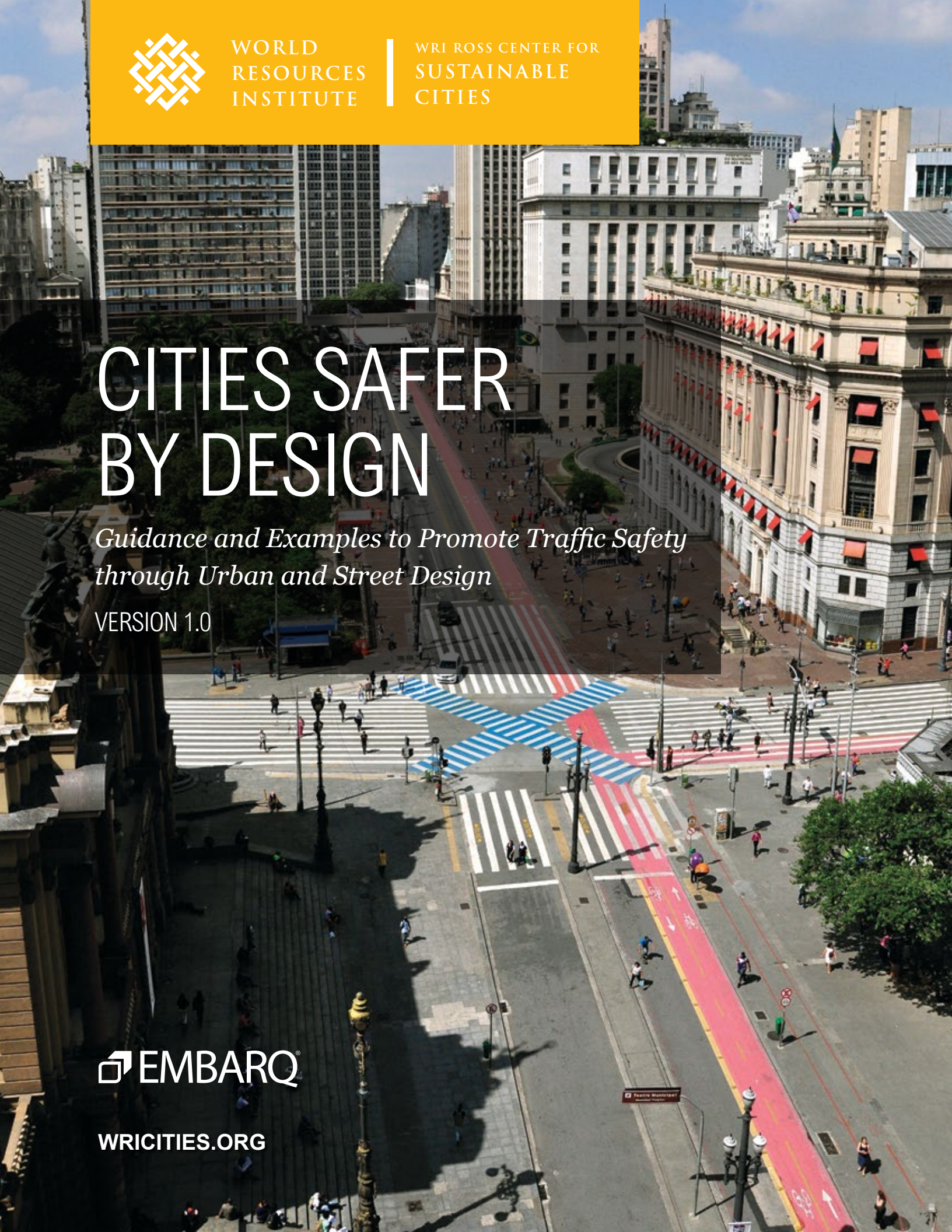

WORLD RESOURCES INSTITUTE

WRI ROSS CENTER FOR SUSTAINABLE CITIES

CITIES SAFER BY DESIGN

Guidance and Examples to Promote Traffic Safety through Urban and Street Design

VERSION 1.0

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BICYCLE INFRASTRUCTURE

Bicyclists require special attention in street design as they are one of the most vulnerable users in terms of traffic fatalities and injuries, yet an increase in safety and usage can lead to greater health and environmental benefits.

