U.S. Department of Transportation

Federal Highway Administration

IMPROVING INTERSECTIONS FOR PEDESTRIANS AND BICYCLISTS

Informational Guide

April 2022

FOREWORD

When designed with pedestrians and bicyclists explicitly in mind, all types of intersections can facilitate safe, accessible, convenient, and comfortable walking and bicycling. The Federal Highway Administration (FHWA) is pursuing the goal of eliminating deaths and serious injuries on our Nation's roads and recognizes the Safe System approach as integral to reaching this goal. At intersections, the Safe System approach involves minimizing risks to all road users by applying a kinetic energy management model that relies on design features that lower vehicle speeds, separate road users, remove conflict points, and reduce conflict point severity. To varying degrees, both traditional and innovative/alternative intersection designs may exhibit some or all these kinetic energy management model characteristics.

Additionally, FHWA promotes an array of strategies and treatments known as the Proven Safety Countermeasures, many of which benefit pedestrians and bicyclists and are applicable at intersections, encourages the pursuit of Complete Streets solutions, and produces guidance on bicyclist and pedestrian facility selection. It is a holistic approach of combining all of these elements – the Safe System approach, innovative/alternative intersection designs, Proven Safety Countermeasures, Complete Streets, and facility selection best practices – that is the foundation of this informational guide intended to help agencies create walkable and bikeable intersections that are safer for all users.

The purpose of this guide is to inform the state of the practice concerning intersection planning and design to implement solutions that help achieve the goal for zero fatalities and serious injuries while also making roads better places for walking and bicycling. This guide serves as a supplement to FHWA's series of intersection informational guides and makes direct connections to other FHWA bikeway and pedestrian facility selection guides.

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Intersections are critical points of access to local and regional destinations for all roadway users. When designed with pedestrians and bicyclists explicitly in mind, all types of intersections can facilitate safe, accessible, convenient, and comfortable walking and bicycling. The purpose of this guide is to inform the state of the practice concerning intersection planning and design to implement solutions that help achieve the goal for zero fatalities and serious injuries while improving mobility for bicyclists and pedestrians.

The primary intersection types discussed in this guide include traditional signalized intersections, roundabouts, Median U-Turn (MUT) intersections, Reduced Crossing U-Turn (RCUT) intersections, Quadrant Roadway (QR) intersections, Displaced Left Turn (DLT) intersections, and Diverging Diamond Interchanges (DDI). This guide also includes discussion about stop-controlled and uncontrolled intersection crossings for bicyclists and pedestrians. This guide illustrates integration of bikeways and pedestrian pathways at and across traditional and alternative intersections, describes countermeasures applicable to pedestrian and bicyclist crossings at intersections, and summarizes the application of intersection analysis methods for the safety and mobility of pedestrians and bicyclists.

This guide serves as a supplement to the Federal Highway Administration's (FHWA's) series of intersection informational guides and makes direct connections to other FHWA bikeway and pedestrian facility selection guides. Part I presents three foundational principles for planning and designing intersections for pedestrians and bicyclists. Part 2 presents design concepts for each of the intersection types discussed in this guide and illustrates options and design flexibility for incorporating a variety of pedestrian and bicycling facility types. This guide is intended to supplement, but not replace, design guidance, traffic control standards, and countermeasure selection criteria.</td></tr>
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
	NOTE: volumes greater than 1000 L shall be shown in m^3			
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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ACRONYMS

AADT	annual average daily traffic
AASHTO	American Association of State Highway and Transportation Officials
ADA	Americans with Disabilities Act
AID	Audible Information Devices
AII	alternative intersections and interchanges
APS	accessible pedestrian signal
AWS	All Way Stop
BIKESAFE	Bicycle Safety Guide and Countermeasure Selection System
CFI	continuous flow intersection
CMF	crash modification factor
DDI	Diverging Diamond Interchange
DLT	Displaced Left Turn
DOT	Department of Transportation
FHWA	Federal Highway Administration
HCM	Highway Capacity Manual
HSIP	Highway Safety Improvement Program
HSM	Highway Safety Manual
ICE	Intersection Control Evaluation
ITE	Institute of Transportation Engineers
LED	light-emitting diode
LOS	level of service
LPI	leading pedestrian interval
MOE	measure of effectiveness
mph	miles per hour
MRS	Minor Road Stop
MUT	Median U-Turn
MUTCD	Manual on Uniform Traffic Control Devices
NACTO	National Association of City Transportation Officials
NCHRP	National Cooperative Highway Research Program
PEDSAFE	Pedestrian Safety Guide and Countermeasure Selection System
PHB	Pedestrian Hybrid Beacon
PROWAG	(Proposed) Public Rights-of-Way Accessibility Guidelines
QR	Quadrant Roadway
RCUT	Restricted Crossing U-Turn
RRFB	Rectangular Rapid-Flashing Beacon
RSA	road safety audit
SHSP	Strategic Highway Safety Plan
SPF	Safety Performance Function
SPICE	Safety Performance for Intersection Control Evaluation
SSI	Safe System for Intersections
STEP	Safe Transportation for Every Pedestrian
USAB	United States Access Board
USDOT	United States Department of Transportation
vpd	vehicles per day

INTRODUCTION

Intersections are critical points of access to local and regional destinations for all roadway users. However, intersections are also planned points of potential conflict between road users. For this reason, intersection safety is critical to the overall safety of the transportation system. This is especially true when considering pedestrians and bicyclists, users who are typically more vulnerable compared to their counterparts traveling in motor vehicles. The share of bicyclist and pedestrian fatalities and serious injuries that occur at intersections is notable. From 2015 to 2019, an estimated 57 percent of bicyclist and 39 percent of pedestrian fatalities and incapacitating injuries in the U.S. occurred at intersections or were intersection-related.[1,2]

When designed with pedestrians and bicyclists explicitly in mind, all types of intersections can facilitate safe, accessible, convenient, and comfortable walking and bicycling. The Federal Highway Administration (FHWA) is pursuing the goal of eliminating deaths and serious injuries on our Nation's roads and recognizes the Safe System approach as integral to reaching this goal. The Safe System approach is predicated on six key principles:[3]

1. **Death and serious injury are unacceptable.**
2. **Humans make mistakes.**
3. **Humans are vulnerable.**
4. **Responsibility is shared.**
5. **Safety is proactive.**
6. **Redundancy is critical.**

At intersections, the Safe System approach involves minimizing risks to all road users by applying a kinetic energy management model that relies on design features that lower vehicle speeds, separate road users, remove conflict points, and reduce conflict point severity. To varying degrees, both traditional and innovative/alternative intersection designs may exhibit some or all these kinetic energy management model characteristics.

Intersections that enable safe bicyclist and pedestrian crossings and mobility are integral to the implementation of Complete Streets.[4] Intersections in a Complete Streets system provide consistent facility types and wayfinding for people of all ages and abilities. Complete Streets and intersections increase transportation choices and provide more equitable access to destinations.

The purpose of this guide is to inform the state of the practice concerning intersection planning and design to implement solutions that help achieve the goal for zero fatalities and serious injuries while also making roads better places for walking and bicycling. This works in concert with the U.S. Department of Transportation (USDOT) *Policy Statement on Bicycle and Pedestrian Accommodation Regulations and Recommendations* released in 2010, which provides support for the planning, design, construction, and operation of "convenient, safe, and context-sensitive facilities that foster increased use by bicyclists and pedestrians of all ages and abilities."[5]

The primary intersection types discussed in this guide include the intersection types documented in FHWA's *Alternative Intersections/Interchanges: Informational Report*[6] and the series of informational guides on different types of intersections: signalized,[7] roundabout,[8] Median U-Turn (MUT),[9] Restricted Crossing U-Turn (RCUT),[10] Quadrant Roadway (QR),[11] Displaced Left Turn (DLT),[12] and Diverging Diamond Interchange (DDI).[13] This guide also includes discussion about stop-controlled and uncontrolled intersection crossings for bicyclists and pedestrians.

Broadly stated, studies on the safety performance of roundabouts and various innovative/alternative intersection designs prove they can be effective at reducing fatal and serious injury crashes for all road users when compared to traditional signalized or unsignalized options. However, regardless of intersection form, when pedestrians and bicyclists are not placed at the forefront of the planning and design stages of project development, the post-construction results may be unsatisfactory in terms of accessibility, comfort, and convenience, and even potentially detrimental to the safety of non-motorized users.

FHWA promotes an array of strategies and treatments known as the Proven Safety Countermeasures, many of which benefit pedestrians and bicyclists and are applicable at intersections.[14] FHWA has also produced guidance on bicyclist and pedestrian facility selection and speed management.[15,16,17] It is a holistic approach of combining these elements – the Safe System approach, Complete Streets, innovative intersection designs, Proven Safety Countermeasures, and facility selection practices – that is the foundation of this informational guide intended to help agencies create walkable and bikeable intersections that are safer for all users.

This guide illustrates integration of bikeways and pedestrian pathways at and across traditional and alternative intersections, describes countermeasures applicable to pedestrian and bicyclist crossings at intersections, and summarizes the application of intersection analysis methods for the safety and mobility of pedestrians and bicyclists. The guide presents design scenarios for pedestrians and bicyclists at intersections as part of new construction projects or when contemplating substantive changes to the traffic control or geometry of an existing intersection. The bikeway and pedestrian pathway facilities are shaped by the context of the location and characteristics of all the users approaching and traveling through at-grade intersections and across interchange ramps.

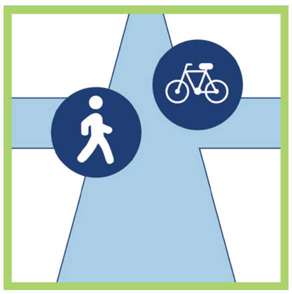
FHWA supports State and local agencies with other guidance and tools that describe decision-making approaches for prioritizing safety, accessibility, and mobility for pedestrians and bicyclists at intersections. FHWA guidance for performance-based project development and design describes the benefits of objective, data-driven decision-making. Intersection Control Evaluation (ICE) guidance notes that a growing number of transportation agencies are creating and adopting ICE policies, procedures, and tools.[18] Although there are differences among these ICE policies, they are consistent in emphasizing transparency, flexibility, and adaptability. Agencies implementing ICE have noted multiple benefits, including:

- **Balanced, cost-effective choices in the selection of intersection solutions.**
- **Consistent documentation that improves the transparency of project decisions.**
- **Awareness of innovative intersection solutions that rely on objective performance metrics for consistent comparisons.**

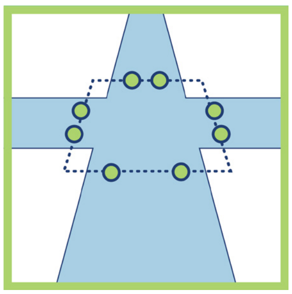
This guide serves as a supplement to FHWA's series of intersection informational guides and makes direct connections to other FHWA bikeway and pedestrian facility selection guides. Part I presents three foundational principles for planning and designing intersections for pedestrians and bicyclists. Part 2 presents design concepts for each of the intersection types discussed in this guide and illustrates options and design flexibility for incorporating a variety of pedestrian and bicycling network types. This guide is intended to supplement, but not replace, design guidance, traffic control standards, and countermeasure selection criteria.

PART I. PRINCIPLES FOR INCLUDING PEDESTRIANS AND BICYCLISTS AT INTERSECTIONS

This guide is grounded in three key principles for planning and designing intersections for pedestrians and bicyclists. Each is described in more detail below and followed by examples of desired outcomes. Refer to Part II of this guide for specific design resources and conceptual illustrations of these principles.



Expect Pedestrians and Bicyclists at All Intersections



Use a Safe System Approach

Provide Access for All Ages and Abilities

EXPECT PEDESTRIANS AND BICYCLISTS AT ALL INTERSECTIONS

People walk or bicycle for a variety of purposes, including to access jobs, schools and services, shop or seek healthcare, engage in recreation and tourism, improve personal health, and limit environmental impacts. Intersection projects are opportunities to provide safer, more equitable, and more accessible facilities for people walking or bicycling through the area. Pedestrians and bicyclists should be expected to cross or be present at all intersections, even if infrequently when compared to motor vehicle traffic volumes.

This principle is consistent with a Complete Streets approach to transportation planning and design. Complete Streets are streets and intersections designed and operated for mobility and safety of all users. Complete Streets are context based and are unique to local conditions, but they typically include features that provide access for pedestrians, bicyclists, transit users, and motorists of all ages and abilities. Intersection projects should include space for sidewalks, bicycle facilities, crossings, traffic controls, and appurtenances to accommodate the changing context and planned network. While new construction or reconstruction may offer more possibilities, routine improvements to existing intersections can benefit pedestrians and bicyclists. Incremental changes at intersections- such as signal timing adjustments, bus stop placement, or installation of vehicle turn lanes – are also opportunities to improve safety and mobility for bicyclists and pedestrians at intersections.

During the planning, scoping, and preliminary design stages of an intersection project, transportation officials should consider the history and needs of people living in and affected by the project area. A quarter-mile to three-mile radius around an intersection typically represents the “walkshed” or “bikeshed” of an intersection location, or the area that people potentially access as pedestrians or bicyclists. An assessment of the demographic and socioeconomic make-up of populations, neighborhoods, and business communities in the walkshed or bikeshed area helps identify people or groups who are underserved or negatively impacted by the existing transportation system.

Practitioners should consider bicyclists and pedestrians with a wide variety of preferences, ages, experiences, accessibility needs, and trip purposes. Some pedestrians have mobility, vision, or hearing disabilities, or walk at slower speeds due to age or health condition. Children, visitors, and people with cognitive disabilities may be less able to assess crash risks or safely navigate complex intersections.

An assessment of affected populations, along with field review and input from residents and stakeholders, helps to characterize the needs and preferences of pedestrians and bicyclists at the intersection. In most cases and developed contexts, according to the FHWA Bikeway Selection Guide, most bicyclists are "interested but concerned" and prefer separated bikeways at intersections.[15] Additionally, especially in areas where the population is aging or transportation options are limited, pedestrians may have limited mobility and access at crossings and intersections.

The following are desirable outcomes of expecting pedestrians and bicyclists at all intersections:

- **Safer intersections in terms of the risk of harm to pedestrians and bicyclists from crashes involving motor vehicles, such as the roundabout shown in Figure 1.**
- **Accessible, comfortable, and intuitive travel paths for non-motorized users, including straightforward paths and visibility enhancements that improve navigation through intersections.**
- **Express consideration given to non-motorized user convenience, travel time, and delay by providing continuous and direct routes across intersections.**
- **Equitable right-of-way and space reserved for appropriately designed bikeway and pedestrian pathway networks in response to increasing development, traffic conditions, and travel demand, such as pedestrian refuge islands.**
- **Incremental changes or modifications to intersection designs that prioritize the pedestrian or bicyclist while still accommodating large vehicles.**

Figure 1. Multilane roundabout with RRFBs at pedestrian crossings. Source: FHWA.

USE A SAFE SYSTEM APPROACH

Given that bicyclists and pedestrians are expected users of intersections and are more susceptible to death or serious injury when involved in a crash with a motor vehicle, it follows that a Safe System approach for pedestrians and bicyclists must prioritize their safety without sacrificing their comfort and convenience.[19] The Safe System approach minimizes crash risk by encouraging the selection of design alternatives that remove conflict points or separate road users, lower traffic speeds, and reduce conflict angles.

The Safe System approach considers crash risk in the functional area approaching an intersection, where turn lanes develop, and operating speeds may change between users. Traffic lanes and bike lanes may transition at "mixing zones" in this area – typically from 100 to 350 feet away from the center of the intersection. More complex intersections, such as signalized intersections with multiple turn lanes or continuous flow operations, have longer transitions between bicycle and vehicle lanes.

Drivers, pedestrians, and bicyclists depend on traffic controls such as signs, signals, lane markings, and geometric features to help them navigate the intersection. The Safe System approach considers how traffic control, speed management techniques, and geometric features work together to separate users, slow vehicle speeds, and mitigate conflicts and crashes.

Planners and designers can identify conflicts and opportunities by conducting a road safety audit (RSA) when improving an existing intersection. RSAs bring together stakeholders representing different disciplines and perspectives to identify current deficiencies, such as paths or routes with poor accessibility, low rates of yielding at crossings, and restricted visibility. Members or representatives of communities or groups disproportionately impacted by the existing transportation system should be invited to join the RSA.

The following are examples of outcomes that may emerge from taking this approach:

- **Controlled, lower speed at turning movements by eliminating higher-speed, free-flowing turning movements, which reduces kinetic energy in the event of a crash.**
- **Minimized conflict points by avoiding vehicle turning movements during pedestrian or bicycle crossing signal phases and limiting the distance of merging or mixing zones with bike lanes.**
- **Increased visibility from overhead lighting and countermeasures for improving yielding at crossings.**
- **Improved visibility at conflict points and use of enhanced pavement markings for conspicuity of merging or mixing zones with bike lanes, as shown in figure 2.**

Figure 2. Green colored pavement used to designate bike lane and mixing zone. Source: FHWA.

PROVIDE ACCESS FOR ALL AGES AND ABILITIES

Within the U.S. transportation context, terms such as "access" and "accessibility" seem similar but actually have different meanings. "Access" speaks to the relative ease with which people can embark on their intended travel via their preferred mode, while "accessibility" refers to whether a transportation facility is usable by individuals with disabilities. Both "access" and "accessibility" are necessary to the planning, design, and operation of intersections and other transportation facilities. Pedestrian facilities must be accessible to and usable by individuals with disabilities, including pedestrians with vision, mobility, hearing, and/or cognitive disabilities. Pedestrian and bicyclist access at intersections also considers the overall demand for connecting people of all ages and abilities to nearby destinations and to the transportation network.

Pedestrian and bicyclist demand is driven by the land use context. The 7th edition of the American Association of State Highway and Transportation Officials' (AASHTO's) *Policy on Geometric Design of Highways and Streets* – referred to as the "Green Book" – includes a new approach for considering both functional classifications and development context for designing roadways.[19] The Green Book refers to each of the following context classifications:

Rural: Areas with the lowest density (widely dispersed or no residential, commercial, and industrial uses) and large setbacks. Pedestrians and bicyclists travel farther distances to destinations in rural areas and walking and bicycling activity is lower than in more developed contexts.

Rural Town: Areas with low density but diverse land uses with commercial main street character, potential for on-street parking and sidewalks, and small setbacks. People may walk or bicycle in or to rural centers, and this activity may increase near community services or neighborhoods where people may be more dependent on transit, walking, or bicycling for basic transportation.

Suburban: Areas with medium density, mixed land uses within and among structures (including mixed-use town centers, commercial corridors, and residential areas), and varied building setbacks. Suburban areas grow rapidly and include destinations where pedestrians and bicyclists frequent (such as transit stops, service centers, and retail markets). High traffic volumes and speeds at intersections present increased risk for fatal and serious injury crashes with pedestrians and bicyclists.

Urban: Areas with high density, mixed land uses with destinations for pedestrians and bicyclists cluster near intersections. Improvements for pedestrians and bicyclists in this constrained environment may lead to consideration for trade-offs with on-street parking, motor vehicle throughput, and turn lane operations.

Urban Core: Areas with highest density, mixed land uses within and among predominately high-rise structures, and short setbacks. The urban core produces the highest levels of pedestrian bicycle activity at intersections. Slower expected vehicle speeds (resulting both from traffic congestion and speed management) support enhanced focus on bicyclists and pedestrians at intersections, including options for exclusive phases or advance movements at crossings.

Table 1 presents a matrix that can help describe demand, given various contexts and roadway functional classifications. Vehicle speeds and pedestrian and bicyclist demand may vary based on roadway classification and other design and context characteristics. Roads that carry higher traffic, such as minor and principal arterials, increase exposure for pedestrians and bicyclists. Higher vehicle speeds increase the likelihood of fatal and serious injury pedestrian or bicycle crashes. Therefore, the safety of bicyclists and pedestrians who cross intersections with higher levels of exposure and increased vehicle speeds calls for more separation from traffic.

Table 1. Identifying Demand: Roadway Characteristics and Context. Source: Modified from NCHRP Report 926, ***Guidance to Improve Pedestrian and Bicyclist Safety at Intersections***.[20]

Roadway Type		Rural	Rural Town	Suburban	Urban	Urban Core
Local Road	Vehicle Speed	Medium	Low	Low	Low	Low
	Bike Demand	Low	Medium to High	Low to Medium	Medium to High	High
	Pedestrian Demand	Low	Medium	Medium	High	High
Collector Road	Vehicle Speed	High	Medium	High	Low	Low
	Bike Demand	Low	Medium	Low to Medium	High	High
	Pedestrian Demand	Low	Medium	Low	High	High
Minor Arterial	Vehicle Speed	High	High	High	Medium	Medium
	Bike Demand	Low	Low	Low to Medium	Medium	High
	Pedestrian Demand	Low	Low	Low	Medium	High
Principal Arterial (Non-Freeway)	Vehicle Speed	High	High	High	High	Medium
	Bike Demand	Low	Low	Low	Medium	Medium
	Pedestrian Demand	Low	Low	Low	Medium	Medium

The following are outcomes that support the safety and comfort of pedestrians and bicyclists with a wide range of accessibility needs and limited familiarity with complex intersection operations:

- **Appropriate separation, based on context, between vehicle traffic, bike lanes, pedestrian pathways and crossings using clear markings, geometric features, and traffic controls, such as depicted in figure 3.**
- **Provisions for user separation and channelization, including refuge islands, and if signalized, signal timing strategies that provide advance and/or extended pedestrian or bicycle signal phases.**
- **Optimized timing to facilitate single-stage crossings through the intersection for all pedestrians and bicyclists.**
- **Minimal changes to pathway and curb ramp gradients at the approaches to and across the intersection.**
- **Intuitive placement of actuators and utility structures along the length of the pathway and pedestrian route for people with vision loss.**
- **Minimal clutter and good visibility of detectable warning surfaces.**
- **Accessible pedestrian signals to communicate pedestrian signal phases.**
- **Automatic (passive) detection and accessible pedestrian features at complex signalized intersections with bike lanes or for two-stage pedestrian crossings.**
- **Use of reliable automatic (passive) detection to activate dynamic warning and/or traffic control devices when pedestrians and bicyclists are approaching or present at an intersection, especially for crossings that consist of more than one stage.**

Figure 3. Signalized intersection with bicycle lanes, wide crosswalks, and bicycle signal face. Source: FHWA.

EXISTING BIKEWAY AND PEDESTRIAN FACILITY SELECTION GUIDANCE

Bikeways and pedestrian pathway types should be selected based on user needs, community goals for mobility and safety, and the role of the facilities within a larger existing and planned bicycle or pedestrian network. The following guidance documents and resources describe how bikeways and pedestrian facilities are selected or how to improve safety at crossings and intersections.

BIKEWAY NETWORK AND COUNTERMEASURE SELECTION

The FHWA *Bikeway Selection Guide* documents the trade-offs for selecting different bikeway types and covers the process of selecting a bikeway from policymaking through the design decision.[15] The *Bikeway Selection Guide* identifies preferred bikeway types based on traffic speed, motor vehicle volumes and contextual factors. As speeds increase above 30 miles per hour (mph) and traffic volumes exceed 6,000 vehicles per day (vpd), separated bikeways are preferred for roadways and intersections in suburban or urban contexts.

Consider all roadway elements and associated design standards when determining alternatives for the design of the bikeway or pedestrian pathway. The *Bikeway Selection Guide* states the following "Where preferred design values cannot be achieved, reduced or minimum widths can be used to preserve the preferred bikeway type in the design. However, the use of minimum width bikeways should be limited to constrained roadways where desirable or preferred bikeway widths cannot be achieved after all other travel lanes have been narrowed to minimum widths appropriate for the context of the roadway. Where it is necessary to go below minimum widths, the preferred bikeway is infeasible, and it will be necessary to select another bikeway type."[15]

National Cooperative Highway Research Program (NCHRP) Report 926, *Guidance to Improve Pedestrian and Bicyclist Safety at Intersections*, discusses how to appropriately identify and treat bicyclist safety issues at intersections.(21) The report includes a comprehensive overview of the current state of practice to implement bicyclist safety improvements at intersections. The guide lists and summarizes bicycle countermeasures for intersections, and the guide explains how they can be applied to specific crash types or safety problems. For example, countermeasures such as bicycle signals are identified as a countermeasure that separates modes or directs motorists to stop turning or traveling straight across bicycle crossings.

The FHWA Bicycle Safety Guide and Countermeasure Selection System (BIKESAFE) is an interactive tool for reviewing bicycle safety countermeasures at intersections and along the network.(22) BIKESAFE includes intersection features or countermeasures such as bicycle signal heads and bike lanes.

The AASHTO *Guide for the Development of Bicycle Facilities* is a comprehensive bicycle facility design guide describing bicycle facility planning, design, and operations.(23) It presents background information about bicycle operations and safety, planning, and bicycle facility selection necessary for effective bicycle facility development. The core of the guide is the design guidance, general elements of design applicable to all bicycle facility types, and detailed guidance for each of the following bicycle facility types: sidepaths, separated bike lanes, bicycle boulevards, shared lanes, and bike lanes.

PEDESTRIAN NETWORK AND COUNTERMEASURE SELECTION

The FHWA *Guide for Improving Pedestrian Safety at Uncontrolled Crossing Locations* includes two tables that assist with pedestrian countermeasure selection at unsignalized crossings.(16) Table 1 in the guide leverages research to identify applicable countermeasures based on tiers of roadway configurations, speeds, and annual average daily traffic (AADT) volumes. As approaching roadway speeds exceed 35 mph or 9,000 vpd, recommended countermeasures include Rectangular Rapid Flashing Beacons (RRFBs), Pedestrian Hybrid Beacons (PHBs), or other traffic control devices. Table 2 in the guide cross-references general safety issues to potential countermeasures, based on surrounding land development context, pedestrian travel patterns, and driver behaviors.

NCHRP Report 926, *Guidance to Improve Pedestrian and Bicyclist Safety at Intersections*, discusses how to appropriately identify and treat pedestrian safety issues at intersections.(21) The guide lists and summarizes pedestrian countermeasures for intersections, and the guide explains how they can be applied to specific pedestrian crash types or safety problems. For example, countermeasures such as curb extensions and crossing islands are identified as a countermeasure that address where there are patterns of motorists and pedestrians failing to yield at intersections.

The FHWA Pedestrian Safety Guide and Countermeasure Selection System (PEDSAFE) is an interactive tool for reviewing pedestrian safety countermeasures at intersections and along the network.(24) PEDSAFE includes intersection features or countermeasures such as RRFBs, PHBs, countdown timers at pedestrian signals, and curb design.

FHWA facility and countermeasure selection tools such as those described above refer to and strongly encourage the use of Proven Safety Countermeasures at intersections.(14) These countermeasures are widely researched for reducing crashes and, for pedestrians and bicyclists, now include: Walkways, Crosswalk Visibility Enhancements, Pedestrian Refuge Islands, Bicycle Lanes, Rectangular Rapid Flashing Beacon (RRFB), Pedestrian Hybrid Beacon (PHB), Leading Pedestrian Interval (LPI), Lighting, and Appropriate Speed Limits for All Road Users.

