Don’t Give Up at the Intersection

Designing All Ages and Abilities Bicycle Crossings

NACTO
National Association of City Transportation Officials

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Top: Vancouver, BC. Madi Carlson
Bottom: Cambridge, MA. Better Bike Share Partnership

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San José, CA
Photo: Peter Bennett

Introduction

Better bike networks need safer intersections

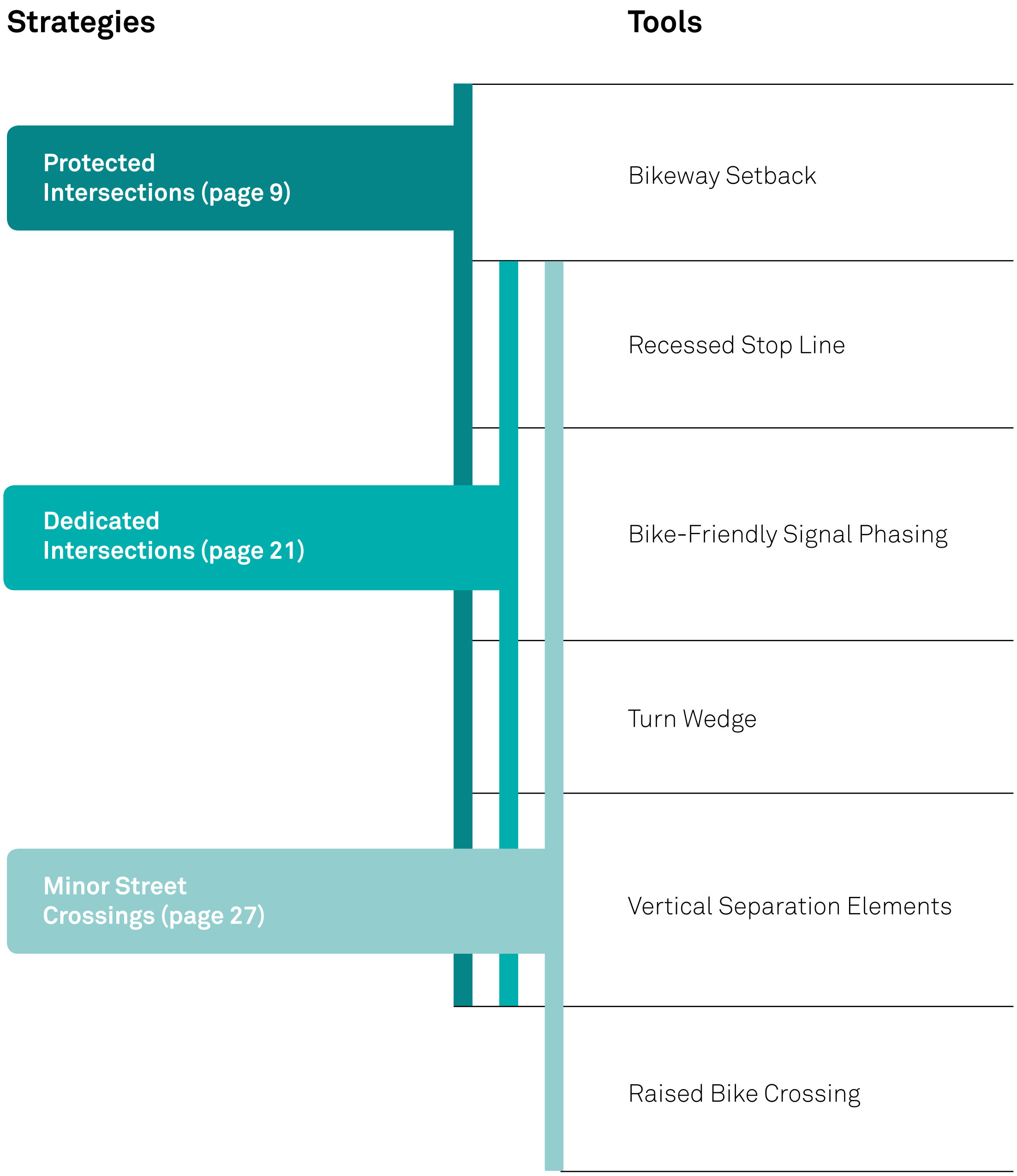
Since the publication of the NACTO ***Urban Bikeway Design Guide*** in 2011, cities across North America have expanded their protected bike lane mileage by more than 600%,[1] opening the door for a dramatic increase in the number of people biking. However, amidst this growth, design strategies for intersections remain a crucial, underdeveloped part of the bikeway design toolbox.

Intersections are the place where the most vehicle-bike conflicts occur. In 2017, 43% of urban bicyclist fatalities occurred at intersections.[2] On many streets, large turn radii and wide lanes encourage drivers to make sweeping, fast turns. These design decisions increase exposure and risk for people walking and biking, reduce the safety and comfort of the bike network, and discourage cycling.[3] As cities work to make streets safer and more welcoming for bicyclists of all ages and abilities, intersection design is key.

Don't Give Up at the Intersection expands the NACTO ***Urban Bikeway Design Guide***, adding detailed guidance on intersection design treatments that reduce vehicle-bike and vehicle-pedestrian conflicts. This guidance covers protected bike intersections, dedicated bike intersections, and minor street crossings, as well as signalization strategies to reduce conflicts and increase comfort and safety. Used in concert with NACTO's ***Urban Bikeway Design Guide*** and ***Designing for All Ages and Abilities***, this guidance provides the tools cities need to build comprehensive, connected, safe bike networks.

Intersections at a Glance

This guide is organized around three intersection design strategies and the specific tools that are most applicable to each. In combination, these tools **reduce turning speeds, increase the visibility of people bicycling,** and **give priority at intersections to people bicycling.**



Reducing Turn Conflicts

Turning vehicles present a specific and outsized risk to people on bikes. Cities can design safer intersections by reducing turn speeds, making bikes visible, and giving bikes clearer priority over turning vehicles.

Reduce turn speed.

Drivers yield more frequently to people walking and biking when speeds are low, making it safer for bikes to pass in front of turning cars. Lower speeds give drivers more time to stop if needed, and reduce the severity of collisions when they occur. Smaller turn radii, centerline hardening, turn speed bumps, and raised bike crossings can all reduce the speed at which drivers turn.[4]

Make bikes visible.

Setting back the bikeway crossing, installing recessed (early) stop lines for motor vehicles, and building raised bikeway crossings all make it easier for drivers to see people using the bikeway. The designer's challenge is to provide good lines of sight without encouraging higher speeds.

Give bikes the right of way.

People on bikes crossing a busy intersection need clear priority over turning motor vehicles. Formal right of way often is not enough, but driver yielding can be improved by prohibiting motor vehicle turns on red, implementing bike-friendly signal strategies, and letting bikes move past stopped vehicles while waiting for a signal.[5]

Chicago, IL
Photo: CDOT

Protected Intersections

Protected intersections have been implemented across North America as cities have expanded their protected bikeway networks. Also known as setback or offset intersections, this design keeps bicycles physically separate from motor vehicles up until the intersection, providing a high degree of comfort and safety for people of all ages and abilities.[6,7] This design can reduce the likelihood of high-speed vehicle turns, improve sightlines, and dramatically reduce the distance and time during which people on bikes are exposed to conflicts. For example, in San Francisco, a protected intersection design resulted in 98% of drivers yielding to people on bikes, and 100% yielding to people walking.[8] A study in New York found that protected intersections had fewer vehicle-bike conflicts than even a dedicated turn lane with a dedicated bike signal phase.[9]

Description

At protected intersections, the bikeway is set back from the parallel motor vehicle traffic. Unlike at conventional bike intersections, people biking are not forced to merge into mixed traffic. Instead, they are given a dedicated path through the intersection, and have the right of way over turning motor vehicles.

The **setback** between the motor vehicle lane and the bikeway makes people on bikes more easily visible to turning drivers than in a conventional intersection.

Corner islands anchor the design, extending the protected bike lane's separation as far into the intersection as possible and tightening the corner's turn radius. They create a **bike queue area** after the crosswalk, the natural place for people on bikes to wait.

The setback creates a **waiting zone** for turning cars, where drivers can yield to bikes after starting to turn but before crossing the path of oncoming bicycles. If it is large enough, this area lets drivers wait while through-traffic passes them, relieving pressure to turn too quickly.

Protected intersections also provide shorter, safer crossings for people walking. With low-speed vehicle turns and room for accessible **pedestrian islands,** people on foot and using personal mobility devices get many of the benefits of curb extensions.

Protected intersections create shorter, simpler crossings, more predictable movements, and better visibility between people on bikes and people driving. As a result, the intersection is more comfortable and safer for people using the bikeway and the crosswalk.[10]

Protected Intersections

No Stopping / No Standing Zone

Motor vehicle parking and stopping are prohibited on the approach to the intersection.

Pedestrian Islands

Islands reduce crossing distances and improve visibility by keeping the intersection clear. Wider islands support high volumes of people walking and biking, raising the capacity of the intersection. In some cases, islands can reduce the signal time needed for pedestrians.

Bikeway Setback

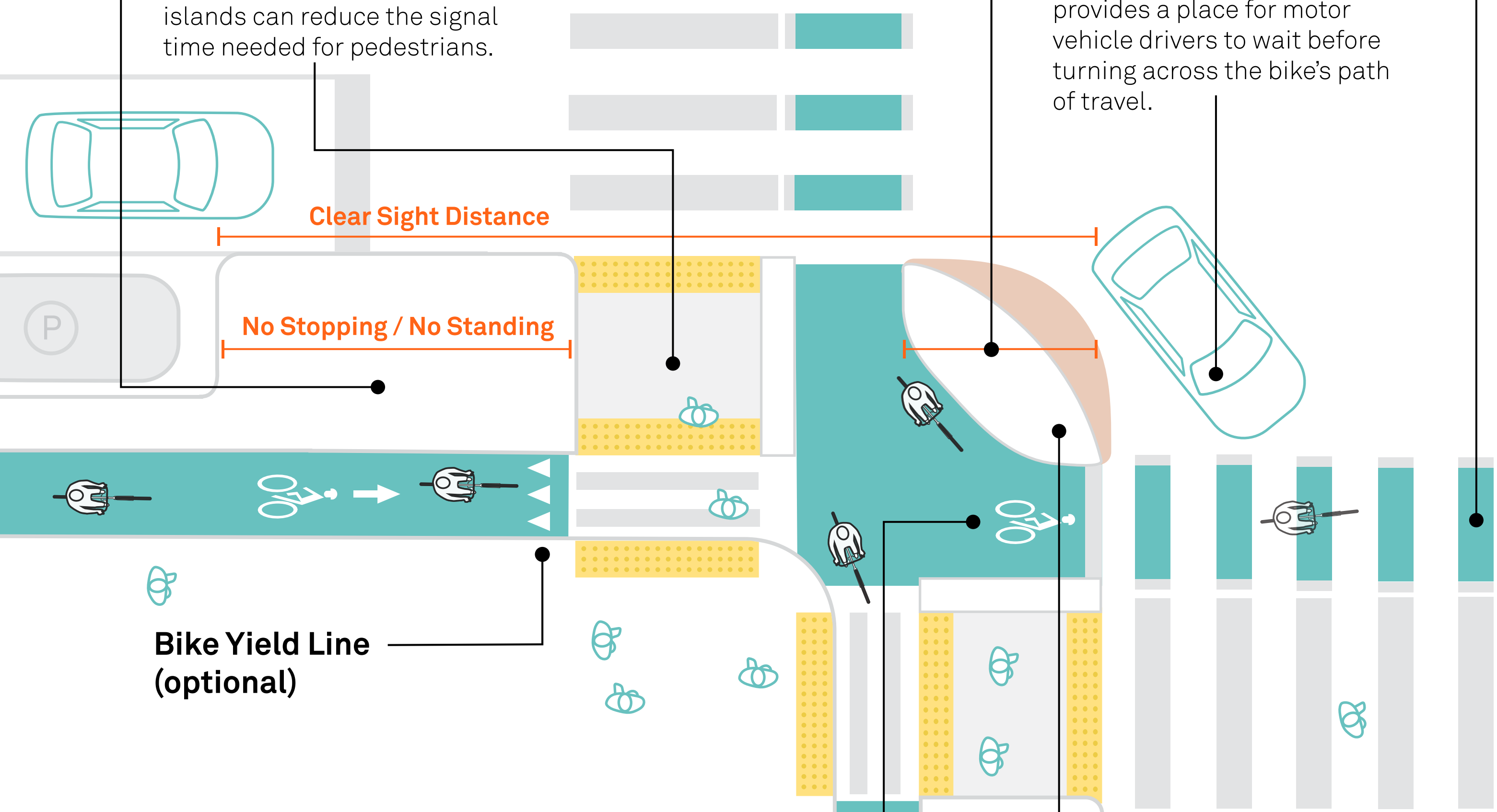
The setback determines how much room will be available for drivers to wait and yield, and the angle at which they cross the bikeway. Larger setbacks provide better visibility and give people bicycling more time to notice and react to turning vehicles.

