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MEMORANDUM

June 6, 2023

To: Keith Hamas
Organization: North Jersey Transportation Planning Authority
From: Michael Blau and Jake Berman
Project: North Jersey Transportation Planning Authority Regional Active Transportation Plan

Re: Case Study 3: Active Transportation Facility Design at Highway Interchanges – FINAL

Introduction

Many regional active transportation network segments are on high-volume state highway corridors that include interchanges, and on major roads that cross through interchanges; as such, these segments are not presently conducive to active transportation. However, walk/bike potential does exist in these areas, and interchanges can be improved to safely accommodate people walking and biking as the network is built out.

Interchanges are designed to move high volumes of traffic while also striving to improve safety primarily for vehicles. In some cases, these intersections can improve bicyclist safety and comfort by limiting conflict points compared to traditional intersections. This memo includes design guidance and provides high-level principles that planners and designers should consider as they implement the regional active transportation network. It is divided into the following sections:

- **Recommendations** – Provides detailed design guidance for accommodating active transportation users at interchanges; recommendations contained herein are based on the draft American Association of State Highway and Transportation Officials (AASHTO) *Guide for the Development of Bicycle Facilities* (2023 edition, publication forthcoming). Design guidance for specific interchanges in the NJTPA region is not included. Table 1 provides a summary of safety issues and recommended design solutions, with links to additional information in the recommendations section.
- **Methodology** – Describes the geospatial analysis that identified existing facilities as well as regional active transportation network segments, developed as part of the NJTPA's regional Active Transportation Plan, that cross highway interchanges within the NJTPA region.
- **Results** – Includes a summary of these segments and their distribution across the region by county. A complete list of locations and dataset have been submitted separately.

Table 1: Summary of Safety and Design Issues and Recommended Solutions

Safety and Design Issues	Relevant Section *(click links for more information)*	Selected Treatments
Crossings of free-flow, potentially high-volume, motor vehicle movements	Bicycle Crossings at Ramps	▪ Transition on-street bike lane to separated bike lane or sidepath ▪ Create a protected intersection ▪ Mountable truck apron ▪ Raised crosswalk (below 30 mph) ▪ Active warning device or traffic signal ▪ Warning signage ▪ Green-colored pavement
Exposure to higher-speed traffic	▪ Bicycle Crossings at Ramps ▪ Minimize Conflicts with Motor Vehicles ▪ Channelized Right-Turn Lanes	▪ Active warning device or traffic signal ▪ Design interchange junctions as right-angle intersections ▪ Minimize high-speed merging lanes and free-flow traffic movements
Weaving movements across a bicyclist's path of travel and other travel lanes	Merging and Weaving Areas	▪ Transition on-street bike lane to separated bike lane or sidepath ▪ Warning signage ▪ Green-colored pavement
Designs which require unconventional travel paths and may result in routing confusion	Bicyclist Routing and Delay	▪ Provide a highly visible and coherent route ▪ Provide straight line routing through intersections for on-street bike facilities ▪ Provide dotted lane lines through wide intersections ▪ Accommodate desire lines of bicycle travel and reduce out-of-direction travel ▪ Minimize grade changes ▪ Minimize bicyclist exposure to high-speed and/or free-flowing traffic movements
Multi-stage crossings or transitions which can increase bicyclist travel time or delay	Bicyclist Routing and Delay	▪ Minimize the use of multi-stage crossings except where a multi-stage crossing can reduce delay or eliminate crossings of high-volume, free-flow ramps
Long crossings which increase exposure and, in some cases, do not provide adequate clearance intervals at	▪ Minimize Conflicts with Motor Vehicles ▪ Ramp Skew ▪ Exit Ramps and Merging Areas	▪ Minimizing exposure to conflicts with motorists by creating short crossing distances and physically separated bikeways

Safety and Design Issues	Relevant Section *(click links for more information)*	Selected Treatments
signalized crossings for bicyclists to fully traverse the crossing	▪ Additional Conflict Mitigation Treatments ▪ Channelized Right-Turn Lanes	▪ Design perpendicular crossings across exit and entrance ramps ▪ Transition on-street bike lane to separated bike lane or sidepath ▪ Install channelized right-turn refuge island
Bikeways with constrained widths adjacent to higher-speed traffic	Designs that Place Bicyclists in Constrained Areas	▪ Include adequate buffer space ▪ Install crashworthy barriers or other vertical separation
Conditions that require bicyclists to operate with pedestrians in crosswalks and other shared use facilities	Minimize Conflicts with Pedestrians	▪ Maximize visibility between bicyclists and pedestrians ▪ Where separated bike lanes are provided, continue to separate bicyclists and pedestrians at crossings ▪ In shared use paths, ensure that there is adequate width for safe passing between bicyclists and pedestrians ▪ Provide curb ramps which match the full width of shared use paths

Recommendations

This section provides detailed design guidance for accommodating active transportation users at interchanges; recommendations contained herein are based on the draft AASHTO *Guide for the Development of Bicycle Facilities*, (2023 edition, publication forthcoming).

Additional guidance for accommodating bicyclists and pedestrians can be found in the ITE Recommended Design Guidelines to Accommodate Pedestrians and Bicycles at Interchanges[i], NCHRP Report 674, Crossing Solutions at Roundabouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities,[ii] and in NCHRP Report 948, Guide for Pedestrian and Bicycle Safety at Alternative and Other Intersections and Interchanges.[iii]

Basic Design Principles

The design of interchanges should consider the safety and comfort of bicyclists. Where these intersections must accommodate high volumes of vehicles and have design features allowing motorists to operate at speeds exceeding 25 mph, only more experienced bicyclists may feel able or willing to navigate them in shared lanes or bicycle lanes. Additionally, crossings of uncontrolled ramps designed to move higher volumes of traffic, as well as merging and weaving areas, can present safety problems for people riding bicycles. In locations where alternative routes are not available or practical, these locations become major barriers that can discourage bicycling and walking.

For a separated bikeway to provide the desired level of comfort and safety, crossings of traffic streams will require special consideration. The geometric and operational design of interchanges, alternative intersections, and roundabouts will vary widely to suit the contextual conditions for each location.

Identifying Conflict Scenarios

Interchanges include one or more of the following geometric design features which can create challenges and present barriers to bicyclists compared to traditional intersections:

- Crossings of free-flow, potentially high-volume, motor vehicle movements,
- Exposure to higher-speed traffic,
- Weaving movements across a bicyclist's path of travel and other travel lanes,
- Designs which require unconventional travel paths and may result in routing confusion,
- Multi-stage crossings or transitions which can increase bicyclist travel time or delay,
- Long crossings which increase exposure and, in some cases, do not provide adequate clearance intervals at signalized crossings for bicyclists to fully traverse the crossing,
- Bikeways with constrained widths adjacent to higher-speed traffic, and
- Conditions that require bicyclists to operate with pedestrians in crosswalks and other shared use facilities.

These common scenarios should be reviewed at all interchanges. Figure 1 illustrates an example interchange between an arterial and a limited access highway to show the location of these potential conflicts. The right half of the interchange is structured in the familiar partial cloverleaf style and the left half uses diamond interchange movements.

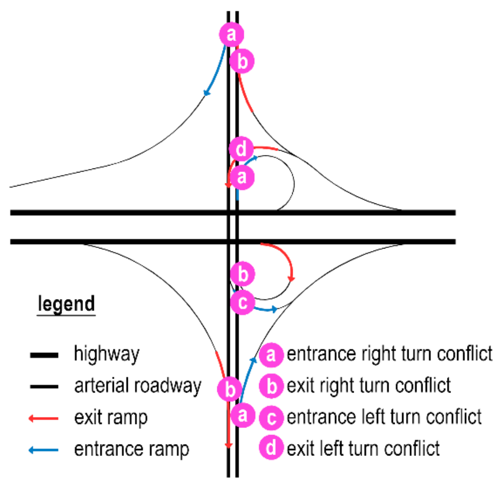


Figure 1: Example Interchange Bicyclist/Motorist Conflict Areas

Common design challenges at interchanges along with potential countermeasures to eliminate or reduce the safety risk associated with these challenges are discussed throughout this section.

Bicyclist Routing and Delay

The design principles associated with best practices for bicyclist routing and minimizing delay include:

- Provide a highly visible and coherent route.
- Allowing bicyclists to proceed through the intersection in a relatively straight line if on-street bike facilities are provided.
- Dotted lane lines should be provided to guide bicyclists through wide intersections.
- Accommodating the desire lines of bicycle travel and reducing out-of-direction travel.
- Minimize grade changes (unless grade separation is provided).
- Minimizing the use of multi-stage crossings except where a multi-stage crossing can reduce delay or eliminate crossings of high-volume, free-flow ramps.
- Minimizing bicyclist exposure to high-speed and/or free-flowing traffic movements.

Minimize Conflicts with Motor Vehicles

The design principles associated with best practices for minimizing bicyclist/motorist conflicts include:

- Maximizing visibility between bicyclists and motorists by:
  - Providing bicycle crossings that are as perpendicular to conflicting motorists as possible,
  - Providing bicycle crossings in conspicuous locations,
  - Providing adequate lighting at the crossing locations where night travel is likely, and
  - Ensuring required sight distance is provided between motorists and bicyclists.
  - Providing separated bikeways or transitioning bicyclists to off-street bikeways through high-speed and/or high-volume conflict areas.
  - Minimizing motor vehicle speed differential to bicyclists at conflict areas by:
    - Reducing motorist speeds to 20 mph or less where bicyclists cross a motorist's path,
    - Minimizing or avoiding the use of high-speed merging lanes and free-flow traffic movements,
    - Design interchange junctions as right-angle intersections or providing a roundabout (see Section 11.10.),
    - Minimizing corner radii to slow turning speeds, and
    - Using traffic calming measures such as raised crossings.
- Minimizing the severity of crashes occurring at conflict points where they cannot be eliminated by:
  - Separating movements using traffic controls,
  - Minimizing exposure to conflicts with motorists by creating short crossing distances and physically separated bikeways,
  - Avoiding designs that require bicyclists to merge across multiple lanes of traffic to execute a turn, and
  - Minimizing speed differential at conflict points.