The AASHTO *Guide for the Planning, Design, and Operation of Pedestrian Facilities* provides comprehensive guidance on pedestrian facility design.(25) The core of the guide is design guidance including a discussion of elements of design and various facility types including walkways, sidewalks, sidepaths, roadway shoulders, shared streets, pedestrian malls, and transit streets. With respect to intersections, the guide includes discrete sections on crossing design and traffic control. Pedestrian crossing design principles are defined as: clarity, predictability, access, visibility, short wait, adequate pedestrian queuing area, adequate crossing time, limited exposure, clear crossing, and speed management.

COMMON PEDESTRIAN AND BICYCLE DESIGN FEATURES AND COUNTERMEASURES FOR INTERSECTIONS

A well-designed intersection maintains the desired bikeway or pedestrian pathway through the intersection, including crossing widths and setbacks consistent with the pedestrian pathways and bikeways approaching the intersection. The specific type of separation for pedestrians and bicyclists at intersections corresponds to the facility type selected for the approaching or planned networks. This guide highlights several of the Proven Safety Countermeasures and network design features common to most or all intersection types.[14] The following describes these features and their functional purposes to pedestrian and bicycle operations at the intersection.

Sidewalks: Pedestrian pathway and sidewalk widths reflect the development context and level of pedestrian activity approaching the intersection. Sidewalks must be accessible to and usable by individuals with disabilities, including those assisted by sighted guides and caregivers. Sidepaths allow for both pedestrians and bicyclists to share a separated facility, and the width should be sufficient to allow bicyclists and pedestrians to pass while maintaining minimum operating space.[15] In areas where higher levels of pedestrian and/or bicyclist activity is expected, wider sidewalks and paths are desirable.

Crosswalks: Crosswalks are an extension of the pedestrian pathway, and the width of the crosswalk corresponds to the context and width of approaching pedestrian networks. The *Manual on Uniform Traffic Control Devices* (MUTCD) includes examples of crosswalk marking patterns and stipulates that crosswalks should be at least 6 feet wide (Section 3B.18)[26]. Crosswalks may be wider than six feet to match the width of the sidewalks they connect to, or to allow two groups of pedestrians to pass each other comfortably while remaining within the crosswalk. Additionally, crosswalks should be aligned with curb ramps to provide a straightforward crossing experience for all pedestrians.[27,28] FHWA recommends three main crosswalk visibility enhancements as part of the Proven Safety Countermeasures: high-visibility crosswalks, improved lighting, and enhanced signing and pavement markings. High-visibility crosswalk markings use more durable and reflective marking materials (e.g., thermoplastic tape or inlay instead of paint or brick markings) and crosswalk designs that improve visibility to both drivers and pedestrians compared to traditional transverse line crosswalks. FHWA recommends that high-visibility markings be considered at all uncontrolled crossings.[29]

Pedestrian Refuge Islands: Refuge islands are medians that provide space for pedestrians and bicyclists to wait in between stages of a crossing movement. Refuge islands decrease the complexity of crossing movements for pedestrians and bicyclists by allowing them to focus fewer lanes or fewer movements at a time while waiting for an acceptable gap to cross the roadway. Pedestrian refuge islands should match the width of the crosswalk or be wide enough to provide a safe, comfortable, and convenient crossing experience for wheelchair users, bicyclists, or groups of pedestrians.[31] Push buttons can be used at crossings for a pedestrian who stops in the median to call the WALK phase for a two-stage crossing, or to extend the WALK phase.

Bikeways and Bike Crossings: Bicycle facilities are selected based on the users, roadway cross section, development context, traffic volumes, vehicle speeds, and their function within the overall bikeway network. "Interested but concerned" bicyclists are the majority of the bicycling population.[14, 15] Separated bicycle facilities, such as sidepaths and separated bike lanes, present many benefits for this type of user. Other bikeway types include marked bike lanes and buffered bike lanes. Paved shoulders, wide outside lanes, and travel lanes with shared lane markings are not formal bikeways; however, these may be used to increase bicyclist comfort where more confident bicyclists choose to travel along roads without formal bikeways. Bike lane extension markings and intersection treatments designate where the bike lane or bicyclist crosses the intersection or stages for entering the intersection. The markings in these areas can be supplemented with green colored pavement to highlight where bicyclists cross vehicle paths through the intersection. Additional signs and markings may also be used to identify these bikeway crossings through the intersection. Use of green colored pavement for bike lanes, bicycle signal faces, intersection bicycle boxes, and two-stage bicycle turn boxes are included in the MUTCD under interim approval.[32,33,34,35] Jurisdictions that desire to use traffic control devices under interim approval shall request permission from FHWA.

Traffic Signals and Beacons: Traffic control signals, or traffic signals, offer numerous benefits when properly applied, such as promoting the orderly flow of traffic through the intersection, reducing the severity and frequency of certain crash types, and providing opportunities for vehicles, bicyclists, or pedestrians to cross a street or merge into traffic. The MUTCD includes nine warrants to guide installation of a traffic signal.[26]

Accessible Pedestrian Signals (APS) relay information about the status of the pedestrian signal indication in audible and tactile formats to communicate more effectively to pedestrians with vision loss or cognitive disabilities. When installing APS at an intersection, review curb ramp placement, roadway geometry and crossing distance to determine where to install push buttons and settings for audible indications. MUTCD sections 4E.08 through 4E.13 provide guidance on the consideration of these and other factors when installing APS.

Traffic signals may be designed with a leading pedestrian interval (LPI). LPI gives pedestrians the opportunity to enter the crosswalk before vehicles are given a green indication.[36] This allows pedestrians to establish their presence in the crosswalk before vehicles begin to move through the intersection, increasing the visibility of pedestrians to drivers and improving driver behavior. For pedestrians with low or no vision to have access to the safety benefits of LPI, the use of APS should also be considered when implementing LPI.

Pedestrian Hybrid Beacons (PHBs) and Rectangular Rapid Flashing Beacons (RRFBs) are proven safety countermeasures that can be implemented to control traffic at midblock crossings or uncontrolled intersections.[14] The FHWA *Guide for Improving Pedestrian Safety at Uncontrolled Crossing Locations* includes PHBs for strong consideration at uncontrolled crossings on roads with speeds at or over 40 mph.[16] FHWA recommends RRFBs at multilane crossings with speed limits less than 40 mph.[24]

Bicycle signal faces may be an additional consideration at signalized intersections. Bicycle signal faces are included in the MUTCD under interim approval where it is desirable to provide separate control for bicycle movements.[33]

ASSESSMENT TECHNIQUES FOR INTERSECTION ALTERNATIVES

Each intersection type is unique and presents different considerations for bicycling and pedestrian travel. There are several existing tools summarized here that can be used to analyze and compare intersection types with respect to pedestrian and bicyclist safety, comfort, and operations. These include the TRB *Highway Capacity Manual* (HCM), the AASHTO *Highway Safety Manual* (HSM) and other crash-based methods, the FHWA Safe System for Intersections (SSI) method, and the NCHRP Report 948 Design Flag Assessment technique. These tools help identify the conditions that benefit or impact bicyclists and pedestrians for each intersection type and assist with selecting a preferred intersection alternative. For additional information about these analysis tools, see the Resources section of this guide.

INTERSECTION LEVEL OF SERVICE AND DELAY

The HCM evaluates the quality of service available to pedestrians and bicyclists traveling on different facilities in urban street settings.[37] Pedestrian level of service (LOS) in the HCM considers a variety of factors, including pedestrian delay, pedestrian travel speed, presence of street parking, sidewalk width, and motor vehicle speed. Higher vehicle speeds or volumes result in a lower pedestrian LOS score. Alternately, increased separation between motor vehicle movements and pedestrians increases the pedestrian LOS score. The HCM Bicycle LOS score is based on similar factors to the pedestrian LOS score, such as bicycle delay, bicycle travel speed, motor vehicle speed, and volume. It also considers the pavement condition rating.

Pedestrian and Bicycle LOS in the HCM is a limited measure of pedestrian or bicyclist operational efficiency at intersections. Pedestrian delay in the HCM is determined based on the effective walk time to cross the major street and the cycle length. However, pedestrian delay is also a factor of overall travel distance and time between origins and destinations along the network. The HCM describes bicyclist delay as a factor of cycle length and vehicle turning movement volumes. Bicyclists who do not operate as other vehicles at the intersection experience different delay and travel time outcomes, similar to pedestrians.

THE HIGHWAY SAFETY MANUAL AND CRASH-BASED METHODS

The traditional approach to safety performance analysis is based on observed crash data. Safety Performance Functions (SPFs) and Crash Modification Factors (CMFs) are two of the primary building blocks of crash-based approaches. SPFs are equations that relate site characteristics (such as volume, traffic control, presence of turn lanes, and more) to the number of expected crashes. CMFs are factors developed through studies of crash data that represent the expected change in crashes after implementing a given countermeasure. The HSM is an authoritative guide to crash-based safety analysis.[38] The HSM contains predictive methods based on established SPFs and CMFs that can be used to estimate the safety performance effects of infrastructure improvements. Not all countermeasures or design treatments included or referenced in this guide have CMFs. Likewise, SPFs are not widely available for bicycle and pedestrian crashes. Additional research and data collection is needed to create or improve CMFs and SPFs and decision-making for bicycle and pedestrian safety at intersections.

NCHRP studies have developed spreadsheet tools by which to apply the HSM predictive methods.[39] These tools address intersections of rural two-lane roads, rural multilane highways, and urban and suburban arterials. The predictive method for urban and suburban arterials directly addresses pedestrian and bicyclist safety. It accounts for observed pedestrian and bicyclist crashes at the intersection, considers a variety of characteristics that affect pedestrian safety (e.g., pedestrian crossing volume, presence of transit, presence of schools, number of lanes crossed by a pedestrian), and allows the user to apply a variety of pedestrian- and bicyclist-specific CMFs corresponding to the appropriate improvement. There are limited CMFs available for bicycle and pedestrian facilities and countermeasure options at intersections, but this research is a high priority, with several efforts ongoing and information added to the CMF Clearinghouse,[40] FHWA's web-based repository of CMFs, as it becomes available.

SAFE SYSTEM FOR INTERSECTIONS (SSI) METHOD

FHWA developed the Safe System for Intersections (SSI) method for characterizing the extent to which an intersection design in a given context aligns with the principles of kinetic energy management and a Safe System approach.[41] The method is readily implementable by intersection planners and designers and it dovetails with the typical project development process, designed to operate within Stage I ICE, at the scoping phase of project development where intersection alternatives are analyzed with respect to whether they meet project needs and are practical to pursue. The goal is to provide a technical basis by which intersection planners and designers can apply kinetic energy management to common intersection projects in the United States.

The method is made up of five components:

- Conflict point identification and classification.
- Conflict point exposure.
- Conflict point severity.
- Movement complexity.
- SSI measures of effectiveness and SSI scores.

The SSI method accounts for pedestrians and bicyclists by identifying all the conflict points at the intersection and computing their exposure (based on bicycle, pedestrian, and motorist volumes), severity (based on motor vehicle speed), and complexity. The complexity of conflict points encompasses several factors, including traffic control at the intersection, the number of conflicting lanes crossed without refuge, the speed of conflicting traffic, and the presence of either indirect paths for pedestrians and bicyclists or nonintuitive motor vehicle movements. The results of the SSI method include scores and other measures of effectiveness (MOEs) specific to bicyclists and pedestrians.

FHWA's *Pedestrian and Bicyclist Safety Indices: User Guide* can be used to evaluate crosswalks and intersection approaches for pedestrian and bicyclist safety.[42] The safety indices address many of the same concepts as the SSI method, including conflict point identification and movement complexity for nonmotorized road users. The safety indices are useful if the intersection in question would benefit from a more granular analysis than that provided by the SSI method, particularly in the case of bicyclist routes through intersections.

DESIGN FLAG ASSESSMENT

NCHRP Report 948, *Guide for Pedestrian and Bicycle Safety at Alternative Intersections and Interchanges (AII)*, addresses safety in AII designs.[(43)] It includes specific material on pedestrian and bicyclist considerations at MUTs, RCUTs, DLTs, and DDIs. It also provides an approach to analyzing pedestrian and bicyclist factors that applies to all intersection types, known as the Design Flag Assessment. The guide presents a system of 20 flags for identifying individual design features at alternative intersections that affect safety, comfort, and movement complexity for pedestrians and bicyclists. A particular flag can be assigned to an intersection design as either a red (direct safety concern) or yellow (user comfort concern) flag. Some flags apply only to bicyclists, some only to pedestrians, and some apply to both groups.

Applying the principles described in this guide, intersections should be designed to account for how people currently move through the broad planning area. The planning and design process includes collecting information about people who live and work in the planning area to better define the characteristics of the expected users of the intersection. This information, along with consideration for the appropriate operating speed of the approaching roadways, helps identify the types of bikeways and pedestrian pathways that best serve all users and fit the changing roadway and context. Figure 4 presents some of the questions planners and designers might be asking as they begin planning an intersection project.

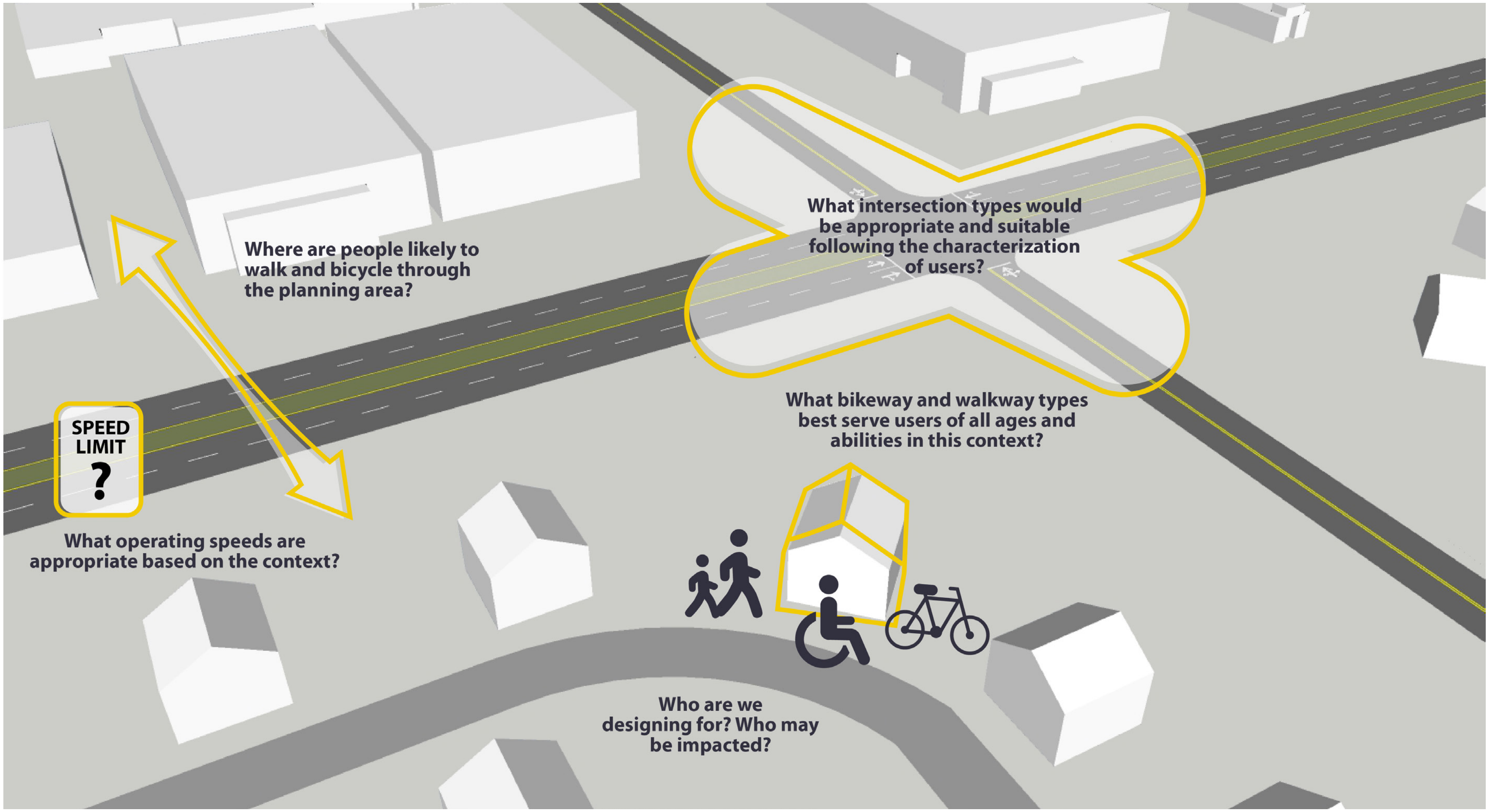


Figure 4. Early considerations for intersection projects. Source: FHWA.

The planners and designers further consider how the desired bikeway and pedestrian pathway networks would connect through the intersections and where risk is highest for fatal and serious injury bicycle or pedestrian crashes. The planners and designers also consider the routes connecting people to destinations near the intersection and the overall travel time to cross the intersection. While all roadway users benefit from direct routes and minimal travel times between destinations across the intersection, it is reasonable to conclude that non-motorized users benefit even more than motorized users because they are operating under human power. Figure 5 shows some of the questions the planners and designers might be exploring during this stage of the planning and design process.

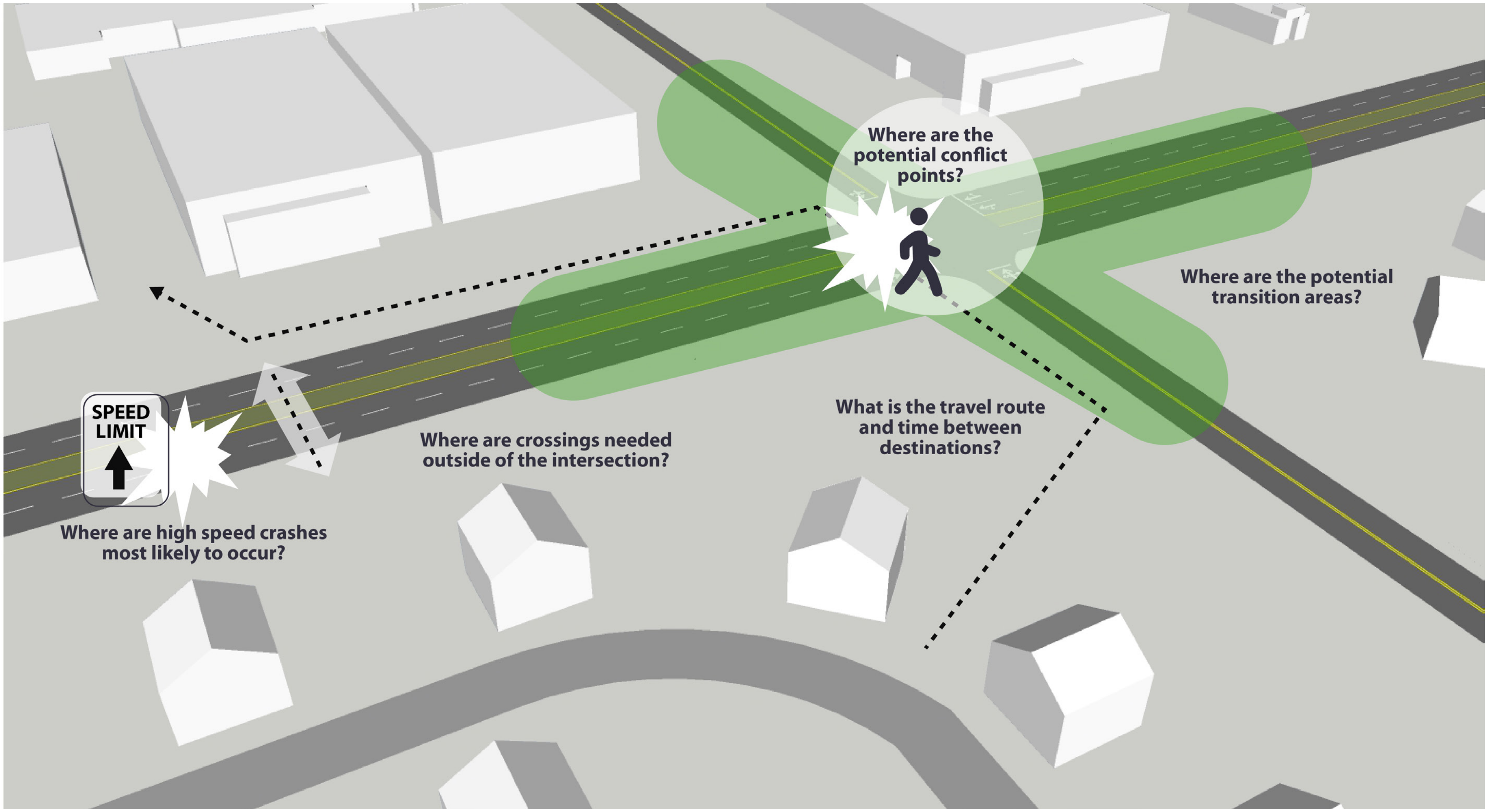


Figure 5. Considerations for designing the pedestrian and bicyclist network at intersections. Source: FHWA.

PART II. DESIGNS FOR INTERSECTION TYPES

An intersection design process consistent with the principles in Part 1 uses facility selection and intersection analysis tools that consider the needs of bicyclists and pedestrians of all ages and abilities. This process leads to several desired outcomes for intersection design. The planners and designers review context and site-specific conditions to make final design decisions for intersections.

The following elements should be considered for all intersections:

- **Include pedestrian and bicycle crossings on all legs, at conspicuous locations with clear sightlines, such as perpendicular crossings.**
- **Mark stop lines or advance yield lines in advance of marked crosswalks.**
- **Evaluate on-street parking and driveway access in the immediate vicinity of intersections and determine if restrictions would be beneficial for pedestrian and bicycle facilities, particularly for mutual sight distance and visibility.**
- **Provide lighting at all crossings and along bikeways and pathways inside the intersection influence area.**
- **Indicate transitions with clear markings and signage in advance of and shorten mixing zones with bike lanes.**
- **Extend bike lanes into the functional area of the intersection to the left of right-turn only lanes.**
- **Regularly trim vegetation to maintain visibility of pedestrian and bicyclist crossings at intersections.**
- **Minimize intersection skew and install crosswalks along the shortest path across each crossing stage.**
- **Construct curb ramps with landings and detectable warnings at all corners of the intersection where sidewalks are present or planned. When curb ramps and landings are constructed, they must be compliant with Americans with Disabilities Act (ADA) requirements (incorporated by reference into 28 CFR 35.151(i)).[(44)(45)]**
- **If a traffic control signal or a PHB is used, include APS to inform pedestrians with low or no vision that the WALK signal is on. If pedestrian activated warning devices such as RRFBs or other warning beacons are used, install Audible Information Devices (AIDs) to inform pedestrians with low or no vision that the warning device is flashing.**
- **Surpass prescribed accessibility requirements by further minimizing grades and cross slopes and placing push buttons in consistent locations that are easy to locate and access.**
- **Design intersections and interchange ramps to meet at as close to a perpendicular angle as practical for the intersection design.**
- **Implement geometric design and physical features that limits motor vehicle turning movement speed to 20 mph.[(46,47,48)]**
- **Install conspicuity enhancements, such as RRFBs, and minimize turn radii and lane widths for uncontrolled and channelized approaches to pedestrian and bicycle crossings.**

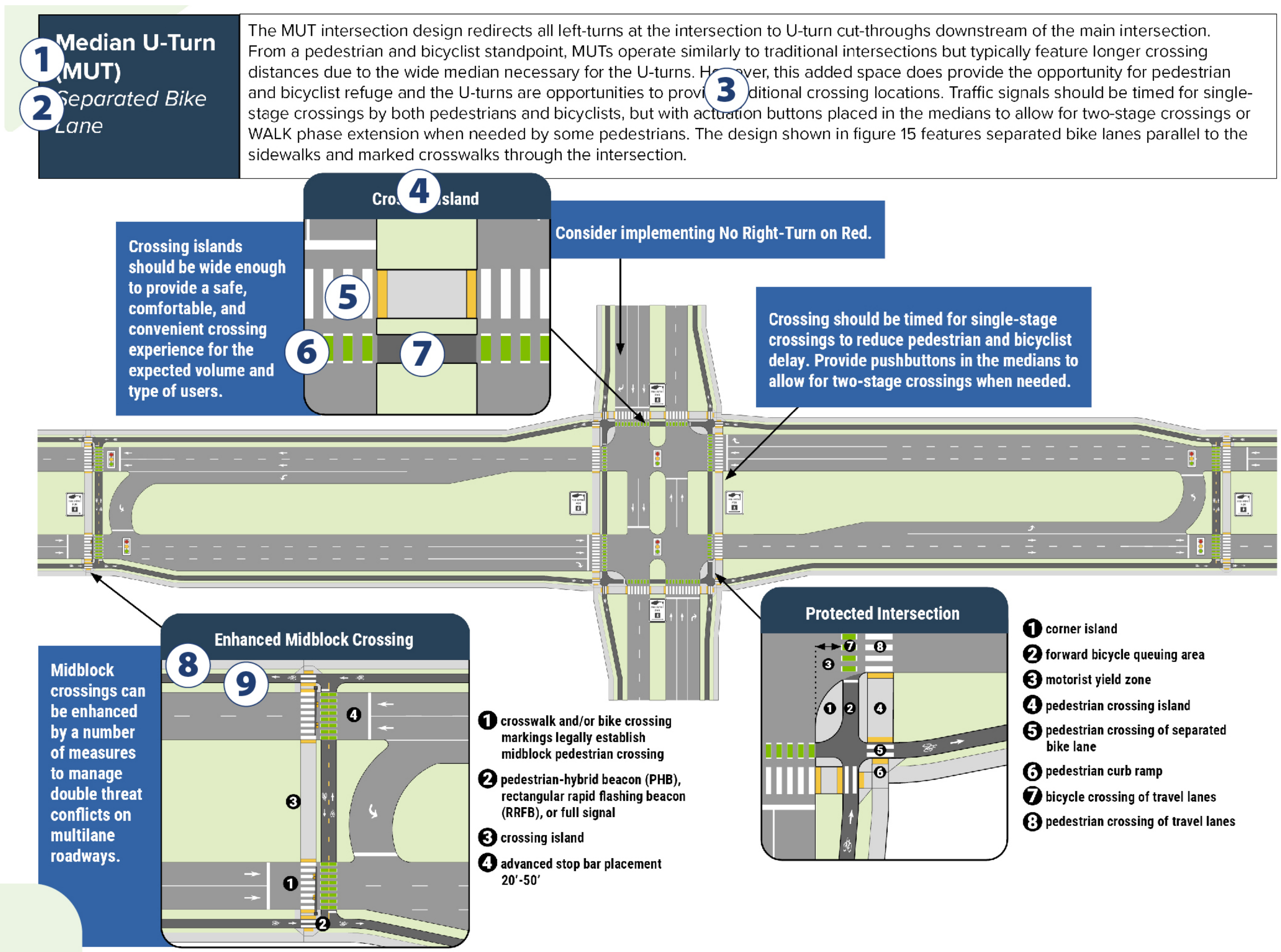
The following elements should be considered for intersections in areas with high bicycle or pedestrian demand:

- **Implement leading pedestrian interval (LPI) at all signalized pedestrian crossings where turning vehicles are permitted during the WALK phase. The use of APS should also be considered when implementing LPI to address the needs of pedestrians with low or no vision.**
- **Maintain temporal separation through intersections using bicycle signals and protected WALK phases as appropriate.**
- **Maintain spatial separation through intersections using geometric features, such as raised islands and curb extensions.**
- **Implement No Right on Red restrictions at signalized intersections.**
- **Install raised crosswalks and/or RRFBs at uncontrolled approaches.**
- **Implement pedestrian-actuated traffic controls, such as PHBs or pedestrian signals, at multilane approaches to bicycle or pedestrian crossings (including channelized dual left-turn or right-turns).**
- **Where median refuge is provided for people crossing wide or complex intersections, include storage space for groups, pedestrians with strollers, or bicyclists with trailers, and push buttons placed accordingly.[25]**
- **Provide a longer or extended WALK phase to allow approaching and slower moving pedestrians and bicyclists to cross intersection in a single stage.**
- **Implement signal phases that allow pedestrians and bicyclists to cross in one stage. Place push buttons in the median for multistage crossings.[25]**

INTERSECTION TYPES AND DESIGN CONCEPTS

This section illustrates how pedestrian and bicyclist facilities can be incorporated into different intersection designs, including stop-controlled intersections, traditional signalized intersections, roundabouts, Median U-Turn (MUT) intersections, Reduced Crossing U-Turn (RCUT) intersections, Quadrant Roadway (QR) intersections, Displaced Left Turn (DLT) intersections, and Diverging Diamond Interchanges (DDI). Each intersection type is featured in multiple design options – one option per page, each integrating a different type of bikeway and pathway. Figure 6 shows an example of an intersection cut sheet with a legend to identify key features. Some intersection types, such as the RCUT, have additional versions to show interactions between different vehicular routes and bikeway or pedestrian routes. The traditional, roundabout, and DDI alternatives include options for bike lanes (not vertically separated from motor vehicle traffic). The QR intersection can be adapted to include a bike lane configuration similar to the traditional intersection. The RCUT, MUT, and DLT show separated bikeway routes because physical separation from motor vehicle traffic is recommended due to typical traffic volumes, speeds, and complexity of the traffic operations.

