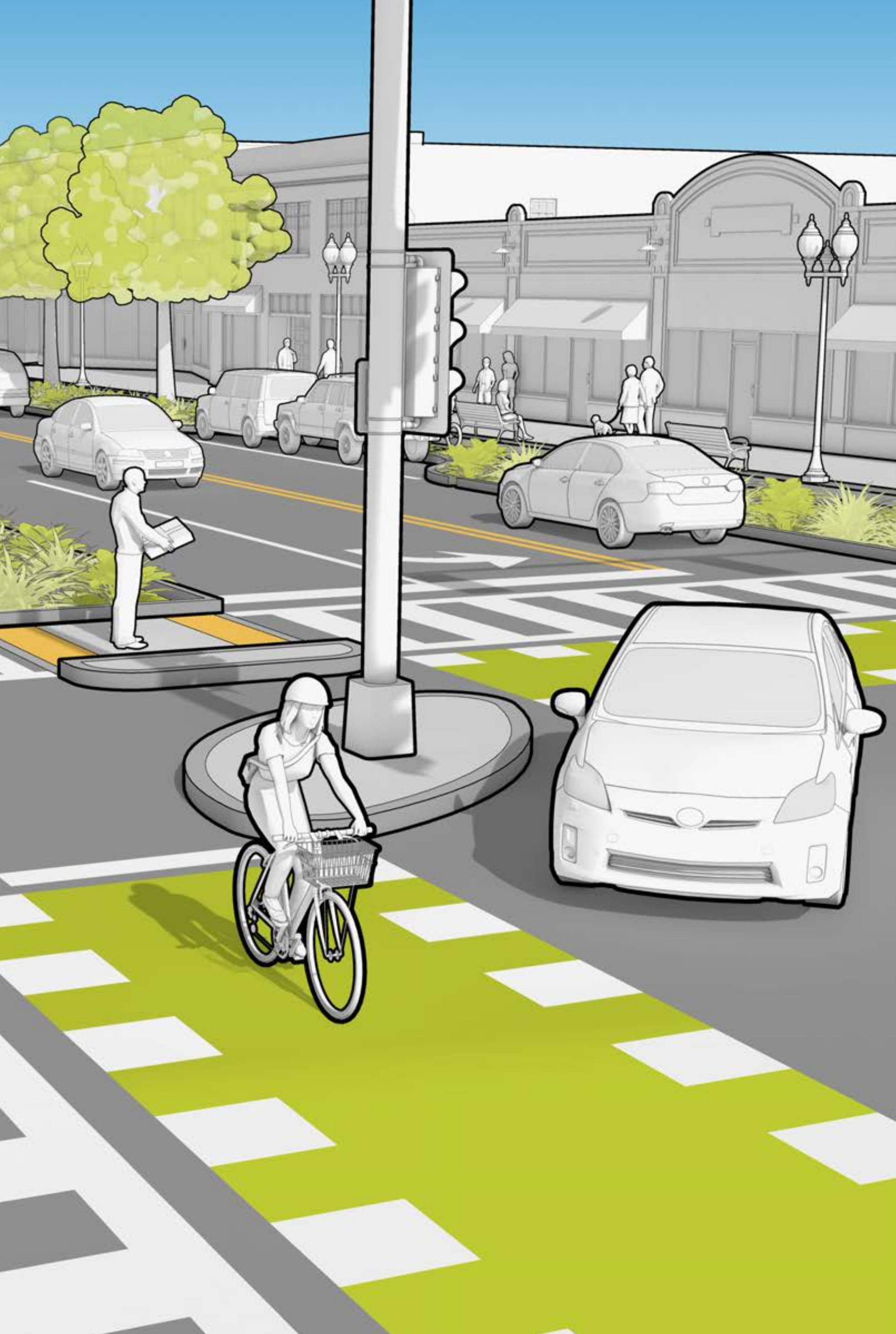


4

INTERSECTION DESIGN

This chapter provides key principles that should be used to develop and evaluate design approaches and treatments that will result in intersections that support all ages and abilities of bicyclists. This chapter illustrates the application of these principles for common intersection configurations which include protected intersections, roundabouts, mixing zones and driveway crossings. Intersection design also requires consideration of parking, loading and bus stops (see **Chapter 5**), and signal operations (see **Chapter 6**).

4.1 CONTEXT

Safe and comfortable intersections minimize delays, reduce conflicts and reduce the risk of injury for all users in the event of a crash. Intersections include not only bicycle crossings of streets, but also crossings with driveways, alleys, sidewalks, shared use paths and other separated bike lanes. Intersections are likely to be locations where bicyclists transition into and out of separated bike lanes to other types of bikeway accommodations. These transitions should be intuitive to all users of the intersection.

The following variables have an impact on intersection design:

VOLUMES

User volumes affect the widths of separated bike lanes and sidewalks, as well as the required number of lanes for motorized traffic.

USER DELAY

A careful balance is needed to minimize delay for all users without favoring one travel mode at the expense of all others.

DESIGN SPEED

Key elements such as sight distance and geometric design at intersections are dependent on the approach speed of the motorist and bicyclist and the crossing speed of a pedestrian. The speed at which motorists merge, weave or turn across a bicyclist's path significantly affects bicyclists' safety and comfort. Intersection geometry and corner radius design affects the merging or turning speed of the motorist.

Bicyclists have operating characteristics that are quite different from pedestrians. The approach speed of a bicyclist operating in a separated bike lane is typically between **10 and 15 mph** on flat ground. This speed can be three to eight times higher than the typical walking speed of a pedestrian entering an intersection, thus additional measures are needed to reduce conflicts between bicyclists and motorists at street crossings.

BIKE LANE OPERATION

The operation of one-way separated bike lanes is similar to normal motor vehicle operations on the street, which can simplify signalized intersection operations. Where a two-way separated bike lane is installed on one side of a street, the contra-flow direction of bicycle travel introduces an unexpected movement at the intersection. The contra-flow movement requires special consideration at intersections and at terminus points.

BUS STOPS

The location of bus stops adjacent to a separated bike lane can potentially introduce conflicts between bus patrons and through-moving bicyclists. The availability of right-of-way and stopping location of the bus (in-lane versus bus bay; as well as near-side, far-side and mid-block stop location) are factors that impact the design of separated bike lanes (see Chapter 5).

TERRAIN

The existing terrain and sight conditions will affect available sight lines and approach speeds of bicyclists and motorists.

ON-STREET PARKING

The presence of on-street parking increases the degree of separation between bicyclists and motor vehicle traffic. This generally improves the comfort of both bicyclist and motorist. However, this will also increase the frequency at which pedestrians have to cross the separated bike lane to access cars in the parking lane. This is a particular concern in areas with high parking turnover. The presence of on-street parking can also reduce sight distances at intersections and driveways; this may require parking restrictions or the removal of parking spaces on the approach to intersections.

LAND USE

Adjacent land uses impact the volume of bicyclists and pedestrians in the corridor. Higher density land uses are likely to have higher volumes of pedestrians and bicyclists with closely spaced intersections and less frequent driveways. Lower-density land uses may have low volumes of pedestrian and bicycle activity but frequent driveway access points for each property and increased distances between street intersections. Separated bike lanes are easier to implement in locations with fewer driveway crossings.

STREET BUFFER

The space available between the motor vehicle travel lane and the separated bike lane affects bicyclist comfort and has a significant impact on geometric design options at intersections.

AVAILABLE RIGHT-OF-WAY

The availability of right-of-way and the placement of utilities may create significant constraints on geometric design options, bike lane widths, buffer widths and sidewalk widths. Where right-of-way is being acquired for roadway projects, sufficient right-of-way should be secured for separated bike lanes.

TYPE OF PROJECT

Reconstruction projects provide the greatest opportunity to achieve preferred design dimensions and intersection treatments. Retrofit projects, which frequently are limited to repaving and restriping, are often constrained by existing street widths.

Copenhagen, Denmark

4.2 DESIGN PRINCIPLES

As separated bike lanes approach an intersection, the designer must determine whether to maintain separation through the intersection or to reintegrate the bicyclist into the street.

Bicycles, pedestrians and motor vehicles inevitably cross paths at intersections (unless their movements are grade separated). Intersections with separated bike lanes should be designed to minimize bicyclist exposure to motorized traffic and should minimize the speed differential at the points where travel movements intersect. The goal is to provide clear messages regarding right of way to all users moving through the intersection in conjunction with geometric features that result in higher compliance where users are expected to yield.

The following principles should be applied to the design of intersections with separated bike lanes to maximize safety and comfort for all users:

1. **MINIMIZE EXPOSURE TO CONFLICTS**
2. **REDUCE SPEEDS AT CONFLICT POINTS**
3. **COMMUNICATE RIGHT-OF-WAY PRIORITY**
4. **PROVIDE ADEQUATE SIGHT DISTANCE**

4.2.1 MINIMIZE EXPOSURE TO CONFLICTS

In urban areas, the majority of crashes between bicyclists and motorists occur at intersections and driveways and are often related to turning or merging movements. **EXHIBIT 4A** provides a comparison of bicyclist exposure at various types of intersections.

While they do occasionally occur, crashes between bicyclists and pedestrians are comparatively rare. It is important to enable pedestrians to see approaching bicyclists at locations where they cross a separated bike lane. Care should be taken to avoid the placement of infrastructure that may block a pedestrian's view of approaching bicyclists.

It is also important to provide clear and direct paths for pedestrians to reduce the likelihood that they use the bike lane as a walkway. For this reason, strategies for accommodating pedestrians on streets with separated bike lanes are provided throughout this guide.

The majority of conflicts and crashes in urban areas between bicyclists and motorists are related to motor vehicle turning movements at intersections. While they do occasionally occur, crashes between bicyclists and pedestrians are comparatively rare.

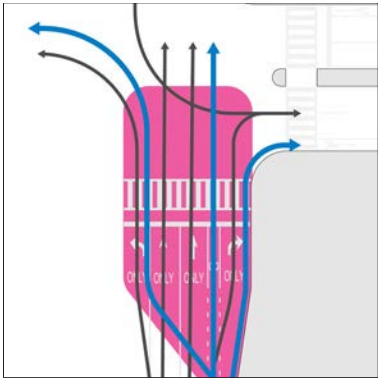
To improve bicyclist comfort and safety, it is preferable to maintain separation within intersections to reduce exposure to merging motor vehicles. Where merging areas, crossings and locations with shared operating spaces are required, they should be designed to minimize exposure. This can be accomplished by:

- **Shortening crossing distance with curb extensions.**
- **Providing two-stage turn queuing areas which allow bicyclists to avoid merging across multiple lanes of traffic during turning movements.**
- **Providing median refuge areas for two-stage crossings.**
- **Providing wider street buffers for bicycle queuing and pedestrian storage to shorten crossing distances.**

EXHIBIT 4A: COMPARISON OF BICYCLIST EXPOSURE AT INTERSECTIONS

The diagrams on this page provide a comparison of the levels of exposure associated with various types of intersection designs.

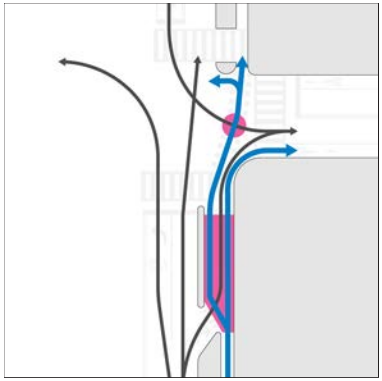
Exposure Level: High



CONVENTIONAL BIKE LANES AND SHARED LANES

Bike lanes and shared lanes require bicyclists to share and negotiate space with motor vehicles as they move through intersections. Motorists have a large advantage in this negotiation as they are driving a vehicle with significantly more mass and are usually operating at a higher speed than bicyclists. This creates a stressful environment for bicyclists, particularly as the speed differential between bicyclists and motorists increases. For these reasons, it is preferable to provide separation through the intersection.

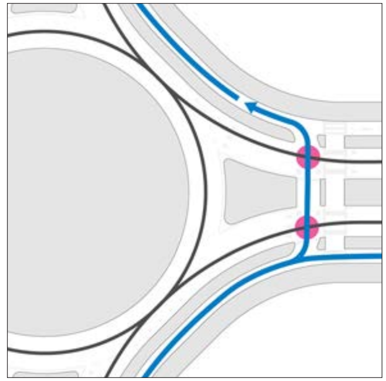
Exposure Level: High to Medium



SEPARATED BIKE LANES WITH MIXING ZONES

One strategy that has been used in the U.S. at constrained intersections on streets with separated bike lanes is to reintroduce the bicyclist into motor vehicle travel lanes (and turn lanes) at intersections, removing the separation between the two modes of travel. This design is less preferable to providing a protected intersection for the same reasons as discussed under conventional bike lanes and shared lanes. Where provided, mixing zones should be designed to reduce motor vehicle speeds and minimize the area of exposure for bicyclists.

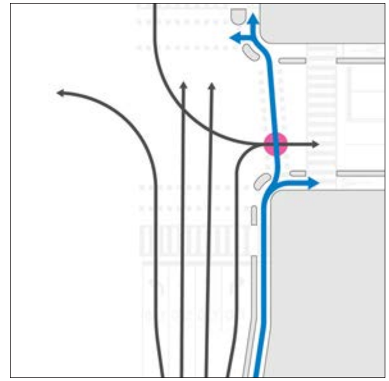
Exposure Level: Medium to Low



SEPARATED BIKE LANES THROUGH ROUNDABOUTS

Separated bike lanes can be continued through roundabouts, with crossings that are similar to, and typically adjacent to, pedestrian crosswalks. Motorists approach the bicycle crossings at a perpendicular angle, maximizing visibility of approaching bicyclists. Bicyclists must travel a more circuitous route if turning left and must cross four separate motor vehicle path approaches. Yielding rates are higher at single-lane roundabouts.[1]

Exposure Level: Low



PROTECTED INTERSECTIONS

A protected intersection maintains the physical separation through the intersection, thereby eliminating the merging and weaving movements inherent in conventional bike lane and shared lane designs. This reduces the conflicts to a single location where turning traffic crosses the bike lane. This single conflict point can be eliminated by providing a separate signal phase for turning traffic

bicycle →
motor vehicle →
conflict area ●

Where conflicts with motor vehicles are more significant due to high traffic volumes, high speed turns across the separated bike lane, or at locations with limited sight distance, steps should be taken to reduce or eliminate conflicts with other strategies, such as restricting turn movements (see Section 4.3.7), providing traffic signal phasing that allows for fully protected bicycle movements (see Section 6.4), or providing grade separation (see Section 4.3.8).

4.2.2 REDUCE SPEEDS AT CONFLICT POINTS

Reducing motor vehicle speeds at intersections improves the motorist's ability to appropriately react to and yield to bicyclists and pedestrians. Slower motor vehicle speeds reduce stopping sight distance requirements and reduce the likelihood of severe injuries and fatalities for bicyclists and pedestrians in the event of a crash.

Intersections with separated bike lanes should be designed to ensure slow-speed turning movements (**10 mph or less**) and weaving movements (**20 mph or less** in the area where weaving movements occur). Mixing zones should be designed to encourage the weaving movement to occur in close proximity to the corner at a location where motorists have slowed their speed in anticipation of the turn so they are more likely to yield to bicyclists (see Section 4.3.3).

MINIMIZE CURB RADIUS

The smallest feasible curb radius should be selected for corner designs based upon the design vehicle's effective turning radius. A small curb radius requires motorists to slow down, which improves yielding and reduces stopping distance requirements. This strategy can also help to increase the size of bicycle and pedestrian queuing areas, thereby enabling greater flexibility in the placement of curb ramps and reducing crossing distances.

Many factors influence corner design, and a flexible approach is necessary depending on the type of street, the number and configuration of travel lanes, and characteristics of the design vehicle. The design vehicle should be selected according to the types of vehicles using the intersection with consideration given to relative volumes and frequencies under normal traffic conditions. Further information on selecting the appropriate design vehicle can be found in Section 6.3.3 of the PD&DG.

At locations where the accommodation of trucks and buses is required, consideration should be given to allowing encroachment into approaching and/or departure lanes to reduce the design curb radius to the minimum (see Section 6.7.2 of the PD&DG). Where encroachment is not desirable a compound curve may be used in place of a simple curve to minimize the effective curb radius to slow turns while still accommodating larger vehicles.