Providing adequate signal timing for bicyclists to completely clear intersections before permitting conflicting movements to proceed or providing bicyclists with an option to operate outside the roadway to cross at locations where they can be accommodated.

Minimize Conflicts with Pedestrians

The design principles associated with best practices for minimizing bicyclist/pedestrian conflicts include:

- Maximizing visibility between bicyclists and pedestrians,
- Where separated bike lanes are provided, continuing to separate bicyclists and pedestrians at crossings,
- In shared use paths, ensuring that there is adequate width for safe passing between bicyclists and pedestrians, and
- Providing curb ramps which match the full width of shared use paths.

Exit and Entrance Ramps

Exit and entrance ramps are common in many large intersection types. The potential for conflicts between motorists and bicyclists at these ramps is greater in locations where geometry encourages higher motorist operating speeds and higher traffic volumes reduce the availability of gaps at uncontrolled crossing locations. In Figure 7, shown previously, entrance and exit ramp conflicts can be seen where the ramp to the highway diverges from the arterial roadway. The merging conflicts present higher risks where there are multiple threats (i.e., where bicyclists must cross multiple lanes of vehicular traffic) or allow free-flow speeds. The left turn conflicts present higher risks where they require motorists to judge gaps on multiple lane approaches and on roadways where operating speeds are higher as they turn across the arterial roadway to enter or leave the highway ramps.

Ramp Skew

A motorist's speed approaching a ramp conflict point is often a function of the angle of the ramp where it intersects the roadway. Where the ramp approach angle is less than 60 degrees, motorists can maintain higher operating speeds as they near a crossing or merge point with the intersecting roadway. Flatter approach angles of 20-30 degrees are common in locations where roadways are intended to operate at higher speeds to facilitate merging and maintain traffic flow. A flat approach angle at the point where the roadways merge or diverge also increases bicyclist exposure to merging and weaving traffic by lengthening the crossing distance. Motorists are less likely to yield to a pedestrian or bicyclist when they are approaching a crossing at speeds over 30 mph.

Some motorists have difficulty with skewed approaches, due to a restricted range of motion in their bodies which can make it harder to scan for approaching conflicts which can increase crash risks if a conflict is imminent. Approach angles between 75 and 90 degrees are preferable to help these users navigate intersections.

Where an uncontrolled ramp approach angle is greater than 60 degrees, motorists will have to slow substantially or stop before executing their merge or turn onto the intersecting roadway, increasing the likelihood that the motorist will yield appropriately to a pedestrian or bicyclist at a crossing or in the merging area. Approaches with angles between 60 and 90 degrees minimize bicyclist exposure at the point where the roadways merge by shortening the crossing distance (see Figure 2). Accordingly, to provide a low stress bicycle crossing, ramp approach geometry should be evaluated for opportunities to manage motor vehicle speeds at crossings and at locations where motorists must merge across bikeways.

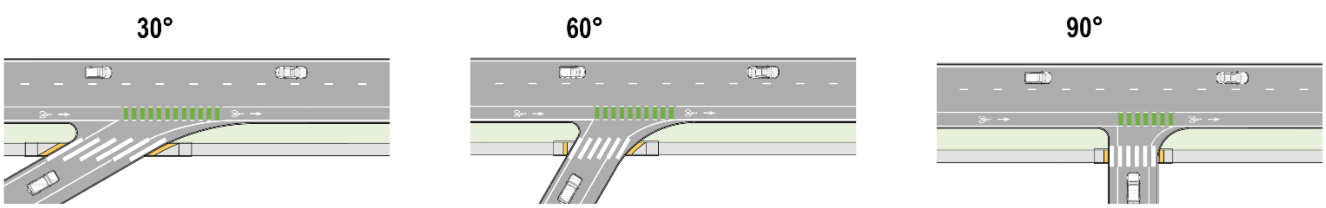


Figure 2: Examples of 30-, 60-, and 90-Degree Roadway Intersections

Potential Conflict Mitigation Treatments

To promote motorist yielding, ramps should be designed to lower motorist speeds to 20 mph or less at the point of conflict by designing the ramps to intersect the crossing roadway at an angle between 60 and 90 degrees.[iv] For existing skewed ramps, consider retrofit treatments until reconstruction can be undertaken. These retrofit treatments may include:

- Pavement markings and flexible delineator posts to reduce the skewed angle and to define and shorten conflict areas,
- Raised crossings and speed tables to reduce vehicle speeds at conflict areas,
- Mountable truck aprons, and
- Actuated beacons or traffic signals.

Bicycle Crossings at Ramps

Ramps can present challenges for bicyclists where motorists expect to accelerate onto a freeway or high-speed roadway. Locations where bicyclists must cross a ramp should be managed according to the design principles above. At all bicycle crossings of ramps the designer should consider whether a bicycle lane, separated bike lane, or a side path is most appropriate.

Entrance Ramps

Many of the safety challenges associated with entrance ramps are due to right- and left-turn movements across a bikeway to access the ramp. Right-turn movements may be free-flow, stop-controlled, or signalized.

Ramp Crossings with Low Volumes of Right Turns

For ramp crossing locations where vehicle speeds are likely to be 20 mph or less at the crossing and low right turning motor vehicle ramp volumes result in regular gaps in traffic, it may be acceptable to provide on-street bike lanes through the ramp as shown in Figure 3. The conflict zone with turning motorists is recommended to be marked with dotted lines with Bicycle-Pedestrian Warning signs (W11-15) signs at the crossing.

Where enhanced conspicuity is critical due to vehicles speeds exceeding 20 mph or where motorists are failing to yield, additional emphasis can be provided by one or more of the following strategies:

- green-colored pavement within the bike lane and bike crossing,
- wider bicycle lane lines, or
- advanced warning signs or regulatory signs advising motorists to yield to bicyclists when turning.

At locations where the ramp geometry will result in vehicle speeds being higher than 20 mph at the conflict point, consideration should be given to providing a truck apron to slow turning motorists while still accommodating the needs of larger vehicles.

Ramp Crossings with Moderate to High Volumes of Right Turns

At locations with moderate to high volumes of right turning motor vehicles where right-turn lanes cannot be provided, a curbside on-street bike lane may result in increased conflicts between motorists and bicyclists at the ramp entrance. In these locations, it may be desirable to transition the on-street bike lane to a separated bike lane to consolidate the pedestrian and bicycle crossing to a consolidated conflict point (see Figure 4) and create a protected intersection. The separated bike lane crossing and pedestrian crosswalk should be set back 6 ft to 16.5 ft to improve yielding. Where it is desired for the yielding vehicle to not block a through lane, the crossing should be set back at least one motor vehicle length.

Mountable truck aprons may be considered to slow vehicle speeds approaching the crossing where a larger turn radius is required or existing to accommodate larger vehicles. Alternatively, in urban contexts where operating speeds are below 30 mph, a raised crosswalk may be considered for the bicycle and pedestrian crossing.

In locations where bicyclists are operating in shared lanes, shoulders, or bicycle lanes, consideration should be given to providing a bike ramp in advance of the entrance ramp to allow bicyclist to avoid the merging zone and to cross within a pedestrian crosswalk on a sidewalk or sidepath as shown in Figure 5. Where bicycle lanes are provided, they should continue through the ramp area to benefit those bicyclists who do not exit the roadway with consideration given to providing enhanced conspicuity treatments.

Where vehicle speeds and volumes limit yielding or traffic gaps, or where sight distance does not meet minimum stopping distance guidelines, it may be necessary to consider an active warning device or traffic signal. As vehicle speeds and volumes increase, the designer may consider grade separation to increase the level of safety and comfort for bicyclists and pedestrians and minimize delays for all users.