Each intersection type is described by a table listing typical conditions that may pose challenges or opportunities for pedestrians and bicyclists navigating the intersection. The table also includes information from the analysis tools introduced in Part 1 that further explain these challenges or opportunities. The analysis informs the overall selection of intersection types for sites, and the analysis identifies need for additional design features to be considered for bicyclists and pedestrians at the intersection.

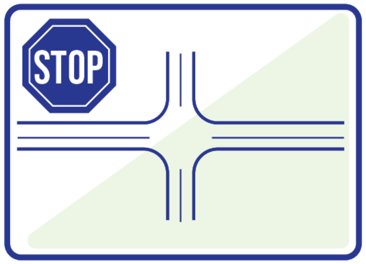


KEY

1 - Intersection Type	4 - Key Factors	7 - Refuge Island	Signalized Intersection
2 - Bikeway Type	5 - Pedestrian Crosswalk	8 - Sidewalk	Crossing with Pedestrian Hybrid Beacon
3 - Intersection Information	6 - Bike Crossing	9 - Bikeway	Supplemental Pedestrian Push Button

Figure 6. Intersection design cut sheet key. Source: FHWA.

STOP-CONTROLLED INTERSECTIONS



Conventional intersections where one or more approaches are controlled by a STOP sign are generally categorized as stop-controlled intersections. However, there are significant differences between multi-way stop control (typically all-way) and minor road stop control (major road uncontrolled). The respective descriptions that follow address the more typical scenarios of all-way stop (AWS) and minor road stop (MRS).

AWS intersections feature STOP signs controlling all approaches. AWS intersections are used in a wide range of conditions, from low volume, low speed local roads to high speed rural highways. Because stopping is mandatory for all movements, vehicle speeds are typically lower and opportunities for pedestrians and bicyclists to cross should be frequent. Generally, AWS intersections tend to have relatively compact footprints, although additional through lanes or turn lanes add complexity to the intersection and increase crossing distances.

MRS intersections feature STOP signs controlling the minor road approach(es), while the major road approaches are uncontrolled. Crossing the uncontrolled approaches of a MRS intersection involves a higher risk to pedestrians and bicyclists because of the free-flow and higher-speed traffic conditions. Additionally, opportunities to cross may be less frequent, or even infrequent, due to the need to wait for a gap in major road traffic.

There are opportunities to enhance pedestrian and bicycle crossings at both AWS and MRS intersections. Creating space within the intersection functional area that makes pedestrians and bicyclists more visible and conspicuous supports improved driver awareness and yielding, and makes the intersection safer and more usable for people walking and bicycling. High-visibility crosswalks and effective intersection lighting are two treatments that can be implemented routinely. Other treatments that should be considered and implemented as often as possible include wide refuge islands (especially where crossings involve more than two lanes of traffic), separated bikeways with channelization at the intersection, and raised crosswalks (for MRS intersections) or tabled intersections (for AWS intersections). Stop-controlled intersections that involve multilane approaches or more complex arrangements of through lanes and turn lanes should also be evaluated for treatments such as RRFB or PHB, as appropriate. Table 2 describes typical conditions and evaluation techniques that correspond to challenges or opportunities for improved safety, access, and comfort for pedestrians and bicyclists at AWS and MRS intersections.

Table 2. Assessment considerations for conditions at Stop-Controlled intersections.

Condition	Description	Assessment Technique
Uncontrolled crossings; Multilane crossings	For pedestrians and bicyclists, risk of crash harm is higher and convenience and comfort are lower, at uncontrolled or multilane crossings, especially along higher speed or rural roads.	» The Design Flag Assessment includes a flag for "yield- or uncontrolled vehicle paths" and a flag for "multilane crossings" emphasizing consideration at multi-threat or high-speed crossings.
Crossing distance	Stop-controlled intersections with multiple through or turn lanes can lead to longer pedestrian and bicyclist crossing distances and greater exposure to traffic. Certain road users may need extended time to cross longer distances, further increasing exposure and stress for the user.	» The SSI method considers the number of through lanes crossed as a concern for pedestrian and bicyclist exposure. » Travel time data collection can be used to identify locations with long crossing distances.
Visibility of pathway and bikeway crossings	The mutual visibility among pedestrians, bicyclists and motor vehicle drivers is essential for effective yielding and stopping behaviors. Further, the need to identify and act upon gaps in traffic for uncontrolled crossings or alternating stop-and-go for controlled crossings makes sight distance and view angles critical.	» The Design Flag Assessment includes a flag for "Sight Distance for Gap Acceptance Movements"

Minor Road Stop (MRS)
Sidepath

Where pedestrians cross minor street stop-controlled or uncontrolled approaches as shown in figure 7, marked crosswalks align with sidewalk or shared use path approaches. Multi-lane, uncontrolled pedestrian crossings should include additional countermeasures (16). Traffic control devices, such as the Pedestrian Hybrid Beacon (PHB) shown in figure 7, should be considered for higher speed and traffic volume crossings. Bicyclists travelling along major roadways may travel along and cross minor street stop-controlled approaches at separated, shared use path crossings. In rural contexts, bicyclists may travel along and cross minor and major roadways in the road, in bike lanes, or as a pedestrian at the crosswalk.

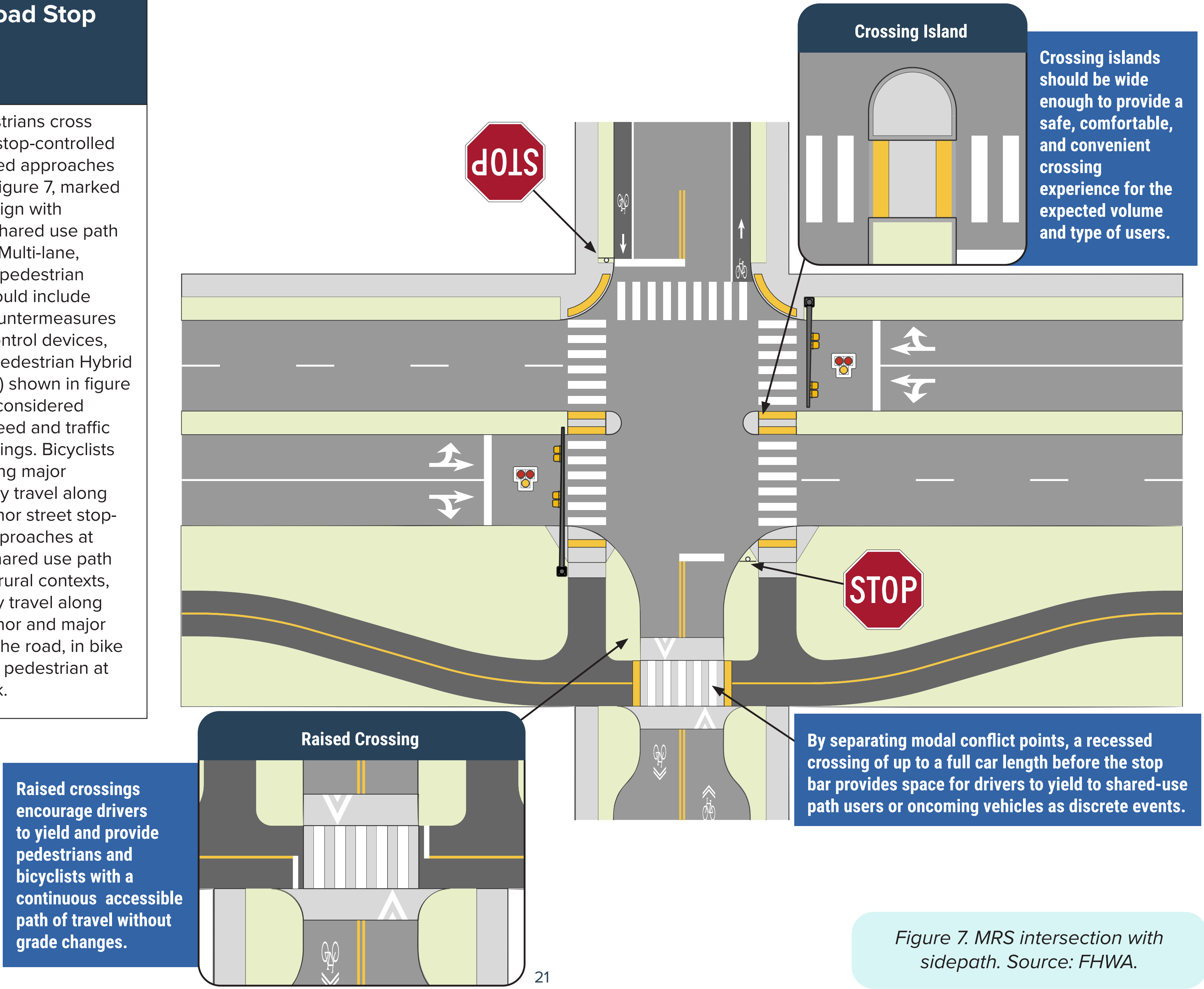


Figure 7. MRS intersection with sidepath. Source: FHWA.

All Way Stop (AWS)
Bike Lane

At all-way stop intersections as shown in figure 8, pedestrians cross at marked crosswalks that align with the sidewalk and stop lines are set closely to the crosswalk. Bike lanes may merge with the vehicle travel path at raised intersections as shown in figure 8, or bike lanes may continue through the intersection using green colored pavement to give space to bicyclists and enhance visibility. Where there are no bike lanes at the intersection or at typical stop-controlled intersections in rural areas, bicyclists may merge into turn lanes in advance of the intersection to navigate left-turns.

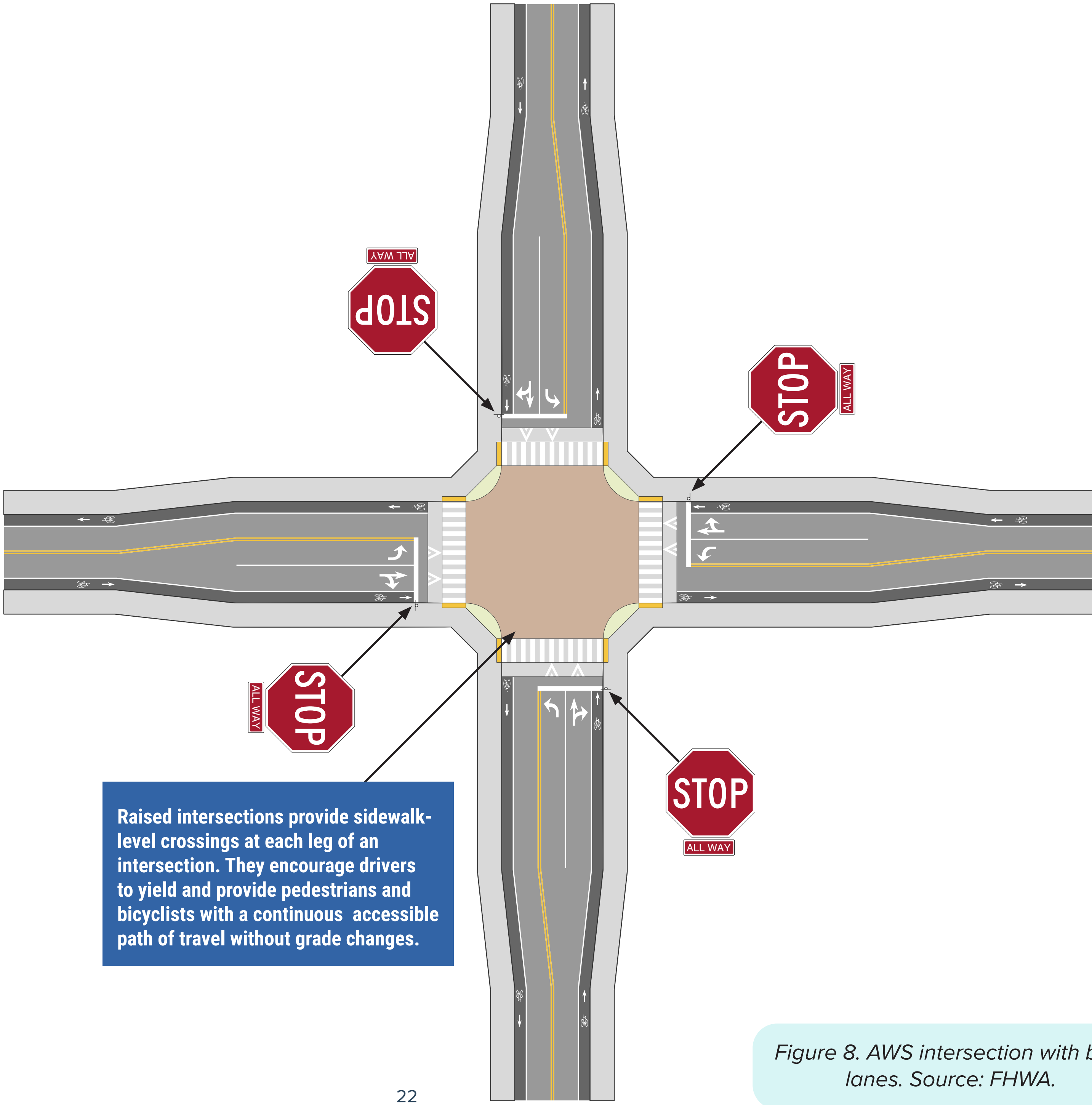
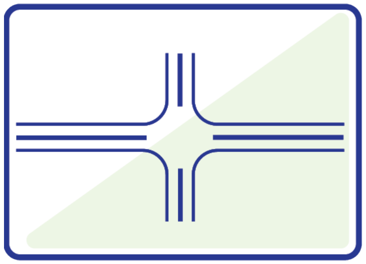


Figure 8. AWS intersection with bike lanes. Source: FHWA.

TRADITIONAL SIGNALIZED INTERSECTION



Traditional intersections are the most common traffic signal-controlled intersection type.[7] Turn lanes increase the complexity and timing of the signal phasing and cycle lengths, and intersections with multiple through lanes and turn lanes increase crossing distance and exposure for pedestrians and bicyclists. Table 3 describes analysis findings and typical conditions that present challenges or opportunities for improved safety, access, and comfort for pedestrians and bicyclists at traditional signalized intersections.

Table 3. Assessment considerations for conditions at traditional signalized intersections.

Condition	Description	Assessment Technique
Crossing distance	With added turn lanes, traditional intersections can lead to longer crossing distances without refuge for pedestrians and bicyclists. Pedestrians that are older, disabled, or children may need extended time to cross long distances, increasing exposure and stress for the user.	» The Design Flag Assessment includes a flag for “multilane crossings.” » The SSI method considers the number of through lanes crossed as a concern for pedestrian and bicyclist exposure. » Travel time data collection can be used to identify locations with long crossing distances.
Direct turning movements	Direct turning movements are those that are permitted to occur at the main intersection, as opposed to indirect turning movements that may require U-turns or other combinations of movements. Direct turning movements improve mobility for motor vehicles, but they increase the number of conflict points at the main intersection for motorists, bicyclists, and pedestrians. Increasing the number of turning movements may also lead to increased traffic signal cycle lengths and complexity and delay for pedestrians and bicyclists	» The Design Flag Assessment includes flags for “motor vehicle right-turn” and “motor vehicle left-turn.” It also includes a flag for “long red times,” which may be triggered through adding phases for direct turning movements. » The SSI method accounts for severity of different conflict points depending on vehicle speed. » HCM delay data collection can be used to assess added pedestrian and bicyclist delay due to phasing for direct turning movements.
Channelized right-turns	Channelizing islands that accompany channelized right-turns can provide refuge for pedestrians but may also encourage higher motor vehicle turning speeds. If a channelized right-turn is uncontrolled (or free-flow), this can be problematic for pedestrians with disabilities.	» The Design Flag Assessment includes a flag for “crossing yield or uncontrolled vehicle paths” that may apply to channelized turns as well as a bicyclist-only flag for “channelized lanes.”
Signal timing	Depending on signal phasing, left-turns may conflict with bicyclist and pedestrian movements. Long signal cycles with many phases may increase pedestrian and bicyclist delay.	» The SSI method accounts for left-turn phasing for motor vehicles (permitted, protected/permitted, or protected). » HCM delay data collection can be used to assess pedestrian and bicyclist delay due to traffic signal timing changes.
Driveways	Nearby driveways can introduce additional complexity and conflict points.	» The Design Flag Assessment includes a flag for “intersection driveways and side streets” to account for driveways within the intersection influence area. » The SSI method can be modified to account for additional conflict points resulting from nearby driveways.
General	Signal coordination or steady traffic volumes may decrease natural gaps in traffic at midblock crossings.	» The HCM and simple traffic volume studies may be a tool to assess gaps in traffic flow, describing added pedestrian and bicyclist delay.

Traditional Signalized
Bike Lane

Traditional intersections provide direct access for all turning movements and are the most common intersection design found throughout the United States. This design, shown in figure 9, incorporates bike lanes with green colored pavement to emphasize continuity through the intersection, as well as two-stage left-turn boxes to allow cyclists to make left-turns without merging across lanes of through-moving vehicle traffic. Pedestrian facilities include sidewalks on both sides of all four legs, marked crosswalks, and pedestrian refuge islands on two legs. Pedestrian refuge islands simplify the pedestrian crossing by reducing the number of lanes crossed in one stage. Traffic signal phasing plans will depend on the traffic volumes, sight distance, and context of the intersection.

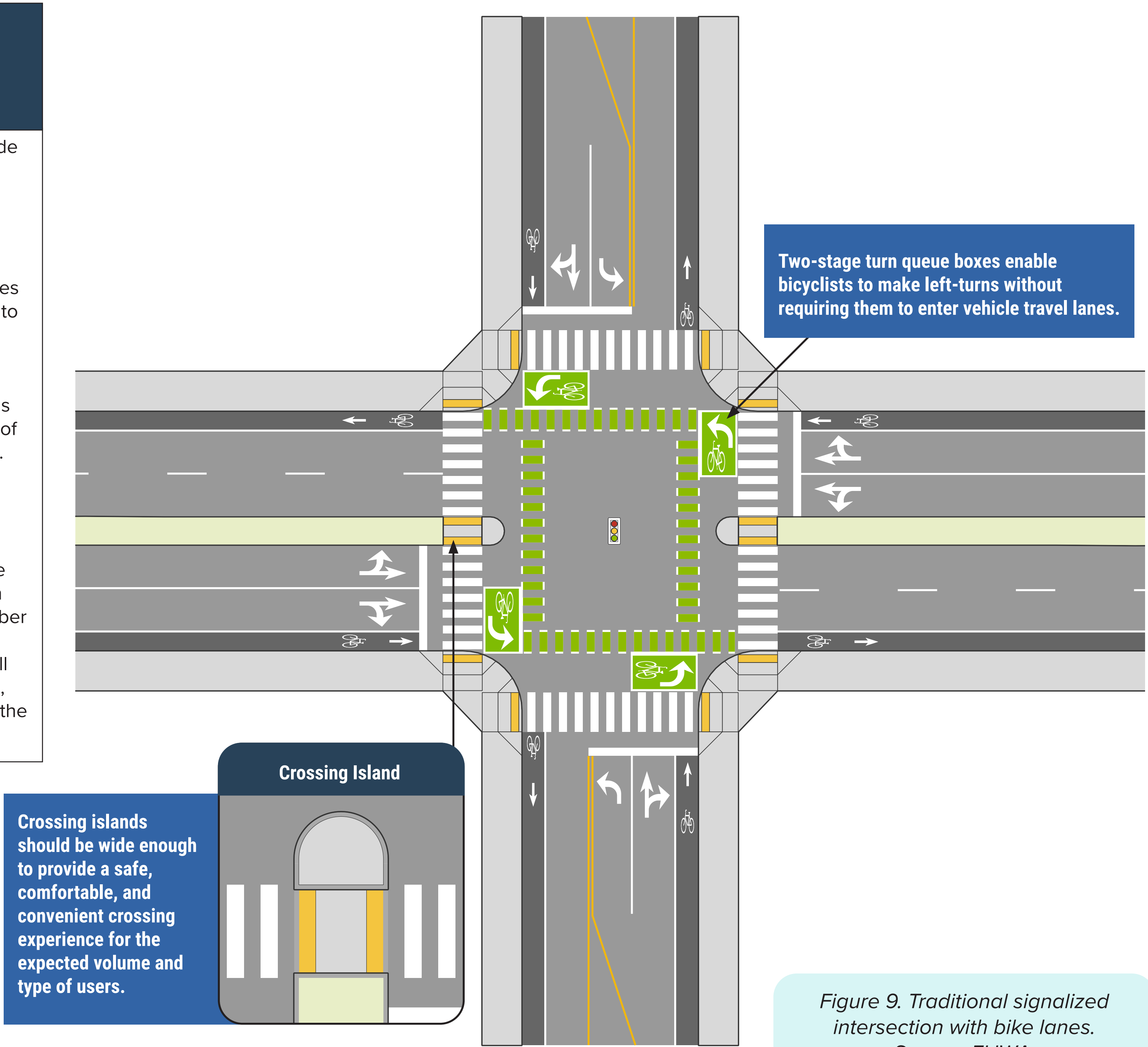


Figure 9. Traditional signalized intersection with bike lanes. Source: FHWA.

Traditional Signalized
Separated Bike Lane

This traditional intersection design, shown in figure 10, features bike lanes that are separated from motor vehicle traffic vertically and horizontally along the intersection legs. The one-way, separated bike lanes cross through the intersection following the routes designated by green colored pavement. Pedestrians travel on sidewalks that are separated from the bike lanes and cross through the intersection at marked crosswalks. In this design, it is important to consider the interactions between pedestrians and bicyclists at the corners and at medians where people may wait in groups to cross the intersection.

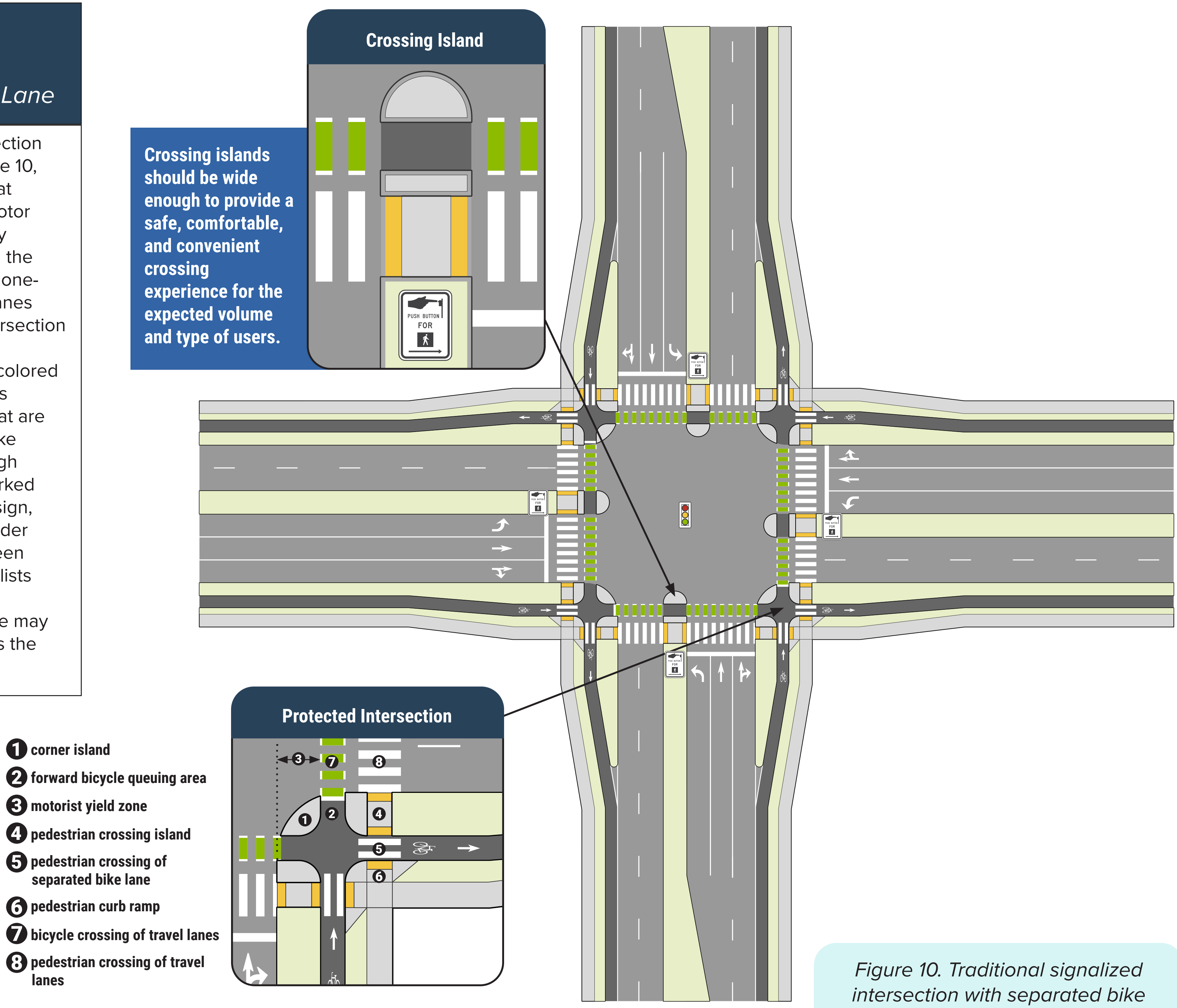


Figure 10. Traditional signalized intersection with separated bike lanes. Source: FHWA.