Crossbikes / Intersection Crossing Markings

Markings provide conspicuity and directional guidance to bikes in the intersection. They are marked with dotted bicycle lane line extensions and may be supplemented with green color or bike symbols between these lines.[11]

Motorist Waiting Zone

The space between the motor vehicle lane and the crossbike provides a place for motor vehicle drivers to wait before turning across the bike's path of travel.



Bike Yield Line (optional)

Bike Queue Area

People biking can wait ahead of the crosswalk for a green signal or a gap in traffic. This shortens crossing distances, and accommodates the natural positioning of people biking.

Bike detection optional

Corner Island

A corner island separates bikes from motor vehicles, prevents motor vehicles from encroaching on the bikeway, and creates a protected queuing area for people on bikes waiting to turn.

Implementation Guidance

Bikeway Setback: The bikeway setback distance determines most other dimensions of the protected intersection. A 10' setback, created in the shadow of the parking/loading lane, is shown. Where practical, a setback of 14-20' is preferred. If setbacks smaller than 12' are used, they should be accompanied by longer clear distances, and additional signal phasing or speed reduction strategies should be considered. Setbacks larger than 20' may increase turn speeds, and setbacks larger than 25' should be treated as a separate intersection.

Corner Island: Radii should be small enough that passenger cars are discouraged from turning faster than 10 mph.[12] This is accomplished with an effective turn radius of less than 18', usually resulting from a 10' to 15' curb radius. Corner islands may have a mountable override area to accommodate large vehicles. Corner islands may also be implemented as channelization markings that are reinforced by mountable vertical elements such as modular speed bumps.

Pedestrian Islands: Wider islands support high volumes of people walking and biking, raising the person-capacity of the intersection. To serve as an accessible waiting area, the minimum width of a pedestrian island is 6'.[13] The desired minimum width is 8'. If 6' or wider, detectable warning surfaces must be placed at both sides of the island to distinguish the bikeway from the sidewalk, and the island from the bikeway.

No Stopping/No Standing Zones: Zones should be long enough to allow approaching drivers and bike riders to see and recognize one another ahead of the intersection. Many cities already designate 20'-30' of curb before an intersection as a no-standing zone to increase visibility. Features that permit visibility, such as plants, seating, bike parking, and shared micromobility stations, can be placed here.[14]

Bike Queue Areas: Queue areas should be large enough for anticipated bicycle volumes, which often increase substantially after implementation of protected bike lanes. The bike queue area should be at least 6.5' deep, but dimensions of 10' or greater are desirable to accommodate trailers, cargo bicycles, and high bike volumes.[15]

Protected Intersections: Applications

Protected intersections can be applied on any street where enhanced bike comfort is desirable. They are most commonly found on streets with parking-protected bike lanes or buffered bike lanes. Variants can be applied where there is no bike facility on the intersecting street, as well as streets with two-way protected bike lanes. Protected intersections can also be implemented using interim materials.

Where no parking lane exists, a setback can be created by shifting the bikeway or motor vehicle lanes away from one another as they approach the intersection.

Accessible Signals: See MUTCD Chapter 4E, PROWAG, other national guidance, and local standards for signal timing and location guidance.

Bike Yield Line & Bike Lane Crosswalk: Bike traffic should be expected to move forward to the stop bar on any signal phase, and pedestrian traffic should also be expected to cross to the island on any phase. This operation may be formalized with optional yield teeth on the bikeway before the crosswalk.[16] The 2009 US MUTCD calls for a "Yield Here to Pedestrian" sign if yield teeth are used. In some jurisdictions, a yield line is not necessary before a crosswalk.

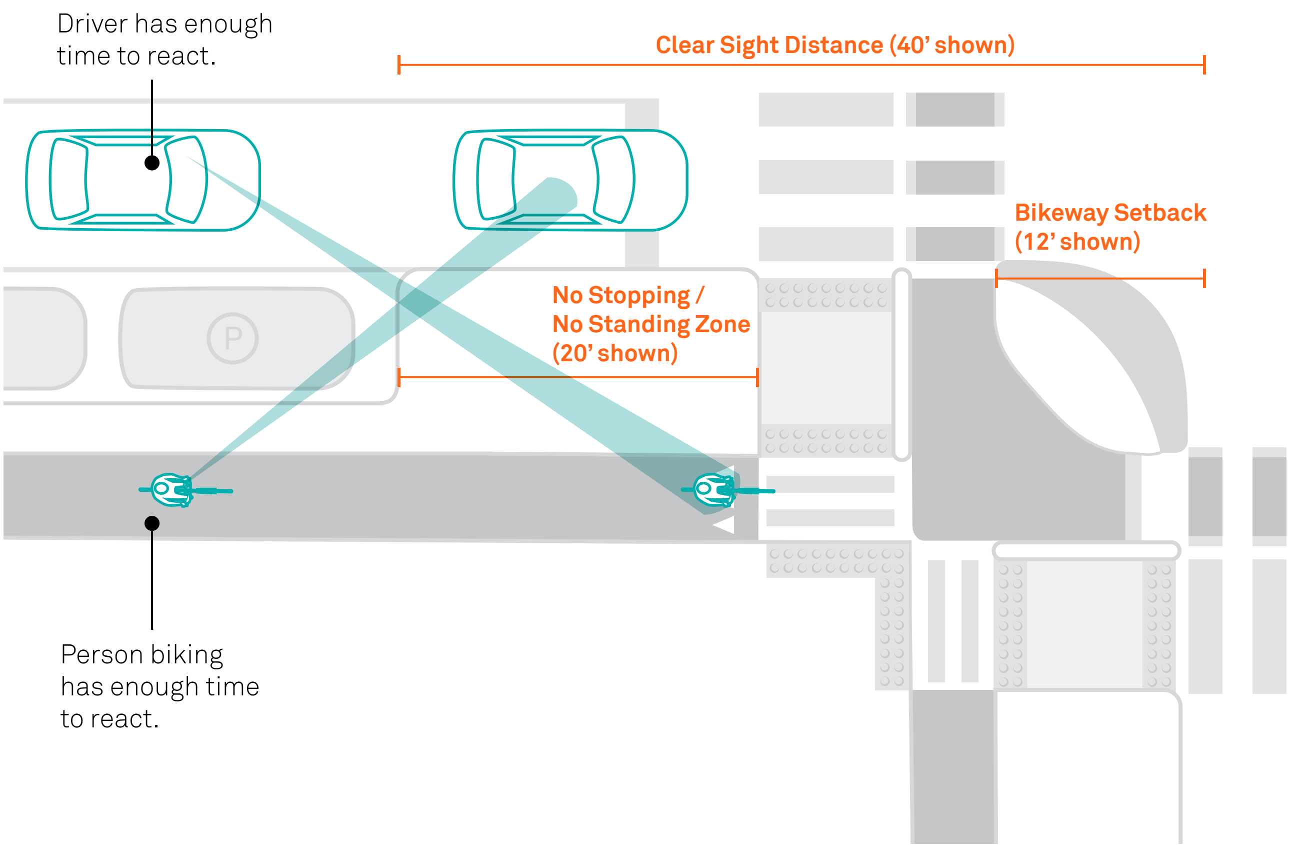
Signs: A modified "Turning Vehicles Yield to Bikes and Pedestrians" sign (R10-15)[17] is recommended where a signalized intersection allows right turns concurrent with bicycle and pedestrian movements. It is required in jurisdictions where state/provincial or local laws are such that pedestrians and bikes do not automatically have the right of way over turning vehicles. The sign should be mounted close to any signal head that regulates vehicles turning across the bikeway and any required location. (This modified sign remains experimental under the 2009 MUTCD.)

Determining Clear Sight Distance

At the approach to a protected intersection, a **clear sight distance** must be provided so that people driving and biking can see one another before the intersection. The **clear sight distance** is calculated by adding the **No Stopping/No Standing Zone,** the **crosswalk** and **crossbike** widths, and the **bikeway setback.**

The length of the **clear sight distance** is determined by the speed at which both cyclists and motor vehicles are traveling. When bike speeds are high, such as at downhills, or when motor vehicle approach speeds exceed 30 mph,[18] or where drivers often proceed through a turn at speeds higher than 10 mph, long **No Stopping/No Standing Zones** are necessary.[19] In these conditions, people using the bikeway need relatively long distances to slow ahead of an intersection if they have been overtaken by a turning vehicle. Shorter sight distances may be applicable where the bike design speed is moderate to low and vehicle turning speeds are very low, such as at small driveways or alleys.

For example, in a protected intersection with a 12' **bikeway setback**, 25 mph traffic, and average bike speeds, the total **clear sight distance** should be at least 40', measured from the front of the last parking space to the point where bikes become exposed to turning vehicles. At this distance, a person on a bike would have approximately 50' or 3 seconds to see a turning vehicle and react.



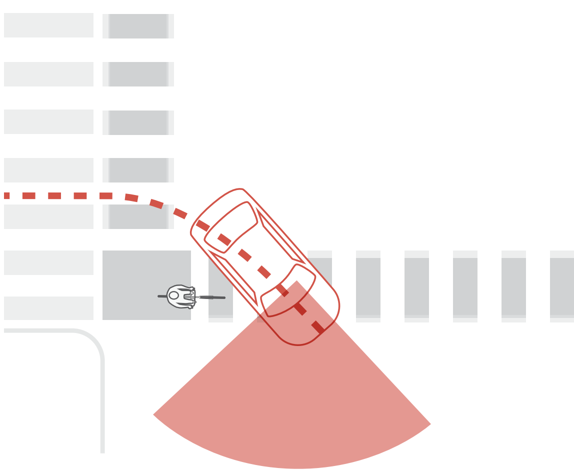
Using Bikeway Setback to Increase Visibility

Protected intersections increase driver visibility of people in the **crossbike** and **crosswalk** by setting back the **crossbike** from the motor vehicle travel lane. The larger the **bikeway setback**, the easier it is for drivers to see people in the bikeway or crossbike without checking mirrors or turning around.

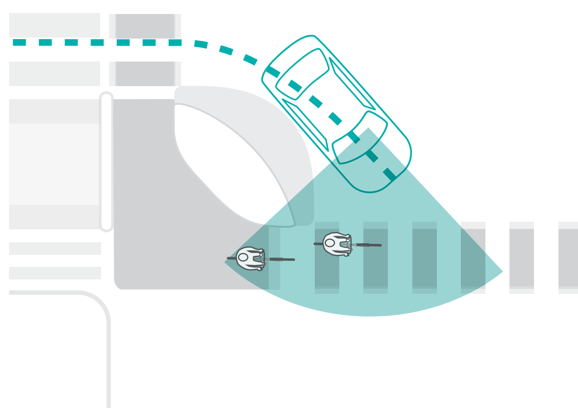
In a conventional bike intersection, the bike spends a long time in the blind spot of an approaching vehicle. Except at the lowest speeds, this sets up an unresolved conflict where bike riders must be prepared for evasive action even though they have the right of way.

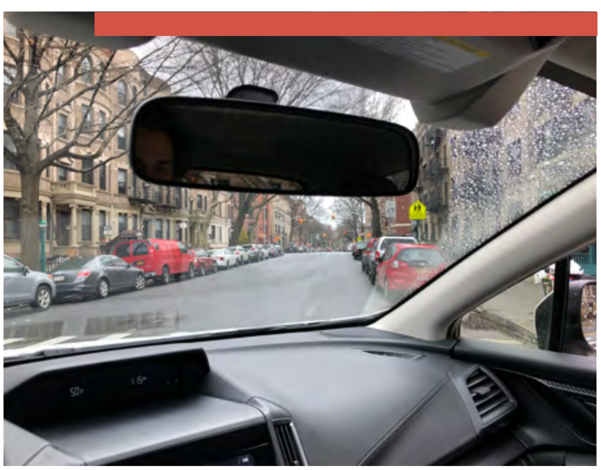
For example, in a protected intersection with the **crossbike** setback approximately 14'-16' from the motor vehicle lane, a car driver approaches the **crossbike** at an angle above 45 degrees and preferably above 60 degrees. This high angle allows the driver to easily see cyclists and keeps cyclists fully outside of the right-side blind spot on large vehicles. In contrast, in a conventional intersection, turning drivers approach the intersection at a very low angle, and would have to check mirrors and turn almost all the way around to see approaching bicycles.

