5 Bicycling Infrastructure for All

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Safe, convenient, low-stress, and well-connected cycling infrastructure is crucial for making the bicycle a practical way to get around cities for daily travel. In the 1890s, when cycling first became popular, the chief need of cyclists was better road pavement to ride on. Today, however, for mass cycling to occur, what is most needed is separation from the danger and stress of traffic. This chapter examines the various kinds of bike route infrastructure and how they can be used to create the connected, low-stress bike network required for cycling to become an everyday mode of transport.

Types of Bike Route Facilities and Separation from Traffic Stress

There are four basic types of bike route facilities. One is stand-alone paths, often situated in a linear park or along an abandoned rail corridor, and sometimes shared with pedestrians. A second type is cycle tracks, also called protected bike lanes, which are bike paths or bike lanes running along or on a road but physically separated from traffic lanes by devices such as curbs, bollards, planters, concrete dividers, or a parking lane (see figure 5.1). A third type is conventional bike lanes, in which a marked stripe designates a portion of the road for bike use but without physical separation. The fourth type is roads where cyclists ride in mixed traffic, which can be considered a bike route if traffic speed and volume are low.

Only stand-alone paths and cycle tracks physically separate cyclists from motor traffic. Because opportunities for stand-alone paths in urban areas are limited, the bicycling networks of bike-friendly European cities such as Copenhagen and Amsterdam rely mainly on cycle tracks (see Koglin, te Brömmelstroet, and van Wee, chapter 18, this volume). For example, the

Figure 5.1
Parking-protected, one-directional cycle track on New York's 9th Avenue. *Source*: New York City Department of Transportation.

Netherlands has 35,000 km of cycle tracks versus only 4,700 km of conventional bike lanes (Fietsersbond 2013).

In the United States, cycle tracks were essentially outlawed until 2011, with only a few exceptions, as this chapter explains. Until then, apart from stand-alone paths, the only choices American transport planners had for accommodating cyclists were conventional bike lanes and mixed-traffic routes on quiet streets. Because continuous quiet streets can be hard to find, many bike lanes and designated mixed-traffic bike routes in the United States have been implemented on roads with traffic levels far in excess of what most people will tolerate.

People vary in their tolerance for interacting with traffic. Roger Geller (2009), a bicycle planner for Portland, Oregon, found it helpful to classify the population into four groups, with size estimates as follows: the "strong and fearless" (1% of the population), who will ride in almost any traffic condition; the "enthused and confident" (6%), who demand a bit more separation but are willing to ride in a bike lane on a multilane arterial road; the "interested but concerned" (60%), who find bicycling appealing and would enjoy a chance to ride in the city, but find it too dangerous; and a group he called "no way, no how" (33%). Geller saw that American bicycle planning at the time was mainly aimed at the "enthused and confident," making it irrelevant to most people. Given the immense societal benefits of mass cycling, Geller argued that cities should focus on serving the "interested but concerned."

Building on Geller's classification, Furth coined the term "traffic stress" to describe the perceived danger that traffic imposes on cyclists and spelled out objective criteria that bike lanes and mixed-traffic segments had to meet in order to be considered a low-traffic-stress environment for cycling (Furth, Mekuria, and Nixon 2016). In the last few years, many US cities have adopted these or similar criteria, which are summarized as follows.

Mixed traffic Riding in mixed traffic is low stress only on streets that fit the profile of the typical local street: no centerline or marked vehicle lanes, a prevailing traffic speed of 20 mph (about 30 km/h) or less, and daily traffic volume less than 2,000 vehicles, which roughly corresponds to one car every 20 seconds during the busiest hour of the day.

Bike lanes Conventional bike lanes can also be low stress, but only if four requirements are met, summarized here and further discussed later in this chapter: (1) the road should have no more than one lane per direction; (2) traffic speed should be no more than 25 mph (40 km/h) wherever the bike lane is next to a parking lane and up to 35 mph (56 km/h) otherwise; (3) if next to a parking lane, the bike lane plus any marked buffer next to it should be at least 7 ft (2.3 m) wide so that one can ride far enough from parked cars to avoid being "doored" (striking a suddenly opened car door); and (4) the bike lane should not frequently be blocked by illegally parked or stopped vehicles.