Traditional Signalized
Sidepath

This traditional intersection design, shown in figure 11, features sidepaths. Bike lanes are shown here with ramps to allow cyclists access to the sidepath upstream of the intersection and return them to the bike lane downstream of the intersection. Pedestrians and bicyclists use the marked crosswalks and refuge islands to cross through the intersection. Using a shared facility through the intersection consolidates conflict points between motor vehicles, bicyclists, and pedestrians. This design leads to increased conflicts between pedestrians and bicyclists, especially at the corners of the intersection, and may be more difficult for pedestrians with disabilities to navigate. It is important to design the width of shared paths, crosswalks, medians, and queuing areas to accommodate groups of people of all abilities. Shared facilities may be appropriate even where only low volumes of bicyclists and pedestrians are expected to use the intersection under present and future conditions.

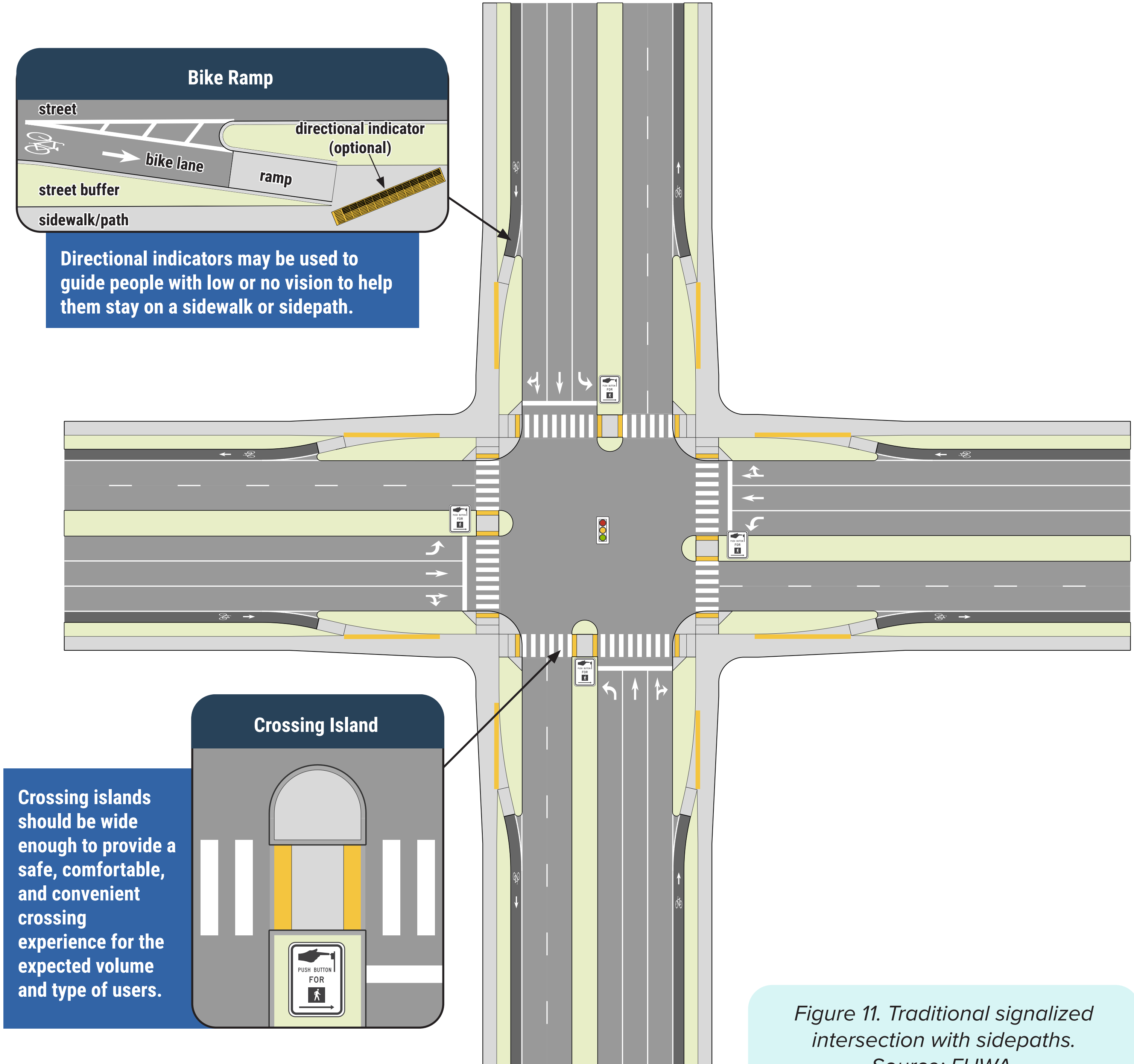
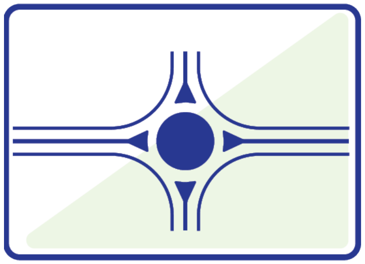


Figure 11. Traditional signalized intersection with sidepaths. Source: FHWA.

ROUNDABOUT



A roundabout is a circular intersection characterized by channelized approaches and counterclockwise traffic flow around a center island.[8] Traffic approaching the roundabout yields to traffic already in the circular roadway. Roundabouts are highly adaptable and have been proven to work across a range of contexts, from high-speed rural to low-speed urban. Roundabouts can offer several benefits to pedestrians and bicyclists, including allowing pedestrians to cross one direction of vehicular traffic at a time, reducing vehicular speeds through the intersection to 15-25 mph, and potentially reducing the total number of lanes to cross at the intersection because of improved operational performance. Pedestrian crossings at roundabouts can present challenges for pedestrians who have low or no vision because the crossings are located off to the side of the intersection, instead of in-line with the approach sidewalk. However, there are solutions that can be applied to make these crossings accessible for all users.[28] A continuous, detectable edge treatment between the sidewalk and vehicle or bike lanes is needed to provide an underfoot cue for pedestrians with low or no vision at locations where pedestrian crossing is not intended. This may be vegetative separation or another continuous, detectable edge treatment. Detectable warning surfaces should not be used for edge treatment.[30] Table 4 describes analysis findings and typical conditions that present challenges or opportunities for improved safety, access, and comfort for pedestrians and bicyclists at roundabouts.

Table 4. Assessment considerations for conditions at roundabouts.

Condition	Description	Assessment Technique
Roundabout geometry	Modern roundabout geometry encourages slower motor vehicle approach speeds. However, the intersection footprint and placement of crosswalks may lengthen the travel distance for pedestrians and bicyclists.	» The SSI method accounts for the slower motor vehicle speeds entering, circulating, and exiting the intersection as compared to other intersection designs. The SSI method also applies an “indirect paths” adjustment to account for the footprint and placement of crosswalks.
Splitter islands	Splitter islands provide pedestrian refuge.	» The SSI method accounts for the splitter islands inherent in modern roundabout design. It factors them in as refuge islands that decrease pedestrian and bicyclist movement complexity.
Bicyclist acceleration	Bicyclists riding in mixed traffic entering the roundabout are slower to accelerate from a stop than motor vehicles.	» The Design Flag Assessment includes a flag for “riding in mixed traffic.” » Gap acceptance studies may help to understand issues surrounding bicyclists entering the roundabout.
Driver yielding	Entries at roundabouts are yield-controlled and exits are uncontrolled. Consequently, pedestrian and bicycle crossings at both entries and exits must be carefully assessed to maximize the conditions for yielding. This is particularly important for making crossings accessible to pedestrians with vision loss.[28]	» The Design Flag Assessment includes a flag for “multilane crossings” that considers the number of lanes crossed.

Roundabout
Shared Lane

This single-lane roundabout design, shown in figure 12, features sidewalks with crosswalks for pedestrians and bike lanes for bicyclists. The crosswalks are perpendicular to the motor vehicle traffic that is diverted by the geometry of the roundabout circular roadway and splitter islands. The bike lanes end shortly upstream of the roundabout entry, and bicyclists merge with motor vehicle traffic to navigate the intersection before returning to the bike lane after exiting (as indicated by the shared lane markings on the intersection legs). Another option would be to provide a ramp from the bike lane onto a sidepath in advance of the roundabout and another ramp from the sidepath to the bike lane following the roundabout, similar to the design shown in figure 14. While roundabout geometry produces lower motorist speeds, bicyclists typically cannot accelerate at the same rates as motor vehicles. Riding in mixed traffic adds some complexity to the task of biking through a roundabout and may not be comfortable for bicyclists of all ages and abilities.

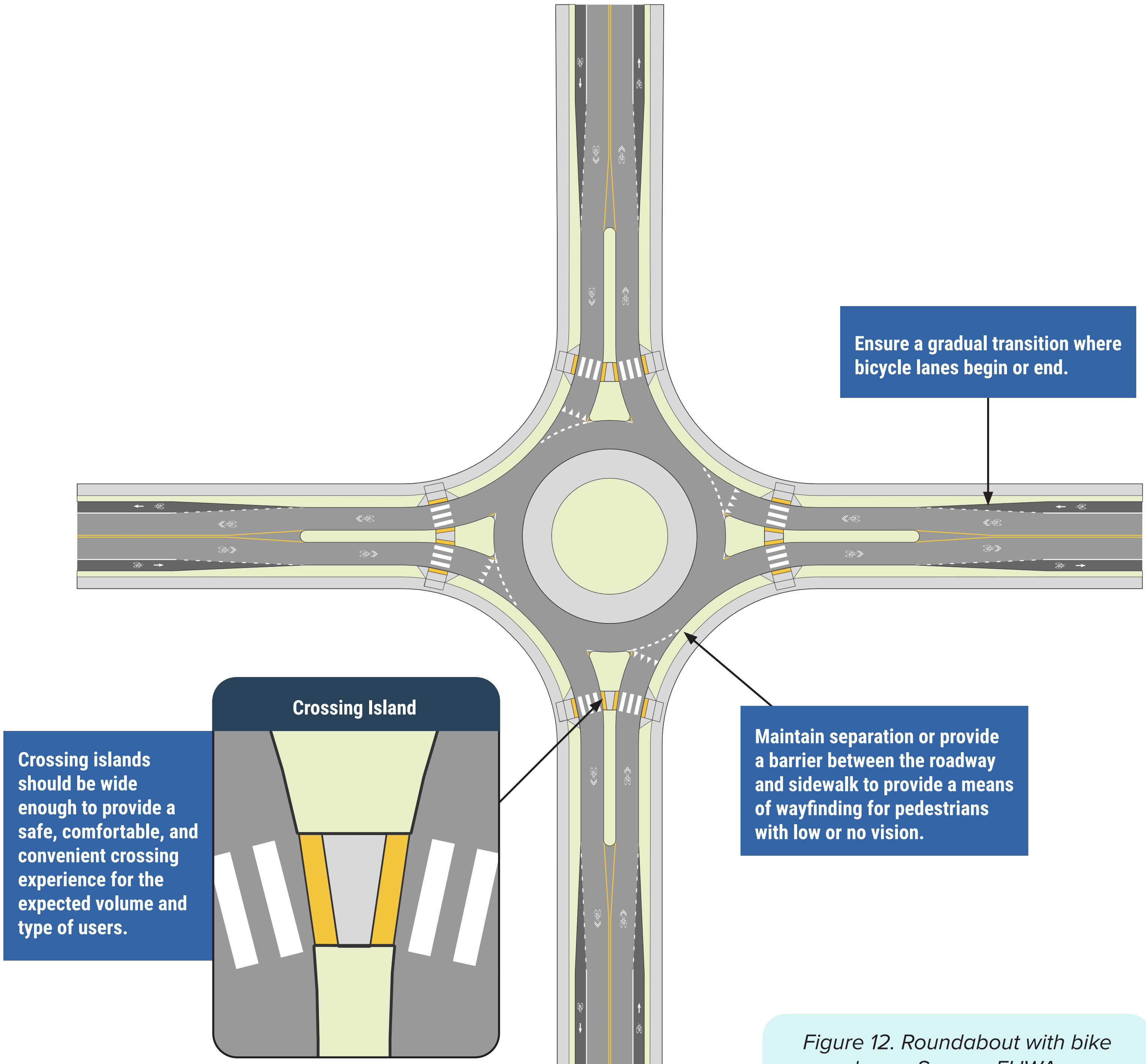


Figure 12. Roundabout with bike lanes. Source: FHWA.

Roundabout
Separated Bike Lane

This single-lane roundabout design, shown in figure 13, features separated bike lanes with bicyclist crossings parallel to the marked pedestrian crosswalks. This consolidates pedestrian and bicyclist activity to the same areas, improves driver visibility of crossing pedestrians and bicyclists, and minimizes conflict points between pedestrians and bicyclists. The interface between the separated bike lanes, bicycle crossings (marked here with green colored pavement), and pedestrian crosswalks are designed to provide enough room for bicyclists and pedestrians to maneuver separately. The use of splitter islands on all approaches in the modern roundabout design provides refuge islands for both pedestrians and bicyclists.

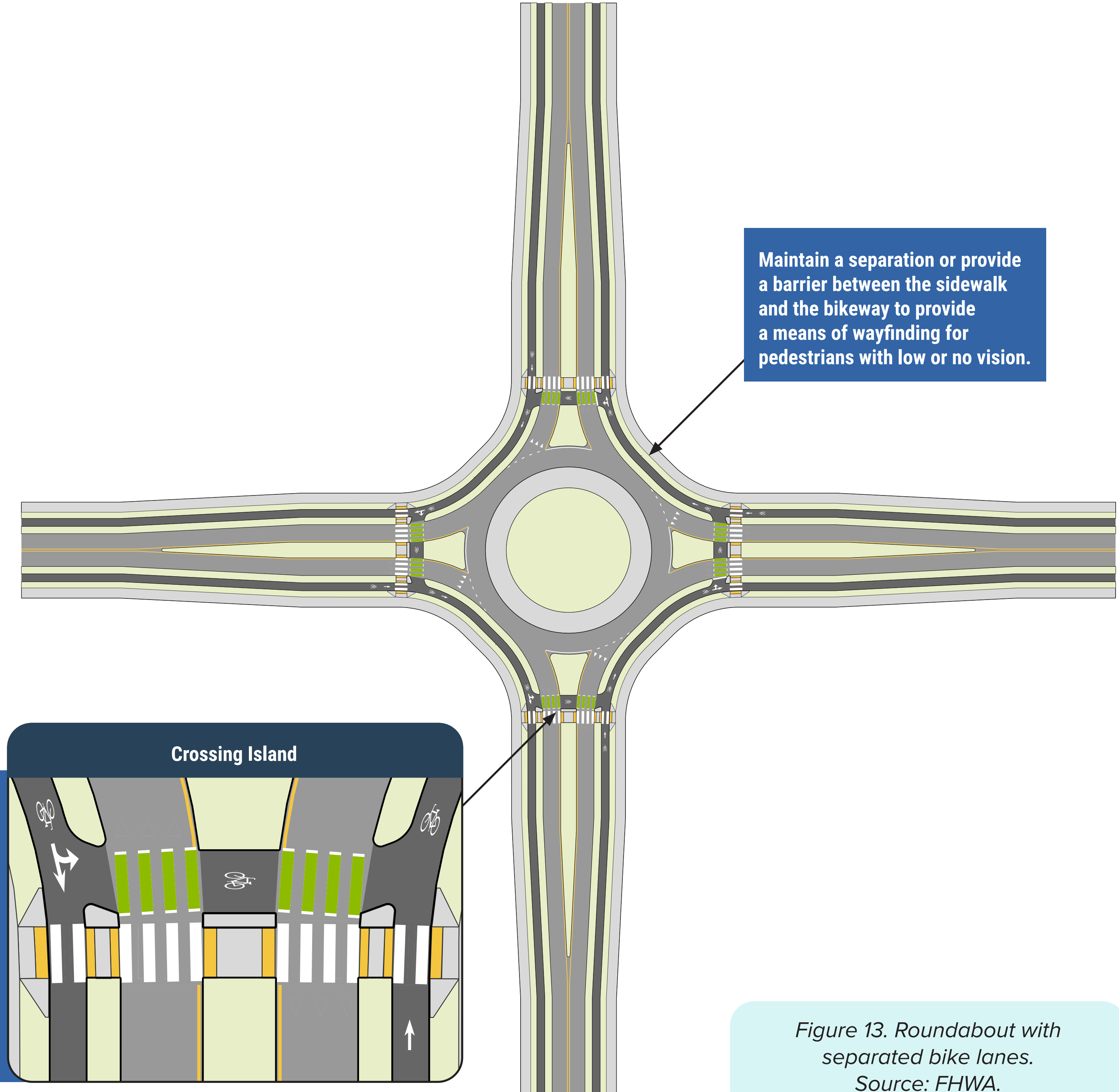


Figure 13. Roundabout with separated bike lanes. Source: FHWA.

Roundabout
Sidepath

This multilane roundabout design, shown in figure 14, transitions bike lanes to sidepaths upstream of the roundabout entrance. For most bicyclists, this provides the option for a more comfortable path across the intersection but increases conflicts with pedestrians. Shared facilities may be appropriate even where only low volumes of bicyclists and pedestrians are expected to use the intersection under present and future conditions The multilane design increases crossing distances over the single-lane design. Bicyclists have the option to transition from the bike lane to the sidepath or merge with motor vehicle traffic to continue through the roundabout. This design also includes raised crosswalks and PHBs across the entering and exiting lanes of the roundabout. These are features that can be added to lower vehicle speeds and improve driver yielding behavior. The splitter islands here are shown in green to indicate landscaping. This is an important detail as landscaping, as opposed to paving, areas like medians and splitter islands can aid pedestrians with vision loss in aligning and staying on the intended path.

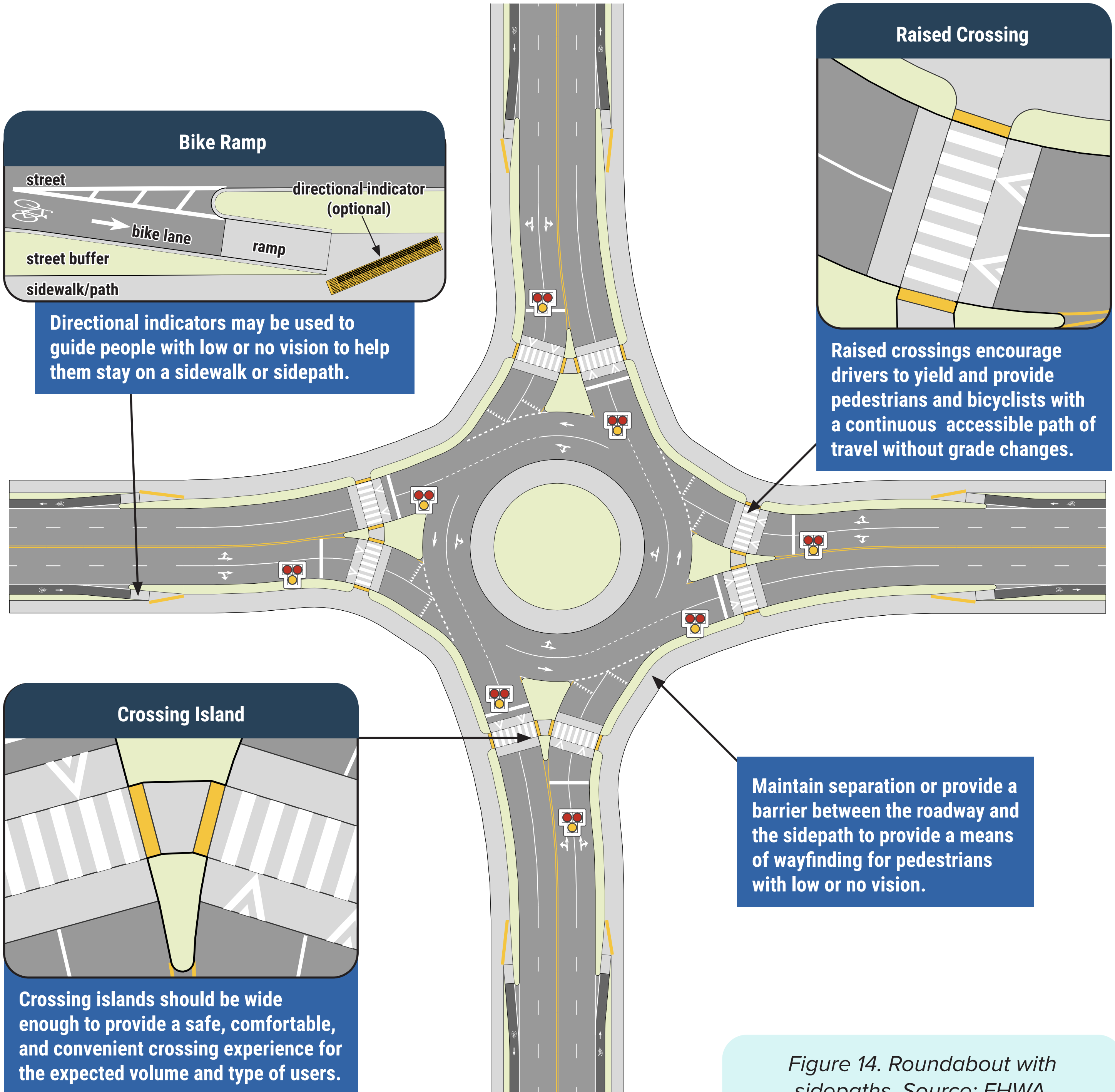
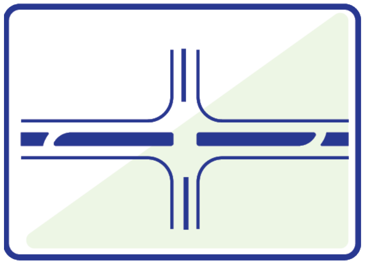


Figure 14. Roundabout with sidepaths. Source: FHWA.

MEDIAN U-TURN (MUT) INTERSECTION



Median U-Turn (MUT) intersections replace direct left-turns at an intersection with indirect left-turns that rely on a U-turn/right-turn combination, while still allowing through movements along each intersecting roadway.(9) The MUT reduces the overall number of vehicular conflict points and presents all users with fewer conflicting movements to cross at a time. The main intersection is signalized but requires fewer traffic signal phases than a traditional intersection due to the elimination of direct left-turns. MUT intersections offer several benefits to pedestrians and bicyclists, such as shorter crossing distances, reduced conflict points, shorter cycle lengths and less delay, and an opportunity to increase connectivity when controlled midblock crossings are incorporated with downstream U-turn intersections. Table 5 describes analysis findings and typical conditions that present challenges or opportunities for improved safety, access, and comfort for pedestrians and bicyclists at MUT intersections.

Table 5. Assessment considerations for conditions at MUT intersections.

Condition	Description	Assessment Technique
Median and footprint	The median provides refuge, but the larger footprint may increase overall crossing distance.	» The SSI method accounts for the refuge that the medians provide to pedestrians and bicyclists through a movement complexity adjustment.
Major road bicyclist left-turn movements	Unless the intersection design provides bike boxes or other features to specifically provide for bicyclist left-turns, bicyclists riding with traffic make left-turn movements at the U-turn median openings. This route option requires bicyclists to travel in and merge across lanes of motor vehicle traffic along the major roadway.	» The Design Flag Assessment includes flags for “indirect paths” and “executing unusual movements,” as well as a bicyclist-only flag for “lane change across motor vehicle lanes.”
U-turn intersections	U-turn median openings provide opportunity for controlled midblock pedestrian crossing, introducing additional conflict points but also improving pedestrian and bicycle mobility.	» The SSI method could be used to capture additional conflict points due to the introduction of midblock crossings at the U-turn cut-throughs.

Median U-Turn (MUT)
Separated Bike Lane

The MUT intersection design redirects all left-turns at the intersection to U-turn cut-throughs downstream of the main intersection. From a pedestrian and bicyclist standpoint, MUTs operate similarly to traditional intersections but typically feature longer crossing distances due to the wide median necessary for the U-turns. However, this added space does provide the opportunity for pedestrian and bicyclist refuge and the U-turns are opportunities to provide additional crossing locations. Traffic signals should be timed for single-stage crossings by both pedestrians and bicyclists, but with actuation buttons placed in the medians to allow for two-stage crossings or WALK phase extension when needed by some pedestrians. The design shown in figure 15 features separated bike lanes parallel to the sidewalks and marked crosswalks through the intersection.