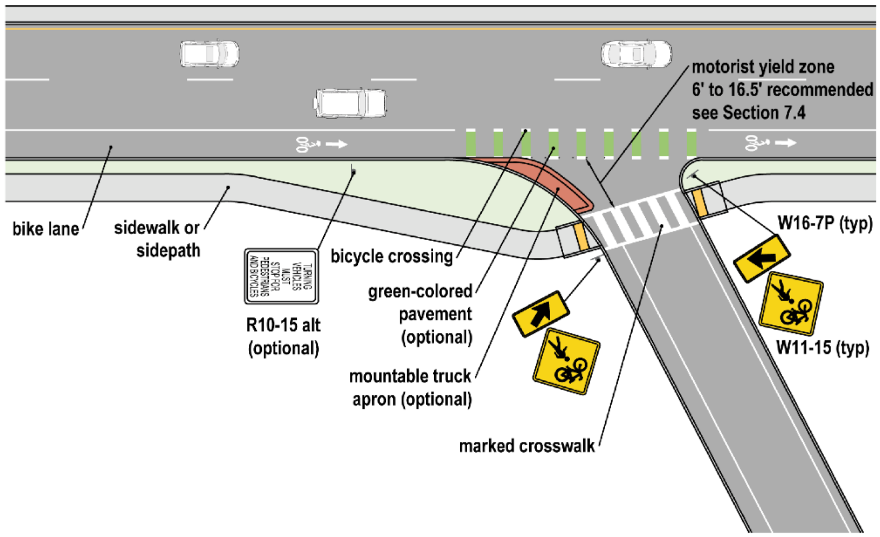


Figure 3: Entrance Ramp with Truck Apron and Bike Lane

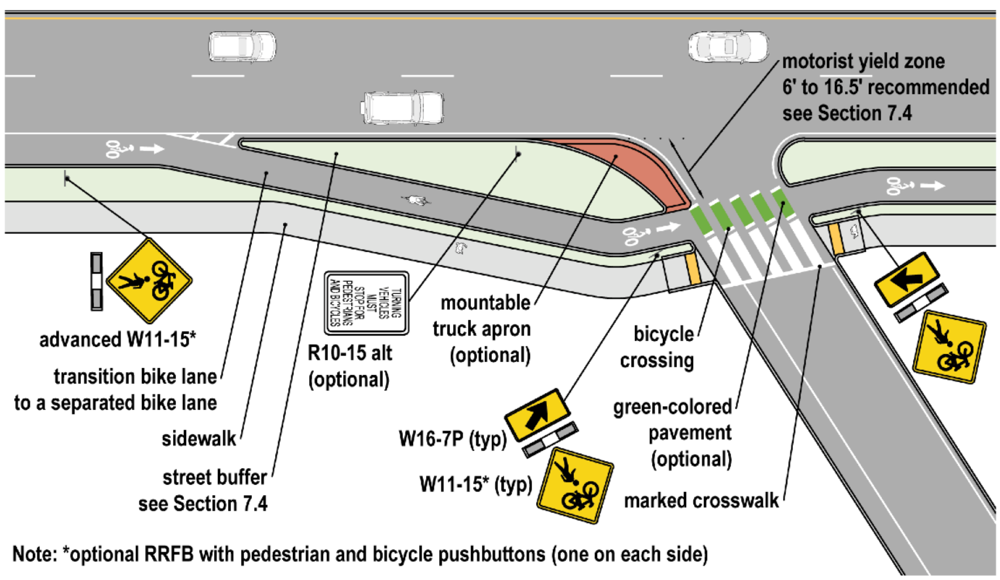


Figure 4: Entrance Ramp with Truck Apron and Separated Bike Lane

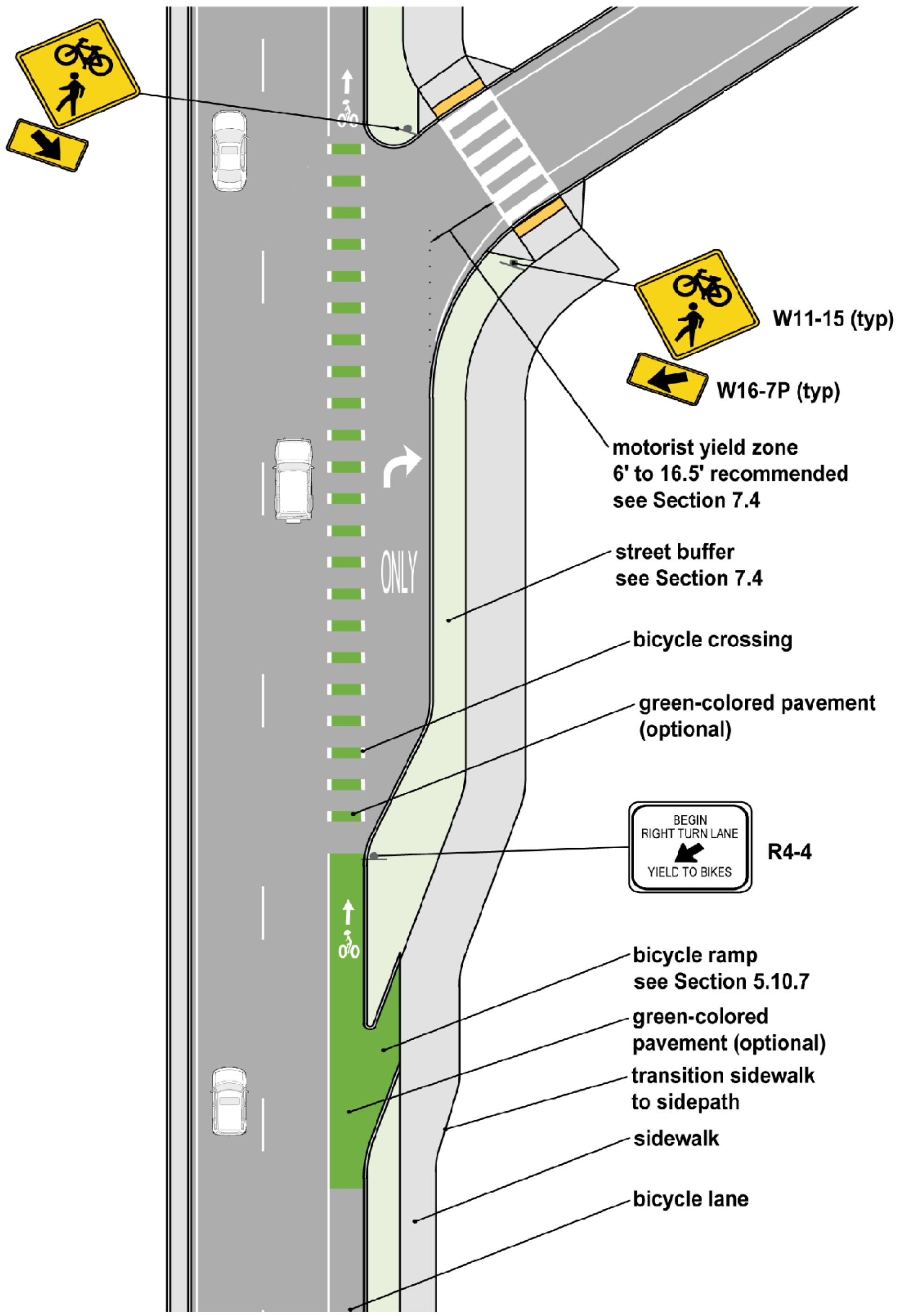


Figure 5: Entrance Ramp with Right-Turn Lane, Bike Lane, and Side Path

Exit Ramps and Merging Areas

Exit ramp configurations can be difficult for bicyclists to traverse due to intersecting roadway angles, undefined areas created by lanes merging, potentially poor visibility or inadequate sight distance between bicyclists and approaching motorists, and the often-significant speed differential between bicyclists and motorists. Some of these challenges can be mitigated by designing ramps to intersect roadways at an angle of 60 to 90 degrees or establishing signal control for the ramp. Where the ramp approach is less than 60 degrees, motorists may be more focused on looking for gaps and accelerating to merge into traffic and may neglect to scan for bicyclists.

Ramp Crossings with Low Volumes of Right Turns

For ramp crossing locations where vehicle speeds are likely to be 20 mph or less at the crossing and ramp volumes result in regular gaps in traffic, it may be acceptable to provide on-street bicycle lanes carried across the throat of the ramp as shown in Figure 12. A marked bicycle crossing with a BICYCLE warning sign (W11-1) should be placed before locations with bike lanes or Bicycle-Pedestrian Warning signs (W11-15) at locations with bicycle lanes, sidewalks or side paths.

Where enhanced conspicuity is critical, additional emphasis can be provided by one or more of the following strategies:

- green-colored pavement within the bike lane and bike crossing, or
- wider bicycle lane lines.

At locations where the ramp geometry will result in vehicle speeds being higher than 20 mph at the conflict point, consideration should be given to providing a truck apron to slow turning motorists while still accommodating the needs or larger vehicles as shown in Figure 6.

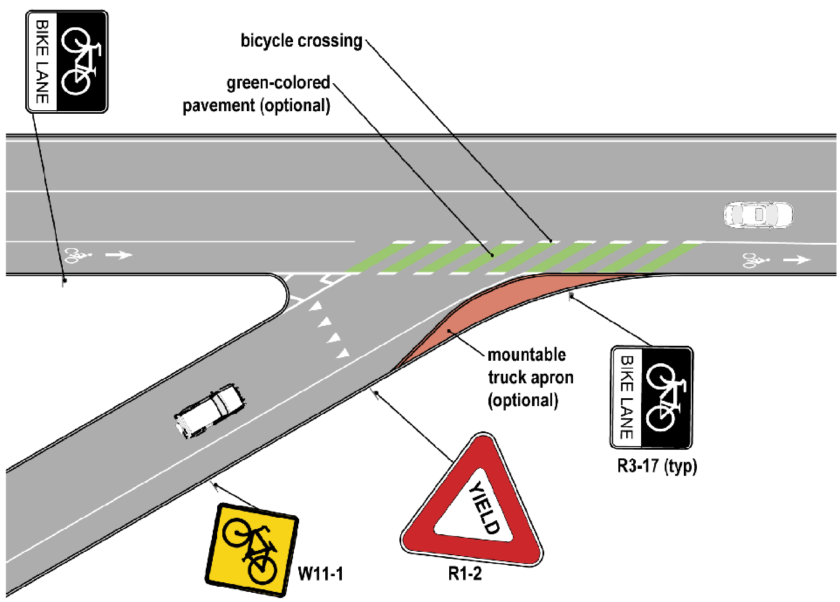


Figure 6: Bicycle Lane Carried Across an Exit Ramp Throat

At exit ramps where vehicle speeds and ramp volumes are high, the crossing distance and associated bicyclist exposure can be reduced by designing a crossing perpendicular to the ramp as shown in Figure 7. While a perpendicular crossing may have the shortest exposure, the crossing should strike a balance between the desired travel path of bicyclists and the minimized crossing distance to maximize bicyclists use. The crossing should be where bicyclists and motorists have adequate lines of sight and before the motorist's attention is focused on merging with traffic. Because motorists exiting a highway may be traveling faster than those turning from an arterial onto an entrance ramp, advance warning signs may be necessary to advise motorists to reduce their speed on the approach to the bike lane or shared use path crossing.