The need for separation from traffic has long been understood in Europe, and in the United States it has been a cornerstone of the nation's recreational trails program. But when it comes to urban cycling, American policy strongly resisted the notion of separation from traffic until recently, promoting instead the idea that bikes should be treated as *part of* traffic. The US experience from 1975 to 2010 was a tragic failure to promote urban cycling without providing separated infrastructure. This misguided policy is illustrated by the case of Camino del Norte, a six-lane, 55 mph (90 km/h) divided highway in San Diego with conventional bike lanes. Approaching a junction where many vehicles turn right, cyclists are expected to weave across a lane of 55 mph traffic and then ride for 900 ft (270 m) in a bike lane with two lanes of traffic on their right and four lanes of traffic on their left. Needless to say, almost no one uses this bike lane.

America's Struggle to Build Separate Cycling Infrastructure

This chapter focuses on the United States because the country provides an example of how challenging it can be to create cycling networks where cycling levels are so low that it is difficult to justify the investment and where most urban travel is by car. Similar situations exist, for example, in Canada, Australia, and New Zealand. The American example describes obstacles that have had to be overcome in the bicycling advocacy community, the engineering profession, the general public, and the political realm.

Interest in urban cycling revived in the United States in the late 1960s with the popularization of the 10-speed bike and social movements, including the environmental movement. At first, it was understandable that American city governments would resist calls to invest in separate bike infrastructure. For generations, people had known roads as having two divisions: one for motor vehicles and one for pedestrians. Adding a third division for bikes seemed like a radical and expensive idea with limited popular support. A chicken-and-egg effect was at work: Why invest in bike infrastructure when so few people are bicycling? But who will ride a bike when there is no safe infrastructure? With time, however, interest in bicycling continued to grow, spurred by external factors such as a desire for a healthy lifestyle. So why did the development of separated infrastructure lag so much?

It is impossible to understand the history of American urban cycling infrastructure without understanding the influence of John Forester's vehicular cycling (VC) theory, which posits that "cyclists fare best when they act as, and are treated as, operators of vehicles" (Forester 1992; Forester 2001). The theory asserts that the key to cycling safety is riding where drivers expect to find other vehicles. Drivers will not hit a vehicle they can see, Forester claimed, so there is no danger to riding in the middle of a traffic lane. (This is a stunning assertion, considering that there were 1.7 million rear-end collisions between motor vehicles in the United States in 2018!) According to Forester, the real danger is riding along the side of a road, where drivers aren't looking for other cars and one might be hit by a vehicle turning right. According to VC theory, cycle tracks and even bike lanes had to be avoided for the sake of bicyclist safety!

Although Forester had no empirical data to support his claims, his ardent defense of cyclists' rights gained him a devoted following. He was elected president of the League of American Wheelmen, now the League of American Bicyclists, which for over a century has been the main bicycling advocacy organization in the United States. From about 1975 to 2005, VC philosophy dominated bicycle advocacy organizations around the country, leading many of them to actively oppose bike lanes and cycle tracks. In several cities and states, VC adherents were hired as bike planners and engineers, where they used their position to prevent bike lanes and separated paths from being built.

Forester's most far-reaching influence came from getting an effective ban on separated paths written into the national handbook for bikeway design, *Guide for the Development of Bicycling Facilities*, published by AASHTO, the American Association of State Highway and Transportation Officials (AASHTO 2012; Schultheiss, Sanders, and Toole 2018). Although the AASHTO guide is not a legally binding standard, engineering officials across the United States generally treat its recommendations as standards that must be followed. The ban on separated paths, first encoded in a California manual in 1978 and then in the 1981 AASHTO guide, became self-perpetuating because the committees that control AASHTO guidelines only accept evidence from US safety studies. Without examples of separate facilities whose safety performance could be studied, the guide's recommendation against separated paths has persisted through every edition since then. (A new edition of the guide, not yet released as of May 2020, is expected to finally reverse its negative recommendations toward cycle tracks.)

Residents of European countries with extensive cycle track networks might find it astonishing that such a patently false theory that separated paths are dangerous could persist in light of decades of evidence from European cities in which millions of cyclists have ridden daily on cycle tracks, with crash rates far lower than in the United States and with far greater appeal to vulnerable populations such as children and seniors (Pucher and Dijkstra 2000; Pucher 2001; Pucher and Buehler 2008).

The Tide Turns to Favor Separation

During the period in which vehicular cycling dominated American bicycle planning and engineering—roughly 1975 to 2010—bicycling accounted for less than 1% of daily trips in almost all American cities, clear evidence of the failure of VC theory. Davis, California, a small university town where both the university administration and city government promoted cycling, stood out as a singular exception, proving that, given the right conditions, Americans would ride bikes. As early as 1980, 28% of work trips in Davis were made by bike, and most children biked to school (Buehler and Handy 2008). Bicycling became well established in a few other university towns as well, such as Boulder, Colorado. Only in the years 2000 to 2015 did Portland, Oregon, emerge as the first large American city with an extensive cycling network, a substantial percentage of trips by bicycle, and a strong cycling culture (see Geller and Marqués, chapter 19, this volume).

