague, The Netherlands: The Hague has planned a network of bicycle “star routes” (*sterrouter*) that will be the city’s primary bicycle transportation corridors, connecting neighborhoods with key bicycling destinations in the city center and also serving as attractive bicycling routes from the city into the countryside. They are intended to be comfortable, direct, fast, and secure. These networks will use a blend of separated facilities and (less preferred) shared use facilities when separated facilities are not possible. To the extent possible, they will avoid areas with arterial roads and preferentially use paths along canals and green spaces (with fewer intersections) or separate paths along roads with lower traffic volumes, which will also allow for providing more bicycle priority at intersections. Separate bicycle paths parallel to the street are preferred, but wide bicycle lanes or bicycle streets can also be considered in constrained areas. Traffic signals will be provided to facilitate crossings of busier streets, with bridges used for major barriers such as arterials, freeways, railroads, and canals. Where

necessary, parking will be removed or traffic circulation adjusted to create space for the bicycle facilities. As much as possible, the routes will be developed as a whole, as it is believed that just one missing link can deter someone from making a longer-distance bicycle trip. New development is intended to connect to the network, and the network is intended to connect to the regional bicycle network.⁽⁷⁾ Other Dutch cities with similar planned networks include **Amsterdam's** "fast bicycle routes" (*snelfietsroutes*) designed for fast, comfortable bicycle commuting and **'s-Hertogenbosch's** star routes, which are discussed further in the Project Prioritization section.^(8, 9)

Priority Bicycle Streets

Priority bicycle streets—mostly former car-oriented streets whose priority has been turned over to cycling—are a different innovation. In these cases, extremely limited auto use is permitted (and cars are expected to travel at cycling speeds), but the predominant user is clearly cyclists. The flow function for bicycles and the access function for cars are the two primary, and potentially conflicting, functions that must be managed (as well as possible) through the design of the streets. The livability and pedestrian functions of the street are also considerations.

Some cities, such as Portland, OR and Seattle, WA, and others are already implementing priority bicycle streets on residential/local streets modeled on examples in the Netherlands and Germany. These may be known as neighborhood greenways and by other names, depending on the city. Earlier bicycle boulevards, as they were known, also fit this concept. The design toolbox being used by U.S. cities may be somewhat different from European cities, but even in the Netherlands, there seem to be a wide variety of design features being used, which may affect the recognizability and function of these streets. See the summary of a study of eight bicycle streets in Zwolle, in the Outcomes section.

These types of routes provide a complementary type of facility to bicycle superhighways or other separated facilities for connecting neighborhoods to other links and potentially for providing for longer, through bicycle trips to connect with transit, link up to bicycle superhighways or off-road facilities, or to reach end destinations. Bicycle and motorist speeds must be managed to achieve the safety and operational goals (bicycle throughput and motorist, pedestrian, and cyclist access to all addresses) as exemplified by the European examples and meet perceptual expectations for safety. The project team is not aware of any major barriers to implementing bicycle streets. There may be limitations in some communities in that the road network may not provide sufficient redundancy to develop bicycle routes on residential types of roads that are sufficiently long or connected to significant origins and destinations. Also, on the streets where implemented in European cities, bicyclists typically outnumber motor vehicles, and the balance of users may also affect success.⁽¹⁰⁾

Aarhus, Denmark: Aarhus implemented two bicycle streets in the city center, inspired by practice in The Netherlands and Germany. Aarhus prohibits motor vehicle stopping and parking along the streets from 7–9 a.m. and 3–5 p.m., with stopping for deliveries allowed outside these hours in designated spaces. Prior to conversion, one street, Mejlgade, had narrow sidewalks and was one-directional for autos (with parking allowed) but bidirectional for the

6,000 bicycles per day that used the street. After conversion, a 4-meter (13-foot) space was provided in the center of the street for cyclists and motor vehicles, with the leftover space used to widen the sidewalks. ⁽¹¹⁾

Næstved, Denmark: Næstved (city pop. 42,000) created a bicycle street in the city center by reducing a 13-meter (42-foot) driving area to a 5.5-meter (18-foot) bicycling area, with motor vehicles allowed (Figure 2).¹² An evaluation of the first phase of the project, in which a one-block (600-foot) section of the street was treated, showed a 30 percent reduction in motor vehicle traffic, a 4 km/h (2.5 mph) reduction in the 85th-percentile speed, and a 16 percent increase in the number of bicycles (from 273 per day to 316). Bicyclists felt safer using the street.⁽¹³⁾



Source: Paul Ryus

Figure 2. Bicycle Street, Næstved, Denmark

Green Waves

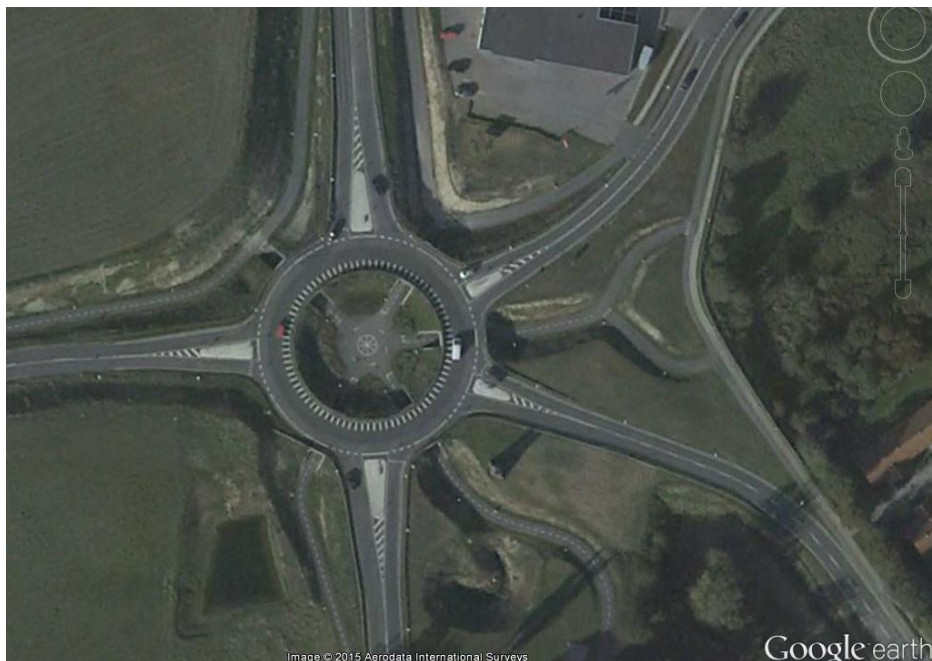
Stockholm, Sweden: A highly publicized and recent advancement from Stockholm is the Götgatan cycling project. *“Realizing that this stretch can easily receive 15,000 cyclists per day, the current city council sought a signature bicycle improvement. In October of 2013, it freed funds to address the under-capacity of the existing protected lanes along this stretch. Following study, design, and deliberation, the city rolled out a redesign of the corridor in mid-June 2014, which entailed removing a lane of auto traffic, creating more pedestrian space, and widening the bike lanes. Accompanied by traffic signals timed in coordination for 18 km/hr travel, Stockholm now has its own 9 km-long ‘Green Wave,’ which allows bicyclists in one direction to travel this distance (if they ride at 18 km/hr) without putting their foot down for a stop light.”* Furthermore, at two traffic lights along this stretch, there is a countdown clock to provide information to approaching cyclists on how much time is remaining to make the wave.⁽¹⁴⁾

Such a treatment could provide improved mobility for commuter cyclists in the U.S. There could be a safety benefit, as well as a time and efficiency benefit, if cyclists are less likely to run red lights, be trapped by signal changes, or face other conflicts with cross street and parallel traffic.

Large Grade Separated Intersections

Given that a major problem for cyclists exists where key routes hit larger intersections, large grade separated intersections have addressed many such instances in foreign jurisdictions. These types of intersection designs may have future value in the U.S. for reducing stress or barriers to travel frequently caused by major intersections crossings. They have potential to provide connectivity for bicycle superhighways or other routes that are intended to encourage longer trips. The advantages of grade separation include improved safety and time savings for both motorized modes and bicyclists. Space constraints may be an issue in areas with denser development

Haderslev Municipality, Denmark: Haderslev Municipality converted a complex series of T-intersections into a five-legged roundabout with a 40-meter (130-foot) diameter (Figure 3). The roadway approaches to the roundabout are elevated, with five underpasses allowing bicyclists and pedestrians to proceed through the intersection without a change in elevation and without traffic conflicts. A bicycle mini-roundabout is provided within the central area of the vehicular roundabout. The project provides a safer connection across a ring road for nonmotorized traffic, including children traveling to a school.⁽¹⁵⁾



Source: © 2015 Google, Image © 2015 Aerodata International Surveys, © 2015 Europa Technologies

Figure 3. Shared Use Path Grade Separations, Haderslev, Denmark

Eindhoven, The Netherlands: Eindhoven (population 216,000) constructed a cable-stayed circular bridge serving pedestrians and bicycles over a reconstructed intersection along one of the entrances to the city. The bridge replaced at-grade pedestrian and bicycle crossings in a busy roundabout, and the roundabout was converted to a signalized intersection serving motorized vehicles only. The bridge connects to shared use paths on both sides of the roadways in all four intersection quadrants. The area around the intersection is rapidly developing with high-density residential units and the facility links to a major bicycle commuter route serving the office parks adjacent to a nearby freeway.⁽¹⁶⁾

C-Roundabouts

There may be jurisdictions in the U.S. with traditional multi-lane roundabouts where improvements are needed to allow bicyclists (and pedestrians) to safely use the roundabout. Two-lane designs tend to be less safe for bicyclists and pedestrians as there are more opportunities for weaving and crossing conflicts and drivers not noticing bicyclists circulating in the roundabout, or outside it (if on a separated path).

Auckland, New Zealand: The C-roundabout or cyclist roundabout design, as developed and tested in Auckland, is intended to improve safety of multilane roundabouts for bicyclists.⁽¹⁷⁾ The design intends to improve safety by slowing vehicle speeds on entry and in circulation to a level so that bicyclists feel comfortable mixing with traffic and taking the lanes on approach and through the roundabout. These two steps, taking the lane and riding with traffic through the roundabout, should help address the most common crash types involving motor vehicles and bicycles in multilane roundabouts, at least as documented in New Zealand and Australia. According to the developers, the C-roundabout should have a design speed of about 30 km/h (18.6 mph). Speeds are slowed by maximizing deflection and by using narrower lanes, ideally minimizing adverse impacts on motor vehicle capacity by retaining the multilane design. The narrower lanes on approach are achieved by widening the existing splitter islands. The central median island is enlarged to narrow the circulating lanes (Figure 4). The design principles are stated as follows:

“Entry width between kerbs should be 5.4 m [17.71 feet]. This is to prevent cars attempting to enter adjacent to heavy vehicles, but also to give minimum acceptable clearance between larger cars that enter side by side (allowing for 0.5 m clearance all round for two 99% sized cars). This is because heavy vehicles from the right-hand lane, in particular, are likely to track over the adjacent lane in the roundabout entry area...

The roundabout circulating carriageway and exits should be wider than the entry, with comfortable clearances between the two streams of car traffic. For two 99 percent sized cars entering side by side (a 0.01 percent chance of occurrence), there should be a minimum of 0.5 m clearance between vehicles and kerbs, and between 0.5 to 1.0 m clearance between vehicles”.⁽¹⁷⁾



Above: Source: © Google, 2015. Image, 2012.

Left: Source: © 2015 Google Map Data Sciences PTY, Ltd, PSMA. Imagery, Terralink International Map Data, 2015.

Figure 4. Example of Wider Median Island, Larger Raised Circle, Narrow Approach Lanes, and Circulating Lanes of Cyclist-Roundabout

Vertical deflection or maximum radius through the roundabout is 30 m. Mountable areas of the center island may be needed for large vehicles. Larger vehicles (buses, trucks) are intended to take both lanes on the approach and through the roundabout to keep from sideswiping smaller vehicles. Pilot evaluation results are discussed in the Measuring Outcomes section.

Lane Lighting Systems

Lane lighting systems are used to illuminate shared use paths. Frequently, the systems use solar powered light-emitting diode (LED) lights. New, more energy efficient, and less environmentally impactful lighting technologies could enhance options for illuminating facilities that may help to increase night-time travel options. The use of new technologies can help minimize energy costs and impacts on the environment, including light pollution. Riding at night tends to be riskier for bicyclists than daytime riding. For example, in the U.S. in 2012, 31 percent of bicyclist fatalities occurred at night time (8 p.m. – 3:59 a.m.); in the same year, roughly 70 percent of pedestrian fatalities occurred between 6 p.m. and 5:59 a.m.⁽¹⁾ Lighting systems similar to those described below are most likely to be of interest to provide important nighttime connections, either on a path or on a street, to transit or other important destinations where the path could potentially provide a safer alternative to existing options for nighttime bicycling. There may be a need to change local policies that restrict use of paths at night (if applied to off-road paths) and to

investigate other potential legal or security concerns. A certain level of activity may also be important personal security.

Leichhardt Municipality, Australia: Leichhardt Municipality (population 52,000), located in the suburbs of Sydney, installed an LED lane lighting system along a shared use path in a creek corridor. When the system detects a path user, it increases the lighting in the vicinity to full strength and then dims the lighting again as the user moves away to avoid excessive light pollution. The system reduces electrical costs and the impacts of nighttime lighting on the creek environment, while providing sufficient light for the safety and security of path users.⁽¹⁸⁾

Eindhoven, The Netherlands: Eindhoven (population 216,000) installed an illuminated cycle path inspired by Van Gogh's *Starry Night*. The 600-meter-long installation creates a glowing bike path that relies on solar-powered LED lights. The result is a more sustainable option for illuminating shared use paths, with reduced costs and less impact on wildlife.^{v (19)}

Trampe Bicycle Lift & CycloCable

Areas with steep topography can face more than usual challenges to encourage walking and bicycling. One jurisdiction has found a way to close "gaps" created by hills rather than traffic safety barriers by providing a "lift" to bicyclists and other active users.