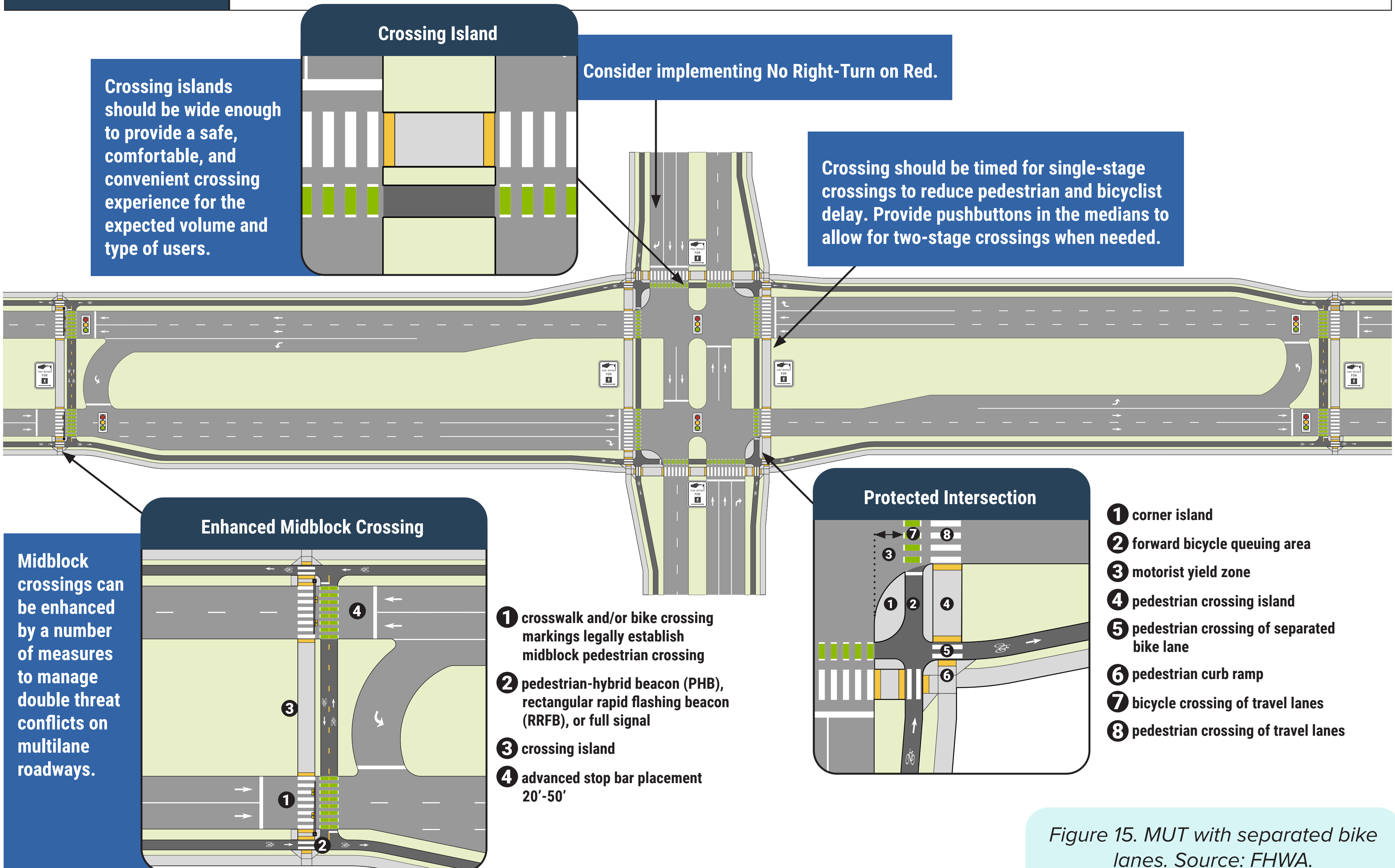


Figure 15. MUT with separated bike lanes. Source: FHWA.

Median U-Turn (MUT)
Sidepath

The MUT design shown in figure 16 features sidepaths through the intersection for use by pedestrians and bicyclists. Bike lanes merge with the sidewalk by way of ramps upstream of the U-turn cut-throughs. Both bicyclists and pedestrians cross through the intersection using marked crosswalks. The design shows the bike ramps prior to the U-turn crossings, before sidepath crossings at the U-turn. Shared facilities may be appropriate even where only low volumes of bicyclists and pedestrians are expected to use the intersection under present and future conditions.

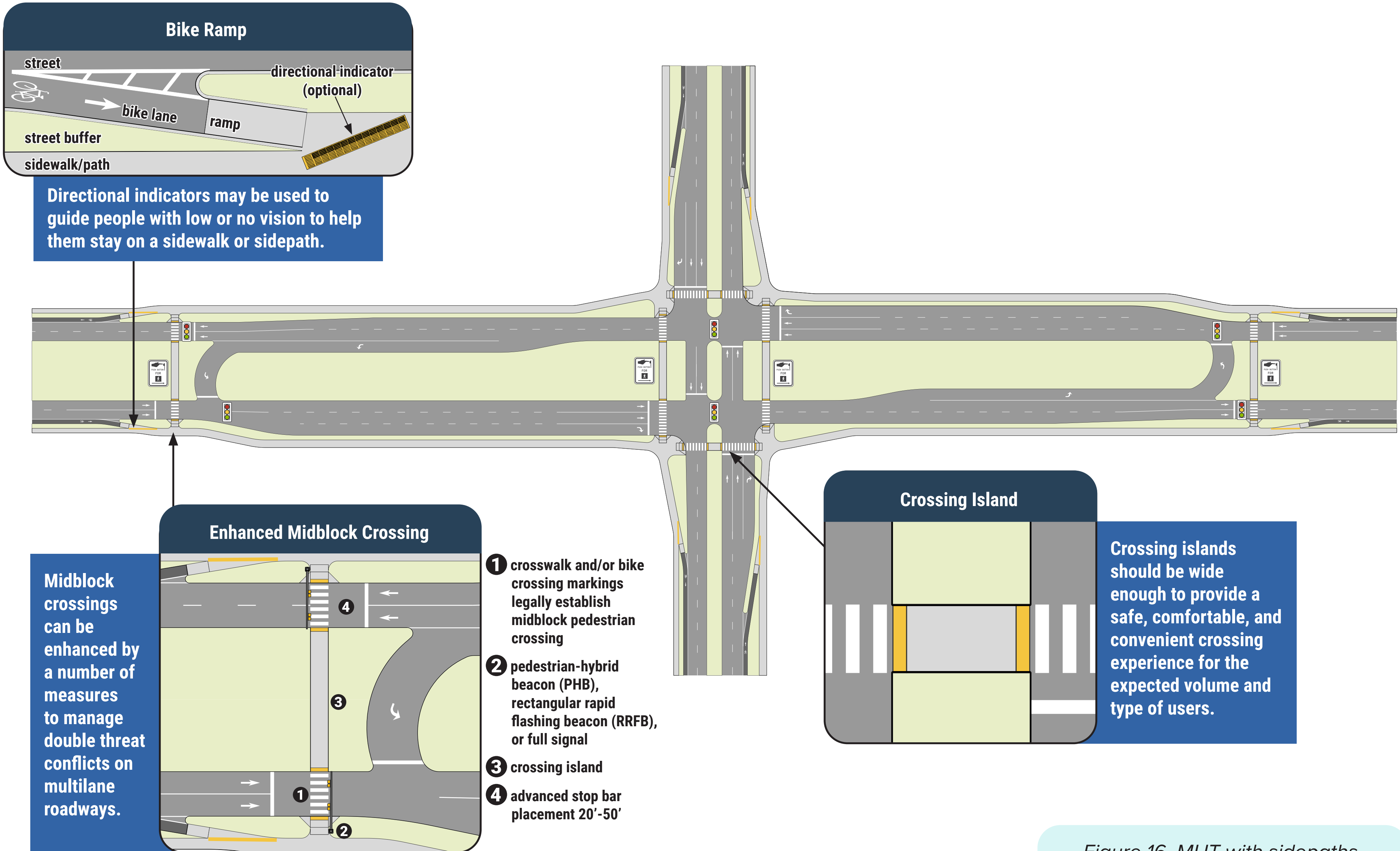


Figure 16. MUT with sidepaths. Source: FHWA.

Median U-Turn (MUT)

Sidepath Bulb

The MUT design shown in figure 17 features sidepaths. However, it also features U-turn bulbs, or “loons,” at the U-turn cut-throughs. The bulbs allow vehicles, especially larger trucks, to make U-turns while minimizing the necessary median width. The narrowed median width decreases the pedestrian and bicyclist crossing distance at the intersection. The sidepath follows the curve of the bulb, and changes in direction of travel are a design consideration for bicyclists or pedestrians with disabilities, but the separation between sidewalk or sidepath, usually landscaping of some kind, helps provide some contrast and non-visual guidance along and around the perimeter of the bulb-out.

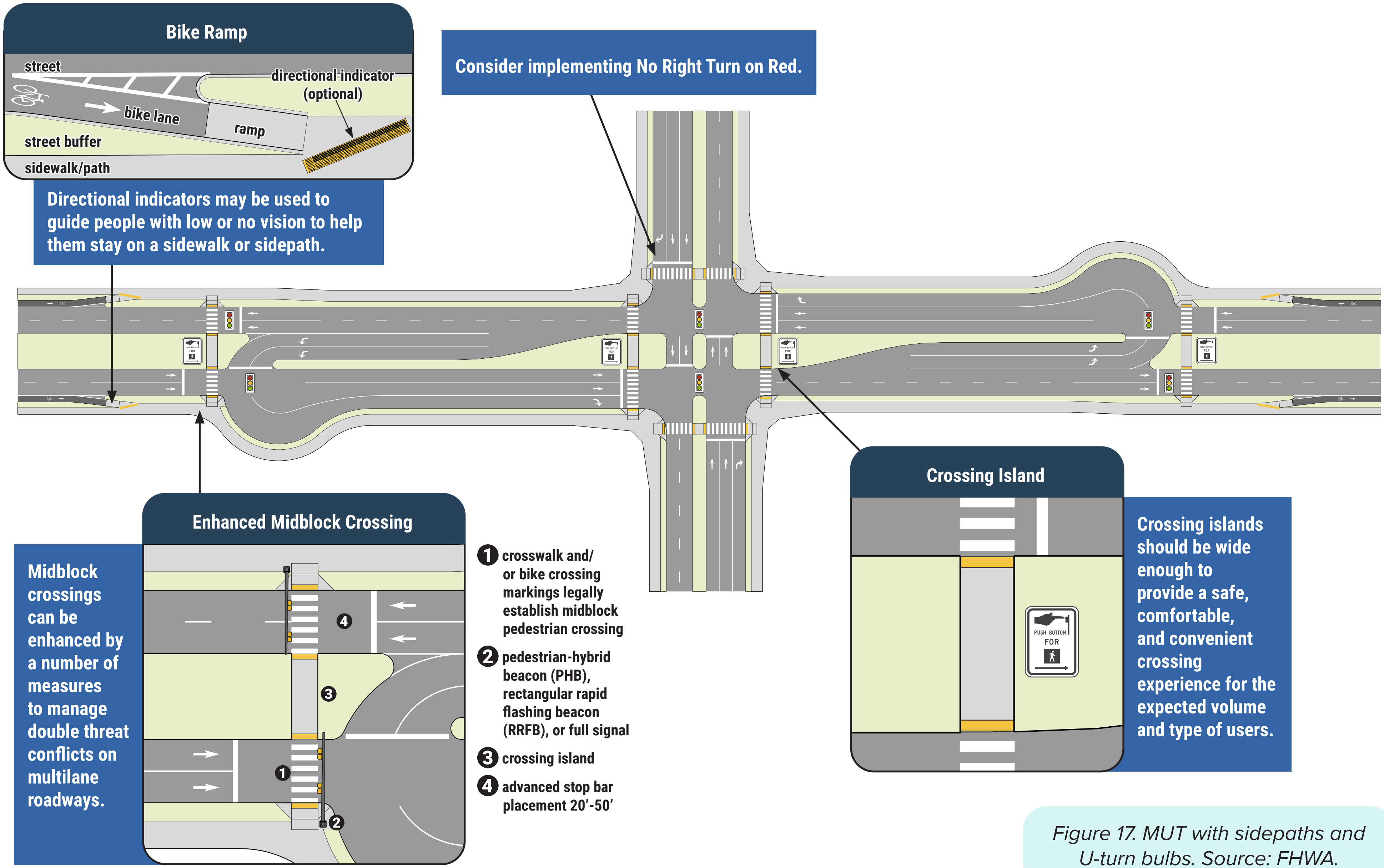
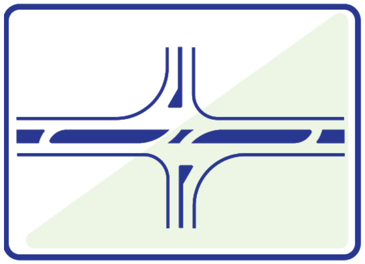


Figure 17. MUT with sidepaths and U-turn bulbs. Source: FHWA.

RESTRICTED CROSSING U-TURN (RCUT) INTERSECTION



Restricted Crossing U-Turn (RCUT) intersections replace direct through and left-turn movements from the minor approaches with an indirect movement of a right-turn/U-turn combination.[10] The RCUT reduces the overall number of vehicular conflict points and presents all users with fewer conflicting movements to cross at a time. An RCUT may be signalized or unsignalized. When signalized, fewer phases are needed as compared to a traditional signalized intersection, resulting in shorter overall cycle lengths. The features of an RCUT may provide benefits to pedestrians and bicyclists. Specifically, the reduced number of conflict points and fewer number of conflicting movements crossed at a time can reduce risk while crossing. Additionally, at signalized RCUT locations, shorter signal cycle lengths can result in less control delay, and signalized U-turns offer the opportunity for controlled midblock crossings, providing additional convenience. Table 6 describes analysis findings and typical conditions that present challenges or opportunities for improved safety, access, and comfort for pedestrians and bicyclists at RCUT intersections.

Table 6. Assessment considerations for conditions at RCUT intersections.

Condition	Description	Assessment Technique
Z-pattern crossing	The typical Z-pattern crossing creates a less direct travel route. This pedestrian route may present wayfinding difficulties for users, especially those with disabilities.	» The SSI method accounts for the conflict points for the typical Z-pattern crossing, including the balance between decreasing the number of bicyclist and pedestrian conflict points while increasing exposure through those conflict points. » The SSI method also accounts for out-of-the-way travel for pedestrians and bicyclists with an “indirect paths” complexity adjustment. » The Design Flag Assessment includes flags for “indirect paths” and “executing unusual movements.”
Median and footprint	The median provides refuge, but the larger footprint may increase overall crossing distance.	» The SSI method accounts for the refuge that the medians provide to pedestrians and bicyclists through a movement complexity adjustment.
Signal cycle length	RCUTs are typically operated as two-phase signals, which can lead to shorter cycle lengths and decreased pedestrian and bicyclist delay.	» HCM delay data collection can be used to assess added pedestrian and bicyclist delay due to two-phase signal operation.
Minor road bicyclist through and left-turn movements	Unless the intersection provides median openings and traffic control for direct crossings, bicyclists riding with traffic make left-turn movements at the U-turn median openings. This route option requires bicyclists to travel in and merge across lanes of motor vehicle traffic along the major roadway.	» The Design Flag Assessment includes flags for “indirect paths” and “executing unusual movements,” as well as a bicyclist-only flag for “lane change across motor vehicle lanes.”
U-turn intersections	U-turn median openings provide opportunity for controlled midblock pedestrian crossing, introducing additional conflict points but also improving pedestrian and bicycle mobility.	» The SSI method could be used to capture additional conflict points due to the introduction of midblock crossings at the U-turn cut-throughs.

Restricted Crossing U-Turn (RCUT)
Sidepath Z-Crossing

The RCUT is similar to the MUT but instead of redirecting left-turns from all approaches, it redirects both left-turns and through movements from only the minor approaches. Like the MUT, the U-turns needed for the RCUT provide opportunities for increasing pedestrian and bicyclist mobility by introducing additional midblock crossing locations. The RCUT layout optimized for motor vehicles calls for a “Z-pattern” pedestrian crossing at the main intersection, as shown in figure 18. This reduces conflict points between motorists, bicyclists, and pedestrians, but causes crossing pedestrians and bicyclists to travel out of their direct, intended path. Wayfinding signage and markings, APS, and carefully placed push buttons on corners and refuge islands, are strongly encouraged to mitigate the complex routes for pedestrians with disabilities.

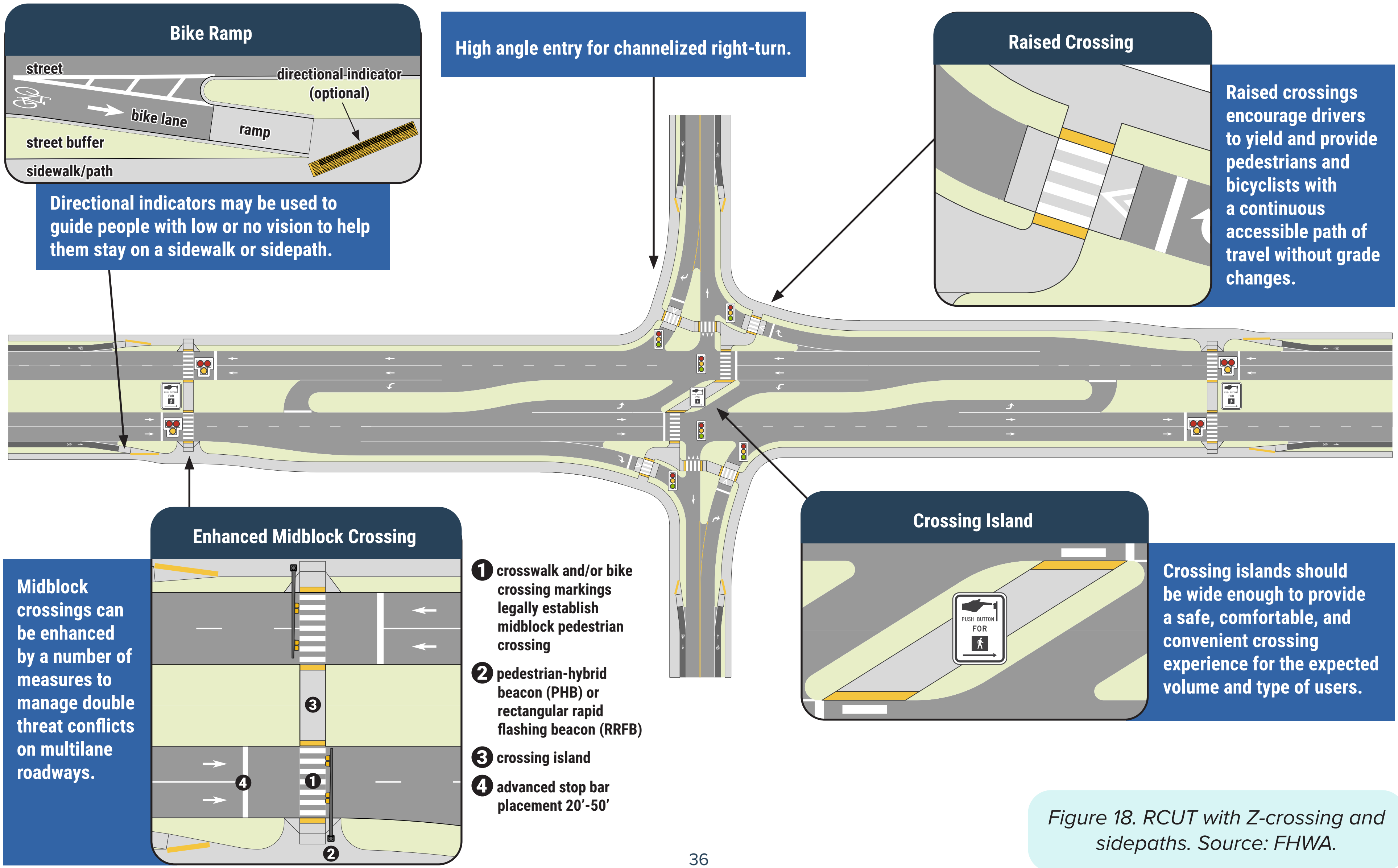


Figure 18. RCUT with Z-crossing and sidepaths. Source: FHWA.

Restricted Crossing U-Turn (RCUT)

Separated Bike Lane

The RCUT design shown in figure 19 features separated bike lanes and a more direct and intuitive pedestrian and bicyclist crossing configuration at the intersection. In order to provide the needed traffic signal phases for pedestrians and bicyclists to cross, the left-turns cannot operate simultaneously with the bicyclist and pedestrian movements crossing the major road unless multi-stage crossings are used. This design also features high angle channelized right-turns, which provide refuge islands for pedestrians and bicyclists and encourage appropriate motor vehicle speeds, increased visibility, and driver yielding behavior.

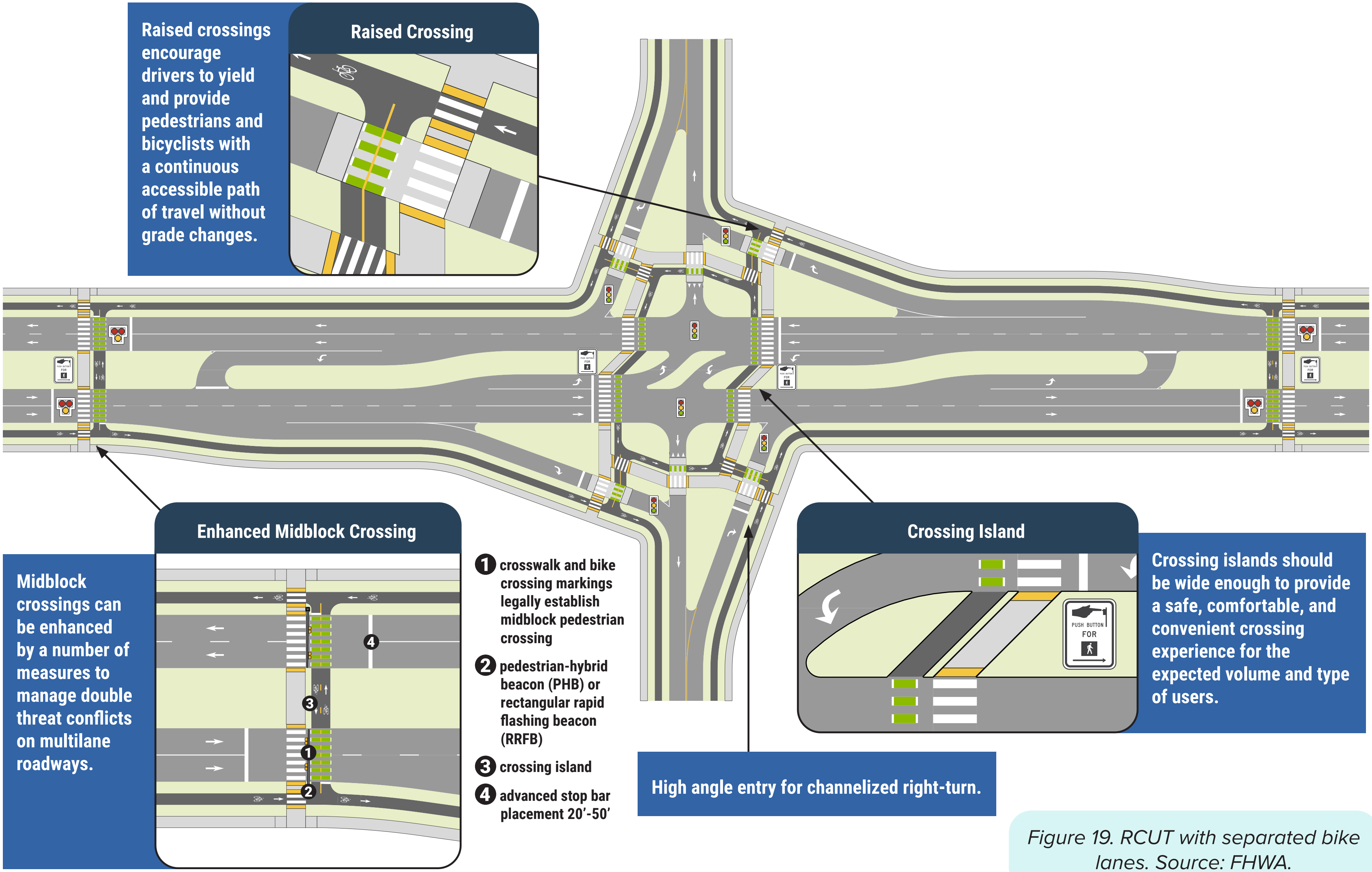


Figure 19. RCUT with separated bike lanes. Source: FHWA.

Restricted Crossing U-Turn (RCUT)
Sidepath

The RCUT design in figure 20 shows sidepaths that allow pedestrians and bicyclists to travel directly through the intersection. It also features the more traditional crosswalk positioning and high angle channelized right-turn lanes. The position of the channelizing islands facilitates staggered crosswalks, which can improve safety by angling pedestrians' and cyclists' field of view towards oncoming traffic but may also make maneuvering more difficult for cyclists and pedestrians using mobility assistance devices or with vision disabilities.

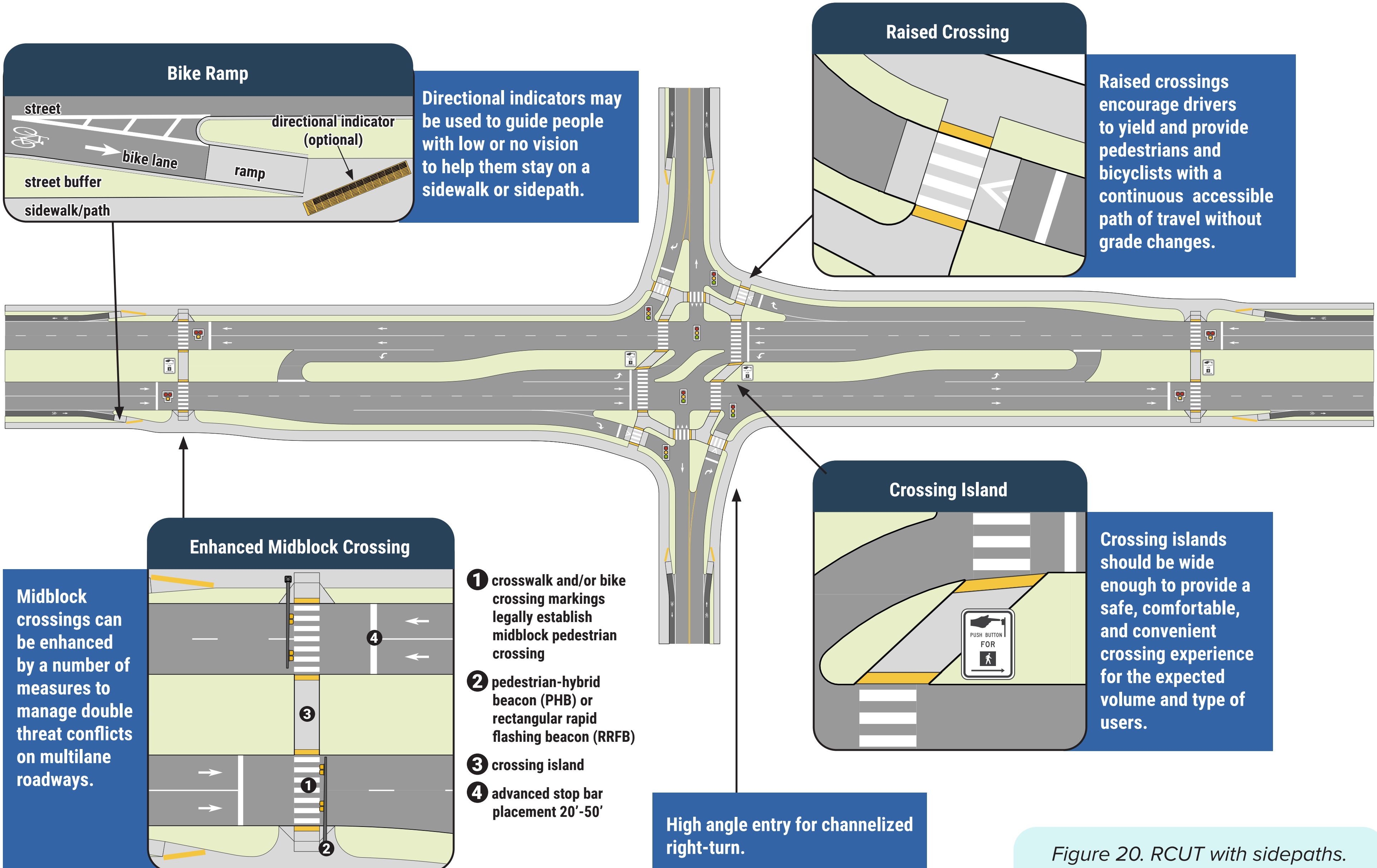


Figure 20. RCUT with sidepaths. Source: FHWA.