Bicycling in many cities is a main form of transport. Asian cities once had a great legacy of bicycling, but this is on the decline in China and increasing in the United States and other developed European countries. Research has shown that U.S and European cities with higher rates of bicycling have fewer overall traffic crashes, and these cities are also home to connected streets and advanced networks of bicycle lanes, off-street paths, ample bike parking, and bicycle sharing systems. This chapter will be focusing on some key issues in providing safer conditions in a bicycle system, using examples and evidence from both the developed and developing countries. The following sections will be included:

- Bicycle networks
- Bike lanes and cycle tracks
- Off-street trails
- Shared bicycle street
- Bicycle safety at intersections
- Bike safety at bus stops
- Bicycle signals

Evidence shows that the crash rate for cyclists is six to nine times as high as for car users (Bjornskau 1993). The risk may be even higher in developing countries due to underreporting. Evidence also shows that through better street design, bicycle injuries and crashes can be greatly reduced. While protected bicycle lanes seem to improve safety through numbers by giving users a perceived security and increased safety between junctions, paying special attention to junction design is crucial for real gains in safety. This includes improving the visibility between cyclists and vehicle drivers and addressing conflicts at junctions with proper markings and signalization. Combining these measures will ensure a safer, more pleasant, and ultimately more successful bicycling system.

6.1 BICYCLE NETWORKS

The needs of bicyclists should be considered throughout the road network. A well-connected bicycle network should consist of interconnected bike lanes, cycle tracks, traffic-calmed streets with priority for bicycles, and special considerations at junctions and intersections, which are designed to prioritize cyclists' needs.

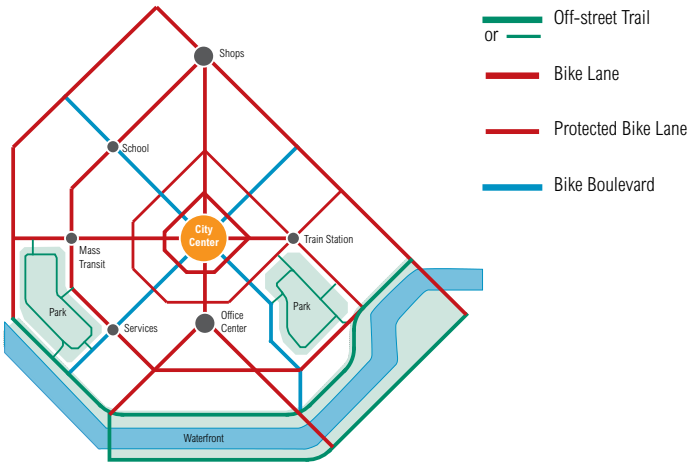


Diagram of a bike network that connects important destinations.

Design Principles

- Provide bicyclists the most direct possible routes and a continuous right-of-way.
- Should be coherent and not interrupted by intersections or building sites.
- Separate from high-speed motorized traffic. Special considerations and clear visibility to bicycles should be given at intersections and junctions.
- Consider bikeway typology/hierarchy, from off-street trails to shared streets to protected bike lanes on streets.
- Establish wayfinding tools, signalization, and integration with other transport modes.
- Provide ample bike parking.
- Safety of bicycle networks can also be enhanced by signalizing.

Benefits

- A well-connected bicycle network can provide bicyclists a continuous biking route without disruption.
- A well-designed bicycle network can ensure bicycle safety and reduce crashes and fatalities.
- A sound bicycle network and adequate biking facilities or programs will encourage biking use and physical activities, as well as reduce vehicle travel and environmental impacts.