Where sight distance is limited between approaching motorists and bicyclists, or where motorist speeds or volumes are high, it may be appropriate to apply yield control to the bicycle approach as shown in Figure 13.

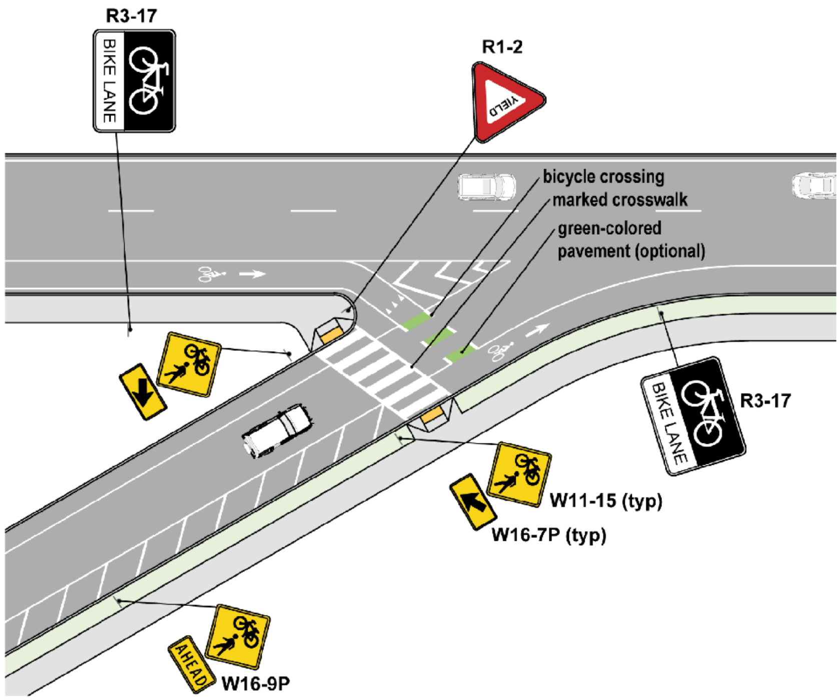


Figure 7: Bicycle Lane Shifted Perpendicular to Crossing of an Exit Ramp

Designs that permit high-speed free-flow movements from the exit ramp to the arterial roadway are not advised if regular bicycle and pedestrian activity is expected at the crossing location. If prevailing vehicle speeds and volumes result in poor yielding behavior or inadequate gaps in traffic, or where sight distance does not meet recommended minimums, it may be necessary to consider an active warning device or a traffic signal as shown in Figure 8.

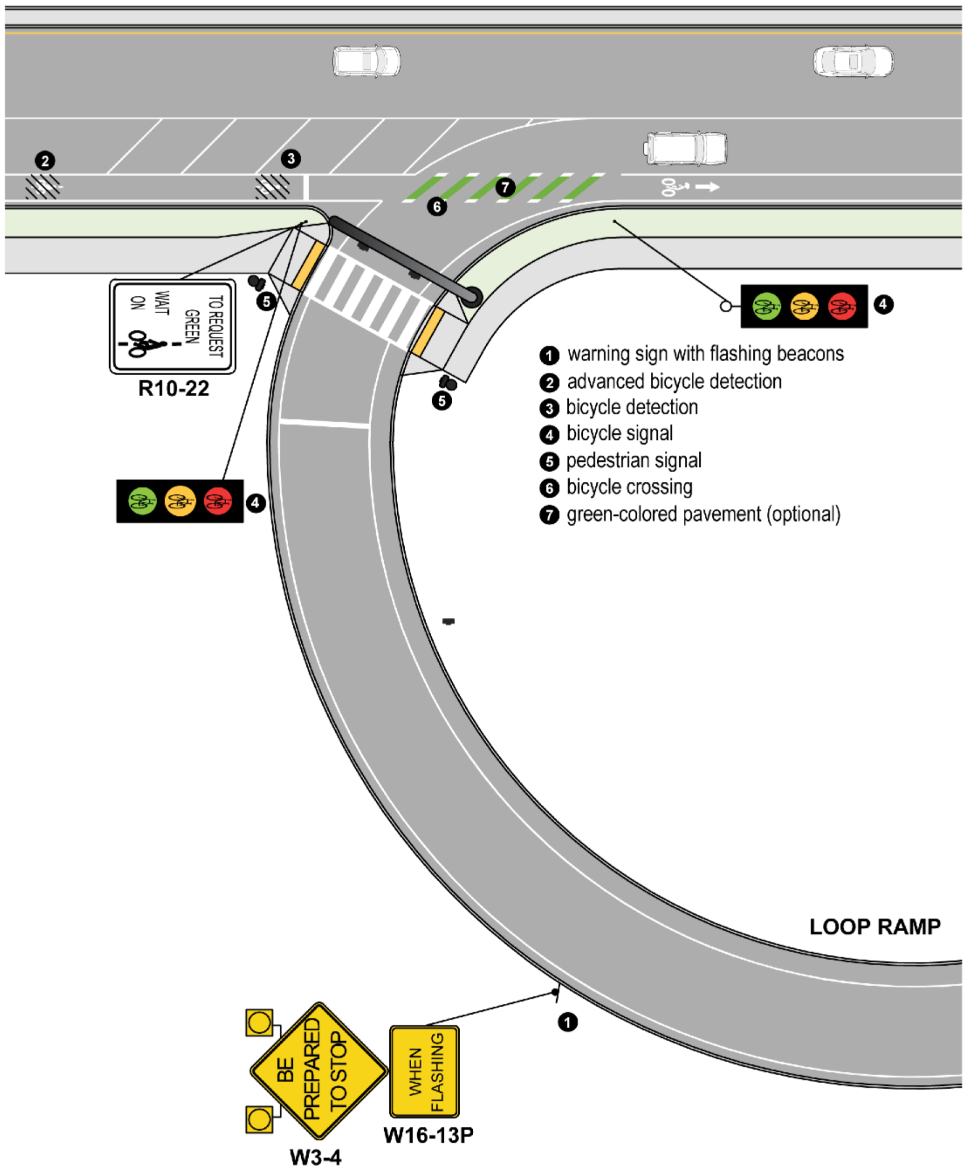


Figure 8: Exit Ramp with Bike Lane Crossing and Advance Warning or Traffic Signal

Additional Conflict Mitigation Treatments

If on-street bike lanes are present on intersection approaches, it may be desirable to provide a bicycle ramp to a separated bike lane or a side path to reduce exposure to merging traffic. This design can benefit less experienced bicyclists who may prefer to exit the roadway to cross ramps at marked crossings. Where on-street bicycle lanes transition to sidewalk level using a bike ramp, the sidewalk should be widened to a side path width until another bike ramp is provided to transition bicyclists back to an on-street bike lane.

Where side paths or separated bike lanes are proposed on intersection approaches, the designer will have to balance the location of the crossing with three key design principles:

- providing a direct crossing, ideally aligned perpendicularly to the entrance or exit ramp,
- locating the crossing to allow a yielding motorist to wait without blocking a through lane, and
- ensuring adequate sight distance is provided between the crossing and approaching motorists.

At bicycle and pedestrian crossing locations, motorists are typically required to stop or yield the right-of-way to people within the crossing. To make this requirement clear, it is recommended that a bike crossing be marked where bike lanes or separated bike lanes cross a ramp, or a wide high-visibility crosswalk be provided at locations where shared use paths cross ramps. To induce motorist yielding, the following treatments should be considered in order of increasing effectiveness:

- High-visibility crossing markings with Bicycle-Pedestrian Warning (W11-15) signs.
- Raised crossings.
- Rectangular Rapid Flashing Beacons (RRFB).
- Pedestrian Hybrid Beacon or Traffic Signal.

Merging and Weaving Areas

Many ramp locations where a merging or diverging movement occurs may also have weaving zones on the approach to, departure from, or between consecutive ramps. Under these conditions, the conflict zone for bicyclists is extended where acceleration/deceleration lanes are long. Ramp designs and weaving areas that create a multiple-threat condition or position bicyclists between two moving streams of traffic can exist in many of these same conflict areas and may be common in alternative intersection designs as well.

Cloverleaf, trumpet, and all-directional-style interchanges commonly include a weaving conflict area where some motorists exiting and entering the highway are crossing paths with each other within a limited distance. The increased motorist workload associated with these designs may degrade a motorist's ability to identify bicyclists in the weaving area. Bicyclists navigating within the weaving area are at increased risk of conflict as motorist operating speeds and volumes increase.

Placing a bike lane between two lanes of weaving motor vehicles exposes bicyclists to frequent and potentially sudden motor vehicle movements over a long distance (see Figure 9). While less than ideal, this design may be acceptable for experienced bicyclists at locations where vehicle speeds are 30 mph or less at the weaving area and traffic volumes result in regular gaps in traffic as a retrofit to existing locations. It is preferable that the bike crossing in these instances be marked with wide lane lines, complemented by supportive signing, to notify motorists of the potential for bicyclist conflicts. Consideration should be given to the use of colored pavement where bicycle volumes are higher.

For less experienced bicyclists, and in locations where vehicle speeds and volumes are high, designs that place the bike lane between travel lanes should be avoided. It may be appropriate through these high-intensity traffic areas to provide a bike ramp on the intersection approaches to relocate the bikeway from the roadway to a separated bike lane or a side path as shown in Figure 9.