Trondheim, Norway: Trampe is the world's first bicycle cable lift mechanism designed for use in urban areas. The prototype was introduced in 1993, and since that time, it has aided more than 200,000 cyclists on a street with a 130 meter long hill in Trondheim. During this time, no accidents were recorded.⁽²⁰⁾ The lift was removed and upgraded in 2013 to meet new safety regulations and to improve operations, and the new version will be known as the *CycloCable*.

Trampe/CycloCable operates similar to a ski lift. The cable and design elements are located just beneath the street surface to allow people and vehicles to pass over the rail without hindrance. Users push a green button at a start station at the base of the hill and wait for a foot plate to rise from the slot. Users then stand up on their bicycles with their left foot, and place their right foot and all their weight on the footplate. The launcher at the start station then accelerates gently to 1.5 to 2 meters per second (4-5 mph). Distance between footplates is 20 meters and for the 130 meter hill, 6 cyclists per minute can ride simultaneously (360 cyclists per hour). The lift can support inclines of up to 20 percent grade and extend up to 500 meters. When the cyclist reaches the top of the hill and takes their foot away, the load then leaves the footplate and it descends back into the rail housing.⁽²¹⁾ According to the designers, the lift is built for use by cyclists in urban areas, however other users have found ways to utilize it safely, such as skaters and pedestrians with baby carriages.

^v Other perspectives on the glow-in-the-dark bike path are at: <http://streets.mn/2014/12/05/glow-in-the-dark-bike-paths/>

The biggest benefit of the lift is that it encourages more people to ride bicycles in cities and urban areas with intimidating topography and steep grades. Trondheim is the third largest city in Norway, yet has the highest share of bicycling when compared with other cities. There is evidence that the lift is part of the reason. A 2007 survey of bicyclists in Trondheim found that 41 percent of lift users claimed they are using their bicycles more often due to the availability of the Trampe/CycloCable.⁽²²⁾

The cities of San Francisco and Pittsburgh, both possessing steep grades and challenging topography, have expressed serious interest in the lift, but implementation would require pilot demonstrations, funding, further engineering analysis within the context of the city infrastructure, and appropriate legislative steps.⁽²⁰⁾ Xie indicates that the main challenges, according to personnel from both cities, are questions of liability. However, the bicycle communities in both cities have expressed support. Given an appropriate cost-benefit analysis and model for operations and maintenance, the use of this innovation in U.S. cities is possible.⁽²⁰⁾

Limited Auto Traffic Areas

Given that automobiles are *usually* responsible for compromising both the safety and attractiveness for walking and cycling, several practices are employed to specifically address (or limit) car presence, thereby yielding important safety benefits.

The standard approach in countless European cities is to simply limit car use in historic cores of cities. However, there are increasing variations to these relatively staid approaches and more cities are experimenting. Some cities are expanding the area of their car-free zones; others are adjusting dimensions of it (e.g., allowing bicycles, motorbikes, or transit; adjusting day or times of day; allowing only residents; allowing car traffic but only at very slow speeds). Three examples from Italy help highlight the variation in strategies:

Florence, Italy: Florence in 2009 implemented a first phase around the Piazza Duomo to make this area inaccessible to motor vehicle traffic (Figure 9). Previously a major hub for bus and private vehicle traffic, more than 1,000 buses per day were rerouted to other hubs, making the Piazza Duomo pedestrian only. In 2011, the second phase was initiated, creating two more pedestrian zones around Piazza Pitti and via Tornabuoni. No cars or other motor vehicles may enter these pedestrian zones, with the exception of taxis with specific hotel destinations and emergency vehicles.^(23, 24)

Bologna, Italy: In Bologna, the entire historic (and relatively large) part of the city restricts all motor vehicle traffic into the area every day at all hours, with liberal exceptions for residents who live in the area, freight operators, and buses. Access control is provided with ITS: two cameras automatically track and photograph violators, who are then fined. Municipal police were present during the implementation phase until the installment of cameras and an automatic tracking and fining system could be completed. A large scale communication

campaign helped educate and inform citizens. A smart card system was distributed for residents and legal entrants to the zone through electronic pillars that detected smart cards. If no smart card was detected, the cameras were alerted to photograph the violation.^(25, 26)

Ferrara, Italy: Arguably the first planned car-free area in all of Italy, Ferrara's traffic limited zone is among the most aggressive. Only those who live within the core are allowed; eight cameras track violators. Parking permits are capped at one per household. Its relative magnitude and character stands out. Ferrara's zone is the third largest in all of Italy (9.81 square meters/habitant). There are 82 km of streets and more than one-quarter of them are traffic limited. In contrast to the larger Bologna, 50 km down the road, Ferrara bans motorcycles from its traffic restricted area.⁽³⁰⁾

New or expanded pedestrian zones were also created in Toronto, Canada and Tokyo, Japan away from the city centers.

Toronto, Canada: University areas in Toronto combined to create 1- to 1.5-block-long pedestrian zones in three locations on two campuses in 2009. The city contributed planning and design resources, along with street furniture, planters, paint, and road signs. The universities contributed landscaping and additional planters, provided on-going street furniture set-up, and committed to ongoing cleaning, maintenance, snow removal, security, and event programming. After a one-year pilot, the zones were made permanent, with some adjustments to traffic control, parking, and delivery activity being made after the pilot tests. A survey of users found very strong (96 percent or better in favor) support for retaining the zones and that benefits extended to both university and non-university users (e.g., safety improved through reduced conflicts; sidewalk capacity improved; and users changed their walking or bicycling routes to pass through the zones, visiting farmers markets and other businesses).⁽²⁷⁾

Tokyo, Japan: Tokyo formed three examples of "pedestrian paradises" –parts of streets that are closed to cars during designated days and times and closed to bicyclists and that prohibit performances and passing out fliers. They are heavily patrolled by police to enforce regulations and maintain safety.⁽²⁸⁾

A different strategy, described next, leverages key corridors and renovates them for pedestrian and bicycle only use.

Helsinki, Finland: In Helsinki, a 1.3 km path was created below street level from an unused former rail line, with frequent street-level access by stairs (Figure 5). The path provides a fast route through the city for pedestrians and bicyclists as well as other recreational amenities such as table tennis, basketball courts, and sculptures.^(29, 30)



Source: Hidden Helsinki website

(<http://www.hidden-helsinki.com/2012/07/baana-pedestrian-passage-through-city/>)

Figure 5. Former Railroad Corridor with Below-Street Grade Alignment Provides Fast Route for Pedestrians and Cyclists Through Helsinki, Finland

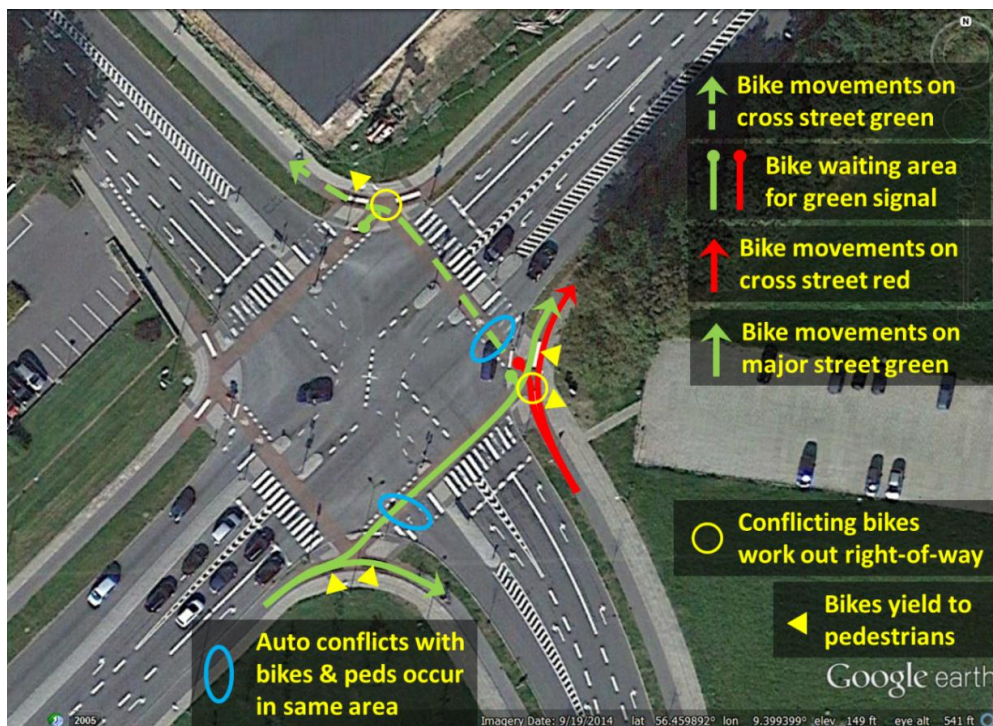
Any of the above strategies might be used in the U.S. to create or expand restricted-traffic pedestrian zones. Some may be more culturally or politically acceptable. The built environment will also affect the feasibility of some options, such as repurposing former railroad corridors or providing public space for multiple uses.

Signalization, Traffic Control, and Intelligent Transport Systems

A third theme revolves around the novel application of unique traffic control, signals, and supporting intelligent transport systems. Such applications may apply to intersections, corridors, or both. Several of the signalization and traffic management strategies may improve safety and mobility for bicyclists and pedestrians, although each needs to be studied further, including in a U.S. context. It would be helpful to examine the below types of systems in operation to better-understand the specific traffic contexts and user behaviors where they have been applied and to identify other issues that might be important for successful implementation in the U.S. There may also be general engineering practices or safety or cultural factors that are different for U.S. versus the jurisdictions where these have been applied. Some of the more promising strategies involve giving greater priority (time) for bicyclists or pedestrians at signalized locations, reduce the amount of stopping needed, or provide more separation of modes at large, busy intersections, which would clearly improve safety. Some of the strategies depend on having separated signals for bicyclists and motorized traffic, a measure identified in the 2009 study tour. Some U.S. jurisdictions have implemented bicycle signals, for example at path crossings of busy streets, but it is likely that their use could be expanded. There is potential for some of the signalization strategies to improve bicycle safety and mobility, in particular as networks are expanded and bicycling increases. More information is also needed about these or similar strategies tried in U.S. jurisdictions.

Aalborg, Denmark: Aalborg (population 130,000) installed **green LED lane lights** in the pavement along a separated bike lane approach to a busy intersection, with the goal to reduce the number of bicyclists entering the intersection on red. If a bicyclist passes a lit LED at a speed of 18 km/h (11 mph), they have sufficient time to pass through the intersection on green. Ten LEDs are placed at 10-meter (30-foot) intervals from 140 to 50 meters prior to the intersection.⁽³¹⁾ Odense and Copenhagen, Denmark have also conducted pilot projects applying lane lights.⁽³²⁾

Viborg, Denmark: In a variant of the above, Viborg has five signalized intersections where the **separated bike lane on the intersection approach continues around the curb radius and on to the intersection departure leg to the right** (Figure 6, and Figure 7 for an example from Odense). Painted bike lanes located just inside the crosswalks serve through bicyclists and bicyclists making two-stage left-turns. Approaching the intersection, **bicyclists proceed past the auto signal without stopping, regardless of the signal indication**, but they have to yield to any pedestrians crossing the separated bike lane at marked crosswalks. Right-turning bicyclists continue around the corner without stopping. Through and left-turning bicycles proceed to their crossing and wait, if necessary, for a green light to continue. This design places all nonmotorized traffic in the same locations within the intersection (making them more visible to motorists), serves as an advanced stop bar for bicyclists, and reduces right-turning delay for bicyclists. Bicyclists crossing the intersection should yield to bicyclists approaching from the right (based on the general traffic rule of yielding to the right in the absence of other traffic control), but in practice, bicyclists work out who has the right-of-way themselves. The design was inspired by similar intersections in Lund, Sweden.⁽³³⁾



Source: © 2015 Google

Figure 6. Bicycle Free Right-Turn/Advanced Bicycle Stop Bar Design, Viborg, Denmark



Source: Paul Ryus

Figure 7. Right-Turn Bypass, Odense, Denmark

Denmark: Several cities in Denmark have signalized T-intersections where **bicycles traveling along the top of T are exempted from the signal indication for parallel auto traffic**, allowing them to proceed straight when auto traffic is stopped and thereby reducing bicycle delay. Bicyclists must yield to pedestrians using the crosswalks. This strategy can be combined with a left-turn pocket and bicycle left-turn signal at the far side of the intersection, allowing bicyclists to make a left turn in one stage, rather than two.^(32, 34) Figure 8 shows a T-intersection in Odense, Denmark where a sign posted below the nearside traffic signal indicates that bicycles are exempted from the traffic signal control, and yield markings in front of the crosswalk indicate that bicyclists should yield to pedestrians in the crosswalk.



Source: Geske Bak

Figure 8. Bicycle Exemption from Traffic Signal Control at T-Intersection, Odense, Denmark

Herning, Denmark: Herning (city pop. 47,000) tested a **bicycle scramble phase** at a signalized intersection with moderate traffic volumes (1,350 entering motor vehicles and 400 entering bicycles and mopeds during the a.m. peak hour). During the scramble phase, only bicyclists (and mopeds) receive a green signal, and they may move in any direction (through, left, right). During the other two phases, bicyclists wait while motor vehicles and pedestrians on first one street and then the other are served. Video observations after implementation found that the scramble phase virtually eliminated bicycle–automobile conflicts in the intersection. In most cases, bicycles did not conflict with each other, because bicycles from the cross street had already cleared the conflict area by the time a potentially conflicting bicyclist arrived from the other street. When potential conflicts did arise, bicyclists generally worked out the right-of-way themselves, with a tendency for bicyclists entering the intersection to yield to bicyclists already in the intersection (i.e., yield-to-the-left, opposite the normal right-of-way practice in Denmark).⁽³⁵⁾ **Amsterdam and Groningen** in the Netherlands have also implemented bicycle-only phases at traffic signals (according to global benchmarking survey response).