Restricted Crossing U-Turn (RCUT)
Sidepath Bulb

The RCUT design shown in figure 21 features sidepaths. However, it also features U-turn bulbs, or “loons,” at the U-turn cut-throughs. The bulbs allow vehicles, especially larger trucks, to make U-turns while minimizing the necessary median width. The reduced median width decreases the pedestrian and bicyclist crossing distance at the intersection. The sidepath follows the curve of the bulb, and changes in direction of travel are a design consideration for bicyclists or pedestrians with disabilities, but the separation between sidewalk or sidepath, usually landscaping of some kind, helps provide some contrast and non-visual guidance along and around the perimeter of the bulb-out.

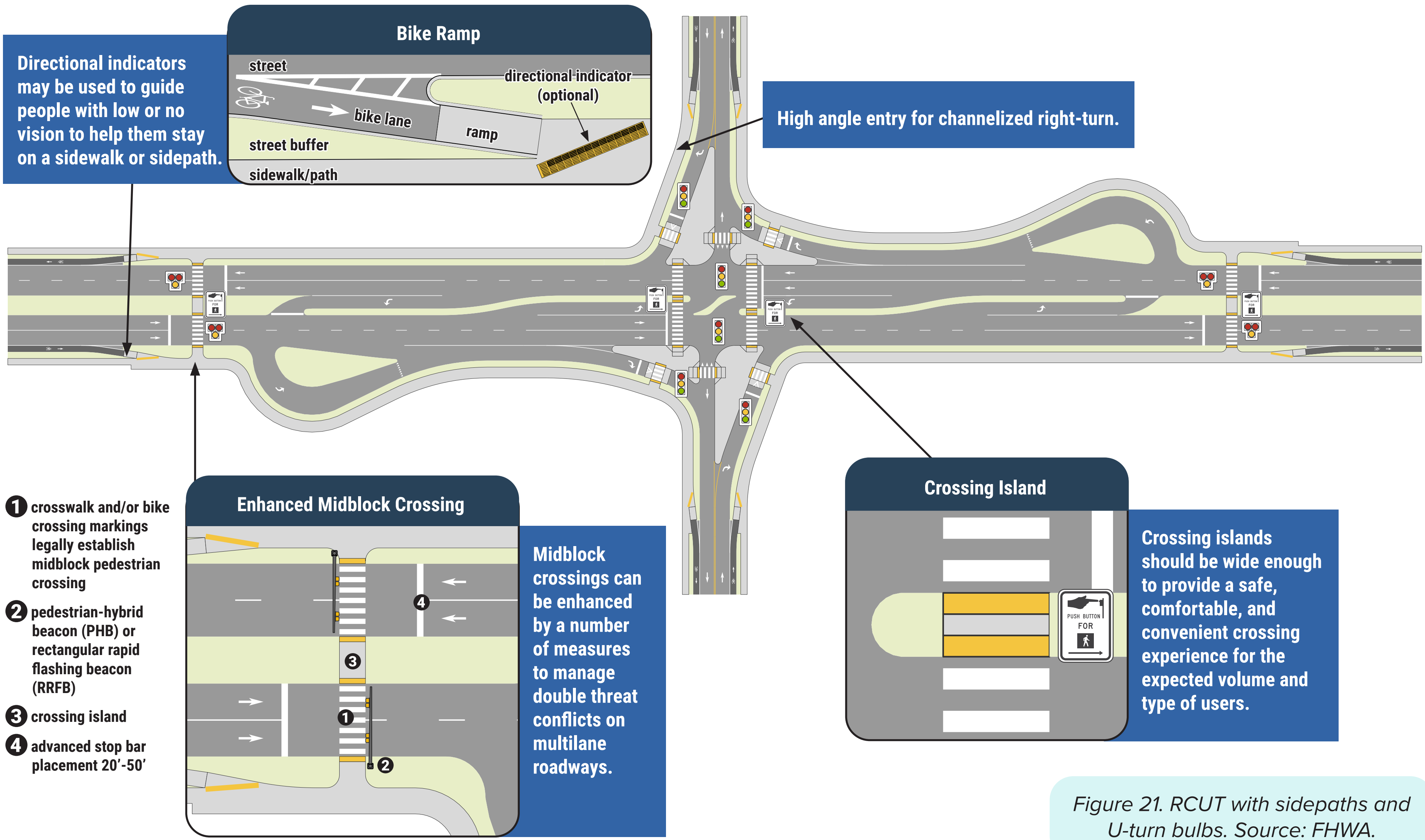
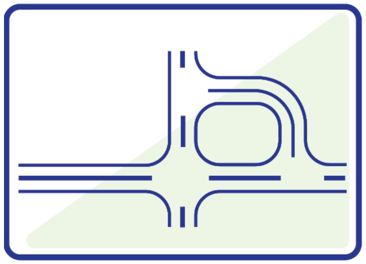


Figure 21. RCUT with sidepaths and U-turn bulbs. Source: FHWA.

QUADRANT ROADWAY (QR) INTERSECTION



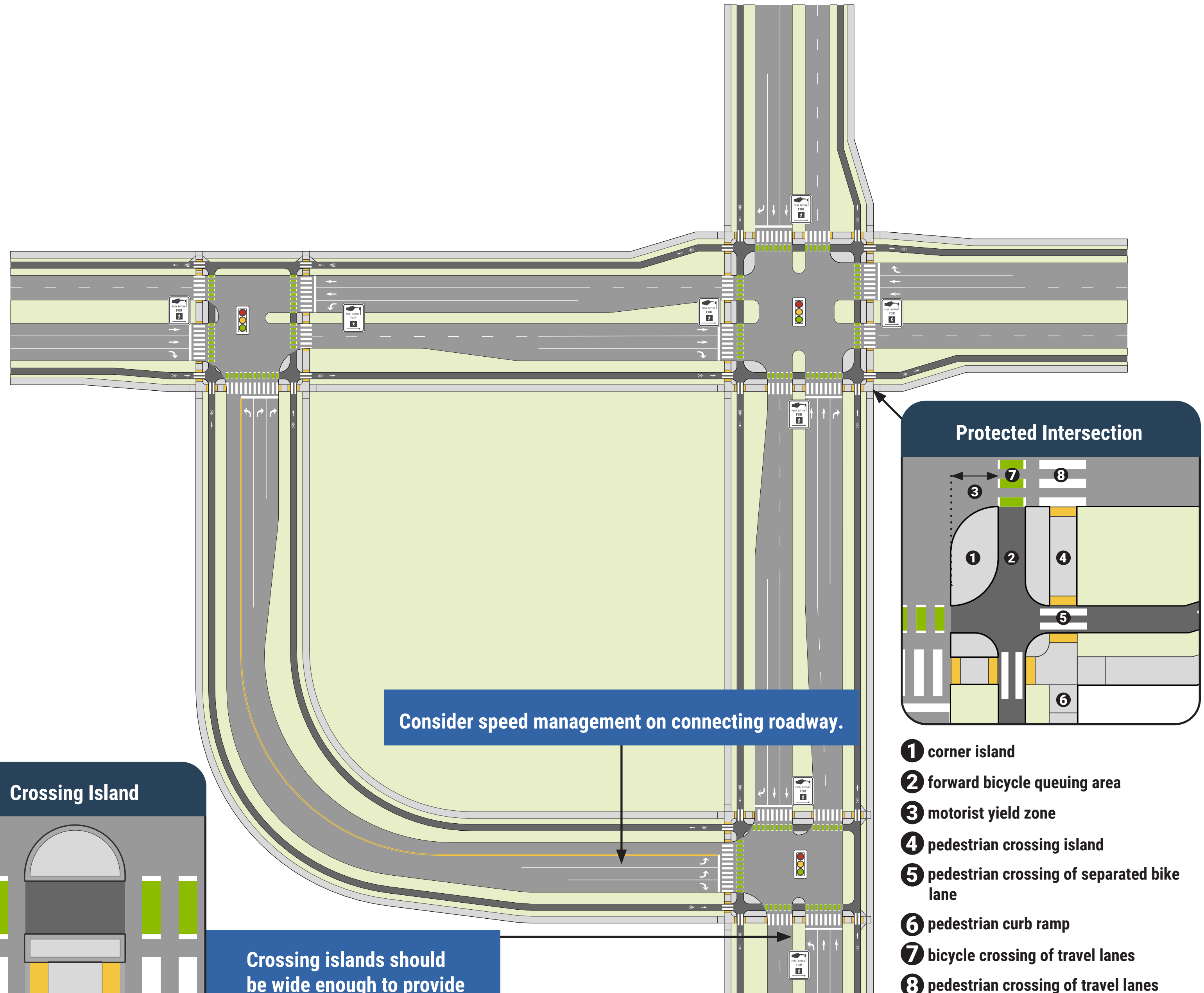
A quadrant roadway (QR) intersection is an intersection design with one main intersection and two secondary intersections where left-turns are displaced to a quarter-arc or 'quadrant' connector road.[11] No left-turns are made at the main intersection. Instead, vehicles turning left from any of the four approaches to the intersection use the secondary intersections and quadrant connector road to complete the movement. Secondary intersections are normally signalized, which is preferable for pedestrian and bicyclist safety, though in some cases they may be unsignalized. Because there are no left-turns at the main intersection, there are no left-turn lanes, benefiting pedestrians and bicyclists through shorter crossing distances, shorter cycle lengths and wait times, and the elimination of left-turning conflicts with pedestrians and bicyclists. Table 7 describes analysis findings and typical conditions that present challenges or opportunities for improved safety, access, and comfort for pedestrians and bicyclists at QR intersections.

Table 7. Assessment considerations for conditions at QR intersections.

Condition	Description	Assessment Technique
Crossing distance and conflict points	Removal of left-turn lanes at the main intersection decreases crossing distance and removes conflict points for pedestrians and bicyclists. However, the introduction of the two auxiliary intersections for the quadrant roadway introduces additional conflict points.	» The Design Flag Assessment includes a flag for "multilane crossings" that considers the number of lanes crossed. » The SSI method captures the removal of conflict points at the main intersection and the addition of conflict points at the auxiliary intersections.
Speed management	Depending on the surrounding context, it may be necessary to implement speed management measures on the quadrant roadway.	» The SSI method movement speed assumptions can be adjusted to account for conditions in the study area.
Signal timing	The main intersection is typically operated as a two-phase traffic signal, minimizing delay for pedestrians and bicyclists. The phasing of the auxiliary intersections depends on traffic volumes and patterns and the surrounding context.	» HCM delay data collection can be used to assess added pedestrian and bicyclist delay due to two-phase signal operation.
Driveways	In some cases, the "infield" of the quadrant roadway may be developed. If so, driveways typically provide access to the destinations within. The introduction of driveways, in addition to the auxiliary intersections, can increase the number and density of pedestrian and bicyclist conflict points.	» The Design Flag Assessment has a flag for "intersection driveways and side streets." It applies to driveways within 250 feet of the main intersection. » The SSI method can be modified to account for additional conflict points resulting from nearby driveways.

Quadrant Roadway (QR)
Separated Bike Lane

The quadrant roadway intersection diverts some motor vehicle movements to an auxiliary (or "quadrant") roadway located in one of the quadrants of the intersection. Pedestrians and bicyclists can travel through the quadrant roadway intersection similar to a traditional intersection. The notable difference is that, depending on their origin and/or destination, they may choose to travel along the auxiliary roadway. The addition of two auxiliary intersections may increase the number of conflict points between motor vehicles, bicyclists, and pedestrians. The quadrant roadway design in figure 22 shows separated bike lanes and sidewalks along the major road, minor road, and auxiliary road.



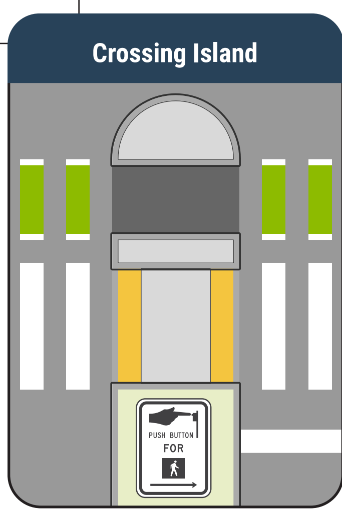


Figure 22. Quadrant roadway intersection with separated bike lanes. Source: FHWA.

Quadrant Roadway (QR)
Sidepath

The quadrant roadway design shown in figure 23 features bike lanes transitioning to sidepaths upstream of the intersections. The sidepaths continue along the auxiliary roadway. Pedestrians and bicyclists travel through the intersections using the marked crosswalks.

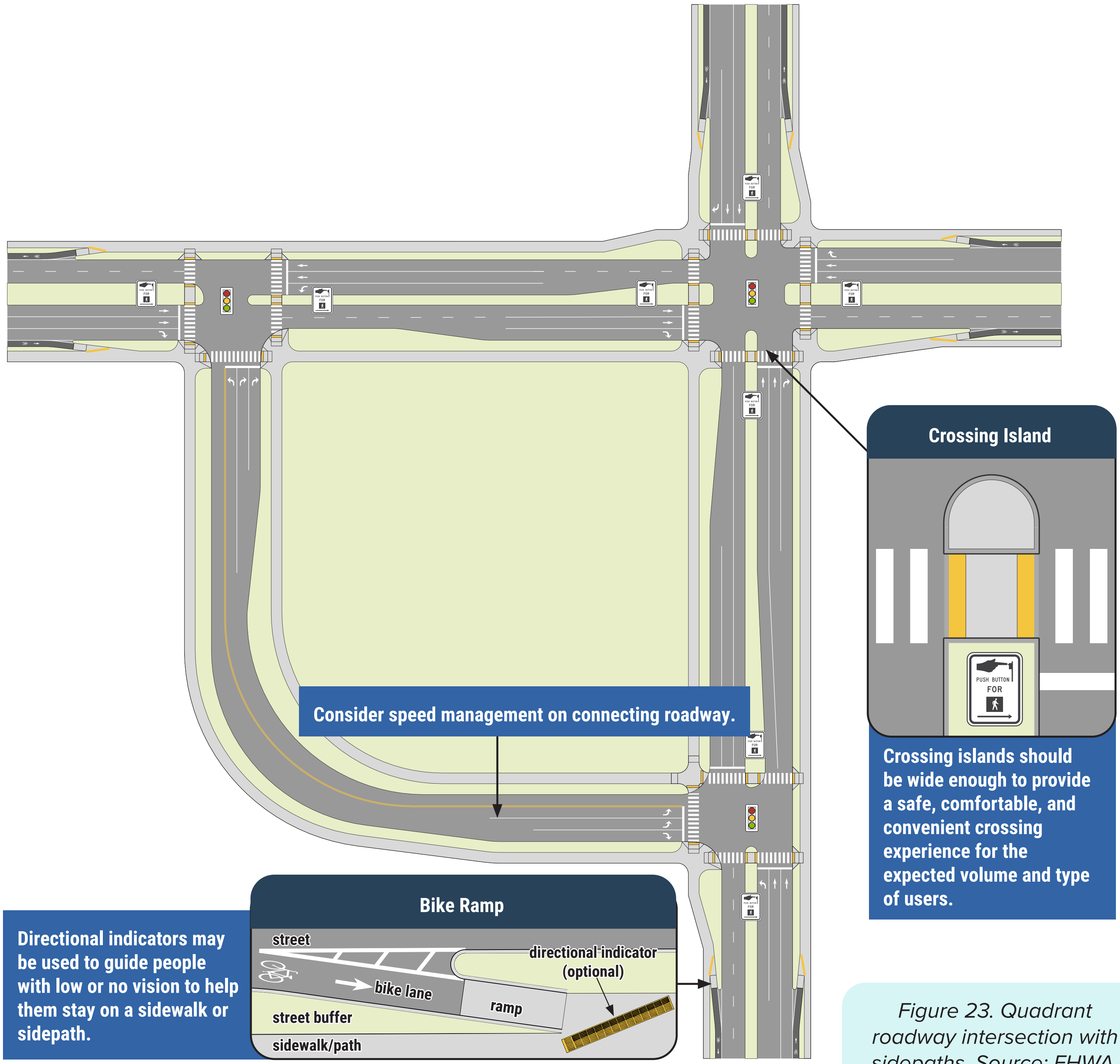


Figure 23. Quadrant roadway intersection with sidepaths. Source: FHWA.

DISPLACED LEFT TURN (DLT) INTERSECTION

A displaced left turn (DLT) intersection, sometimes referred to as a Continuous Flow Intersection (CFI), is a crossover-type design that can be applied to the signalized intersection of high-volume arterials—especially those characterized by heavy left-turn volumes that conflict with heavy opposing through volumes.[12] Left-turning vehicular traffic crosses over to the other side of opposing through traffic at signalized intersections upstream of the main arterial intersection, which allows through movements and left-turns to occur simultaneously at the main intersection. This intersection type requires pedestrians and bicyclists to cross in multiple stages, experience long cycle lengths, and navigate complex travel routes. Grade-separated crossings should also be considered for bicyclists and pedestrians for DLT and other continuous flow intersection types. Table 8 describes analysis findings and typical conditions that present challenges or opportunities for improved safety, access, and comfort for pedestrians and bicyclists at DLT intersections.

Table 8. Assessment considerations for conditions at DLT intersections.

Condition	Description	Assessment Technique
Crossing distance and refuge	Due to the rerouting of left-turns at DLTs, the crossing distance for pedestrians and bicyclists is typically longer than at other intersection designs. Most DLTs include channelizing features and medians to direct vehicle traffic. These also serve to provide refuge for pedestrians and bicyclists. However, in some cases they are narrow and may feature traffic moving on either side at high speeds, resulting in an uncomfortable environment for pedestrians and bicyclists.	» The Design Flag Assessment includes a flag for "uncomfortable/ tight walking environment." » The SSI method factors in the benefit of refuge islands throughout the DLT design in decreasing pedestrian and bicyclist movement complexity.
Nonintuitive Vehicle Movements	Since the DLT design features left-turn movement "crossing over" to the other side of the opposing through movement, a pedestrian or bicyclist crossing the intersection will cross vehicle streams traveling in alternating directions. This may not meet expectation for typical motor vehicle movements.	» The Design Flag Assessment includes a flag for "nonintuitive motor vehicle movement." » The SSI method applies a nonintuitive motor vehicle movement complexity adjustment to the pedestrian and bicyclist conflict points.
Channelized right-turns	DLTs typically feature channelized right-turns. These can provide refuge for pedestrians but may also encourage higher motor vehicle turning speeds. If a channelized right-turn is uncontrolled (or free-flow), this can be problematic for pedestrians with disabilities.	» The Design Flag Assessment includes a flag for "crossing yield or uncontrolled vehicle paths" that may apply to channelized turns as well as a bicyclist-only flag for "channelized lanes." » The SSI method considers the benefit of channelizing islands as refuge islands that decrease pedestrian and bicyclist movement complexity. The SSI method also accounts for out-of-the-way travel for pedestrians and bicyclists with an "indirect paths" complexity adjustment.
Signal timing	Because the DLT is designed primarily to minimize vehicular delay and promote "continuous flow," it can lead to long cycle lengths with increased delay for pedestrians and bicyclists.	» The Design Flag Assessment includes a flag for "long red times." » HCM delay data collection can be used to assess added pedestrian and bicyclist delay due to two-phase signal operation.

Displaced Left Turn (DLT)

Separated Bike Lane

The DLT intersection design is used in situations of high vehicle volumes. Due to the lane arrangements, the DLT produces long crossing distances for pedestrians and bicyclists, increasing delay and conflict points with motor vehicles. DLT designs make use of channelizing features to direct motor vehicle traffic. Pedestrians and bicyclists may make use of the channelizing islands for refuge, diverting the bike lanes and sidewalks from the most direct paths. Channelizing islands should be designed to provide adequate queueing area and refuge from motor vehicle traffic, especially for bicycles, wheelchairs, and other similar devices. The DLT design in figure 24 shows separated bike lanes alongside sidewalks.

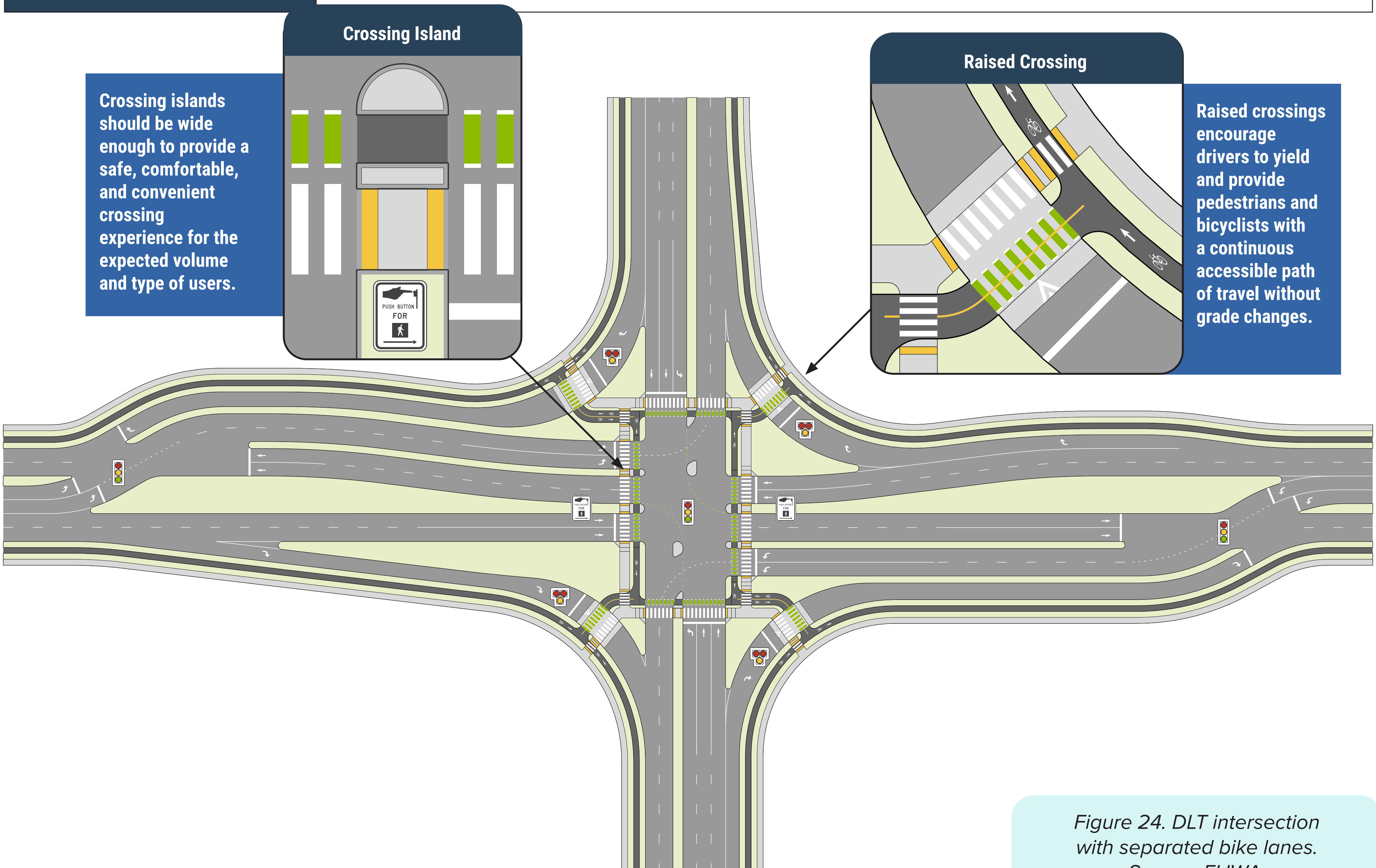


Figure 24. DLT intersection with separated bike lanes. Source: FHWA.

Displaced Left Turn (DLT)
Sidepath

The DLT design shown in figure 25 uses upstream ramps to bring bicyclists out of the bike lane and up to a sidepath at sidewalk level. Both pedestrians and bicyclists then use this sidepath to travel through the intersection. Downstream of the intersection the bicyclists diverge to the bike lane using a similar ramp.

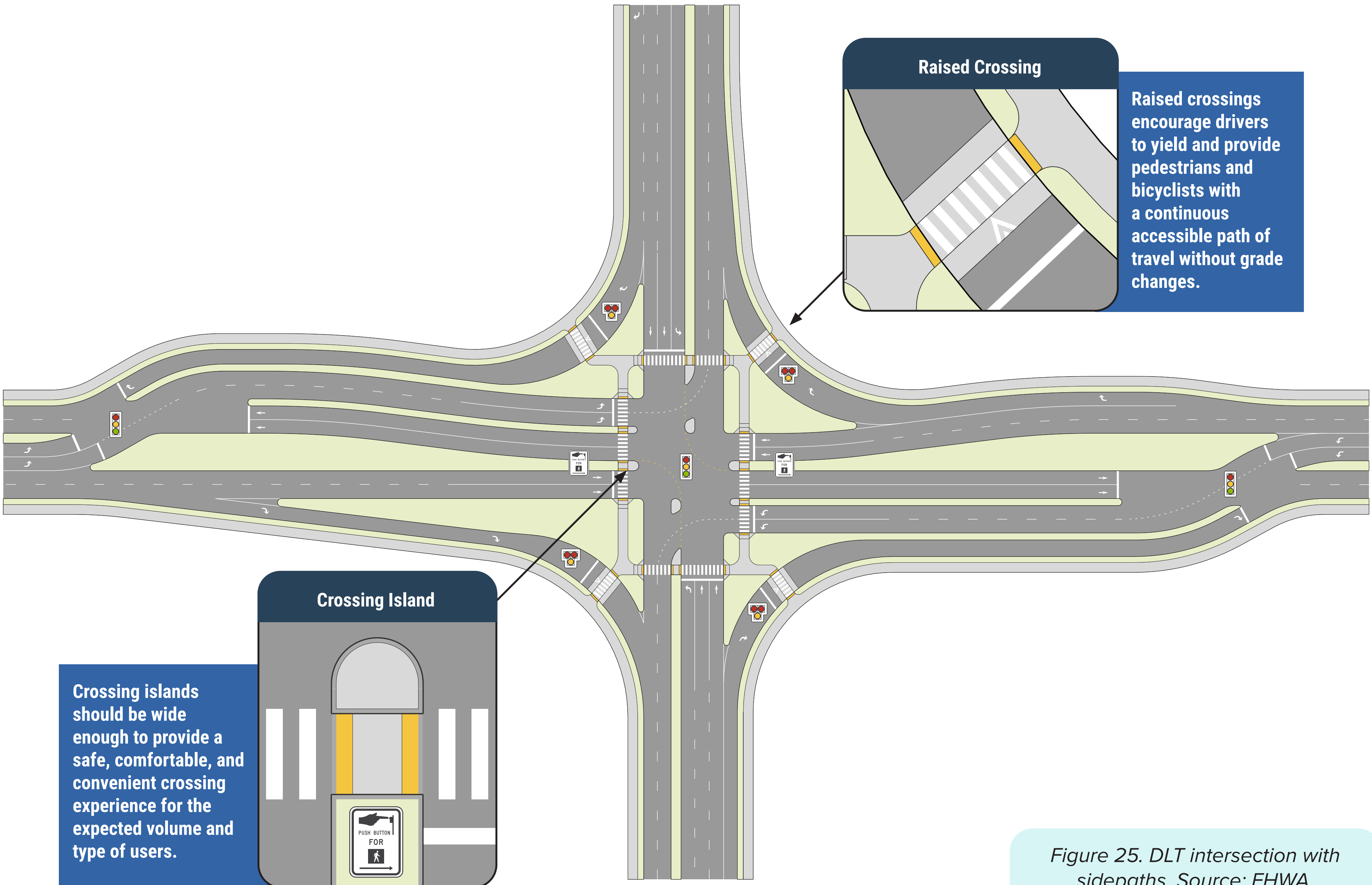


Figure 25. DLT intersection with sidepaths. Source: FHWA.