In none of these places did cycling succeed based on a VC model of bikes being operated like motor vehicles; rather, these cities built extensive networks of low-stress bike routes. Davis and Boulder had long linear parks in which they built stand-alone bike paths. Davis had many wide two-lane collector roads, with far lower speeds and far less traffic than arterial roads, which they outfitted with generously wide bike lanes. Portland built traffic-protected cycle tracks on several critical highway bridges over the Willamette River to connect the two main parts of the city. The city also laid out an increasingly extensive network of local street bikeways on its nearly uninterrupted street grid using various kinds of traffic-calming measures, including diverters and speed humps (for details, see Geller and Marqués, chapter 19, this volume).

As inspiring as Davis, Boulder, and Portland became, they could not provide a general model for other US cities to follow because their special circumstances enabled them to create low-stress bike networks without dealing with the thorny issue of accommodating bikes on arterial roads. In most American cities, the only practical route between most origins and destinations involves travel along arterial roads. For low-stress bike networks to emerge there, cities would need to embrace the concept of protected bike lanes or cycle tracks.

Until 2008, there were virtually no protected bike lanes in the United States—only a few kilometers of "sidepaths" from earlier eras, many of them along beaches. In North America, only one city, Montreal, had an integrated network of modern cycle tracks, built around 1990 after a city official was inspired by a visit to Amsterdam. The success of Montreal, however, was largely ignored by engineers and planners outside Quebec.

A turning point came in 2007, when New York City, advised by consultants from Copenhagen, created a parking-protected cycle track along 9th

Avenue in Manhattan (shown in figure 5.1). More New York cycle tracks followed in 2008 and every year since then, averaging about 10 mi (16 km) per year and accelerating to 30 mi (48 km) per year by 2019 (see Pucher, Parkin, and de Lanversin, chapter 17, this volume). Those cycle tracks violated the recommendations in the AASHTO guide by placing the bike lane on the nontraffic side of a parking lane.

Across the country, bicycle planners and designers watched anxiously, but the success of New York's "experiment" was soon clear. The federal government did not penalize New York City for violating the AASHTO guidelines. Cycling levels rose dramatically on the streets with the new traffic-protected facilities. Moreover, serious cyclist injuries and fatalities fell dramatically relative to the rising number of bike trips, demonstrating the much greater safety of cycle tracks (see Pucher, Parkin, and de Lanversin, chapter 17, this volume; Waters 2018).

In the bikeway planning world, a glass ceiling had been shattered. Across the country, cities scrambled to design and implement cycle tracks like those in New York. Early adopters included Indianapolis, Austin, Washington, DC, Minneapolis, and Chicago, where cycle tracks captured the imagination of citizens and elected officials alike—at last there was a bikeway facility that "normal people" could imagine themselves using! Bicycle advocacy organizations elected new leaders unassociated with vehicular cycling; soon the organized bicycling community came to speak with a united voice in favor of separating bicycles from motor vehicle traffic (see Pucher et al., chapter 20, this volume). People for Bikes, a bicycle industry trade group, became an important promoter of cycle tracks, providing technical assistance for cities interested in creating cycle tracks and taking public officials and city transport staff on study tours to the Netherlands and Denmark. Starting in 2008, the number of kilometers of modern protected bike lanes in the United States roughly doubled every two years (see figure 5.2), reaching 684 km in 2018.

The overthrow of VC philosophy in the United States was formalized in 2011 with the publication of the *Urban Bikeway Design Guide* (NACTO 2011). To produce this manual, officials from New York and other bike-friendly cities worked through a little-known organization called the National Association of City Transportation Officials (NACTO), thereby bypassing AASHTO. By providing clear engineering guidelines for the design of cycle tracks, this manual made it easy for cities around the country to emulate