Application

- Lane markings, lane widths, and waiting and loading areas on main roads need modifying to help cyclists.
- Special consideration of bicycle routes should be given at bus stops and stations to avoid conflicts.
- Introduce bicycle facilities on main roads whenever possible, such as bike lanes, stopping areas, and separate traffic signals at junctions.
- Provide bicycle parking facilities and renting/sharing system.
- Ensure all retail, business, leisure destinations, and public spaces are accessible by bicycle.
- Bike sharing/renting program should be considered to promote bicycle use.

Evidence

- Cities such as Copenhagen, New York City, and Minneapolis have witnessed significant decreases in the rate of fatalities and injuries for cyclists after building a network of safer bike infrastructure over the years (Duduta, Adriazola-Steil, and Hidalgo 2012).

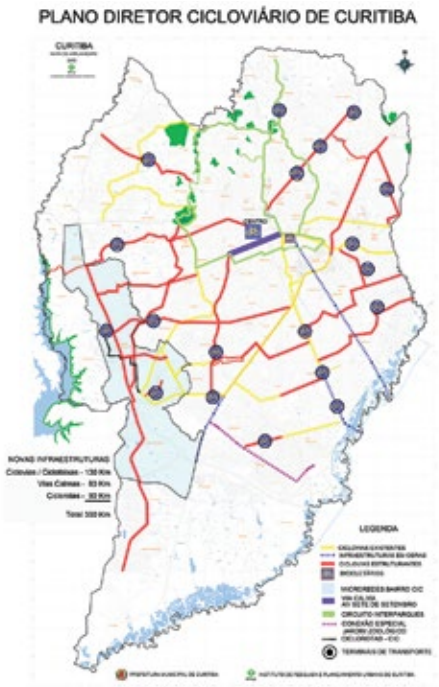


Figure 6.1 | **Bicycle Networks Case**

Curitiba, Brazil has more than 120 km of bicycle lanes and paths, traversing both green areas and city streets. The city is planning another 200 km, linking destinations, transport nodes, and residential areas in a consolidated network.

6.2 BIKE LANES AND CYCLE TRACKS

A portion of the street in one or both traffic directions is designated for exclusive bike use by pavement markings (bike lanes), or a curb or median (cycle tracks). Protected bicycle lanes are intended to physically separate cyclists from motorized traffic and to ensure cyclists mobility and a feeling of security when traveling.

Cycle tracks separated from car traffic through physical barrier.

Design Principles

- Recommended bike lane normal minimum width adjacent to sidewalk curb of 2.2 meters and a 1.7-meter bare minimum if planners see the facility as improving safety and comfort for cyclists. Where an adjacent parking lane does not exist, 1.5 meters may be sufficient if adjacent traffic speeds are low.
- Bidirectional lanes are not preferred but could be considered if they would prevent crossing movements or space is limited. Safety can be enhanced through limited intersections, special signal control for bicycles, traffic calming at intersections, raised bicycle crossings at some intersections, and addressing vehicle accesses. Bidirectional lane widths should be a minimum of 2.5 meters.
- A bike lane next to a parking lane should be located in the inner side of the parking lane to protect bicyclists from motor traffic.
- In high- and medium-volume streets, use physical barriers or buffer zones between bike lane and motor lane but relieve barriers before junctions with right-turning traffic.
- Place on right side on a one-way street (right-side direction countries).

Benefits

- Separated bike lanes enable bicyclists to ride comfortably apart from moving vehicles aside from intersections, providing perceived safety that increases bicycling rates.
- Protected lanes place bicyclists farther away from vehicle exhaust.

Application

- Protected bicycle lanes are safer in between intersections, but can pose problems at intersections when motor vehicles and bicycles can conflict. Care should be taken to increase visibility and decrease conflicts at these points.
- Paint pavement to differentiate, especially at high traffic intersections.
- Bidirectional can be considered on one-way vehicle streets in contraflow configuration with consideration of intersection safety.
- Protected lane is provided by a buffer of some kind, which varies by local context but could include small “armadillo” humps, a linear curb, a raised cycle path, plastic bollard posts within a painted area, or other tools that provide a physical protection.
- Can be at roadbed level, or on level between roadbed and sidewalk but preferably not on same level as sidewalk as this infers shared space of pedestrians and cyclists.