At signalized T-intersections with high volumes of left-turning bicycle traffic, the signal phasing can be arranged to simultaneously serve auto and bicycle turning movements (e.g., in a three-phase operation). The following sequence of phases could be provided:

- Auto and bicycle left turns from the stem of the T, and the parallel crosswalk to the right.
- Auto and bicycle right turns from the stem of the T, the parallel crosswalk to the left, and auto and bicycle left turns from the cross of the T.
- Auto and bicycle through movements and right turns from the cross of the T, and the parallel crosswalk.⁽³⁴⁾

Vancouver, Canada: Vancouver has also implemented **fully protected signal phasing** for all vehicle turns and bicycle movements along with a redesigned intersection.⁽³⁰⁾

Groningen, The Netherlands: Groningen implemented numerous strategies to make its traffic signal system more cycle friendly, including **green waves** and **two green phases for cyclists during one cycle**. (Progressive signalization, or the Green Wave, was also discussed in the preceding section on bicycle network infrastructure.) Recently, the city implemented **optical rain sensors** to further reduce bicyclist waiting times during rain events. The sensors have the ability to detect snow and four levels of rain from drizzle to heavy rain. As a result of committing extra traffic signal green time to cyclists, other road users experience additional delay at a time when more demand is placed on driving and public transit (Groningen).⁽³⁰⁾

The Netherlands: Pedestrian improvements at signalized intersections in the Netherlands include adding **feedback to pedestrian signals on estimated waiting time** to reduce red-light violations (Amsterdam) and **providing more green time** for pedestrians at signal-controlled junctions (Eindhoven).⁽³⁰⁾ The pedestrian feedback may be similar to pedestrian countdown signals, except it appears to count time until crossing is permitted rather than time remaining for crossing. It is unclear if this treatment has been evaluated.

There may be significant opportunities to expand pedestrian green time, even within existing signal cycles without increasing delay to other modes in some U.S. jurisdictions. Optimizing pedestrian green time might reduce pedestrian delay, frustration, and potential violations of traffic controls.

Victoria Province, Australia: VicRoads identified strategic bicycle corridors of approximately 3 to 10 km in Melbourne and carried out **evaluations and walk through assessments** of these corridors to identify critical gaps and improvements. According to the article, 15 percent of vehicles during the morning peak period were bicycles in 2014, up from 4 percent in 2006. The corridors described seem to all be separated, two-way bikeways. Key recommendations to improve bicyclists' safety and travel through complex intersections were described. These included improvements in **bicycle detection and signal operations**. For the low volume local streets, push button activation is provided on a pedestal adjacent to the roadway. Activation calls an **early start for bicycle traffic**, six seconds prior to the vehicle green. In addition, if cyclists wish to cross like a pedestrian using the pedestrian crossing, they can activate a PUFFIN (Pedestrian User Friendly Intelligent Crossing) signal that uses radar detectors to extend the crossing time according to how long the bicyclist (or pedestrian) remains in the crossing. Inductance loops were also installed in the intersections to count bicyclists traveling through.⁽³⁶⁾

Separate bicycle signals (three-aspect lanterns with red, yellow, green phases with displays separate from the motorist signals) and split-phase signal operations were recommended for an intersection with a two-way separated bike lane and combination through/right turn lanes to ensure the right turns do not conflict with bicycles traveling through in the same direction. [Note: this would be applicable to through/left turn lanes in the U.S. with two-way cycle path on the opposite side of the road.] Separate bicycle signals and phasing also allows programming of longer clearance intervals for bicyclists to clear larger intersections.⁽³⁶⁾

Yarra, Australia: Yarra (population 74,000), a suburb of Melbourne, uses **path priority at several intersections** along a shared use path. Traffic on the cross-street must yield to path users. The intent is to improve path user safety at the crossings and reduce bicyclist delay (Figure 9). A speed table is used to slow vehicular traffic at the crossing. A contrasting color from both the street asphalt and the path pavement is used for the path crossing, which helps provide better visibility of the crossing to motorists and path users. In addition, standard Australian path crossing and GIVE WAY (yield) signage are provided on the cross-street at the crossing. Pavement markings on the path warn path users of the crossing ahead.⁽¹⁸⁾ Similar treatments are used on shared-path crossings in Canberra, Australia and in Malmö, Sweden (according to global benchmarking survey response).⁽³⁷⁾ A 1996 study from Finland found that speed humps on approaches to two-way paths slowed motorists and increased looking in both directions. The raised crossing may have a similar effect. (See the Speed Humps study summary in the Outcomes section.)

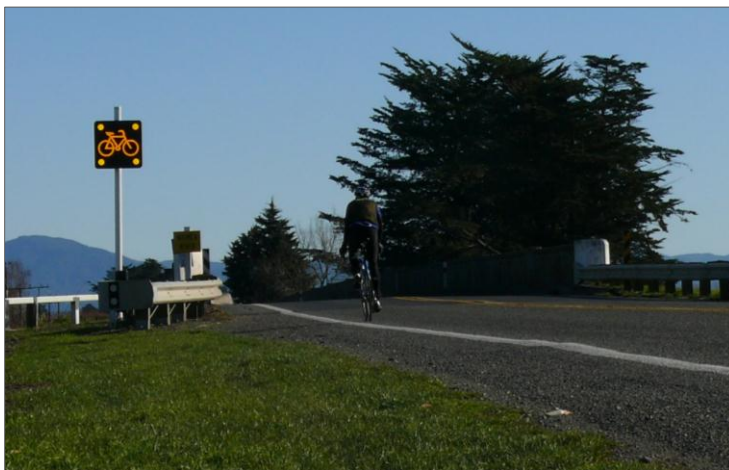


Source: Alistair McDonald.

Figure 9. Raised Priority Crossing, Yarra, Australia

New Zealand: The New Zealand Transport Authority installed **electronic bicycle warning signs** on the approaches to a narrow bridge on a national highway in Appleby, a suburb of Nelson (urban population 64,000). Loop detectors on the road shoulders detect bicycles and activate the signs, which display a bicycle symbol and flashing lights (Figure 10). Compared to the previous static bicycle warning signs, the electronic signs were found to result in a greater likelihood that motorists would drive cautiously and wait behind bicyclists as they crossed the bridge.⁽¹⁸⁾

U.S jurisdictions have tried similar devices under similarly constrained situations (e.g. tunnels), but the project team is unaware of any evidence of effectiveness.



Source: Eco-Counter

Figure 10. Blank-Out Bicycle Warning Sign, Waimea River Bridge, Appleby, New Zealand

Policy Change

Besides policies that may help to restrict auto traffic in pedestrian zones, one other policy concept may have potential for increasing connectivity of trails and paths under carefully determined circumstances. U.S. Federal and State transportation and parks agencies and partners could explore the potential value and viability for the next idea, which proposes situations and criteria for potential use of highway rights-of-way to provide important trail connections.

Alberta Province, Canada: The intent of a potential change in policy is to allow some flexibility where connections are needed between paths (such as in disjunct recreational areas with no other connections) to allow **building path connections in highway rights-of-way corridors**. Such a policy could, as a first step, be explored with State and Parks officials. There may be other potential applications when important bicycle corridors might be connected by a path through such a highway corridor, if no other more desirable options are available and safety concerns can be addressed. Although in general, the highway right-of-way may not be considered the most desirable location for a trail—because of the potential mix of high speed motorists and vulnerable, low speed trail users, quality of the trail user experience next to roadway traffic, and the setting—there may be situations when locating a portion of a trail in a highway right-of-way might be a solution.

There are several key instances when this would be allowed:

- 1) Providing connectivity between trails outside of the right-of-way.
- 2) Facilitating movement across a major barrier (i.e. river, controlled roadway).
- 3) Crossing a highway.
- 4) Providing connectivity between areas of trail user demand by offering a more direct and/or publicly accessible route.⁽³⁸⁾

The eligible trail types and preferred locations for parallel trails in order of preference are: 1) at the edge of the right-of-way and outside the highway clear zone; 2) outside the highway clear zone; and 3) within the highway clear zone but no closer than 2 m from the edge of the shoulder and with a mandatory physical barrier separating the trail from the highway.⁽³⁸⁾

Project Prioritization

Pedestrian and bicycle travel is clearly prioritized in many of the international jurisdictions studied. Performance goals, described in the section after this one, outline ambitious mobility goals for many of the jurisdictions. To help achieve those goals, jurisdictions have identified a number of criteria and a variety of methods to assess their networks and identify priorities for improvement. To assess their networks, jurisdictions most commonly reported reliance on

public input and perception and use of expert knowledge, including that of staff and stakeholder groups, to assess whether the criteria are being met or to perform more subjective assessments. For example, sometimes staff cycle out and perform their own “comfort assessments” of the network. Some of the processes may be formalized, but others may have evolved in a more informal manner (according to global benchmarking survey response).

For bicycle issues in particular, a number of jurisdictions elaborated on public input and assessment processes used, and they reported working with bicycle organizations or bicycle advisory committees. In one city, staff attend neighborhood district meetings to listen to citizens, they commute and travel to meetings by bicycle, and they often use different types of bicycles (cargo bikes, bikes with trailers, etc.) to gain a wider range of perspectives. Another jurisdiction reported conducting pedestrian opinion surveys every five years as a performance measure (next section) and “to identify gaps in the network.” Several documents mentioned public surveys as well.

A majority of jurisdictions also indicated that they have established criteria or procedures for identifying safety problems. Crash analysis processes are widely used, but there is, again, significant reliance on public complaints and ideas about safety problems. Jurisdictions also used qualitative assessment processes such as road safety assessments/audits, relatively often; around 40 percent of pedestrian and bicycle agencies responding indicated that they used some type of road safety assessment to identify pedestrian or bicycle gaps or issues. Fewer agencies indicated that they use level or quality of service assessments and analyses of count data to help prioritize. In addition, bicycle lanes quality monitoring, safety inspections, and black spot (high crash or hazard area) management were also mentioned regarding bicycle safety issues. Regarding quality monitoring, sometimes network infrastructure or intersections are compared to national guidance (such as the CROW facility design manual) to ensure that the facility type or intersection meets the desired standard or complies with national Sustainable Safety principles, but other, less well-defined or more specific types of quality assessments may also be used. Another jurisdiction sometimes uses cameras to identify and analyze location problems, but more details are lacking. Count data are also sometimes used to help assess desire lines.

Although a variety of methods are used to identify network gaps and safety issues, more study is needed to understand how established criteria and formal and informal processes are used to prioritize projects to meet overall performance goals and which processes might be used to best effect. The role of national and regional agencies and guidance may also be important to the overall process. Next are a few examples of documented prioritization criteria or approaches identified from municipal or regional/provincial agencies, followed by some national policies and tools.

Copenhagen, Denmark: Copenhagen's bicycle facility prioritization plan uses the following general criteria for prioritizing projects:

- *Number of bicyclists*—roadways with 5,000+ bicyclists per weekday should have separated bike lanes or satisfactory bike lanes.
- *Crashes*—street sections lacking bike facilities and experiencing a number of bicycle crashes.
- *Discomfort*—streets with high traffic volumes, locations with poor visibility, and locations with a number of complaints from bicyclists.
- *Connection with the overall separated bike lane network*—ability to remove a gap in the network that may discourage persons from bicycling.
- *Need for contraflow bicycling on one-way streets*—either with marked bicycle lanes on wider, busier streets or without on narrower, lower-volume streets in the center city and surrounding inner neighborhoods.
- *Connection with other projects*—ability to incorporate a bike project into another street project, opportunity for a low-cost improvement.

Roadways with fewer than 1,000 bicyclists per day are normally judged to not need separated bike lanes, except in special circumstances, such as high vehicular traffic volumes, high truck volumes, or connections with other roadways that have or should have separated bike lanes.