Locations where travel lanes serve both through traffic and entrance ramp traffic can create a condition where bicyclists or pedestrians waiting to cross an uncontrolled ramp may not be able to discern if a motorist is turning onto the ramp or remaining on the main roadway. A bicyclist's or pedestrian's ability to gauge these gaps in traffic can be further complicated at multilane ramps that can create a potential multiple-threat crash.

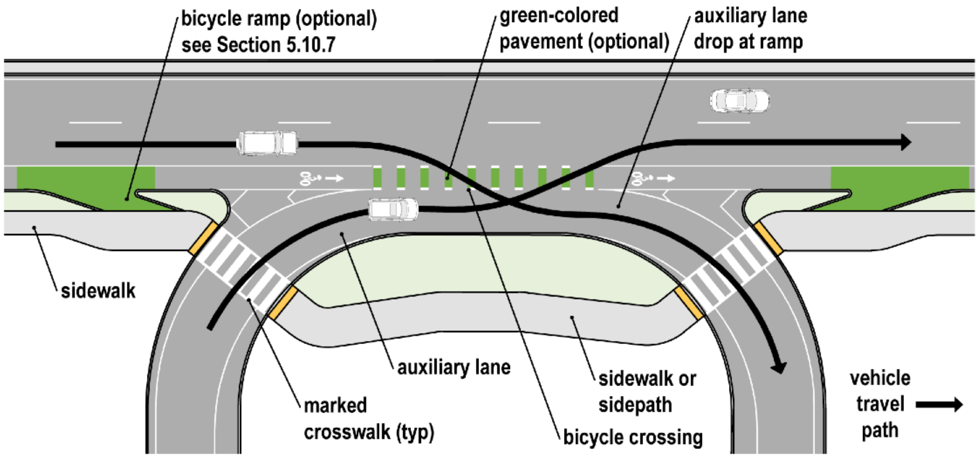


Figure 9: Bike Lane Positioned in High-Exposure Weaving Area

Multiple-Threat Conditions

A multiple-threat condition can exist at ramp or roadway crossing locations where bicyclists must cross more than a single lane of motor vehicle traffic traveling in the same direction. In a multiple-threat scenario, a motorist in the lane closest to the crossing bicyclist has stopped to yield the right-of-way, but a motorist in the adjacent lane approaches the crossing and does not stop. The danger in this scenario occurs when the bicyclist begins crossing based on the yielding behavior of the first motorist but continues into the path of the second motorist who has not yielded. Designs that introduce a multiple threat can occur at any uncontrolled, multiple-lane crossing, including entrance and exit ramps.

The designer should seek to eliminate multiple-threat conditions from any design. If the condition cannot be avoided, treatments to enhance visibility, reduce motorist speeds, or provide advance warning should be incorporated into the design to reduce the risk of a crash. These treatments may include:

- Stop or yield lines that are set back to increase sight distance between all users,
- Raised crossing,
- Pedestrian-activated warning beacons (RRFB or Pedestrian Hybrid Beacon) or signalization, and
- Adjusted geometry to discourage high speeds near the crossing.

Motorist Left Turns

In all intersection configurations, bicyclists are at increased risk of conflict where motorists must identify gaps in traffic before turning left across the bicyclist's path. Diamond interchanges and quadrant interchanges are typically designed with a variation on traditional intersection geometry which requires motorists to slow and stop before turning left across the opposing flow of traffic to access the highway ramp or arterial. In lower-volume locations this left-turn movement may be uncontrolled. As traffic volumes increase, the left turn movement is often signalized with permissive or protected phasing. To mitigate the issues of left turning motorists, the following countermeasures should be considered:

- To heighten motorist awareness of the potential presence of bicyclists or pedestrians in the crossing, the R10-15 sign can be used for left turn movements.
- Verify that adequate sight lines are provided between all users on the approaches to the crossing, including elimination of visual obstructions and ensuring that geometry does not obscure bicyclists on the approach behind queued vehicles.

- Where the motorist left turn can be controlled using a signal and protected left-turn phase, bicycle or pedestrian signals with separate phasing should be implemented to help separate these conflicting movements in time.
- Where enhanced conspicuity is critical, additional emphasis can be provided by one or more of the following strategies:
- green-colored pavement within the bike lane and bike crossing,
- wider bicycle lane lines, or
- advanced warning signs or regulatory signs advising motorists to yield to bicyclists when turning.

Designs that Place Bicyclists in Constrained Areas

Because large intersections are inherently uncomfortable for bicyclists, care should be taken to design bikeways that reduce the perceived threat and improve comfort for these users. Locating non-motorized facilities along medians or in other confined lateral positions between lanes of moving traffic can be uncomfortable for bicyclists and pedestrians.

If these conditions cannot be avoided, the design should include adequate buffer space (a street buffer width of 6 ft is recommended) between the motor vehicle lanes and the separated bike lane or side path (see Figure 10).

In addition, motor vehicle speeds may be high in the lanes bordering the bicycle and pedestrian route, potentially justifying construction of crashworthy barriers or other vertical separation along each side of the shared use path (see Figure 11). While these barriers can shield bicyclists and pedestrians from errant motor vehicles, they may also create a tunnel effect, where users must contend with intense motor vehicle noise and potential conflicts with other users in a physically constrained space. Wider paths or street buffers can improve the experience for all users of this space and create opportunities for the installation of vegetation to further enhance the space.

These designs typically do not provide an escape route from threats or hazards occurring between the walls which can present a personal security issue which may warrant additional mitigation considerations. Designers should weigh the safety benefits of constructing barriers along a side path within a constrained area with the potential experiences or perceptions of the bicyclists and pedestrians who will use the path.

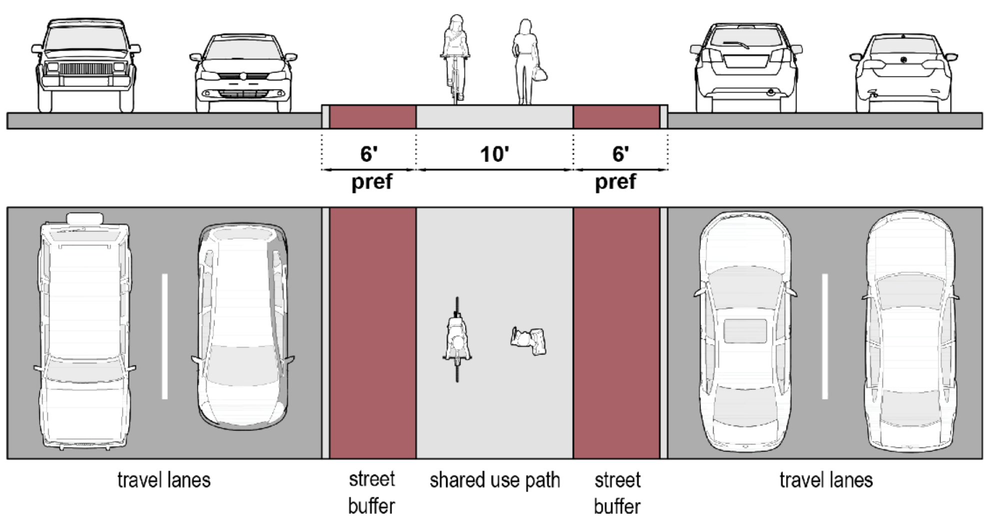


Figure 10: Median Shared Use Path (10 ft wide) with 6-ft Buffers

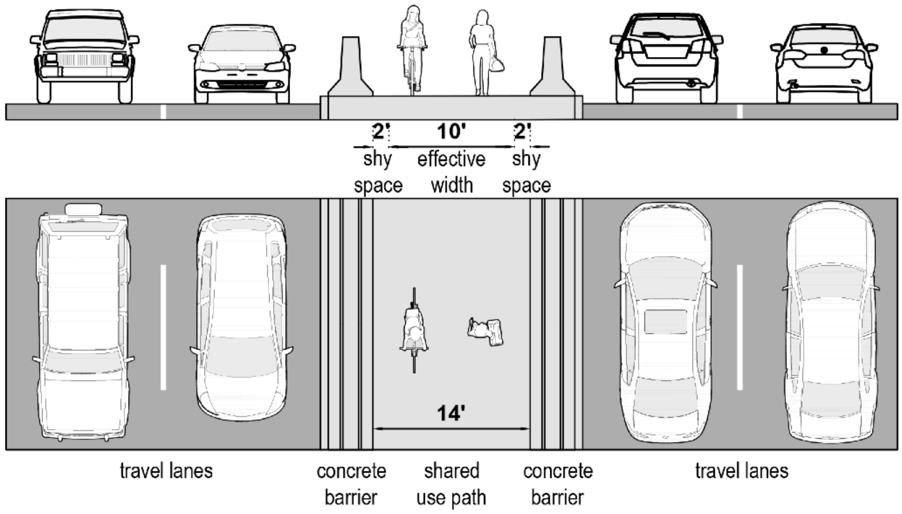


Figure 11: Constrained Median Shared Use Path (10 ft wide) with Concrete Barrier Buffers

Where bridge piers or other vertical elements are present, the preferable shy spaces between these vertical elements and the bikeways should be provided to increase comfort for bicyclists and pedestrians (see Figure 12).