DIVERGING DIAMOND INTERCHANGE (DDI)

A diverging diamond interchange (DDI) is characterized by crossover intersections at the ramp termini where cross-street traffic crosses over to the left-hand side of the roadway between the ramps to allow unopposed left-turns to and from the ramps.[13] The DDI can offer several benefits to pedestrians and bicyclists, such as reduced wait time through two-phase traffic signals and shorter signal cycle lengths; shorter overall crossing distances; and crossings of fewer conflicting movements and directions of traffic at a time.

Between the crossover intersections, pedestrian pathways and separated bikeways are integrated as inside facilities (i.e., within the median and including barrier walls) or outside facilities (i.e., beyond the outside edges of pavement). Barrier walls height should not produce an enclosed "tunnel effect" that reduces visibility at the crossings. Distance between walls and the pathways and bikeways should be wide enough to allow for landscaping and debris to not block the route. Table 9 describes analysis findings and typical conditions that present challenges or opportunities for improved safety, access, and comfort for pedestrians and bicyclists at DDIs.

Table 9. Assessment considerations for conditions at DDIs.

Condition	Description	Assessment Technique
Crossing distance and refuge	Because DDIs are interchanges, they typically feature higher volume, multilane roads. Combined with the large medians and channelizing islands typically present, this results in long crossing distances for pedestrians and bicyclists.	» The Design Flag Assessment includes a flag for "multilane crossing." » The SSI method considers the number of conflicting lanes and their impact on movement complexity for nonmotorized users. It also factors in the benefit of refuge islands throughout the DDI design in decreasing movement complexity.
Nonintuitive Vehicle Movements	Since the DDI design features motor vehicle movements "crossing over" to the other side of the roadway, a pedestrian or bicyclist crossing the intersection will cross vehicle streams traveling in atypical or unexpected directions.	» The Design Flag Assessment includes a flag for "nonintuitive motor vehicle movement." » The SSI method applies a nonintuitive motor vehicle movement complexity adjustment to the pedestrian and bicyclist conflict points.
Channelized right-turns	DDIs typically feature channelized left and right-turns. These can provide refuge for pedestrians but may also encourage higher motor vehicle turning speeds. If a channelized right-turn is uncontrolled (or free-flow), this can be problematic for pedestrians with disabilities.	» The Design Flag Assessment includes a flag for "crossing yield or uncontrolled vehicle paths" that may apply to channelized turns as well as a bicyclist-only flag for "channelized lanes." » The SSI method considers the benefit of channelizing islands as refuge islands that decrease pedestrian and bicyclist movement complexity.
Pedestrian and bicyclist routing	Due to the size of the interchange footprint and other constraints, the designs typically require pedestrians and bicyclists to travel indirect routes. Additionally, routing pedestrians and bicyclists down the center of the road may be uncomfortable.	» The Design Flag Assessment includes a flag for "executing unusual movement" and "uncomfortable/tight walking environment." » The SSI method accounts for out-of-the-way travel for pedestrians and bicyclists with an indirect paths complexity adjustment.
Signal timing	The crossover intersections are typically operated as two-phase traffic signals, minimizing delay for pedestrians and bicyclists.	» HCM delay data collection can be used to assess added pedestrian and bicyclist delay due to two-phase signal operation.

Diverging Diamond Interchange (DDI)
Separated Bike Lane (outer)

The DDI is different from the other intersection designs discussed here in that it is used in situations with grade-separated interchanges. It involves motor vehicle traffic crossing over to the opposite side of the roadway for a segment before crossing back. The DDI design in figure 26 shows separated bike lanes that follow the motor vehicle path, crossing over to the opposite side of the road on one edge of the interchange and crossing back at the other. This arrangement may allow for bicyclists to take cues for wayfinding from motorists and can allow for signage to be consistent between motor vehicles and bicyclists. It can also provide advantages for efficient use of available space.

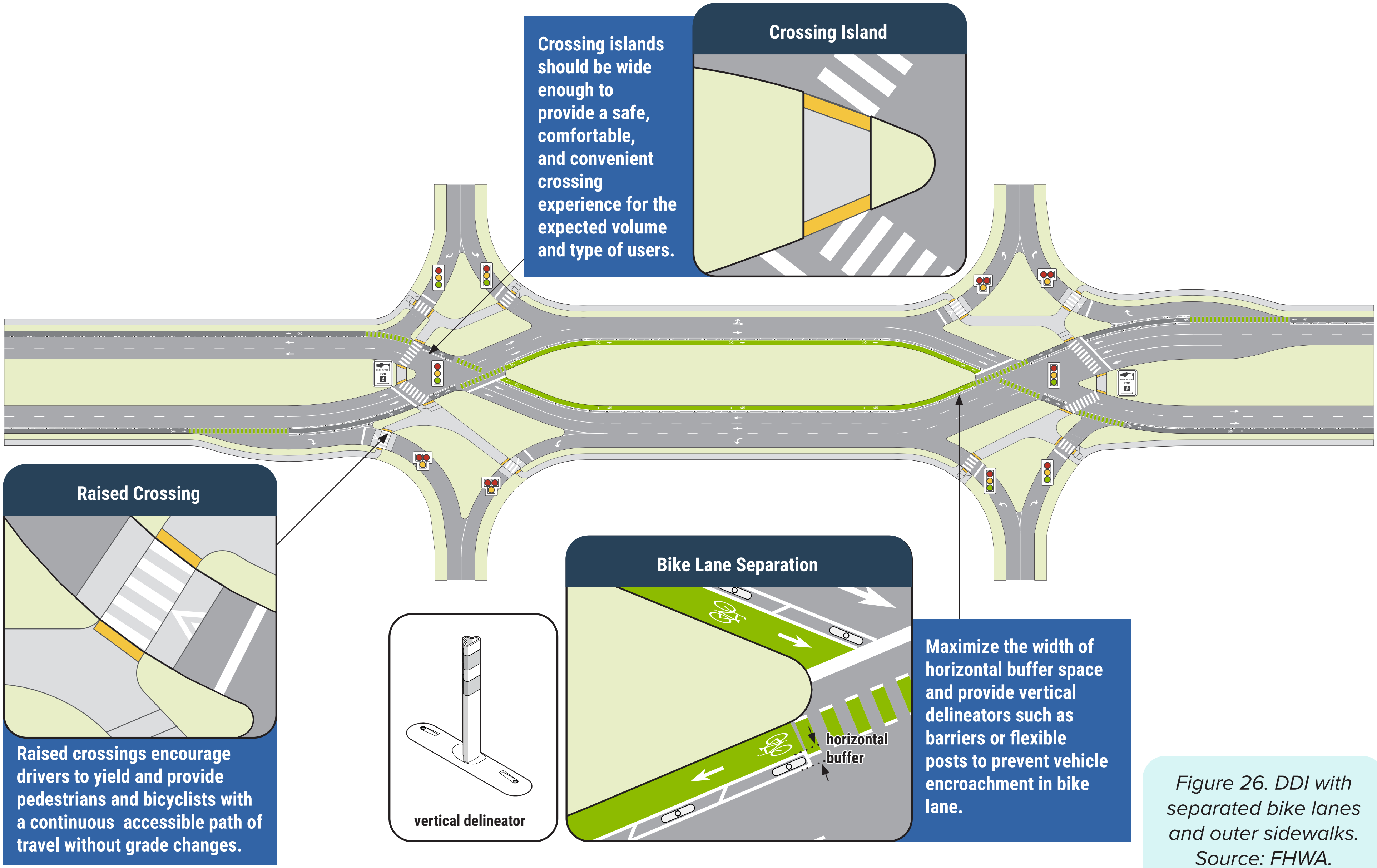


Figure 26. DDI with separated bike lanes and outer sidewalks. Source: FHWA.

Diverging Diamond Interchange (DDI) *Separated Bike Lane (inner)*

The DDI design shown in figure 27 makes use of separated bike lanes and sidewalks that cross the roadway and travel down the center of the median. This can be helpful in minimizing the needed right-of-way. Additionally, crossing to the middle of the road can make use of signal control to provide safe gaps for pedestrians and bicyclists.

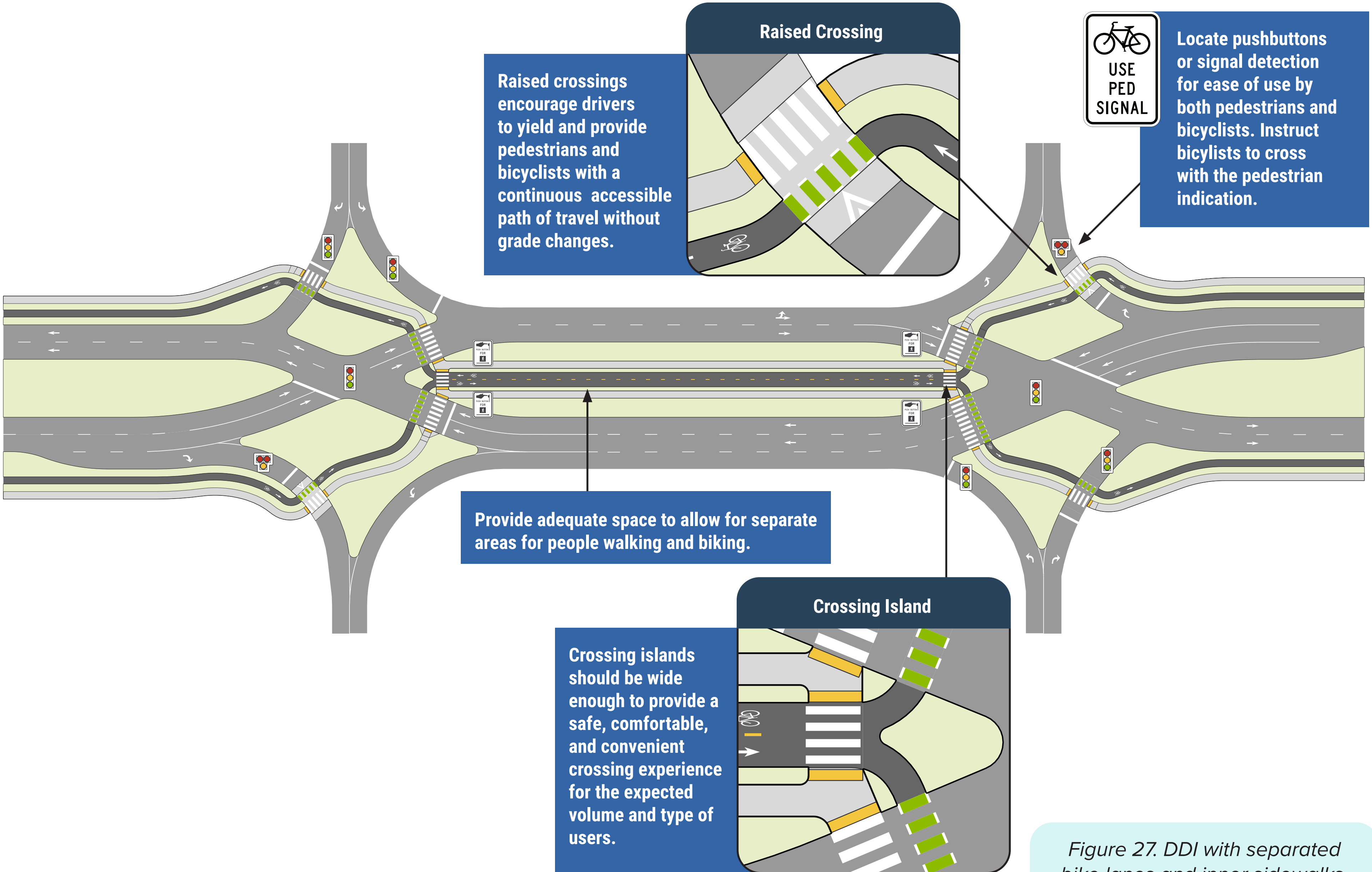


Figure 27. DDI with separated bike lanes and inner sidewalks. Source: FHWA.

Diverging Diamond Interchange (DDI)
Sidepath

The DDI design in figure 28 incorporates sidepaths that travel along the outer edge of the interchange footprint. Pedestrians and bicyclists cross over several entrance and exit ramps to navigate through the intersection. If these ramps are not signal-controlled, they may lead to issues with driver yielding and pedestrians and bicyclists may have difficulty finding adequate gaps in traffic.

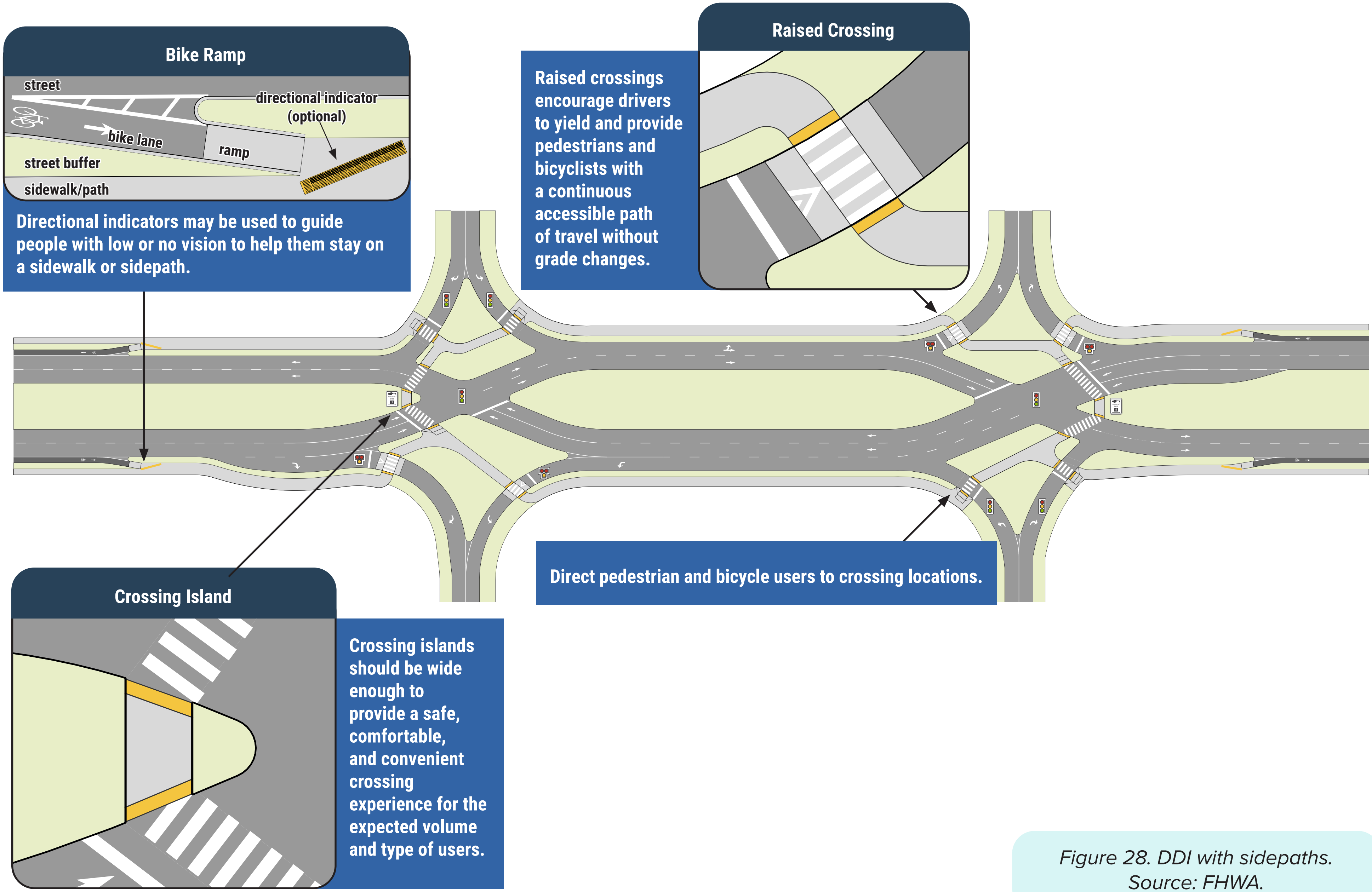


Figure 28. DDI with sidepaths. Source: FHWA.

ADDITIONAL INTERSECTION DESIGN CONSIDERATIONS

There are several circumstances where site conditions are constrained or where design flexibility or enhanced approaches are considered for improved crossings. The following are additional considerations for intersection projects, including design responses that can help improve safety, comfort, and operations for pedestrians and bicyclists.

RIGHT-TURN CROSSINGS

Right-turn conflicts with bicyclists and pedestrians at the intersection occur where motor vehicle travel is free-flowing or not under signal control at crossings, bike lane mixing zones, or where bicyclists are approaching on the right-hand side of the roadway. Interchange ramp approaches designed at a perpendicular angle or close to perpendicular can mitigate the speeds at intersecting exit ramps. As shown in figure 29, as the approach skew angle increases, drivers' approach at higher speeds and the crossing distance is longer.

COMMON EXIT RAMP APPROACH ANGLES

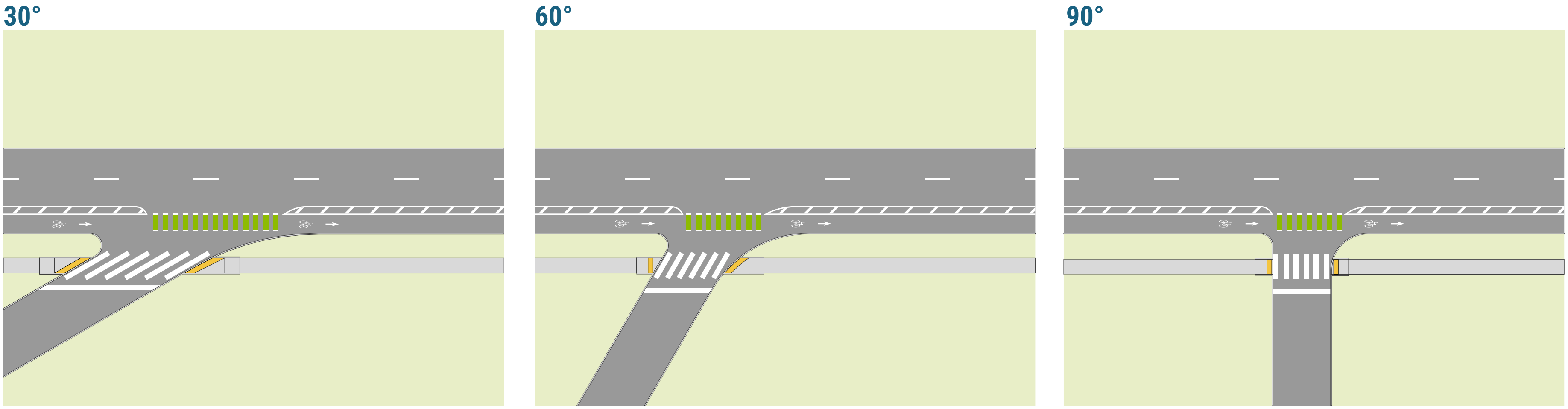


Figure 29. Ramp alignments at intersections with bicyclists and pedestrians. Preferred alignment is the 90 degree or perpendicular approach. Source: FHWA.

Uncontrolled single right-turn approaches are improved with minimal curb radii. Setting the turn radius at the corner based on the selected design vehicle can reduce turning speeds.[54] The curb radii should be designed based on the largest vehicle that turns with frequency at the intersection.[25] The Simple corner approach, as shown in figure 30, is a minimum turn radius based on the smallest design vehicle. A mountable curb and concrete truck apron is an option if a design vehicle includes large trucks, otherwise restrict truck turns where other viable truck routes exist.

Channelizing or separating the uncontrolled right-turn movement is the least preferred option for intersections including pedestrians and bicyclists. Visibility enhancements at crossings, such as the RRFB or raised crossings, should be considered where the right-turn lane is channelized. Raised crosswalks and raised intersections are considered at more urban locations with heavy pedestrian or with separated bicycle traffic. The channelization island should be designed with sufficient width and storage space to provide comfortable refuge for crossing pedestrians and bicyclists. Where sight distance is poor or where turning vehicle speeds are high, place the crosswalk at the center of the island or perpendicular to the channelized turn lane approach, and consider signalizing the crossing from the island.(49)

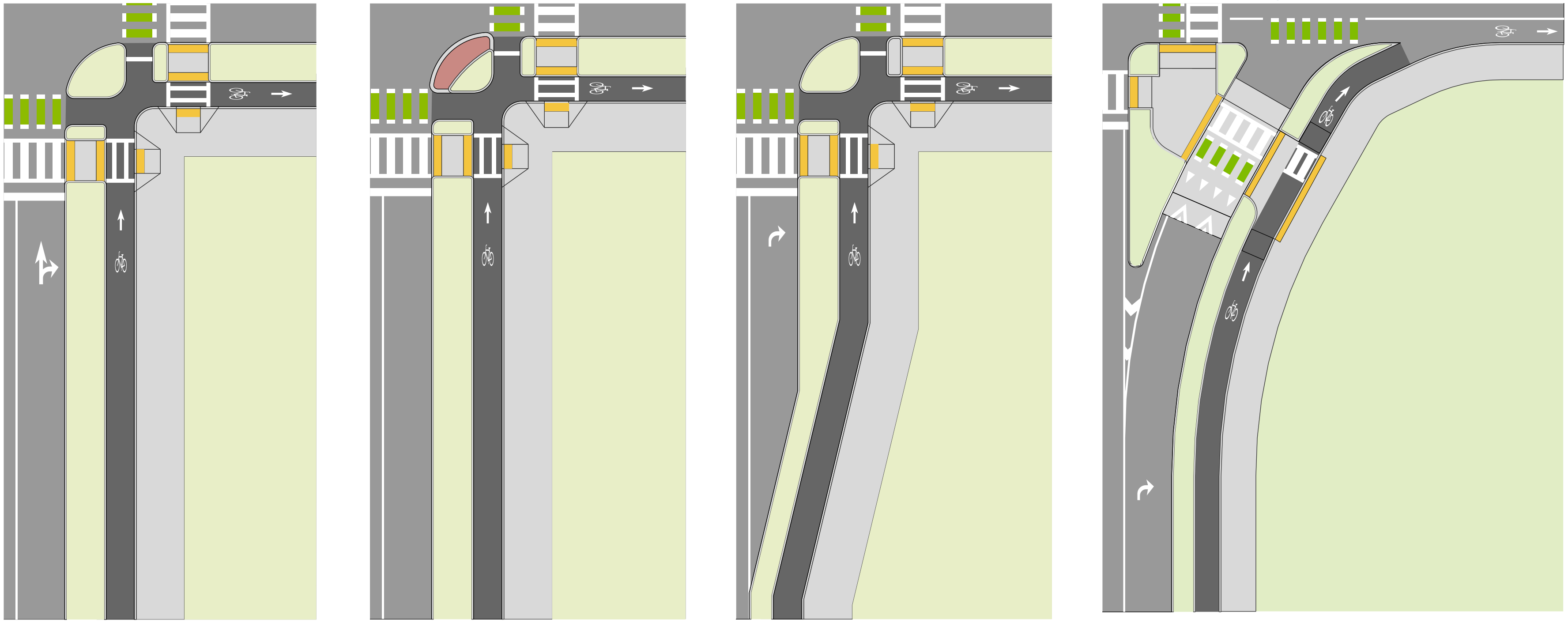


Figure 30. Right-Turn Approaches. Source: FHWA.

Dual right-turn lanes present additional safety concerns for bicyclists and pedestrians, creating a multi-threat (multilane) crossing condition and facilitating higher speed movements. To increase visibility and reduce crashes with the pedestrian or bicyclist at multilane crossings during the WALK phase, designers can place the crossing under full signal or PHB control. When channelized right-turns are signalized, they may create multistage crossings that can increase delay to pedestrian and bicycle travel through the intersection.

Restrictions on Right Turn on Red (or No Turn on Red) should be considered for all intersections incorporating separated bike lanes or other two-way bikeways, LPI and exclusive pedestrian or bicycle phases, or at RCUTs when right-turns are under signal control. No Turn on Red can be implemented through static signage or light-emitting diode (LED) blank out signs. No Turn on Red may also be appropriate for intersections with higher pedestrian or bicyclist activity, or where sight distance is limited and drivers frequently block the crosswalk to look for a gap in traffic.(49)

BIKE LANE TRANSITIONS

Figure 31 shows some examples of different methods for transitioning bike facilities. Bike ramps are one option for transitions between bike lanes and separated bikeways. Bike ramps allow the bicyclist to transition between bike lanes and vertically separated facilities through or around the intersection.