The previous prioritization plan identified improved bicycle lanes (e.g., marked lanes, short separated bike lanes around bus stops, islands, or other physical separation between bicycles and cars) as a low-cost, good-return strategy in situations where there is no need to move the curb or change drainage patterns. However, this proved to be a less-flexible strategy as a result of national traffic laws, as vehicles are allowed to stop for up to 3 minutes in bicycle lanes and municipalities cannot prohibit this practice, while they can prohibit stopping in sections with separated bike lanes. Therefore, sections where improved bicycle lanes are not possible are now considered for separated bike lanes.⁽³⁹⁾ In terms of defining a bicycle network, Copenhagen's network includes:

- *Bicycle superhighways*—low-delay, longer-distance routes continuing into the suburbs that are designed to attract bicycle commuter trips.
- *PLUSnet*—the primary network consisting of the most-used bicycle facilities, with a higher design standard and higher winter maintenance priority; incorporates bicycle superhighways.
- *Green Routes*—a connected network of shared use pedestrian and bicycle routes that include long stretches through open, recreational areas (e.g., through parks, along water features); some portions of the Green Route network are also part of the PLUSnet.
- *Other bicycle facilities*—other separated bike lanes and bicycle lanes that serve as feeders to the PLUSnet.⁽⁴⁰⁾

In addition to constructing more separated bike lanes and improved bicycle lanes, Copenhagen's bicycle strategy identifies a number of other actions to be prioritized:

- Widen existing separated bike lanes to provide more bicycle capacity.
- Develop alternative bicycle routes to remove pressure from the most congested routes.
- Campaign for more considerate bicyclist behavior.
- Work toward competitive travel times with the automobile:
 - Prioritize bridges and tunnels across water barriers, railroads, and major roads.
 - Allow contraflow cycling on one-way streets.
 - Develop traffic signal progression for bicycles (“Green Waves”).
 - Calm traffic.
 - Allow bicycling through pedestrianized squares.
- Convert streets to one-way to create room for bicycles.
- Develop new types of bicycle parking (e.g., for cargo bikes—“one-fourth of all cargo bike owners say that their cargo bike is a direct replacement for a car”).
- Make cobblestone streets attractive for bicycling.
- Provide footrests at intersections.
- Provide more air pumps.⁽⁴⁰⁾

Fredericia Municipality, Denmark: Fredericia Municipality started by prioritizing locations with the most accidents and then progressed to developing safe walking and bicycling corridors to schools. The school projects particularly focused on reducing traffic speeds along school routes, providing safer crossings (e.g., pedestrian crossing refuges in the center of the street or painted bike lanes through intersections along the school route) and improving what already existed (e.g., upgrading path undercrossings with better lighting). In addition, the agency places more weight on improving routes to school, as there is often more traffic, less daylight, and less time to clear snow in the morning when children are traveling to school.⁽⁴¹⁾

Marrickville, Australia: Marrickville (pop. 24,000), a suburb of Sydney relied on volunteers from a local bicycle advocacy group to document problems with the community’s bicycle facilities. This audit identified specific locations requiring repairs or upgrades to improve bicyclist access and safety, as well as specific actions, such as better parking regulation enforcement to discourage illegal parking in a contraflow bicycle lane.⁽³⁷⁾

Christchurch, New Zealand: In Christchurch, the process of rebuilding the cycling corridors (following extensive destruction of the city by an earthquake) was determined first, with specific street/path alignments and bicycle facility types to be determined during route-specific planning and design efforts. The ranking criteria used to prioritize routes were as follows:

- *Strategic fit*—how well the route connected communities with places of employment and education.
- *High use potential*—the number of bicycle trips forecasted to use the route, based on the bicycle component of the city’s transportation model.
- *Travel time reliability*—the number of new bicycle trips forecasted to use the route, thereby reducing auto trips and auto congestion.

- *Improve safety*—opportunities to reduce bicycle-related crashes along the corridor.
- *Economic support*—Access to current and proposed activities and facilities that support or enhance the local economy. ⁽⁴²⁾

On the basis of these criteria, routes were programmed for construction according to the following:

- Construct routes delivering the greatest benefits as early as possible.
- Complete full routes within a reasonable timeframe, recognizing that some sections may take longer due to land acquisition needs or public opposition to a particular alignment.
- Consider constructing stand-alone sections that provide a significant benefit in advance of constructing the full route, when they can be connected to the full route without any subsequent rework. ⁽⁴²⁾

The criteria used to select specific alignments are based on New Zealand national guidance and consist of the following:

- *Safety*—contributing to actual and perceived safety and security and limiting conflicts between bicyclists and other facility users.
- *Cohesiveness and connectivity*—continuous, recognizable, linking desired origins and destinations and offering a consistent standard of protection.
- *Directness*—reasonably direct, based on desire lines and resulting in few delays.
- *Comfort*—“smooth, nonslip, well maintained, and free of debris, have gentle slopes, and be designed to avoid complicated maneuvers.”
- *Attractiveness and social safety*—“integrate with and complement their surroundings, enhance public security, look attractive, and contribute positively to a pleasant cycling experience.”
- *Risk to project delivery*—prefer alignments that can be readily constructed within the timeline established for the project. ^(43, 42)

National Priorities

Innovations include efforts to incorporate public health benefits of cycling and walking and travel time for all transport modes into cost-benefit assessments (Finland); establishing ambitious safety goals, with a focus on child and older pedestrians, and following up with extensive analyses of the safety problems and solutions (Japan). Sweden developed a tool for aggregating data measured at different scales to develop predictions of walking and cycling mode shares at a scale small enough to help prioritize projects.

Finland: Finland’s Ministry of Transport and Communications developed guidelines for performing cost-benefit assessments of measures and programs related to all modes, including rail, walking, and cycling projects. The guidelines do not detail the assessment process but do provide a detailed manual on performing socio-economic assessments of both projects and programs in general that include public health benefits of cycling and walking, value of time for different transport modes, the long-term impacts of increases in modal share, and quality

assessments concerning mobility. At the present, the health impact of each new active pedestrian and cyclist is valued at 1,200 Euros per year. Data limitations are acknowledged, but the authors encourage application of the Guidelines to further the practice reviewed abstract only; main document in Finnish).⁽⁴⁴⁾

Japan: Japan's Ministry of Land, Infrastructure, Transport, and Tourism, (MLIT) along with the NPA, adopted in 2012 a new plan to rebuild the pedestrian and bicycle infrastructure in Japan's largest prefectures to decrease overall accidents as well as the high numbers of pedestrian versus bicycle accidents. The MLIT identified specific goals: reduce the annual number of deaths resulting from traffic accidents to below 3,000 so that Japan becomes the nation with the world's safest road traffic; reduce injuries to 0.7 million or fewer; and ensure the safety of elderly and children pedestrians and cyclists and road users on residential (community) and arterial roads. These accidents take place mainly on arterial and residential roads and at busy intersections. MLIT conducted additional detailed analyses and began implementing "effective and efficient" measures to address the safety problems at these locations. MLIT identified 3,396 sections with particularly high incidence of death and injury accidents and undertook intensive measures for accident prevention at these locations.⁽⁴⁵⁾

Another new management program involved the inspection of school-commuting roads by police and road administrators in cooperation with school boards. The designated school routes were inspected, and they identified about 60,000 spots where improvements would be necessary.⁽⁴⁶⁾

Sweden: The Swedish Transport Administration developed a pedestrian and bicycle tool to predict pedestrian and bicycle walk-to-work share within small geographic areas as needed to develop priorities for small scale pedestrian and bicycle infrastructure. Prediction models used data from the high-geographic resolution Swedish national register on the entire Swedish population (which lacks data about the mode for journey to work) combined with data from the Swedish national travel survey to fill in the mode information. The quality of predictions obtained varied for different counties as evaluated using bootstrap cross-validation (reviewed abstract only).⁽⁴⁷⁾

Performance Measurement

When asked about the basis for determining what is a complete bicycle network and how it is measured, several (but by no means all) jurisdictions mentioned that they have adopted plans or mapped networks and can determine what percentage of planned networks is completed on that basis. This section describes a few highlights of innovative and ambitious goals established for recognized bicycle- and pedestrian-friendly cities as well as "emerging" ones. In addition to traffic safety and mobility goals for pedestrians and bicyclists, a number of the studied jurisdictions have environmental, sustainability, and public health goals tied to performance of their pedestrian and bicycle networks and may also have a goal to reduce automotive travel, as the Lund example illustrates. As mentioned in some of the examples of prioritization criteria,

some attention is being paid to factoring in economic benefits of bicycling or walking including the value of time. See the example from Copenhagen.

The focus in some jurisdictions that have historical networks in place is now on improving those networks, with upgrades to enhance mobility and safety and thus, the development of longer, and less obstructed bicycle routes and intersection improvements that were described in the infrastructure treatments sections. A jurisdiction with a “younger” bicycle network, mentioned goals such as developing a network based on guidelines for route spacing and volumes suitable for all ages or that there should be pedestrian access for every physical address. These jurisdictions may be more similar to the U.S. in their trajectory of developing networks suitable for more use.

A number of jurisdictions with goals of improving network mobility and amounts of riding specifically mentioned performance goals of providing connected facility types or linear continuity of specific types of facilities including separated bike lanes, segregated paths, and easy-to-use cycle streets. Some jurisdictions also mentioned mobility goals for routes such as travel times, number of stops, and detour factor; for junctions such as junction type and bicycle priority; and for street-level measures such as surface and type of path/lane/street. Other performance measures included safety measures (and these were widely used), numbers of yearly cycle trips (and change in the numbers), travel time improvement, mode share, and perceptual measures such as user experience. The latter is in line with the use of public input to help assess the network and determine priorities.

For pedestrian networks, performance measures included the percentage of streets with sidewalks and or locations missing curb ramps and pedestrian accessibility for all physical addresses in the municipality. Other measures mentioned were sidewalks up to standards, results of annual public satisfaction surveys, and traffic design performance measures based on CROW or NACTO guidelines.

In addition to gathering public input and performing assessments of the network itself, 16 of 25 jurisdictions reported that they have a formal bicycle counting program that they use to track mode share and changes in amounts of riding at network, and frequently at facility levels. Six out of 14 jurisdictions reporting on pedestrian networks have pedestrian counting programs.

Several examples of municipalities with ambitious goals for bicycle or pedestrian mobility are outlined below. Some municipalities have taken care to define the types of facilities that will meet network goals; an example is illustrated by ‘s-Hertogenbosch. These may be more akin to network criteria, which are used to meet higher level mobility and safety goals. The Dutch Cyclists’ Union developed an assessment for Netherlands cities that incorporates quantitative and qualitative characteristics of the bicycle network, including safety and design aspects. Measures that were used for the city of Eindhoven are summarized below.

Copenhagen, Denmark: The Greater Copenhagen Region (pop. 1.7 million) publishes an annual bicycle account that tracks how cycling patterns change over time. It uses two main data sources: field measurements of bicycle travel times along nine routes designated as future “bicycle superhighways” and an annual survey of residents of the region on their bicycle travel.

The field measurements were conducted using GPS-equipped bicycles ridden by members of a bicycle club over 1.5 months, collecting a total of 238 hours of data. There were 1,912 survey respondents. The performance measures reported by this effort included:

- Average bicycle speed by bicycle superhighway route.
- Millions of bicycle trips per year by geographic area (region-wide, Copenhagen and Frederiksberg, suburbs, and outlying areas).
- Mode to work/school by geographic area.
- Bicycling kilometers per day.
- Per-capita bicycling kilometers per day.
- Number of sick days reduced per year (assumes one day reduced per 1,200 km cycled by a person).
- Reduction in car trips and car kilometers traveled during peak periods due to bicycling.
- Average bicycle trip length.
- Economic worth of faster road travel due to reduced auto travel demand as a result of bicycling.
- Reduction in carbon dioxide emissions. ⁽⁴⁸⁾

Amsterdam, The Netherlands: Pedestrian accessibility is assessed for every physical address in Amsterdam, which is then tracked over time. Amsterdam also uses density and land use functions for predicting pedestrian volumes. For public transportation exercises, the city uses the VISSIM simulation program to estimate pedestrian volumes and flows, based on Fruin's crowd dynamics models. ⁽³⁰⁾

Groningen, The Netherlands: Groningen evaluates its transportation investments against travel-time improvement, mode split, and user experience, which is a subjective measure of comfort and convenience. ⁽³⁰⁾

's-Hertogenbosch, The Netherlands: The municipality of 's-Hertogenbosch (population 140,000), has identified design standards for its bicycle network. Existing facilities can be compared against these standards to identify desired improvements. ⁽⁹⁾ Examples include:

- Route-level quality (primary network/other main routes)
 - Ratio of actual travel distance to straight-line distance: 1.15/1.25.
 - Intersections per km without bicyclist priority: maximum 1.5/2.0.
 - Turns per km along route: maximum 1.0/1.5.
 - Wait time at traffic signals: maximum 40/60 seconds.
- Street-level facility design by bicycle network type
 - Facility type and width (e.g., one-way separated bike lane, two-way separated bike lane, bicycle lane).
 - Pavement color.
 - Presence and shape of speed humps.
- Intersection level
 - Desired traffic control by combination of road network type (arterial, collector, other) and bicycle network type (primary, other main)—see Table 1.

Table 1. Desired Intersection Traffic Control, 's-Hertogenbosch, The Netherlands

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

The Netherlands: The Dutch Cyclists' Union evaluated quantitative and qualitative characteristics of the bicycle network, including safety and design aspects, in five Dutch cities. One report focused on the **City of Eindhoven** (population 216,000).⁽⁴⁹⁾ The performance measures that were evaluated consisted of:

- Bicycle mode share for trips up to 7.5 km (4 miles) from the city center—the distance where bicycling is considered to be most competitive with other modes.
- Serious crashes involving bicycles per 1 million bicycle km traveled.
- Bicycle facility density (km of exclusive bicycle facilities per square kilometer).
- Bicycle facilities per capita (km of exclusive bicycle facilities per 1,000 residents).
- Connector density (connectors per square kilometer), where a connector is a location where one can switch from one bicycle facility to another within the network.
- Route directness factor (distance between two points via the bicycle network, divided by the straight line distance)
- Percent of bicycle trips made using the bicycle network.
- Percent of bicycle facilities with smooth, hard pavement (asphalt or concrete), as opposed to pavers, cobblestones, or unpaved sections.
- Percent of network represented by each bicycle facility type.
- Percent of network along roads with speed limits higher than 50 km/h (30 mph)—a lower percentage is considered better.
- Intersections per kilometer along the bicycle network (total, signalized, and roundabouts).
- Percent of intersections of the bicycle network with the auto network (e.g., arterial streets) with grade separations for bicyclists.

LundaMaTs II- Lund, Sweden: LundaMaTs II is the 2006 updated version of the City of Lund's first traffic strategy plan, LundaMaTs I, which was adopted in 1999.⁽⁵⁰⁾ LundaMaTs stands for environmentally adapted transport systems, and the plan is based on the idea that it is possible to combine growth with ambitious environmental goals. One of LundaMaTs overall goals is to *reduce motor-vehicle traffic in favor of alternative modes of travel*. The plan recognizes this goal as also being a means of achieving other plan goals, such as improving quality of life and health and attracting people and companies to the city.

Pedestrian Traffic is one of seven focus areas of interest because the relatively dense urban structure of Lund makes it possible to meet various transport demands by walking. Bicycle Traffic is also an area of focus because Lund is already one of Sweden's foremost cycling cities with established bicycle infrastructure, network, and facilities. (The other focus areas are public transport, road transport, commercial transport, with mobility management being added in the 2006 update.) The project proposals cover transport safety, security, health, and physical accessibility.