At signalized intersections where additional space is needed to accommodate turning vehicles, consideration can be given to recessing the stop line on the receiving street to enable a large vehicle to use a portion of or the entire width of the receiving roadway (encroaching on the opposing travel lane) as shown in EXHIBIT 4B.

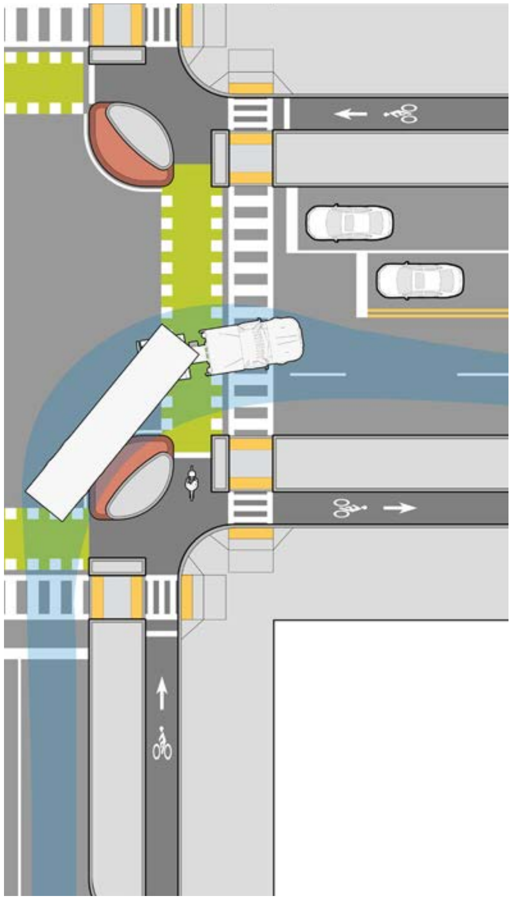


EXHIBIT 4B: Recessed Stop Line for Large Vehicle Turn with Mountable Truck Apron

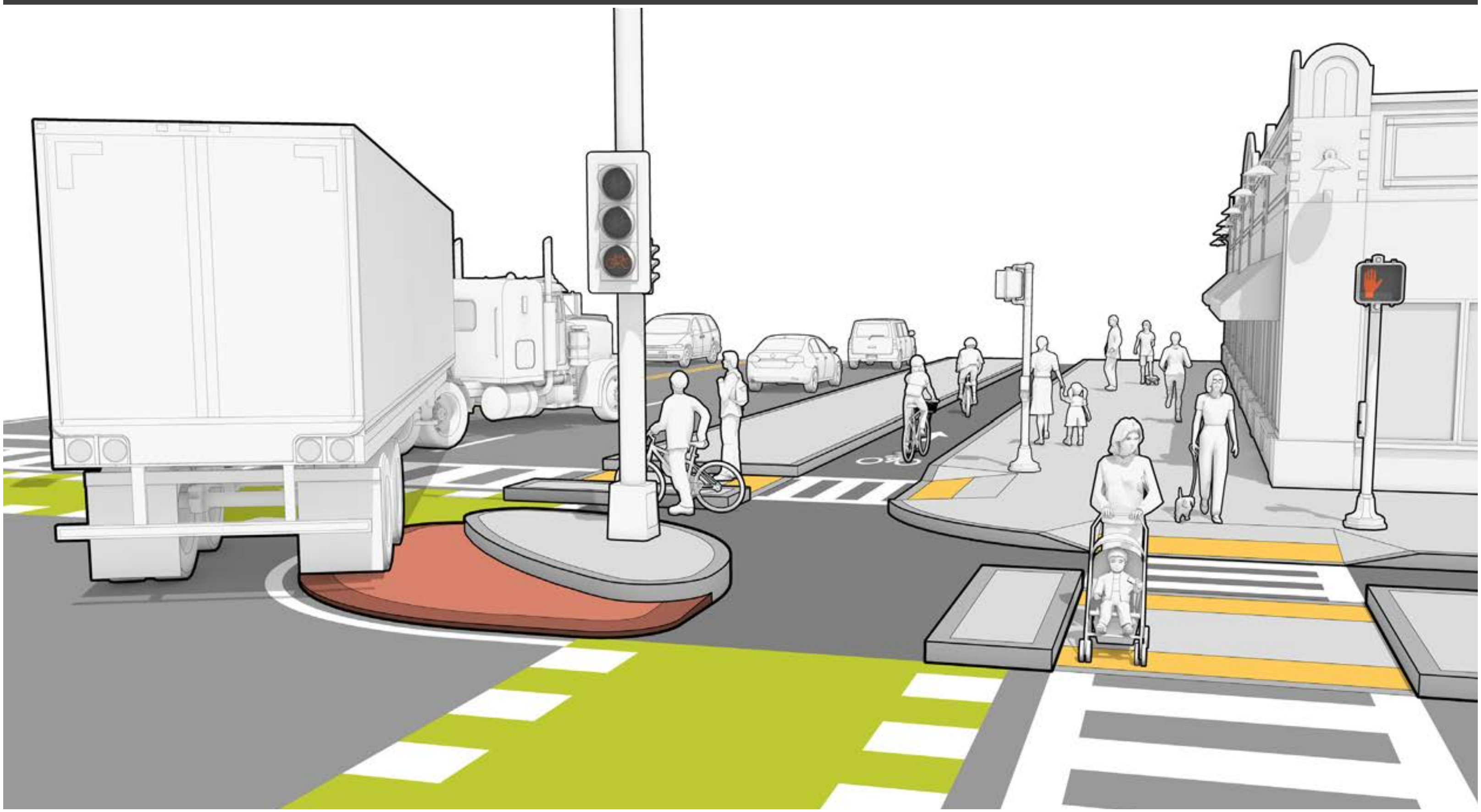
MOUNTABLE TRUCK APRONS

While bicyclist and pedestrian safety is negatively impacted by wide crossings, bicyclists and pedestrians are also at risk if the curb radius is too small. This can result in the rear wheels of a truck tracking over queuing areas at the corner. Maintenance problems are also caused when trucks must regularly drive over street corners to make turns.

Mountable truck aprons are a solution that can reduce turning speeds for passenger vehicles while accommodating the off-tracking of larger vehicles where a larger corner radius is necessary (see **EXHIBIT 4C**).

Mountable truck aprons are part of the traveled way and as such should be designed to discourage pedestrian or bicycle refuge. Bicycle stop bars, detectable warning panels, traffic signal equipment and other intersection features must be located behind the mountable surface area. The mountable surface should be visually distinct from the adjacent travel lane, sidewalk and separated bike lane. The heights of mountable areas and curbs should be a maximum of **3 in.** above the travel lane to accommodate lowboy trailers.

EXHIBIT 4C: MOUNTABLE TRUCK APRON



Delft, Netherlands

RAISED CROSSINGS

Raised crossings are an effective strategy for reducing crashes between motorists and bicyclists because they slow the turning speed of motor vehicles, increase visibility of vulnerable street users, and increase yielding behavior of motorists.[2,3,4] Raised crossings should be considered for separated bike lane crossings where motorists are required to yield the right-of-way to bicyclists while turning or crossing. Examples where this treatment may be particularly beneficial are at the following types of crossings:

- **Collector and local street crossings (see Section 16.3 of the PD&DG).**
- **Crossings of driveways and alleys.**
- **Crossings of channelized right turn lanes and roundabouts.**
- **Intersections where a large corner radius is required to accommodate heavy vehicles.**

Raised crossings are usually appropriate only on minor road crossings. Raised crossings across an arterial roadway require a design exception.

Raised crossings should have the following design characteristics (see EXHIBIT 4D, EXHIBIT 4E, and EXHIBIT 4F):

- They should be elevated **4-6 in.** above the street.
- Motor vehicle approach ramps should be sloped as follows:
  - Streets: 5-8 percent slope
  - Driveways and alleys: 5-15 percent slope
- Yield lines or speed hump markings should be used on uncontrolled motor vehicle approaches.
- The surface materials, color and texture of the separated bike lane and adjacent sidewalk should extend through the crossing, maintaining visual continuity to encourage motorists to yield at the crossing.
- Intersection design must meet the accessibility requirements of the **Americans with Disabilities Act (ADA)** and the **Massachusetts Architectural Access Board (MAAB)**. Special attention should be given to ensuring people with vision impairments are given sufficient cues at intersections to prevent them from unintentionally moving into the street.

See Section 4.4 for additional traffic control considerations.

Where the bike lane is not at the same elevation as the raised crossing, it is necessary to provide transition ramps for bicyclists. The ramp should provide a smooth vertical transition with a maximum slope of **10 percent**. To allow bicyclists to focus their attention on the crossing, the transition ramp should generally not be located within a lateral shift or curve in the bike lane alignment. Speed hump markings on the transition ramp should be provided for ramps **6 ft. or more** in length with slopes that exceed **5 percent**, otherwise they are optional.

Designers should consider raising the entire separated bike lane to intermediate or sidewalk level where the density of bus stops, driveways, alleys or minor street crossings would otherwise result in a relatively quick succession of transition ramps. Too many transition ramps in close proximity can result in an uncomfortable bicycling environment.

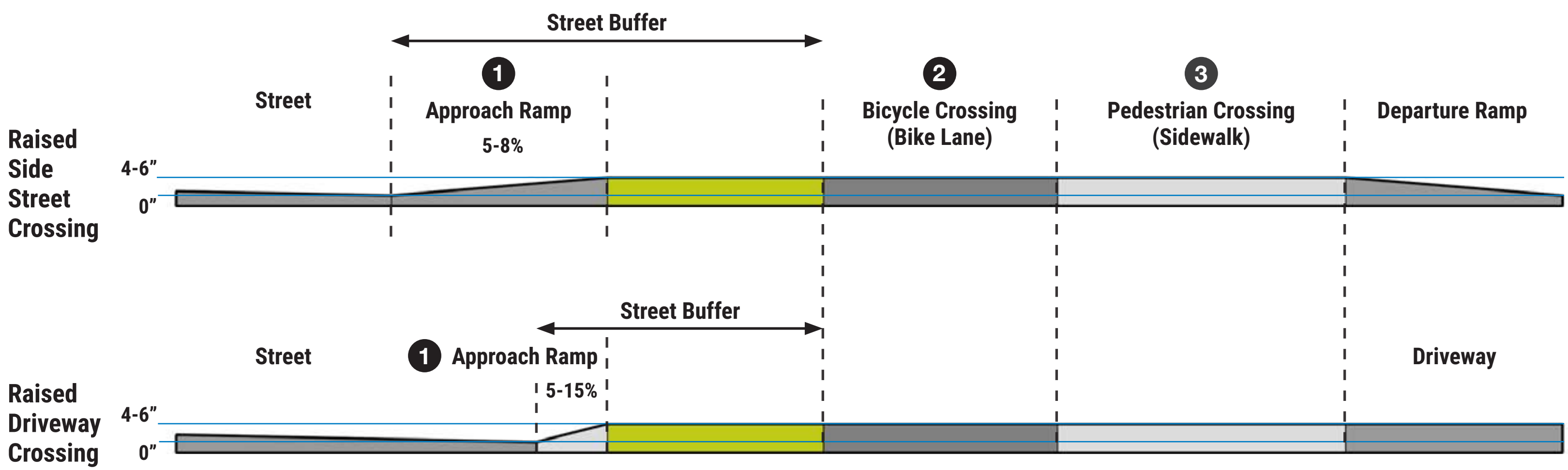
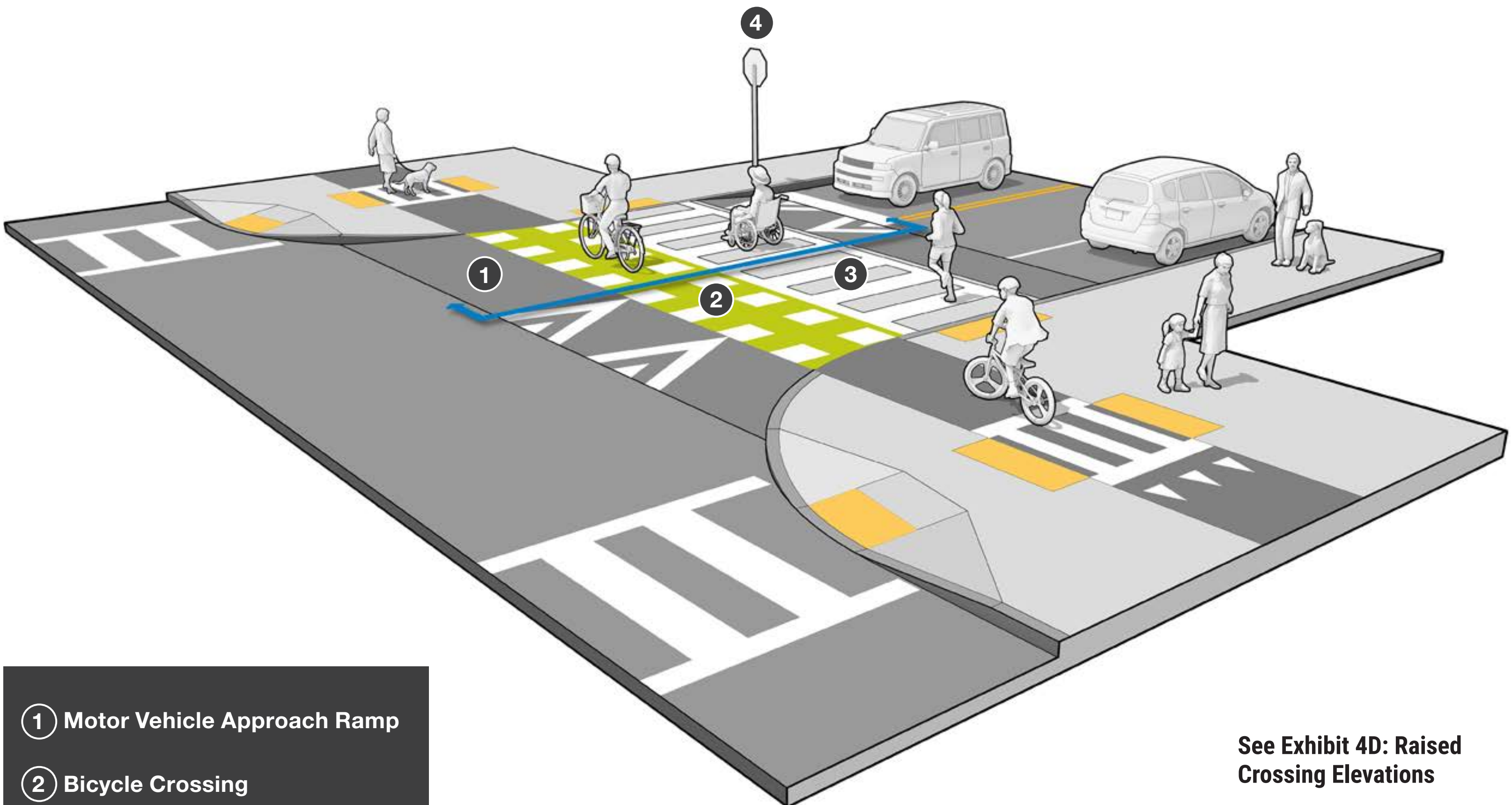


EXHIBIT 4D: Raised Crossing Elevations (Profile View)