Conventional Intersection

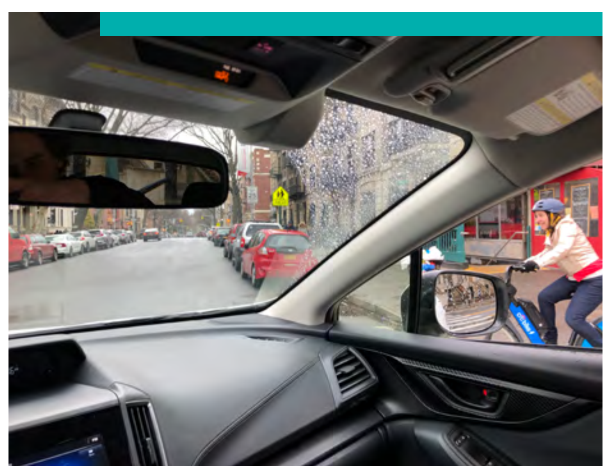


Protected Intersection





At a conventional intersection, the bike rider is hidden from the driver's view as the driver makes the turn.



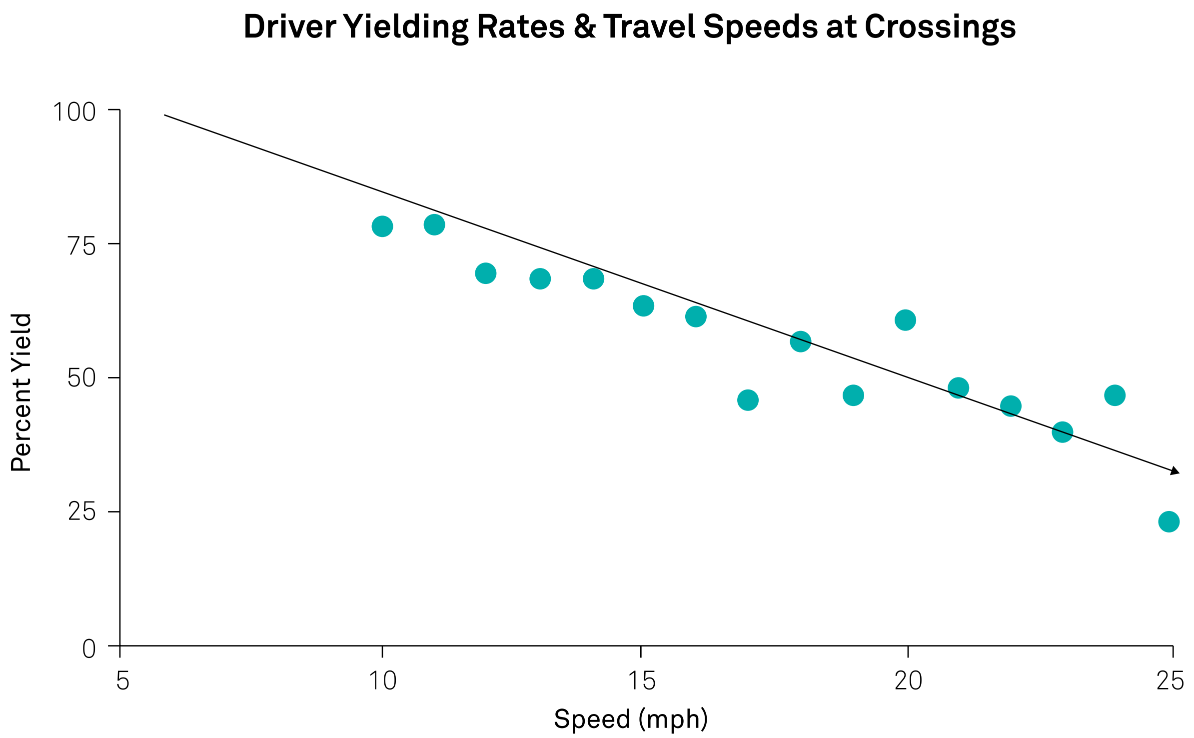
At a protected intersection, the bike lane is set back from the motor vehicle through/turn lane, so the bike rider is visible as the driver turns.

Setting Turn Speeds through Curb Radii

Research shows that driver yield rates decline as speeds increase.[20] As a result, motor vehicle turn speeds should generally be lower than 10 mph in protected intersections.[21] This is achieved by building **corner islands** with small curb radii, typically 10-15' or less, that guide drivers to take the turn at slower speeds.

When the **bikeway setback** is small or when the receiving lane of the turn is wide, a smaller curb radius is recommended. In most cases, the curb radius should not be larger than the setback.

The width of the cross-street receiving the turn also influences turn speed. This width should be kept as low as practical. **Pedestrian islands** or **centerline hardening** may be used to reduce turn speeds. **Pedestrian islands** can also reduce the distance that people biking and walking will be exposed to turning vehicles.

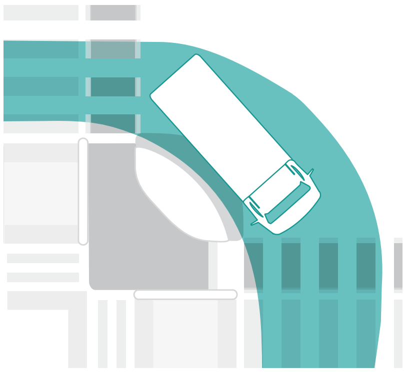


Lower speeds lead to higher driver yielding rates at urban roundabouts. Roundabouts share important geometric features with protected intersections. Graph source: Geruschat, D.R., Driver Behavior in Yielding to Sighted and Blind Pedestrians at Roundabouts. 2005.

Design, Control, & Managed Vehicles

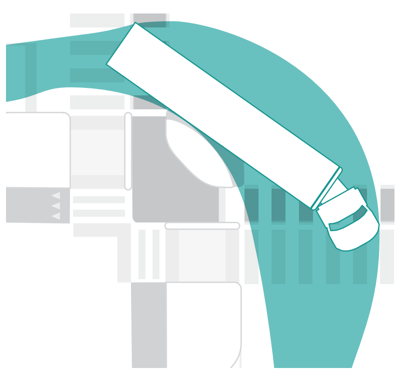
The selection of the Design, Control, and Managed vehicles informs the design of the corner radius at a protected intersection, as well as the need for any vertical features.

Design Vehicle



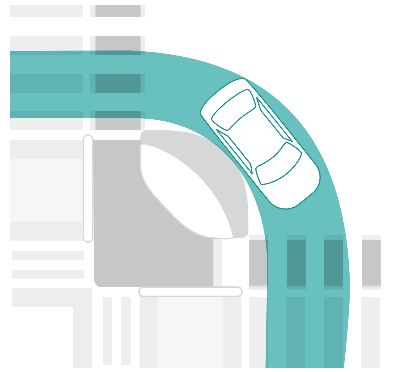
The **Design Vehicle** is the largest typical vehicle that will frequently use the street. For major streets and downtown settings, a DL-23 delivery truck is a typical design vehicle. In protected intersections, it is acceptable for the design vehicle to use all of the first lane, and part of the second lane of the receiving street. In a neighborhood setting, a 15' car/light truck is a typical design vehicle, allowing for a tighter turn radius. In locations where truck turn volumes are high, a single-unit 30'-40' truck is a typical design vehicle. A city bus should be used as a design vehicle only if a scheduled/planned bus route makes that turn. In most cases, this affects only one corner. Turn speeds of 3-5 mph should be used for modeling the design vehicle.

Control Vehicle



The **Control Vehicle** or accommodated vehicle is the largest vehicle that will infrequently use the street. For major streets and downtown settings, a WB-50 truck is a typical control vehicle. In protected intersection designs, this vehicle can make the turn at a very low or 'crawl' speed. It is expected to turn over mountable elements, and may enter the lane adjacent to its lane of origin. In a neighborhood setting, sanitation or fire emergency vehicles are control vehicles. Turn speeds should be set 1-5 mph for the control vehicle. For turn speeds under 5 mph, field testing or observation is recommended as software may be inaccurate at low speeds.

Managed Vehicle

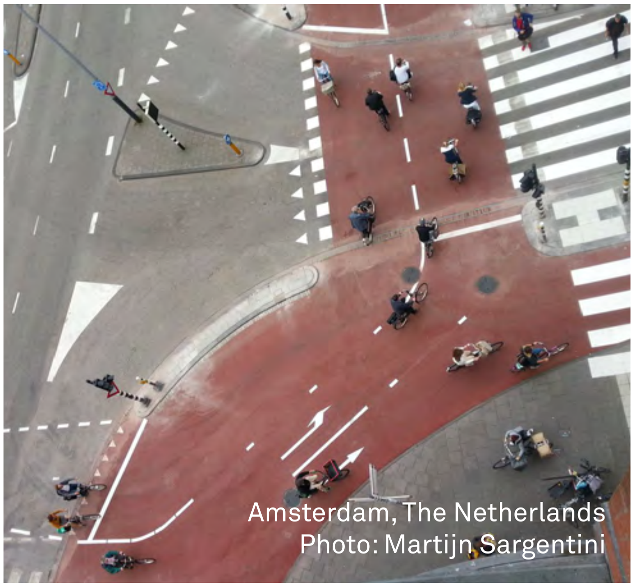


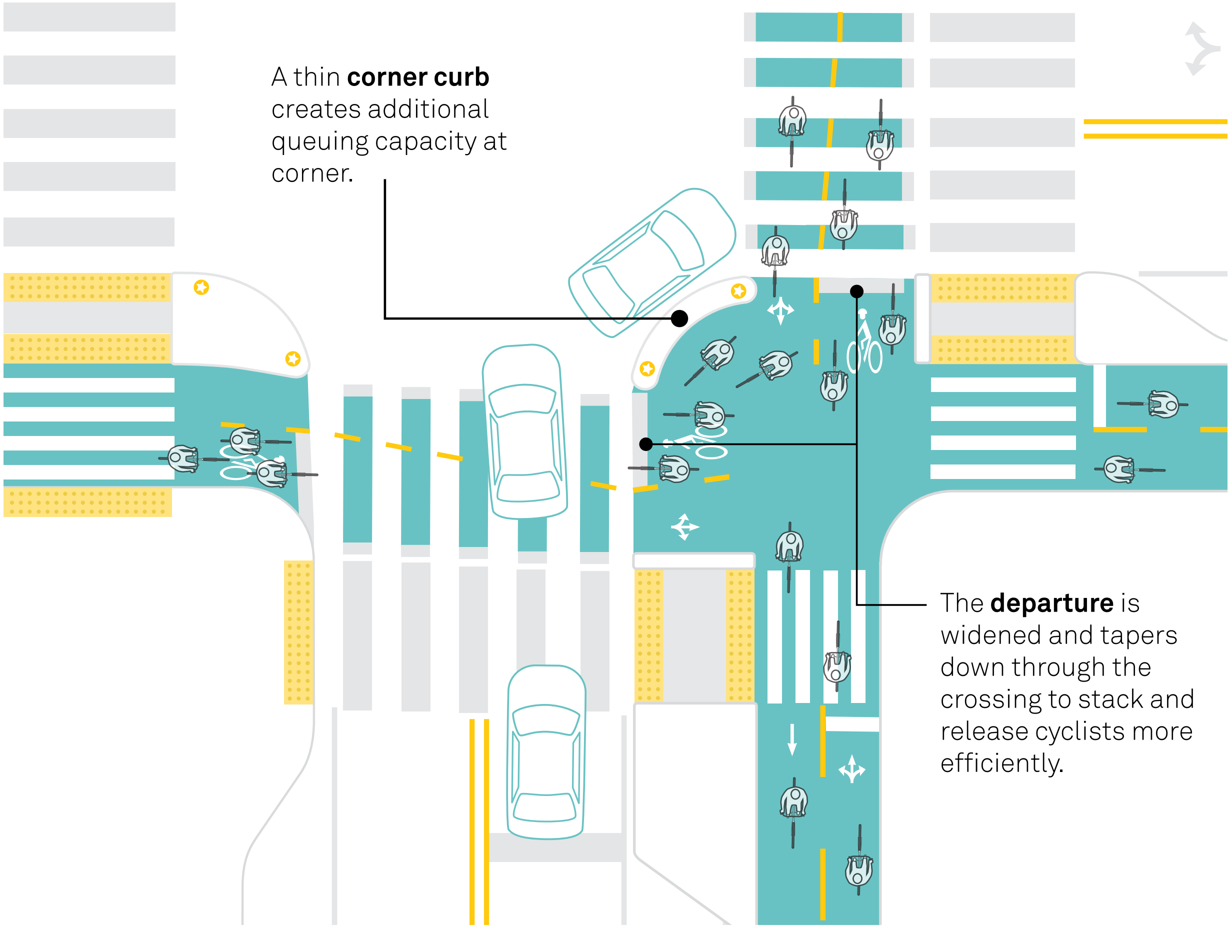
The **Managed Vehicle** is the most common vehicle to use the street. It is typically smaller than the design vehicle which means it is capable of higher, more dangerous speeds. In most urban streets, the managed vehicle is a personal vehicle or taxi. In protected intersections, the goal for a managed vehicle is to keep turn speeds below 10 mph. In some cases, this requires that the design vehicle turns over a mountable element.