The plan includes defined hard or physical measures contained within an overall target matrix of 18 targets that relate to the area of interest project proposals. Targets that relate to pedestrian and bicycle traffic areas are as follows:

1. The length of walkways and cycle-ways will increase 10percent by 2013 and 30 percent by 2030.
2. The proportion of safe crossings for pedestrians and cyclists will be 30 percent by 2013 and 100 percent by 2030.
3. Walking trips per resident will increase.
4. Cycling trips per resident will increase 5 percent by 2013 and 10 percent by 2030.
5. The bicycle/car travel time ratio for new developments will be less than 1.5 for travel to city and district centers (including housing and workplaces).
6. Accessibility for the disabled, children and elderly will increase.

Other targets relate to the pedestrian and bicycle traffic areas in terms of improving safety and safety perceptions. The plan includes cost estimates for running and implementing projects, investment costs, and an annual increase estimate as a result of new services and investment. Overall, if the projects and reforms are implemented along the established target timelines and benchmarks, the city will achieve movement in a sustainable direction.

Canberra, Australia: The ACT describes the vision and policy context of cycling participation and pedestrian activity (among other modes) in the Transport for Canberra 20-year sustainable transport plan.⁽⁵¹⁾ New policy directions include land use and transport integration, social inclusion, active travel, strategic management of the road network, parking, motorized vehicles, freight, travel demand management across all modes including pedestrians and cyclists, transport system performance measurement, and an action plan detailing 34 policy actions. Many of the policy actions focus on land use, transit, and active transport strategies to provide transportation choices. Infrastructure goals include expanding and improving networks, developing master plans to guide network development, completing cycling and walking

networks in town centers, and piloting a shared, low-speed street space, among other goals that include developing partnerships and private funding sources. Performance measures for active travel include:

- Assessment of pedestrian distances travelled and routes used –from annual pedestrian interception surveys at key destinations.
- Continued benchmarking in partnership with the international pedestrian network Walk21 (identified current levels of walking and physical, social, and institutional barriers).
- Monitoring shared paths to identify areas where improvements are required.
- Analysis of crashes involving pedestrians identifying type, number, and severity.
- Review of transport modelling capability.

Norway: Norway's *National walking strategy* identifies the following performance measures related to measuring progress toward meeting the national goals: percent of persons making a walking-only trip each day; percent of all trips that are walk-only by demographic group (e.g., gender, age, income); average kilometers walked per day on trips; percent of walk-only trips made within 2 km (1.2 miles) of home; and percent of children who walk or bike to school.⁽⁵²⁾

Finland: In Finland, a key aspect of cyclist comfort and safety is surface evenness. In an effort to develop objective measurement that reflect cyclists' concerns about this specific safety factor, laser sensors mounted on a small car were used in conjunction with GPS and a camera to assess the surface quality of cycle paths in the Town of Malmö. The method measured the longitudinal profile of the cycle path of the entire pedestrian and bicycle path network. Complementary measurements using another system were made to assess the variability of conditions in the transverse direction. The findings suggested that good measurement of longitudinal evenness were obtained with only two lasers. Some of the practical issues of the method involved narrow surfaces, significant loose material, and poor sight in curves and beneath vegetation. The measurements were associated with bicyclists' perceptions of riding quality (also measured by the study) along test sections of variable quality and from more objective riding tests using bars of varying thickness. Models were developed to account for measurement issues and classification of facilities into three categories representing fundamentally unacceptable (priority for repair/improvement with 30 percent or more of maximum values exceeding the threshold), yellow (between 10 and 30 percent exceeding the threshold), and green.⁽⁵³⁾

Data from a National Highway Traffic Safety Administration (NHTSA) survey suggest that surfaces are an important safety issue in the U.S. as well.⁽⁶⁰⁾

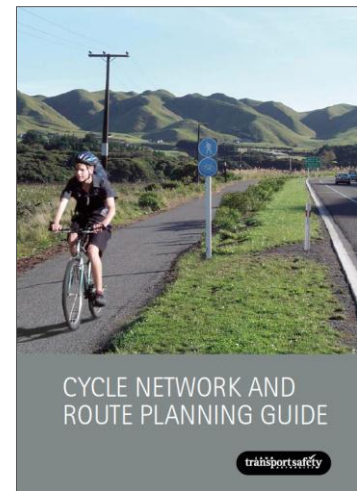
Guidance Documents

Recent guidance developed by some international jurisdictions helps to put approaches and priorities as well as types of infrastructure being implemented into context. For example, New Zealand's guide identifies five approaches that can be used for decision-making for bicyclist network provision. Guides on facility inspection and on network signing and the others mentioned below may provide useful tips or insights relevant for the U.S. The guide developers could be invited to present key lessons from the below guides or others to a U.S. audience.

Bicycle Network Design

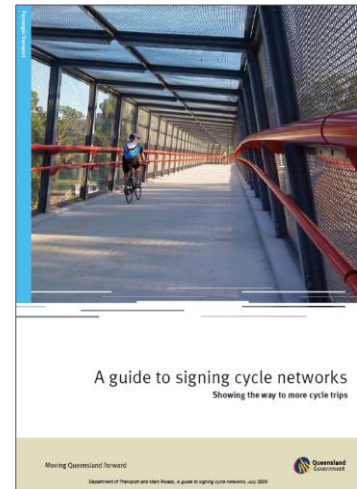
The Land Transport Safety Authority in New Zealand developed a *Cycle Network and Route Planning Guide* that includes, among other topics, guidance on approaches to developing a bicycle network, locating routes within the network, and selecting bicycle facility components for specific routes.⁽⁴³⁾ It also provides guidance on estimating demand, evaluating options, prioritizing projects, and implementing and maintaining the network. The guide identifies five approaches to a cycle network:

- *Every street*—whether a given street has a specific bicycle facility, bicyclists' needs are considered on every street and no formal network is designated.
- *Roads or paths*—the community focuses on providing a high-quality network either through the use of segregated paths (typically only fully possible in new communities) or a high-quality road-based network (typically based on the arterial road network).
- *Dual networks*—parallel facilities are provided along arterial roadways to accommodate both experienced bicyclists (e.g., a bicycle lane) and less-experienced bicyclists (e.g., a shared use path).
- *Hierarchy*—a bicycle functional classification system (e.g., primary, collector, local) is developed and used to set bicycle facility design standards and bicycle level of service targets (e.g., principal routes are designed for longer-distance trips and provide minimal delays).
- *Needs approach*—the option selected for a specific location considers bicyclists' and other stakeholders' needs, along with the unique local context; it is the option recommended by the guide.



Bicycle Network Signing

The State of Queensland, Australia has developed a guidebook on signing bicycle facilities.⁽⁵⁴⁾ Although written in an Australian context, using standard Australian bicycle signage, the guide's general principles of bicycle network signing are generally applicable, and U.S. equivalents of the signs presented in the guide can be found in the *Manual on Uniform Traffic Control Devices*. The guidebook emphasizes the importance of signing by destination, both to inform bicyclists of potentially more-direct, lower-traffic routes to their destination and to inform the community at large of the range of destinations that can be reached by bicycle. Route numbers or names can be incorporated into wayfinding signage but will not have meaning to those unfamiliar with the network. Signage should be conspicuous, legible, coherent, and functional. Guidance is provided on planning the overall wayfinding program, designing specific signage elements, and installing and maintaining signage.



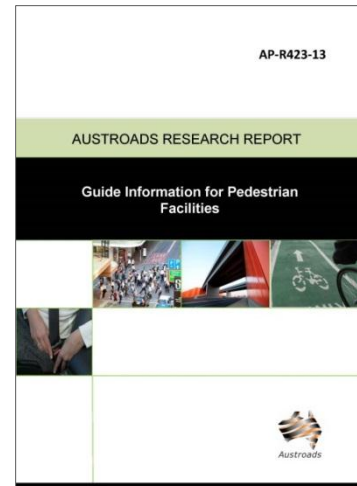
Bicycle Facility Inspection

The Danish Cyclists' Federation, with financial support from the Danish government, produced a handbook on bicycle facility inspection.^(55, 56) It would be helpful to know how many jurisdictions in Europe use the handbook. The handbook identifies problems with bicycle facility construction and maintenance that impact cyclists' safety, comfort, and mobility and provides a catalog of ideas for addressing problems, which can be used to prioritize improvements. By focusing on small details that have great importance, even municipalities with relatively small infrastructure and maintenance budgets can make changes that improve the quality of bicycling in their communities. A program has been developed to certify bicycle facility inspection.



Guide Information for Pedestrian Facilities

Austrroads (2013) developed a comprehensive report on the state of practice internationally and implications for the provision of pedestrian facilities that account for pedestrian activity and transport needs, the perceptions of pedestrians in assessing quality, and the consequences for selecting and managing pedestrian facilities.⁽⁵⁷⁾ In particular, the report identifies a need for comprehensive tools for assessing and evaluating pedestrian facilities in Australian and New Zealand that incorporate “walkability, level of service, and safety considerations.”



Bicycle Travel Space Development Guideline

In 2012, after considerable study to address the issue of a lack of bicycle specific infrastructure throughout Japan, the MLIT issued the *Guideline for the Creation of Safe and Comfortable Bicycle Use Environments in Japan*. This document states “*principles for the provision of road space to allow bicycles to travel safely and comfortably on roads.*”⁽⁵⁸⁾ Japan has a problem with pedestrian versus bicyclist collisions. Because of a lack of infrastructure to allow bicyclists to ride safely on roads, bicyclists since the 1970s have been allowed to ride on sidewalks with pedestrians.

“The guideline is intended to be used by regional road manager or prefectural police to prepare plans for bicycle networks and to encourage the establishment of such networks while ensuring compliance with bicycle travel rules.”⁽⁵⁸⁾ It presents three patterns for bicycle space on roads: separated bike lanes, bicycle lanes, and mixed use (shared) on roads by vehicle and bicycles. It lays out the requirements for choosing between these three measures related to traffic speeds, volume, and road size. It also lays out specifications for the implementation and design of each type of bicycle space. Further, it presents the criteria for assessing traffic speed and volume as a means for determining and studying the need for bicycle separation on a road.^(58, 59)

Outcomes

Responses from a number of jurisdictions indicated they have monitored or measured the safety and operational impacts of recently implemented treatments on pedestrians, bicyclists, and other road users, or have carried out other assessments during the process to develop innovative solutions to identified problems. National and regional officials from the Netherlands provided information about safety monitoring and analysis and activities performed to address recent safety trends in that country. Following a brief summary of those activities, is information from evaluation studies identified from the literature and jurisdictions' input. In addition, there are descriptions of a few studies identified to develop new prioritization or risk assessment tools.

National Safety Monitoring

The Netherlands has historically had a high bicycling mode share, still higher than any other country, and therefore there has long incorporated cyclist (and pedestrian) needs in engineering and planning university education and training programs that contribute to staff expertise used in local assessments. However, because of an increasing number of seriously injured cyclists, the ministry has asked municipalities to come up with new policies to improve safety. The Dutch Cycling Embassy [*Fietsberaad*] is a public private partnership established to make the Dutch cycling expertise internationally available and monitors the progress on this issue. Although it does not play a direct role in planning or design of infrastructure, the Dutch Ministry of Infrastructure and the Environment [*Rijkswaterstaat*, part of the Dutch National Ministry] helped to identify the cause of increasing bicyclist injuries as related to an increasing number of single bicycle falls and crashes that was uncovered through analyses of medical data in conjunction with traffic crash data (Paul Schepers, personal communication, April 7-8, 2015). Crashes between bicyclists and motor vehicles (including mopeds) have continued slightly downward or leveled off over the past two decades, whereas these bicycle-only events have risen sharply. In 2012, single-bicycle crashes made up 60 percent of injured cyclists and 9 percent of fatalities. The reasons are thought to be related to increased bicycling, and an aging population, which is also bicycling more (Paul Schepers, personal communication; and see <http://www.fietsberaad.nl/?lang=en>). Information and data from the U.S. suggest that bicycle only falls and surfaces are an important safety concern in the U.S. as well, with bicyclists in a nationally representative survey reporting concerns about surface quality second only to concerns about interactions with motorists.⁽⁶⁰⁾

To help address the problems, the Ministry is financing an innovative project, in cooperation with local governments, to develop a so-called 'forgiving bicycle path'. The Dutch National Ministry will also sponsor an update of the CROW bicycle manual in 2015, in part to address identified issues that may contribute to bike-only falls and crashes (Paul Schepers, personal communication; and Dutch Ministry of Infrastructure and the Environment).

A national Sustainable Safety program also began around the year 2000. Through this program, national funds were provided that incentivized local jurisdictions to develop road safety plans

and helped to build infrastructure such as roundabouts and traffic calming. During the implementation, there also was an increase in decentralized decision-making and merging of the national road safety organizations (*Fietsberaad*, and KPPV in 2001, which then merged with CROW in 2009). Decentralization in planning and decision-making and flexibility in design that is allowed by the national policies seem to contribute to an environment where experimental treatments may be tried, as long as there is a compelling reason and justification (Paul Schepers, personal communication).

Innovative Treatment Evaluations

The next sections describe results of studies of innovative treatment evaluations. Some of the evaluations are for treatments previously described such as bicycle superhighways, priority bicycle streets, and cyclist roundabouts, while others are for new treatments, new uses, or combinations of treatments not described in the previous sections. Several of these additional innovations might be worthwhile to consider for a U.S. context, in particular, a new type of accessible pedestrian signal tested in Japan and new ITS technology that seems to use a combination of pedestrian detection, pedestrian scramble, and extended time during peak pedestrian periods. There might be a need for some differences in the devices used to fit MUTCD guidelines or experimental approval to try the systems in the U.S.