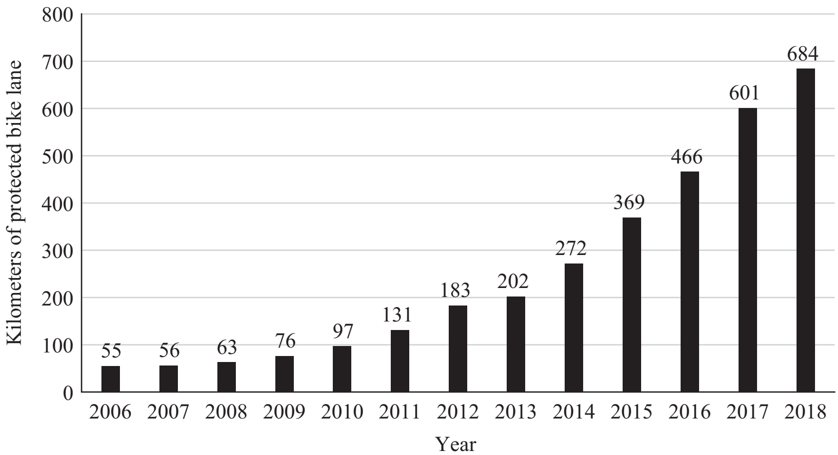

Figure 5.2

Growth in centerline kilometers of protected bike lanes (cycle tracks) in the United States from 2006 to 2018. *Source*: Data from People for Bikes.

the example of New York and other early adopters. The US secretary of transport endorsed the NACTO manual soon after its publication, freeing engineering officials across the nation to follow this alternative to the AASHTO guidelines and ending the hegemony of vehicular cycling theory over bikeway planning and design.

However, the struggle to create good bicycling infrastructure had other obstacles to overcome—taking roadway space from motor vehicles, finding economical bikeway designs, and gaining the public and political support to fund the creation of a cycling network.

Finding Space for Bikes

There are many competing demands for space in the road right-of-way, making it a challenge to find space for bike lanes and cycle tracks. One way to make space for bikes is to resize travel lanes, parking lanes, and shoulders with appropriate widths. Since before the motorized era, the standard travel lane in the United States has been 10 ft wide (about 3 m). To this day, all vehicles except those needing special permits are required to be operable within 10 ft lanes. For example, the widest bus or truck cannot exceed a width of 8.5

ft (2.6 m). Because 12 ft (3.65 m) lanes are standard on freeways, many state and local officials believed that all safe modern roads needed lanes that wide. However, an extensive study done for the Federal Highway Administration found that on urban and suburban arterial roads, lanes 9 or 10 ft (2.75 or 3.05 m) wide are just as safe as those 11 or 12 ft (3.35 or 3.65 m) wide (Potts, Harwood, and Richard 2007). Many city streets have lanes that are up to 16 ft (4.9 m) wide; shrinking travel lanes to 10 ft (3.05 m) will not reduce a road's safety or traffic-carrying capacity, while freeing up needed space for bike lanes.

Parking lanes similarly vary surprisingly in width. The widest common personal motor vehicle in the United States is 6.6 ft (2.0 m) wide; thus, parking lanes that extend 7 ft (2.15 m) from the curb are sufficient. In addition, roads often waste space with oversized shoulders, sometimes called "edge offsets." State design guidelines sometimes call for 4 ft (1.3 m) shoulders even though the national road design manual states that, where the speed limit is 35 mph (56 km/h) or less, having no offset is acceptable (AASHTO 2018).

An even more radical way to find space for bikes is to reduce the number of travel lanes, called a "road diet." Many urban arterial roads in the United States have four lanes, two in each direction. This is inefficient because cars waiting to turn left block the inside lanes and, as a result, traffic can flow freely in only one lane per direction. A road with a three-lane layout can have the same traffic capacity: one through lane in each direction and a central zone that can be a left-turn lane where needed and elsewhere can be a raised median, making it easier for people to cross the street. San Francisco and Charlotte are examples of American cities that have each implemented more than 20 road diets, with the freed-up space usually reallocated to bike lanes.

Opposition to repurposing roadway space for bikes can be intense. In a widely publicized example, a group of prominent citizens sued the city of New York in a failed attempt to prevent a pilot road diet project on Prospect Park West from becoming permanent. Reducing the number of travel lanes on this one-way street from three to two was approved by a community board, based on traffic studies showing rampant speeding and finding that traffic would still flow smoothly with a road diet. After the road diet's implementation, data showed that neither vehicle throughput nor travel time changed, while the safety benefits were astounding. The percentage of cars exceeding 40 mph (64 km/h) fell from 47% to 2%; the percentage of cyclists riding on the sidewalk (illegal in New York City) fell from 46% to

3%; and the number of traffic injuries in six months fell from five to two. At the same time, cycling volumes doubled on weekends and tripled on weekdays. Nevertheless, the opposition group continued a draining appeal process for five more years before giving up (Sadik-Khan and Solomonow 2016).