Variations

High-Capacity Protected Intersection

At this two-way bikeway intersection, the corner island is thinner than in typical protected intersections. This shape maximizes the available queuing and maneuvering space. To reduce wait times, the crossbike is also wider on the intersection approach than at the receiving side. This configuration allows more riders to wait side-by-side and depart at the same time. Faster riders tend to accelerate through the intersection first, and pass slower riders before reaching the narrower receiving side. As shown in the drawing below, the approaches are 6' wide and the receiving side 4' wide for a total 10' two-way approach.


Amsterdam, The Netherlands
Photo: Martijn Sargentini



Variations

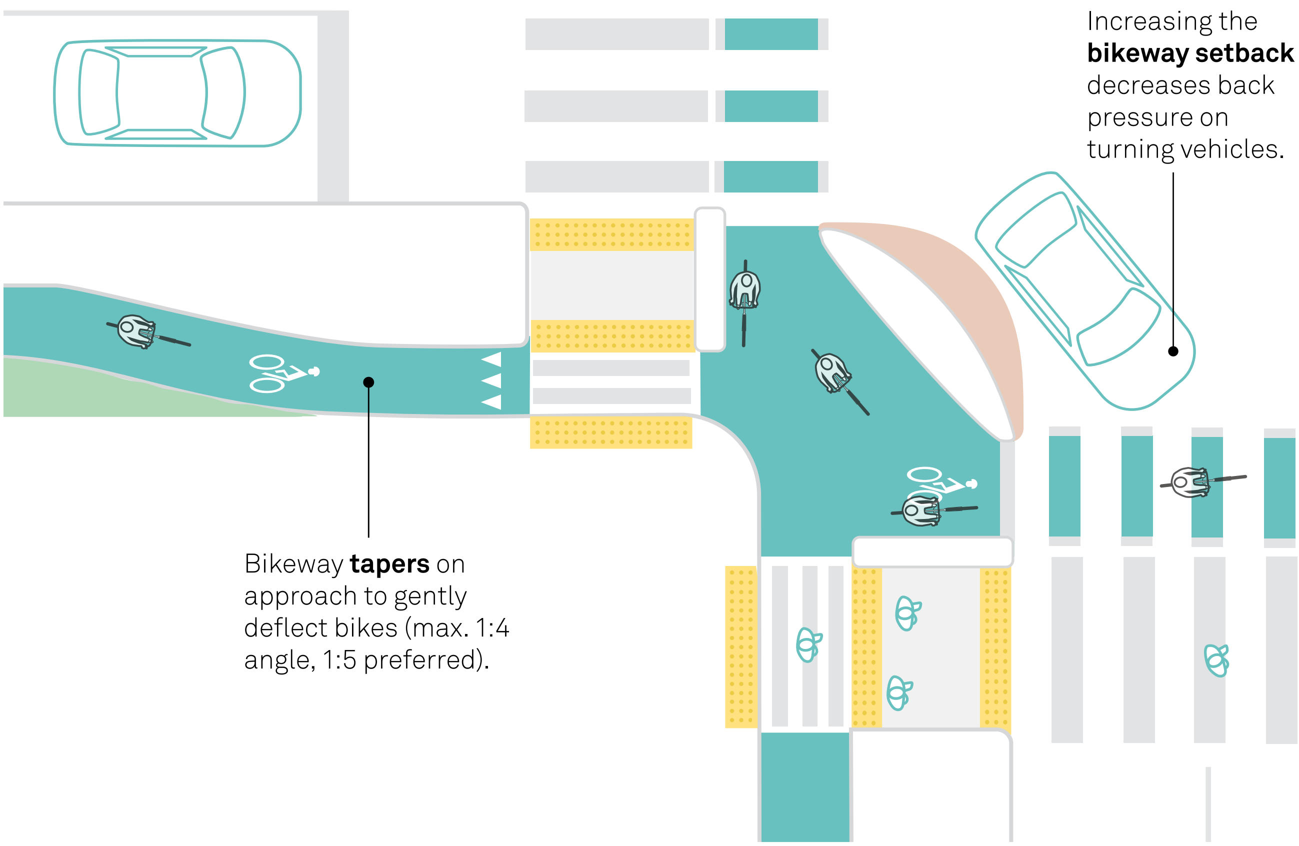
Bend-Out

To set back the bikeway further, the bikeway can be 'bent-out' away from the motor vehicle lanes. This design enhances visibility by raising the angle at which cars cross the bikeway. Increasing the bikeway setback can also provide room for turning cars to wait before making the turn.

As it approaches the intersection, the bikeway can be bent away from the motor vehicle lanes and toward the sidewalk. If the bikeway bends out before the intersection the taper angle should be gradual, typically 1:4 or 1:5, allowing for a smooth transition to the intersection.[22] When possible, the taper should end before the crosswalk to provide good visibility for approaching pedestrians.

The bikeway can also bend out after crossing the crosswalk, and before crossing the motor vehicle lanes.

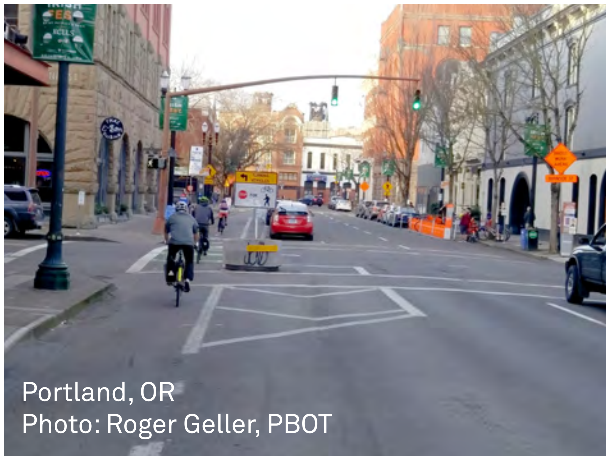

San Francisco, CA
Photo: SFMTA

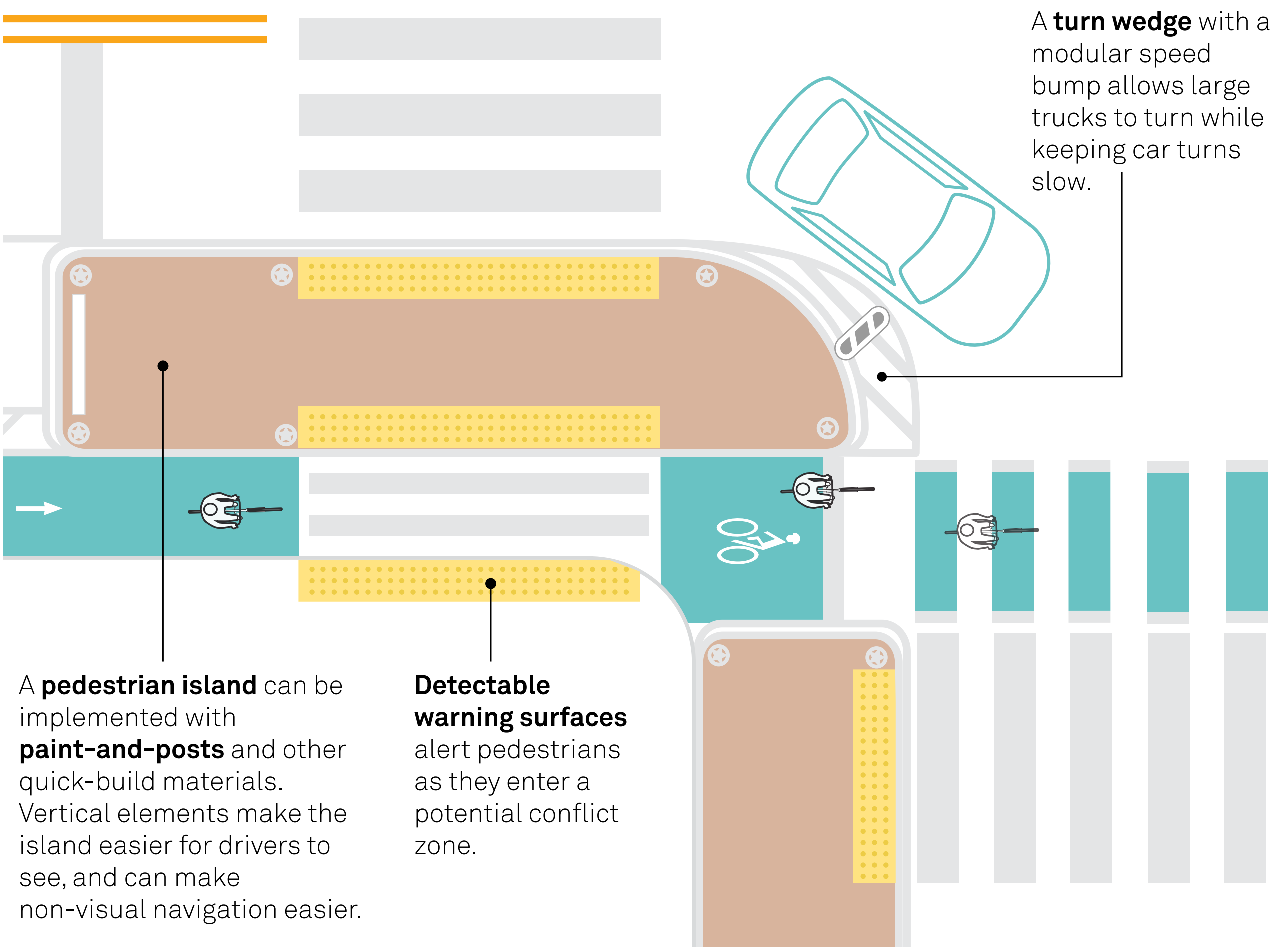


Variations

Interim Materials

Quick-build or interim materials can be used to implement protected intersection designs, even when building a refuge and corner island is not possible. As shown below, a pedestrian safety area is marked between the bikeway and the motor vehicle lane. This area is outlined in a double white line to prohibit motor vehicle crossings, and a pedestrian-friendly color and texture has been applied to this area. Flexible delineators or other vertical devices are used to separate this space from the roadway. Modular speed bumps can be placed at the corner, in lieu of a concrete truck apron.


Portland, OR
Photo: Roger Geller, PBOT



Accessibility for Interim Design

Protected intersections with interim materials often have flush, roadway-level pedestrian areas. These can be made accessible for pedestrians who are blind or have low vision by following either of the following design and regulation options:

- **Interim Island:** Place detectable warning surfaces on each side of the refuge area, as would be done at a raised pedestrian island. This allows pedestrians who are blind to use the intersection the same way other pedestrians do. The interim refuge area should include detectable elements when the pedestrian path changes direction at the refuge area, or if the refuge is so wide that pedestrians might diverge into the bikeway or street, or if other alignment concerns are present.
- **Pedestrian Safety Zone:** Mark the crosswalk all the way through the surface-level pedestrian area. This does not designate the pedestrian area as a refuge or stopping place. In some conditions, this arrangement may be simpler to navigate.

New York, NY
Photo: NACTO

TAMAYO
MODERN MEXICAN CUISINE
CoBiz Fi
Larimer ST 1300
ONE WAY
STARBUCKS COFF
FOURTEENTH ST.

Denver, CO
Photo: NACTO

Dedicated Intersections

People on bikes can be given a dedicated path through the intersection even where there is not enough space for a full bike setback. By providing excellent visibility and low turn speeds, dedicated bikeway intersections provide key improvements over conventional bike lane intersections.

Description

To reduce conflicts between bikes and turning vehicles on busy streets, turn speed reduction techniques and new signal phasing patterns can complement the design of the dedicated bike intersection. These techniques include **corner wedges,** which feature a modular speed bump or similar element over which vehicles are permitted to turn at low speeds. Where the bikeway is on a two-way street or intersects with one, the speed of left turns across the bikeway can be reduced with **centerline hardening** or pedestrian safety islands.

When combined with a **protected-permissive bike signal phasing**, dedicated intersections may have fewer conflicts even than similarly-designed intersections with a fully protected bike signal phase due to higher signal compliance. People riding bikes rate these intersections as intermediate in comfort between protected intersections and conventional bike lane intersections.[23]

Dedicated bike intersections may be more challenging to use than a protected intersection. With a relatively narrow buffer or no buffer, the angle at which turning drivers see pedestrians is lower than at protected intersections, so people on bikes cannot always confirm that a turning driver has recognized them and will remain stopped. In addition, people on bikes do not generally have a queue space within the intersection, and instead wait before the crosswalk, or use a conventional turn queue box to turn across traffic.