Evidence

- Bike lanes lead to small changes in the number of injury crashes. The mean estimate of 4 percent reduction of injury crashes is statistically significant (Elvik, Hoye, and Vaa 2009).
- A new cycle track in New York has reduced speeding rates from 74 percent to 20 percent. Crashes and injuries of all kinds dropped by 63 percent (Schmitt 2013).

Figure 6.2 | **Bike Lanes and Cycle Tracks**

A one-way cycle track from Mexico City protects bicycles with physical barriers and markings where the barriers give way at a vehicle access point.
Bottom: Cycling infrastructure seen here in Shanghai, China provides physical separation from motor vehicles through a fence. Pedestrians are also kept from entering the area.

6.3 OFF-STREET TRAILS

A path is provided in an off-street location that is exclusive to bicycles and pedestrians. Off street trails are sometimes called greenways or green routes and located on linear corridors, parks, utility or former rail corridors, along streams or waterfronts.

An off-street trail that segregates bicyclists and pedestrians to reduce conflicts.

Figure 6.3.1 | **Off-Street Trails Case**

A bidirectional lane along the edge of a park in Belo Horizonte, Brazil allows the adjacent path to be solely devoted to pedestrians. The bicycle lane is protected from motor vehicle traffic with concrete separators. Bidirectional lanes are most applicable when along corridors such as parks and waterfronts where turning conflicts are fewer.

Figure 6.3.2 | **Off-Street Trails Case**

This off-street bike trail on the edge of a park in Bogotá, Colombia provides separate paths for pedestrians and cyclists, helping to reduce conflicts between the users.

Design Principles

- Segregate bicycle traffic from pedestrian traffic using a striped line or separate path, providing at least 3.0m for a bidirectional bicycle lane and 1.5m for the pedestrian path.
- Junctions or points of conflict with vehicles should be designed carefully to reduce vehicle speed, control the approach to the junction, and provide appropriate signage.
- Ideal for streams and waterfronts, abandoned rail corridors, utility corridors, or plan as part of an interconnected parkway system.
- Closure of streets can be used to create bicycle greenway.
- Connect to on-street bicycle and pedestrian routes.

Benefits

- Can lead to greater connectivity of cycling and pedestrian paths.
- May provide economic benefits for surrounding development.
- Segregated completely from traffic for safer experience.

Application

- Ensure separation of cyclists and pedestrians, but if not possible, limit speeds of bicyclists and give pedestrians priority.
- Provide ample lighting and security features.
- Avoid sharp curves.

Evidence

- Clearly marked, bike-specific paths were shown to provide improved safety for cyclists compared to mixed-user bike paths (Reynolds at al. 2009).
- Off-street bike paths were found to be one of the safest bicycle routes in Vancouver, Canada (Teschke et al. 2012).

6.4 SHARED BICYCLE STREET

Shared bicycle streets—also known as bicycle boulevards—are low-vehicle-volume and low-speed streets that have been optimized for bicycle travel through treatments such as traffic calming, vehicle reduction and redirection, signage and pavement markings, and intersection crossing treatments.

A shared bicycle street, bike boulevard design with road markings and traffic calming measures.

Design Principles

- Locate on streets with low traffic volumes designed for vehicle speeds between 20 and 30 km/hr, with an ultimate maximum of 40 km/hr.
- Use traffic calming measures to limit the volumes and speeds of motor vehicles.
- Introduce traffic reduction measures such as diverters, traffic circles that restrict or prevent vehicles from passing through all junctions but allow cyclists.
- Prioritize intersection treatment to create safer crossings and reduced conflict with fast-moving vehicles, such as bicycle boxes, signaling, traffic calming for perpendicular traffic, median refuge islands, etc.
- Prioritize bicycle travel by the use of pavement markings and signage.

Benefits

- Can make better use of low-volume traffic and neighborhood streets.
- Homeowners and the local community may benefit from the safer, quieter, and pleasanter environment created by shared bicycle streets.