EXHIBIT 4E: RAISED SIDE STREET CROSSING



1 Motor Vehicle Approach Ramp

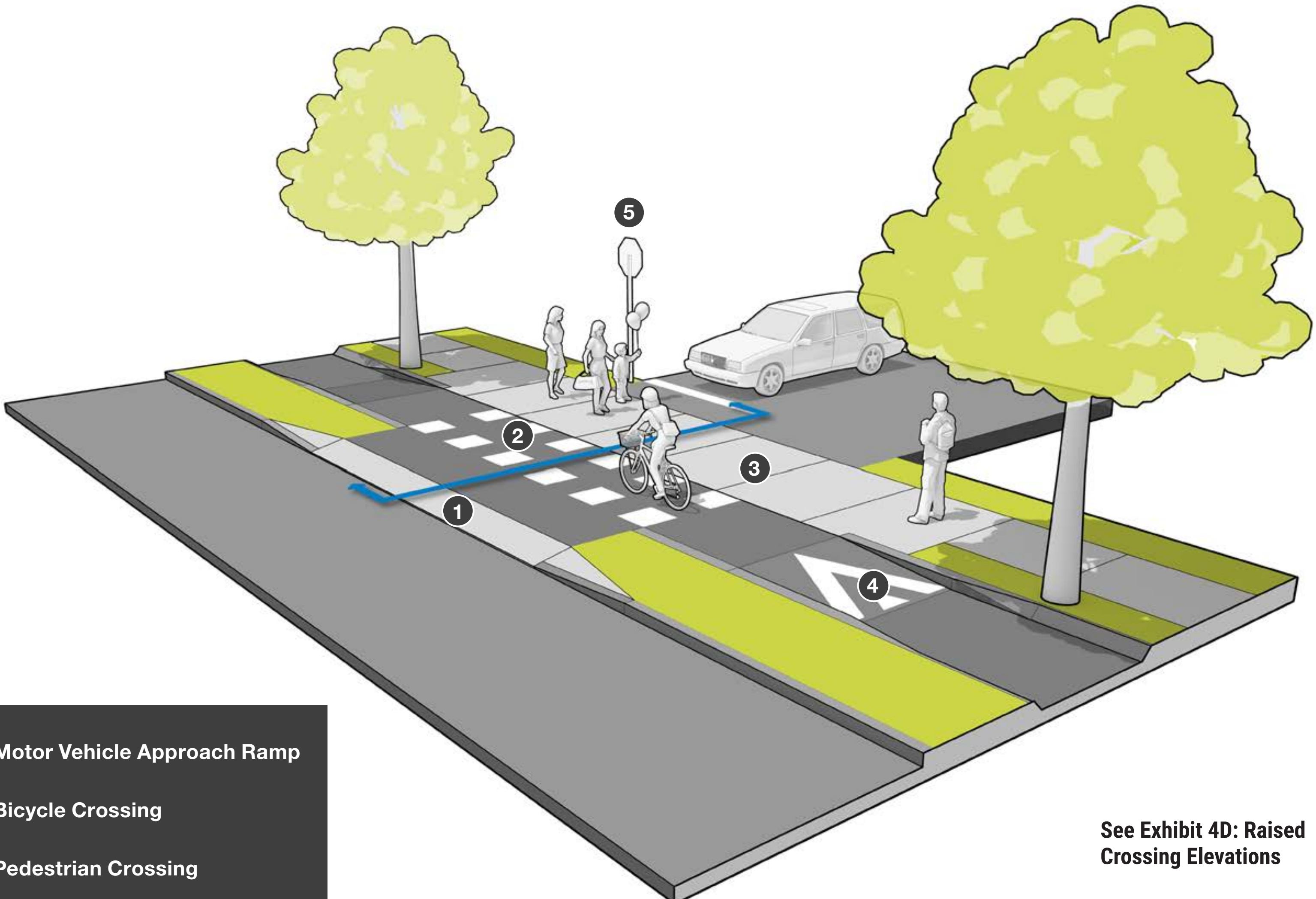
2 Bicycle Crossing

3 Pedestrian Crossing

4 Stop Sign

See Exhibit 4D: Raised Crossing Elevations

EXHIBIT 4F: RAISED DRIVEWAY CROSSING

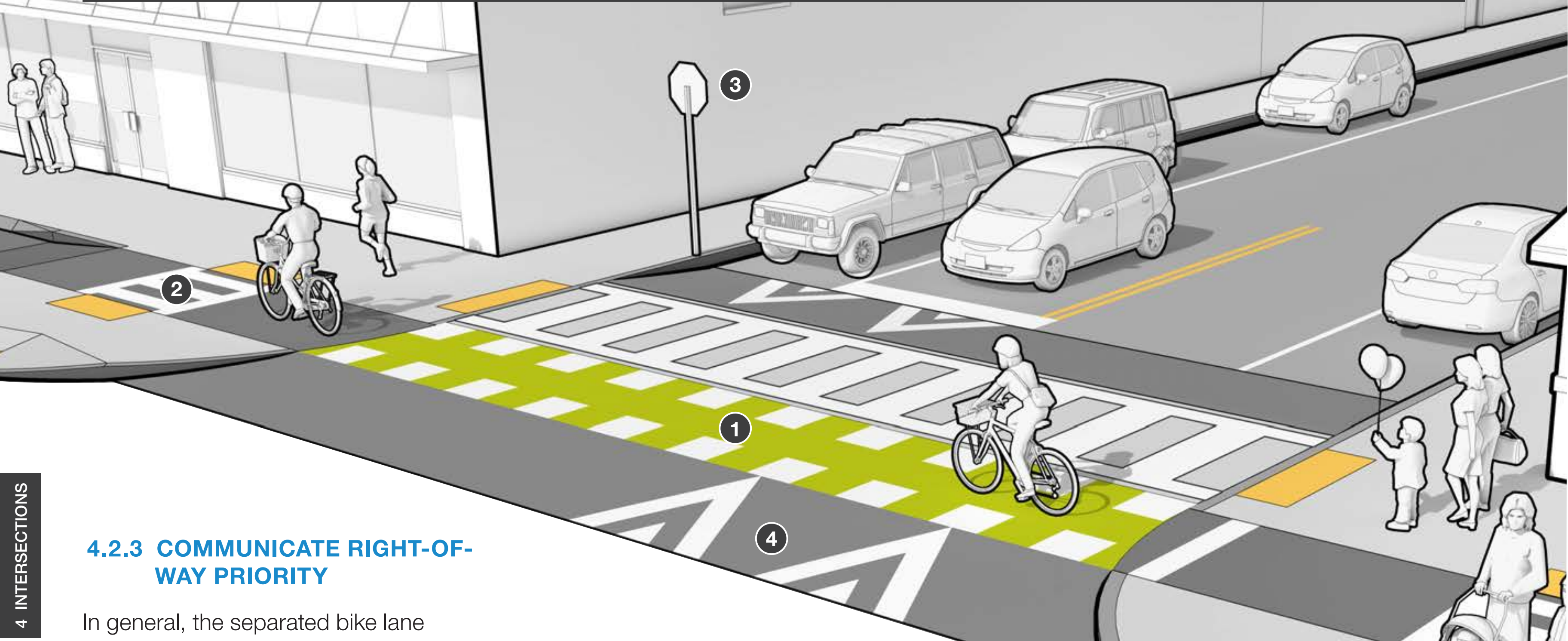


1. Motor Vehicle Approach Ramp
2. Bicycle Crossing
3. Pedestrian Crossing
4. Bicycle Transition Ramp*
5. Stop Sign

See Exhibit 4D: Raised Crossing Elevations

* Speed hump markings are typical for ramps 6 ft. or more in length with slopes that exceed 5 percent; otherwise they are optional.

EXHIBIT 4G: ASSIGNING PRIORITY AT CROSSINGS



4.2.3 COMMUNICATE RIGHT-OF-WAY PRIORITY

In general, the separated bike lane should be provided the same right-of-way priority as through traffic on the parallel street. Exceptions to this practice may be considered at:

- Locations with high volumes of conflicting turning traffic (see Section 6.1.3)
- Locations where bicyclist must cross high speed (**greater than 30 mph**) traffic

All street users should be provided with visual cues that clearly establish which users have the right of way and consistently communicate expected yielding behavior (see **EXHIBIT 4G**).

The priority right-of-way should be communicated through the provision of:

- Marked bicycle crossings (1) (see Section 4.4.1)
- Marked pedestrian crossings of separated bike lanes (2) (see Section 4.4.6)
- Regulatory signs, if appropriate, for merging or turning traffic (see Section 4.4.4)
- Regulatory signs, if appropriate, for side street or driveway traffic (STOP or YIELD) (see Section 4.4.5) (3)
- Protection from high volume traffic conflicts (see Section 4.3.7) (4)

Locations with two-way separated bike lanes may benefit from placement of warning signs that indicate two-way bicycle travel in advance of the crossing.

4.2.4 PROVIDE ADEQUATE SIGHT DISTANCE

Under Massachusetts General Law (M.G.L. c.90 §14), a turning motorist must yield to a through bicyclist unless the motorist is at a safe distance from the bicyclist and making the turn at a reasonable speed. Bicyclists must yield to motorists that are within the intersection or so close thereto as to constitute an immediate hazard. Bicyclists and motorists must yield to pedestrians within a crosswalk at uncontrolled locations. To comply with this law, it is necessary to provide adequate sight distances between bicyclists, motorists and pedestrians as they approach intersections with streets, alleys, and driveways. In general, sight distances that conform to standard street design principles established in the AASHTO Green Book and AASHTO Bike Guide are sufficient for streets with separated bike lanes.

When a separated bike lane is located behind a parking lane, it may be necessary to restrict parking and other vertical obstructions in the vicinity of a crossing to ensure adequate sight distances are provided. To determine parking restrictions near the crossing, it is necessary to know the approach speed of the bicyclist and the turning speed of the motorist. The overall objective of the design is to provide adequate sight distances for each user to detect a conflicting movement of another user and to react appropriately. The approach to the conflict point is comprised by these three zones:

MASSACHUSETTS GENERAL LAW (M.G.L. CHAPTER 90, SECTION 14)

"No person operating a vehicle that overtakes and passes a bicyclist proceeding in the same direction shall make a right turn at an intersection or driveway unless the turn can be made at a safe distance from the bicyclist at a speed that is reasonable and proper . . . When turning to the left within an intersection or into an alley, private road or driveway an operator shall yield the right of way to any vehicle approaching from the opposite direction, including a bicycle on the right of the other approaching vehicles, which is within the intersection or so close thereto as to constitute an immediate hazard . . ."

- **Recognition zone** – the approaching bicyclist and motorist have an opportunity to see each other and evaluate their respective approach speeds.
- **Decision zone** – the bicyclist or motorist identifies who is likely to arrive at the intersection first and adjust their speed to yield or stop if necessary.
- **Yield/stop zone** – space for the motorist or bicyclist to stop if needed.

At intersections with permissive turning movements where bicyclists and motorists are traveling in the same direction, there are two yielding scenarios that occur depending upon who arrives at the crossing first.


Chicago, IL

RIGHT TURNING MOTORIST YIELDS TO THROUGH BICYCLIST

This scenario occurs when a through moving bicyclist arrives at the crossing prior to a turning motorist, who must stop or yield to the through bicyclist. Parking must be set back sufficiently for the motorist to see the approaching bicyclist (see **EXHIBIT 4H**).

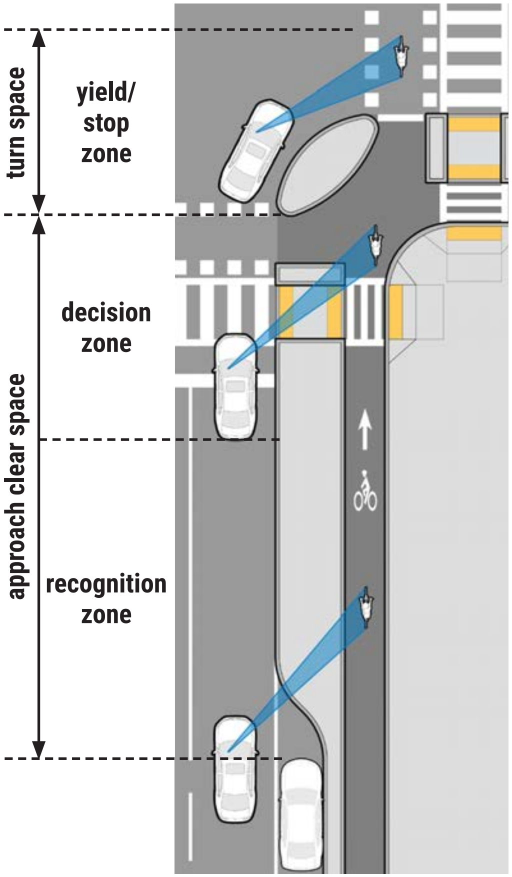


EXHIBIT 4H: Right Turning Motorist Yields to Through Bicyclist

THROUGH BICYCLIST YIELDS TO TURNING MOTORIST

This scenario occurs when a turning motorist arrives at the crossing prior to a through moving bicyclist. Again, parking must be set back sufficiently to enable bicyclists and motorists to see and react to each other (see **EXHIBIT 4I**).

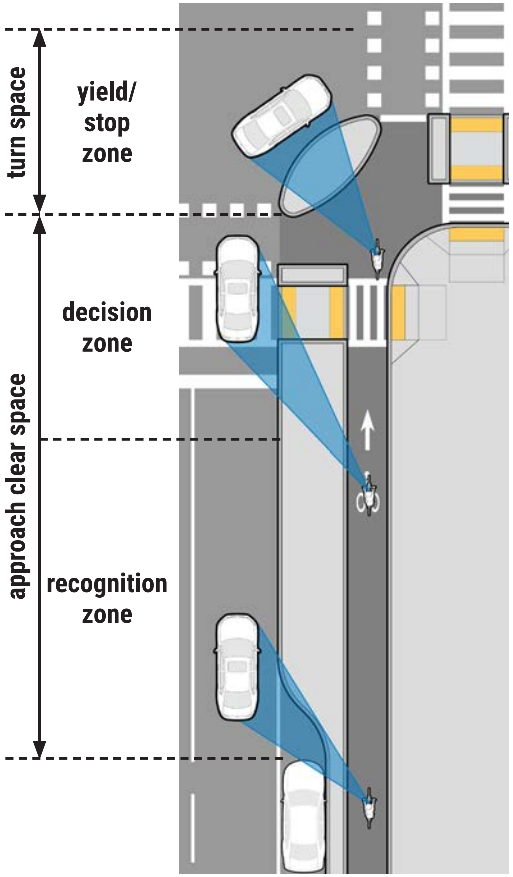


EXHIBIT 4I: Through Bicyclist Yields to Right Turning Motorist

4.2.5 APPROACH CLEAR SPACE

The following provides sight distance considerations for situations where motorists turn right, left, or cross separated bike lanes. The recommended approach clear space assumes the bicyclist is approaching the intersection at a constant speed of **15 mph**. Clear space recommendations are provided for various turning speeds of motorists which may vary from **10 to 20 mph** based on the geometric design of the corner and the travel path of the motorist. The recommended clear space allows one second of reaction time for both parties as they approach the intersection. If bicyclists' speeds are slower (such as on an uphill approach) or motorists' turning speeds are slower than **10 mph**, the clear space can be reduced. Where either party may be traveling faster, such as on downhill grades, the clear space may benefit from an extension.

EXHIBIT 4J provides various examples of how to determine the approach clear space for different turning movements.

Vehicular Turning Design Speed	Approach Clear Space
10 mph	40 ft.
15 mph	50 ft.
20 mph	60 ft.

EXHIBIT 4J: Approach Clear Space Distance by Vehicular Turning Design Speed[5]

CASE A – RIGHT TURNING MOTORIST

This case applies when a motorist is making a permissive right turn at a traffic signal or from an uncontrolled approach (e.g., a right turn from an arterial onto a local street or driveway), and a parking lane is present on the approach (see **EXHIBIT 4H and EXHIBIT 4I** on the previous page).

In this case the motorist will be decelerating for the right turn in advance of the intersection. The motorist's turning speed will be controlled by the corner geometry and width of the receiving roadway. **EXHIBIT 4J** identifies the minimum approach clear space measured from the start of the point of curvature (PC) of the curb or pavement edge. This table applies to intersections with streets or higher volume commercial driveways and alleys. For locations with two-way separated bike lanes additional approach clear space will not be required as the recognition zone between the contra-flow movement bicyclist and right turning motorists exceeds the recommended clear space. Low volume driveways and alleys where motorist turning speeds can be anticipated to be less than **10 mph** should provide a minimum clear space of **20 ft**.

CASE B – LEFT TURNING MOTORIST

This case applies when a motorist is making a permissive left turn at a traffic signal or from an uncontrolled approach (e.g., a left turn from an arterial onto a local street or driveway) (see **EXHIBIT 4K**). On one-way streets with a left side separated bike lane, this case has the same operational dynamics and approach clear space requirements as Case A since the left turning motorist will be turning adjacent to the separated bike lane. For locations with two-way separated bike lanes on the left side, additional approach clear space will not be required as the recognition zone between the contra-flow movement bicyclist and left turning motorist exceeds the recommended clear space. Low volume driveways and alleys where motorists' turning speeds can be anticipated to be less than **10 mph** should provide a minimum clear space of **20 ft**.