Dedicated Intersections

Crosswalk Separator

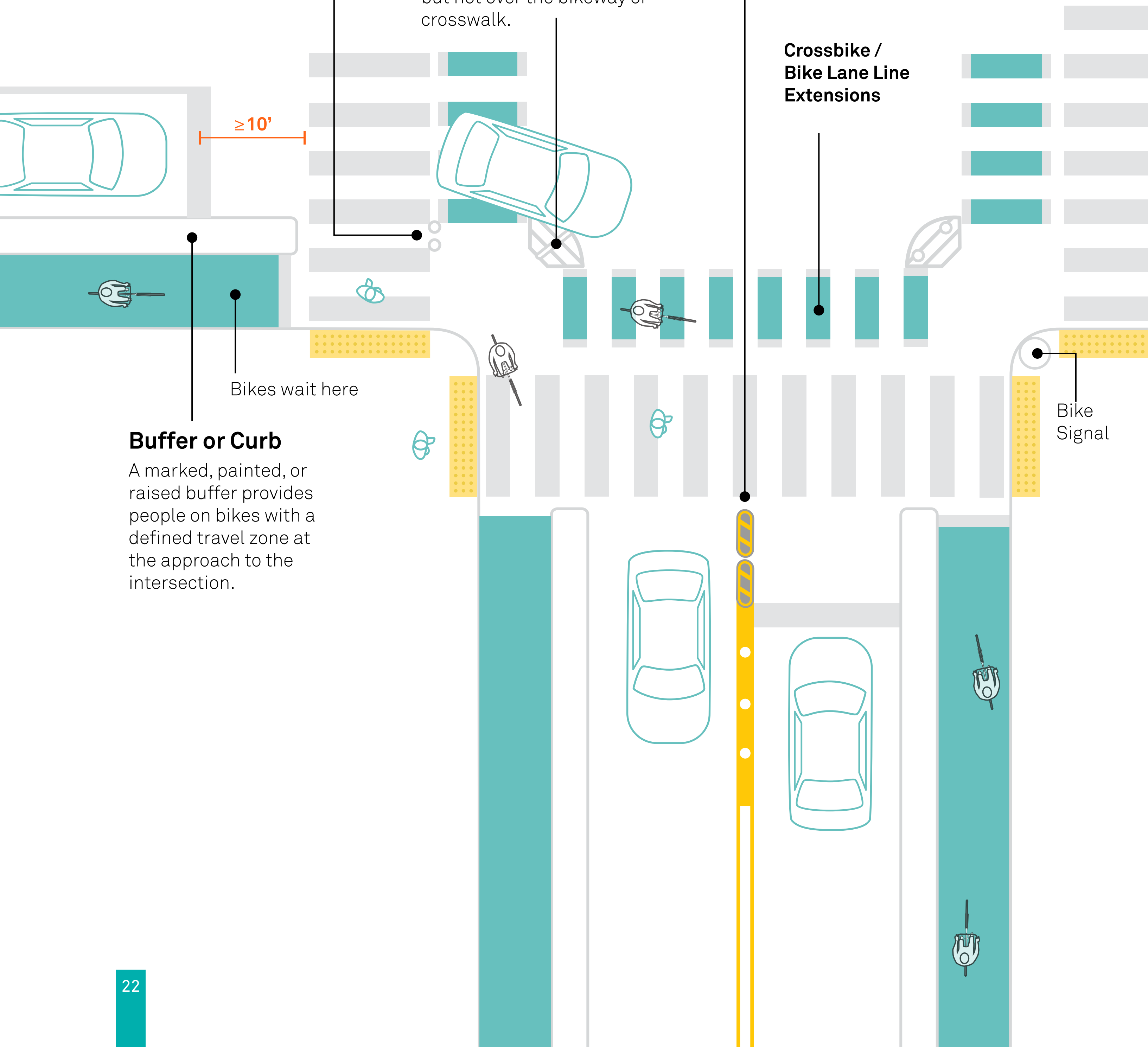
A raised element such as mountable curb or a pair of flexible delineator posts discourages turning vehicles from cutting across the bikeway when turning right.

Corner Wedge & Speed Bump

Speed reduction devices, such as modular speed bumps, help prevent high-speed turns and are expected to improve driver yielding. They can extend over the space used by turning vehicles but not over the bikeway or crosswalk.

Centerline Hardening

Modular curbs with or without vertical delineators reduce the speed of turns across the bikeway and shorten the conflict zone.



Buffer or Curb

A marked, painted, or raised buffer provides people on bikes with a defined travel zone at the approach to the intersection.

Implementation Guidance

Vertical Elements: Vertical elements in the buffer are recommended. The same vertical separation used on the rest of the bikeway can generally be continued until the intersection.

Traversable Separation: In some cases, it is desirable to provide flush or traversable buffers to allow riders to exit the bike lane ahead of the intersection. If high bicycle volume or speeds are anticipated, or if turning drivers are expected to block the bikeway temporarily, it is desirable to provide people on bikes with points where they can exit the lane ahead of the intersection.

The combination of flexibility and separation from motor vehicles can be provided with a marked buffer with flexible delineator posts or other discontinuous, low-impact elements. To reduce interference with street sweeping or snow clearing operations, short raised elements, such as modular speed bumps, should be placed in line with curbs or higher raised elements, such as vertical delineators.

Curbs: Curbs or other hard elements that end at the crosswalk can prevent turning cars from encroaching on the bikeway before the intersection. If built curbs, medians or other continuous vertical elements are used in the buffer, the recommended minimum bikeway width is 6'.

Raised Bike Lanes: Often separated by a mountable curb but no other buffer, raised lanes can also use dedicated intersection geometry. The bike lane can slope down to the grade of the cross-street, or can remain slightly raised to encourage turning vehicles from the main street to yield.

Buffer Markings: Buffers less than 2' wide can be marked as a double white line indicating that crossing is prohibited or a wide single white line indicating that crossing is discouraged. If wider than 2', two pairs of parallel white lines should be marked.[24] Optional color pavement treatments between the white lines contribute to the conspicuity of the buffer, add aesthetic value, and reinforce the walking-friendly nature of the space.

If the buffer is 4' wide or wider, either color pavement or channelization chevrons should be used. If the bikeway buffer is 6' or wider at the intersection, see Protected Intersections.

Dedicated Intersections: Applications

Dedicated intersection geometry should be considered where there is not enough space to set back the bikeway from mixed traffic at the intersection. This condition often arises when a protected bike lane runs close to mixed traffic lanes without a parking or loading lane between them. Even where a bikeway generally has a large buffer, some intersections have high enough motor vehicle turn volumes that a dedicated turn lane is preferred over a protected intersection design. The combination of high turn volumes and low turn speeds are common in high-activity, walkable downtown streets and neighborhood main streets.

Dedicated intersections can be implemented at signalized, stop-controlled, and unsignalized locations, with small geometric variations. Specific design elements, such as turn wedges and centerline hardening, are also applicable to protected intersection designs.

Crossbike / Bike Lane Line Extensions: Broken white lines with dashed green bars should be used across the intersection.

Signals: Using a combination of a leading bike signal phase or interval, and setting back the stop bar for motor vehicles, people on bikes get a head start before cars start turning. A Leading Bike + Pedestrian Interval (LBI) can be provided if a shared through/turn lane is next to the bikeway. If a dedicated right or left turn lane is next to the bikeway, protected-permissive bike signal phasing should be considered.[25] Protected signal phases should be considered if turn volumes from the adjacent lane exceed 120 to 150 vph. Protected signal phases should also be considered if conflicting left turn volumes (on two-way streets) across the bikeway exceed 60 to 90 vph, or if these turns cross multiple traffic lanes.[26]

Signs: A modified "Turning Vehicles Yield to Bikes and Pedestrians" sign (R10-15) is recommended at dedicated intersections.[27] It is required in jurisdictions where pedestrians and bikes do not automatically have the right of way over turning vehicles. The sign should be mounted in accordance with existing location standards. (This modified sign is experimental under the 2009 MUTCD.)

Reducing Turn Speeds and Mitigating Conflicts

Lacking a full bikeway setback, dedicated intersections typically make use of turn speed reduction techniques. Most of these techniques are also applicable on protected and major-minor intersections. Signal strategies and advance stop bars are also applicable in most situations, but geometric speed reduction techniques are often easier to implement. These techniques are applicable whether or not dedicated turn lanes exist adjacent to the bikeway.

Bikeway-Crosswalk Conflicts

- Gradually bend the bikeway (3:1 angle at steepest) as it approaches the crosswalk; straighten before crossing the crosswalk.[28]
- Raise the pedestrian crossing over the bikeway. The bike climbing ramp should be gradual (1:12 or shallower), and a 6' flat approach area should be provided to allow bikes to stop without slipping backward.[29]

Right Turns, and Left Turns from One-Way Streets

- Create a tighter effective corner radius, using mountable elements if necessary to accommodate truck turns.
- Install speed reduction devices, such as modular speed bumps or a mountable truck apron, inside the swept path of large vehicles or all vehicles.
- Install a median island or centerline hardening on the receiving street to prevent 'corner cutting.'
- Raise the bikeway crossing.
- Provide a leading bike interval, protected bike phase, or protected-permissive bike phase.

Left Turns from Two-Way Streets

- Install a median refuge island or centerline hardening on approach street and receiving street to prevent 'corner cutting.'
- Raise the bikeway crossing.
- Provide a leading bike interval, lagging left turn phase, or protected bike phase.

San Jose, CA
Photo: Peter Bennett

Variations

Philadelphia, PA
Photo: NACTO

Dedicated Turn Lane

At locations with high volumes of motor vehicle turns, a right turn lane or a left turn lane (on one-way streets) is sometimes implemented next to a protected bike lane. A protected or protected-permissive bike signal phase is recommended.

Paris, France
Photo: NACTO

Bend-In

'Bend-in' approaches can be implemented where pedestrian bulbouts already exist and cannot easily be altered. The bend-in bikeway intersection approach reduces bike speeds, increases visibility between people in the bikeway and people driving, and reduces the likelihood of visual obstructions between people driving and people on bikes. This design is compatible with a variety of signal designs.

Cambridge, MA
Photo : Cara Seiderman

Minor Street Crossings

The point where a bikeway crosses a minor street or driveway is a transition zone between a moderate-speed, signalized traffic environment and a very-low speed street. A well-designed minor-street intersection gives everyone—people driving, biking, and walking—a clear indication that bikes and pedestrians have the priority when crossing the minor street.

In addition, minor intersection redesigns are an opportunity to improve pedestrian safety and access as well. Many major streets have no existing crossing accommodations for pedestrians at minor streets. Minor crossing features, such as compact corners, can also reduce pedestrian crossing distances and increase visibility, creating a safer overall bicyclist and pedestrian environment.

Description

Minor street crossings use **compact corners** and **raised elements** to keep turn speeds low. The raised crosswalk and bikeway indicate to drivers that they are entering a low-speed environment, and must prepare to yield to other users. Traffic control devices, such as signals, are uncommon. Ensuring a clear **approach sightline** is essential to encourage drivers to yield to people in the bikeway or the crosswalk.

On minor street crossings, a number of design features work to keep speeds low. These include **pedestrian islands** or bulbouts, marked pedestrian safety zones, planters, in-street bike parking, or bike share stations. As in dedicated intersections, **turn wedges** and/or **hardened centerline** treatments can reduce turn speeds while providing turn flexibility for emergency vehicles and trucks.