This global benchmarking study was intended to identify treatments that may have promise for use in the U.S. The below evaluation study reports provide support for some of the earlier-described treatments and also introduce some new ideas that may have potential. However, the information available (including English language studies) through this desk review is limited for some of these, so further study is necessary to assess the potential value and issues or barriers to implementation in the U.S. It would be helpful to see many of these treatments first hand to more fully understand how and where they are used and the interactions of road users in context.

Bicycle Network Infrastructure

Bicycle Superhighway – Copenhagen, Denmark: An evaluation of the first bicycle superhighway in the Copenhagen region (the 17.5-km/10.5-mi Albertslund route) found significant improvements in bicycle volumes from 2010–2012 at two of five counting stations, but no change at the other three counting stations. Approximately 10 percent of new users of the facility had shifted modes; the other new users had used other routes or had previously had a different commuting pattern (i.e., a different destination). The evaluation noted that travel time had not significantly improved along the route, as there were still a relatively high number of stops required for traffic signals and several bottleneck locations that had not yet been addressed. The five municipalities along the route reported that the project established working relationships that previously had not existed and that the new relationships worked well.⁽⁶¹⁾



Source: Rick Delbressine

Figure 11. One lane, with on-street parking, and two-lane priority bicycle streets in Oss, the Netherlands.

Priority Bicycle Streets - Zwolle, the Netherlands: Delbressine, in a study of eight bicycle streets in Zwolle, defines the most important functions of bicycle streets as providing a “flow function” for bicyclists to ride through calmed and comfortable neighborhood streets and a (local) “access function” for motor vehicles.⁽¹⁰⁾ He studied four two-lane and four single-lane bicycle streets in Zwolle. Delbressine examined user behaviors and conflicts for the different designs (which included other variations besides number of lanes), and operational consistency with the Netherlands’ Sustainable Safety principles. The longest bicycle street studied was 850 m (0.53 mi), and the shortest was 240 m (0.15 mi); both the longest and shortest were two-lane designs. After analyzing all the data and behavioral observations collected, including speed behavior and conflicts, the author concluded that the variety of designs used to achieve bicycle streets, even in one city, produced low consistency and recognizability of the street functions. The functions of the eight streets also differed from each other, with commercial trucks allowed on some and transit on one, and some of these purposes were observed to create additional conflicts. Parked or stopped vehicles also sometimes added to conflicts. Streets in residential-only neighborhoods appeared to have fewer conflicts than those on streets with a commercial use. The one-lane streets had less speeding and fewer conflicts related to passing maneuvers than the two-lane streets. Speed humps or other traffic calming could be needed to keep speeds to the sustainable safety target of 30 km/ hr (18.6 mph). A certain type of crossing street intersection design also seemed to reduce the incidence of motorists accepting too small

gaps between bicycles on the bicycle street. The author also concluded that design cannot reduce all the conflicts that are inherently a result of the mix of functions (bicyclist flow and motorized access), but that use of a consistent design would improve recognizability and consistency with sustainable safety principles.

C-Roundabout – Auckland, New Zealand: Asmus, Campbell, and Dunn described results of safety and mobility studies at two intersections that were changed to C-roundabout (cyclist roundabout) designs in Auckland, New Zealand, a treatment described earlier.⁽⁶²⁾ However, only one of the C-roundabouts studied conformed to the design principles and guidance described by Campbell, Jurisich, and Dunn in the 2006 report. In the conforming application, wider markings and closer spacing were used for lane lines to improve lane keeping. Signs advising large vehicle to use both lanes also were used. Speed studies for the junction that conformed to the C-roundabout design principles found reductions in entering, exiting, and circulating speeds, although crash results were inconclusive. Construction costs were estimated at 25 percent less than for standard, multilane roundabouts. Capacity was not adversely affected, but volumes were also low at the roundabout described.

Pavement Markings – Denmark: The relative safety of different forms of traffic control and pavement markings was studied at Danish intersections where a bidirectional bicycle path crossed the side street.⁽⁶³⁾ A total of 776 intersections from around Denmark were studied, and 11 years' worth of crash data for those intersections (involving 384 crashes with a path user) were evaluated. The observed crash rates for the six most common crossing forms, relative to the form with the lowest crash rate, were as follows:

- Yield markings on the side path at the crossing, yield markings on the street at the main intersection (lowest crash rate).
- Yield markings and signs on the side path at the crossing, yield markings on the street at the main intersection (twice the crash rate of the lowest crossing form).
- Path centerline striping continues across the street at the crossing, yield markings and yield sign (with bidirectional bicycle traffic plaque) on the cross-street approach to the intersection at the path crossing, yield markings on the cross-street at the main intersection (four times the crash rate).
- Path centerline striping stops at the crossing, yield markings and yield sign (with bidirectional bicycle traffic plaque) on the cross-street approach to the intersection at the path crossing (five times the crash rate).
- Path centerline striping continues across the street at the crossing, yield markings and yield sign (with bidirectional bicycle traffic plaque) on the cross-street approach to the intersection at the path crossing (eleven times the crash rate).
- Path centerline striping continues across the street at the crossing, supplemented with blue paint marking the path crossing, yield markings and yield sign (with bidirectional bicycle traffic plaque) on the cross-street approach to the intersection at the path crossing (eighteen times the crash rate).

A doubling of the motor vehicle volume entering the intersection (crossing the path or not) increased the count of crashes by 21–25 percent. A doubling of path users increased the count of crashes by 26–31 percent.⁽⁶³⁾

Speed Humps – Helsinki, Finland: Although speed humps are a long-standing traffic calming device, this application is a very specific and perhaps innovative one. A common crash type in Helsinki involved motorists at T-intersections failing to look and yield to bicyclists approaching the intersections from the right on a two-way bike facility. Legally, motorists are required to yield to bicyclists at these junctions. Drivers were observed scanning for traffic only to the left before making right turns. Speed humps were implemented at two of these intersections and evaluated. Drivers were observed to look to the right more often after the speed humps were installed and were slowed on the approaches to the intersections.⁽⁶⁴⁾

The use of a raised speed table for the crossing itself was described in the Yarra, Australia example of giving right-of-way priority to the path users. Applying speed humps on approaches to a crossing might be an alternative treatment to improve yielding at two-way locations such as two-way paths or separated bikeways where the path or bikeway has priority.

Stop Bars – Denmark: A study was conducted of 189 intersection approaches at 123 signalized intersections in Denmark (primarily in Copenhagen and two neighboring municipalities) where the stop bar for motor vehicle traffic was set back relative to the bicycle facility stop bar.⁽⁶⁵⁾ Danish road standards recommend a 5-meter (16-foot) setback, as illustrated in Figure 12. (Right turn bypass is illustrated in Figure 7).

The number of motor vehicle vs. bicycle crashes in a 5-year period prior to setting back the stop bar was compared to the number of crashes afterwards, with adjustments for changes in motorized traffic volumes and changes in the background crash rate (determined from a control group of intersections). No regression-to-the-mean correction was made, as the Copenhagen installations had been made as part of a city-wide initiative (i.e., were not installed specifically at intersections with high crash rates), and no evidence was found of a higher-than-normal incidence of crashes in the “before” period at the sites in the other municipalities. The study found no significant reduction in the number of right turn vs. bicycle crashes but did find a small increase in the number of injury crashes. It was hypothesized that possibly only a small portion of crashes occurred after both parties had been stopped for a red light or that during the “before” period bicyclists had tended to stop in the pedestrian crosswalk beyond the stop bar and thus already benefitted from better visibility. The researchers suggested that set-back stop bars might have a better effect in cities with fewer bicyclists, where motorists are less used to looking for bicyclists.⁽⁶⁵⁾ The results of the study are considerably different from those a 1990s-era study reported in the Danish *Collection of Cycle Concepts*, where a 35 percent reduction in right-turn vs. bicycle crashes and a 50 percent reduction in bicyclist injuries were reported.⁽⁶⁶⁾ These differences suggest that measures that may be effective in one place or time may not be equally effective at another place or time. Study methods may also potentially affect results obtained.



Source: Geske Bak

Figure 12. Set-Back Stop Bar, Odense, Denmark

Bollards - Australia: Grzebieta and Rechnitzer describe an example of how “formalized Interface Analysis and Design methods can be applied to improve road safety across different domains, in this case, that of pedestrians and motorized vehicles.”⁽⁶⁷⁾ The article discusses how bollards of different designs might be used as barrier lines to protect pedestrians against vehicle ingress in locations and situations where traditional barriers are unsuitable (roadside cafes/open spaces, footpaths, bus stop, etc.). The paper also describes a methodology for designing, testing, and rating crashworthiness, and gives examples of inappropriate and potentially dangerous uses of roadside barriers (unforgiving, sharp edges, etc.) that could be replaced with safer bollard designs.

Signals and Traffic Controls

Enhanced Information [FIVO] System, Sweden: Anund and Söderström (2010) evaluated the effect of an “enhanced information” [FIVO] system on motor vehicle speeds at three pedestrian crosswalks.⁽⁶⁸⁾ The system consists of rectangular rapid flash beacons mounted on crosswalk signs located at the crosswalk; the beacons turn on automatically when passive infrared sensors detect path users. At the three study sites, motorists reduced their speed by an average 6-7 km/h (3.5-4 mph) when pedestrians were present; 2 km/h (1.2 mph) of this reduction is attributed to the effects of the beacons, based on before-and-after speed measurements at one of the sites. The locations of the passive infrared sensors were not provided for two of the sites. At the third site, a path crossing a street without sidewalks, the sensors were placed high on a pole on the side of the path, 5 meters (16 feet) in advance of a chicane-like pair of gates used to slow bicycles and prevent unauthorized motor vehicle access. These gates were located a few meters away from the crossing itself. The researchers noted several issues with the location of these sensors: (1) on one side of the crossing, the sensor was mounted on the side of the path farthest away from the entrance to the chicane; (2) on the other side, an open, grassy setting, pedestrians could approach the crossing without being on the path; and (3)

while the sensors were well-situated to activate the system in time for pedestrians, they were too close to the crossing to give sufficient warning about bicyclists. The first two issues led to missed pedestrian detections and nonactivations of the beacons, while the third issue activated the system too late to benefit bicyclists.⁽⁶⁸⁾

Intersection Controls – Denmark: The safety of four intersection control types used in Denmark to reduce bicycle delays at traffic signals was investigated for the Danish Road Directorate, based on 7–8 hours of videotaping at each of 16 intersections with and without the following studied treatments:

- 1) Exempting right-turning bicyclists from the requirement to stop for a red signal.
- 2) Right-turn bypass facilities in advance of a traffic signal.
- 3) Exempting through bicyclists traveling along the top of the cross at a T-intersection from the requirement to stop for a red signal.
- 4) Same as No. 3, except that left-turning bicyclists also proceed across the T and then observe a left-turn bicycle signal on the far side of the intersection.⁽⁶⁹⁾

With regard to pedestrian–bicycle conflicts, there was no significant difference in the rate of conflicts between any of the treatment types and comparable untreated intersections. At the four control intersections where right-turning bicyclists are not permitted to turn right on red, approximately half of them did anyway. Accident statistics and hospital records point, however, to a low incidence of pedestrian–bicycle crashes. Although not the primary purpose of the study, conflicts between bicyclists and right-turning automobiles were also observed, and it was noticed that eight of the 14 observed conflicts occurred in conjunction with the end of a right-turn overlap phase, where the right-turn arrow had turned off and the parallel green phase had not yet started.⁽⁶⁹⁾ *[In Denmark, right-turn overlap phases where traffic can also turn right on a circular green indication are indicated only with a green right-turn arrow and no yellow right-turn arrow.]*

Accessible Pedestrian Signals – Japan: Japan has approximately 170,000 signalized intersections, of which 10,570 have accessible pedestrian signals (APS). There are a wide variety of types from audible to infrared. The authors found the preponderance of numerous APS audible overhead speakers to be at times confusing and distracting. Portable receiver-based APS systems are being developed and tested. Infrared types are the PICS-A speech based, for visually impaired and PICS-B image based, for hearing and mobility impaired. PICS-A uses an FM transmitter to send a vibration message to a hybrid receiver worn by the pedestrian. When within 10 meters, the vibration alerts the pedestrian to the presence of a transmitted signal. The speech message then identifies the intersection. When arriving at the crosswalk and facing the opposite corner transmitter, the receiver gets a speech message indicating the status of the pedestrian signal. A third function extends the pedestrian phase when a button on the receiver is pushed. PICS-B sends green-lights and provides route guidance and information about the surrounding area on a visual display. Portable receivers are pointed at the IR transmitters located near pedestrian traffic signals to extend the pedestrian signal timing, make emergency contacts, and obtain route guidance information. They found the PICS-A system to work efficiently, and radio transmitted information was useful. A large array of transmitters was

required for each intersection. A head mounted receiver has now been developed and put into use, and the study authors found it to be efficient, reliable, and useful. ⁽⁷⁰⁾

Pedestrian Priority Signal System – Japan: The pedestrian priority signal system (PPSS) is a signal device for busy intersections with high pedestrian peak time volumes that was developed and tested by the Saitama Prefectural Police and first put in to operation in Japan in 2011. ⁽⁷¹⁾ The operations of the PPSS, according to Yamazaki, are as follows:

- The lights for pedestrians and lights for vehicles are separately controlled and displayed.
- The signal for pedestrians is indicated in green.
- An image sensor recognizes the approach of a vehicle and then lights the corresponding green signal for the vehicle for minimum necessary time duration.
- To prevent a driver from misidentifying a pedestrian signal as a vehicle signal, a hood is placed on the pedestrian lights to restrict the angle of view for the driver to the pedestrian signal.
- To prevent nonoperation of the sensor, when a vehicle has not been detected for a certain amount of time, the sensor is activated to complete one signal cycle.

Due to substantial requests at a local school for authorities to install some kind of pedestrian signal at a nearby problem intersection, the PPSS was tested close to the school and in a residential area with residential roads.