Stand-alone Paths and Linear Parks

Stand-alone bike paths, often built along waterways and abandoned rail corridors, enjoy strong political support because they are popular for recreation. When built in urban areas, such paths can also be valuable for utilitarian bicycle transport, particularly when they lead to a city center or other major destination.

In urban settings, dual paths—one for cyclists and another for pedestrians—are standard practice in Europe, though infrequently used in North America, where bike paths are typically shared with pedestrians. According to Dutch guidelines, bike paths should always be sized to support cyclists riding side by side (CROW 2017). In the United States, following the AASHTO guide, shared-use paths are usually 10 ft (3.05 m) wide—an arbitrary and misguided standard because this dimension is too narrow to support side-by-side cycling except where path use is very low. If paths were instead 11 ft (3.35 m) wide, the path would in effect have three lanes, enabling two people to ride side by side without one of them having to fall back every time they met a cyclist traveling in the opposite direction.

While most stand-alone paths take advantage of historical opportunities such as old rail lines and canal towpaths, new opportunities can sometimes be created. New York created the nation's busiest bike path by replacing a riverside highway with an at-grade boulevard and linear park hosting bike and pedestrian paths. Another example is Davis, California, where a private developer built a linear park with a multiuse path through its new housing development. The success of that path resulted in the city laying out plans for a connected network of linear parks and paths that successive developers were legally required to build as the city expanded (Buehler and Handy 2008). Similarly, Scottsdale, Arizona (a suburb of Phoenix), and Eagle, Idaho (a suburb of Boise), have adopted plans for bike paths following irrigation canals in undeveloped parts of those towns; developers are required to build any part of the bike path network lying in their development.

Cycle Tracks

Cycle tracks, also called protected bike lanes, are bike paths or bike lanes running within the road right-of-way yet physically separated from motor traffic. Cycle tracks can be either at sidewalk level or at street level. At sidewalk level, separation from pedestrians is best achieved either by a row of trees or light poles or by a small, rounded curb that makes the cycle track about 1.5 in (4 cm) lower than the sidewalk, a design used widely in Denmark and the Netherlands. Dividing a sidewalk using only differing paving materials or a painted line (common in the United Kingdom, Germany, and Japan) is also possible where space is limited. However, merely designating part of a sidewalk as a bikeway can be unsatisfactory if the sidewalk lacks the space and sight lines needed for safe riding at normal bicycling speed.

For street-level cycle tracks, the traditional means of separation from motorized traffic is a raised median, common in Rotterdam and Montreal. American cities have discovered less expensive means of separation—planters, flexposts (plastic bollards that fall down when hit and then spring back up), and, most notably, parking lanes. When a parking lane is used as the barrier, a marked buffer roughly 3 ft (0.9 m) wide is needed between the parking lane and the cycle track for visibility and so that cyclists will not be injured or blocked by a car whose door is open while loading. While flexposts offer no structural resistance to vehicles, studies show that they provide the same sense of physical separation as structural barriers.

Cycle tracks can be one-way, like bike lanes; however, because they are physically separated from the street, they can also be two-way. The main advantage of two-way cycle tracks is that a single bidirectional cycle track requires less space than a pair of one-way tracks. For example, a typical pair of parking-protected one-way cycle tracks requires 16 ft (4.9 m) in total, including buffers, while a two-way cycle track requires only 11 ft (3.4 m). Moreover, during times of lighter use, two-way paths offer the possibility of riding side-by-side or passing without requiring any extra width.

One concern with two-way cycle tracks is that they complicate intersections and create safety concerns involving motor vehicles turning left. For these reasons, Copenhagen does not allow two-way cycle tracks. Amsterdam and other Dutch cities have historically favored one-way cycle tracks for the same reasons; however, Dutch guidelines allow two-way cycle tracks provided designers take appropriate measures to ensure intersection safety.

At signalized intersections, the key safety measure is separate left-turn phases for cars, a practice New York City has also followed in building its new cycle tracks (see Pucher, Parkin, and de Lanversin, chapter 17, this volume). At unsignalized intersections, the key safety measure has proven to be "side street crossing tables," also called "continuous sidewalks" (see figure 5.3); when crossing a minor street, a major street's sidewalks and cycle tracks remain elevated instead of dropping to street level. Cars entering or leaving the minor street are thereby forced to ramp up and down to cross the sidewalk and cycle track, which they do at very low speed because the ramps are dimensioned like speed humps. This treatment, which originated in Sweden (Garder, Leden, and Pulkkinen 1998), spread rapidly in the Netherlands starting around 2002. A study found that side street crossing tables halve the crash risk at unsignalized intersections, making two-way cycle tracks with this treatment as safe as one-way cycle tracks without them (Schepers et al. 2011). Thanks to this new intersection design, two-way cycle tracks have become more common than one-way tracks on Dutch arterials, and many one-way cycle tracks have been reconfigured as two-way.