Minor Street Crossings

Clear Sight Distance

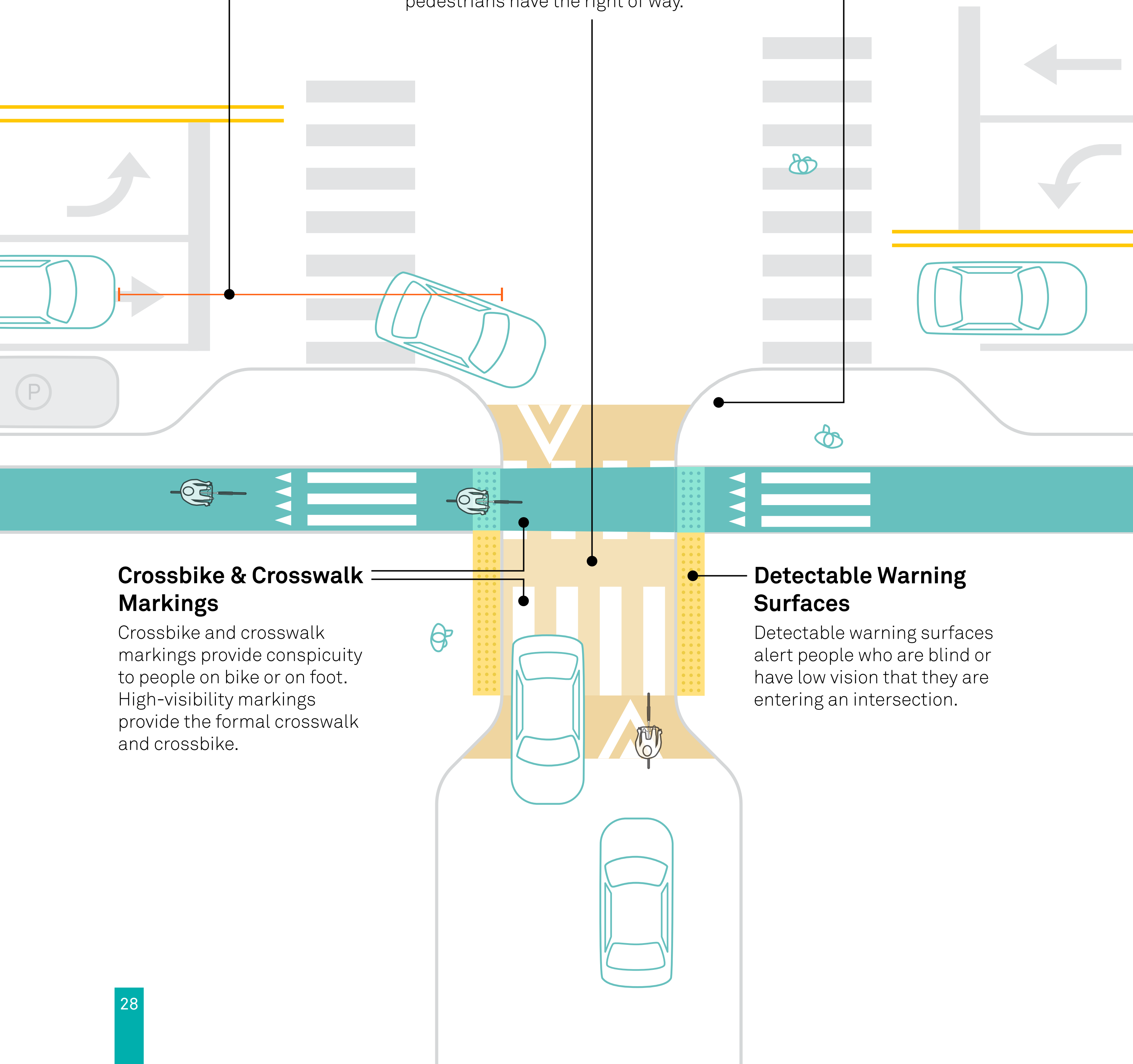
A clear approach sightline gives drivers time to see and yield to people in the crossbike, and gives people on bike or on foot time to see and react to turning cars.

Raised Crossing

Raised crossings improve bicyclists' visibility and reduce the speed at which vehicles turn by bringing the vehicle crossing up to (or near) the sidewalk level. In addition, the raised crossing is a signal to turning cars that through-moving bikes and pedestrians have the right of way.

Compact Corners

Small turn radii force turning drivers to slow down. If there is no raised crossing, the corner radius is the primary method to reduce turn speed.



Crossbike & Crosswalk Markings

Crossbike and crosswalk markings provide conspicuity to people on bike or on foot. High-visibility markings provide the formal crosswalk and crossbike.

Detectable Warning Surfaces

Detectable warning surfaces alert people who are blind or have low vision that they are entering an intersection.

Implementation Guidance

Raised Crossing slopes should be designed for very low speeds. On minor streets that accommodate through traffic, a 5-8% slope is recommended. On alleys and driveways, a slope of up to 15% may be used.[30] When a sharp grade is used, care should be taken to design the top of the raised crossing smoothly enough that the control vehicle can climb and descend at a low speed (<5 mph) without bottoming out. If large vehicles such as buses routinely use the ramp, a sinusoidal shape should be used for the vehicle ramp and crossing.[31]

The sidewalk and bikeway may gradually slope downward to meet the raised crossing as they approach the intersection. These slopes should be 1:24 or gentler in most cases. Even an ADA-compliant slope (1:12), can jolt riders on a bike, in a wheelchair, or using other mobility devices. If necessary, the entire roadbed can be slanted gradually up when approaching the minor-street intersection, generally at no more than a 1:20 slope.[32]

Compact Corner radius should be designed based on the effective turning radius, which is typically larger than the curb radius itself since vehicles rarely turn from a position exactly at the curb.

Minor Street Crossings: Applications

Raised bikeway crossings should be considered where bikeways cross minor streets, neighborhood streets, driveways, and other small streets. Where the bikeway is not signalized, such as at uncontrolled or stop-on-minor intersections, the raised crossing provides unambiguous priority to bikes in the intersection.

Detectable Warning Surfaces should be placed across the transition between the sidewalk and the crosswalk, and may extend across the bikeway. Green or another contrasting color may be used across the bikeway to support people with low vision in distinguishing between the crossbike and the crosswalk.

Clear Sight Distance is determined by the desired bicycle approach speed.[33]

Particularly where there is no raised crossing, green bike intersection markings should be used in the **crossbike.** Provide detectable warning surfaces across the entire raised crossing unless local guidance indicates that it should be limited to the crosswalk entrance.

New York, NY
Photo: NACTO

Signal Phasing Strategy

Signal phasing strategies are a core tool for better intersection design. This section provides signal phasing options for protected and dedicated bike intersections, with an emphasis on mitigating conflicts between motor vehicle and bicycle movements. It supplements, and in some cases updates, the NACTO ***Urban Bikeway Design Guide***'s recommendations for bicycle signals. The following phasing options reflect the recent experience of North American cities and should be adapted to local standards and practices.

Trade-offs between comfort and convenience are present in all signal operations. Motor vehicle turning movements consume a large amount of time and space at intersections. At the same time, many riders express a comfort preference for protected bicycle signal phases, with fully separate motor vehicle turn phases. However, in some cases, fully separated phases may result in longer wait times for both bike and automobile travel, reducing perceived convenience.

Setting signal progressions to bike-friendly speeds can reduce bicycle delay caused by a separate turn movement, while supporting bus transit reliability and disincentivizing speeding. At some intersections, it is more effective to provide flexibility to people walking and biking, allowing them to proceed even after motor vehicles begin to turn across the bikeway. This operation is represented by leading bike intervals and protected-permissive bike signals.

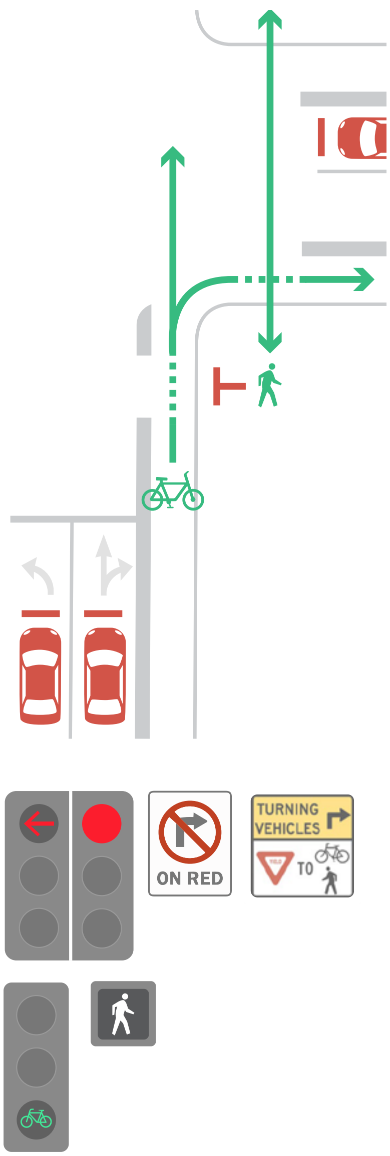
The relative risks and efficiencies among these options are important considerations for the practitioner. Intersection and corridor signal timing analysis, the existing risks and issues at an intersection, and an understanding of how people using the street will respond to signals are all important factors in bike intersection operations decisions.

Leading Bike Interval (LBI) & Lagging Left Turn

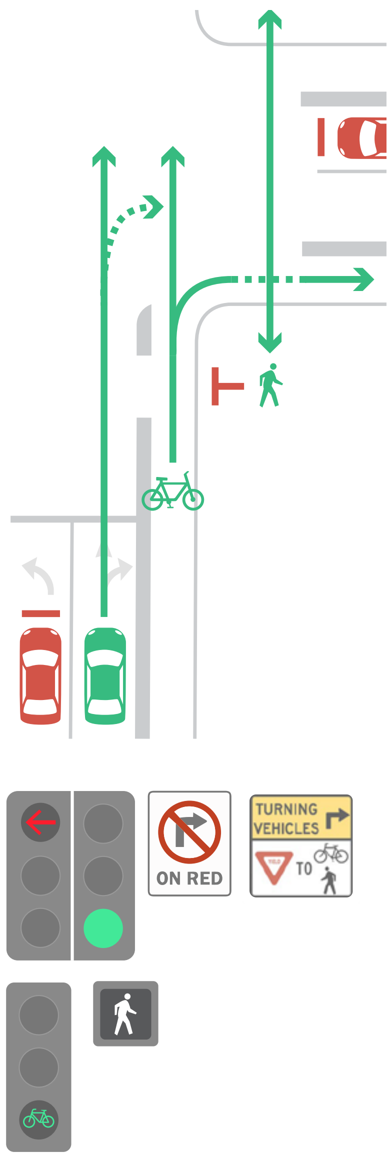
A leading bike interval gives people on bikes a head start in front of turning vehicles, providing a priority position in the right of way. The leading pedestrian interval (LPI), which can accompany the LBI, is a proven measure to reduce serious crashes and injuries for pedestrians.[34] Bike signal heads or "Bikes Use Pedestrian Signal" plaques may be used to provide LBIs in some jurisdictions. This use of a bike-symbol signal is considered experimental under MUTCD Interim Approval IA-16.22.[35]

On two-way streets with signalized left turns, bike and through/right motor vehicles should generally be given the first phase, with right turns yielding to bikes and pedestrians. Left turns are then accommodated in a dedicated phase after oncoming bikes receive a red signal, to reduce bike-left turn conflicts and pedestrian-left turn conflicts.