Application

- Bicycle boulevards should provide connectivity to key destinations such as schools, employment or commercial centers, recreational facilities, and transit.
- Shared bicycle streets, as they contain mixed traffic, require careful attention to keep motor vehicle speed safe for cycling. They may not improve safety if this is not addressed along the corridor and at intersections with major streets.
- Better integrated with green storm water treatments, public art, landscaping and street trees, pedestrian amenities, and end-of-trip facilities (adequate and safe bike parking).

Evidence

- Evidence from Berkley, CA shows that collision rates on bicycle boulevards are two to eight times lower than those on parallel, adjacent arterial routes. The difference is highly statistically significant (Minikel 2012).

Figure 6.4 | **Shared Bicycle Street Case**

A fietsstraat (bike way) in the Netherlands has pavement markings and signage of a bike boulevard.

6.5 BICYCLE SAFETY AT INTERSECTIONS

A safer intersection for bicyclists may include elements such as colored pavement, markings, bike boxes, bicycle signals, and simultaneous green phases for cyclists. Special attention to bicycle facilities at intersections and driveways should be given to maintain visibility of the bicyclists to motorists and to reduce the risk of turning conflicts with motor vehicles.

An intersection enhances the view between drivers and cyclists as they approach the intersection, and a two-step left-turn box.

Design Principles

- Minimize the potential conflict points at intersections, and ensure low motor vehicle speeds at approaches, using raised crossings, speed humps or other treatments.
- Eliminate any curbside parking spaces at least 10 meters before intersection to help ensure visibility between drivers and cyclists.
- Set back stop line for motor vehicles ideally by 5 meters to provide visibility of bicyclists (sometimes this area is marked in form of painted box); stop line for bicycles should be just behind the pedestrian crossing.

Figure 6.5 | **Bicycle Safety at Intersections Case**

An intersection in Amsterdam is designed to show visibility between cyclists and vehicles, with the parking lane gradually eliminated to improve visibility between motorists and bicyclists.

- Two-step left turns where cyclists approach the opposite corner, turn, and then proceed straight are regarded as safer than allowing cyclists to make left-turning movements from the left side of the vehicle travel lane. A bicycle box can be provided in front of the pedestrian crossing of the intersecting street to provide space for bicyclists to queue for left turns. (See page 73 for more).
- Bidirectional lanes are considered less safe as they involve unpredictable movement of cyclists, especially at intersections. If these facilities are to be implemented, special traffic calming, such as raised bicycle crossings, speed humps, or other features should be applied at intersections, in addition to signal control that eliminates conflicts with turning vehicles.

Benefits

- Intersections are where bicyclists come most into conflict with motorists, so increasing visibility and protection of bicyclists improves both comfort and safety.
- Good conditions for bicyclists can improve delineation between pedestrians and cyclists.
- Raised crossings, median refuges reduce motor traffic speed at the intersections.

Application

- Intersections should be designed to fit each particular space and designed with the needs of traffic at this location.
- Bike boxes usually are used at signalized intersections with high volumes of bicycles, especially where bicycle left-turns and motorist right-turns often conflict.
- Colored paving and markings are recommended to increase bicyclists' presence.
- Bike boxes may be combined with a separate bicycle signal phase to allow bicyclists to cross the intersection ahead of motorists.

BOX 6.1 | LEFT TURNS ON STREETS WITH BICYCLE LANES

Left turns are one of the more complicated movements at intersections, and it is important to know the varying safety aspects of certain designs.

Some guidance, such as the NACTO Urban Bikeway Design Guide from the United States, outlines bicycle boxes where cyclists are placed ahead of cars to make a left turn (NACTO 2013). Similarly, manuals from Ireland and the Netherlands describe an option where cyclists weave into a feeder lane for a left turn, though this places cyclists at risk while turning (CROW 2007; NTA 2011).