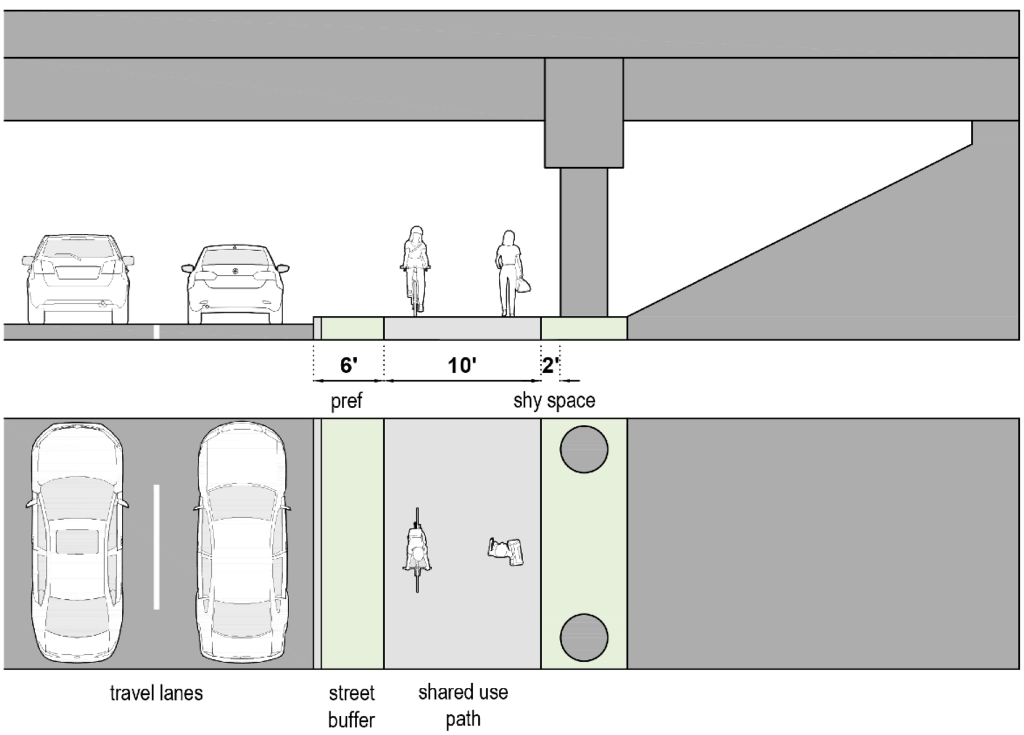


Figure 12: Side Path Between Travel Lanes and Bridge Piers with Preferred Buffers

Conflicts between Bicyclists and Pedestrians in Shared Space

While side paths can provide comfortable bikeways for bicyclists (and pedestrians) at interchanges, alternative intersections, and roundabouts by separating them from high-speed motor vehicle traffic, these shared facilities can introduce conflicts between path users. If bicycle and pedestrian activity is low, conflicts are likely to be rare.

However, in locations where bicycle and pedestrian activity is expected to be high, the designer may consider implementing separate facilities for each mode or building a wider shared facility.

To avoid pinch points at crossings, curb ramp widths should match the width of the facility to which they connect, whether a shared use path or wide sidewalk where bicycle use is expected.

Channelized Right-Turn Lanes

The geometric challenges and motorist behaviors that are prominent at entrance and exit ramps can also be seen at channelized right-turn lanes, which are common at many intersections. They are typically implemented to:

- Increase capacity by allowing right-turning motorists to execute turns independent of signal controls, or
- Minimize intersection size at skewed intersections while accommodating the turning needs of large vehicles.

As discussed in the *AASHTO Pedestrian Guide*, a key geometric design element of the channelized lane is the approach angle to the receiving roadway which may have a flat approach or a low-angle approach as shown in Figure 13.

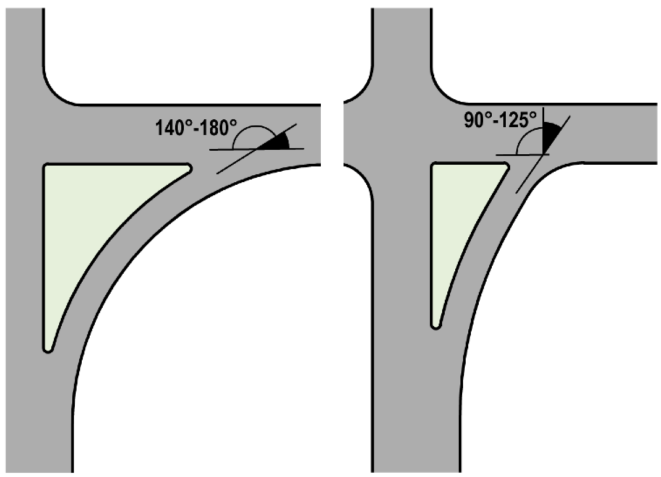


Figure 13: Channelized Right-Turn Lane Approach Angles

Right-turn channelizing lanes designed for higher-speed operation with flat approach angles (> 140 degrees) should be avoided where motorists must yield:

- To pedestrians or bicyclists at crossings located within the turn lane, or
- To motorists on the receiving roadway.

Flat approach angles inhibit motorists' sight lines to pedestrians and bicyclists who may be approaching from the right, while the driver's attention is focused on vehicle movements coming from the left. Therefore, where yielding is required, it is preferable to use a low angle approach (90 to 125 degrees) to the intersecting roadway because it improves sight lines and requires motorists to slow on their approach.

However, in some corridors, it may not be feasible to adjust the skew of intersecting roadway alignments. In locations where the intersecting angle is less than 75 degrees, a right-turn channelizing lane may be beneficial to decrease the overall size of the intersection and minimize pedestrian and bicycle crossings.

Where their design cannot be avoided or is necessary at a skewed intersection, the triangular channelization island formed between the right-turn lane and the through lanes should be raised and constructed of concrete, rather than simply striped with pavement markings. As shown in Figure 14, the raised island provides the opportunity for refuge for bicyclists and pedestrians with a shorter crossing across the main portion of the intersection. The refuge must be designed to be accessible.

The raised concrete island should be designed with adequate queuing space to accommodate the expected volume of users. Queuing areas within the refuge median for any path of travel should be a minimum of at least 6 ft. long, though 10 ft. is preferable so that a bicyclist with a trailer can be fully within the protection of the refuge median. Achieving this storage space may require balancing the size of the refuge median with the outer radius of the right-turn lane against potential need to increase right-of-way.

Where the bicyclist/pedestrian crossing traverses the channelized right-turn lane, the marked crossing should be placed at the point in the curve where the bicyclist or pedestrian will be most visible and where motor vehicle speeds are lowest. It is important to separate motorist driving tasks so that motorists are scanning for bicyclists and pedestrians in the crossing prior to beginning to scan for gaps in traffic approaching from their left. To encourage motorist yielding, a raised crossing may supplement the crossing of the channelized right turn.

If a raised refuge median cannot be built, the channelized right turn should be eliminated if possible and the associated corner radius reduced to the minimum needed for a conventional right turn. This revised geometry will create a shorter crossing distance for bicyclists and pedestrians, reducing their exposure to high-speed vehicle movements.

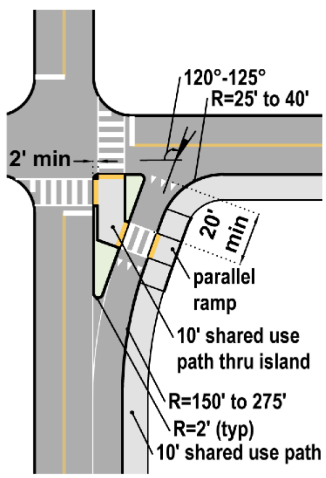


Figure 14: Channelized Right-Turn Refuge Island

Methodology

A geospatial analysis was used to determine the locations where existing facilities and proposed regional active transportation network segments cross highway interchanges, including interchanges located along a proposed facility. The project team completed the following steps as part of the analysis:

1. Identified all points where highway ramps intersect with existing and proposed bicycle facilities.
2. Interchanges generally contain multiple ramps and therefore pose multiple conflict points between bicyclists and vehicles; these points were grouped together to approximate the rough center of the interchange.
3. Identified intersections between ramps and bike networks by locating the points where existing and proposed networks approached a road segment designated as a “motoryway_link” based on the NJ street centerlines dataset from OpenStreetMap (OSM).
4. Located the ramp intersection points where the existing and proposed networks intersect or cross near a highway ramp. A 5-foot buffer distance was used to locate where the proposed network intersects with a

ramp, because the regional active transportation network is routed along the same OSM dataset as the highway ramps. A larger 20-foot buffer distance was used for the existing facilities, which comprises datasets from multiple sources, and is not derived from OSM. This step created multiple points at each interchange, as each interchange contains multiple ramps.

5. Located the center of each interchange by calculating the centroid of the ramp intersection points that are within 1,000 feet of each other.
6. Joined key attribute information such as highway route designations and other street names from OSM centerlines that are within 250 feet of the interchange center points.

Results

This analysis identified 58 locations in the NJTPA region at which existing bicycle facilities intersect with highway interchanges, and 187 locations at which the regional active transportation network intersects with highway interchanges. Figures 15-20 display a summary of the results.