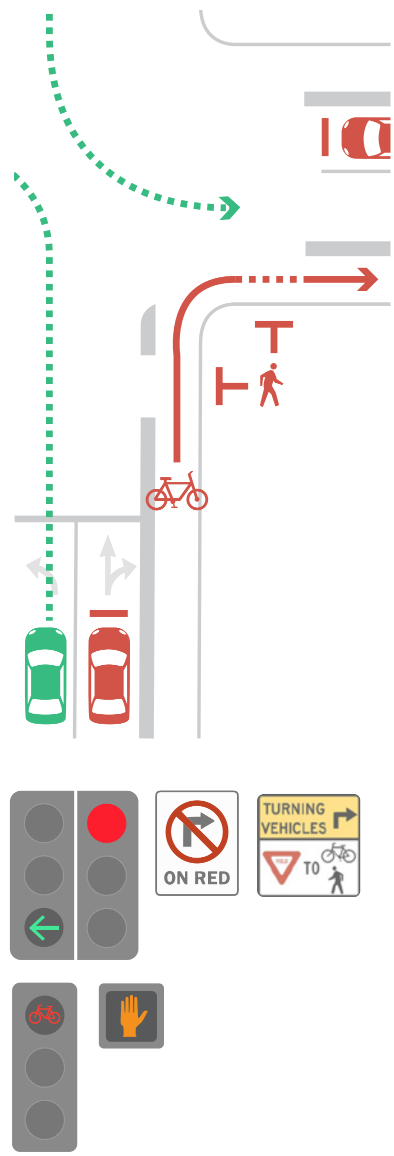
Phase A



Phase B

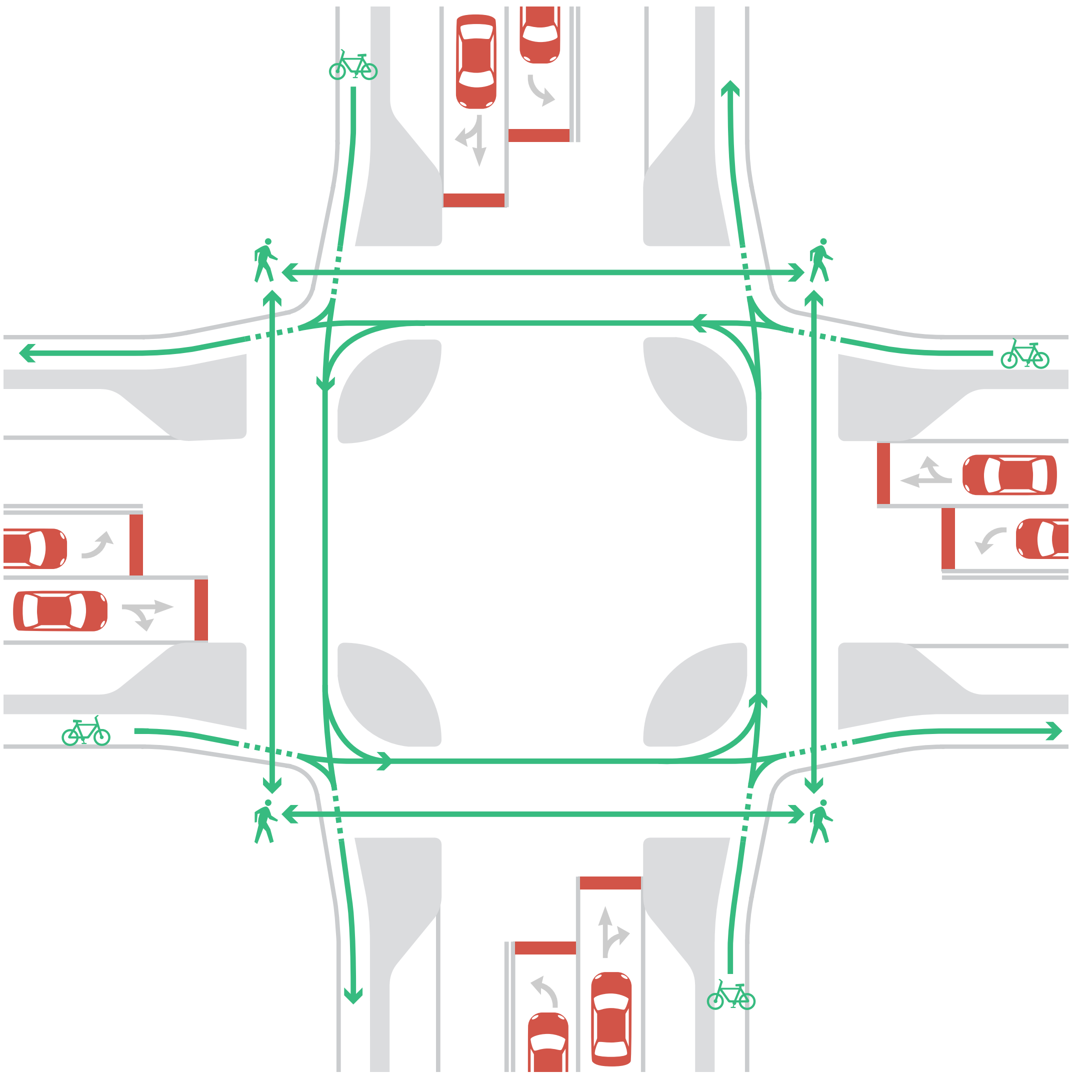


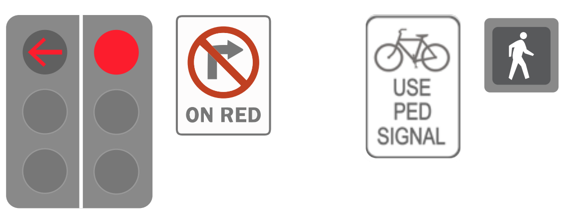
Phase C



Bike Scramble

The bicycle all-cross phasing is an option at high bike-volume locations to allow more time to move through the intersection, especially if diagonal movements are in high demand. The bike scramble is compatible with protected intersections, since the geometric scheme organizes otherwise conflicting right-angle bike movements. It is also useful at other intersections where an LBI might otherwise be used to mitigate motor vehicle turn conflicts, but where bike turn volumes are also high. Pedestrian signals should be placed on the pedestrian island or corner island where practical to avoid signalizing the bike-pedestrian and bike-bike interaction.

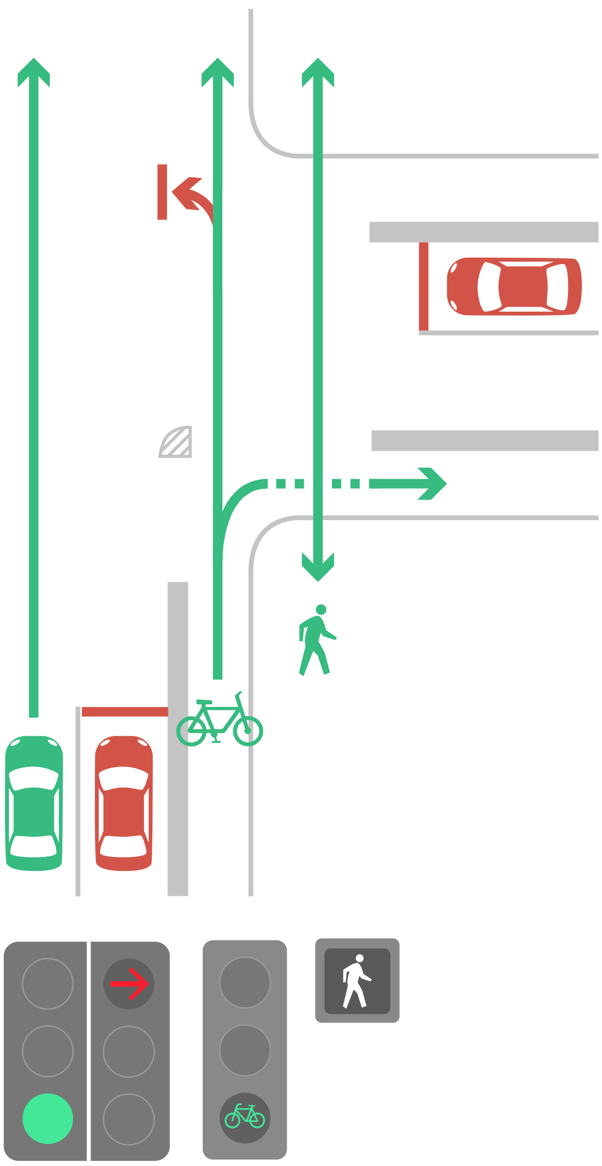




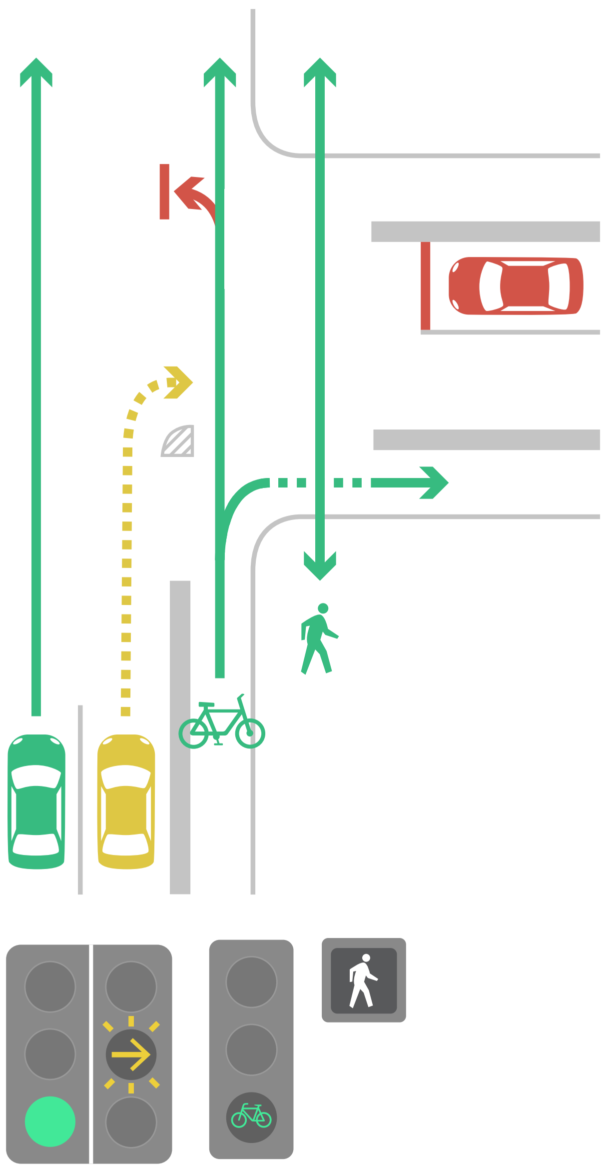
Protected-Permissive Bike Signal

The protected-permissive bike signal, also known as the Split LBI, allows through-moving motor vehicles to start at the same time as parallel bikes. Bike and pedestrian movements continue, as turning motor vehicles receive a flashing yellow arrow turn phase. Protected-permissive signal phasing can reduce the number of conflicts per turning motor vehicle, even compared with full signal protection.[36] Protected-permissive bicycle signal operations allow riders to decide for themselves whether it is safe to go during the motor vehicle phase, or whether to wait for a fresh protected bike phase. Protected-permissive bicycle signals are most applicable on streets where turn volumes are moderate to high and vehicle storage is needed, but prevailing motor vehicle speeds are relatively low, preferably 25 mph or below. This use of a bike-symbol signal is considered experimental under MUTCD Interim Approval IA-16.

Phase A



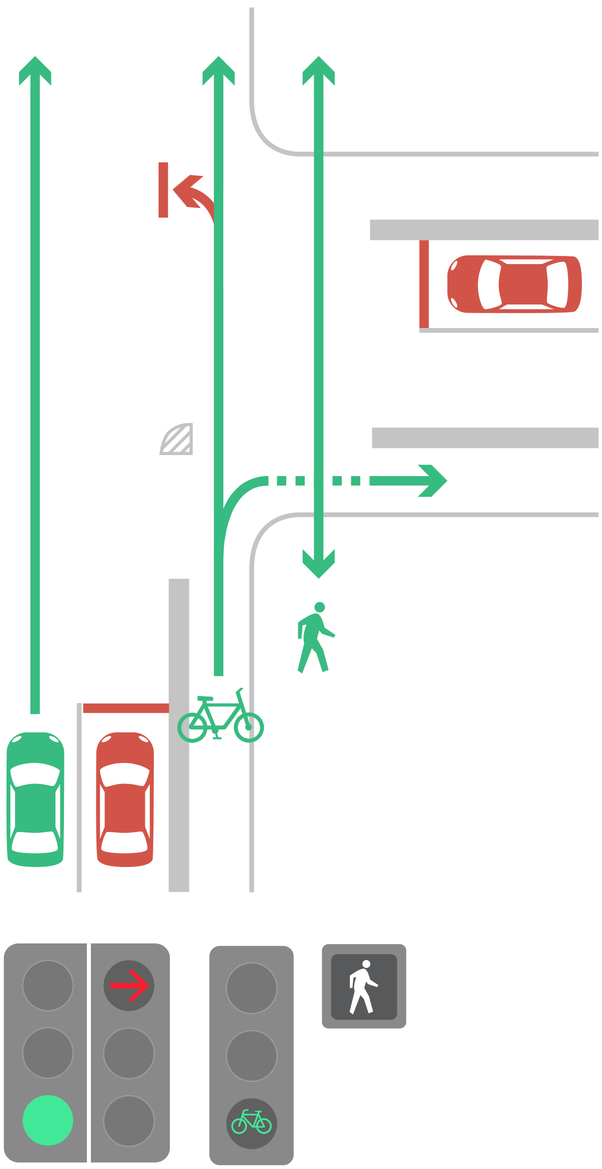
Phase B



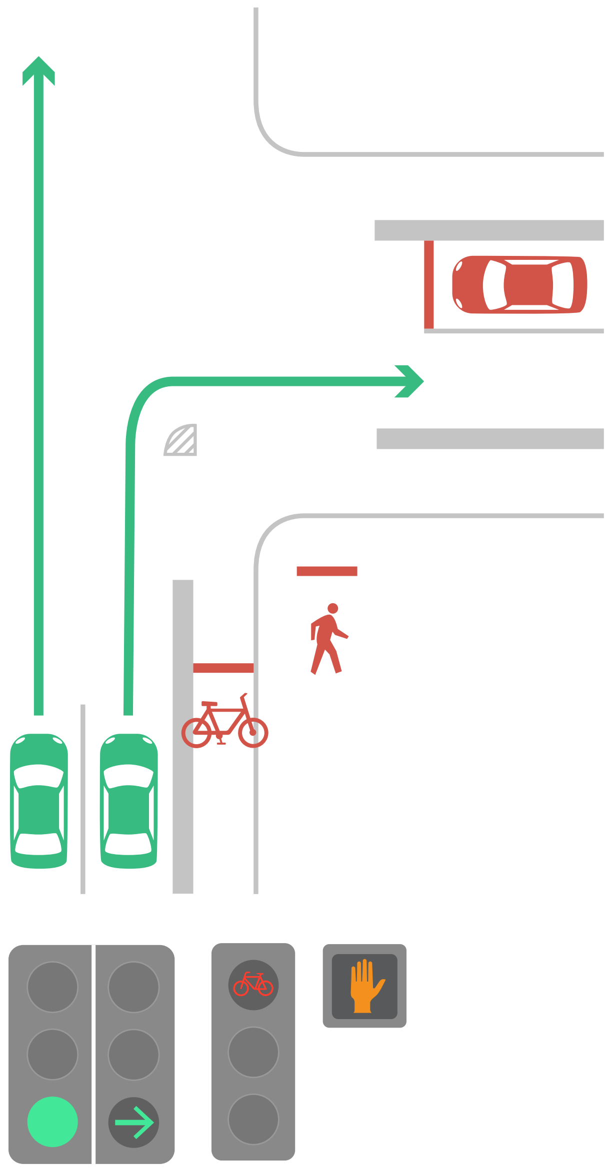
Protected Bike Signal

Fully separate signal phases for bikes and turning vehicles provide a green bike phase and pedestrian Walk phase during a motor vehicle red arrow phase, followed by a motor vehicle turn phase accompanied by a red bike signal.[37] This condition is most applicable at high-volume turn locations (above 150 turns per hour), or where prevailing speeds are 30 mph or higher, where motor vehicle yielding is low, or at locations where multiple lanes turn across a bikeway.[38]

Phase A

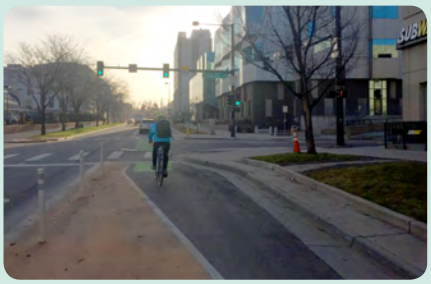


Phase B



Build Toolkit

Implementation of safer crossings can wield a full suite of design tools, from tactical to interim to capital construction. A wide variety of modular, pre-cast, and cast-in-place materials can be used to separate bikeway approaches from motor vehicles. The following suites of materials have been used successfully in North America.