Figure 5.3
A side street crossing table forces cars to slow down as they have to ramp up and down steeply when crossing the cycle track and sidewalk. *Source*: Peter Knoppers.

Conventional Bike Lanes

Conventional bike lanes, separated from traffic lanes by only a painted line, are inexpensive to install and require less space than protected bike lanes (cycle tracks). That makes them an attractive option where space or funding for cycle tracks is difficult to find.

Some organizations and advocacy groups eschew conventional bike lanes altogether. Under the banner "all ages and abilities," they argue that cycle tracks are the only acceptable option on all roads except quiet local streets (NACTO 2017). However, in the appropriate setting, conventional bike lanes can provide a low-stress place for cyclists to ride, and they offer significant safety benefits compared to cycling in mixed traffic. Both the Dutch bikeway manual (CROW 2017) and the Level of Traffic Stress criteria (Furth 2017) consider conventional bike lanes an acceptable accommodation on moderate-speed roads with one lane per direction.

Riding next to a parking lane, whether in a conventional bike lane or in mixed traffic, involves a risk of being "doored." A suddenly opened car door can catch a bicycle's handlebar and throw the rider forcefully to the ground, often causing serious injuries and subjecting the victim to the risk of being run over by a motor vehicle. Typical bike lanes in US cities are too narrow to eliminate this hazard; to ride clear of car doors, cyclists in typical bike lanes have to encroach on the adjacent traffic lane. Nevertheless, studies have shown that, compared to riding in mixed traffic, painting a line to designate a bike lane reduces dooring risk, because it induces cyclists to ride farther from parked cars—presumably because that painted line makes them confident that cars approaching from behind will stay on their side of the line (Van Houten and Seiderman 2005). Still, it is preferable for bike lanes to be extra wide so that cyclists can keep a safe distance from hazards on both sides. To keep a wide bike lane from having the appearance of a parking lane, a narrow, hatched buffer can be painted on either side of a normal-width bike lane.

In commercial areas, conventional bike lanes are often blocked by illegally parked cars and delivery vehicles. One study found that almost 50% of cyclists in commercial areas had to leave the bike lane because it was blocked by a vehicle (Meng 2010). Thus, protected bike lanes are vastly preferred in commercial areas.

Local Street Bikeways

Local streets with low traffic speed and volume, on which cyclists can comfortably ride in mixed traffic, are not only vital for access to the bicycle network; they can also be used to form main bicycle routes across the city. Bike routes that mainly follow local streets have been variously called bicycle boulevards, neighborhood greenways, and local street bikeways. In the Netherlands, such routes have proven to be safer and more popular with schoolchildren than main roads with cycle tracks.

The concept is more complex than it may first appear, because the factors that keep through traffic from using local streets—for example, being discontinuous or labyrinthine—also make them unsuitable for through bicycling. Creating a city-scale bike route using local streets can be approached in two ways. One is to take an existing long, continuous street and install infrastructure and signage to divert and slow motor vehicle traffic while allowing bikes to pass through. The West Coast cities of Berkeley, Palo Alto, and Portland in the United States and the Canadian city of Vancouver have taken advantage of their nearly uninterrupted street grid networks to turn some long local streets into local street bikeways by using partial street closures and median barriers to divert through motor traffic along with traffic circles and speed humps to slow traffic (Walker, Tressider, and Birk 2009). Older, narrow roads in or near centers of cities and towns often present a similar opportunity. As traffic demand grows, it is often impractical to widen such roads, so a bypass road is built for motor vehicles. In the Netherlands, for example, many such roads have been downgraded to local streets, using full or partial closures to force motor vehicle traffic to use the bypass road while letting bikes pass through. Such converted roads can make ideal bike routes because they follow an axis of historic urban development and generally avoid steep grades.

The second approach to developing local street bikeways is to stitch together shorter segments of local streets to form a longer route. Joining discontinuous segments can involve building connectors such as a footbridge over a creek, an underpass to cross a highway or railroad, or a path connecting nearby cul-de-sacs. In one situation in Davis, the city purchased a property that separated two quiet streets, Drexel Drive and Loyola Drive, demolished the house, and built a short path connector. Planners in Europe—and, in a few cases, in the United States as well—often incorporate short path connectors into new housing developments, creating local streets that are discontinuous for cars but continuous for bikes and pedestrians.