In-Street or Raised Bike Lane to Protected Intersection

In-Street or Raised Bike Lane to Sidewalk or Sidepath

Raised Bike Lane to Street Level

Raised Bike Lane to Street Level with Bike Lane Extensions

Protected Bike Lane with Right-Turn Mixing Zone

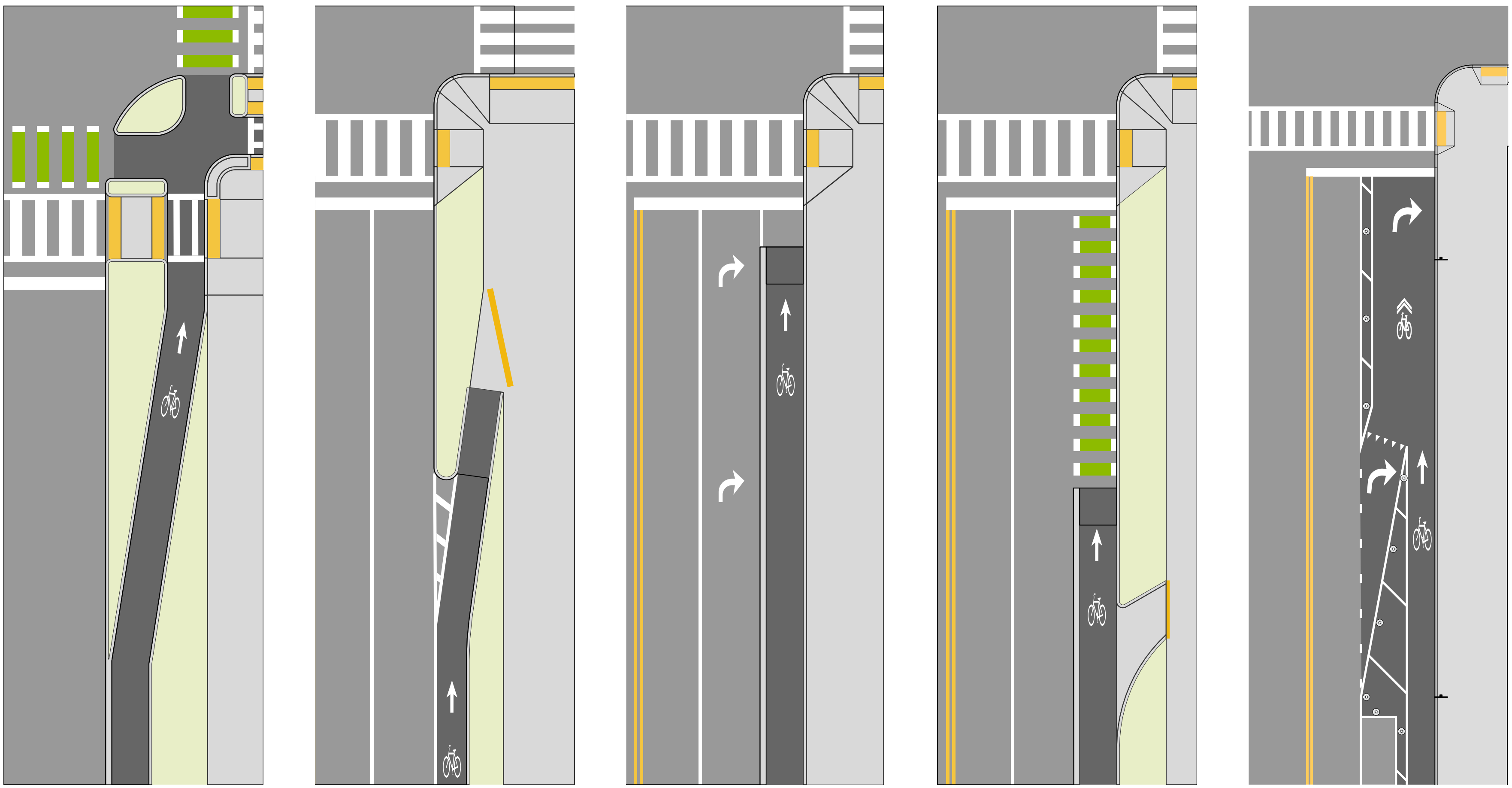


Figure 31. Bikeway transitions at intersections. Source: FHWA.

Green colored pavement is used to draw extra attention to bike lanes, especially near and through intersections, where turning vehicles and bicycles are more likely to mix. Green colored pavement helps differentiate bicyclist facilities where they cross or travel adjacent to pedestrian facilities. Green colored pavement can be used along an entire segment, or as a dashed spot treatment to call attention to potential conflict areas at intersections. Figure 32 shows different bikeway options and how they might incorporate green colored pavement at intersections.

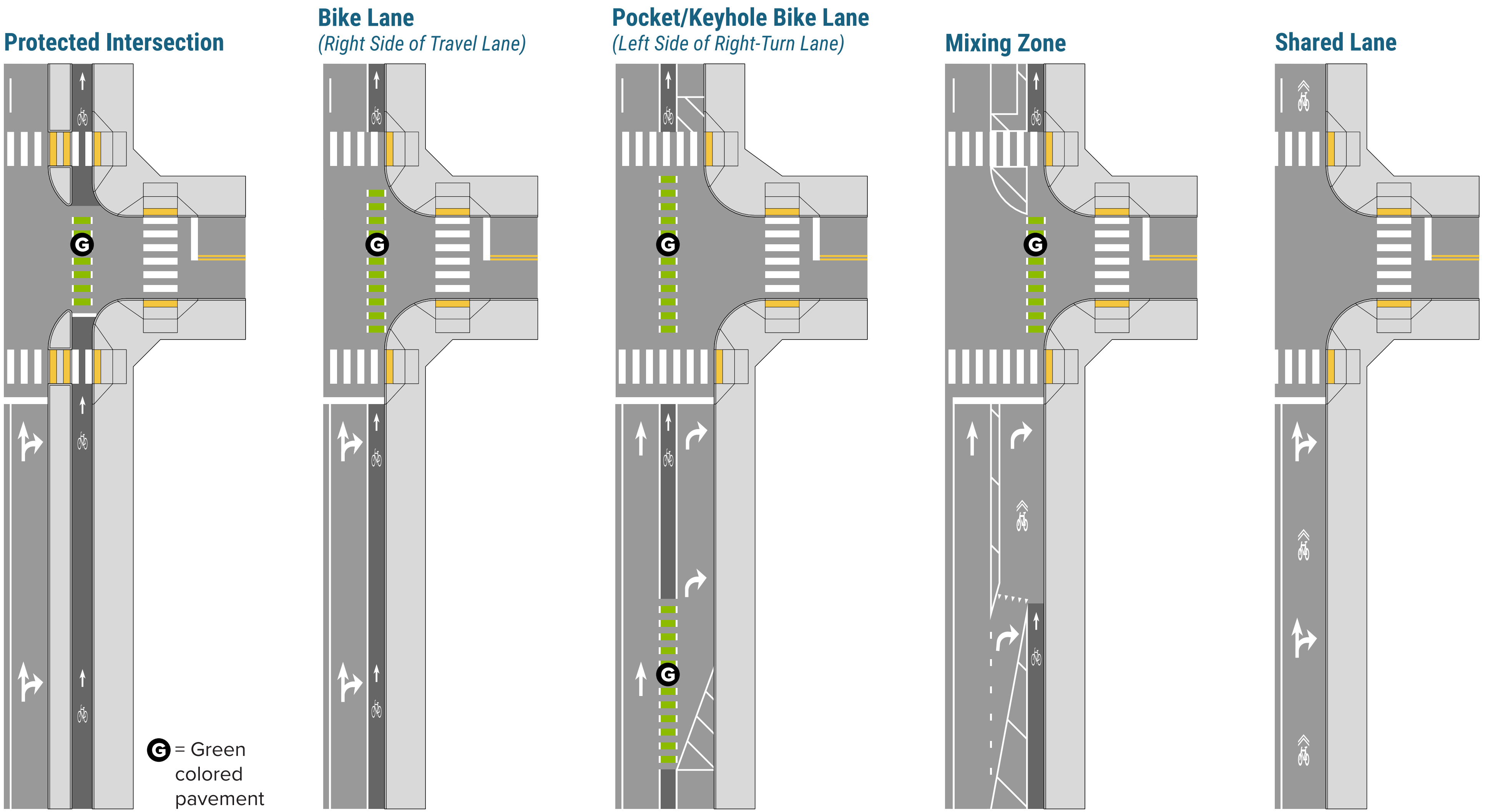


Figure 32. Different bikeway options. Source: FHWA

SIGNAL PHASING AND TIMING

Exclusive bicycle and pedestrian phases allow all bicyclist and pedestrian movements to cross the intersection in any direction, while providing a red signal indication to all motor vehicle traffic. This is appropriate for urban settings with high pedestrian volumes and at intersections with high volumes of turning traffic. Signals can include bicycle-specific signal heads to control bicycle phases. Bike signal phases can permit bicyclists to run concurrent with vehicle phases or as an exclusive separate phase.

The intersection design should ensure audible cues are provided to persons with low or no vision. APS communicates the start and duration of the WALK phase to pedestrians with low or no vision through audible tones or speech messages and vibrating surfaces. The proposed Public Rights-of-Way Accessibility Guidelines (PROWAG) includes a provision that, if adopted, would require APS wherever pedestrian signals are installed. It refers to MUTCD standards for APS features and functioning (incorporated by reference into 23 CFR 655.601(d)(2)(i)).

Cycle length for a signalized intersection affects delay and travel time for all roadway users. Shorter signal cycles, creating pedestrian delay less than 60 seconds, improves likelihood of pedestrian compliance.[49] Short cycle lengths can also produce consistent gaps in traffic for downstream midblock pedestrian crossings.

Pedestrians with disabilities, children, or the elderly may not be able to completely cross the intersection before opposing traffic is released, depending on the duration of the walk interval and pedestrian change interval. The MUTCD stipulates that an average pedestrian walking speed of 3.5 ft/s should be used to determine the pedestrian clearance time. However, at locations where pedestrians who use mobility assistance devices or walk slower than 3.5 ft/s routinely use the crossing, the MUTCD suggests that practitioners consider a walking speed less than 3.5 ft/s (MUTCD Section 4E.06, paragraph 10).[26]

Traffic signals may be designed with a leading pedestrian interval (LPI). LPI gives pedestrians the opportunity to enter the crosswalk before vehicles are given a green indication.[36] This allows pedestrians to establish their presence in the crosswalk before vehicles begin to move through the intersection, increasing the visibility of pedestrians to drivers and improving driver behavior. For pedestrians with low or no vision to have access to the safety benefits of LPI, the use of APS should also be considered when implementing LPI.

DETECTION

The most common form of pedestrian detection is push button detection. Section 4E.08 of the MUTCD contains guidance on where to place pedestrian push buttons.[26] Proper push button placement assists in pedestrian navigation of the intersection and encourages compliance with pedestrian signals. Push buttons are placed with the face of the button parallel to the corresponding path of travel.

Automated (or passive) detection systems are designed to sense or identify when a pedestrian or bicyclist has approached the crossing and then places a call for the appropriate traffic signal phase. The inclusion of advanced bicyclist detection can extend the green phase when necessary to allow bicyclists (who may be moving slower than motor vehicle traffic) to clear the intersection before the phase ends.

Consider automatic call ("pedestrian recall") for all signals in areas with heavy pedestrian activity. Automatic recall eliminates the need for pushbutton or detection, is more convenient for pedestrians, and can improve safety by decreasing pedestrian crossings out-of-phase.

GRADE-SEPARATED CROSSINGS

Grade-separated facilities, including overpasses and underpasses, separate bicyclists and pedestrians from motor vehicle traffic or in some cases, railcars. Grade-separated crossings are prioritized for high-speed and high vehicle-volume highways and intersections, railroad corridors, and natural barriers. Grade-separated crossings may be alternatives to the largest and most complex intersections described in this guide, such as the DLT. Some pedestrians and bicyclists may have personal safety concerns using grade-separated crossings when they are crossing under traffic, especially where the tunnels are long or are not well-lit. Other design considerations for grade-separated crossings include drainage and debris in tunnels, accessibility, and slope of routes to tunnels and bridges.

INTERSECTIONS IN CONTEXT

Planning and designing intersections for safe and comfortable travel for all roadway users begins by considering the approaching corridors. Traffic speed and volume are key determinants for identifying the user, and the preferred bikeway and pathway types for the context and users, according to the *Bikeway Selection Guide*.(15) Speed and traffic volume also influence access to development, including the frequency of and design of driveways and intersections.

The same principles that guide decisions for including bicyclists and pedestrians at intersections apply to corridors. Complete Streets policies and projects call for the planner and designer to expect pedestrians and bicyclists along all roadways. Land use context and needs of the users establish the cross section for the corridor, including bicycle and pedestrian networks, landscaping, and street amenities.

The decision-maker should consider the target speeds for roadways leading to the intersection before determining the design speed for the intersection. As corridors or an area becomes more developed, levels of access to destinations change, traffic movements become more complex, and operating speeds adjust. These factors redefine the purpose of the roadway and inform target speeds, as bicycle and pedestrian exposure increases.

Selecting and managing speeds along the corridor minimize the likelihood of fatal and serious injury crashes and support safer travel for bicyclists and pedestrians, in accordance with the Safe System approach. Safer design speeds along the corridor also support more frequent midblock crossings and signal coordination. These approaches to corridor planning and intersection design increase visibility and operations at the intersections for all roadway users.

RESOURCES FOR ADDITIONAL INFORMATION

The following is a summary of key resources referenced in the formation of this guide. Each are also listed in the References section of this guide with specific citations. Use of these resources is not required under Federal law or regulation. The resources are listed in alphabetical order for each of the following topic areas:

- **Planning for and Selecting Bikeways and Pedestrian Pathways.**
- **Design Guidance for Bikeways and Pedestrian Pathways at Intersections.**
- **Assessment Techniques for Including Bicyclists and Pedestrians at Intersections.**

PLANNING FOR AND SELECTING BIKEWAYS AND PEDESTRIAN PATHWAYS

Achieving Multimodal Networks: Applying Design Flexibility and Reducing Conflicts is organized around principles and case studies for applying design flexibility and reducing conflicts.[50] Factors for design flexibility, such as vehicle types and speeds, encourage consideration for features such as mountable aprons and alternative turn lane configurations. The document discusses conflict reduction strategies and priority for separating bike lanes at intersections.

The *Bikeway Selection Guide* documents the trade-offs for selecting different bikeway types and covers the process of selecting a bikeway from policymaking through the design decision.[15] This guide is a resource to help transportation practitioners consider and make informed decisions about trade-offs relating to the selection of preferred bikeway types based on design speed, motor vehicle volumes, and contextual factors (primarily urban versus rural land use). As speeds increase above 30 mph and traffic volumes exceed 6,000 vpd, separated bikeways are preferred for roadways in suburban or urban contexts.

Designing Walkable Urban Thoroughfares: A Context Sensitive Approach released by the Institute of Transportation Engineers (ITE) describes a process for designing walkable urban thoroughfares, according to series of context categories (e.g., rural, suburban, urban, urban core) and roadway type.[51] The document provides guidance for pedestrian walkway and street design based on the different needs and constraints of these context categories. For example, as the context becomes more urban and traffic volumes increase, the document recommends increased minimum width for pedestrian throughways. The document also includes recommended minimum street side zones and wider pathways in the urban core.

The *Guide for Improving Pedestrian Safety at Uncontrolled Crossing Locations* was developed as part of the FHWA Safe Transportation for Every Pedestrian (STEP) program.[16] The guide outlines a six-step process to identify potential crossing locations and provides information on selecting potential countermeasures or crosswalk enhancements at uncontrolled locations. The guide includes two tables that assist with potential countermeasure selection. Table 1 in the guide leverages current research to identify applicable countermeasures based on tiers of roadway configurations, speeds, and AADT ranges. As approaching roadway speeds exceed 35 mph or 9,000 vpd, recommended countermeasures include RRFBs, PHBs, or other signal controls. The guide also includes Table 2, cross-referencing general safety issues to potential countermeasures, based on surrounding land development context, pedestrian travel patterns, and driver behaviors.

NCHRP Report 926, *Guidance to Improve Pedestrian and Bicyclist Safety at Intersections*, discusses considerations at the outset for general types of intersection projects, data types and analysis methods, and suggested criteria for selecting and refining potential countermeasures.[21] The report includes factors and guiding principles for intersection design, and it includes a comprehensive and descriptive list of countermeasures for improving yielding and separation by intersection type, crash type, context, user type, and trade-offs.

The *Primer on Safe System Approach for Pedestrians and Bicyclists* is a basic overview of the Safe System approach and how it relates to bicycle and pedestrian safety.[19] The document includes a summary of the five elements of the

Safe System approach and their relevance to pedestrians and bicyclists. This is a resource for the Highway Safety Improvement Program (HSIP) and State Strategic Highway Safety Plan (SHSP), with each providing an opportunity for institutionalizing Safe System approach.[52,53]

The FHWA Bicycle Safety Guide and Countermeasure Selection System (BIKESAFE) is an interactive online tool for bicycle safety countermeasures and strategies to help agencies select appropriate countermeasures.[22] BIKESAFE addresses intersection features or countermeasures such as bicycle signal heads and bike lanes.

The FHWA Pedestrian Safety Guide and Countermeasure Selection System (PEDSAFE) is an online and interactive database of countermeasures intended to improve pedestrian safety with tools assisting in countermeasure selection and problem identification.[24] PEDSAFE addresses intersection features or countermeasures such as RRFBs, PHBs, countdown timers at pedestrian signals, and curb design.

FHWA's Proven Safety Countermeasures is a list of countermeasures chosen based on proven safety benefits and promoted to encourage widespread implementation.[14] The list includes several pedestrian- and bicyclist-oriented countermeasures which could be applied at intersections, including Walkways, Crosswalk Visibility Enhancements, Pedestrian Refuge Islands, Bicycle Lanes, Rectangular Rapid Flashing Beacon (RRFB), Pedestrian Hybrid Beacon (PHB), Leading Pedestrian Interval (LPI), Lighting, and Appropriate Speed Limits for All Road Users.

FHWA's *Pedestrian and Bicyclist Road Safety Audit (RSA) Guide and Prompt Lists* are a resource for agencies interested in conducting RSAs focused on pedestrians and bicyclists.[54] The guide includes information on the RSA process and background on safety for nonmotorized road users at different locations including intersections. The main feature of the guide is updated prompt lists designed to help practitioners identify, understand, and mitigate pedestrian and bicyclist safety issues. The prompt lists are broken out by location, allowing practitioners to easily pinpoint the prompts most applicable to intersections.

DESIGN GUIDANCE FOR BIKEWAYS AND PEDESTRIAN PATHWAYS AT INTERSECTIONS

The AASHTO *Guide for the Development of Bicycle Facilities* is a comprehensive bicycle facility guide for bicycle facility planning, design, and operations.[23] It presents comprehensive background information about bicycle operations and safety, planning, and bicycle facility selection for effective bicycle facility development. The core of the guide is the design guidance, general elements of design applicable to all bicycle facility types, and detailed guidance for each of the following bicycle facility types: sidepaths, separated bike lanes, bicycle boulevards, shared lanes, and bike lanes. A new edition of the AASHTO *Guide for the Development of Bicycle Facilities* is expected for release.

The AASHTO *Guide for the Planning, Design, and Operation of Pedestrian Facilities* offers design guidance including a discussion of elements of design and various facility types including walkways, sidewalks, sidepaths, roadway shoulders, shared streets, pedestrian malls, and transit streets.[25] Geometric design considerations at crossings are addressed in greater detail, including effective and actual corner radii, simple versus compound curves, and curb extensions. Additional topics related to pedestrian crossings include sections on curb ramps, crosswalks, interchanges and roundabouts, midblock crossings, and traffic control/pavement markings/signs.

The United States Access Board's (USAB's) *(Proposed) Public Rights-of-Way Accessibility Guidelines* (PROWAG) details proposed design requirements for pedestrian access routes including sidewalks and other pedestrian paths (or portions thereof), pedestrian street crossings and at-grade rail crossings, overpasses and underpasses (and similar structures), curb ramps and blended transitions, access ramps, platforms, and doorways, doors and gates.[30] The proposed requirements address pedestrian route width, medians and refuge islands, passing space, vertical alignment, curb ramp design, detectable warning surface size, pedestrian signal phase timing, and other subjects relevant to pedestrian accessibility.

The *Accessible Transportation Technologies Research Initiative (ATTRI) User Needs Assessment* identifies practices for designing pedestrian pathways and crossings.[55] The document explains that pathways should have sufficient width and height for persons who are blind or have low vision who may not see overhanging branches or signs, or items such as benches encroaching into the pathway. In addition to standard features such as tactile surfaces and curb ramps at crossings, the resource recommends that crossings include time for people with walking disabilities and center islands for crosswalks that span multiple lanes.

The *Intersection Safety Issue Brief: Pedestrian Design for Accessibility Within the Public Right of Way* discusses the importance of designing intersections that are accessible to and usable by individuals with disabilities to meet the obligations set forth in the ADA.[27] This includes meeting varying needs of people with disabilities. It includes recommendations for designing an accessible intersection by reducing vehicle speeds at vehicles/pedestrian conflicts, provision of curb ramps at all crosswalks, and accessible pedestrian signals to communicate the presence of a push button (where applicable) and the WALK indication to pedestrians with vision disabilities.

The National Association of City Transportation Officials' (NACTO) *Don't Give Up at the Intersection* guide focuses on design strategies and tools for safer accommodation of bicyclists through intersections using design modifications.[56] The design strategies covered are protected intersections, dedicated intersections, and minor street crossings. The guide discusses design tools, which include bikeway setbacks, recessed stop lines, bike-friendly signal phasing, turn wedges, vertical separation elements, and raised bike crossings.

NCHRP Report 834, *Crossing Solutions at Roundabouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities*, emphasizes the importance of incorporating features for pedestrians with vision disabilities into projects that include roundabouts or channelized turn lanes.[28] Key strategies for planning their path related to this project include (1) using auditory and tactile cues to maintain the line of travel and (2) aligning with the sound of traffic proceeding straight ahead on the street beside them.

ITE's *Recommended Design Guidelines to Accommodate Pedestrians and Bicycles at Interchanges* identifies practices regarding specific dimensions, safety features, signing, pavement markings, design geometries, and other treatments to improve the safety and accommodation of pedestrians and bicyclists at interchanges.[57] It also presents several case studies used to illustrate treatments.

The FHWA *Separated Bike Lane Planning and Design Guide* documents the process of designing separated bikeways, including detailed intersection design guidance.[58] It outlines planning considerations for separated bike lanes and provides a menu of design options covering typical one-way and two-way scenarios. The guide includes detailed intersection guidance covering different time and space separation techniques, including motor vehicle and bicycle turning movements, pavement markings, and signalization strategies and phasing.

NCHRP 969, Traffic Signal Control Strategies for Pedestrians and Bicyclists, references performance measures for bicyclists and pedestrians at signalized intersections and provides tools to support signal design. The report considers how various geometric design configurations, timing strategies, and phasing options serve bicyclists and pedestrians. The report emphasizes treatments for increasing accessibility for pedestrians and bicyclists.[49]

ASSESSMENT TECHNIQUES FOR INCLUDING BICYCLISTS AND PEDESTRIANS AT INTERSECTIONS

The *Primer on Intersection Control Evaluation (ICE)* is a brief document describing an overview of ICE, potential policies pertaining to ICE, and when to use ICE.[59] Additionally, the primer references three types of resources to help agencies carry out ICE processes: (1) intersection reference guides, (2) tools to evaluate operational and safety performance, and (3) life-cycle cost analysis tools. The alternatives selection stage of ICE, or Stage II ICE, is more detailed and aims to compare alternatives with each other to arrive at the best solution for the intersection. It includes more detailed and robust safety and operational analyses, benefit-cost analysis, and more detailed estimates of environmental, utility, right-of-way, and other costs and impacts. These analyses typically draw on methods and performance measures contained in other resources such as the HSM and HCM as well as other tools such as traffic simulation software. One of the primary scoping-stage ICE analyses is the Safety Performance for Intersection Control Evaluation (SPICE).[60] SPICE is a Microsoft Excel-based spreadsheet tool that assesses the safety performance of different intersection type and control type alternatives using HSM techniques. The tool takes in a variety of data inputs including vehicle volumes, pedestrian volume, turn lane presence, lighting, left-turn signal phasing, number of lanes, transit presence, and other factors. It computes crash predictions over the project life cycle for both total crashes and fatal and injury crashes.

A Safe System-Based Framework and Analytical Methodology for Assessing Intersections introduces an intersection analysis method, known as the Safe System for Intersections (SSI), using typically available project data, such as speed (specifically, posted speed limit), AADT volumes, and the number of through lanes on the intersecting roads.[41] The SSI method considers several optional inputs such as vehicle speeds for different intersection movements and volumes of bicyclists and pedestrians. The SSI method offers assumptions and default values for their use, but agency-prescribed or project-specific values should be used if available. The metrics that result from this method can complement crash-based metrics that come from predictive approaches like those in the HSM and SPICE. Users can focus on fatalities and serious injuries and the key mechanisms that lead to these injuries (for example, speeds, collision angles). Additionally, the method provides a metric for the safety of bicyclists and pedestrians while robust crash-based metrics are still in development; and, finally, the document communicates tradeoffs between vehicle-vehicle conflict SSI results and vehicle-pedestrian conflict SSI results across different intersection alternatives.

NCHRP Report 948, *Guide for Pedestrian and Bicycle Safety at Alternative Intersections and Interchanges (AII)*, introduced the concept of design flags as a qualitative performance measure of potential safety, accessibility, operational, or comfort issues for pedestrians and bicyclists at intersections.[43] NCHRP Report 948 suggests the following key questions regarding pedestrians and bicyclists be considered as the general intersection footprint and configuration are being developed:

- **What general type of pedestrian facility will be provided on each intersecting street?**
- **What general type of bicycle facility (e.g., separated bicycle facility, on-street bike lanes, or sidepath) will be provided on each intersecting street?**
- **How will each origin-destination route for pedestrians be routed through the intersection (e.g., around the perimeter, through the interior)?**
- **How much space and what design treatments are needed to enable this pedestrian routing? How will each origin-destination route for bicyclists be routed through the intersection (e.g., around the perimeter, through the interior)?**
- **How much space and what design treatments are needed to enable this bicyclist routing?**

The design flag analysis defines measures of effectiveness and threshold values for red (safety) and yellow (user comfort) flags, and it proposes design techniques to mitigate each flag. The report lists 20 flags and denotes whether they apply to pedestrians, bicyclists, or both. Changes in red flags result from prevalence of lane crossing, left-turning vehicles, and red times or bicycle clearance times. Changes in yellow flags primarily come from intersection unfamiliarity and indirect walking paths or bikeway routes. Each flag can typically be assigned with little associated data collection, simply by reviewing an image or drawing of the intersection. The guide also presents potential countermeasures or actions that can be taken to mitigate the design flag.

Traffic Analysis and Intersection Considerations to Inform Bikeway Selection, which is a supplement to the FHWA *Bikeway Selection Guide*, provides tips and considerations for projecting future year volumes, estimating growth rates, selecting an analysis period, and understanding impact of peak traffic periods on analysis.[61] It discusses width for bike lanes and street buffers per different bikeway types, such as separated bikeways, bike lanes and at mixing zones.

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