On streets with two-way traffic flow, the operational dynamic of a motorist looking for gaps in traffic creates unique challenges that cannot be resolved strictly through the provision of parking restrictions to improve sight distance. This is a challenging maneuver because the motorist is primarily looking for gaps in oncoming traffic, and is less likely to scan for bicyclists approaching from behind. Unlike for Case A or Case B on one-way streets where the motorist is decelerating towards the crossing, the motorist in this instance will be accelerating towards the crossing once they perceive a gap in traffic. This creates a higher potential for conflict on streets with:

- **High traffic volumes and multiple lanes**
- **Higher operating speeds**
- **Heavy left turn volumes**

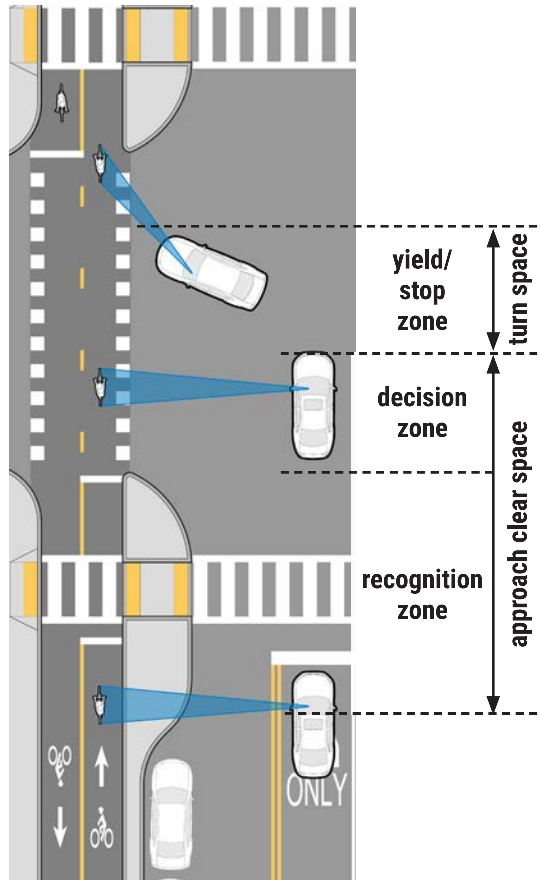


EXHIBIT 4K: Left Turning Motorist Yields to Through Bicyclist

4 INTERSECTIONS

Rotterdam, Netherlands

For this reason, one or more of the following design elements should be considered to mitigate conflicts:

- **Implement a protected left turn phase for motorists that does not conflict with the bicycle crossing movement (see Chapter 6).**
- **Install a TURNING VEHICLES YIELD TO BICYCLES AND PEDESTRIANS sign (R10-15 alt.) (see Section 4.4.4).**
- **Supplement the bicycle crossing with green surfacing.**
- **Raise the crossing (see Section 4.2.2).**
- **Recess the crossing (see Section 4.3.6).**
- **Restrict left turns (see Section 4.3.7).**

Where these measures prove ineffective, or where it is not feasible to eliminate the conflict, it may be necessary to reevaluate whether a two-way separated bike lane is appropriate at the location.

CASE C1 – MOTORIST CROSSES NEAR SIDE SEPARATED BIKE LANE

This case applies when a motorist exits a non-signal controlled street, alley or driveway to cross a near side separated bike lane (see **EXHIBIT 4L**). These intersections are commonly stop controlled.

Providing a minimum clear space of **20 ft.** between the stop line and the bicycle crossing will typically provide an approaching motorist with the ability to see approaching bicyclists in the separated bike lane. In many locations, the effective clear space will be larger than **20 ft.** to accommodate pedestrian crosswalks. At locations where the motorist must pull into the crossing to view traffic gaps and is likely to block the separated bike lane, other treatments such as signalizing the crossing (see **Chapter 6**), raising the crossing (see **Section 4.2.2**), or recessing the bicycle crossing (see **Section 4.3.6**) should be considered.

CASE C2 – MOTORIST CROSSES FAR SIDE SEPARATED BIKE LANE

This case applies when a motorist exits a non-signal controlled street, alley or driveway to cross a far side separated bike lane (see **EXHIBIT 4L**). These intersections are commonly stop controlled.

As with Case B, this case creates a challenging dynamic that is difficult to resolve with additional parking restrictions on the cross street. It may be difficult to restrict parking enough to provide the required sight distance to judge gaps that allow a crossing of all the travel lanes and the separated bike lane on the opposite side of the street. As such, designers should consider the frequency of through movements at these types of intersections and provide adequate sight distance for bicyclists to perceive a crossing vehicle and stop if necessary.

For this reason these potential mitigations should be considered:

- **Install a traffic signal (see Chapter 6).**
- **Raise the crossing (see Section 4.2.2).**
- **Recess the crossing (see Section 4.3.6).**
- **Restrict crossing movements (see Section 4.3.7).**

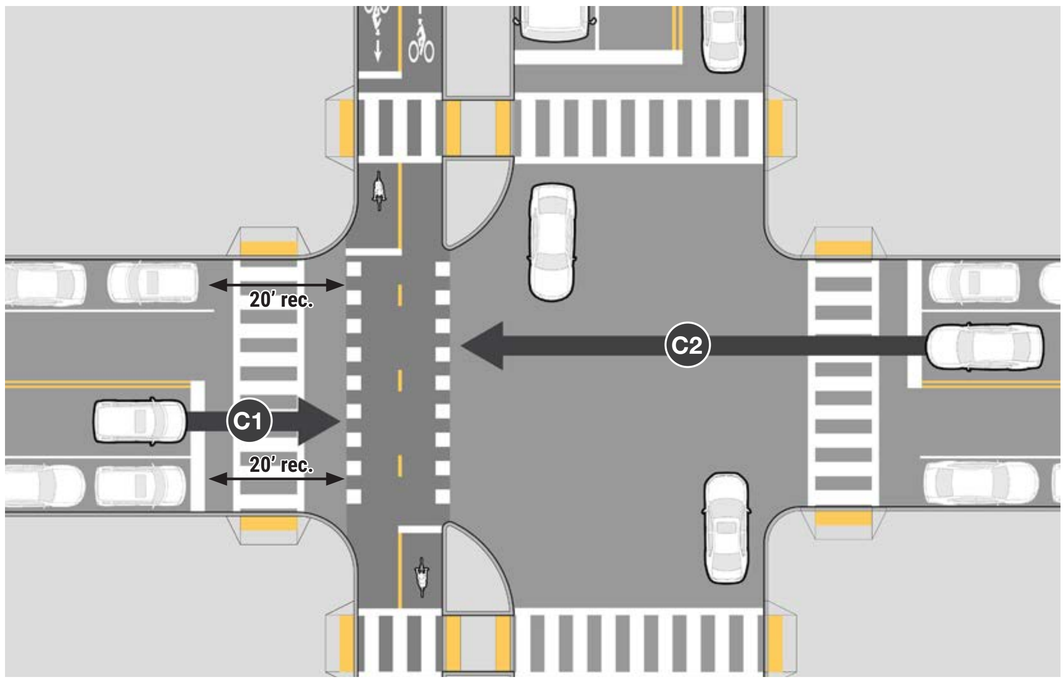


EXHIBIT 4L: Case C1 and C2 – Motorist Crossing Near- and Far-side Separated Bike Lane

4.3 COMMON INTERSECTION DESIGN TREATMENTS

This section provides guidance for the design of separated bike lanes at common intersection configurations to improve comfort, efficiency and safety for bicyclists. Each configuration includes examples of the application of signs and markings. Signal design is discussed in **Chapter 6**.

4.3.1 ELEMENTS OF PROTECTED INTERSECTIONS

Well-designed protected intersections are intuitive and comfortable, provide clear right-of-way assignment, promote predictability of movement, and allow eye contact between motorists, bicyclists and pedestrians. They also clearly define pedestrian and bicyclist operating spaces within the intersection and minimize potential conflicts between users.

The following discussion focuses on design guidance for the geometric elements of a protected intersection (see **EXHIBIT 4M and EXHIBIT 4N**).

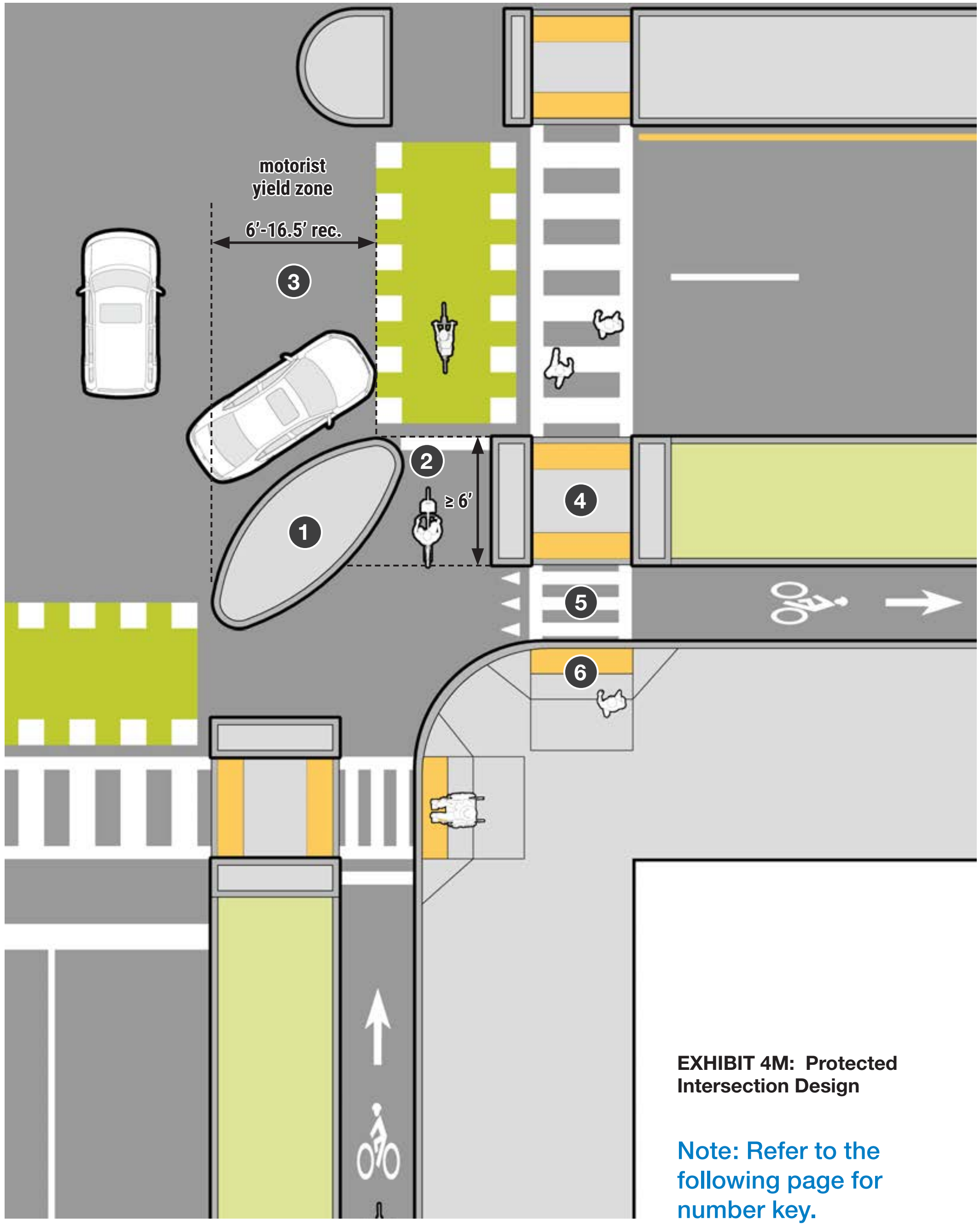
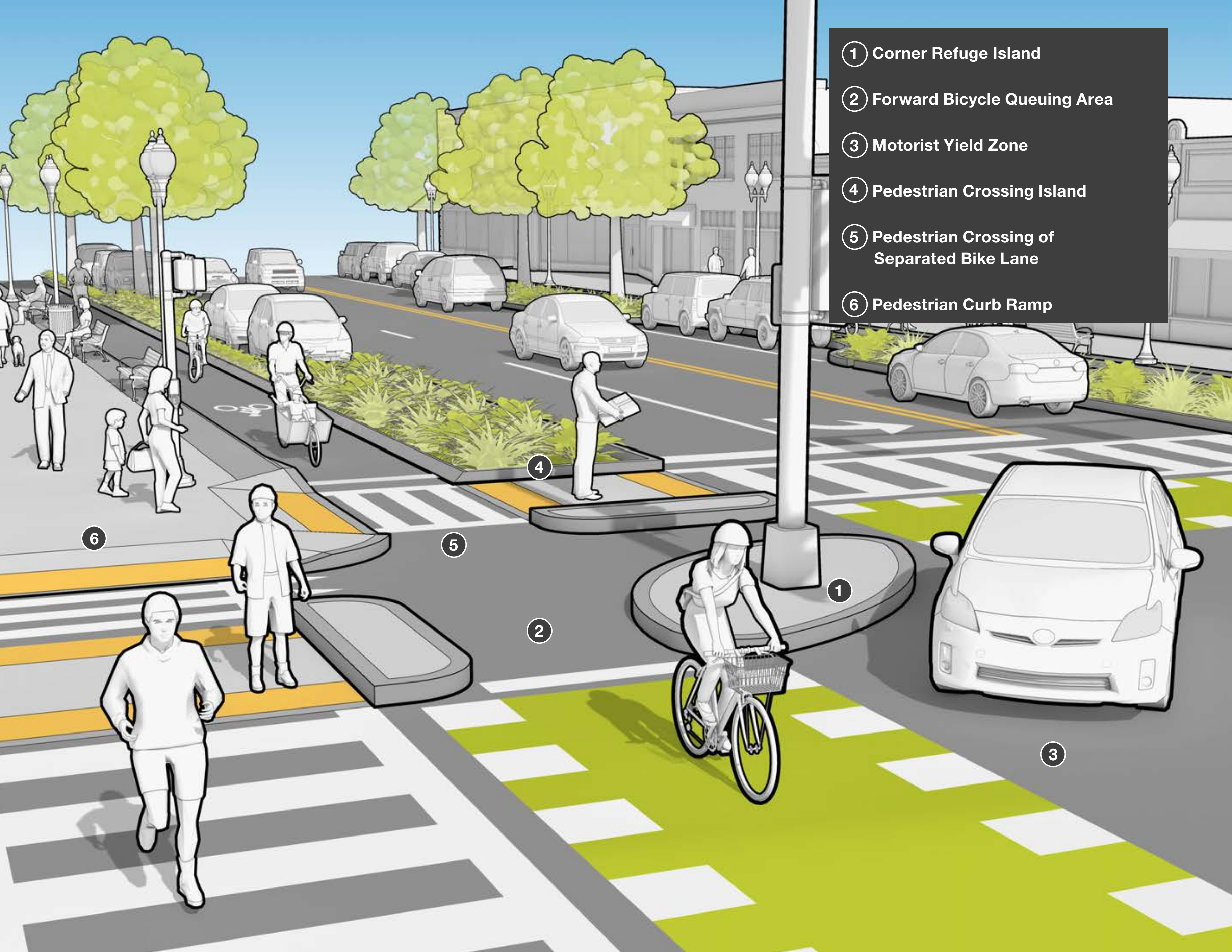


EXHIBIT 4M: Protected Intersection Design

Note: Refer to the following page for number key.

EXHIBIT 4N: ELEMENTS OF PROTECTED INTERSECTIONS



1. CORNER REFUGE ISLAND

The corner refuge island allows the bike lane to be physically separated up to the intersection crossing point where potential conflicts with turning motorists can be controlled more easily. It serves an important purpose in protecting the bicyclist from right-turning motor vehicle traffic. The corner island also provides the following benefits:

- **Creates space for a forward bicycle queuing area.**
- **Creates additional space for vehicles to wait while yielding to bicyclists and pedestrians who are crossing the road.**
- **Reduces crossing distances.**
- **Controls motorist turning speeds.**

The corner island geometry will vary greatly depending upon available space, location and width of buffers, and the corner radius. The corner island should be constructed with a standard vertical curb to discourage motor vehicle encroachment. Where the design vehicle exceeds an SU-30, a mountable truck apron should be considered to supplement the corner refuge island (see **Section 4.2.2**).