However, the concept of local street bikeways can be abused if the routes are too indirect. In both the United States and Europe, cities that have tried to channel cyclists onto local street routes that require large detours have found that cyclists spurn them in favor of a more direct route following main streets. A study from Portland, Oregon, found that cyclists are willing to ride only about 10% to 20% farther, depending on trip purpose, to enjoy a quieter route (Broach, Dill, and Gliebe 2012).

Shared Road Treatments: Advisory Bike Lanes versus Sharrows

On streets lacking the space needed to create bike lanes but with more traffic than a typical local street, both Europeans and Americans have developed treatments intended to make it safe and comfortable for bikes to share a road with motor vehicles.

The American approach, marking bike silhouettes called "sharrows" in the middle of travel lanes, is both a failure and a farce. Sharrows were conceived in the days of vehicular cycling as a way to embolden cyclists to assert their right to ride in the middle of a car lane, away from the door zone, while prompting motorists to respect cyclists' right to do so. The primary study used to defend their effectiveness (Alta Planning + Design 2004) actually shows them to be quite ineffective—when cars were passing, sharrows shifted cyclists' position only 4 in (10 cm) farther from the parking lane, with most cyclists still riding in the door zone rather than in line with the sharrows. Sharrows may embolden a few of the "enthused and confident" to take the lane, but for most people sharrows do nothing to lower traffic stress. Motorists, for their part, do not understand their meaning at all.

Worse still, sharrows are a farce because cities can paint them on a road and then claim that they have created a "shared lane bicycling facility." National guidelines allow sharrows on multilane roads and on roads with speed limits up to 35 mph (56 km/h). By trying to normalize a kind of bicycling that most people eschew (riding in the middle of a travel lane on a busy road with fast traffic), sharrows make a city's cycling program appear to be out of touch with the mainstream, eroding public support for funding legitimate cycling infrastructure.

By contrast, the European treatment for road sharing, advisory bike lanes (figure 5.4), has been very effective. Dashed white lines indicate the part of the road bicyclists are expected to use. Vehicle lanes are *not* marked. Because there is no striped centerline, motorists will often drive in the middle of the road, shifting right into an advisory lane when a vehicle approaches from the opposite direction. If the advisory lane is occupied, the car will stay behind the bike until it is clear to pass.

The dashed lines of advisory lanes make the passing maneuver predictable and low stress—the bike and car each stay on their side of the line, just as they would if there were a conventional bike lane. The outcome is that advisory lanes give cyclists the same security as if they were riding in a conventional bike lane, even when there is no space for bike lanes.

Figure 5.4
Advisory bicycle lanes in the Netherlands. *Source*: Peter Knoppers.

Advisory bike lanes are used extensively in European countries, including the Netherlands, Germany, Denmark, and Switzerland. In the United States, they remain almost unknown. As of late 2019, only 19 streets in the entire United States had advisory lanes.

A subtle but important difference between sharrows and advisory lanes is that advisory lanes are a *shared road* treatment, while sharrows are a *shared lane* treatment. The American approach delineates motor vehicle lanes and invites cyclists to ride in them like any other vehicle. The European approach delineates the bicyclists' space and allows motor vehicles to use it when they need to. The absence of a striped centerline is critical. On streets without centerlines, it is normal for motorists to drive in the middle of the road, shifting position when encountering other vehicles. Where drivers operate with this mindset, sharing a road with bikes fits naturally. Once a centerline is marked, drivers see bikes as something blocking their lane, making the street a hostile environment for cycling.

Planning Bicycle Networks

The requirements for bike networks can be summarized in one phrase, *low-stress connectivity*, meaning that links with low stress form a network in which origins and destinations are connected to each other without excessive detours or excessive climbs (Furth, Mekuria, and Nixon 2016). Low-stress connectivity can be decomposed into five requirements that correspond closely with those listed in the Dutch bikeway design guide (CROW 2017).

1. *Separation from traffic stress*. As described earlier in this chapter, bike infrastructure must separate cyclists from fast and heavy traffic. That can be accomplished with stand-alone paths, cycle tracks, bike lanes (including advisory lanes) under conditions described earlier, and in mixed traffic on local streets with low traffic volume and speed.
2. *Pleasant, well-lit, and low-crime surroundings*. Unlike people in motor vehicles, cyclists are not physically separated from their environment, so the environment around them is important. Where crime is a concern, cyclists prefer a route that is well lit and where homes with windows and active street life give it "eyes on the street." Cyclists also prefer streets with little traffic noise and with natural beauty or attractive buildings.