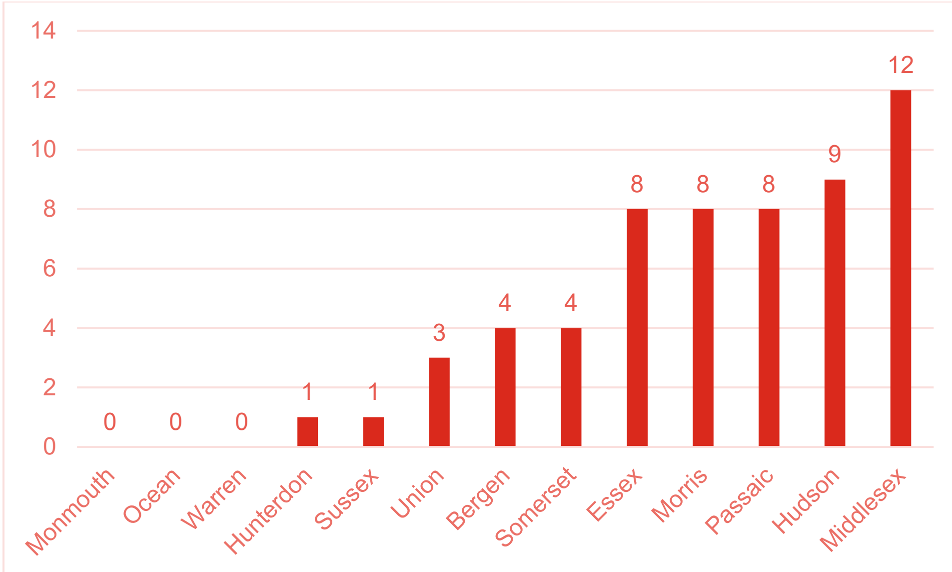


Figure 15: Interchange crossings on existing and proposed trails and bike lanes

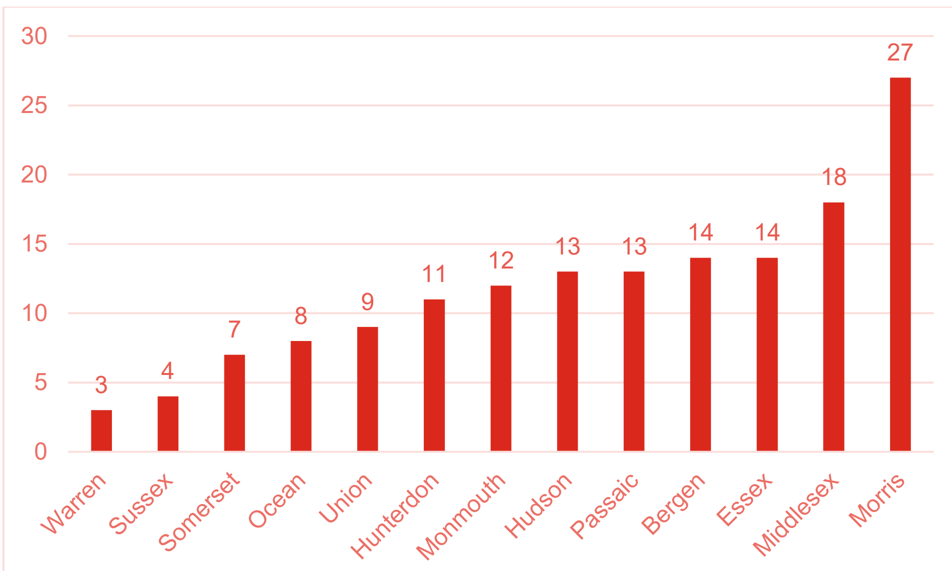
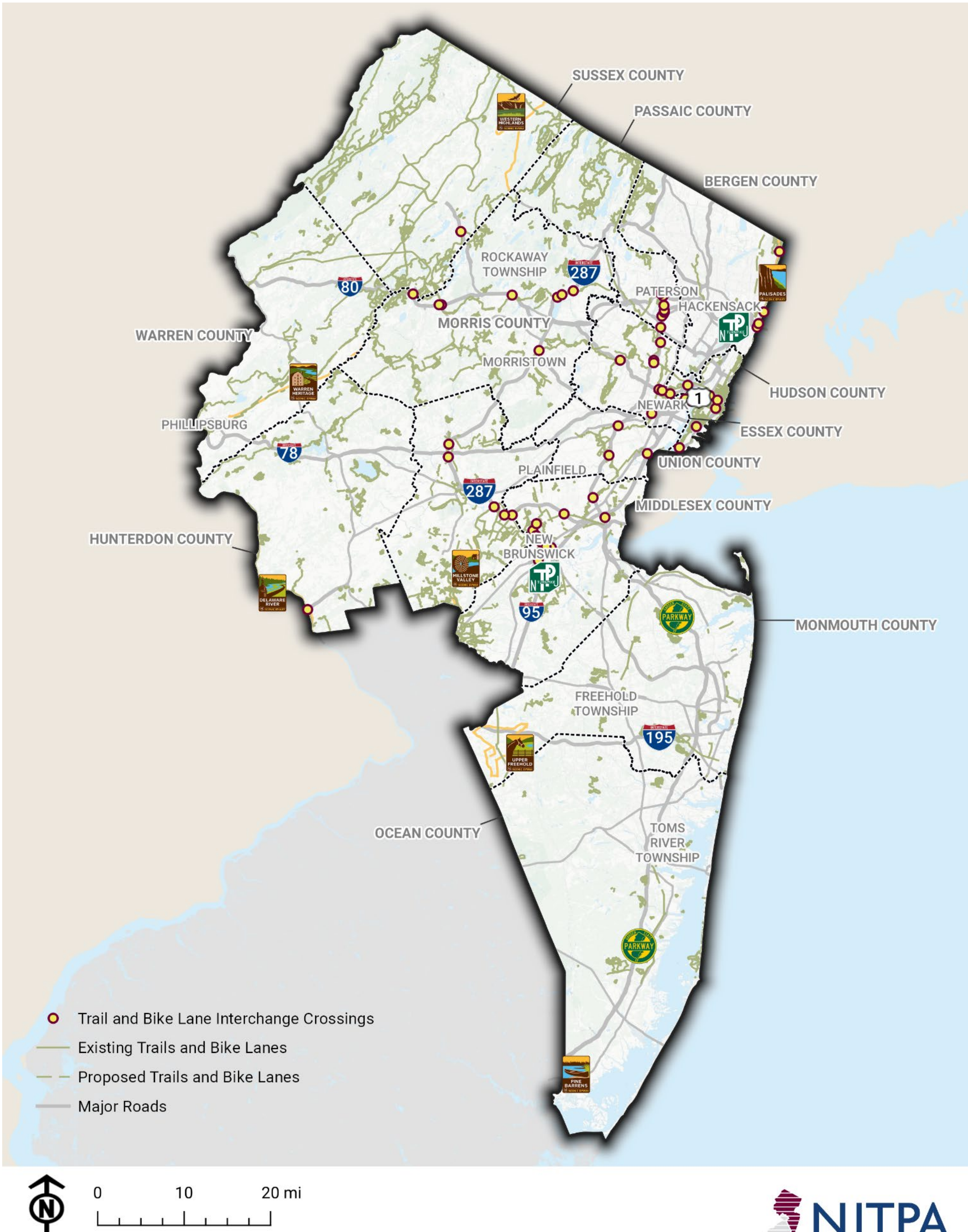