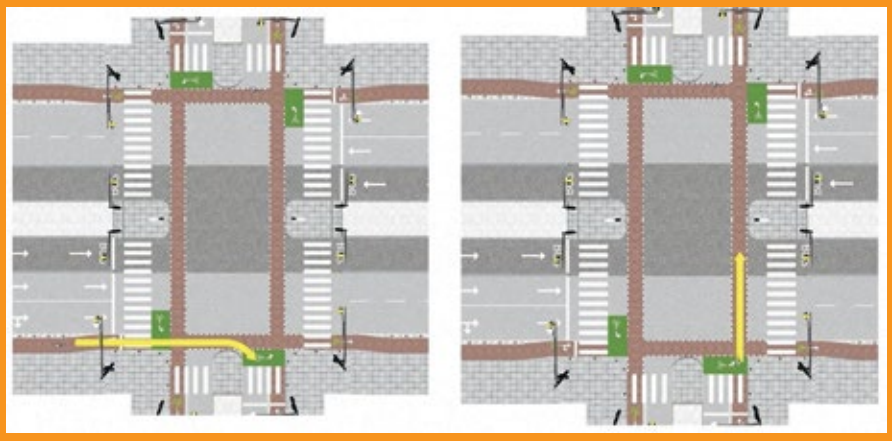
A safer design may be found in two-step turns. Guidance from the Netherlands indicates that two-stage left turns are one option that can reduce the conflicts (CROW 2007). A national-level guide for Mexican cities also suggests this design (ITDP 2011). Research from China also shows the two-step design to be beneficial (Wang et. al 2009). One problem is that this can leave cyclists in a subjectively unsafe situation waiting in the street. As such, NACTO suggests that bicyclists be placed in line with a curb or parking area. The Irish bicycling guide echoes this, saying the "stacking area" must be clearly visible and not obstruct crossing pedestrians or straight ahead cyclists. A frequent signal cycle may entice cyclists to wait in a design that requires two steps.

Lastly, the Netherlands' CROW 2007 indicates that simultaneous green signal phases exclusive to cyclists can be provided to allow bicycle left turns on all arms of an intersection. This may be ideal for high cyclist-volume intersections, though it could increase waiting times for all road users. Again, a quick signal cycle may relieve this issue.

More research is needed on the safety effects of these interventions and the impacts of whatever facility is put in place ought to be measured.

Two-Step Left Turn Design Example

Cyclists should continue straight along the road on a green light, stop in the queue box to the right and wait for the light to change before proceeding on the other street.



Evidence

- Seventy-seven percent of cyclists felt bicycling through the intersections was safer with bike boxes, and bike boxes reduce motor vehicle encroachment at intersections by almost 20 percent (Monsere and Dill 2010).
- Improving intersection design to provide two-step left turns resulted in a reduction in safety conflicts between motor vehicles and bicyclists by 24 percent in Beijing (Wang et. al 2009).
- A study from Finland and another from the Netherlands found that speed-reducing countermeasures (e.g. raised bicycle crossings) improved drivers' visual search patterns in favor of the cyclists coming from the right, giving more time to notice cyclists (Summala et al. 1996; Schepers et al. 2011).

6.6 BIKE SAFETY AT BUS STOPS

Bicyclists conflict with pedestrians embarking and disembarking at bus stops. Special design should accommodate the needs of both. A bike path behind bus stops can help avoid collisions between bicyclists and bus passengers, though if this is not provided priority should be given to pedestrians in some form.

Bike path design should accommodate the needs of both bicyclists and pedestrians at a bus stop.

Figure 6.6 | **Bike Safety at Bus Stops Case**

A bus station bypass in Rio de Janeiro, Brazil that raises the bicycle lane to the sidewalk level while bypassing the bus waiting area.

Design Principles

- Ensure easy access to bus stops for people with reduced mobility.
- Design can place bike lanes at the same level of sidewalk or bike lanes at street level with curb cuts enabling better pedestrian passage to the bus platform area.
- Design and markings should ensure that cyclists slow down and give way to pedestrians crossing in shared spaces.
- Bike lanes should be widened at the curves so that cyclists don't risk falling.
- The minimum width of the embarking/waiting area is 3m and the recommended length is 20m.