The PPSS allowed for pedestrians to cross diagonally when no vehicle was present. Testing results showed that the signal successfully prevented pedestrians from ignoring traffic signals, prevented vehicles and pedestrians from coming into close proximity, and traffic flows and volumes were improved during the two busiest pedestrian commuting times of day, going to and from school. Pedestrians were treated to a significant increase in total pedestrian signal time, as the signal adjusted relative to vehicle traffic volume. Other positive results and effects were:

- Waiting time for school children to cross was reduced by 48 percent.
- Signal cycle was reduced by 22 percent.
- No traffic congestion occurred.

Vehicle slowing while approaching the new PPSS controlled intersection greatly increased. ⁽⁷¹⁾

Effects of Infrastructure on Bicycle and Pedestrian Mobility

A number of studies evaluated whether changes in infrastructure, or changes in infrastructure and encouragement measures, significantly affected the amounts of walking and cycling and/or reduce auto use. These studies should be placed within the context of other research on travel demand and mobility shifts.

Encouragement Initiatives – Camberwell, Australia: A demonstration project was used to assess whether infrastructure and behavior change (encouragement) measures could have a measurable impact on walking and reduce car use in Camberwell. GIS modeling, questionnaires, pedestrian counts, research, and corridor audits were used to select two walking corridors for the demonstration and prioritize the treatments. Evaluation and pedestrian counts indicated a clear increase in pedestrian activity and a reduction in car use following the infrastructure improvements and behavior change (Try Walking) initiatives. ⁽⁷²⁾

Quiet Lanes – United Kingdom: The Quiet Lanes initiative was part of England's Countryside Agency plan, supported by the Department for Transport, to *"form a network of country lanes suitable for use by pedestrians, cyclists, equestrians, and motor vehicles, with the aim of helping to preserve the character and tranquility of rural areas and encouraging an increase in nonmotorized use whilst maintaining vehicular access."* ⁽⁷³⁾ A project was undertaken to measure the success of two Quiet Lanes projects in Norfolk and Kent, between 2000 and 2004. The lanes were seen as a long term solution due to the goal of creating a shift in attitudes towards nonmotorized travel.

Key findings were as follows:

- No change or small decrease in measured traffic on Quiet Lanes at the same time as an increase in traffic on control roads.
- Little change in measured vehicle speeds on Quiet Lanes and control roads.
- Little change in pedestrian numbers in Norfolk while a small increase in pedestrians in Kent.
- Strong and sustained public support for the Quiet Lanes idea in both towns, but one-third of those surveyed in Norfolk and half in Kent say the scheme is not working in practice.
- Small declared increase in nonmotorized use.
- Small declared decrease in motorized use.
- Declared increase in careful driving practices.
- Concerns for safety remain.
- Perceived problems on Quiet Lanes remain.

There were larger increases in the numbers of pedestrian users than there were in the numbers of bicyclists. These findings were possibly due to the lack of lighting in the rural segments and long distances that made commuting by bicycle less convenient than by vehicle and that the majority of nonmotorized use was for leisure and recreation, not commuting. Conclusions were that the scheme did not substantially cause drivers to decrease their speed but may have improved some other safe driving practices and awareness of nonmotorized users. The authors of the study concluded that the Quiet Lanes initiative was a partial success and achieved some of the aims, but it did not meet the expectations of the stakeholders and planners. The authors suggested that the scheme needs to be implemented alongside other measures, such as traffic calming, pedestrian and bicycle infrastructure and facilities, public awareness and feedback campaigns, and parking policies. ⁽⁷³⁾

National Cycling Network – United Kingdom: The UK National Cycle Network (NCN) developed by the transport organization known as Sustrans developed a network of about 20,000 km of bicycle and walking infrastructure paths around England’s rural and urban areas and communities. ⁽⁷⁴⁾ About one-third of these are known as Urban Traffic-free paths, which are separated from the public highways and roads. Though they form only one-third of the entire network, they account for 80 percent of its bicycle trips. There is little research on the effect of these paths on the local communities for which they serve, though it is assumed that they stimulate new bicycle users. This study analyzed a typical portion of one of the NCN paths to determine its quantifiable potential for encouraging cycling for everyday travel amongst a community living near that section.

The characteristics of the NCN urban traffic-free path are similar to greenways in the U.S. Many are developed along the paths of abandoned rail lines and also river corridors (Figure 12). Some are developed on low-traffic roads that are linked between urban centers through the countryside. The principle aim of the entire NCN as well as its urban traffic-free paths is to “encourage people to take up cycling for the first time or to start cycling again...by providing the opportunity for less experienced cyclists to gain the confidence and experience (without worrying about vehicular traffic) necessary to enable them to cycle more.” ⁽⁷⁴⁾

The study results reveal that the availability of an urban traffic-free path alone is not sufficient to encourage a modal shift from car to cycling for everyday travel purposes or commuting. The data suggests that a multifaceted approach that combines marketing with physical measures is required to stimulate increased daily travel by bicycle. These physical measures include wider speed restrictions in urban areas, investment in high quality segregated bicycle facilities along major roads, and land use/transport policies that advantage cycling in general while reducing the convenience of travel by car. ⁽⁷⁴⁾

Greenways – Girona, Spain: Mundet and Coenders reported on a survey of 1,261 randomly selected users along 106km of greenway and car-free trails that link the Pyrenees and Mediterranean through multiple communities in Spain (known as the Girona Greenway Consortium). ⁽⁷⁵⁾ Management recommendations were formulated from these survey results, which included user profiles, their perceptions of the greenway systems, and direct and indirect impacts of the greenways on the communities through which they pass.

The communities surveyed spanned from small villages to large towns and urban areas and were administered in 12 locations (six urban, six rural) throughout the year during two, two-hour periods on both weekends and weekdays.

Respondents were asked about use of the greenway (mode of travel); trip lengths and purpose; use of services along the greenways; frequency and time of use; what they like and dislike most; their evaluation of different aspects of the greenway; place of residence; gender, age and other demographics; and from where they found out about the greenways. Comparisons between local and tourist use were also determined.

Results showed that the greenway’s positive impacts were much greater for resident members of the communities and locals than for the tourist activities they generated or tourist users.

Physical activity was the number one type of use. Management recommendation and implications included several infrastructure related conclusions, particularly including the need for better connecting infrastructure to the towns, improved wayfinding, and other amenities.⁽⁷⁵⁾

New Assessment Tools

U.S. jurisdictions use a variety of methods to prioritize improvement locations, but a clearer process for identifying and prioritizing network needs would likely help many jurisdictions. There are also relatively few reliable safety performance models (in the U.S., crash modification factors or CMFs) for predicting safety effects of calming and safety measures for pedestrians or bicyclists. A few research studies were identified that have explored development of new assessment or prediction tools.

Montreal, Canada: A Montreal project aimed to find the best location for biking facilities “to best serve the needs of current cyclists and attract new ones.”⁽⁷⁶⁾ Efforts used three sources of data that were considered readily available in similar forms in other major metropolitan areas, including:

- 1) Data from an online survey of cyclists asking for three types of data: socio-demographic; bicycling preference data including origin and destination, path/facility choice, and type; and opinions on where new bicycling infrastructure and facilities are most needed.
- 2) Collision data.
- 3) Regional household survey.

The researchers employed a four step GIS process as follows:

- 1) Identify pertinent indicators that could be used to prioritize locations for infrastructure, with five indicators chosen based on substantial review of available relevant research, including:
 - a. Number of observed cycling trips and their locations.
 - b. Number of potential cycling trips and their locations (car trips short enough that they could feasibly be replaced by bicycle trips).
 - c. Identification of specific links by current cyclists in which they named specific streets where they believed there was a high need and/or potential for bicycle path additions.
 - d. The location of cycling collisions obtained from the Insurance database: these were geo-coded in GIS.
 - e. The location of and mapping of the existing bicycle infrastructure to identify where it ends; named “dangling nodes.”
- 2) Create a grid and spatially aggregate the above pertinent indicators into grid cells.
- 3) Combine these grid cells into a “prioritization index” such that the higher the index, the more appropriate the grid cell is as a location for infrastructure.

- 4) Map the index: allowing analysis of where existing infrastructure is with respect to the highest priority regions (or grid cells). Each grid cell would also provide characteristic data, information on existing infrastructure, and disaggregate data.

The authors suggest that the GIS methodology and analyses developed in the study can be used to provide a balanced analysis that allows for effective and objective spatial planning for locating additions to a city's bicycle infrastructure and facilities network. ⁽⁷⁶⁾

Further assessment of this and other approaches is needed to compare prioritization methodologies.

Victoria Province, Australia: A nonprofit organization developed a Cycling Level of Service audit tool for VicRoads that incorporates section and intersection measures. ⁽⁷⁷⁾ Scoring is from 0 to 16 representing F- to A, and the collective score yields the LOS for a section or intersection. Section or midblock scoring elements include primarily measures of facility type and degree of bicyclist separation from motorized traffic, speed limits, parking, lateral clearance, and surface evenness.

Intersection measures include intersection type (two-lane roundabout = 0, with other types having a negative score), signal phase = green on approach, intersection approach lane straight, or deviated to curb, storage box, lane continued through intersection, departure lane presence, early start, speed limits, left turn volume, and crossing delay. A case study demonstrated that the weakest links on the test route were the intersections. Additional tools were developed for assessing bike boulevards and off road paths. The article discusses whether the tool could be used to help prioritize investment strategy. ⁽⁷⁷⁾

Pedestrian Environment Review System – United Kingdom: Another tool and methodology for understanding and evaluating the performance of existing facilities in terms of safety, accessibility, and comfort is the Pedestrian Environment Review System (PERS). In 2001, the UK Transport Research Laboratory (TRL) developed PERS to evaluate the performance of existing pedestrian walking environments. ⁽⁷⁸⁾ In 2004 and 2009, the Transport for London agency assisted with upgrading the method, and it is now a reliable, repeatable, and quantifiable tool for planners and managers to evaluate existing pedestrian environments for improvements. TRL has used PERS to audit more than 150 miles of London's streets, and also in planning for pedestrians at local and strategic levels.

PERS divides pedestrian environments into separate commonly found components in walking environments and uses a holistic approach to identify deficiencies in those specific environments. However it is also usable as a tool during the design process. It consists of an on-street objective and quantitative assessment of various street environment components, organized into six review types:

- *Link review*—Sections of sidewalks (footways), subways, and footbridges.
- *Crossing review*—Signalized and unsignalized intersections; Informal desire for crossing lines where no crossing infrastructure exists.
- *Public transit waiting area review*—Bus stops, tram stops, and taxi stands.

- *Interchange space review*—Spaces between different public transport modes (e.g. rail station to bus station).
- *Public space review*—Parks, plazas, squares, and any formal or informal common areas.
- *Walking route review*—Origin to destination, between key trip attractors (e.g. rail station to town center).

Each review type is divided into parameters for the type and quality of the provided infrastructure as well as observed pedestrian behaviors and interactions. This allows for a multidimensional assessment.

During the audit, the assessor gives each parameter a score on a seven point scale (-3 to +3) and justifies that score in a detailed commentary. These scores are marked and totaled, and detailed photographs are included. Assessments are also taken from the perspective of vulnerable pedestrians (elderly, disabled, children, or tourist unfamiliar with area). Once the on-street audit is completed with as many assessments as possible, results are entered into the PERS software. This allows full data outputs like graphs, charts etc., and results can also be integrated with GIS for mapping outputs. PERS incorporates weightings of results that create best possible recommendations for improvements in two categories, physical and environmental. The software will allow profiles for each analyzed facility along with the recommended improvement and a photograph.

According to the authors, PERS is a repeatable, quantifiable, and data-based system of analysis that has been used extensively and successfully in Europe, and to a lesser extent in Australia and South Africa, to help implement successful improvements and upgrades.⁽⁷⁸⁾

Pedestrian Risk Index – Valencia, Spain: A new model - the Pedestrian Risk Index (PRI) - was developed using surrogate safety measures (with empirical relationships to probability of a crash and severity of a crash) to estimate safety improvement of different pedestrian crossing countermeasures.⁽⁷⁹⁾ The U.S. Tool, the Pedestrian Intersection Safety Index is, in contrast, a safety screening tool that is based on expert ratings of safety based on different intersection designs, built environment, and traffic conditions. In the PRI, variables of Time to Stopping for a vehicle and Time to Collision are mathematically linked to analyze the probability of a pedestrian collision. To measure collision severity, impact speed of the motor vehicle is used (taking into account braking deceleration and distance factors). A correlation of the two mathematical outputs and factors is performed to arrive at the PRI.

The PRI was used to test safety effects (changes in driver behavior) in a pilot test using data collected on a succession of traffic calming and pedestrian safety devices implemented at a four legged intersection in Valencia, Spain. The configurations with speed tables most effectively calmed road users, per the PRI results, above and beyond that of speed humps that were placed prior to pedestrian crossings. The repainting of zebra crosswalks without any other treatments did not have an effect on the PRI. The authors concluded that the PRI was a sensitive measure to highlight modifications in driver behavior due to various safety

improvements at crosswalks, even though validation of an association between PRI and crash effects (occurrence and severity) is still needed.

Such an index, once validated, could be a useful predictive tool since crash data are often insufficient to evaluate treatment effects or predict changes due to treatments.⁽⁷⁹⁾

Summary and Conclusions

The purpose of this desk-based review was to identify noteworthy and innovative international designs, treatments, and practices that might be transitioned for use to improve bicycle and pedestrian safety and access in a U.S. context. However, even within the U.S., there is a wide variety of contexts, and treatments and practices that may work well in some locations may not work well in others at the present time, or they may require modifications. This report summarizes the best examples of network infrastructure with potential for enhancing bicycle and pedestrian travel in the U.S., in particular (1) bicycle network improvements, (2) limited auto traffic areas or pedestrian priority zones, (3) signalization, traffic control and intelligent transport systems, to improve safety and priority for bicyclists and pedestrians, and (4) policy change. Two topic areas focused on innovations and examples of: (1) methods or criteria for prioritizing improvements, and (2) network goals and measures used to assess network performance.