3. *Smooth, well-maintained pavement*. To avoid injury-inducing falls, the pavement must be well drained and well maintained, including clearing leaves, sand, and snow (or, where ice formation is not a concern, packing the snow hard). Smooth pavement improves cyclist comfort and reduces the physical effort needed to ride.
4. *Avoiding long, steep climbs*. Cycling uphill greatly increases the effort needed to propel a bicycle, so bike routes should avoid steep hills where possible.
5. *Connected and direct*. The network links that meet the first four requirements should connect people's origins and destinations without excessive detours and with safe intersection crossings. An upper limit for a detour is about 20% longer than the most direct path using *any* road or path legally open to bicycles. Because origins and destinations tend to be scattered, this requirement is tantamount to requiring that the bike network form a dense mesh (CROW 2017). The Dutch suggest a route spacing of 500 m (0.3 mi) in cities, though in practice route spacing in Dutch cities often reaches 700 m (0.4 mi), and 1 to 2 km (0.6 to 1.2 mi) outside the built-up area, where trip lengths tend to be longer.

Funding for Bicycling Infrastructure

For a city or metropolitan region starting from scratch, creating a low-stress bicycling network is a radical initiative, akin to creating a highway or rail transit network. Bicycling infrastructure is actually very inexpensive compared to highway or rail infrastructure, but it costs more than can be accomplished without dedicated funding. While many US cities have published bike network plans, few have provided the necessary funding stream. Too often, bicycling infrastructure is funded on a piecemeal basis without any permanent budget line and at a rate at which bike network completion could take many decades.

Bicycling infrastructure costs vary depending on the specifics of each project, but here are some ballpark figures. Reconstructing a street in order to create curb-separated cycle tracks costs \$10 to \$20 million per mile (although full reconstruction projects can sometimes be financed by a city's road reconstruction budget). Stand-alone paths cost \$1 to \$2 million per mile, not counting bridges. Parking-protected cycle tracks cost around \$1 million per mile, not counting traffic signal work, although at least one city (Portland, Maine) has managed to build a pair of one-way, parking-protected cycle tracks for only \$100,000 per mile. Bike lane striping costs only about $15,000 per mile, and the incremental cost can be zero when part of a repaving project; however, striping has to be replaced every few years and thus requires not only an initial capital budget but also an ongoing maintenance budget. The cost of creating local street bikeways depends on the treatments involved; a typical project might cost $200,000 per mile (again, far less expensive examples can be found), plus $250,000 for every new traffic signal needed.

By comparison, highway infrastructure commonly costs $300 million to $2 billion per mile. One city's feasibility study found that the cost of building a low-stress bike network was roughly $1,000 per city resident (Götschi 2011); spread over 20 years, that would be $50 per resident per year. By comparison, per capita annual spending by Boston metropolitan area governments is $400 for public transport and $600 for roads. The Boston metro area is currently spending $2 billion to build a 4.3 mi (7 km) light rail extension that will increase the length of the rapid transit network by 5%. The same investment would suffice to create a low-stress bike network covering the entire metropolitan area.

As this comparison shows, bicycling infrastructure is clearly affordable. The issue is generating enough political and public support to make governments realign transport spending priorities so that they invest in bike network development at a meaningful pace. A few North American cities—all in Canada—provide good examples of this. Vancouver's current capital plan will invest US$34 per person per year into its bike network (City of Vancouver 2018, 79), while Ottawa and Montreal are investing US$12 per person per year (City of Montreal 2018; City of Ottawa 2017). Only a few US cities have attained this level of cycling investment, including Seattle, New York, San Francisco, and a few small university towns.

Conclusion

Mass cycling requires bike infrastructure that separates cyclists from traffic and forms a dense, connected network. Compared to highway and rail transport, bike infrastructure is affordable and requires little space. There are many types of bicycling facilities, making it feasible to create a low-stress bicycling environment in almost every context.

Although this chapter has focused on the United States, the American experience is instructive for other car-dominated countries beginning with very low levels of cycling. Getting American cities to develop the needed bicycling network has faced four main challenges: (1) getting the engineering profession to adopt the correct design guidelines; (2) reorienting bicycling advocacy organizations to advocate for infrastructure that serves the mainstream population rather than hard-core cyclists; (3) growth in public support for bicycling; and (4) garnering political support and leadership in prioritizing investment in cycling infrastructure. In the United States, the first three have been accomplished; the last one remains a challenge.

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