Benefits

- Reduce crash risks for both pedestrians and bicyclists at bus stops.
- Guarantee an easy access for bus users while accommodating a bicycle lane around a bus stop.

Application

- If it is prohibitive to raise the bicycle lane to the pedestrian pavement grade or to bring the lane behind the station area, then paint or markings could mark the pedestrian priority area.
- Waiting area sizes may need to be adjusted to match the passenger boarding and alighting volume at bus stops.

Evidence

- Studies have shown that collisions between cyclists and pedestrians result in significant injuries, and that increased controls of shared spaces may reduce the burden on pedestrian injury, particularly older pedestrians (Chong et al. 2010). Reducing this conflict at bus stops is one area that may be considered.

6.7 BICYCLE SIGNALS

Bicycle signals make crossing intersections safer for bicyclists by clarifying who and when to cross an intersection and by giving bicyclists priority crossing by signal phasing. Push buttons, bike boxes, and colored pavement and markings may be combined with bicycle signals to enhance bicycle crossing safety.

Bicycle signals can be clearly placed to inform when cyclists can cross.

Design Principles

- The bicycle signal head should be placed and designed so it is visible to bicyclists and not visible to motorists, as motorists may head start upon seeing the bicycle signal.
- Bicycle signal shall be used in combination with an existing conventional traffic signal at the intersections.
- Use three-lamp signal so cyclists can distinguish it from pedestrian signals.

Benefits

- Provides priority to bicyclists at intersections; the pre-green for cyclists will increase their visibility.
- Avoids bicyclist and motorist conflicts at the intersection by separating the crossing movement into phases.

Application

- Recommended at intersections with a high volume of crossing bicycles.
- Give bicyclists advanced green (e.g. a leading crossing interval) where bicyclists turning movements are high.
- Useful at complex intersections that may otherwise be difficult for bicyclists to cross.
- Useful at intersections close to schools and universities.

Evidence

- Evidence from Portland, OR shows that bicycle signals can reduce the number of bicycle/vehicle collisions (Thompson et al. 2013).

Figure 6.7 | **Bicycle Signals Case**

A bicycle signal is provided along this protected bicycle lane in Istanbul, Turkey.

BOX 6.2 | BICYCLE SHARING

Introducing new bicycle infrastructure can help enhance bicycling rates and provide residents the choice to use a form of transport that is incredibly healthy when considering the physical activity benefits. Cities can go beyond safer bicycling lanes to also provide the bicycles themselves through bicycle sharing, which has found success in low- and middle-income countries such as China and Mexico.

One of the most notable is Mexico City's Ecobici bike sharing program, which was launched in 2010 and today has an estimated 73,000 users and 27,500 daily trips over 4,000 bikes and 275 stations. In China, the systems are the largest in the world. The bicycle share system in Hangzhou, China has 66,500 bicycles operating from 2,700 stations. Globally, there are now over 500 cities with bicycle sharing systems in place (Hidalgo and Zeng 2013).

Studies of bicycle sharing are showing a potential in providing health benefits. A study of users of Barcelona's bike sharing system showed that there was near-zero percent increase in risk associated with exposure to air pollution and traffic crashes, but that over twelve lives were saved per year from the physical activity of people switching to more active transport (Rojas-Rueda et al. 2011). A review of bicycle share systems in the United States, Canada, and Europe reveals that bicycle share riders have a lower rate of crash risk than the average bicyclist (Kazis 2011). Experts have noted that this may be because bicycle-share bicycles move at lower speeds, are sturdier, are designed to keep riders in an upright position, have built-in lighting, and are often taken for short trips that may limit exposure.

Further study is needed regarding the safety aspect of bicycle sharing—especially those in Latin America and China—being instituted in countries with higher rates of traffic crashes. It is also important that cities interested in introducing bicycle sharing take actions to improve the safety of infrastructure on streets.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