The report also describes recent evidence of effectiveness from evaluation studies of designs and treatments that may merit follow-up, and highlights a few guidance documents that may be valuable to study further. The project team used three main criteria as the basis for selecting and prioritizing treatments for further study:

- 1) It is in step with one or more of FHWA's goals and objectives related to pedestrian and/or bicycle travel, such as developing low-stress networks, creating Ladders of Opportunity, retrofitting streets, developing Toward Zero Death strategies, and others.
- 2) Empirical assessments or formal studies conducted provide evidence of potential benefits or effectiveness in promoting pedestrian or bicycle safety, mobility, and/or connectivity.
- 3) It is considered to have a high potential for use in the U.S. (e.g., there are large numbers of places, places with sufficient numbers of existing cyclists or walkers, or expectation of potential bicyclists or walkers), where the treatment/process is applicable based on U.S. safety needs and transport goals, and the treatment or process could be practically applied without major policy barriers.

The following information provides a summary of key insights and innovations, indicates what the next steps might be, and provides a rationale for further investigations or information sharing.

Performance and Prioritization

One of the biggest challenges in the U.S. is to provide a network of facilities that addresses real safety barriers and is perceived as safe and complete enough to attract more people to try walking and bicycling for more or longer trips. One of the lessons from international jurisdictions with high levels of walking and bicycling is that bicycling and walking have been prioritized and are seen as having value to help achieve public health, environmental, livability,

economic, and transport sustainability goals, as well as providing transportation options in their own right. Therefore, project decisions reflect greater priority to make bicycle and pedestrian travel safer, faster, and more convenient, even if changes sometimes negatively affect motorized mobility or access. These types of decisions, made through planning and public input and political processes, may be critical for the remaining steps and successful outcomes.

The research team identified a variety of criteria, methods, and guidance for assessing networks used to achieve the ambitious goals established. Framing the decision process are often histories and cultures that have long had a high degree of biking and walking. More recently, jurisdictions have considered national safety policies and priorities (Vision Zero or Sustainable Safety in many of the countries studied) and the design principles intended to minimize severe injury and death from collisions that may occur. These principles seem to be widely used to help determine how much users should be separated on different types (and speeds) of facilities and at intersections. However, most national and regional jurisdictions indicated that municipalities have significant autonomy to make decisions, so it is of great interest to learn more about how local jurisdictions are making decisions. Some practitioners indicated that mobility is the primary planning concern in their jurisdictions at present, so safety may be considered somewhat outside of the network planning and prioritization processes.

The project team gained insights into various formal and informal processes that foreign jurisdictions use to prioritize pedestrian and bicycle treatments. Key among these are methods of garnering public and user opinions. Processes used abroad included leveraging staff expertise (many of whom were themselves walkers and bicyclists), performing quality assessments, applying risk indexes to develop priorities, examining complaint data, applying a broader goal or policy framework, and gathering input from the public (including a broad array of potential roadway users) and from bike unions. Some jurisdictions take proactive measures whereby staff go into the community, cycle to meetings, and meet with residents to listen to concerns. Others have used bicycle organizations to help assess their networks, while some jurisdictions regularly conduct formal public surveys. These different types of processes, used alone or in combination, may each work well in European jurisdictions with already high levels of biking and walking. However, the U.S. should study these processes further to help determine what may work best here to ensure broader, more equitable representation in transportation prioritization processes.

To develop ideas for innovative infrastructure to help meet network needs, most jurisdictions indicated they rely on existing design guidance, internal staff and consultant expertise, and seek technical assistance from other jurisdictions, including through meetings and exchanges. As noted earlier, many of the best ideas are expansions of past concepts rather than totally new ideas. Some of the most promising types of infrastructure and other innovations, prioritized based on the criteria identified above, are highlighted below. Other types mentioned in this document also have potential for use by U.S. jurisdictions to enhance pedestrian and bicycle networks. Another recommendation to help move valuable innovations forward is for FHWA to consult with U.S. practitioners on ideas of most interest and to foster greater international exchange of ideas, research, and experiences through a variety of means. (Note that in the

discussion below, we have combined treatments somewhat differently than in previous sections.)

Network Infrastructure

Some of the more notable designs or featured types of infrastructure include:

- **Bicycle superhighways** (*cykelsuperstier*) are an example of facilities where separation is preferred, if possible. Superhighways are intended to support longer trips, specifically to increase the number of persons bicycling for trips longer than 5 km (3 mi). The bicycle superhighways are intended to be a space to themselves within the roadway right-of-way and may link a variety of facility types and supporting amenities such as air stations. Underpasses may be used to bypass junctions with major highways or natural barriers. Cities that have goals of increasing bicycle mobility, reducing motor vehicle use, improving livability, improving air quality, or reducing energy use (climate change goals) may be good candidates for discussing this measure further. In addition, the use of electric-assist bikes may expand the numbers of potential cyclists who would travel farther distances, increasing the cost-effectiveness of such facilities.
- **Widened, separated bike lanes along with “green wave” traffic signal progression** is a different type of bicycle corridor in that the route uses wide, separated bike lanes but passes at grade through signalized intersections, where the signal progression is timed for bicycle speeds to help reduce stopping and improve bicycle flow and safety.
- **Priority bicycle streets** are mostly former local, car oriented streets whose priority has been turned over to cycling. In these cases, extremely limited auto use is permitted (and motorized vehicles are expected to travel at cycling speeds). The predominant user is clearly cyclists. These shared use, low speed streets therefore help to complete cycle networks where separated facilities are infeasible. There are already some U.S. cities that have developed bicycle boulevards or neighborhood greenways, which seem to be similar concepts with intended similar functions. It seems clear that designs may vary even within a city, and further looks at research examples in Europe and in the U.S. can help U.S. cities determine where priority bicycle streets are a feasible, and preferred option and what designs might work best. For example, one issue may be to determine key design elements to help keep motorist speeds low and reduce conflicts in the shared space. One-lane bicycle streets may operate somewhat better than two-lane ones according to some European research. There is also some evidence that priority bicycle streets may operate with fewer conflicts in residential areas, compared to areas with commercial uses.
- A network of bicycle “**star routes**” (*sterrouter*) that serve as the city’s primary bicycle transportation corridors prioritizes comfortable, direct, fast, and secure routes, connecting neighborhoods with key bicycling destinations in the city center and also serving as attractive bicycling routes from the city into the countryside. Star routes may combine features of bicycle superhighways with bicycle priority (shared) street links when needed, although separated facilities along non-major corridors or green spaces (canals) with few intersections are preferred by some European jurisdictions. The

concept seems to be a prioritization plan for a complete network that links all areas of a city or region with important destinations. Again, there seems to be no reason that similar bicycle networks cannot be created in a number of U.S. metropolitan areas.

Bicycle paths in the U.S. are often seen as “lower stress” routes for many bicyclists. Bicycle superhighways may provide such lower stress routes in European cities but are also intended to connect residential and outlying cities with urban and employment centers, helping to make the bicycle a viable option for more types and longer trips. Such bicycle superhighways or shared use, off-road paths may have a greater role in future U.S. bicycle networks, as they may be able to help connect suburban to urban centers, enabling trips from areas that are often underserved. But, separated facilities or paths cannot typically provide access to all locations. For this purpose, some type of low-stress street network is needed. That is where bicycle priority (shared) streets may serve, as has already been discovered by some U.S. cities that have developed streets known as bike boulevards or neighborhood greenways. Bicycle priority streets might be used to connect neighborhoods to larger, separated bicycle facilities or to fill gaps in bicycle superhighways or “star route” type networks, when separated facilities cannot be provided. It may also be possible to provide longer, linearly connected, shared bicycle priority street facilities if neighborhoods are supportive of greater volumes of through-bicycle traffic. Bicycle streets will likely be most feasible in cities with a well-connected street network that provides sufficient redundancy to develop bicycle routes on residential or low volume streets that are parallel with and connected to other facilities. U.S. and international practitioners should be able to participate in some valuable exchanges of experiences and research that may be mutually beneficial. One idea, according to Dutch research, is that it may be beneficial to create a consistent type and design of bicycle street to achieve greater recognition and compliance with desired user behaviors. There is more discussion of issues in the descriptions of this treatment and cited resources.

- An LED **lane lighting system** along a shared-use path is another possibility. When the system detects a path user, it increases the lighting in the vicinity to full strength and then dims the lighting again as the user moves away. The system reduces electrical costs and the impact of nighttime lighting on the surrounding environment, while providing sufficient light for the safety and security of path users.

This might be a favorable option to provide an alternative to busy streets for nighttime cycling. Currently, many shared use paths in the U.S. are unavailable for nighttime cycling due to a lack of lighting, and such lighting could provide new options.

Some options for junctions include grade-separated interchanges, described earlier, and design improvements to at-grade, multilane roundabouts (C-roundabout).

- An at-grade, cyclist-roundabout (**C-roundabout**) design was created to retrofit multilane roundabouts to address problems of bicyclists mingling with higher speed traffic and crashes resulting from vehicles entering/exiting the roundabout and not observing circulating bicyclists. The design principles involve narrowing the approach legs to slow entering speeds and narrowing the two circulating roundabout lanes by enlarging the

center island to slow travel speeds to a level more comfortable for bicyclists to take the lane. Speed studies found that the design did slow motor vehicle speeds.

Similar roundabout designs could be studied in U.S. jurisdictions where multilane roundabouts are common and bicyclists need to travel through these junctions. Slower speeds are also expected to enhance safety for pedestrians crossing at legs of the roundabouts.

- **Path priority** at intersections along a shared use path involves requiring traffic on the cross-street to yield to path users. The intent is to improve path user safety at the crossings and reduce bicyclist delay. A speed table is used to slow vehicular traffic at the crossing. This treatment may help to reduce conflicts at junctions, especially those with two-way separated paths or bike lanes.

Traffic Restrictions, Signalization and Traffic Control

A number of other signalization and traffic control applications identified have potential to reduce conflicts and improve safety throughout traffic restricted areas and at intersections, and to improve bicycle and pedestrian travel time and efficiency. Several of the strategies rely on bicycle traffic signals; others allow bicyclists to continue through movements that do not conflict with other motorized movements, even when parallel motor vehicle traffic is stopped. Traffic control strategies that include more green time and priority for pedestrians and bicyclists, where appropriate, and signal phasing that separates conflicting movements, are both types of measures that may have widespread potential for expanded use in the U.S. More investigation is needed into the potential for some of the other types of measures, including where they are most useful, and potential barriers to use in the U.S. such as possible conflicts between pedestrians and bicycles. Examples of strategies with potential include the following:

- The use of **limited vehicular traffic areas**, while documented in the earlier study tour reports, have been further developed and offer a contrast to most U.S. streets where automobiles are *usually* the primary road user. Several cities in Europe are striving to limit motorized travel and increase bicycling and walking in the downtown cores of a city. Other cities have restricted traffic during certain times of day or allow cars at very low speeds. Selection of new pedestrian zones, as created in Toronto, Canada and Tokyo, Japan, can also be viable away from city centers. Toronto has expanded pedestrian zones near universities that have been well-received and have served public space needs as well as pedestrian traffic.

There are U.S. situations where different types of traffic restrictions might be considered to reduce traffic congestion and enhance nonmotorized travel in certain areas.

- **Extended walk time for pedestrians, early starts, and more green time for bicyclists** at signalized locations as well as **more split phases** to provide greater protection against conflicting movements. **Separate bicycle signals** are often used to provide some of

these improvements for bikes. These measures could obviously impact delay for other modes but could be prioritized at pedestrian or bicyclist-oriented locations.

- At signalized T-intersections with high volumes of left-turning bicycle traffic, the signal phasing can be arranged to **simultaneously serve auto and bicycle turning movements** and reduce conflicts and potential for crashes.
- **Bicycles traveling along the top of T are exempted from the signal indication for parallel auto traffic**, allowing them to proceed straight when auto traffic is stopped and thereby reducing bicycle delay. Bicyclists must yield to pedestrians using the crosswalks. This strategy can be combined with a left-turn pocket and bicycle left-turn signal at the far side of the intersection, allowing bicyclists to make a left turn in one stage, rather than two. It could apply at many U.S. roadways.
- **Separated bike lane on the intersection approaches** is continuously carried around the curb radius and continues on the intersection departure leg to the right. More testing would be needed to determine the feasibility of such treatments in the U.S.
- **Green LED lane lights in the pavement along a separated bike lane approach to a busy intersection**, with the goal of reducing the number of bicyclists entering the intersection on red. If a bicyclist passes a lit LED at a speed of 18 km/h (11 mph), they have sufficient time to pass through the intersection on green. This strategy could be used in conjunction with a separated bike lane and Green Wave type traffic signal progression.

Most of the roadway and traffic control measures listed above differ from what have been used in most U.S. jurisdictions. Some of these innovative measures would logically provide safety and/or operational benefits to pedestrians and/or bicyclists when used under certain conditions. However, in most cases, treatments should be studied further in European contexts and also evaluated in the U.S. since effects may be different. There may also be details of some signal types or supporting signs or designs that may require experimental approval in the U.S. or else substitution of similar measures (which could in turn, have different effects).

In conclusion, there are a number of planning and decision processes and novel infrastructure treatments that have potential for use in the U.S. Most of the innovations are expanding on ideas that were working well and improving on designs and traffic controls to correct safety and other issues. Some of the ideas seem to have significant potential for improving bicycle and pedestrian safety and mobility in the U.S. *if well implemented*. Additional study and information exchange will be needed to help identify and facilitate the best ideas and refine them as needed for use by U.S. jurisdictions. Among the ideas are to examine different processes for incorporating public and user input and perspectives, along with other types of data and input, into decision processes to help build networks that will best provide transportation choices for a wide variety of the populace.

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