2. FORWARD BICYCLE QUEUING AREA

The forward bicycle queuing area provides space for stopped bicyclists to wait that is fully within the view of motorists who are waiting at the stop bar, thus improving bicyclist visibility. This design enables bicyclists to enter the intersection prior to turning motorists, enabling them to establish the right-of-way in a similar manner as a leading bicycle interval. Ideally, the bicycle queuing area should be **at least 6 ft.** long to accommodate a typical bicycle length. The opening at the entrance and exit of the crossing to the street should typically be the same width as the bike zone, but no less than **6 ft.** wide. Where stops are required, a stop line should be placed near the edge of the crossing roadway.

Where feasible, the designer should consider providing additional queuing space on streets with high volumes of bicyclists.

3. MOTORIST YIELD ZONE

Bicycle and pedestrian crossings set back from the intersection create space for turning motorists to yield to bicyclists and pedestrians. Research has found crash reduction benefits at locations where bicycle crossings are set back from the motorist travel way by a distance of **6 ft. to 16.5 ft.**[6,7,8,9] As shown in **EXHIBIT 4U** in **Section 4.3.6**, this offset provides the following benefits:

- **Improves motorist view of approaching bicyclists by reducing need for motorists to turn their head.**
- **Eliminates the need to rely on the use of mirrors to look behind for bicyclists.**
- **Creates space for a motorist to yield to bicyclists and pedestrians without blocking traffic and to stop prior to the crossing.**
- **Provides additional time for bicyclists and pedestrians to react to turning motorists.**
- **Bicycle and pedestrian crossings should be separate but parallel to consolidate conflicts for motorists unless the crossing is a shared use path.**

4. PEDESTRIAN CROSSING ISLAND

The pedestrian crossing island is a space within the street buffer where pedestrians may wait between the street and the separated bike lane. It should be a **minimum of 6 ft.** wide and should include detectable warning panels. Pedestrian islands provide the following benefits:

- **Enable pedestrians to negotiate potential bicycle and motor vehicle conflicts separately.**
- **Shortens pedestrian crossing distance of the street.**
- **Reduce the likelihood that pedestrians will block the bike lane while waiting for the walk signal.**

The crossing island path may be directly adjacent to the forward bicycle queuing area, but these spaces should not overlap unless the facility is a shared use path. Separation via a raised median improves comfort and compliance among pedestrians and bicyclists (pedestrians are less likely to wander into the bike lane zone, and vice versa). The opening in the crossing island should match the width of the pedestrian crosswalk.

5. PEDESTRIAN CROSSING OF SEPARATED BIKE LANE

Pedestrian crossings should be provided to indicate a preferred crossing of the separated bike lane and to communicate a clear message to bicyclists that pedestrians have the right-of-way. The crossing should typically align with crosswalks in the street. Yield lines in the bike lane in advance of the pedestrian crosswalk are typically used to emphasize pedestrian priority.

It is also important to provide clear and direct paths for pedestrians to reduce the likelihood that they will step into or walk within the bike lane except at designated crossings.

6. PEDESTRIAN CURB RAMP

Pedestrian curb ramps may be required to transition pedestrians from the sidewalk to the street where there is a change in elevation between the two. It is preferable to use perpendicular or parallel curb ramps. The ramp must comply with ADA and MassDOT guidelines. Detectable warning panels must be provided at the edges of all street and bike zone crossings.

Rotterdam, Netherlands

4.3.2 DESIGN STRATEGIES FOR CONSTRAINED LOCATIONS

At constrained locations, it may not be feasible to maintain the preferred widths of motor vehicle lanes, buffers, bike lanes, and sidewalks to the corner. (However, sidewalk widths cannot be reduced below the required ADA minimums.) As discussed in Section 3.6 it may be necessary to narrow a zone to the minimum dimensions or to eliminate the sidewalk buffer to achieve the desired design. At locations where there are no conflicts with turning vehicles, the street buffer can be minimized and the motorist yield zone can be reduced or eliminated. See EXHIBIT 4N for an illustration of the motorist yield zone. Where conflicts remain, it is preferable to maintain a motorist yield zone.

Where it is necessary to laterally shift the separated bike lane within a constrained intersection, the shift should generally occur gradually, at no greater than **a taper of 3:1**. Additionally alternative curb ramp designs, spot sidewalk widening, or modifications to the sidewalk and/or bike lane elevation may be required to provide a satisfactory design solution.

The minimum width of a raised street buffer zone is **2 ft.**

The following strategies may be considered to maintain a protected intersection design in a constrained location.

I. Bend–out Deflection

It may be desirable to bend-out the separated bike lane as it approaches the intersection (see EXHIBIT 4O). This creates:

- **A larger yielding zone for motorists.**
- **Larger queuing areas for bicyclists and pedestrians within the street buffer.**

This may be particularly beneficial at locations with permissive left turn conflicts where turning motorists are focused on identifying gaps in opposing traffic, as it can be used to provide a place for a left-turning vehicle to wait while yielding to bicyclists.

Bend-out deflection may also be desirable where it is necessary to create a pedestrian platform for transit stops, queueing space for loading or parking activities (see Chapter 5).

II. Bend–in Deflection

In general, it is not desirable to bend-in the separated bike lane unless it is to maintain minimum sidewalk widths in constrained corridors that require elimination of sidewalk buffers and narrowing of street buffers. The provision of a motorist yield zone should be provided by increasing the size of the corner island as shown in EXHIBIT 4P.

New York, NY

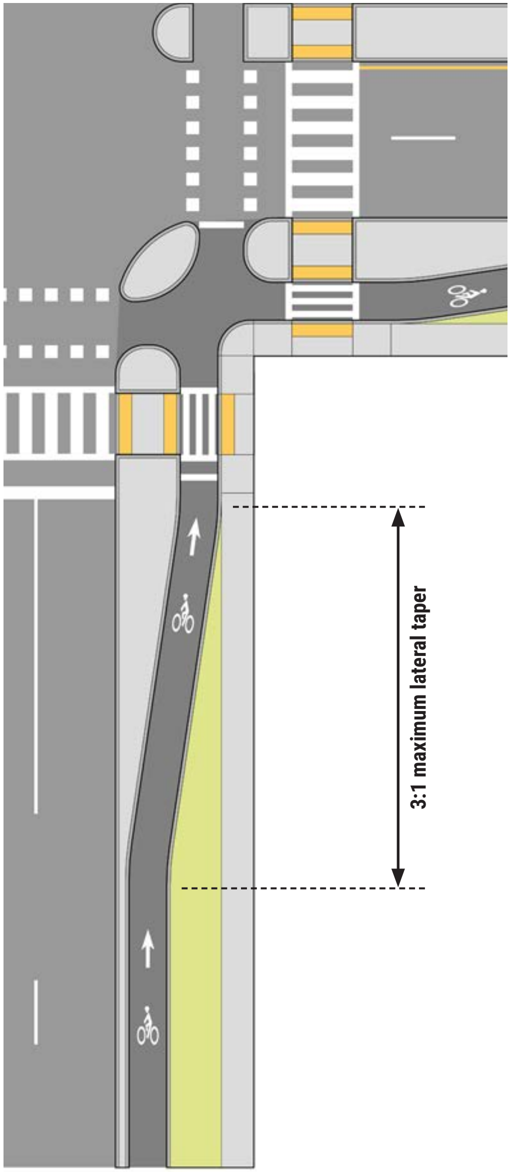


EXHIBIT 4O: Bend-out Example

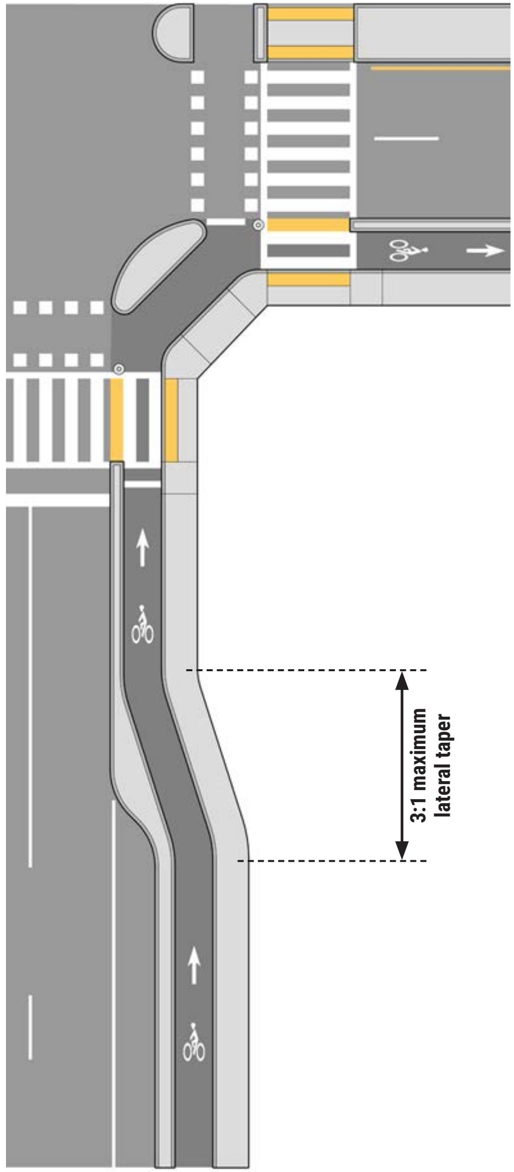


EXHIBIT 4P: Bend-in Constrained Example

Zwolle, Netherlands

4.3.3 MIXING ZONE TRANSITIONS

Mixing zones create a defined merge point for a motorist to yield and cross paths with a bicyclist in advance of an intersection. They require removal of the physical separation between the bike lane and the motor vehicle travel lane. This allow motorists and bicyclists to cross paths within a travel lane to either reach a conventional bike lane near the stop bar (see **EXHIBIT 4Q**), or to share a motor vehicle lane (see **EXHIBIT 4R**). For both situations, a clearly defined, slow speed merging area increases the predictability and safety of all users.

Protected intersections are preferable to mixing zones. Mixing zones are generally appropriate as an interim solution or in situations where severe right-of-way constraints make it infeasible to provide a protected intersection.

Mixing zones are only appropriate on street segments with one-way separated bike lanes. They are not appropriate for two-way separated bike lanes due to the contra-flow bicycle movement. The following design principals should be applied to mixing zones:

- **Locate the merge point where the entering speeds of motor vehicles will be 20 mph or less by:**
    - **Minimizing the length of the merge area (50 ft. minimum to 100 ft. maximum).**
    - **Locating the merge point as close as practical to the inter-section.**
- **Minimize the length of the storage portion of the turn lane.**
- **Provide a buffer and physical separation (e.g., flexible delineator posts) from the adjacent through lane after the merge area, if feasible.**
- **Highlight the conflict area with a green surface coloring and dashed bike lane markings, as necessary, or shared lane markings placed on a green box.**
- **Provide a BEGIN RIGHT (or LEFT) TURN LANE YIELD TO BIKES sign (R4-4) at the beginning of the merge area.**
- **Restrict parking within the merge area.**
- **At locations where raised separated bike lanes are approaching the intersection, the bike lane should transition to street elevation at the point where parking terminates.**

Where posted speeds are **35 mph** or higher, or at locations where it is necessary to provide storage for queued vehicles, it may be necessary to provide a deceleration/storage lane in advance of the merge point.


New York, NY

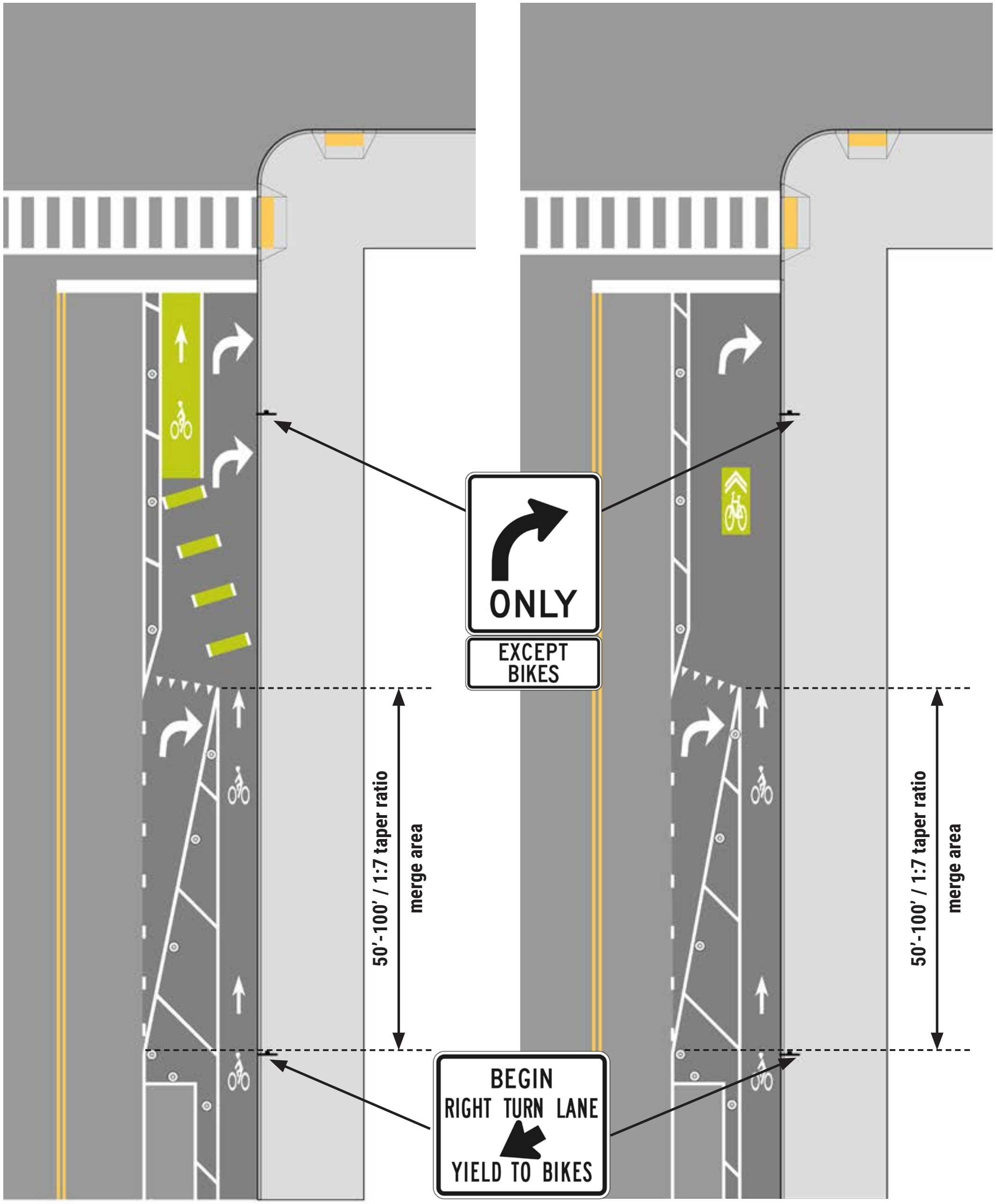
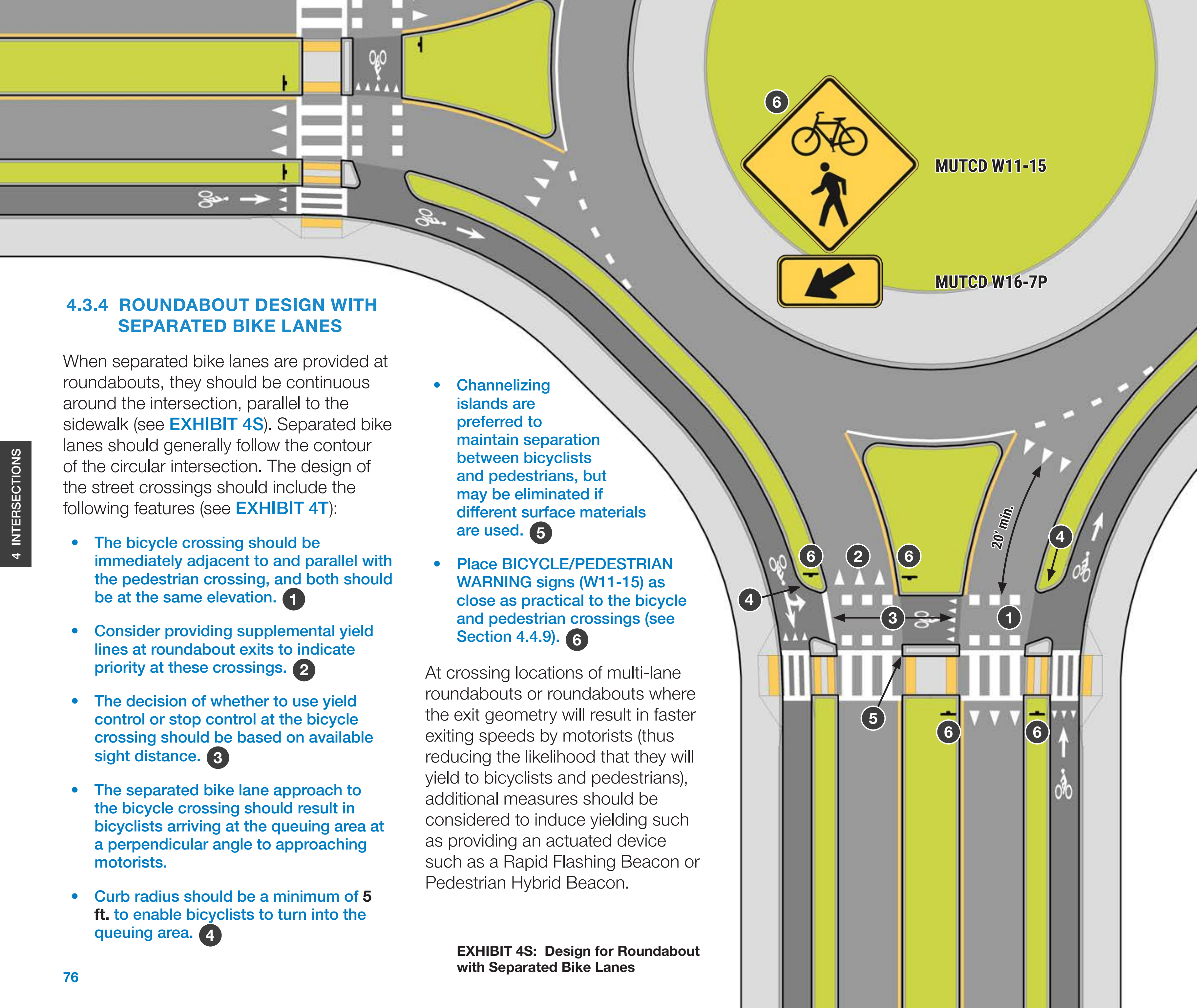