Markings & Color

Directional markings, especially using green color, highlight the "cross-bike" path through the intersection and draw attention to potential conflict zones. Markings are also used to create two-stage turn boxes or bike boxes as storage for bikes waiting to cross, increasing intersection efficiency and comfort.

Low Delineators

Low-to-the-ground objects such as temporary curbs are useful where a long mountable curb is desired but impractical. Angling the elements toward the center of the roadway allows bikes to easily exit the bikeway while dissuading drivers from entering the bikeway.

Quick-build

Paint & Posts

Bollards and other low-vertical elements can be installed to formalize exclusive turning and refuge spaces. They can be implemented relatively quickly and at low cost.

Mountable Rubber Speed Humps

Molded rubber and plastic speed humps are mountable by motor vehicles at low speeds suitable for turns. They are an easy-to-implement speed reduction alternative to raised truck aprons or textured pavement. These off-the-shelf devices can be secured to asphalt or concrete road surfaces.

Example Combination:

- Paint and posts
- Channelization markings and flex posts for buffer
- Modular speed hump for large-vehicle overrun area and/or inside the channelization area to prevent early turns
- Optional: flow-through planters

Bike Parking

Bike parking, street-grade bike corrals, and bike share stations make positive use of the clear zone. Since these features do not block the view of approaching cars and bikes, they can replace automobile parking at the approach.

Surface Concrete

Concrete elements can be implemented for relatively low cost where drainage is not an issue. Concrete refuge islands, extruded curb, and cast-in-place curbing, can often be built by sidewalk or highway repair crews. Pre-cast concrete, including parking stops or specially designed mountable elements, is more expensive but, like other modular elements, can be implemented quickly.

Permanent

Modular Islands & Bulbs

Modular refuge islands and bus boarding islands can be used at bikeway intersections, creating a level accessible boarding platform or simply a protected waiting area between the bikeway and the street.

Full Construction

In larger capital implementations or roadway reconstruction, raised bike lanes and full truck aprons can be built to create a long-lasting addition to the streetscape.

Citations

1. People for Bikes (2019). Inventory of Protected Bike Lanes. Retrieved from https://peopleforbikes.org/green-lane-project/inventory-protected-bike-lanes/
2. NACTO analysis of NHTSA FARS data: Non-Freeway Urban Bike Fatalities (U.S., 2017):
   Intersection or Intersection-Related: 226
   Total Known: 531
   Percent Intersection or Intersection-Related: 43%
3. Fitzpatrick, K. and Schneider W. (2005) Turn speeds and crashed within right-turn lanes (Report No. 0-4365-4). College Station, TX: The Texas A&M University System
4. New York City Department of Transportation (2016, August). Don't Cut Corners:Left Turn Pedestrian and Bicycle Crash Study. Retrieved from: http://www.nyc.gov/html/dot/downloads/pdf/left-turn-pedestrian-and-bicycle-crash-study.pdf
5. New York City Department of Transportation (2018, September). Cycling at a Crossroads: The Design Future of New York City Intersections. https://www1.nyc.gov/html/dot/downloads/pdf/cycling-at-a-crossroads-2018.pdf
6. Monsere, C., McNeil, N., Sanders, R., Wang, Y, Burchfield, R. Schultheiss, W. (2019). Contextual Guidance at Intersections for Protected Bicycle Lanes. (Report No. NITC-PF-987). National Institute for Transportation and Communities (NITC)
7. Madsen, T.K.O., Lahrmann, H, (2017). Comparison of five bicycle facility designs in signalized intersections using traffic conflict studies. Transportation Research Part F: Traffic Psychology and Behaviour. 46(B), pp. 438-450.
8. San Francisco Municipal Transportation Agency (2017). 9th Street/Division Street Protected Intersection Proof-of-Concept Evaluation. Retrieved from:https://www.sfmta.com/sites/default/files/reports-and-documents/2018/03/9th_division_fact_sheet.pdf
9. New York City Department of Transportation (2018, September). Cycling at a Crossroads: The Design Future of New York City Intersections. https://www1.nyc.gov/html/dot/downloads/pdf/cycling-at-a-crossroads-2018.pdf
10. Aldred, Rachel et al (2016). Cycling provision separated from motor traffic: a systematic review exploring whether stated preferences vary by gender and age. Transport Reviews. 37(1), pp. 29–55.
11. Seattle Department of Transportation (2017). Seattle Streets Illustrated. Retrieved from: https:// streetsillustrated.seattle.gov/designstandards/bicycle/bike-intersection-design/ The NACTO Urban Bikeway Design Guide provides further details.
12. Massachusetts Department of Transportation (2015). Separated Bike Lane Planning and Design Guide. Retrieved from: https://www.mass.gov/lists/separated-bike-lane-planning-design-guide
13. United States Access Board (2005). R305.4.1 Length in Public Right of Way Accessibility Guidelines. Retrieved from: https://www.access-board.gov/guidelines-and-standards/streets-sidewalks/public-rights-of-way/background/revised-draft-guidelines/chapter-3
14. Massachusetts Department of Transportation (2015). Separated Bike Lane Planning and Design Guide. Retrieved from: https://www.mass.gov/lists/separated-bike-lane-planning-design-guide
15. Alta Planning + Design (2015, December). Lessons Learned: Evolution of the Protected Intersection. Retrieved from: https://altaplanning.com/wp-content/uploads/Evolution-of-the-Protected-Intersection_ALTA-2015.pdf
16. Alta Planning + Design (2015, December). Lessons Learned: Evolution of the Protected Intersection. Retrieved from: https://altaplanning.com/wp-content/uploads/Evolution-of-the-Protected-Intersection_ALTA-2015.pdf
17. U.S. Department of Transportation Federal Highway Administration (2015, May). Separated Bike Lane Planning And Design Guide. Retrieved from: https://www.fhwa.dot.gov/environment/bicycle_pedestrian/publications/separated_bikelane_pdg/separated-bikelane_pdg.pdf
18. Massachusetts Department of Transportation (2015). Separated Bike Lane Planning and Design Guide. Retrieved from: https://www.mass.gov/lists/separated-bike-lane-planning-design-guide
19. Massachusetts Department of Transportation (2015). Separated Bike Lane Planning and Design Guide. Retrieved from: https://www.mass.gov/lists/separated-bike-lane-planning-design-guide
20. Geruschat, D. R., & Hassan, S. E. (2005). Driver behavior in yielding to sighted and blind pedestrians at roundabouts. Journal of Visual Impairment and Blindness, 99(5), 286-302.

21. Alta Planning + Design (2015, December). Lessons Learned: Evolution of the Protected Intersection. Retrieved from: https://altaplanning.com/wp-content/uploads/Evolution-of-the-Protected-Intersection_ALTA-2015.pdf
22. Massachusetts Department of Transportation (2015). Separated Bike Lane Planning and Design Guide. Retrieved from: https://www.mass.gov/lists/separated-bike-lane-planning-design-guide
23. Monsere, C., McNeil, N., Sanders, R., Wang, Y, Burchfield, R. Schultheiss, W. (2019). Contextual Guidance at Intersections for Protected Bicycle Lanes. (Report No. NITC-PF-987). National Institute for Transportation and Communities (NITC)
24. U.S. Department of Transportation Federal Highway Administration (2009). Manual on Uniform Traffic Control Devices. Retrieved from: https://mutcd.fhwa.dot.gov/pdfs/2009/pdf_index.htm
25. New York City Department of Transportation (2018, September). Cycling at a Crossroads: The Design Future of New York City Intersections. https://www1.nyc.gov/html/dot/downloads/pdf/cycling-at-a-crossroads-2018.pdf
26. Massachusetts Department of Transportation (2015). Separated Bike Lane Planning and Design Guide. Retrieved from: https://www.mass.gov/lists/separated-bike-lane-planning-design-guide
27. U.S. Department of Transportation Federal Highway Administration (2015, May). Separated Bike Lane Planning And Design Guide. Retrieved from: https://www.fhwa.dot.gov/environment/bicycle_pedestrian/publications/separated_bikelane_pdg/separatedbikelane_pdg.pdf
28. Massachusetts Department of Transportation (2015). Separated Bike Lane Planning and Design Guide. Retrieved from: https://www.mass.gov/lists/separated-bike-lane-planning-design-guide
29. Massachusetts Department of Transportation (2015). Separated Bike Lane Planning and Design Guide. Retrieved from: https://www.mass.gov/lists/separated-bike-lane-planning-design-guide
30. Massachusetts Department of Transportation (2015). Separated Bike Lane Planning and Design Guide. Retrieved from: https://www.mass.gov/lists/separated-bike-lane-planning-design-guide
31. Webster D.C., Layfield R.E.(1998, December) Traffic calming - Sinusoidal, 'H' and 'S' humps. Workingham, Berkshire United Kingdom: Transport Research Laboratory
32. Massachusetts Department of Transportation (2015). Separated Bike Lane Planning and Design Guide. Retrieved from: https://www.mass.gov/lists/separated-bike-lane-planning-design-guide
33. Massachusetts Department of Transportation (2015). Separated Bike Lane Planning and Design Guide. Retrieved from: https://www.mass.gov/lists/separated-bike-lane-planning-design-guide
34. Van Houten, R., Retting, R., Farmer, C., Houten, J., Field Evaluation of a Leading Pedestrian Interval Signal Phase at Three Urban Intersections. Transportation Research Record: Journal of the Transportation Research Board 1734, 86–92, Washington DC: Transportation Research Board
35. US Department of Transportation Federal Highway Administration (2013). Manual on Uniform Traffic Control Devices: Interim Approval for Optional Use of a Bicycle Signal Face (IA-16). Report No. HOTO-1. Retrieved from: https://mutcd.fhwa.dot.gov/resources/interim_approval/ia16/
36. New York City Department of Transportation (2018, September). Cycling at a Crossroads: The Design Future of New York City Intersections. https://www1.nyc.gov/html/dot/downloads/pdf/cycling-at-a-crossroads-2018.pdf
37. Furth, P., Koonce P., Miao, Y., Peng. F., Littman, M. (2014). Mitigating Right-Turn Conflict with Protected Yet Concurrent Phasing for Cycle Track and Pedestrian Crossings. Transportation Research Record 2438(1), pp. 81- 88.
38. Massachusetts Department of Transportation (2015). Separated Bike Lane Planning and Design Guide. Retrieved from: https://www.mass.gov/lists/separated-bike-lane-planning-design-guide

Additional Resources

Monsere, C., Dill, J., Clifton, K., McNeil, N., (2014) Lessons from the Green Lanes: Evaluating Protected Bike Lanes in the U.S. Portland, OR: Transportation Research and Education Research Center

Harkey, D., Carter, D., Barlow, J., Bentzen, B., (2007) Accessible Pedestrian Signals: A Guide to Best Practices. National Cooperative Highway Research Program Web-Only Document 150, Washington DC: National Cooperative Highway Research Program

Blackburn, L., Zegeer, C., Brookshire, K., (2017) Guide for Improving Pedestrian Safety at Uncontrolled Crossing Locations (Report No. FHWA-SA-17-072) Washington DC: Federal Highway Administration Office of Safety

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