Figure 16: Interchange crossings on regional active transportation network



NJTPA

Figure 17: Interchange crossings on existing network

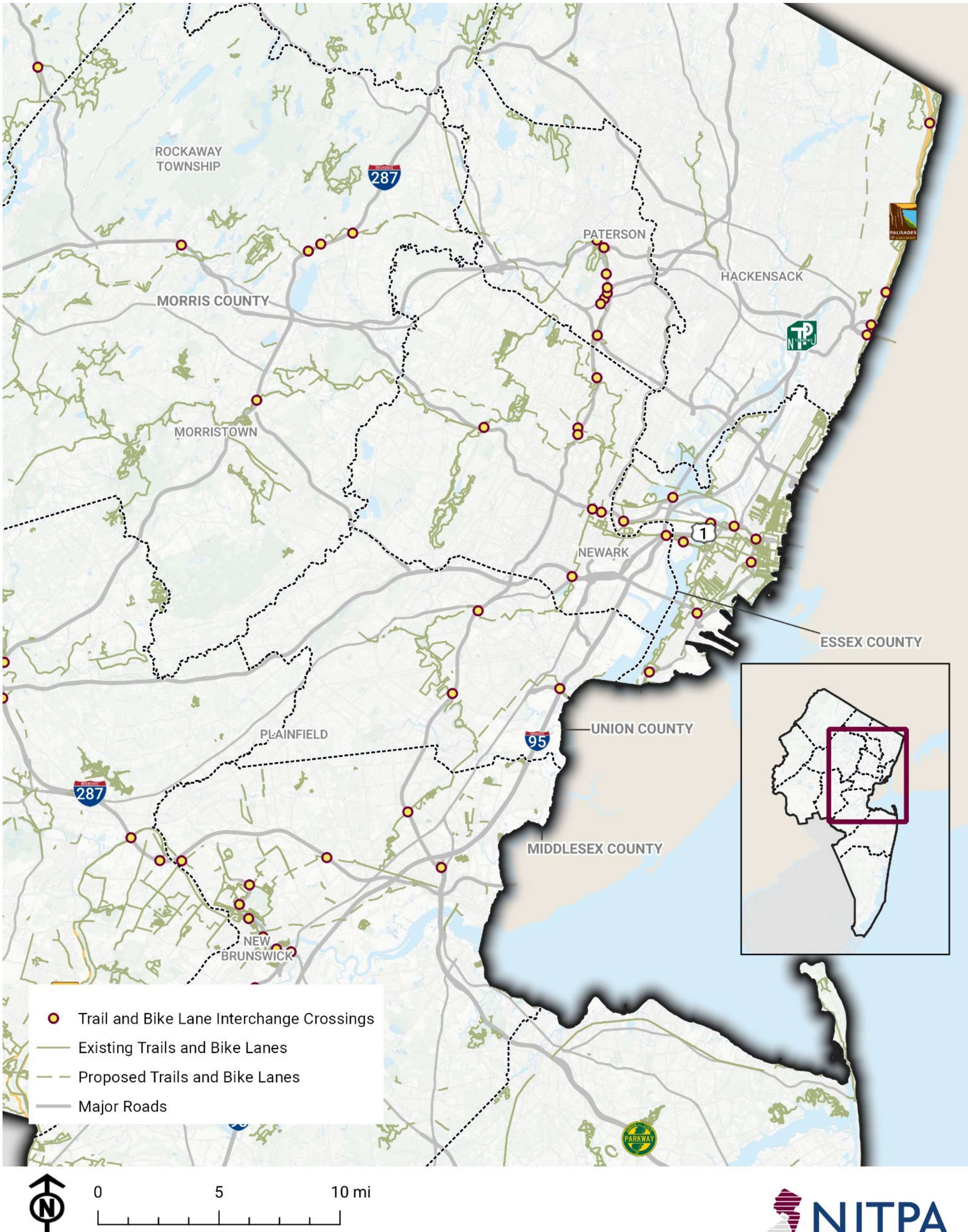


Figure 18: Interchange crossings on existing network, eastern portion of Region

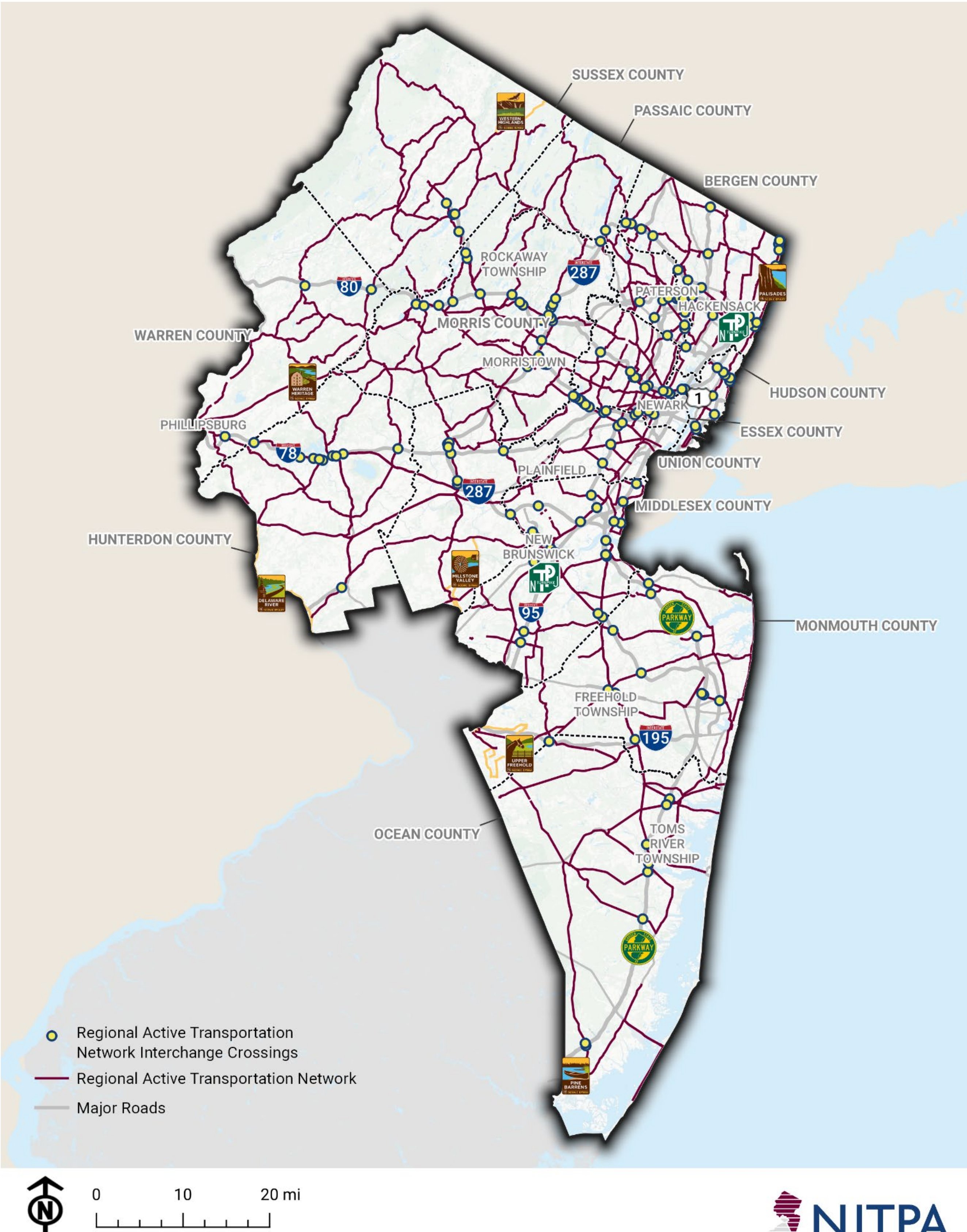


Figure 19: Interchange crossings on regional network

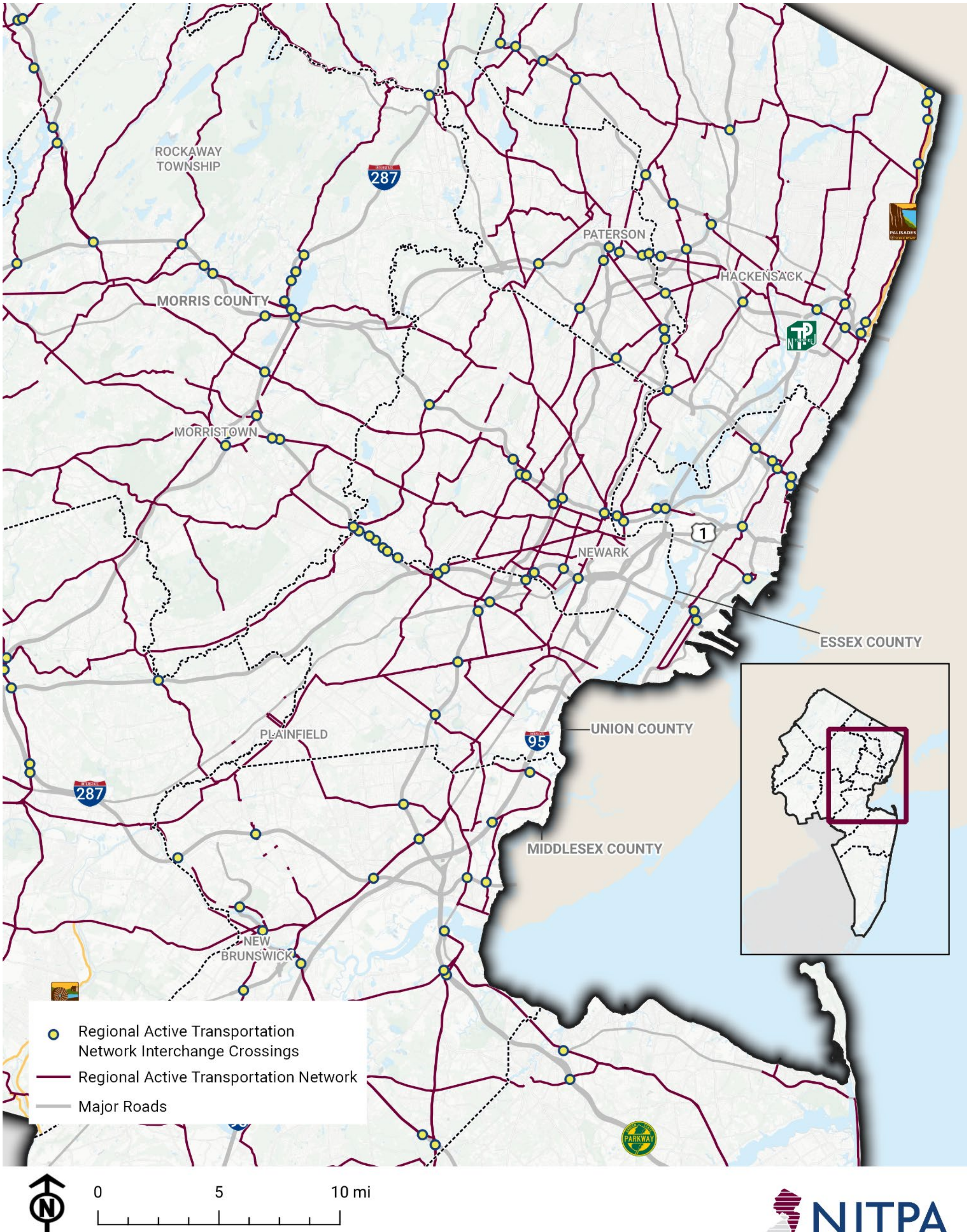


Figure 20: Interchange crossings on regional network, eastern portion of Region

[i] ITE. Recommended Design Guidelines to Accommodate Pedestrians and Bicycles at Interchanges: A Recommended Practice. Institute of Transportation Engineers, Washington, DC, 2016.

[ii] Schroeder, B., Long, R., Barlow, J., Rodegerdts, L. *National Cooperative Highway Research Report Crossing Solutions at Roundabouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities*. NCHRP, Transportation Research Board, Washington, DC, 2011.

[iii] Kittelson & Associates, Toole Design Group, Accessible Design for the Blind, ATS America. National Cooperative Highway Research Report *948, Guide for Pedestrian and Bicycle Safety at Alternative Intersections and Interchanges*. NCHRP, Transportation Research Board, Washington, DC, 2021.

iv FHWA. Road Design in Safer Journey. Federal Highway Administration, U.S. Department of Transportation, Washington, DC. Available from https://safety.fhwa.dot.gov/saferjourney1/Library/countermeasures/15.htm