EXHIBIT 4Q: Angled Crossing Mixing Zone with Bike Lane

EXHIBIT 4R: Angled Crossing Mixing Zone with Shared Lane

New York, NY



4.3.4 ROUNDABOUT DESIGN WITH SEPARATED BIKE LANES

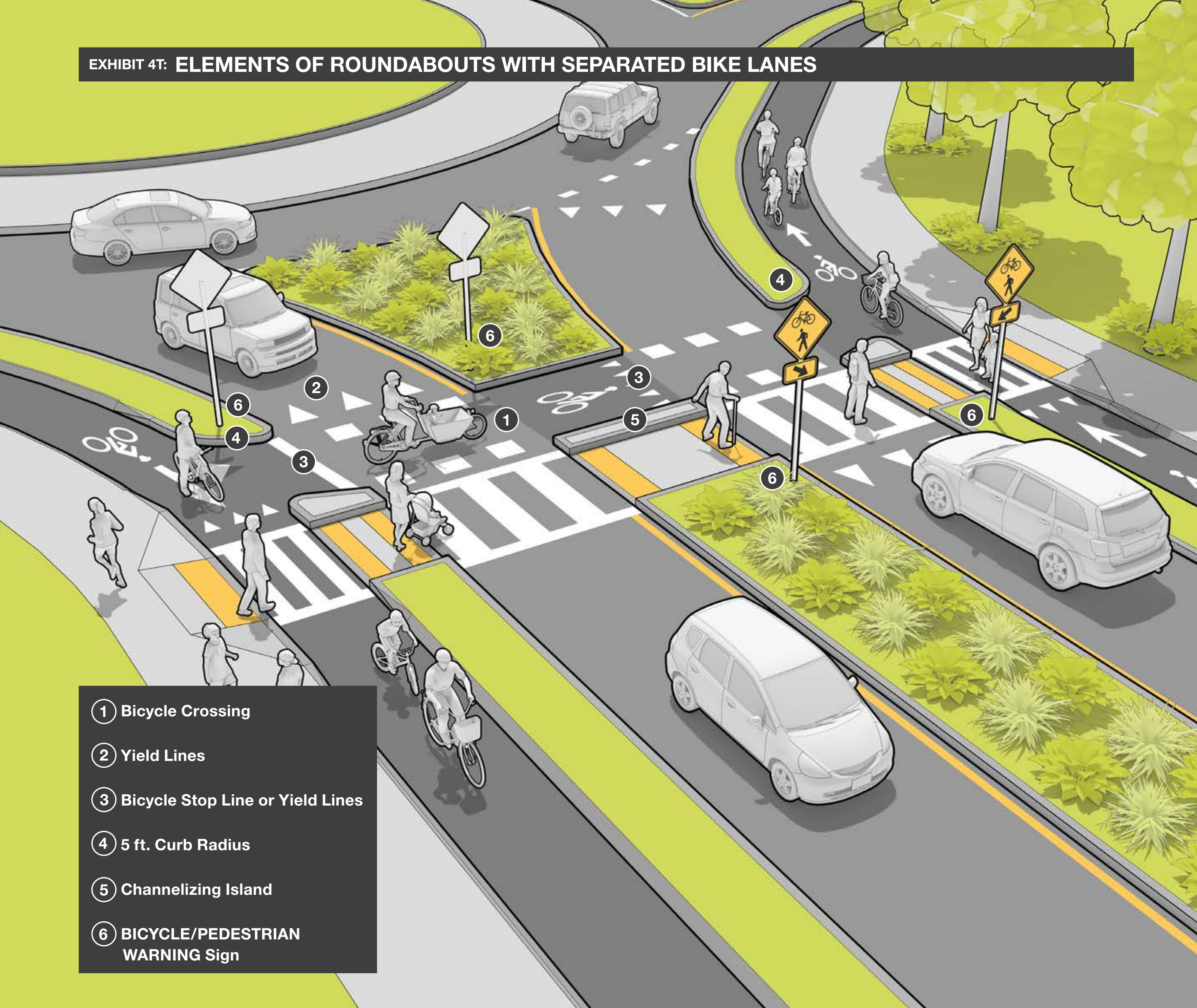
When separated bike lanes are provided at roundabouts, they should be continuous around the intersection, parallel to the sidewalk (see **EXHIBIT 4S**). Separated bike lanes should generally follow the contour of the circular intersection. The design of the street crossings should include the following features (see **EXHIBIT 4T**):

- **The bicycle crossing should be immediately adjacent to and parallel with the pedestrian crossing, and both should be at the same elevation.** 1
- **Consider providing supplemental yield lines at roundabout exits to indicate priority at these crossings.** 2
- **The decision of whether to use yield control or stop control at the bicycle crossing should be based on available sight distance.** 3
- **The separated bike lane approach to the bicycle crossing should result in bicyclists arriving at the queuing area at a perpendicular angle to approaching motorists.**
- **Curb radius should be a minimum of 5 ft. to enable bicyclists to turn into the queuing area.** 4
- **Channelizing islands are preferred to maintain separation between bicyclists and pedestrians, but may be eliminated if different surface materials are used.** 5
- **Place BICYCLE/PEDESTRIAN WARNING signs (W11-15) as close as practical to the bicycle and pedestrian crossings (see Section 4.4.9).** 6

At crossing locations of multi-lane roundabouts or roundabouts where the exit geometry will result in faster exiting speeds by motorists (thus reducing the likelihood that they will yield to bicyclists and pedestrians), additional measures should be considered to induce yielding such as providing an actuated device such as a Rapid Flashing Beacon or Pedestrian Hybrid Beacon.

EXHIBIT 4S: Design for Roundabout with Separated Bike Lanes

EXHIBIT 4T: ELEMENTS OF ROUNDABOUTS WITH SEPARATED BIKE LANES



4.3.5 DRIVEWAY CROSSINGS

The design of driveways will follow the **PD&DG**, which has design criteria based on the primary use of the driveway: residential, commercial or industrial (see **Chapter 15 of the PD&DG**). In general, the width of the driveway crossing should be minimized and access management strategies should be considered along separated bike lane routes to minimize the frequency of driveway crossings.

Where separated bike lanes cross driveways, the design should clearly communicate that bicyclists have the right-of-way by continuing the surface treatment of the bike lane across the driveway. Per **Section 4.2.2**, raised crossings should be considered to improve bicyclist safety.

For low volume residential driveways, the driveway crossing should be clearly marked with a bicycle crossing. It does not need stop or yield signs for motorists exiting the driveway unless an engineering study indicates a need.

At crossings (both controlled and uncontrolled) of high volume residential or commercial driveways, or any industrial driveway, a protected intersection design is preferred. If a protected intersection is not feasible, the driveway should provide a raised crossing with green conflict zone pavement markings.

At uncontrolled high volume driveways where a protected intersection is not feasible, a raised crossing with green conflict zone markings should be provided along with a BICYCLE WARNING sign (W11-1) or BICYCLE/PEDESTRIAN WARNING sign (W11-15) (see **Section 4.4.8 and Section 4.4.9**). At locations with two-way separated bike lanes, the W11-1 or W11-15 sign should be supplemented with a two-directional arrow (W1-7 alt.) supplemental plaque (see **Section 4.4.8**).

If parking is allowed parallel to the separated bike lane, it should be restricted in advance of the driveway crossing to achieve adequate approach sight distance (see **EXHIBIT 4J**). A clear line of sight should be provided between motorists exiting and entering the driveway and approaching bicyclists. Sight lines should be examined before major reconstruction projects to identify strategies to further improve visibility while balancing on-street parking availability (e.g., relocating streetscape elements, lengthening curb extensions, etc.).

Utrecht, Netherlands

4.3.6 RECESSED (SET BACK) CROSSINGS

Recessed bicycle and pedestrian crossings are a central element of the protected intersection discussed in **Section 4.3.1**. The benefits of a recessed crossing apply equally to shared use path intersections with streets, driveways or alleys where permissive motorist turns are allowed. Similar to roundabouts, a recessed crossing can reduce conflicts at crossings by creating space for the motorist to yield to approaching bicyclists followed by an additional space of approximately one car length to wait at the edge of the roadway to look for a gap in traffic without blocking the path. Raised crosswalks and refuge islands can be incorporated into the treatment to provide additional safety benefits. **EXHIBIT 4U** provides an example of a recessed crossing at a shared use path intersection.

Rotterdam, Netherlands

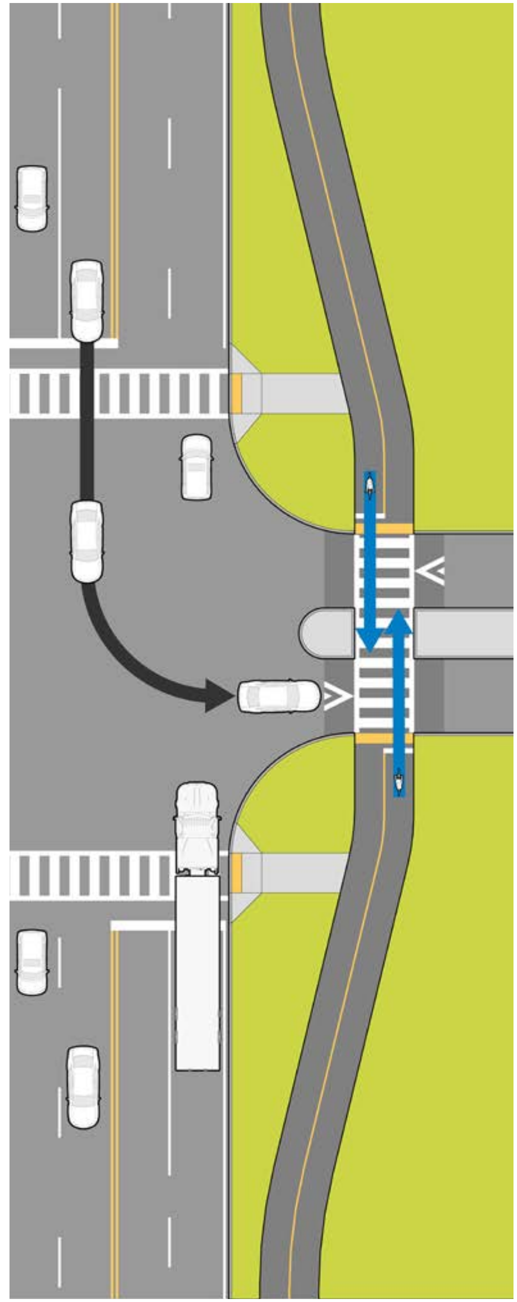
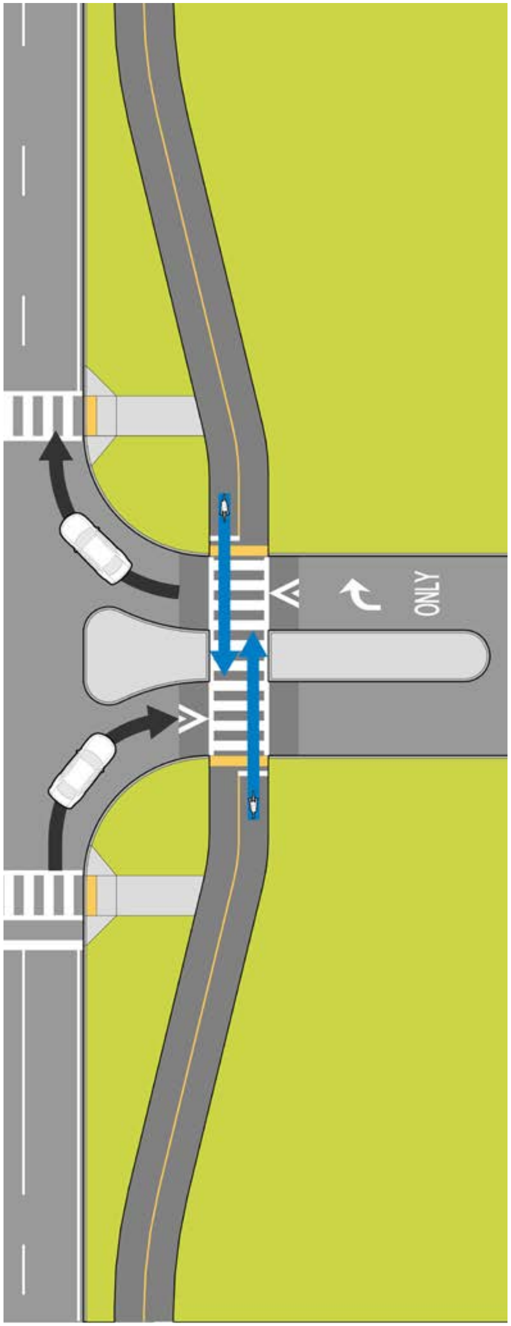


EXHIBIT 4U: Recessed Crossing at Shared Use Path Intersection



4.3.7 ACCESS MANAGEMENT

It may be feasible or desirable in some locations to implement access management principles to improve overall traffic flow and safety within a corridor as well as to eliminate motorist conflicts with bicyclists in the separated bike lane. Specific strategies that should be considered include:

- **Restrict left turns and/or through crossings of a separated bike lane.**
- **Construct medians.**
- **Introduce regulatory sign restrictions.**
- **Consolidate driveways to reduce potential frequency of conflicts.**
- **Restrict turn-on-red to maintain integrity of crossings and bicycle queuing areas.**

EXHIBIT 4V provides an example of a recessed crossing combined with a median refuge to restrict through crossings and left turns across a shared use path intersection.

EXHIBIT 4V: Recessed Crossing at a Shared Use Path Intersection with Left Turn and Through Crossing Restrictions

4.3.8 GRADE SEPARATION

Grade separation is achieved through the provision of a bridge or underpass. This is likely to be a relatively rare design strategy due to cost and space constraints. It may be a desirable solution for crossing limited access highways or other high volume (**more than 20,000 vehicles/day**), high speed (**more than 45 mph**) streets where motorists are not likely to yield, gaps in traffic are infrequent, and provision of a signalized crossing is not viable. The structure should be constructed to accommodate bicyclists and pedestrians. The design of a bridge or tunnel for a separated bike lane should follow the guidance provided for shared use paths in **Chapter 11 of the PD&DG** and **Section 5.2.10 of the AASHTO Bike Guide**. In areas where pedestrian and bicycle volumes are higher, it is recommended that separate treadways for bicyclists and pedestrians be maintained across the structure.

4.4 PAVEMENT MARKING AND TRAFFIC SIGN GUIDANCE

The design of traffic control devices is controlled by the **Manual on Uniform Traffic Control Devices (MUTCD)** as adopted with amendments by MassDOT and the Standard Municipal Traffic Code. The following discussion provides an overview of key traffic control markings and signs that are frequently required at separated bike lane crossings. Traffic signals are discussed in **Chapter 6**.

4.4.1 BICYCLE CROSSING

A bicycle crossing is a marked crossing of an intersection with a street, driveway or alley. The purpose of the crossing is to

- **Delineate a preferred path for people bicycling through the intersection.**
- **Encourage motorist yielding behavior, where applicable.**

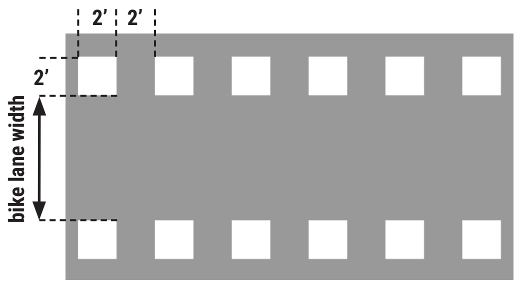


EXHIBIT 4W: One-way Bicycle Crossing

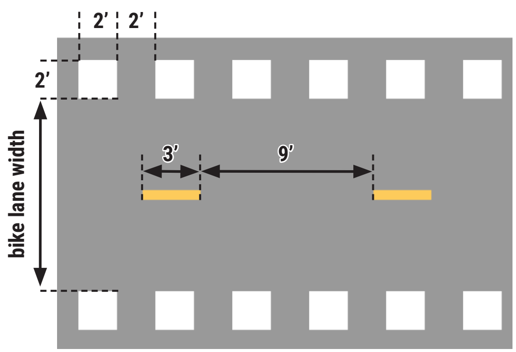


EXHIBIT 4X: Two-way Bicycle Crossing

EXHIBIT 4W and EXHIBIT 4X indicate the standard dimensions of marked bicycle crossings. It is preferable, if adequate space exists, to place the markings on the outside of the bike lane width (i.e., maintaining the clear width of the bike lane through the intersection with the markings placed on the outside). If this is not feasible due to space constraints, the markings can be placed on the inside of the bike lane. The bicycle crossing may be supplemented with a green colored surface to improve contrast with the surrounding roadway and adjacent pedestrian crossing, if present. Green surfacing may be desirable at crossings where concurrent vehicle crossing movements are allowed.

4.4.2 BICYCLE STOP LINE

Bicycle stop lines indicate the desired place for bicyclists to stop within a separated bike lane in compliance with a stop sign (R1-1) or traffic signal. At locations with bicycle queuing areas, a **1 ft.** wide stop line should be placed near the edge of the crossing roadway. In constrained locations where there is no bicycle queuing area, the stop line should be located prior to the pedestrian crosswalk or crossing separated bike lane to prevent queued bicyclists from blocking the path of a crossing pedestrian or bicyclist.

4.4.3 YIELD LINES

Yield lines (**12 in. by 18 in.**) are typically used in advance of pedestrian crossings of separated bike lanes to emphasize pedestrian priority (see **EXHIBIT 4Y**). Yield lines (**24 in. by 36 in.**) may be used to in advance of bicycle crossings to emphasize bicyclist priority at the following locations (see **EXHIBIT 4Z**):

- **Uncontrolled crossings.**
- **On the exit leg of signalized intersections where motorists turn across a bicycle crossing during a concurrent phase.**
- **Bicycle crossings located within roundabouts.**
- **Motorists yield points at mixing zones with advanced queuing lanes (see Section 4.3.3).**

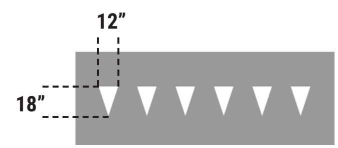


EXHIBIT 4Y: Yield Lines for Use in Separated Bike Lanes

EXHIBIT 4Z: Yield Lines for Use in Roadways

4.4.4 TURNING VEHICLES YIELD TO BICYCLES AND PEDESTRIANS SIGN

The TURNING VEHICLES YIELD TO BICYCLES AND PEDESTRIANS (R10-15 alt.) sign may be used to notify permissive left or right turning motorists of the requirement to yield to bicyclists at the crossing (see **EXHIBIT 4AA**). If used at a crossing, the sign should be mounted on the far side of the intersection to improve visibility to left turning motorists. If possible, it should be mounted on the vehicle sign face.

R10-15 alt.

EXHIBIT 4AA: TURNING VEHICLES YIELD TO BICYCLES AND PEDESTRIANS Sign

4.4.5 YIELD HERE TO BICYCLES SIGNS

At locations where yield lines are provided to denote the location for motorists to yield to bicyclists in crossings of separated bike lanes, a YIELD HERE TO BICYCLES (R1-5 alt. A) sign may be used (see **EXHIBIT 4AB**). If the yield condition includes pedestrians, the YIELD HERE TO BICYCLES AND PEDESTRIANS (R1-5 alt. B) sign may be used (see **EXHIBIT 4AC**). These signs are not required, and should not be used in locations where sign clutter is an issue.

R1-5 alt. A

EXHIBIT 4AB: YIELD HERE TO BICYCLES Sign

R1-5 alt. B

EXHIBIT 4AC: YIELD HERE TO BICYCLES AND PEDESTRIANS Sign

Washington, DC

4.4.6 PEDESTRIAN CROSSING

Marked crosswalks delineate the desired crossing point for pedestrians across a separated bike lane. They increase awareness of the crossing point for bicyclists and pedestrians, indicate priority for pedestrians at the crossing, and guide pedestrians across the bike lane in a direct path. Pedestrian crossings of the bike lane should be marked with continental striping. At uncontrolled crossings, yield lines may be provided on the bike lane approach to the crossing to indicate pedestrian priority. Section 4.3.1 provides additional guidance on curb ramps and accessibility considerations, such as detectable warning panels. EXHIBIT 4AD and EXHIBIT 4AE illustrate crosswalk design options for pedestrian crossings of separated bike lanes. Narrower width crosswalks are preferable at locations where separated bike lanes are less than **6 ft.** in width.

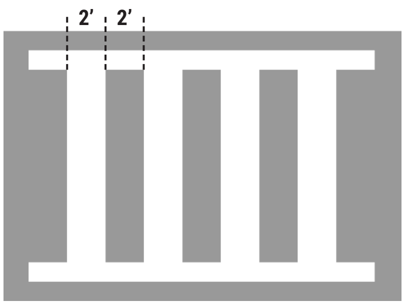


EXHIBIT 4AD: Pedestrian Crosswalk in Bike Lane, Option 1

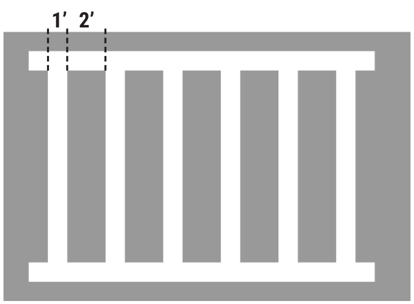


EXHIBIT 4AE: Pedestrian Crosswalk in Bike Lane, Option 2

4.4.7 BEGIN RIGHT TURN YIELD TO BIKES SIGN

The BEGIN RIGHT TURN YIELD TO BIKES sign (R4-4) should be placed at locations where the beginning of the right turn lane corresponds with the merge point where motorists cross the separated bike lane (see EXHIBIT 4AF).

MUTCD R4-4

EXHIBIT 4AF: BEGIN RIGHT TURN YIELD TO BIKES Sign

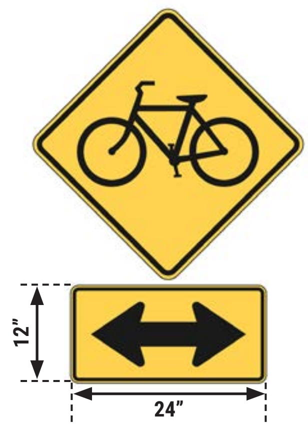
4.4.8 BICYCLE WARNING SIGN

The BICYCLE WARNING sign (W11-1) may be placed at, or in advance of, uncontrolled crossings of separated bike lanes to alert motorists of approaching bicyclists.

The use of the sign should be limited to locations where the bike lane may be unexpected to crossing motorists. A TWO-WAY (W1-7 alt.) supplemental plaque should be mounted below the W11-1 where the separated bike lane operates as a two-way facility (see EXHIBIT 4AG).

If used at a crossing, the sign should be mounted as close as practical to the crossing.

If used in advance of the crossing, the sign should be located a minimum of **100 ft.** prior to the crossing in a location visible to the motorist. A NEXT RIGHT or NEXT LEFT supplemental plaque may be mounted below the W11-1 if appropriate.



MUTCD W11-1

W1-7 alt.

EXHIBIT 4AG: BICYCLE WARNING Sign and TWO-WAY sub-plaque

4.4.9 BICYCLE/PEDESTRIAN WARNING SIGN

The BICYCLE/PEDESTRIAN WARNING sign (W11-15) may be used in lieu of the W11-1 at locations where a sidewalk is parallel to the separated bike lane and motorists may not be expecting to cross either the bicycle or pedestrian crossing (see **EXHIBIT 4AH**).

MUTCD W11-15

EXHIBIT 4AH: BICYCLE/PEDESTRIAN WARNING Sign

4.4.10 TWO-STAGE TURN QUEUE BOX

A two-stage turn queue box should be considered where separated bike lanes are continued up to an intersection and a protected intersection is not provided. The two-stage turn queue box designates a space for bicyclists to wait while performing a two-stage turn across a street at an intersection outside the path of traffic (see **EXHIBIT 4AI**).

At the present time, two-stage turn queue boxes are considered experimental, therefore FHWA must approve the RFE prior to the 100 percent design submittal.

Two-stage turn queue box dimensions will vary based on the street operating conditions, the presence or absence of a parking lane, traffic volumes and speeds, and available street space. The queuing area should be a **minimum of 6.5 ft.** deep (measured in the longitudinal direction of bicycles sitting in the box). The box should consist of a green box outlined with solid white lines supplemented with a bicycle symbol. A turn arrow may be used to emphasize the crossing direction.

The turn box may be placed in a variety of locations including in front of the pedestrian crossing (the crosswalk location may need to be adjusted), in a 'jug-handle' configuration within a sidewalk, or at the tail end of a parking lane or a median island. The queuing area should be placed to provide clear visibility of bicyclists by motorists. Dashed bike lane extension markings may be used to indicate the path of travel across the intersection. NO TURN ON RED (R10-11) restrictions should be used to prevent vehicles from entering the queuing area.

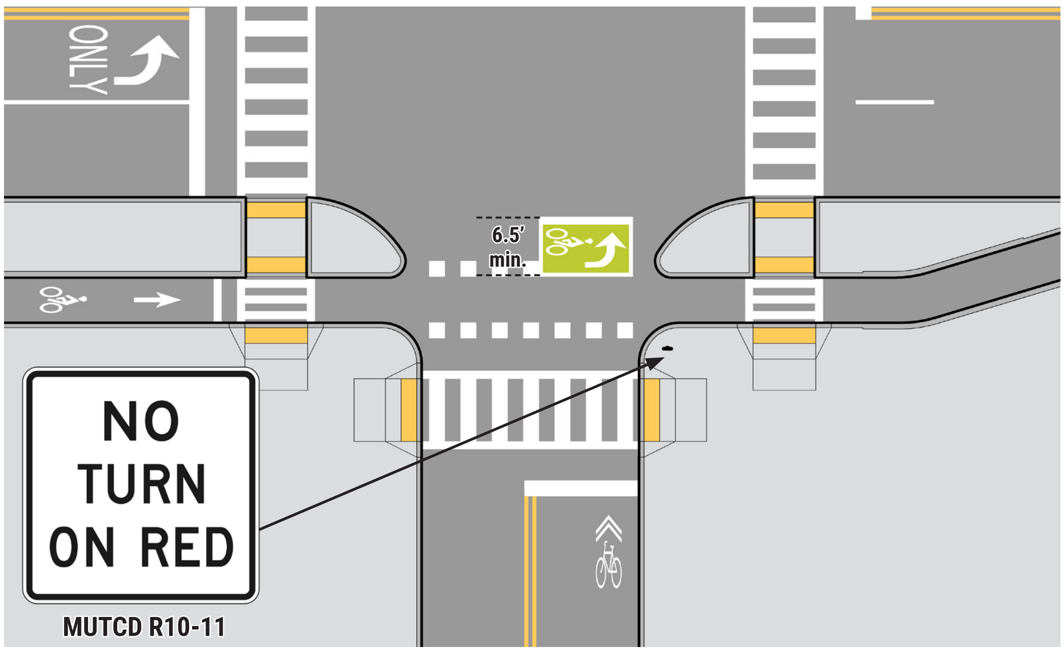


EXHIBIT 4AI: Two-stage Turn Queue Box and NO TURN ON RED Sign

4.5 EXAMPLES OF TRANSITIONS BETWEEN BIKEWAY TYPES

Transitions between separated bike lanes and other bikeways types will typically be required for all projects. The actual transition design will vary greatly from location to location depending upon many of the contextual factors discussed in Section 4.1. The transition design should clearly communicate how bicyclists are intended to enter and exit the separated bike lane minimizing conflicts with other users.

Transitions of two-way separated bike lanes to bikeways or shared streets that require one-way bicycle operation require particular attention. Bicyclist operating contra-flow to traffic will be required to cross the roadway. Failure to provide a clear transition to the desired one-way operation may result in wrong way bicycle riding. The use of directional islands can provide positive direction for bicyclists to follow the desired transition route. It may also be desirable to use green crossings and two-stage queue boxes to provide strong visual guidance to all users of the intended path across the intersection. The crossing may warrant bicycle signals at signalized crossings. The signal should be coordinated with the cross street signal phase.

EXHIBIT 4AJ to EXHIBIT 4AM provide illustrations of some example transitions.

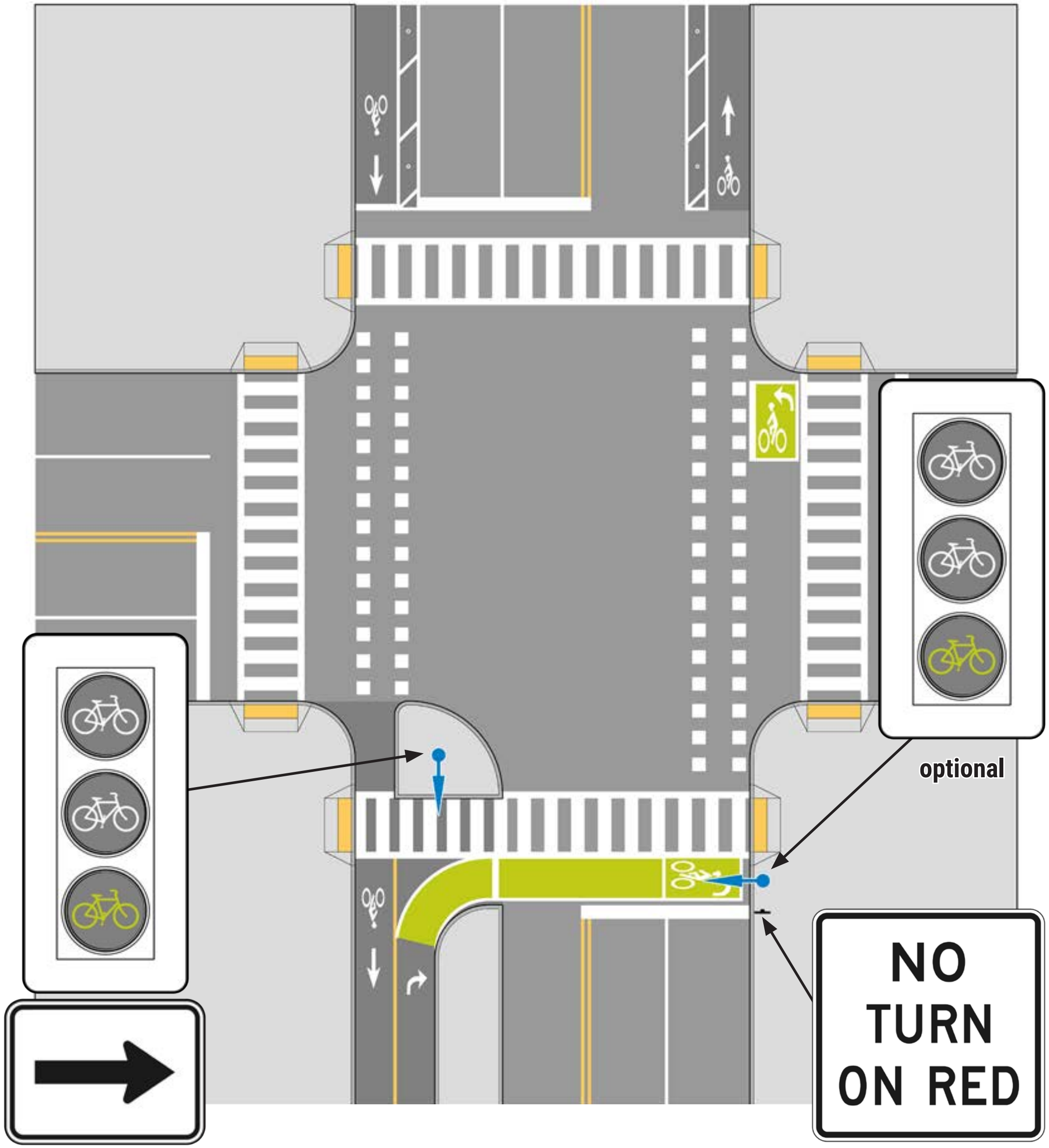


EXHIBIT 4AJ: Transition from a Two-way Separated Bike Lane

EXHIBIT 4AK: TRANSITION INTO A TWO-WAY SEPARATED BIKE LANE

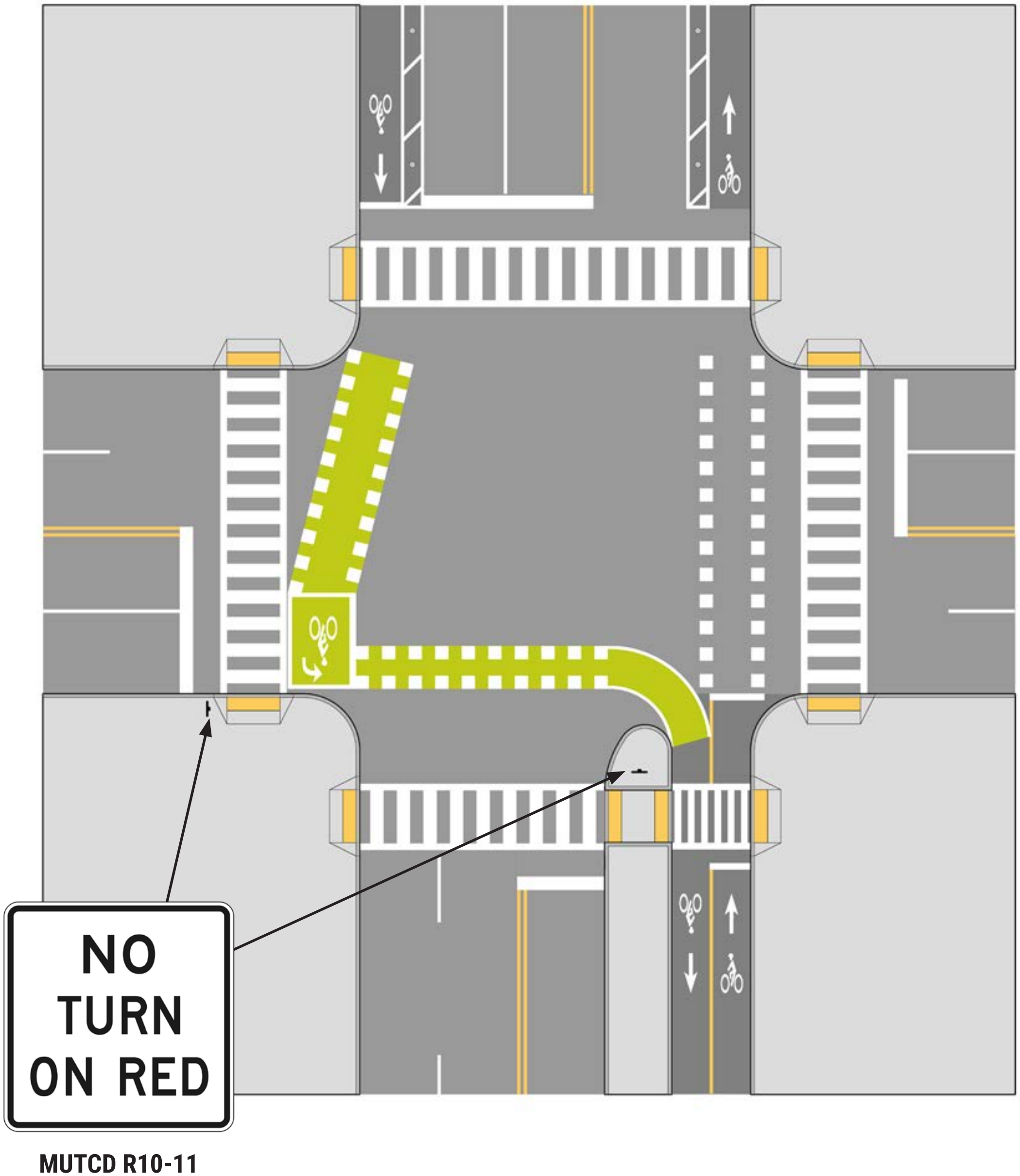
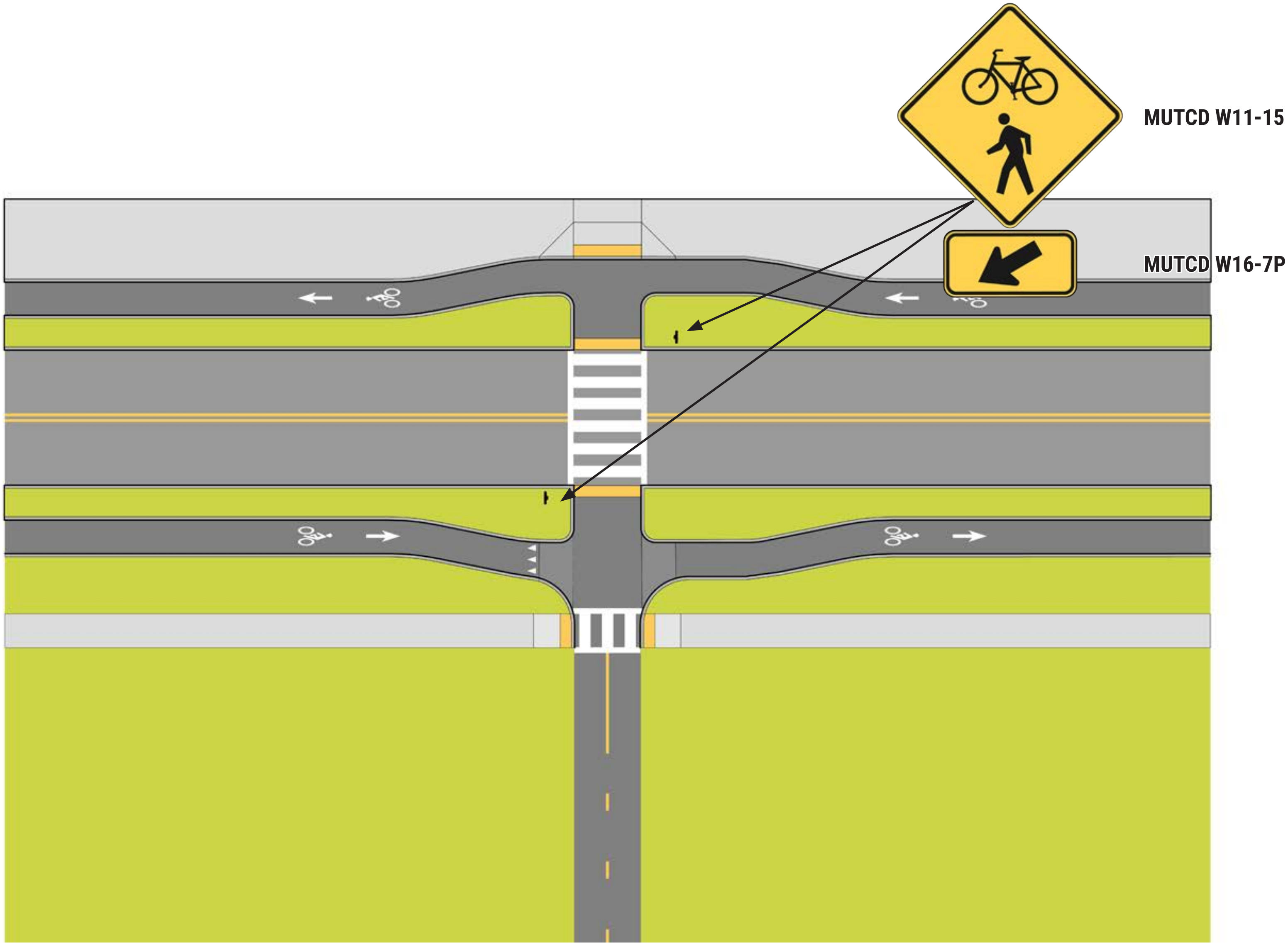


EXHIBIT 4AL: TRANSITION BETWEEN SEPARATED BIKE LANES AND SHARED USE PATHS



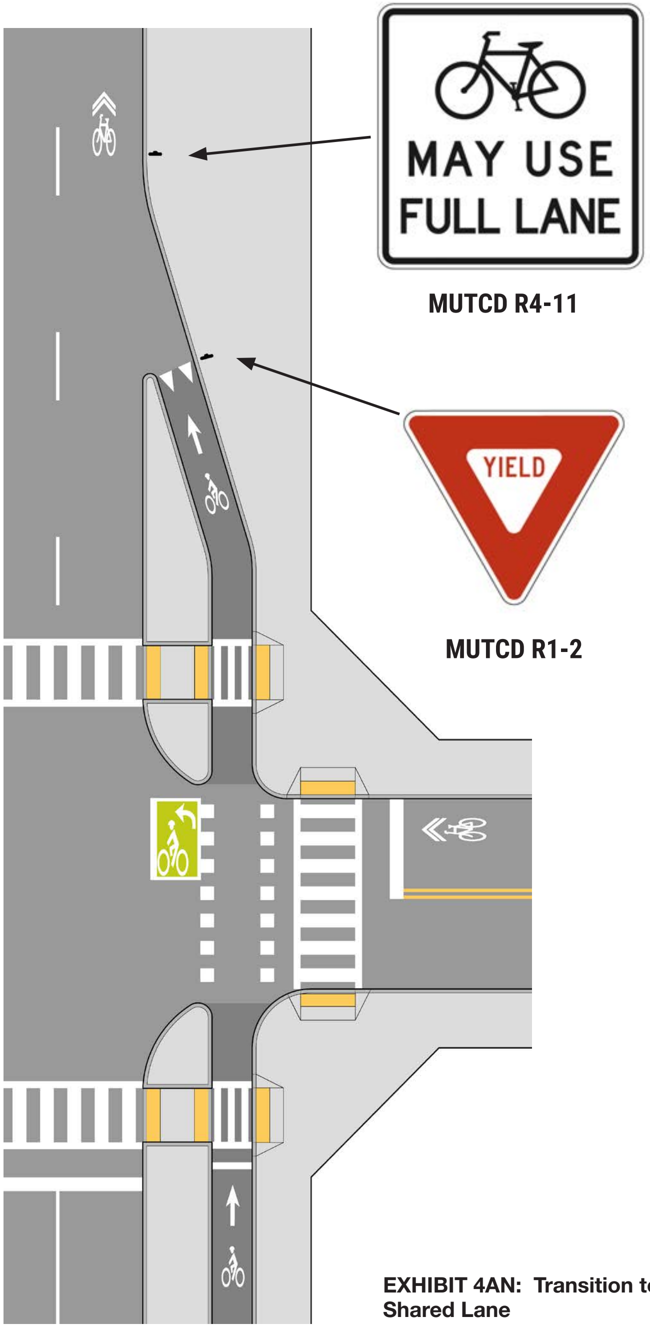


EXHIBIT 4AN: Transition to Shared Lane

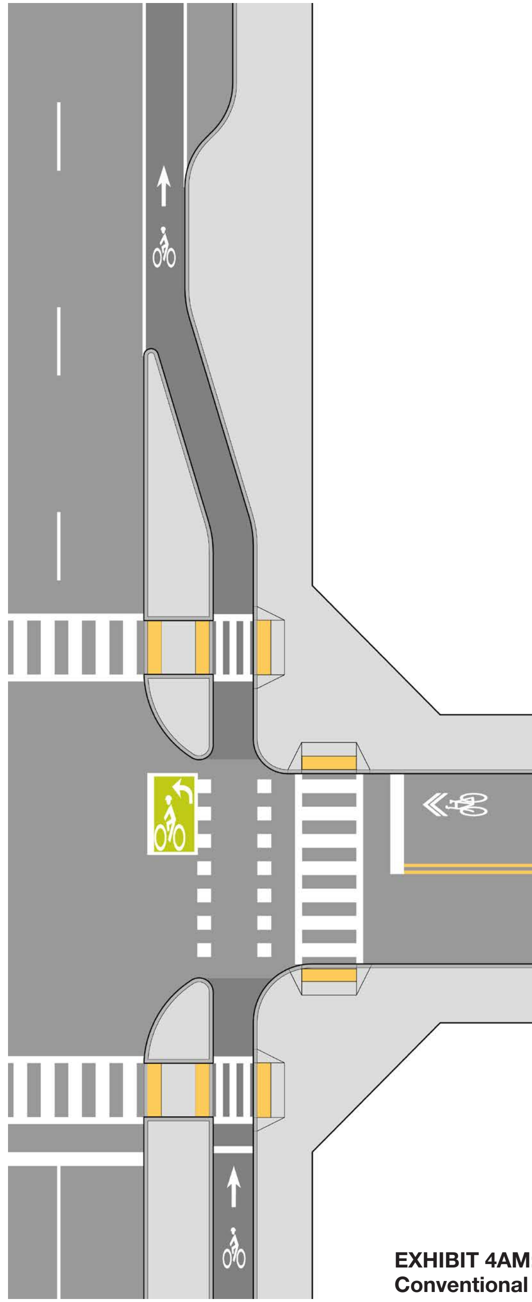


EXHIBIT 4AM: Transition to Conventional Bike Lane

4.6 ENDNOTES

1 Salamati et al., 2013. Event-based Modeling of Driver Yielding Behavior to Pedestrians and Two-Lane Roundabout Approaches. Transportation Research Record, 2013(2389): 1-11. Accessed via: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3947582/

2 Schepers et al., 2010. Road factors and bicycle-motor vehicle crashes at unsignalised priority intersections

3 Garder et al., 1998. Measuring the safety effect of raised bicycle crossings using a new research methodology

4 Schepers J, Kroeze P, Sweers W, Wust J, 2010. Road factors and bicycle-motor vehicle crashes at unsignalized priority intersections. Accidents Analysis and Preventions 43 (2011) 853-861.

5 Assumes motorists approach turn decelerating at rate of 11.2 ft./sec.^{2}, constant bicycle speed of 14 mph on level terrain, 1 second reaction times for bicyclists and motorists

6 Schepers, J. P., Kroeze, P. A., Sweers, W., & Wüst, J. C., 2011. Road factors and bicycle–motor vehicle crashes at unsignalized priority intersections. Accident Analysis & Prevention, 43(3), 853-861.

7 Brüde, Ulf and Jörgen Larsson, 1992. "Road Safety at Urban Junctions." Swedish Road and Traffic Research Institute. Report VTI Meddelande 685, 1992.

8 Schnüll, R., Lange, J., et al., 1992. Cyclist Safety at Urban Intersections , in German (Sicherung von Radfahrern an städtischen Knotenpunkten). BASt [German Federal Highway Research Institute], Bergisch Gladbach.

9 Welleman, A.G., Dijkstra, A., 1988. Safety Aspects of Urban Cycle Tracks (Veiligheidsaspecten van Stedelijke Fietspaden). Institute for Road Safety Research, Leidschendam.

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